On the Development and Implementation of GFS.v15 with FV3 Dycore and Updated Physics for Operation

Presented by:

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NOAA/NWS/NCEP

Based on work done by EMC MDA, VPPP, and EIB Brances, GFDL and PSD collaborators, and various GFS downstream code managers and external collaborators

Change History of GFS Configurations

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	
Apr 1985	18	R40 (300km)	Sigma Eulerian	GFDL Physics
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
Oct 1998	28	T170 (80km)	Sigma Eulerian	the restoration
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
Jun2017	64	T1534 (13km)	Hybrid Semi-Lag	NEMS GSM, advanced physics
June 2019	64	FV3 (13km)	Finite-Volume	NGGPS FV3 dycore, GFDL MP

GSM has been in service for NWS operation for 38 years !

NGGPS FV3GFS-v1 Transition to Operations

FV3GFS is being configured to replace spectral model (NEMS GSM) in operations in June 2019

Configuration:

- **FV3GFS C768 (~13km deterministic)**
- **GFS Physics + GFDL Microphysics**
- **FV3GDAS C384 (~25km, 80 member ensemble)**
- **64 layer, top at 0.2 hPa**
- **Uniform resolution for all 16 days of forecast**

Schedule:

- **5/25/2015 – 9/10/2018: retrospectives and case studies**
- **9/24/2018: Field evaluation due; EMC CCB**
- **10/01/2018: OD Brief, code hand-off to NCO**
- **12/22/2018 ~ 01/25/2019: government shutdown**
- **1/26/2019-4/3/2019: implementation on hold; investigating model cold bias and excessive snowfall issues**
- **05/10-06/10/2019: NCO 30-day IT Test**
- **06/12/2019: Implementation ! *(original date 01/24/2019)***

Topics

- GFS.v15
  - Science Changes
  - Product changes
  - System configuration and resource requirement
  - General performances
  - Benefits and concerns
  - Last minute changes to reduce cold bias and excessive snowfall
- GFS.v16 – configuration and preliminary evaluation

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

↓

FV3

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

Physics still runs at 64-bit precision

Zhao-Carr MP

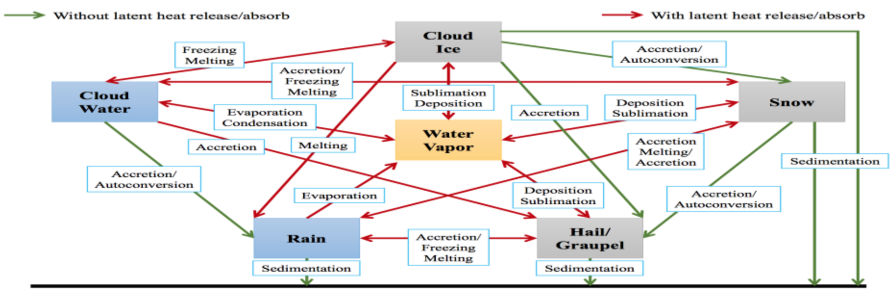
Prognostic could species: one total cloud water

↓

GFDL MP

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

more sophisticated cloud processes



Revised Bare-Soil Evaporation For Reducing Dry and Warm Biases

$$FX = (\Theta_1 - \Theta_{dry})/(\Theta_{sat} - \Theta_{dry})$$

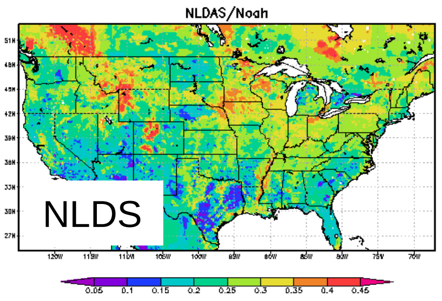
$$E_{dir} = (1 - \sigma_f)(FX)^{fx} E_p$$

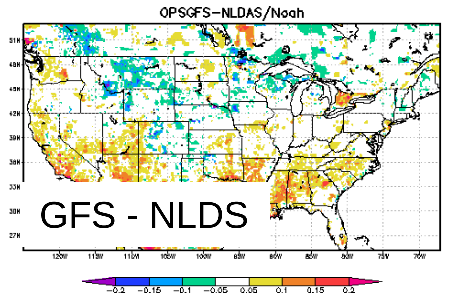
where FX is the fraction of soil moisture saturation in the upper soil layer, Θ_1, Θ_{dry}, and Θ_{sat} are the soil moisture in the upper soil layer, air dry (minimum), and the saturation (porosity) values, respectively, and fx is an empirical coefficient. Nominally, $fx = 1$ yielding a linear function

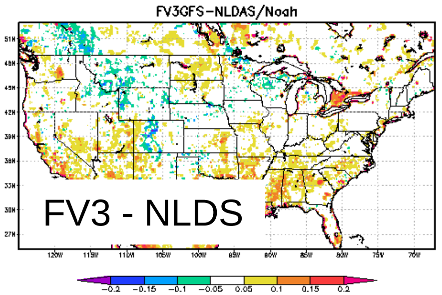
In the current model, θ_{dry} is set to the same as wilting point θ_{ref}. In reality, θ_{dry} is usually lower than θ_{ref}

The latent heat flux now contributed more from the bare soil evaporation which is directly dependent on the first layer soil moisture. Thus we have strong and fast coupling between precip and soil moisture.

The goal is to keep or increase the latent heat flux while keeping the deep soil moisture intact







4th-layer Soil Moisture

Reduced dry bias

From: Helin Wei

Updated Ozone Physics in FV3GFS

Funded by NOAA Climate Program Office

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

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

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

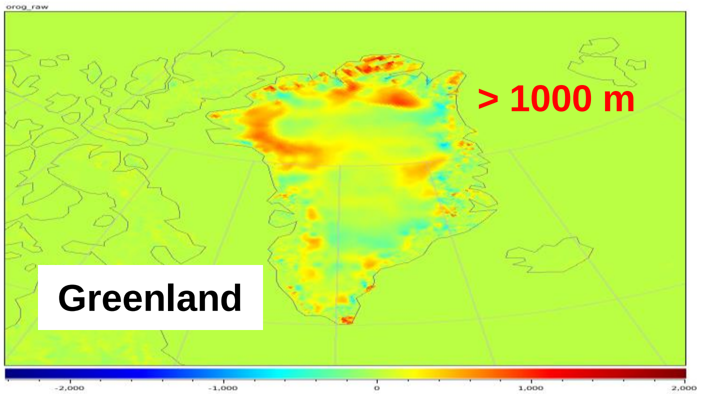
- The scheme mirrors that of ozone, with only production and loss terms.

From: Shrivinas Moorthi

Terrain: GMTED2010 vs GTOPO30

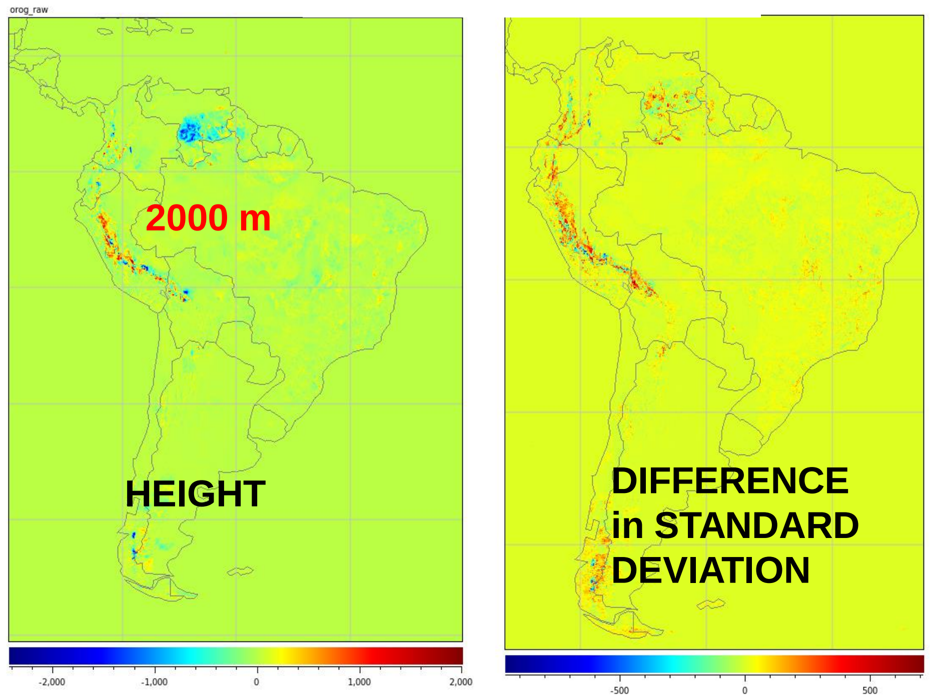
GMTED2010:
A **more accurate** replacement for GTOPO30 data, created by USGS in 2010. Primarily derived from NASA Shuttle Radar Topography Mission (SRTM) data.

GMTED minus GTOPO30

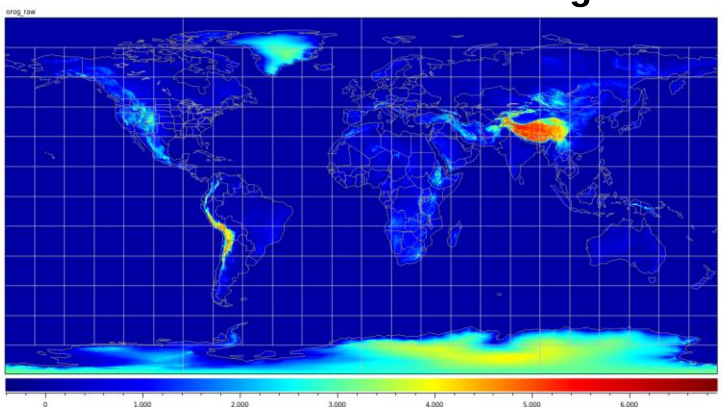


DIFFERENCES IN GREENLAND ARE LARGE IN MAGNITUDE AND AREAL EXTENT.

South America

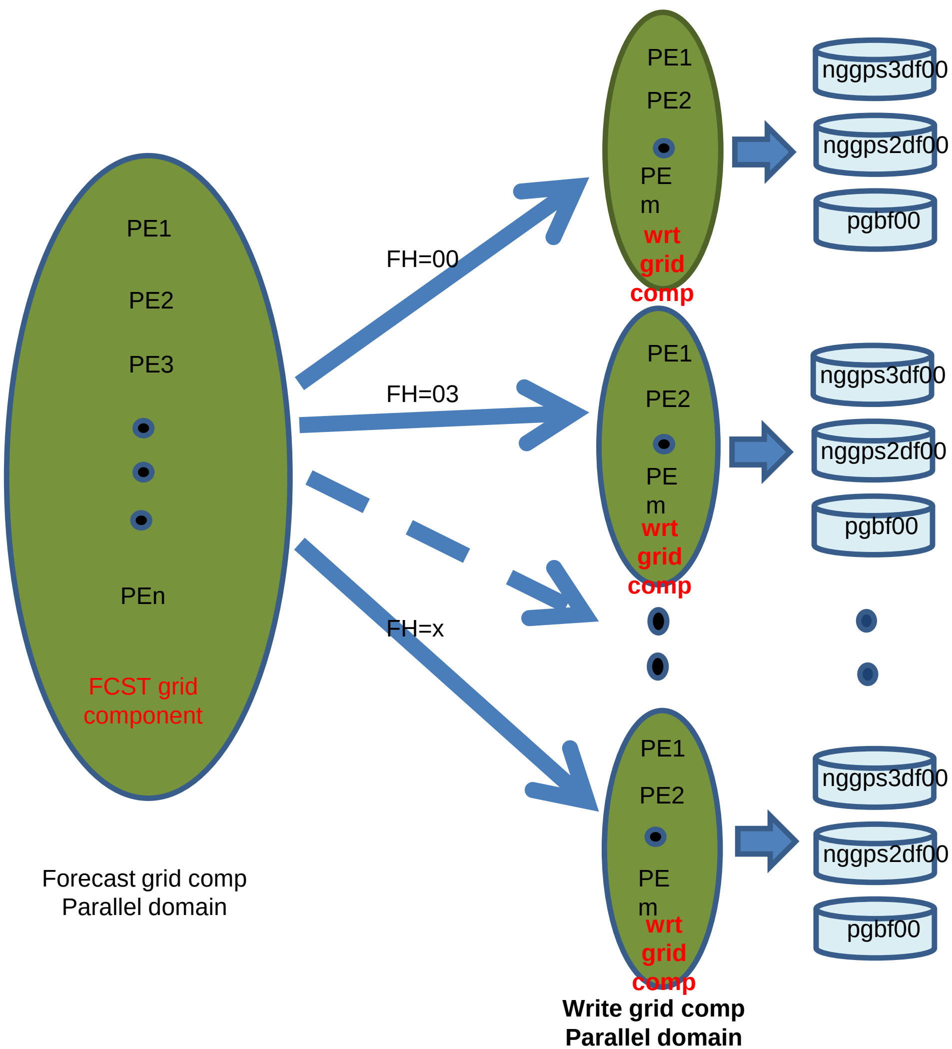


GMTED2010 – Terrain height



From: George Gayno & Fanglin Yang

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

DA: Infrastructure Changes

See Dr. Kleist's presentation on Wednesday

Post Processing Upgrade and Changes

- **Changes in products:**
  - **Vertical velocity from FV3GFS is dz/dt in m/s but omega will be derived in UPP using hydrostatic equation and still be provided to users**
  - **GFS Bufr sounding will output nonhydrostatic dz/dt only**
  - **Global aviation products have been adjusted to new MP and FV3 dynamic core**

- **Several new products are added:**
  - **More cloud hydrometers predicted by the advanced microphysics scheme**
  - **Global composite radar reflectivity derived using these new cloud hydrometers**
  - **Isobaric (3D) cloud fractions**
  - **Continuous accumulated precipitation**
  - **Complete list can be found in this Google Sheet**

- **GFS DNG products over Guam will be discontinued. EMC has coordinated with users to switch to new and better products.**

From: Hui-ya Chuang & Wen Meng

Workflow Unification

- ➢ **Almost all scripts adopted from the NEMS GFS were rewritten for the FV3GFS**
- ➢ **The old psub/pend job submission system is replaced by Rocoto drivers**
- ➢ **The 4-package superstructure workflow was merged into one package with a flat structure**
- ➢ **All JJOBS were rewritten. Both EMC parallels and NCO operation will use the same JJOBS**
- ➢ **EMC parallels and NCO operation follow the same file name convention and directory structure**

An important achievement to simplify and unify the GFS systems between the development (EMC) and operation (NCO)

Retrospective and Real-Time Parallels

- Initially, six streams of retrospective parallel were carried out to cover the period from May 2015 through May 2018.
- Most of the streams were run on WCOSS DELL, which was used as a dedicated computing resource for running fv3gfs with *all other uses blocked.*

http://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/prfv3rt1	**real-time parallel**
http://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/fv3q2fy19retro1	hord=6, Dec2017 ~ May2018
http://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/fv3q2fy19retro2	hord=6, Jun2017 ~ Nov2018
http://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/fv3q2fy19retro3	hord=6, Dec2016 ~ May2017
http://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/fv3q2fy19retro4	hord=6, Jun2016 ~ Nov2016
http://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/fv3q2fy19retro5	hord=6, Dec2015 ~ May2016
http://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/fv3q2fy19retro6	hord=6, Jun2015 ~ Nov2015

http://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/gfs2019

Aggregated: Comparing NEMS GFS with FV3GFS (hord=6). Including all streams

HORD5 v.s. HORD6

- It was found **hurricane intensity was too weak** in the first set of parallels.
- GFDL suggested we rerun the deterministic forecast using an alternative advection scheme (HORD5), while keep using the original scheme (HORD6) in the data assimilation cycle.
- A set of experiments were conducted to demonstrate that using HORD5 does improve hurricane intensity and does not degrade other forecast skills
  http://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/gfs2019c

A Brief Guide to Advection Operators in FV3, by Lucas Harris, Shian-Jiann Lin, and Xi Chen .

…The operators in the most recent version of FV3 all use the piecewise-parabolic method (Collella and Woodward 1984), …Here we briefly describe three PPM operators, all formally the same fourth-order accuracy but with different reconstruction limiters: An unlimited (also called linear) “fifth-order” operator (hord = 5), an unlimited operator with a 2dx filter (hord = 6), and the monotone Lin 2004 operator (hord = 8). … **They do not change the order of accuracy of the advection, only the diffusivity and shape-preserving characteristics.**

…Hord = 6 uses a much stronger 2dx filter: the hord = 5 method is extended by reverting to first-order upwind flux if the difference in cell-interface values exceeds the mean of the two interface values by a tunable threshold (1.5x by default).

Retrospective and Real-Time Parallels

NCEP Director approved the use of HORD5 starting from the 2018081518 cycle in the real-time parallel. We also reran all past hurricane seasons and one winter/spring season with HORD5.

http://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/prfv3rt1	**real-time parallel**
http://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/fv3q2fy19retro1c	hord=5, Dec2017 ~ Aug2018
http://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/fv3q2fy19retro2c	hord=5, Jun2017 ~ Nov2018
http://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/fv3q2fy19retro4c	hord=5, Jun2016 ~ Nov2016
http://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/fv3q2fy19retro6c	hord=5, Jun2015 ~ Nov2015

In total
11 streams,
2000 days,
8000 cycles

Aggregated STATS

http://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/gfs2019b

Comparing NEMS GFS with FV3GFS, including all cases from hord5 runs, and 2015 and 2016 winter/spring streams with hord6.

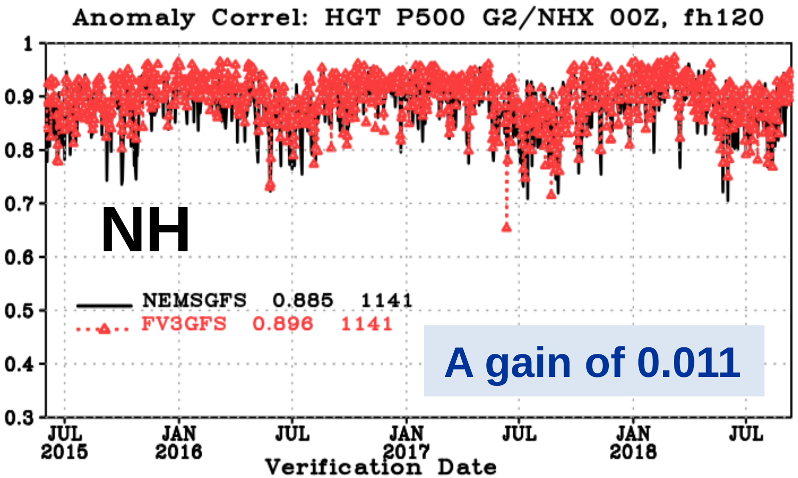
http://www.emc.ncep.noaa.gov/users/Alicia.Bentley/fv3gfs/ MEG evaluation page
http://www.emc.ncep.noaa.gov/gmb/STATS_vsdb/ International models

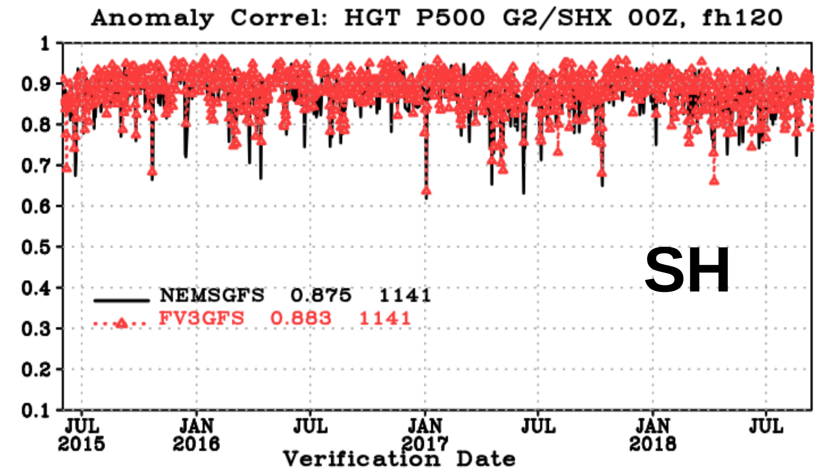
Verification & Evaluation

nomenclatures:
ops GFS, NEMSGFS or GSM referred in this talk are the same spectral model

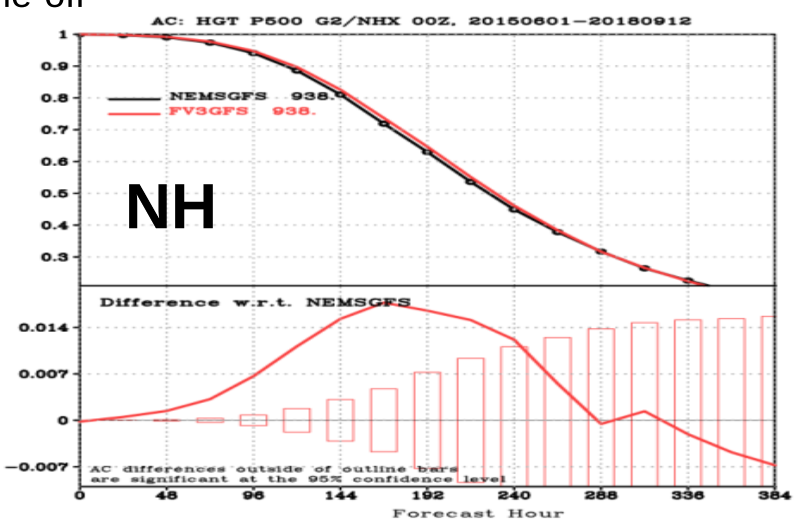
500-hPa HGT Anomaly Correlation
(20150601 ~ 20180912)

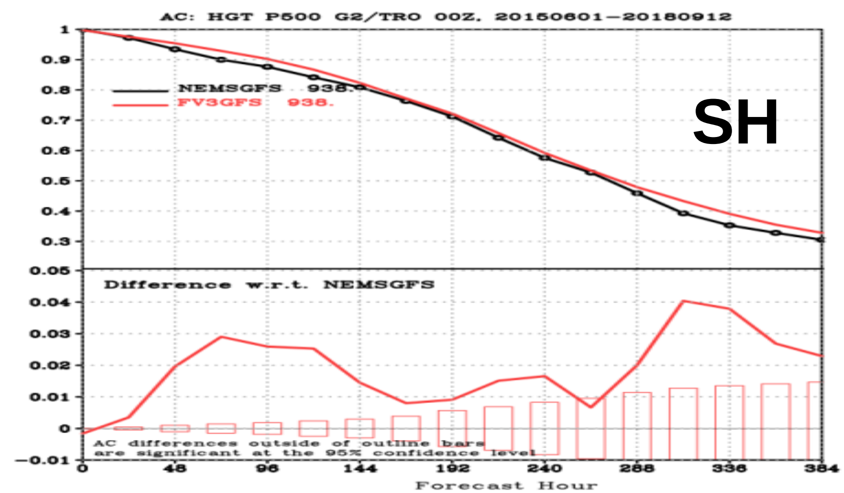
Day-5





Die-off



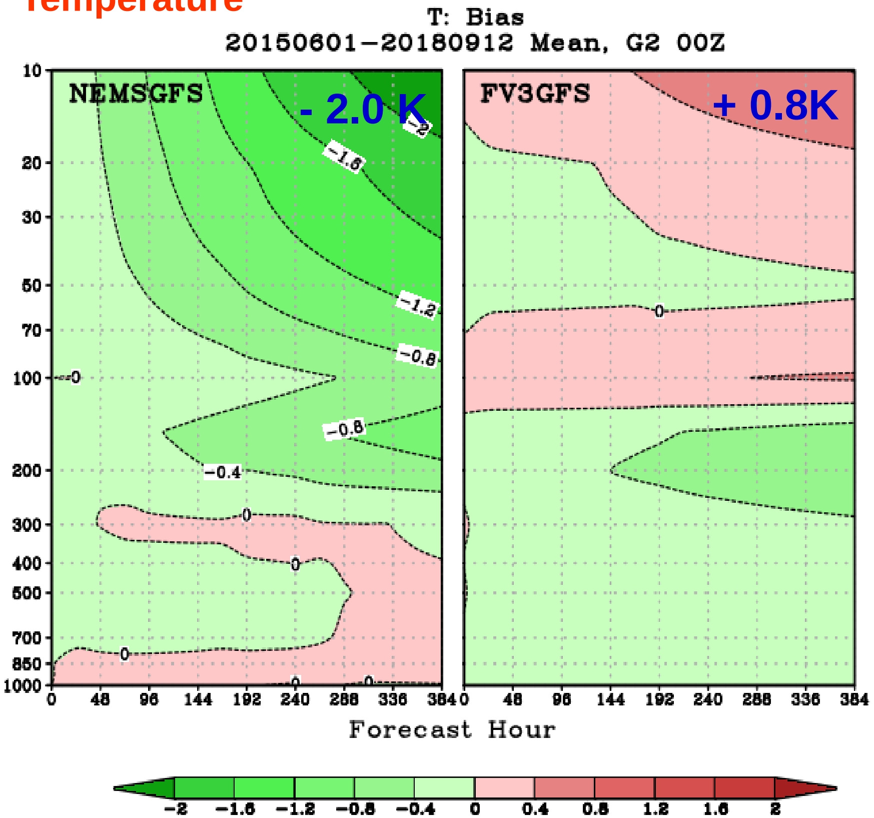


Increase is significant up to day 10

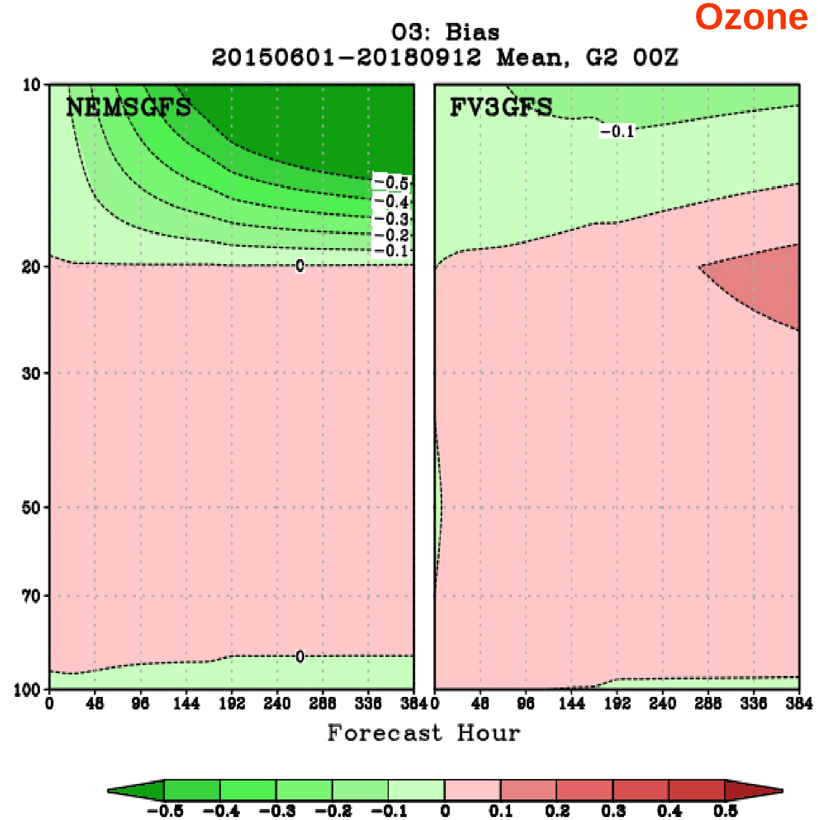
Global Mean Temperature & Ozone Bias

Verified against analyses

Temperature



Ozone

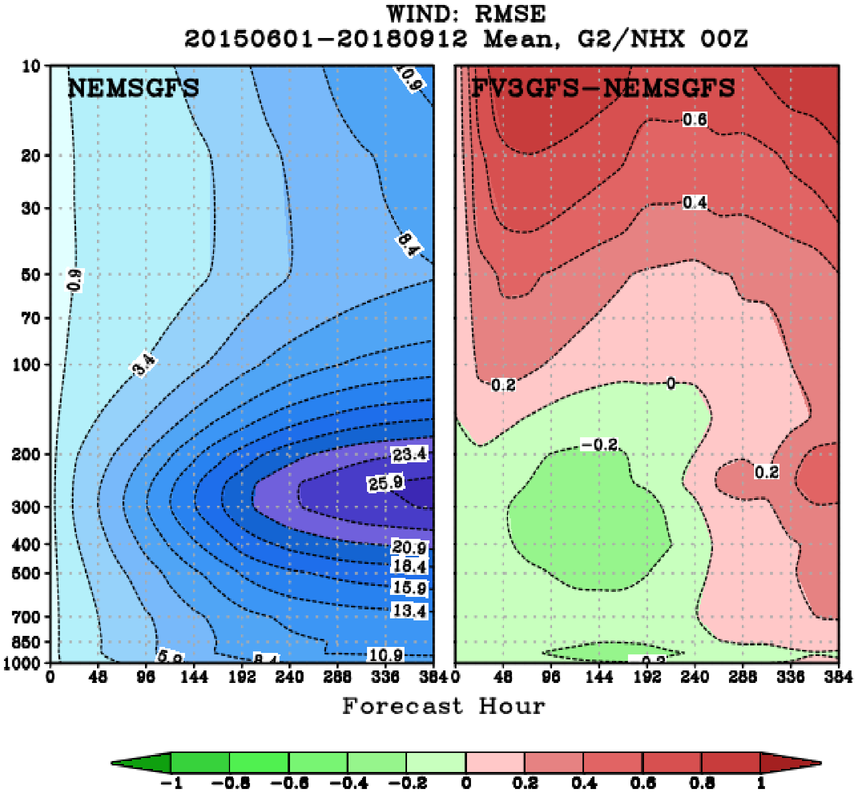


GSM has strong cold bias in the middle to upper stratosphere (- 2K).
FV3GFS warm bias (+0.8K) is caused by a radiation bug (more to come)

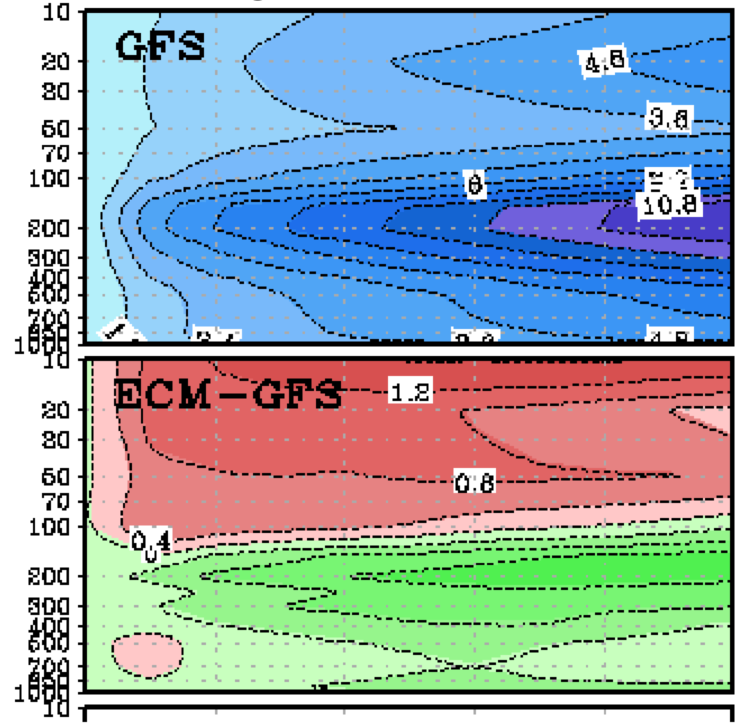
GSM loses ozone in forecast.
FV3GFS conserves better.

NH WIND RMSE

Verified against analyses



August 2018

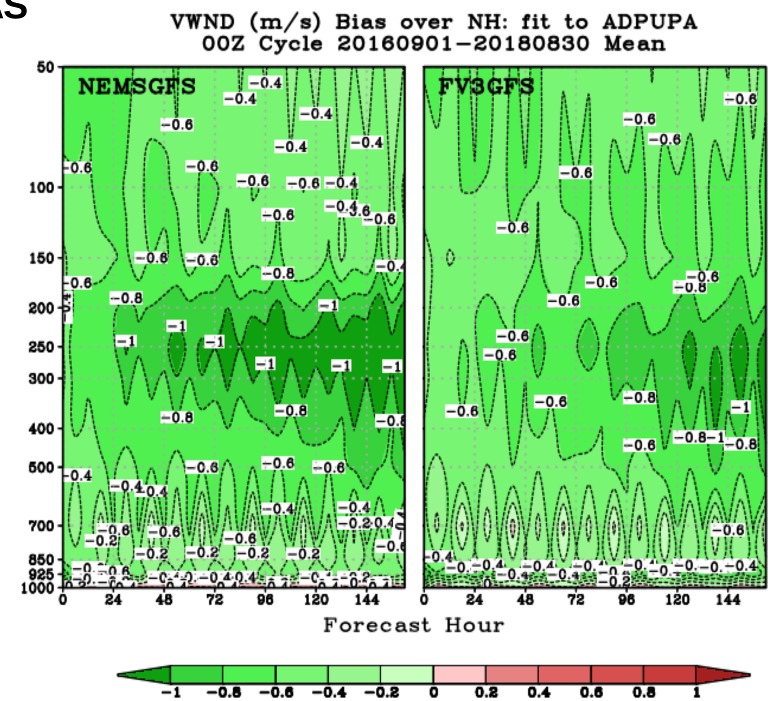


- FV3GFS has larger RMSE than GSM in the stratosphere
- FV3GFS RMSE is similar to ECMWF RMSE
- GSM winds in the stratosphere is too smooth due to strong damping

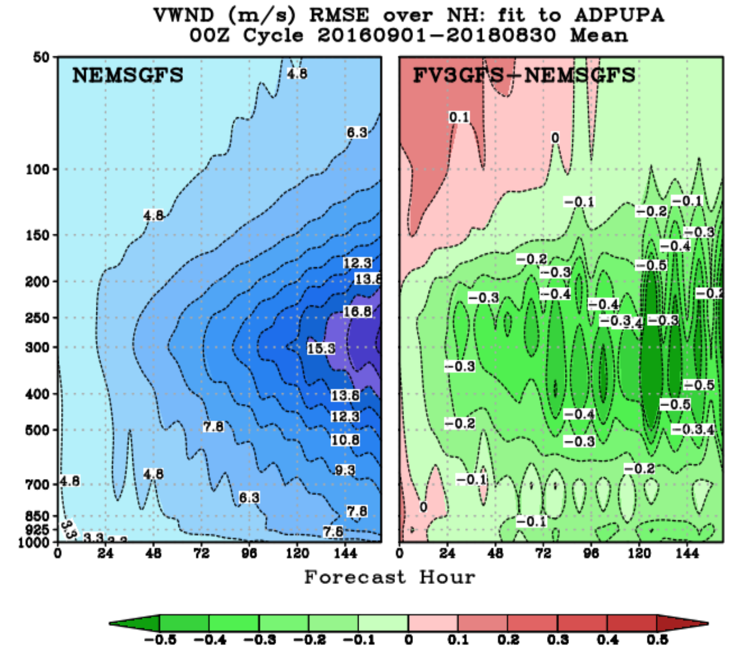
NH WIND BIAS and RMSE

Verified against ROBS, 20160901 ~ 20180831

BIAS



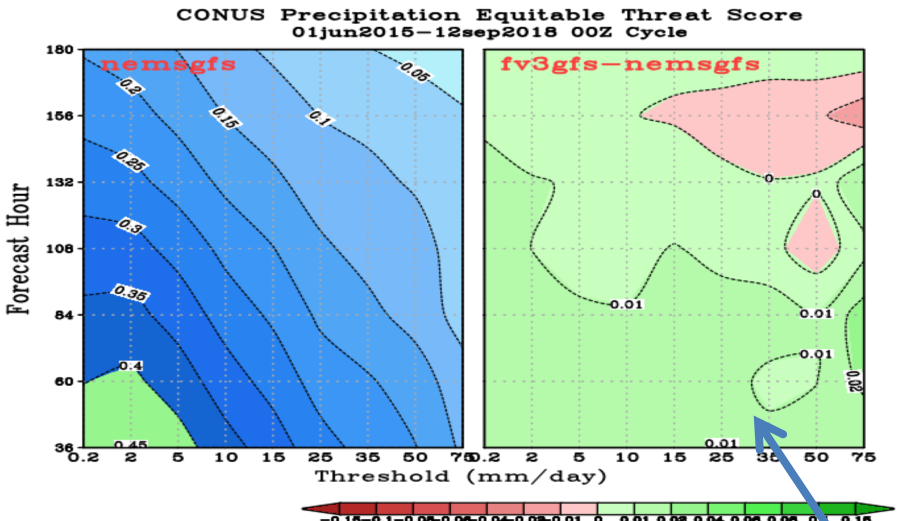
RMSE

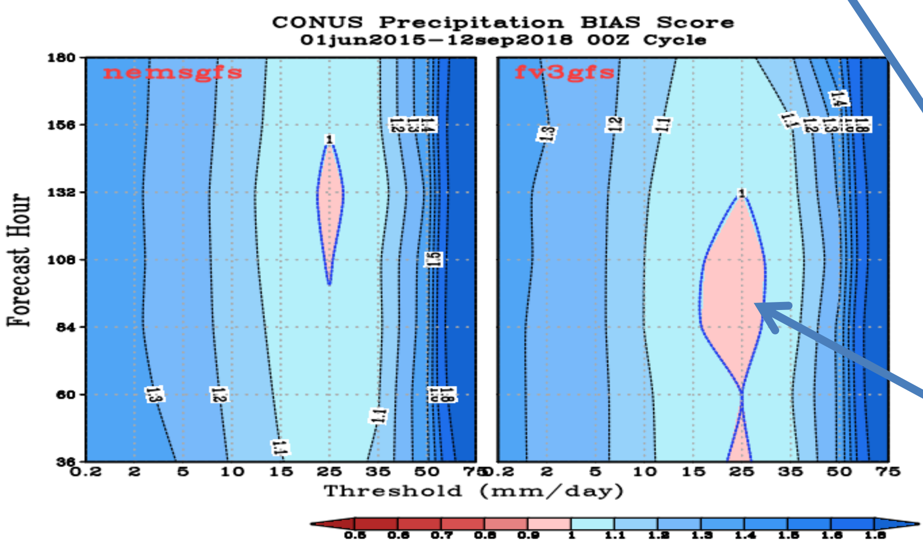


- Winds in both GSM and FV3GFS are weaker than observed, but **FV3GFS is closer to the observation**.
- FV3GFS has stronger winds at the jet level, **reduced RMSE in the troposphere**, but worse in the stratosphere

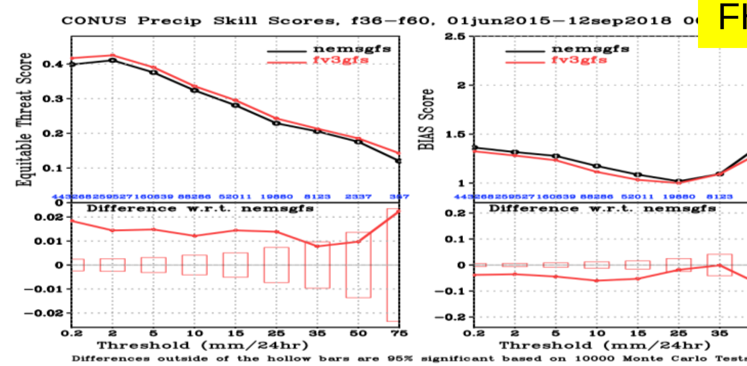
CONUS Precip ETS and BIAS SCORES

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

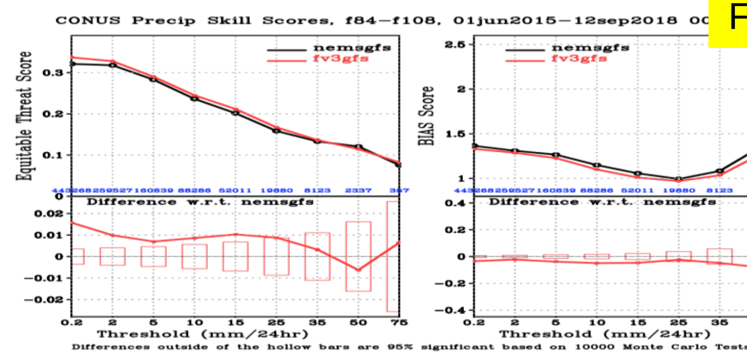




FH 36-60



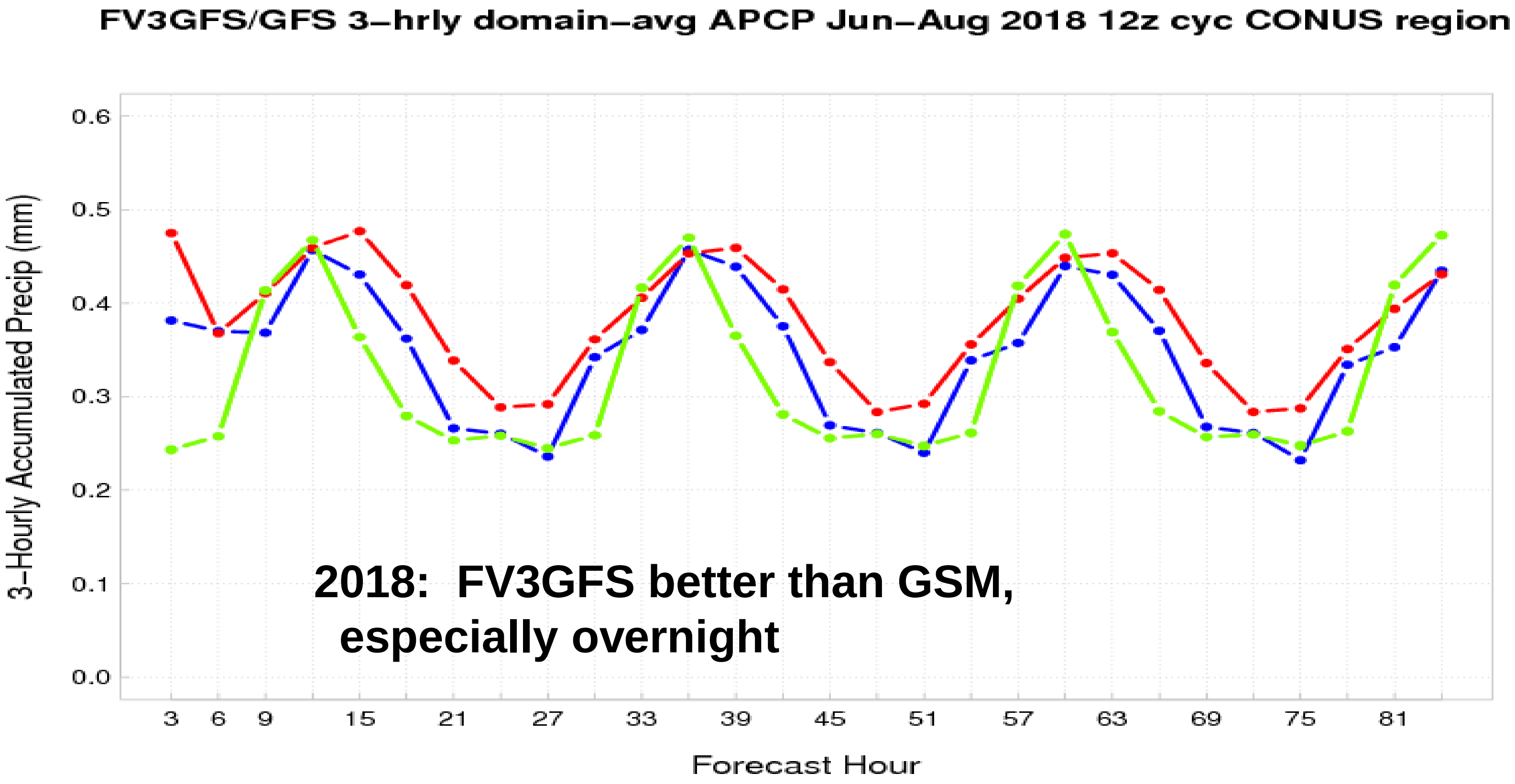
FH 84-108



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

Improved Precipitation Diurnal Cycle

SUMMER 2018 CONUS DOMAIN-AVG PCP



FV3GFS **ops GFS** **OBS**

From: Ying Lin

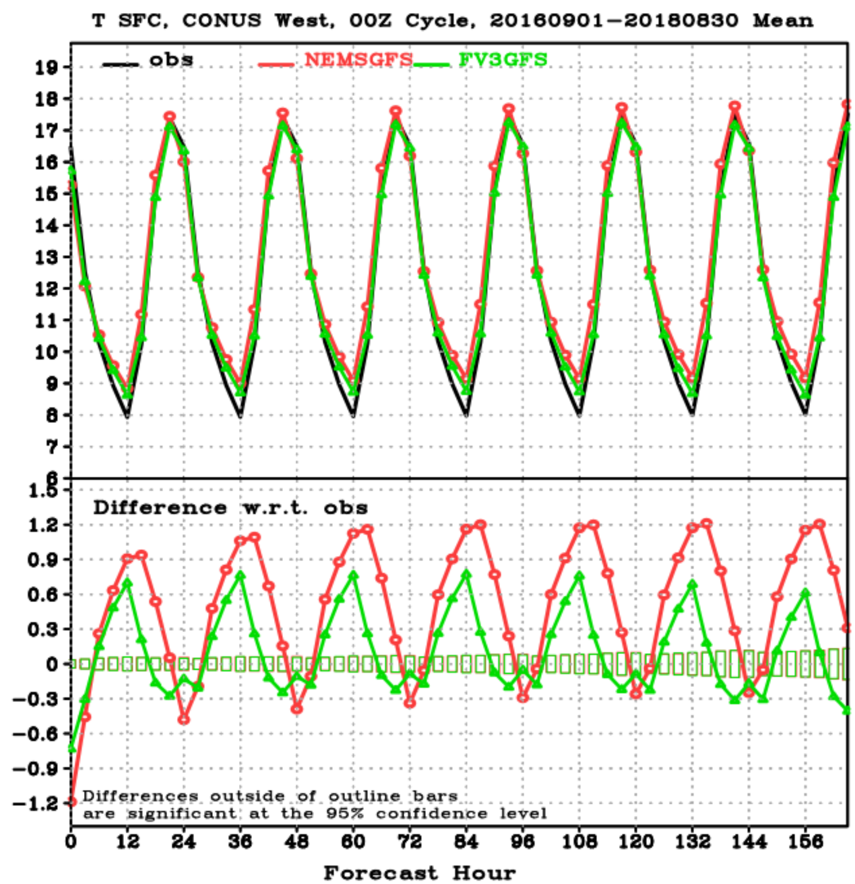
CONUS 2-m Temperature

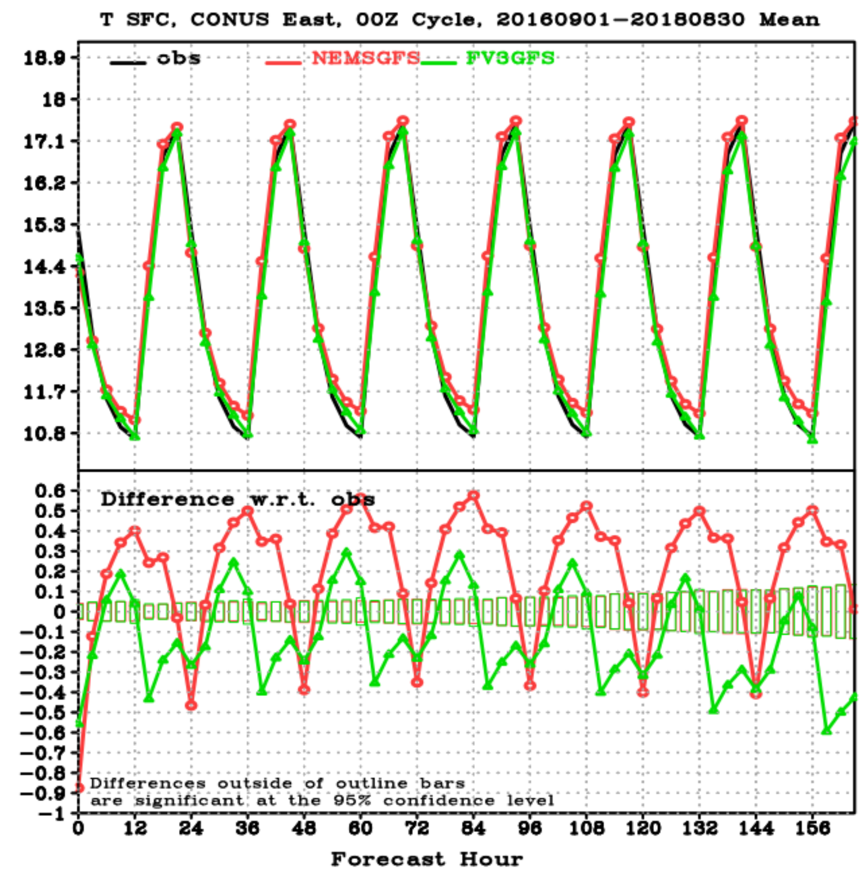
Verified against Station Observations, 3-year mean

WEST

OBS GFS FV3GFS

EAST





Slight FV3GFS improvement in both the min and the max

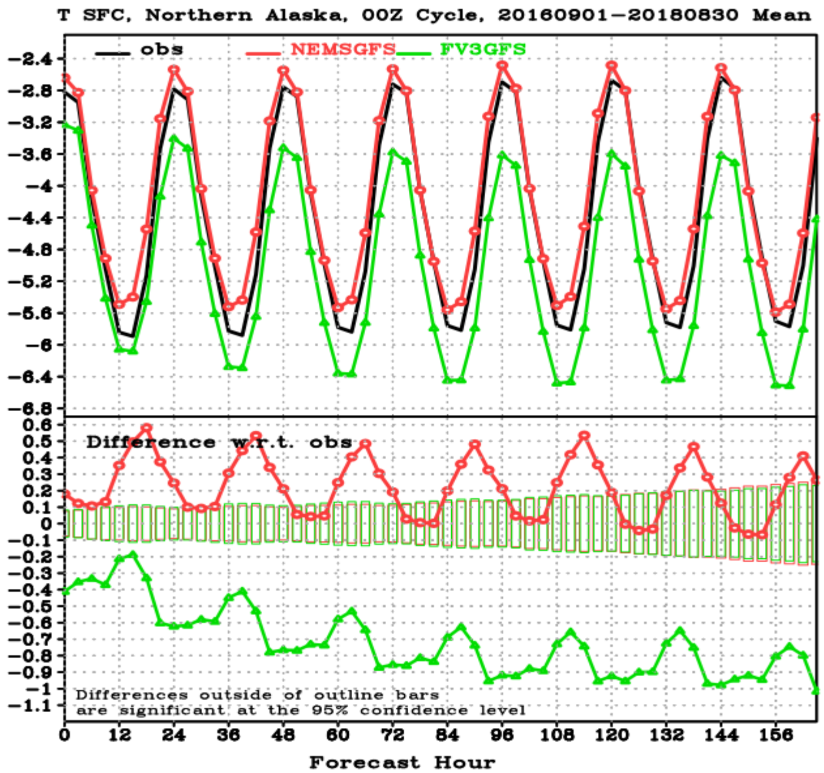
2-m Temperature over Alaska

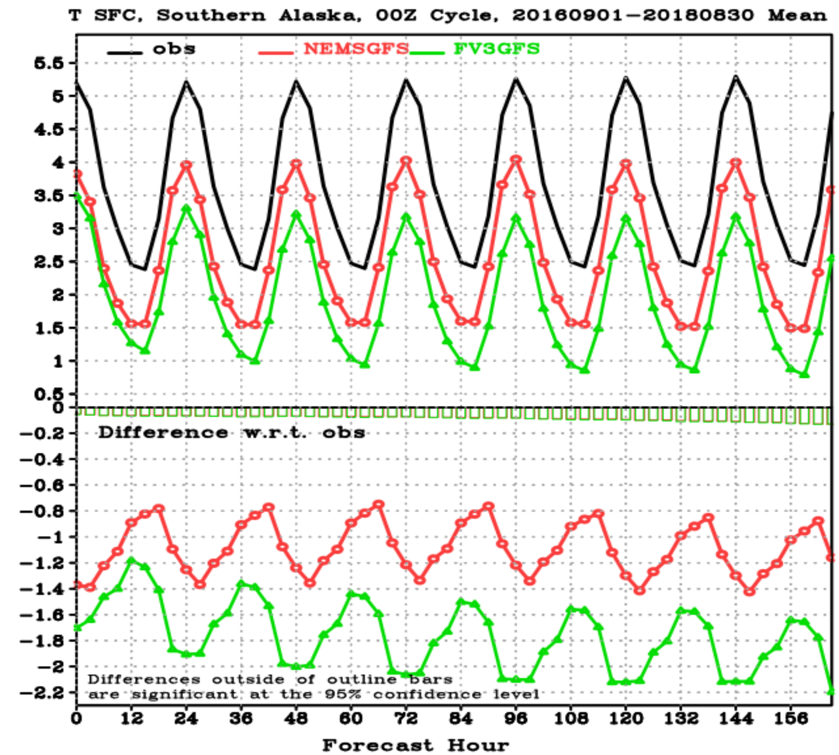
Verified against Station Observations, 3-year mean

NORTH ALASKA

OBS GFS FV3GFS

SOUTH ALASKA





FV3GFS has large cold bias !

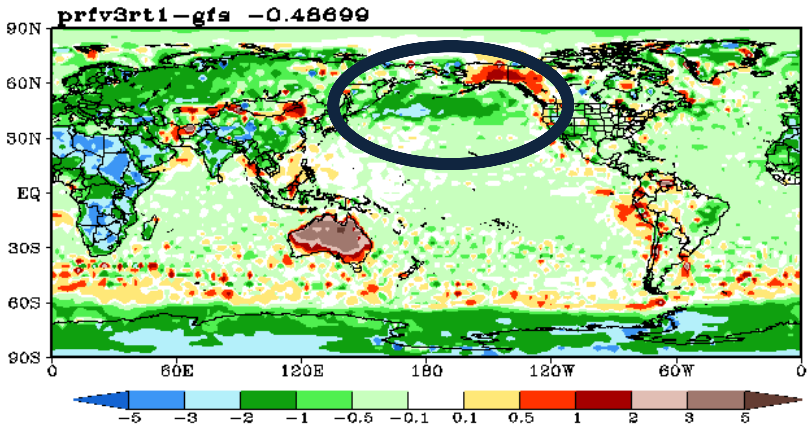
Likely caused by a cold NSST and an overestimate (underestimate) of cloud in summer (winter)

Diagnosing and Fixing the NSST Issue

- In response to feedback on how well gulf stream was resolved, the background error correlation lengths were revised to be more consistent with those used in other operational SST analyses (50km).
- After a number of months of pre-operational testing an SST anomaly of ~3K was noted in the northern Pacific. This was a symptom of a lack of observations in the area and the reduced influence of distant observations because of the reduction in length scales.
- At the same time anomalies in lake temperatures were noted by the MEG team which was also traced to a lack of observations being assimilated.

Both of these are solved by switching on a climatological update of the tref to the background SST field. This option is currently being tested along with an increase in background error length scales to 100km.

Tref, 26 May – 18 September 2018



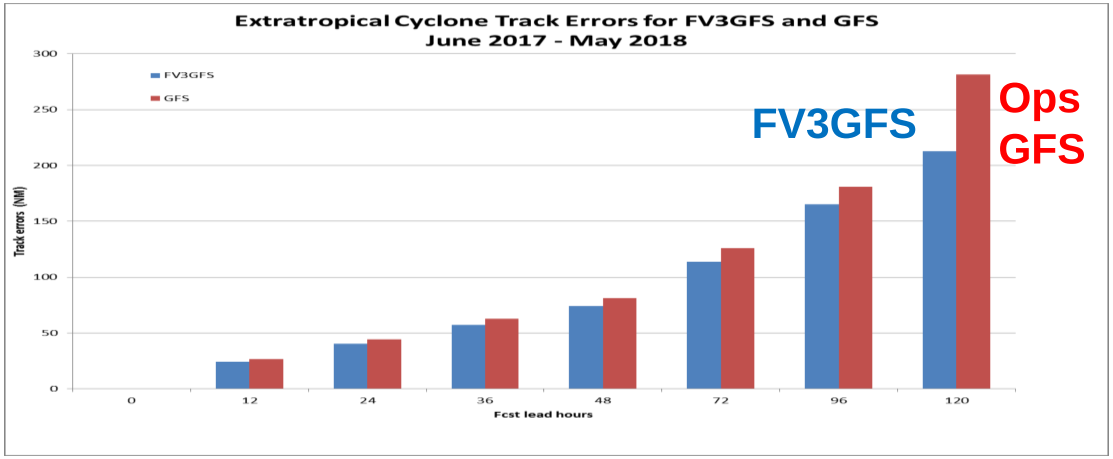
gcycle is now called hourly in GDAS forecast step

From: DA Team

Extratropical Cyclone Track

Jun 2017 ~ May 2018

FV3GFS track errors are consistently smaller than that of GFS. Error at 120 hour is substantially smaller. (Unit: NM)



Track errors

FCST hr	0	12	24	26	48	72	96	120
FV3GFS	0.0	24.09	40.38	57.04	73.91	113.66	165.22	212.75
GFS	0.0	26.59	44.17	62.87	81.08	125.89	180.85	281.57
diff	0.0	-2.50	-3.79	-5.83	-7.17	-12.23	-15.63	-68.82

Number of cases

FCST hr	0	12	24	26	48	72	96	120
FV3GFS	15490	14895	13904	10069	6231	2285	799	239
GFS	16672	16156	15031	10906	6776	2563	925	281
diff	-1182	-1261	-1127	-837	-545	-278	-126	-42

FV3GFS captures slightly smaller number of cases.

From: Guang-Ping Luo

Tropical Cyclone Genesis

		AL2015	AL2016	AL2017	EP2015	EP2016	EP2017
# Cases	Ops GFS	139	145	119	210	234	100
	FV3GFS		171	145		196	104
Hit (POD)	Ops GFS	63%	60%	92%	74%	65%	63%
	FV3GFS		65%	71%		77%	67%
False Alarm	Ops GFS	65%	49%	64%	49%	28%	57%
	FV3GFS		51%	49%		63%	68%

FV3GFS has overall higher POD, but also higher false alarm rate.

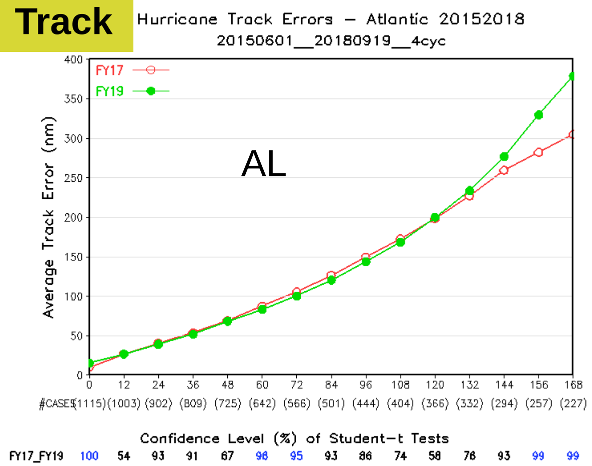
From: Jiayi Peng

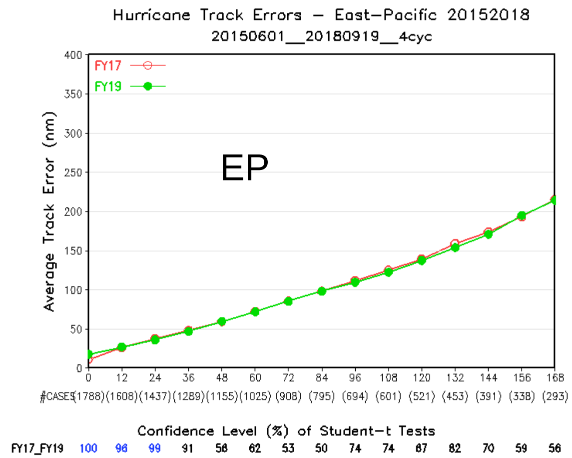
Hurricane Track and Intensity

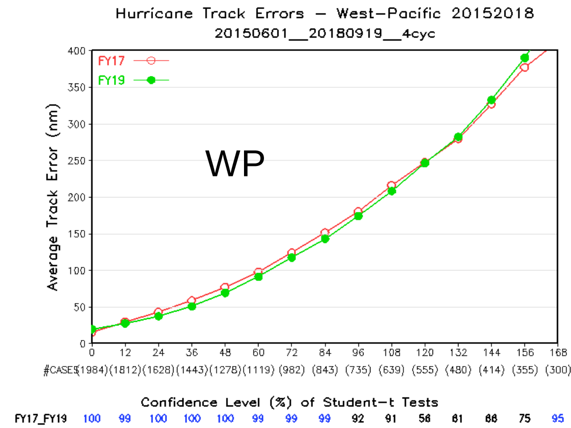
20150601 ~ 20180919

Red: NEMS GFS; Green FV3GFS

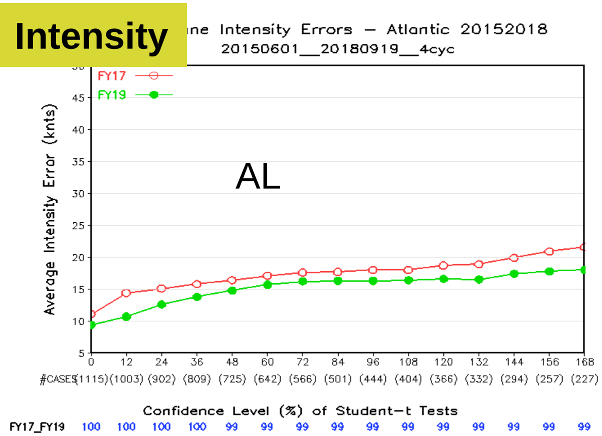
Track

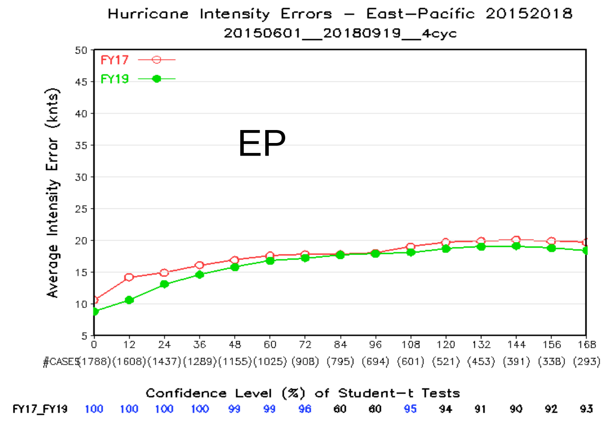


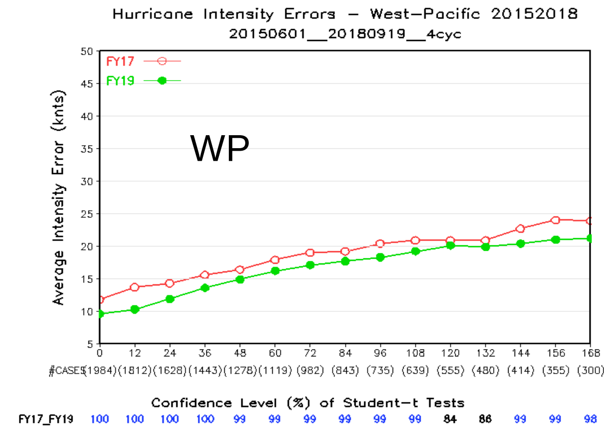




Intensity





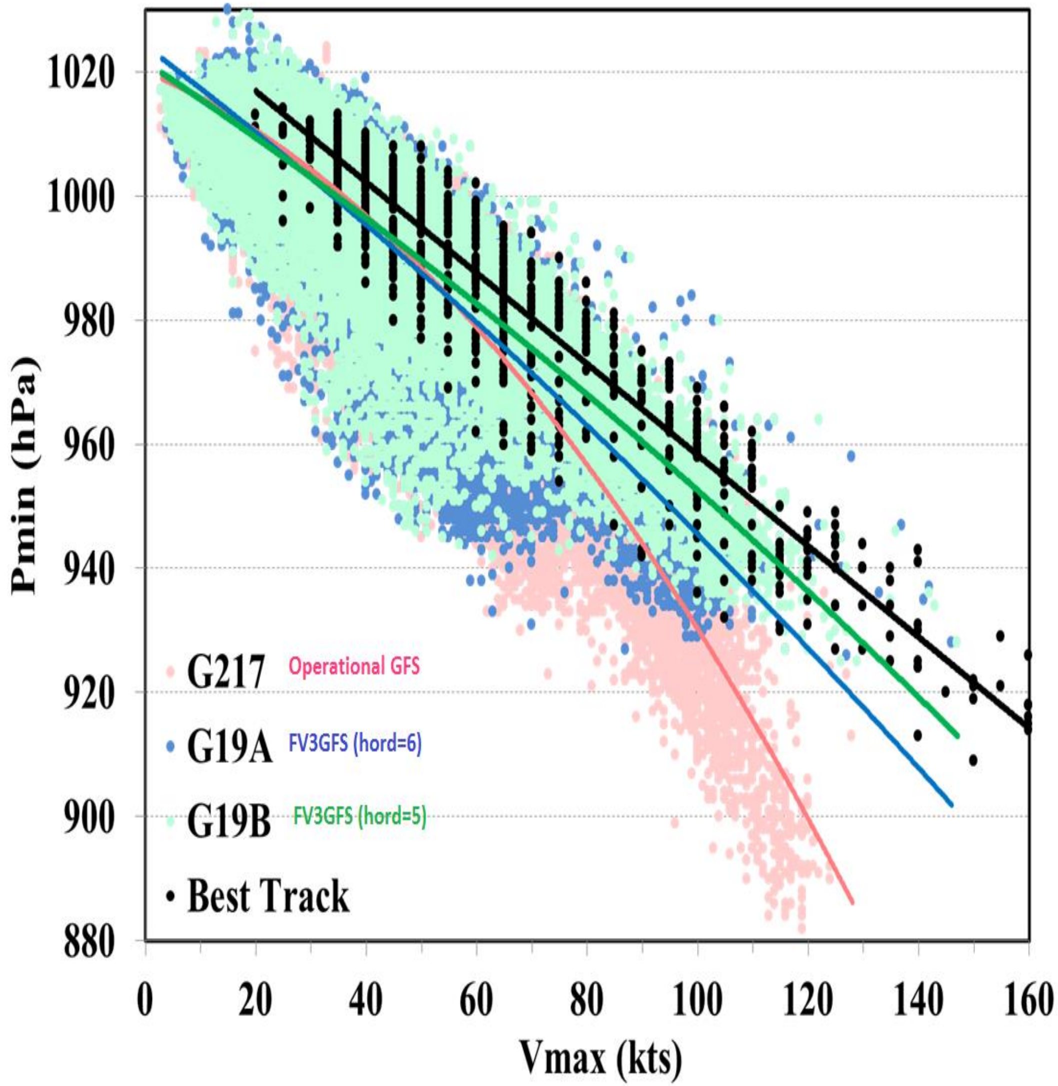


- **Intensity is improved over all basins**
- **Tracks in AL and WP are improved for the first 5 days except at FH00, and degraded in day 6 and day 7. Track in EP is neutral**

Improved Wind-Pressure Relationship

FV3GFS shows a much better W-P relation than ops GFS for strong storms

For FV3GFS, W-P relation with hord=5 is better than hord=6

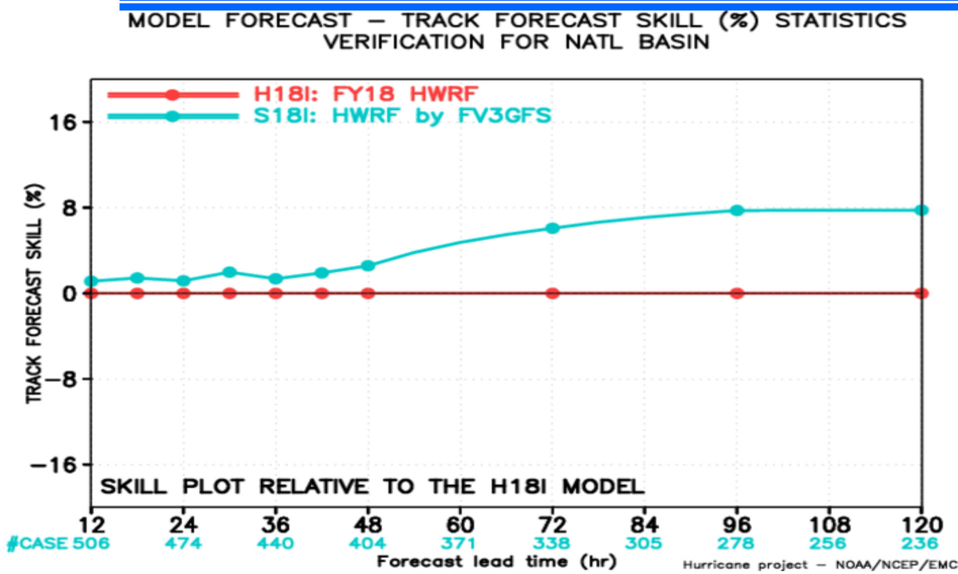


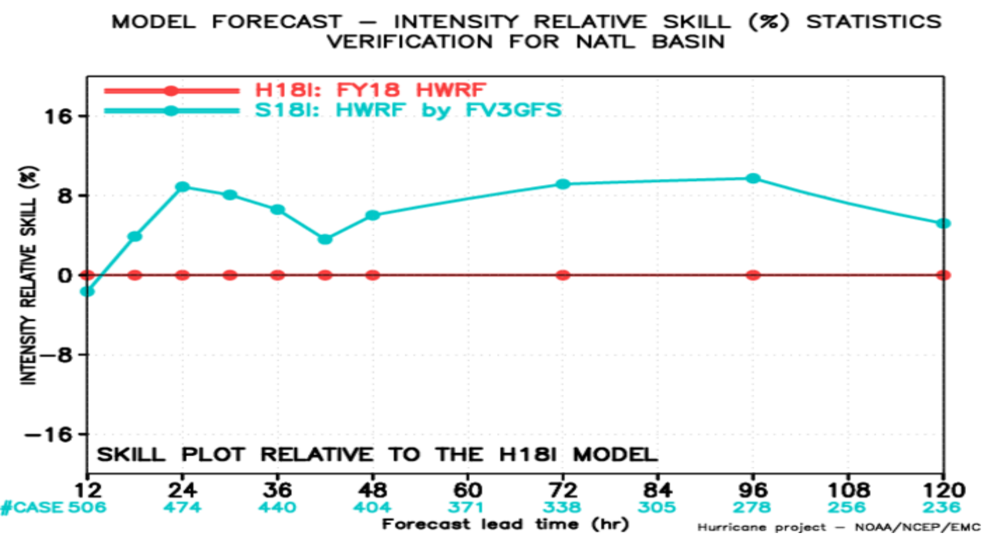
Graph made by HWRF group

HWRF Tests
forced by FV3GFS

FY18 HWRF Testing with FV3GFS

Priority Storms, Early Model





Atlantic

There is good improvement in track skill especially for longer lead times reaching 8% at Days 4 and 5.

Intensity skill improvements are evident at all lead times with more than 8% improvements at Day 1 and again at Day 4.

2015-2017

NATL priority storms

2017 17L Ophelia*
2017 16L Nate*
2017 15L Maria*
2017 14L Lee
2017 12L Jose*
2017 11L Irma*
2017 09L Harvey*

2016 15L Nicole
2016 14L Matthew*
2016 12L Karl*
2016 09L Hermine*
2016 07L Gaston
2016 06L Fiona
2016 05L Earl*

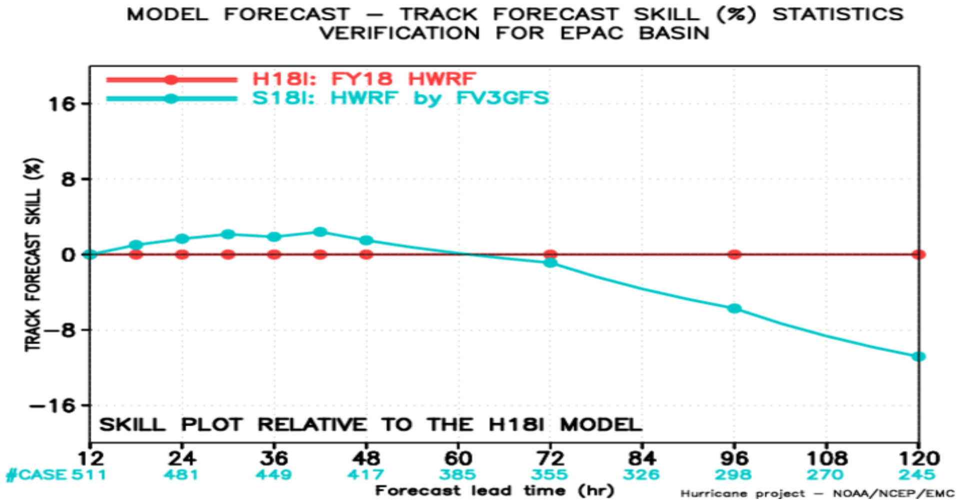
2015 11L Joaquin*
2015 07L Grace
2015 06L Fred
2015 05L Erica*
2015 04L Danny*

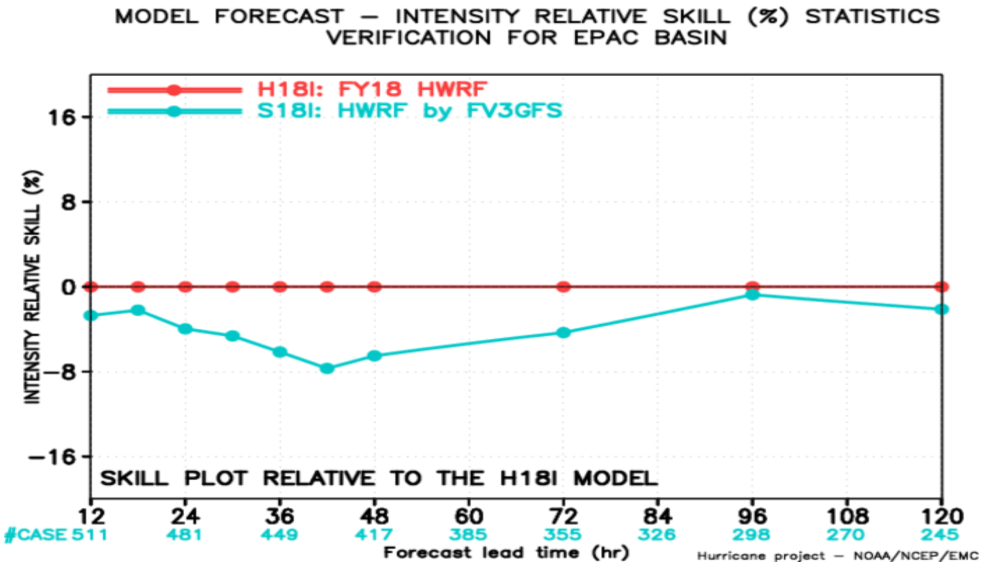
* This list was jointly devised by NHC and EMC based on criterion related to best representation of basins

From: Avichal Mehra

FY18 HWRF Testing with FV3GFS

Priority Storms, Early Model





Eastern Pacific

Track forecast skill is improved for the first 2 days and then neutral for Day 3, but behind for Days 4 and 5.

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

2015-2017

EPAC priority storms

2017 17E Norma
2017 15E Otis
2017 13E Kenneth
2017 10E Irwin
2017 09E Hilary

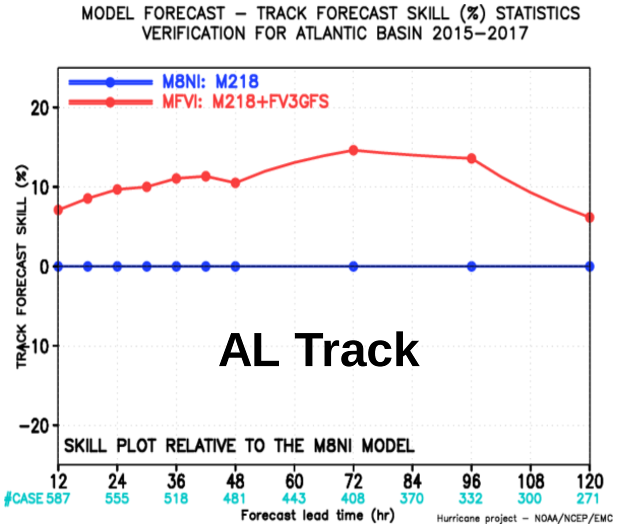
2016 15E Newton
2016 13E Lester
2016 11E Javier*
2016 07E Frank
2016 05E Darby
2016 04E Celia

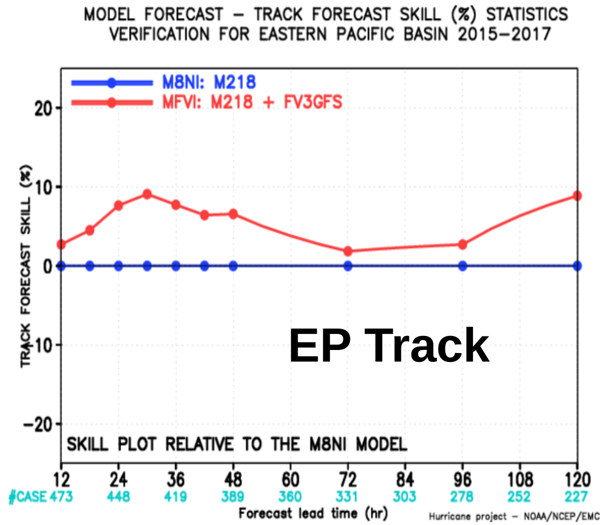
2015 20E Patricia*
2015 19E Olaf
2015 13E Jimena
2015 12E Ignacio
2015 06E Enrique

From: Avichal Mehra

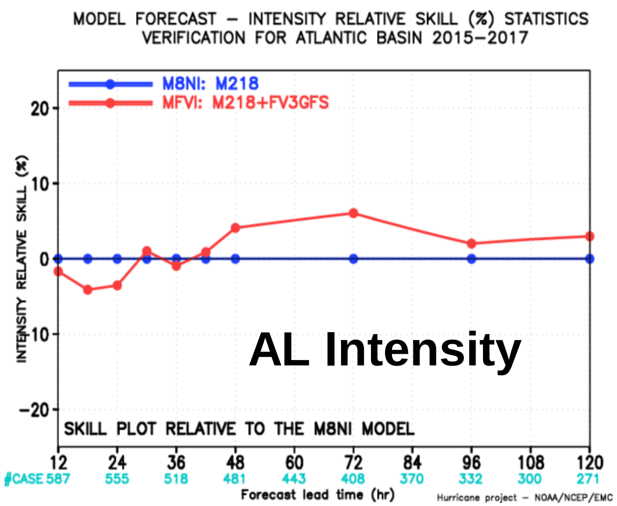
FY18 HMON Testing with FV3GFS

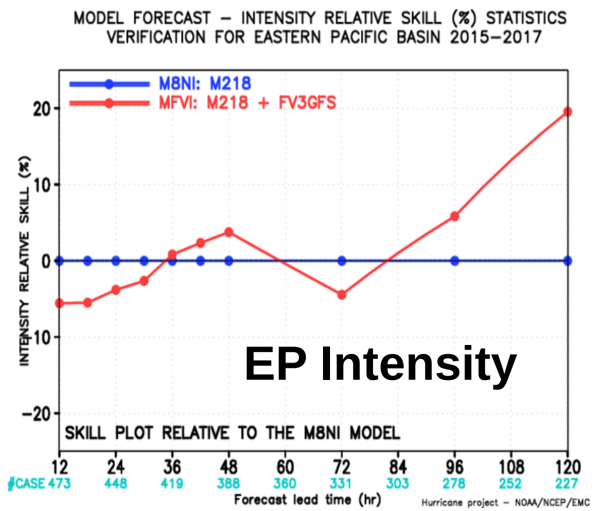
Priority Storms, Early Model





AL: improvement in **track** skill for all lead times peaking at around 14 % (at Day 3) while giving an **average improvement of 10%. Intensity** skill improvements start after Day 2 with **4-6% improvements at Day 2 and 3.**





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

From: Avichal Mehra

While the model is ready for its prime time in January 2019

The Unexpected Happened

Implementation was On Hold

The Unexpected Implementation On Hold

- **It was noticed in late January (while the government was still closed) that FV3GFS was becoming colder and colder in the troposphere.**

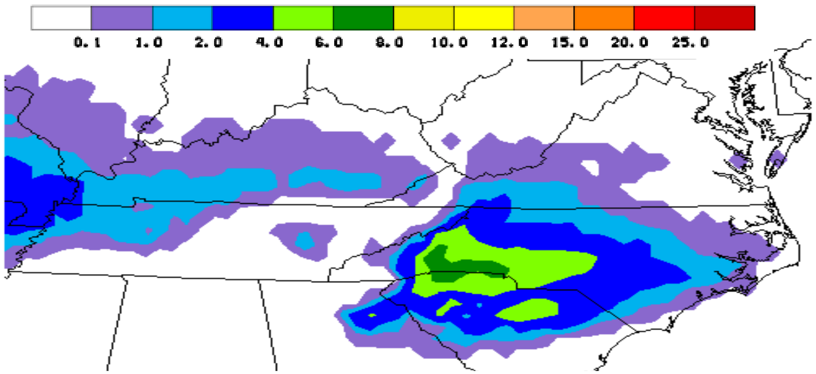
- **FV3GFS produced too much snow in US east coast region during a February storm. This event caught a lot of media attention.**

1. ***A July 2018 bug fix to address erroneous snow in the tropics inadvertently caused excessive snow issue.***

2. ***A September 2018 bug fix to address erroneous solar zenith angle in the radiation inadvertently exaggerated the cold bias.***

3. ***A supersaturation constraint in data assimilation led to excessively cold polar temperature***

Issue #1
Excessive Snowfall in FV3GFS



FV3GFS 6-hr snow accumulation (inches)
102-108hr Fcst, valid 18Z19Feb ~ 00Z20Feb, 2019

0/0000V108 : 190219/1800V102 108-HR GFSX SNOW DEPTH (I

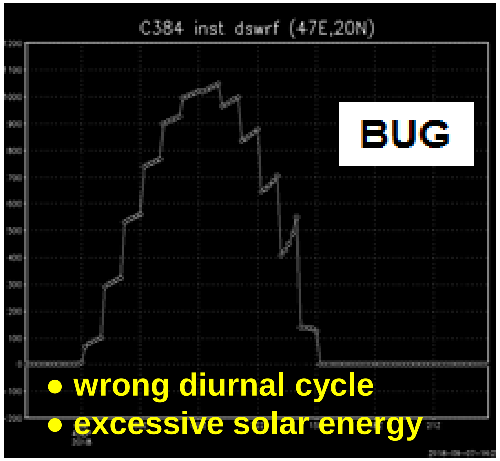
FV3GFS predicts wide spread snowfall over NC, KY, northern GA, and northern SC, which was not consistent with other forecast guidance

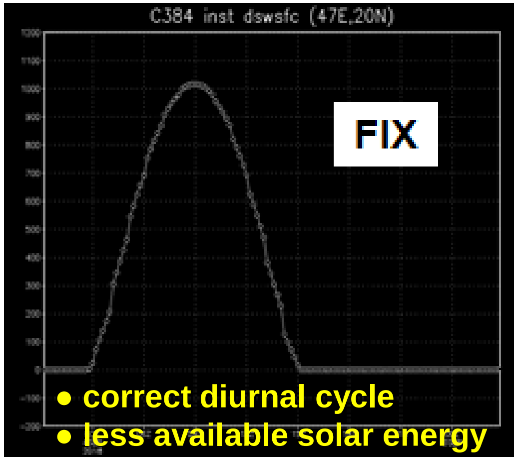
One cause: snow depth calculation in the model

- Prior to July 2018, if there was more liquid precipitation than frozen, the land surface model (LSM) ignored the frozen precipitation and would not melt it, even in warm environments.
- A fix was put in July 2018 so that when *any* frozen precip is present, the LSM treats *all* precip (frozen and liquid) as frozen. In a warm environment, the LSM will melt it, but in colder environments, snow depth will be overestimated.

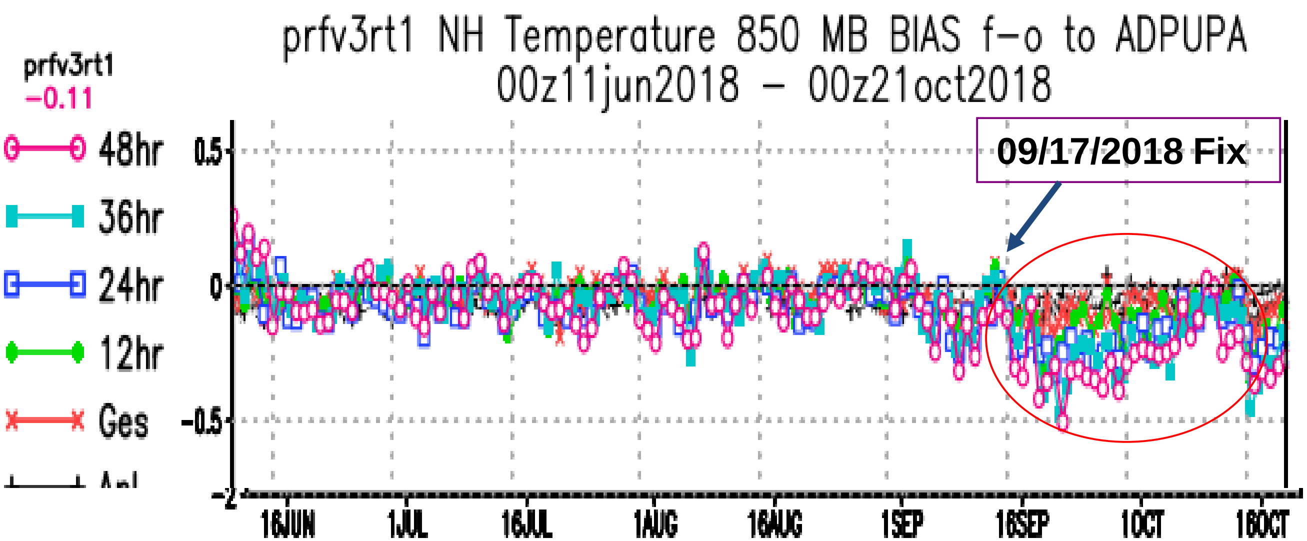
Issue #2
Exacerbated cold bias in the lower atmosphere

Hrly surface downward SW radiation





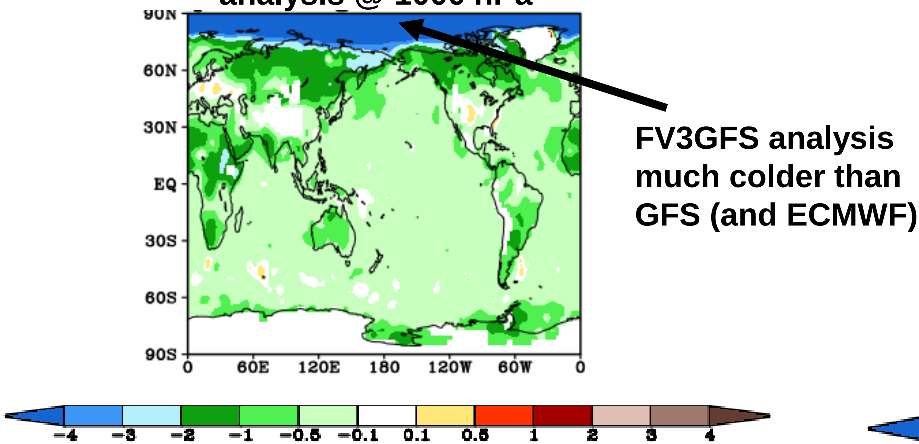
The cause: Bug fix for erroneous Solar Zenith Angle computation in the radiation



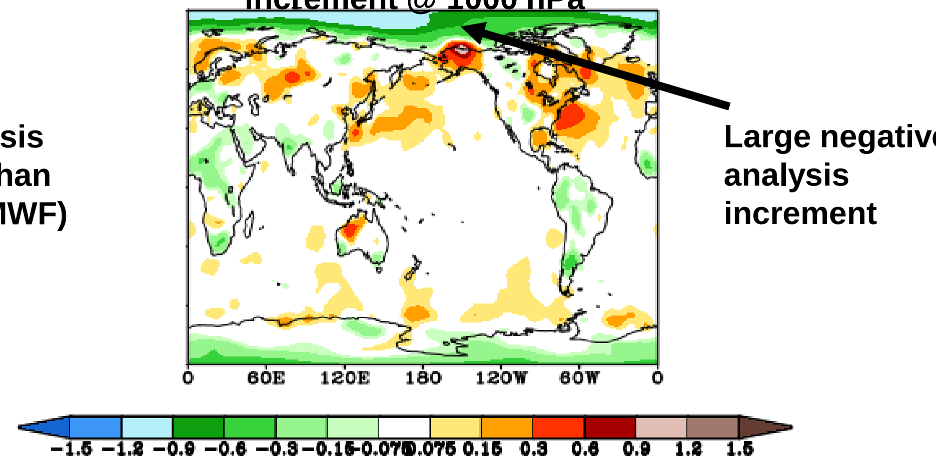
The bug fix was introduced on Sept. 17, 2018 in the real-time parallel, which coincided with signs of increased cold bias in the lower troposphere.

Issue #2
Exacerbated cold bias in the lower atmosphere

FV3GFS – GFS temperature analysis @ 1000 hPa



FV3GFS temperature analysis increment @ 1000 hPa



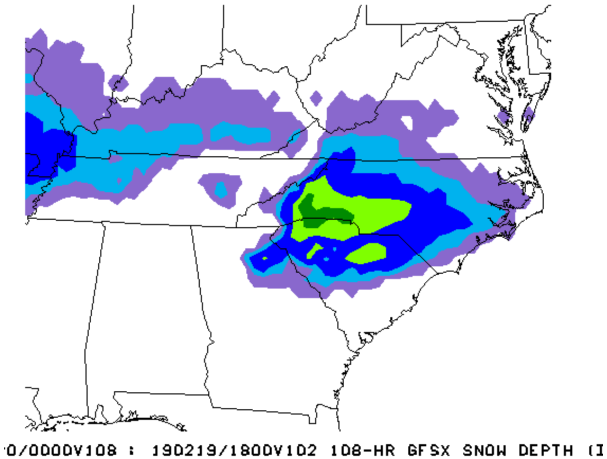
The cause: FV3GFS analysis has a stronger constraint on supersaturation than GFS at very low levels near the pole in cold season (combination of more grid points & physics changes)

- Analysis has a weak constraint on the amount of supersaturation allowed. The impact of the constraint depends on the density of gridpoints.
- The GFS and FV3GFS have different gridpoint densities near the poles, so the constraint must be weighted differently. Right now, it is not.

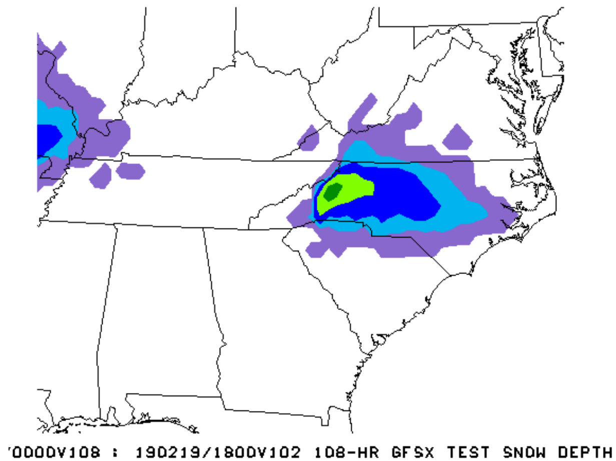
Issue #1
Excessive Snowfall in FV3GFS

Remedy: Use only the frozen part of precipitation falling on the ground to compute snow depth inside the LSM

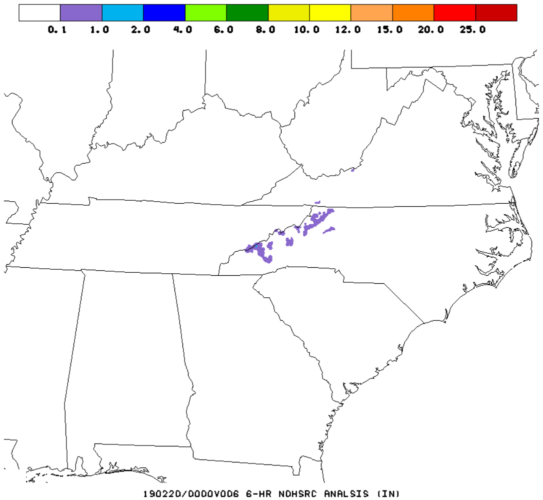
6-hr snow accumulation valid for 18Z19Feb~00Z20Feb, 2019



real-time parallel 102-108hr Fcst



sensitivity expt. with fractional srflag 102-108hr Fcst



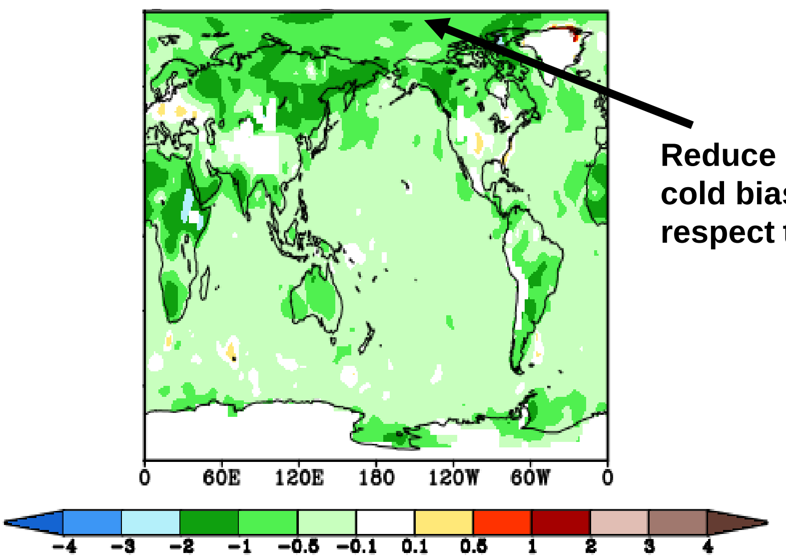
NOHRSC Analysis

Excessive snow amounts reduced in the experiment, still exhibits over-prediction (could be linked to cold bias in the lower troposphere - issue #2)

Issue #2
Exacerbated cold bias in the lower atmosphere

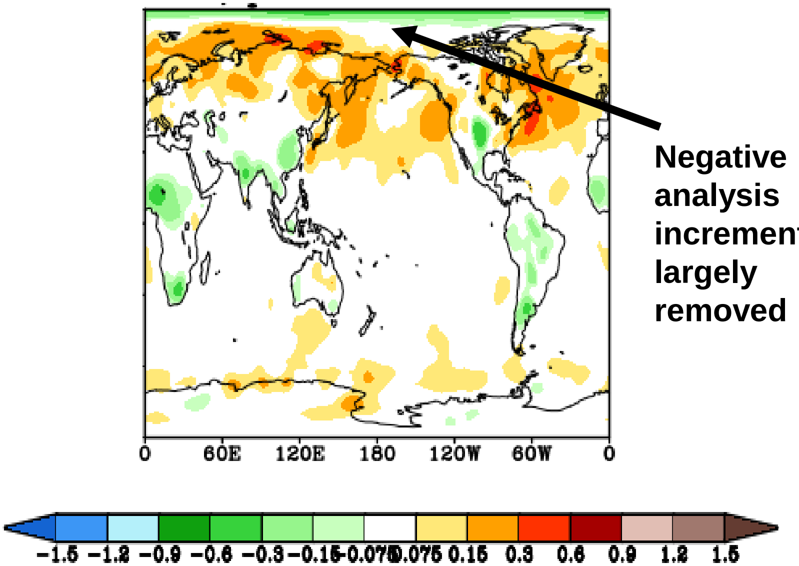
Remedy #1: Reduce weighting factor for supersaturation constraint in the data assimilation system for FV3GFS

FV3GFS – GFS temperature analysis @ 1000 hPa



Reduce FV3GFS cold bias with respect to GFS

FV3GFS temperature analysis increment @ 1000 hPa



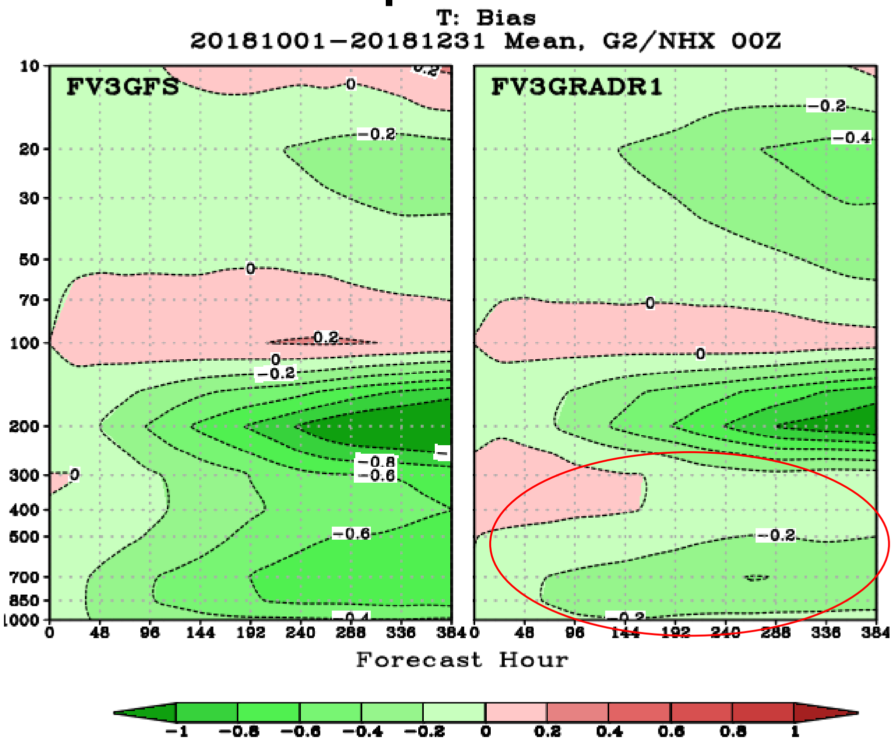
Negative analysis increment largely removed

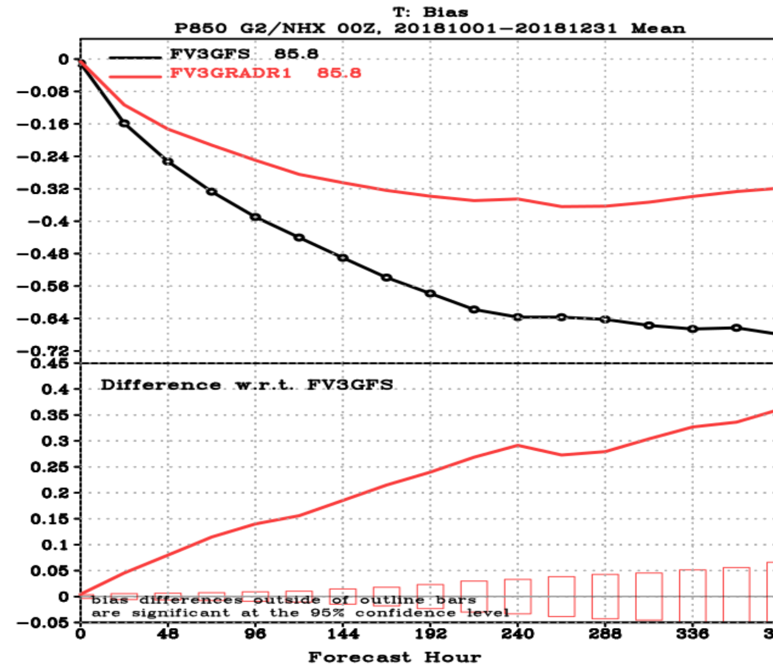
Reduced cold temperature bias over the Arctic region

Issue #2
Exacerbated cold bias in the lower atmosphere
Remedy #2: More consistent cloud-radiation interactions*

- Modify the model physics so that the radiation can interact with each hydrometeor type from cloud microphysics directly instead of assuming empirical classification of hydrometeors. **This is expected to warm the lower atmosphere.**
- This improves representation of cloud-radiation interactions and is not directly related to the solar zenith angle bug fix.

NH Temperature Bias



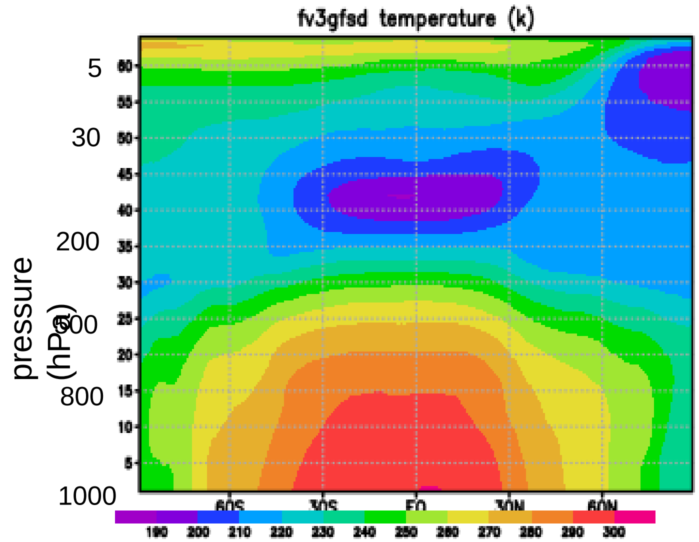


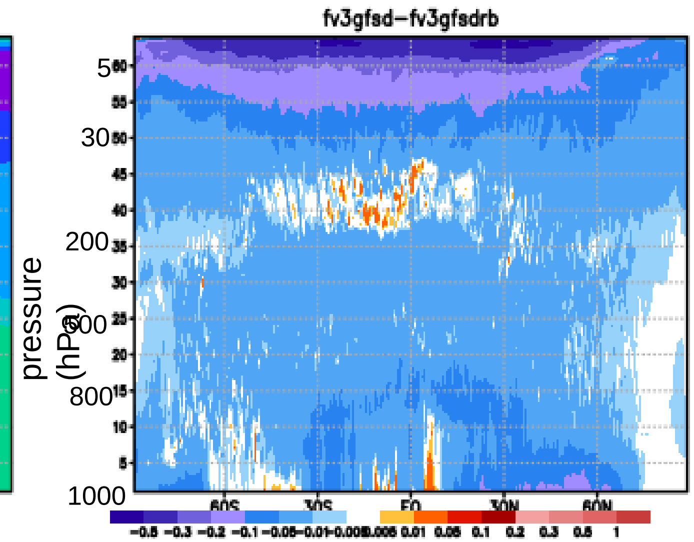
Cold Bias at 850hPa reduced by ~50%

**The revised cloud-radiation interaction algorithm and zeinth angle bug fix were included in the GEFS R&R configuration last fall, addressing similar issues found with the FV3 based ensemble system.*

Zonal Mean Temperature
Lat-HGT Cross Section, FH24

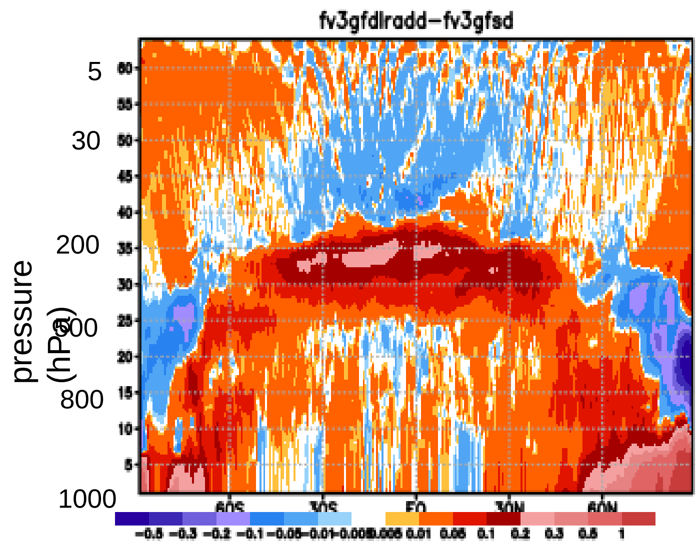
Control (w/bug)





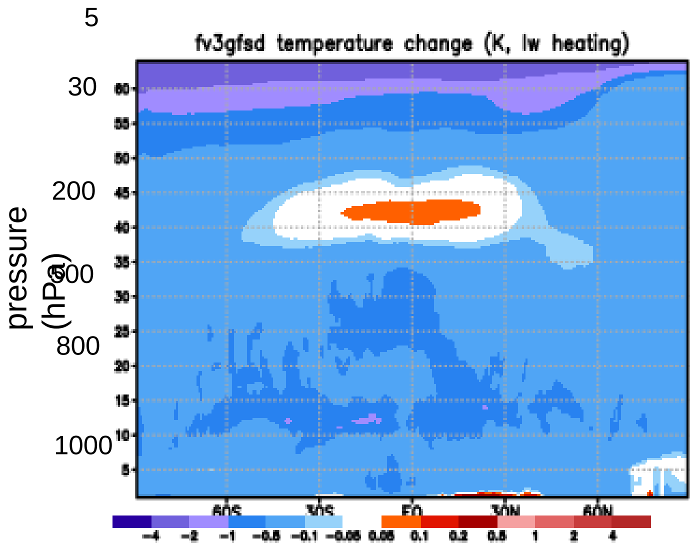
Impacts of radiation bug fix: cooled the atmosphere due to reduced SW heating

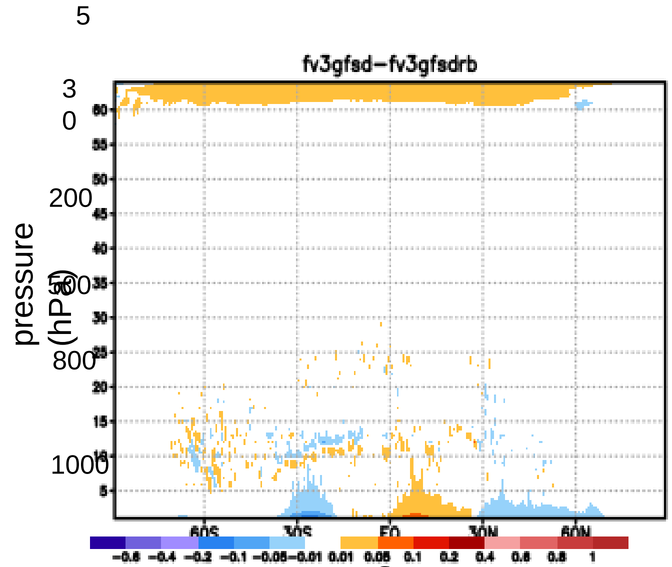
Impact of new cloud-radiation interactions: recover most of the cold bias in the lower atmosphere



Longwave Heating Rate (K/6hr)

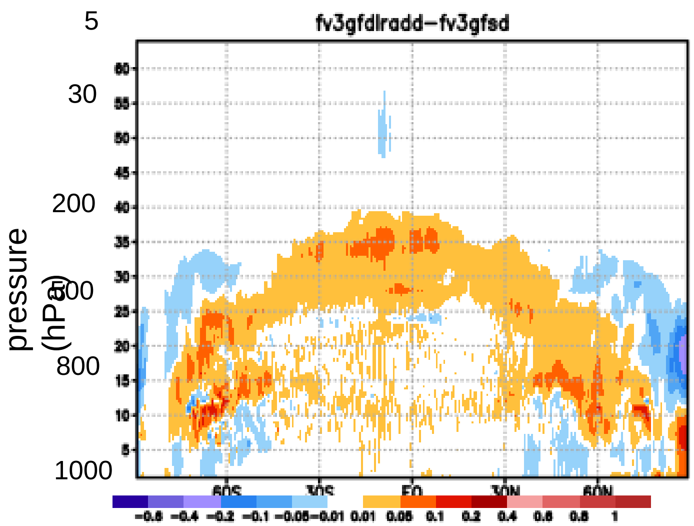
Control





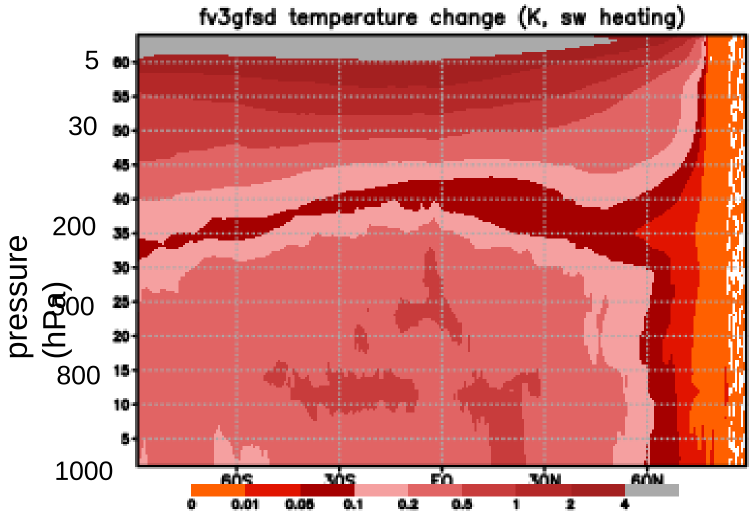
Impacts of radiation bug fix

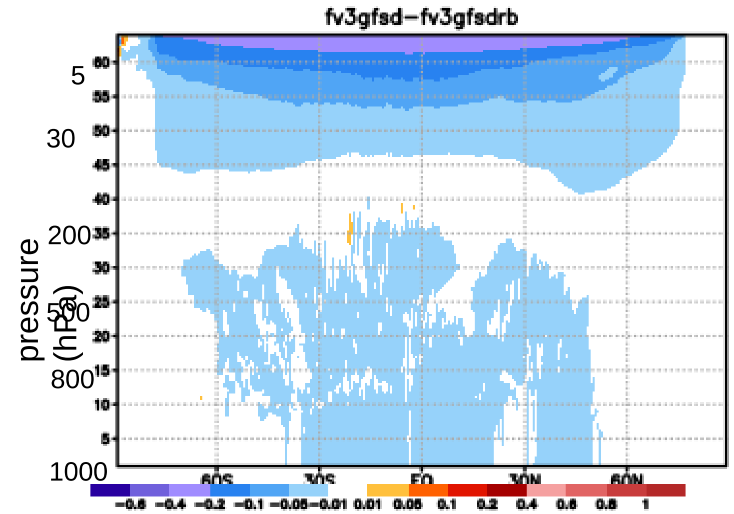
Impact of new cloud-radiation interaction: reduced longwave cooling in the troposphere



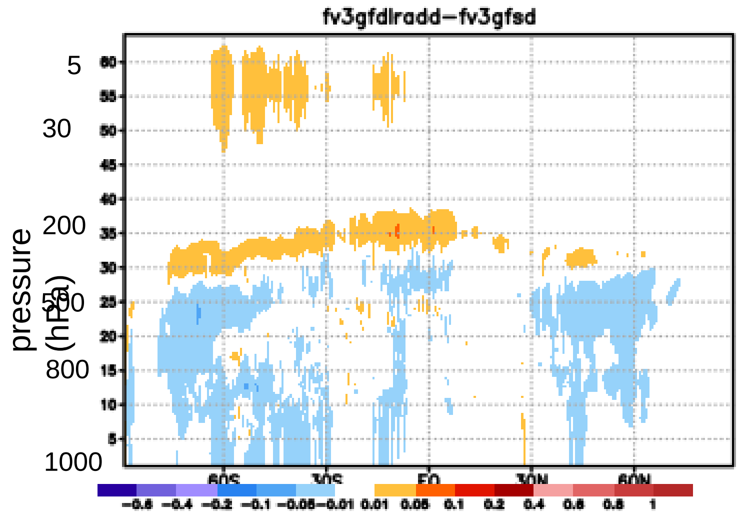
Short Wave (Solar) Heating Rate (K/6hr)
Zonal Mean lat-height cross sections

Control (w/bug)





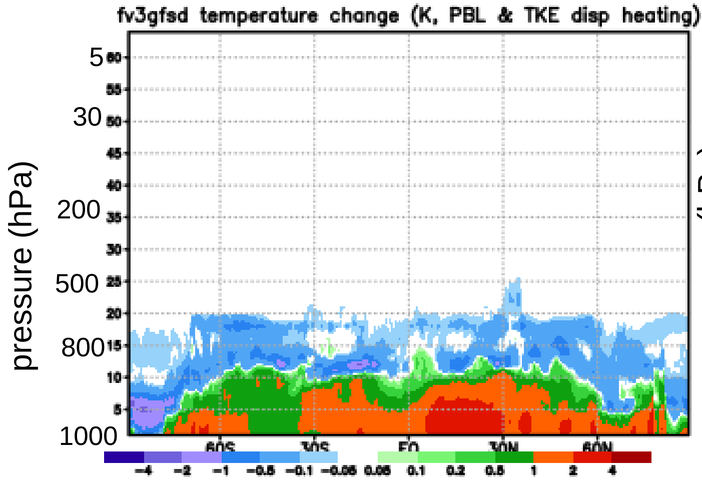
Impact of new cloud-radiation interaction

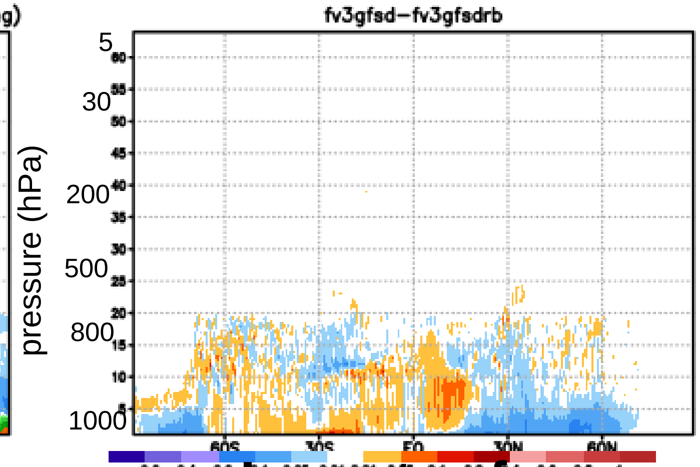


Impacts of radiation bug fix: reduced short-wave heating rate

PBL Mixing and TKE Dissipation Heating Rate (K/6hr)

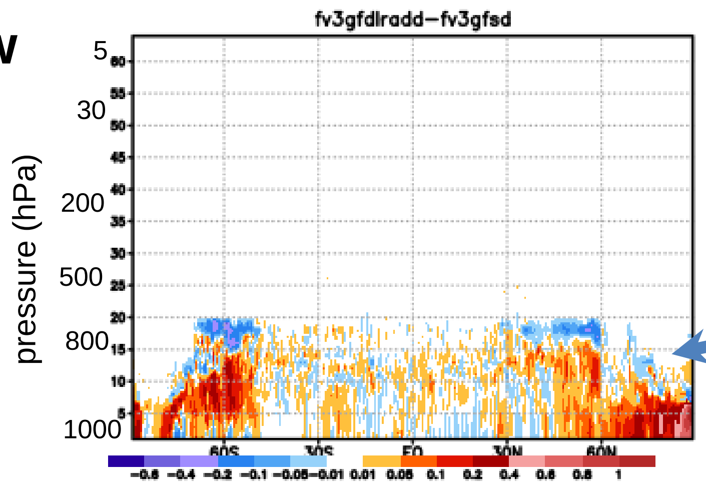
Control





Impacts of radiation bug fix

Impact of new cloud-radiation interaction



Reaction of the PBL mixing to the near surface temperature differences

changes in heating rates due to deep convection, shallow convection and microphysics phase conversion are small.

Fully Cycled New Parallel Experiments

- **We've shown the individual impact of each fix.**

- **New Parallel configuration includes all three fix/updates in : 1) fractional snow/ice/graupel flag, 2) cloud-radiation interaction, 3) supersaturation adjustment in DA, Model Tag nemsfv3gfs_beta_v1.0.16**

- **The winter New Parallel will catch-up with real-time by March 20th.**

The following slides show evaluation of New Parallel for

- **Winter with cycled DA (12/15/2018 - realtime)**

https://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/prfv3rt3/

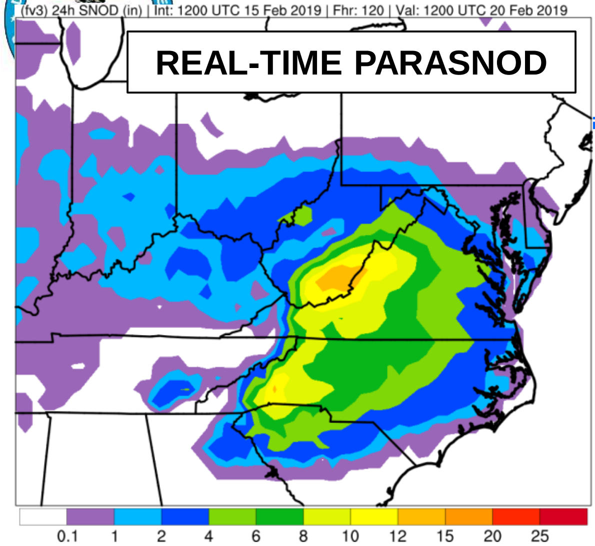
- **Hurricane season with cycled DA (8/26/18 - 10/31/18)**

https://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/prfv3rt3s/

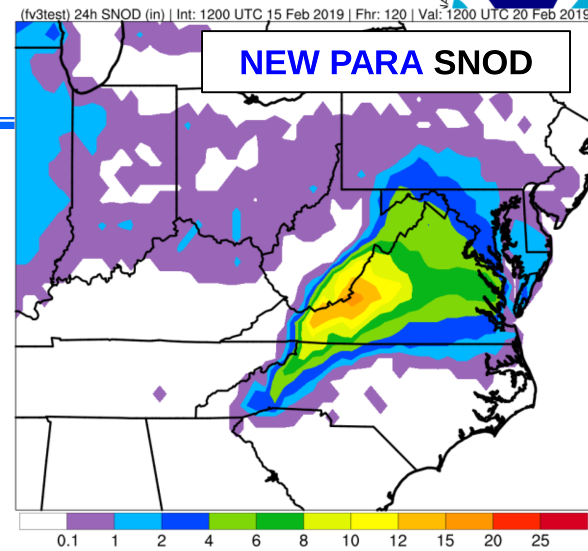
48

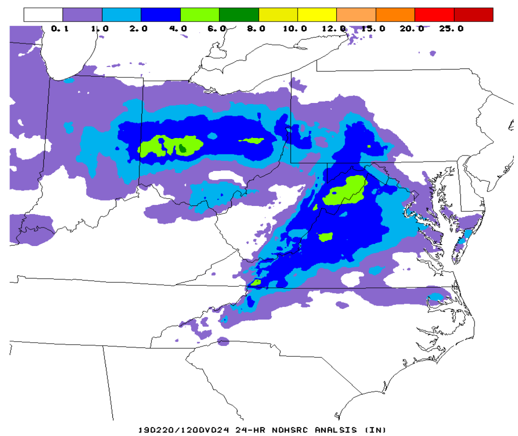
Results from Cycled Parallel Experiments ("NEW PARA")

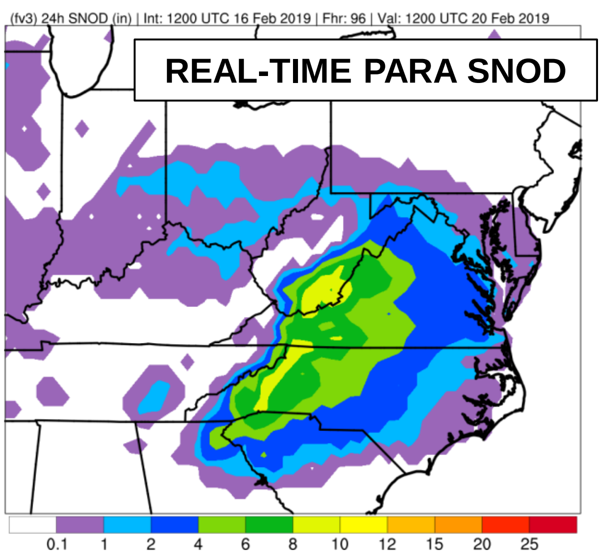
- **Winter with cycled DA (12/15/2018 - realtime)**
- **Hurricane season with cycled DA (8/28/18 - 10/31/18)**



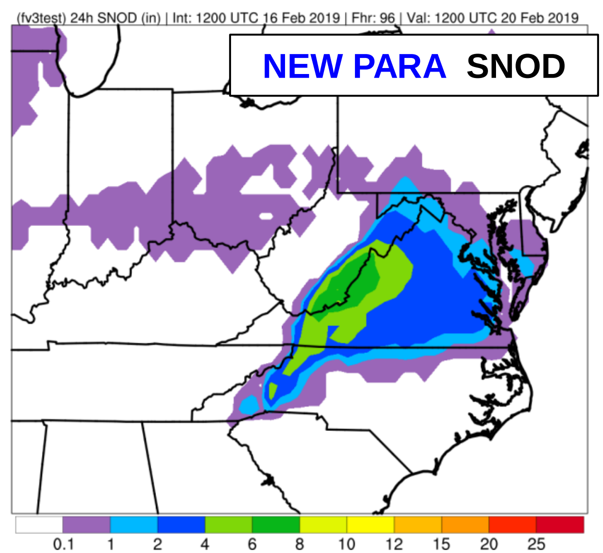
120-h Forecast
(Valid: 12Z 20 FEB 2019)





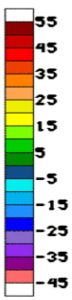


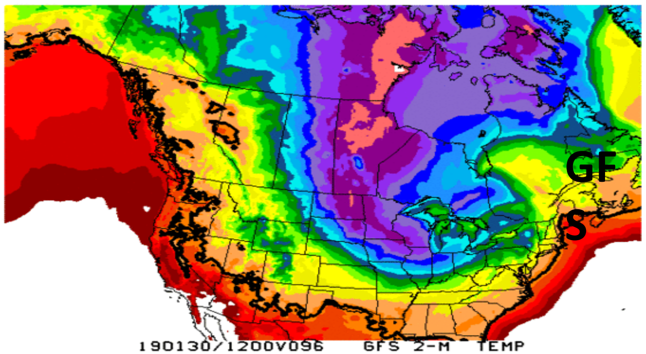
96-h Forecast
(Valid: 12Z 20 FEB 2019)

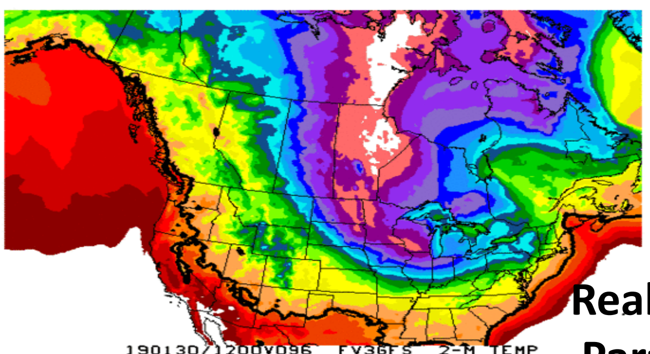


The Arctic Blast of Late January

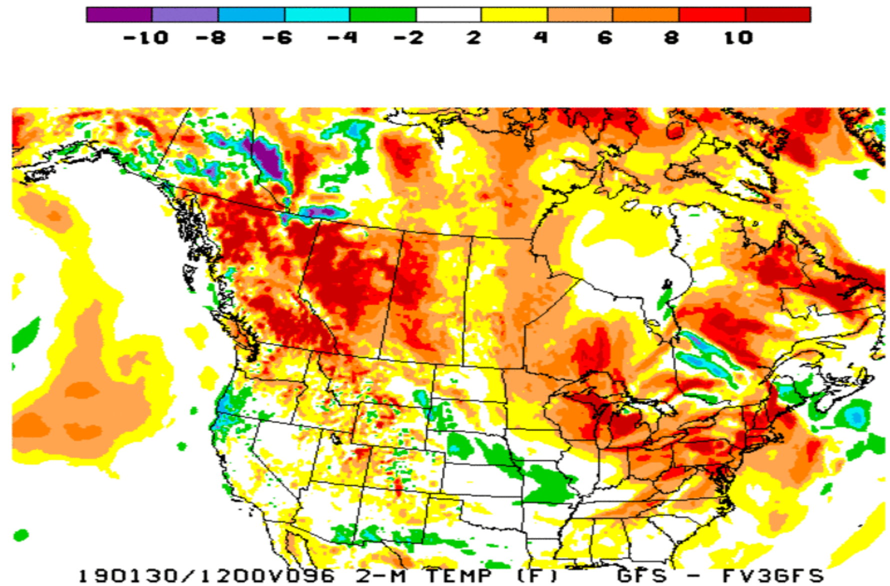
12z 1/26/19 CYCLE F96







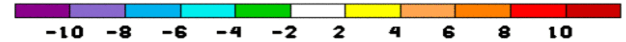
Real-Time Parallel



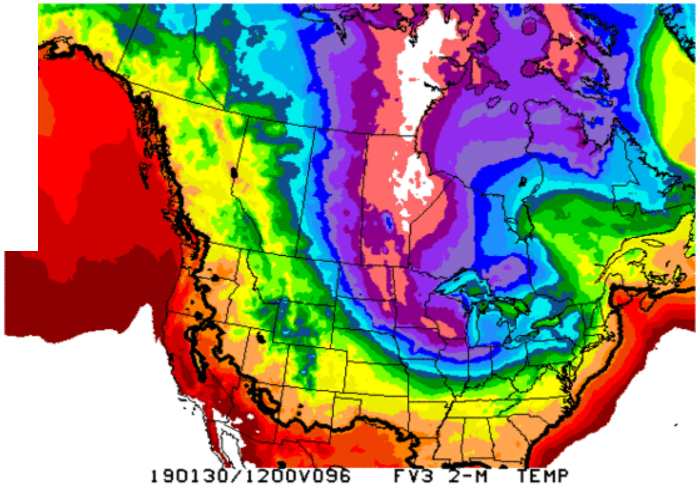
GFS – Real Time Para

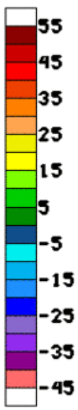
REAL-TIME PARA much colder than GFS

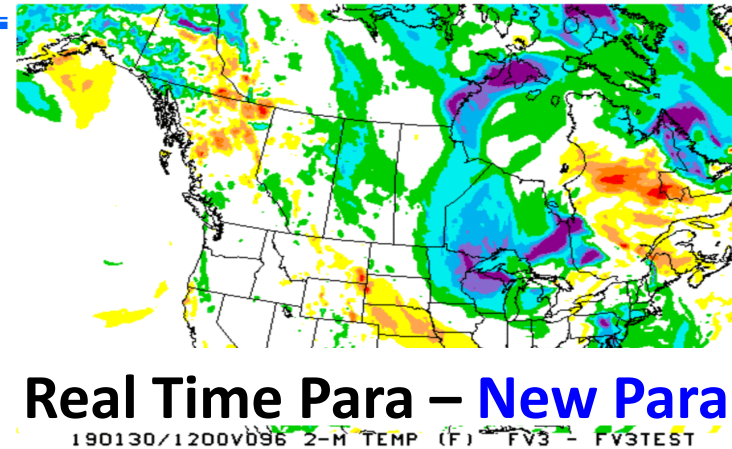
12z 1/26/19 CYCLE F96



Real Time Para

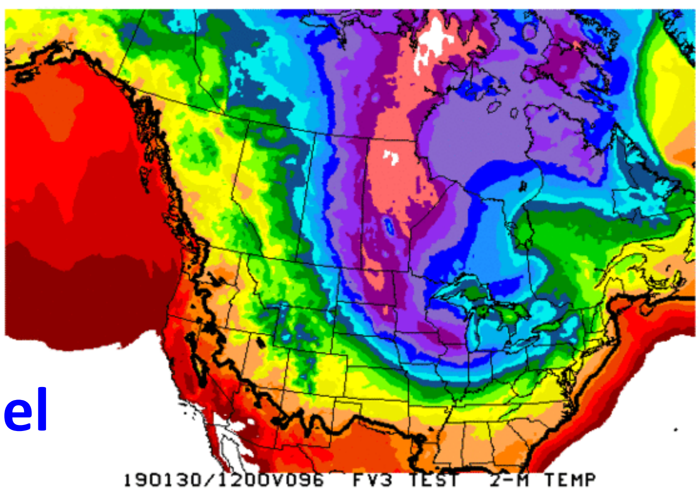


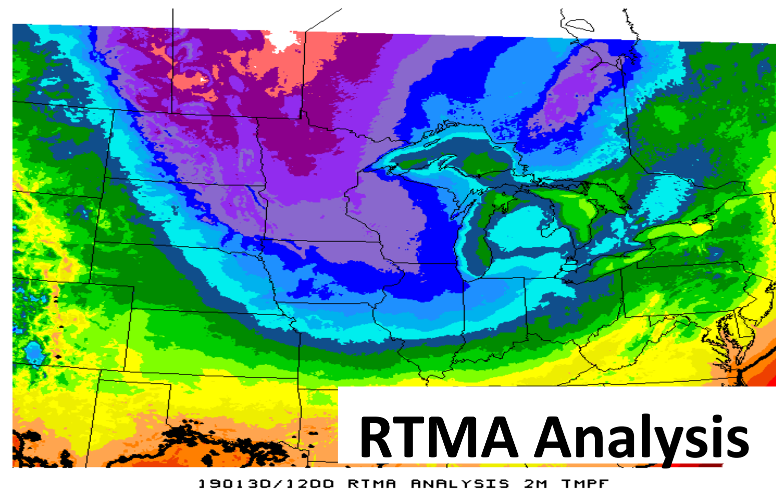




Real Time Para – New Para

New Parallel

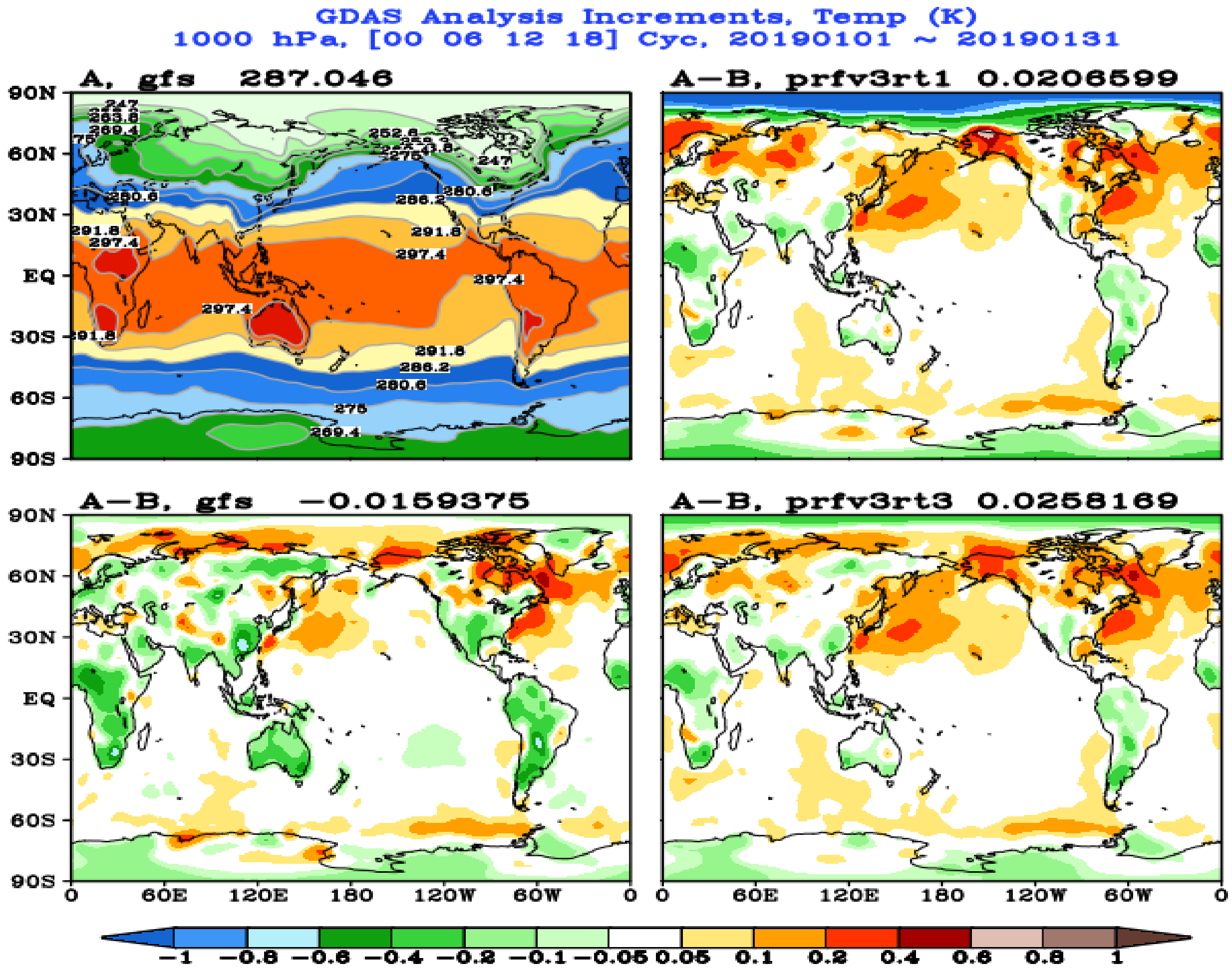




RTMA Analysis

New Parallel is warmer than real-time parallel and while it is still too cold it shows a clear improvement.

Analysis temperature increments improved



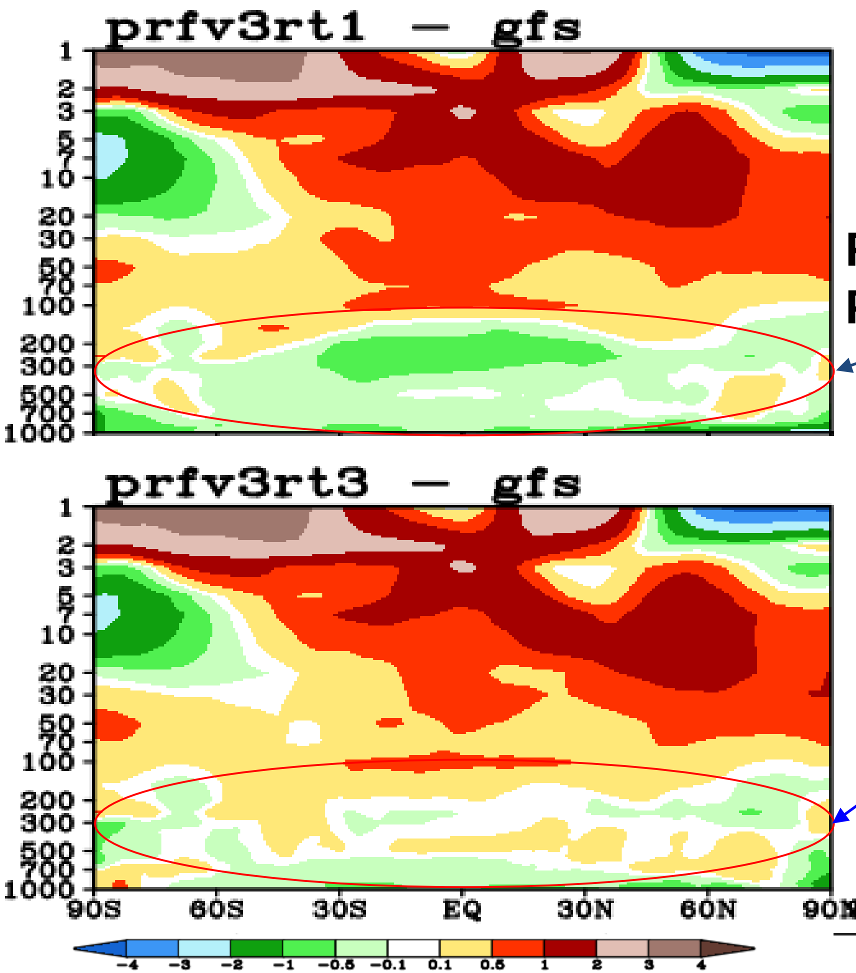
Real-Time Parallel

New Parallel

Spurious large negative analysis temperature increments over the winter polar region are removed in New Parallel.

Tropospheric temperature cold bias reduced (Winter 2018/19)

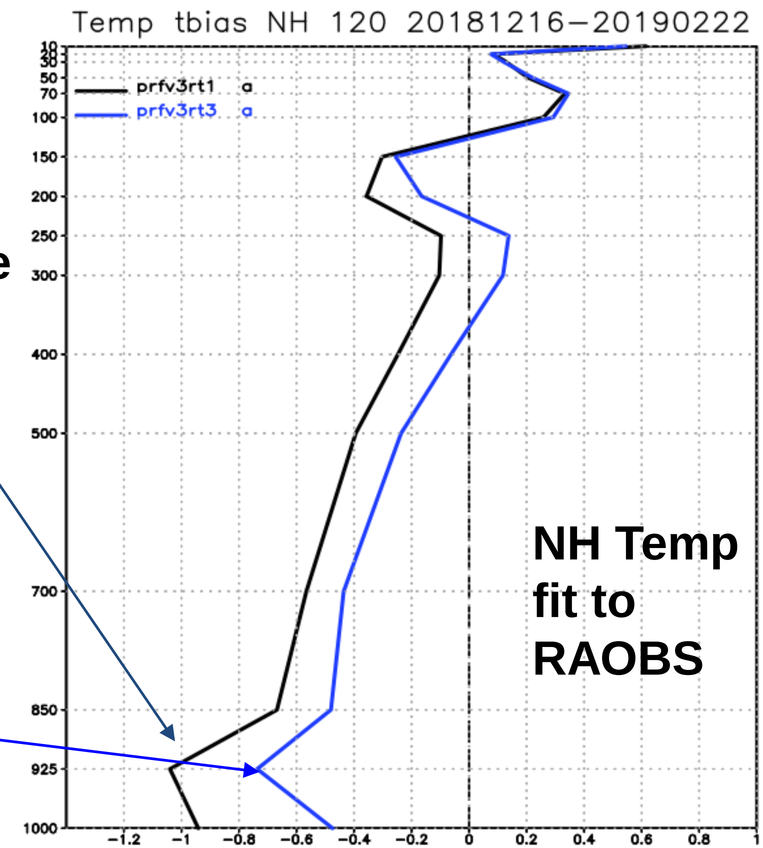
Zonal Mean NH Temp, 120hr fcst



Real-Time Parallel

New Parallel

NH Temp. Bias 120hr fcst

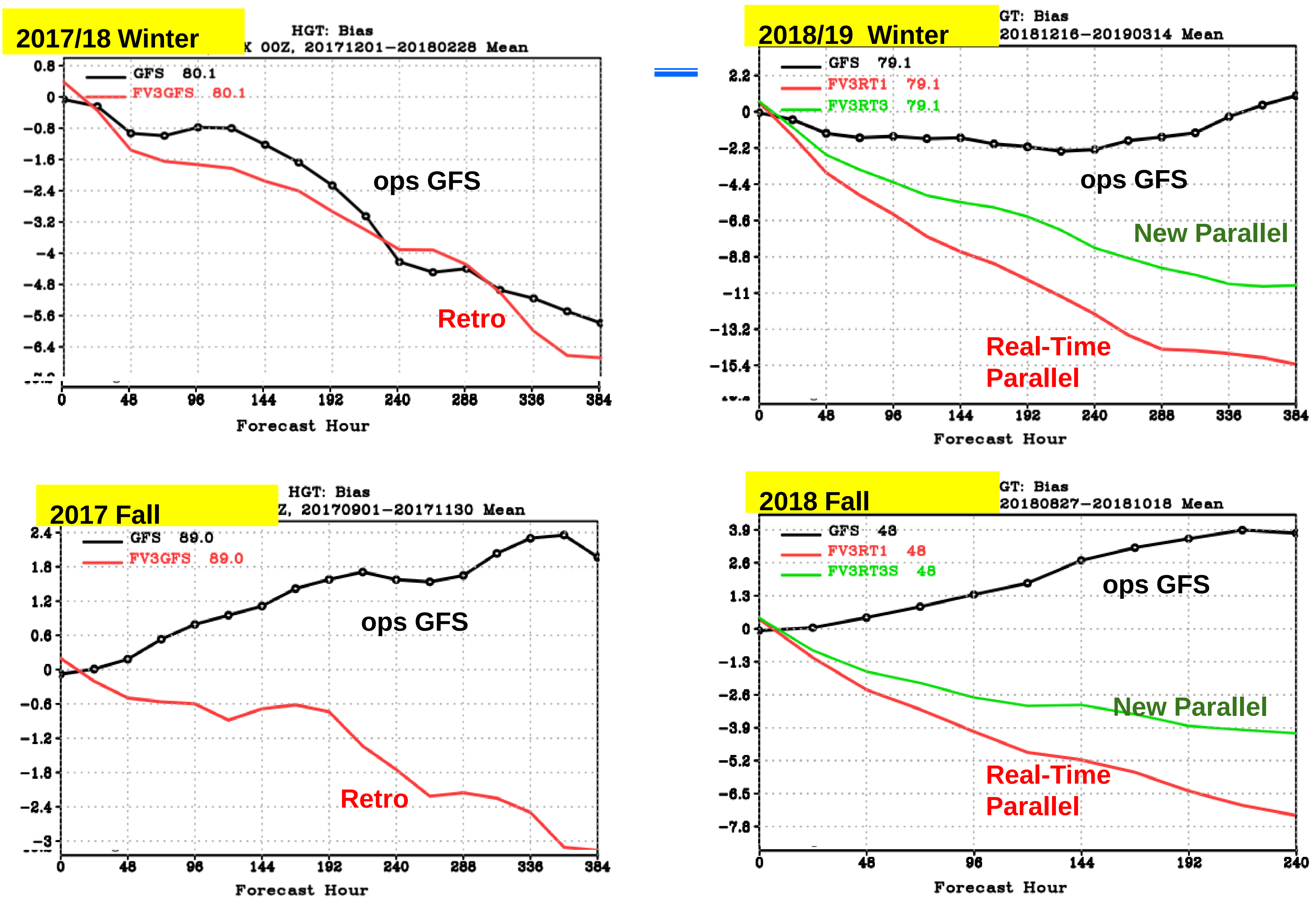


NH Temp fit to RAOBS

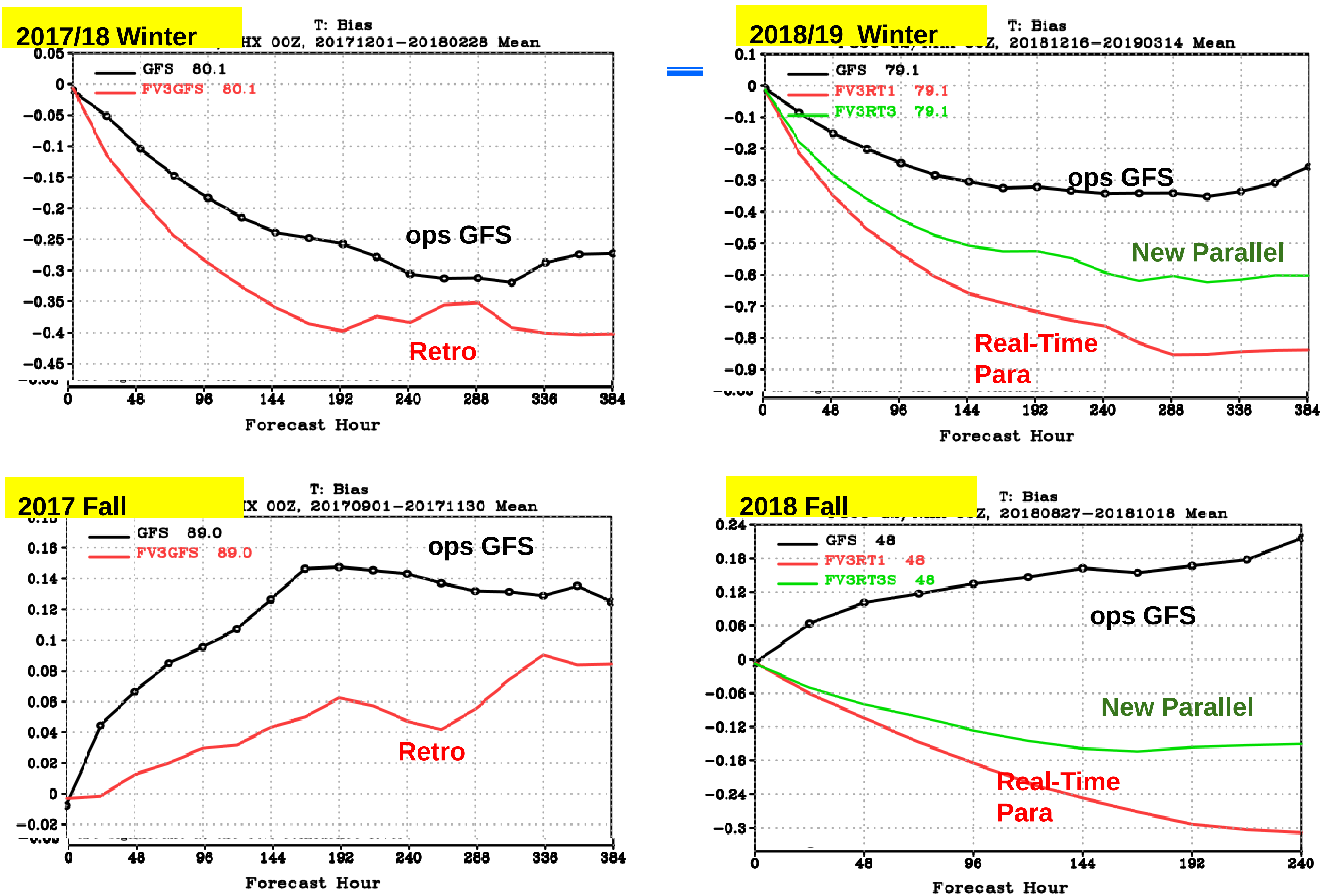
54

12/16/18 - 02/22/19

NH 500-hPa Height Biases, Verified against analyses



NH 850-hPa Temperature Biases, Verified against analyses



Summary of Evaluation and
GFS.15.1.0 Final Configuration

To be implemented
on June 12, 2019

Improvements over operational GFS in retrospective runs

✓ = Retained in the new configuration

- ✓ (significantly) Improved 500-hpa anomaly correlation (NH and SH)
- ✓ Intense tropical cyclone deepening in GFS not observed in FV3GFS
- ✓ FV3GFS tropical cyclone track forecasts improved (within 5 days)
- ✓ Warm season diurnal cycle of precipitation improved
- ✓ Multiple tropical cyclone centers generated by GFS not seen in FV3GFS forecasts or analyses
- ✓ General improvement in HWRF and HMON runs
- ✓ New simulated composite reflectivity output is a nice addition
- ✓ Some indication that fv3gfs can generate modest surface cold pools from significant convection
- FV3GFS with advanced GFDL MP provides better initial and boundary conditions for driving stand alone FV3, and for running downstream models that use advanced MP.
- FV3 based GEFS V12 showed significant improvements when initialized with FV3GFS
- ✓ Improved ozone and water vapor physics and products
- Improved extratropical cyclone tracks
- ✓ Improved precipitation ETS score (hit/miss/false alarm)
- Overall reduced T2m biases over CONUS

Documented concerns include:

- FV3GFS can be too progressive with synoptic pattern
- Precipitation dry bias for moderate rainfall
- Extremely hot 2-m temperatures observed in mid-west
- Spurious secondary (non-tropical) lows show up occasionally in FV3GFS since the advection scheme change was made
- ✓ T2m over Alaska is too cold, likely caused by cold NSST and/or cloud microphysics issue in the Arctic region – **mitigated with NSST fix**
- NHC reported that FV3GFS degraded track forecast of hurricanes (initial wind > 65 kts) in the Atlantic basin
- *Both GFS and FV3GFS struggle with inversions*
- *Both GFS and FV3GFS often has too little precip on the northwest side of east coast cyclones*

Code changes for new model configuration (GFS v15.1)

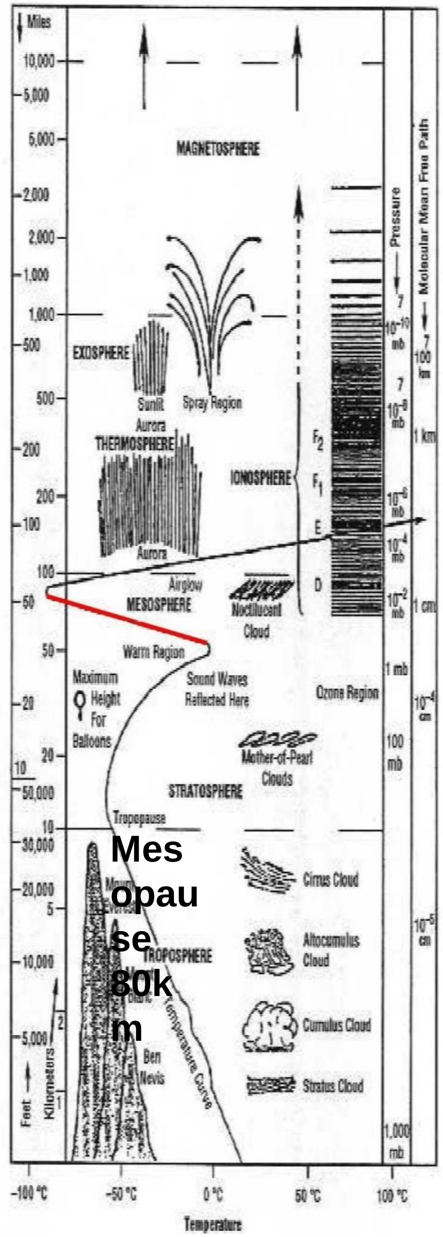
- **Fractional Snow Flag:**
  - The cloud model (GFDL MP) predicts rain, snow, graupel and ice falling on the ground. Convective parameterization also predicts rain and snow. Redefine snow flag in the LSM (srflag) as a fractional number between frozen precipitation and total precipitation.
- **Zenith angle bug fix**:
  - A bug in the computation of solar zenith angle was discovered in September 2018 after all retrospective parallels had been completed. It causes a slight shift of the solar radiation diurnal cycle and adds more solar energy to the system. This bug has been fixed.
- **Enhanced cloud-radiation interactions:**
  - In the retrospective and real-time parallels, total cloud condensate from GFDL MP is partitioned into water and ice clouds using an empirical temperature dependent function. Cloud ice effective radius is parameterized as a function of cloud mixing ratio and temperature. Cloud water effective radius is prescribed but set differently over land and ocean. In the new configuration, individual hydrometeors are directly fed into radiation. Snow and graupel are combined together. Cloud effective radii are derived from different empirical functions for different hydrometeors that vary with hydrometeor mixing ratio and temperature.
- **Restart capability:**
  - NCO requires, in case of a computer crash, the forecast model can be restarted at a crashing point instead of rerunning the model from the beginning to ensure timely product delivery and downstream model application. The model and workflow have been updated to write out restart files at a given interval, and to restart GFS forecast with these files at a break point. Continuously accumulated fields including precipitation are added to the restart files to maintain their continuity in forecast output before and after a computer crash.

Code changes for observation/DA upgrades (combined to avoid originally planned additional implementation in July 2019)

- **Modifications to GSI related to satellite data:**
    - Add ECMWF AMV quality control to address known deficiencies with GOES AMVs
    - Monitor GOES-17 AMVs, and assimilate pending evaluation after May update
    - Assimilate Meteosat-11 SEVIRI channels 5 and 6
    - Place NOAA-19 SBUV/2 in monitor mode due to degrading quality
    - Assimilate NPP OMPS profile and total column ozone
    - Monitor Metop-C AMSUA and MHS, assimilate select Metop-C AMSU and MHS channels pending evaluation
- **Modifications to ObsProc and GSI related to SST:**
    - Add code to process drifting and moored buoy data and assimilate pending evaluation
- **GSI upgraded to tag fv3da.v1.0.42**

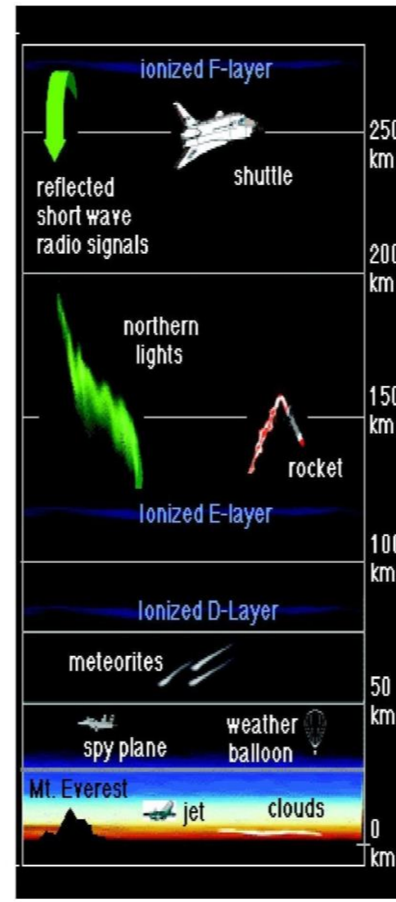
Get ready for

GFS V.16

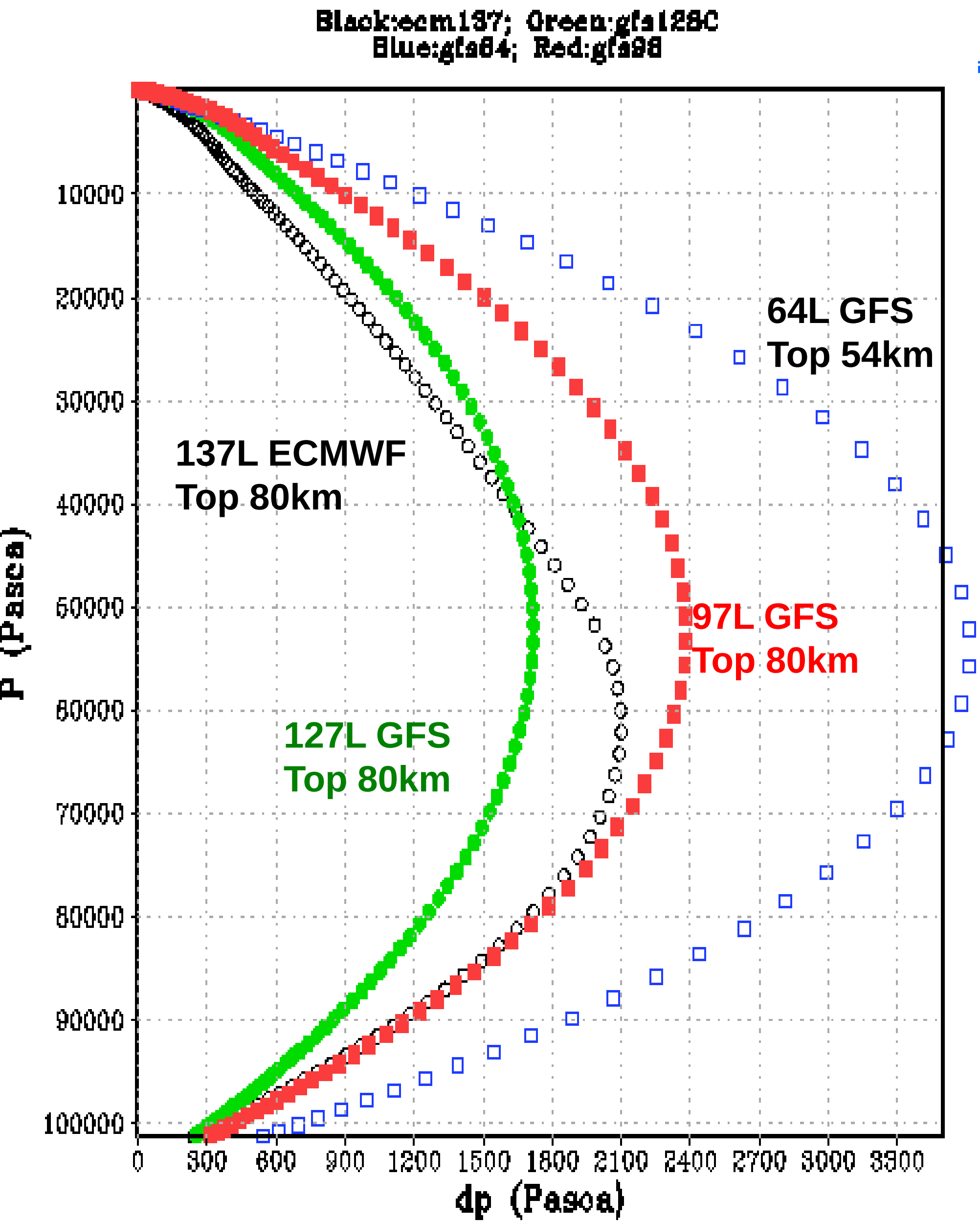


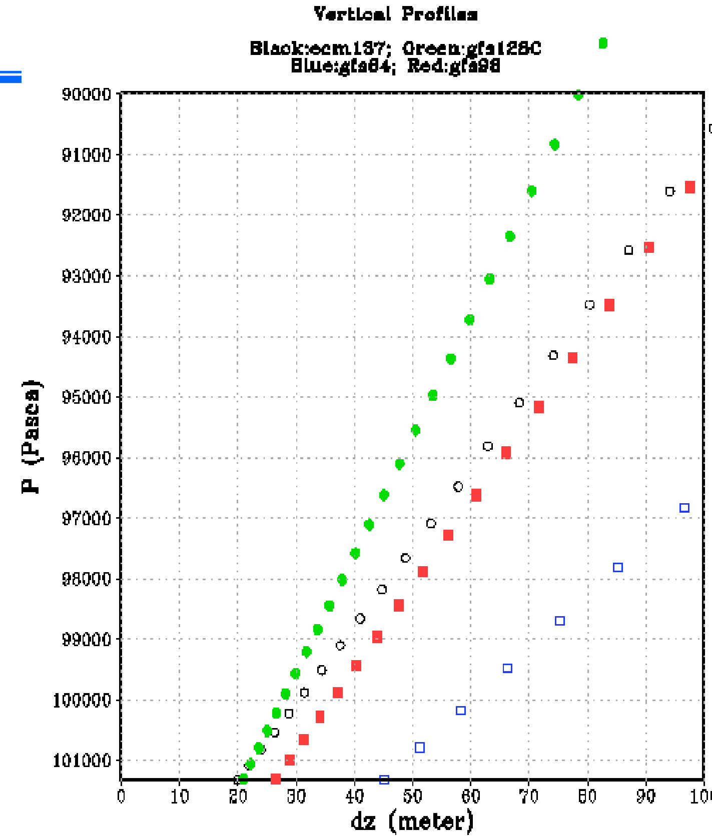
The atmosphere

An overview



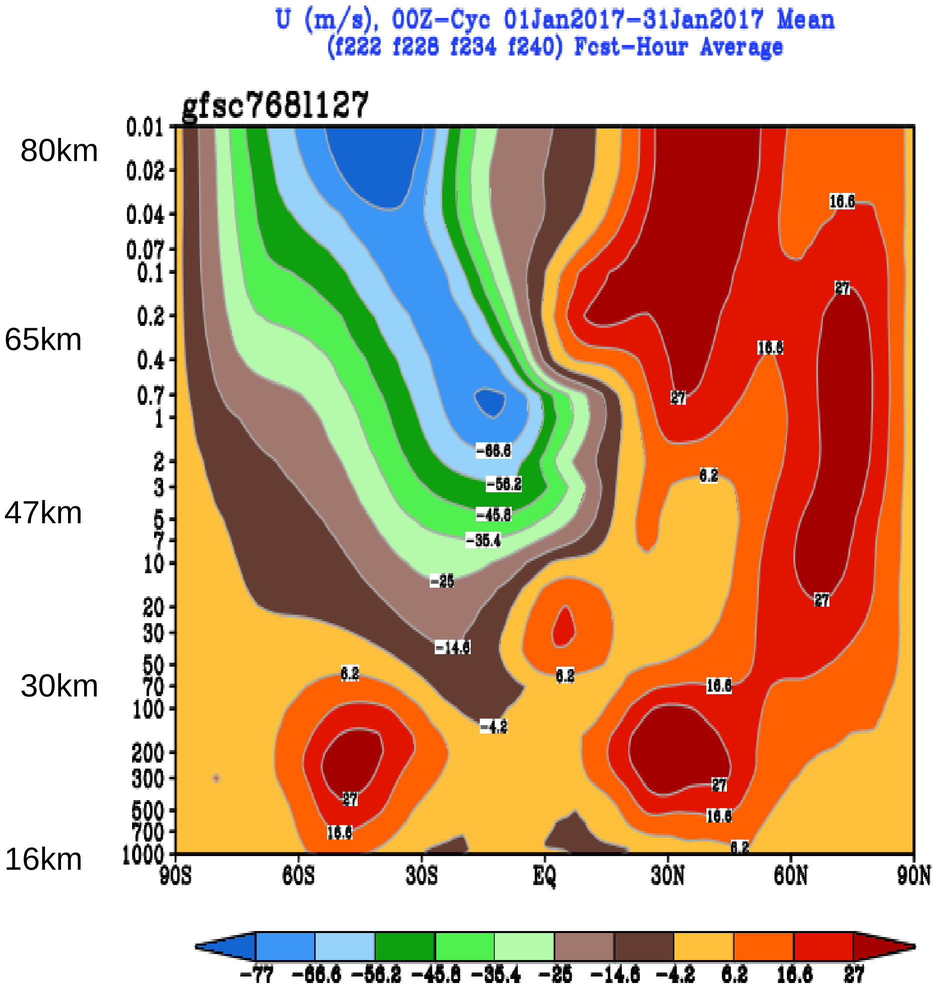
GFS Vertical Profiles



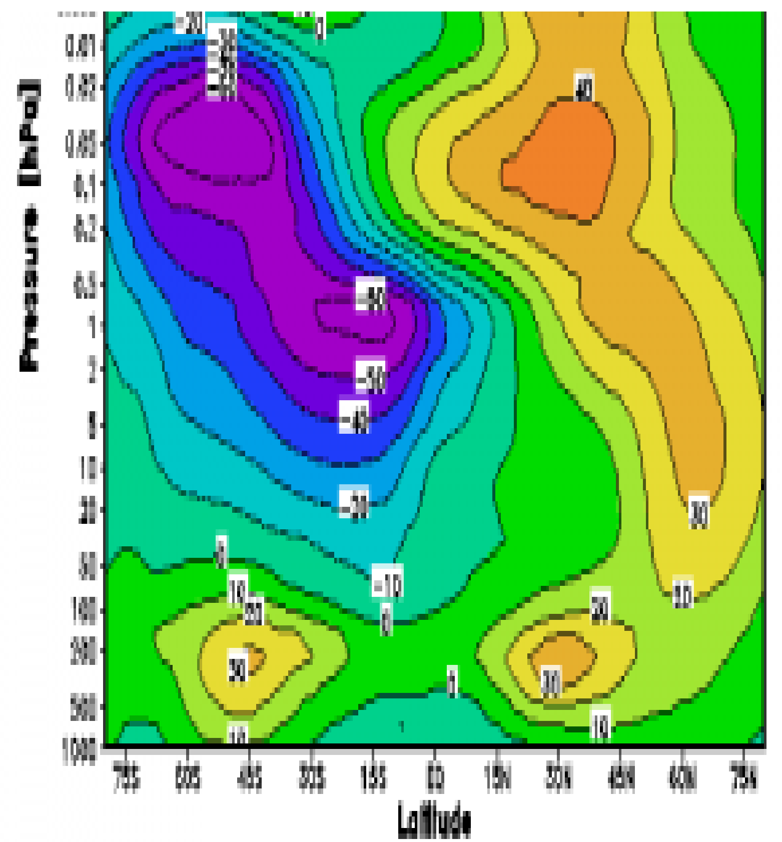


- 127L GFS has higher resolution than 137L IFS in the middle to lower troposphere, but coarser resolution above 400 hPa.
- 127L GFS 1st layer is 20m thick; 64L GFS 1st layer is 40m thick.

127-L GFS Forecasts with IFS ICs, GFS.v15.1 Physics Package
Jan 2017, 10-Day Forecasts, IFS ICs

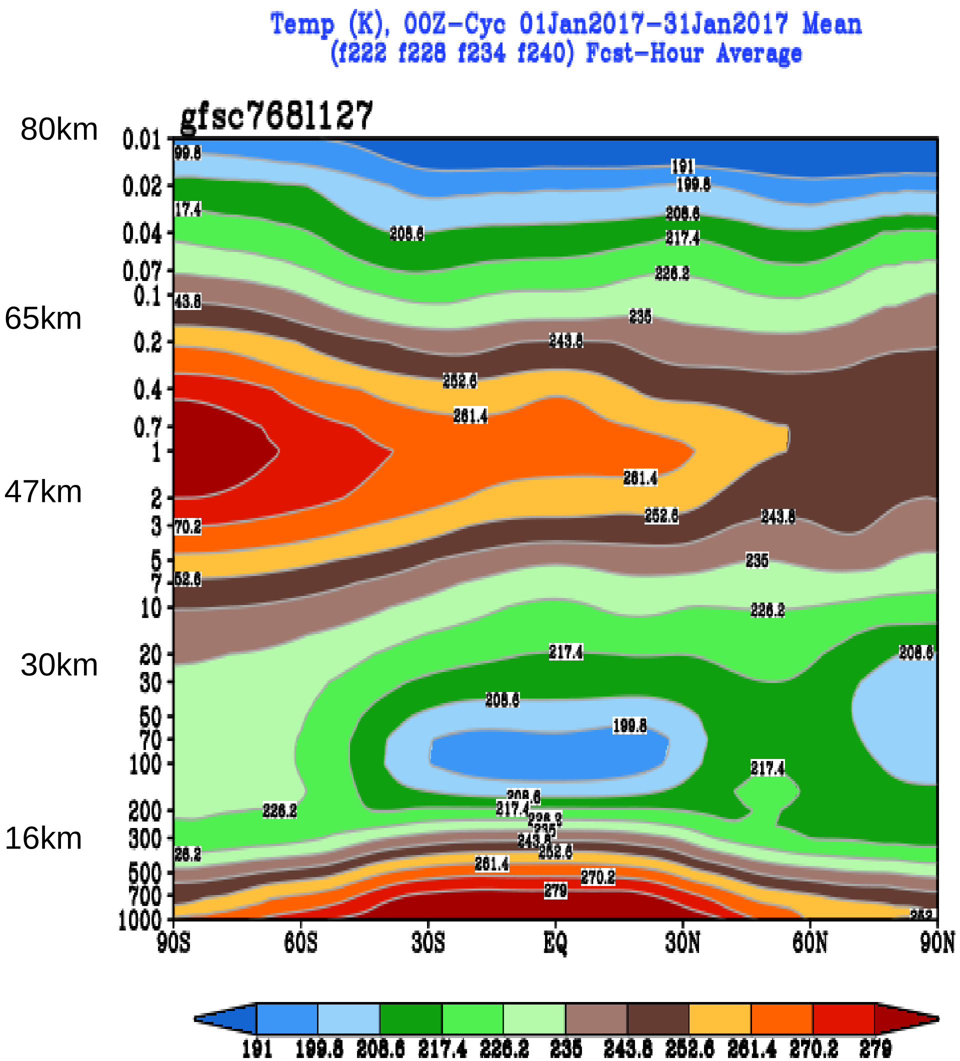


COSPAR Climatology

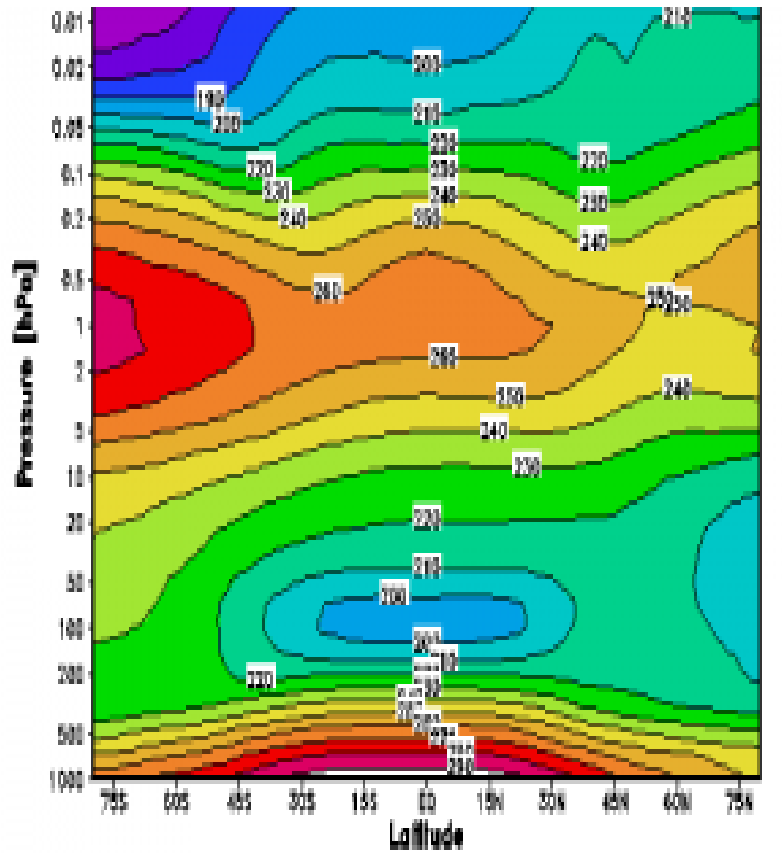


The model captured the observed basic circulation structure, but the NH winter polar night jet does not have the correct shape.

127-L GFS Forecasts with IFS ICs, GFS.v15.1 Physics Package
Jan 2017, 10-Day Forecasts, IFS ICs



COSPAR Climatology



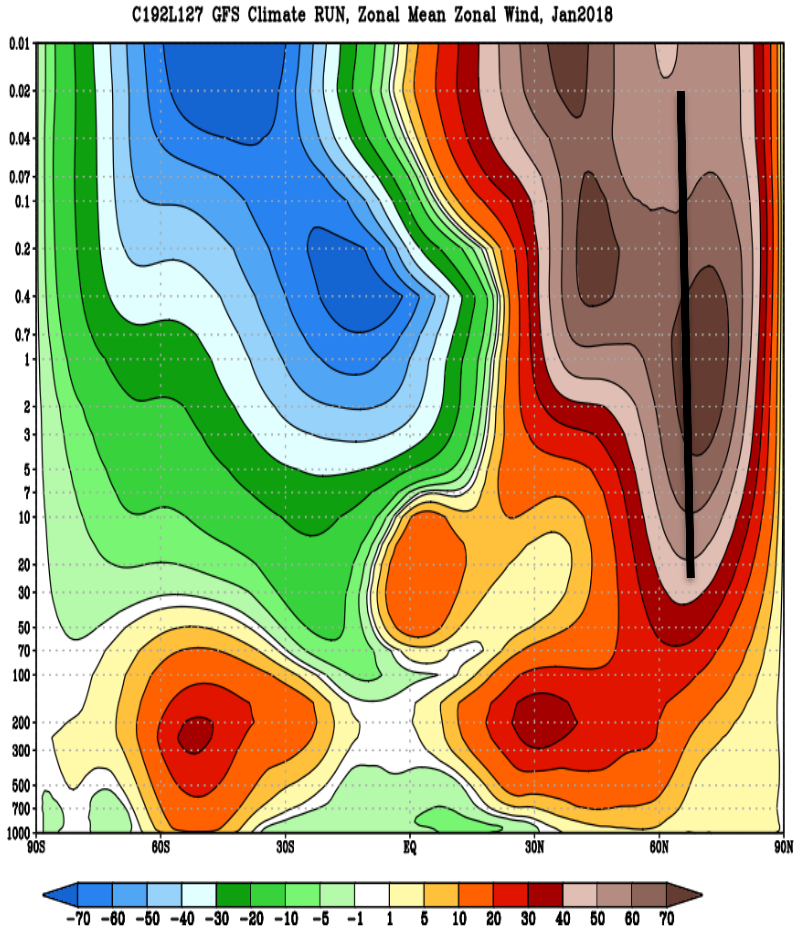
Captured the basic structure, except for that temperature gradient in the upper mesosphere is incorrect

The model's climate mean state
is from satisfactory

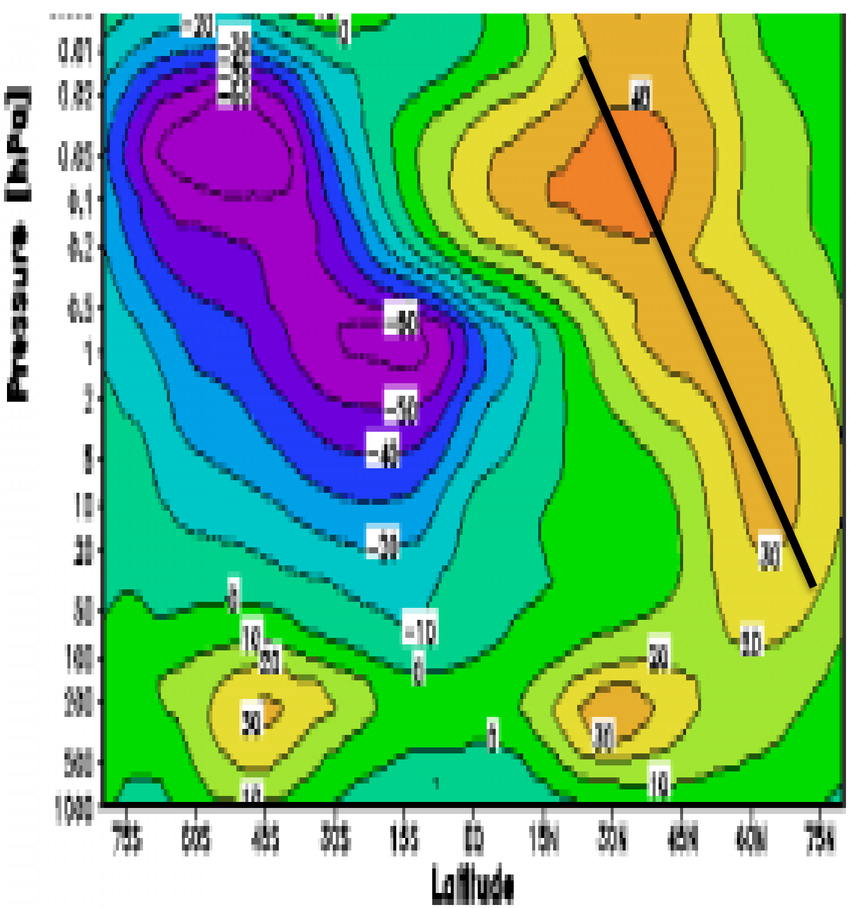
2-year C192L127 Climate/AMIP Run
IC 5Jan2017

Zonal Mean Zonal Wind

Jan 2018

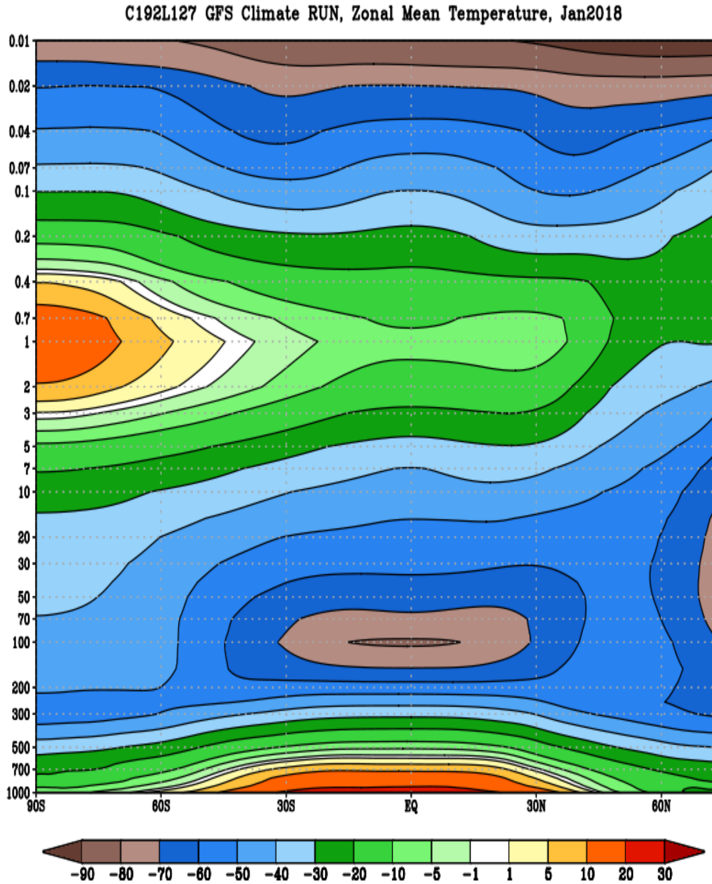


COSPAR Climatology

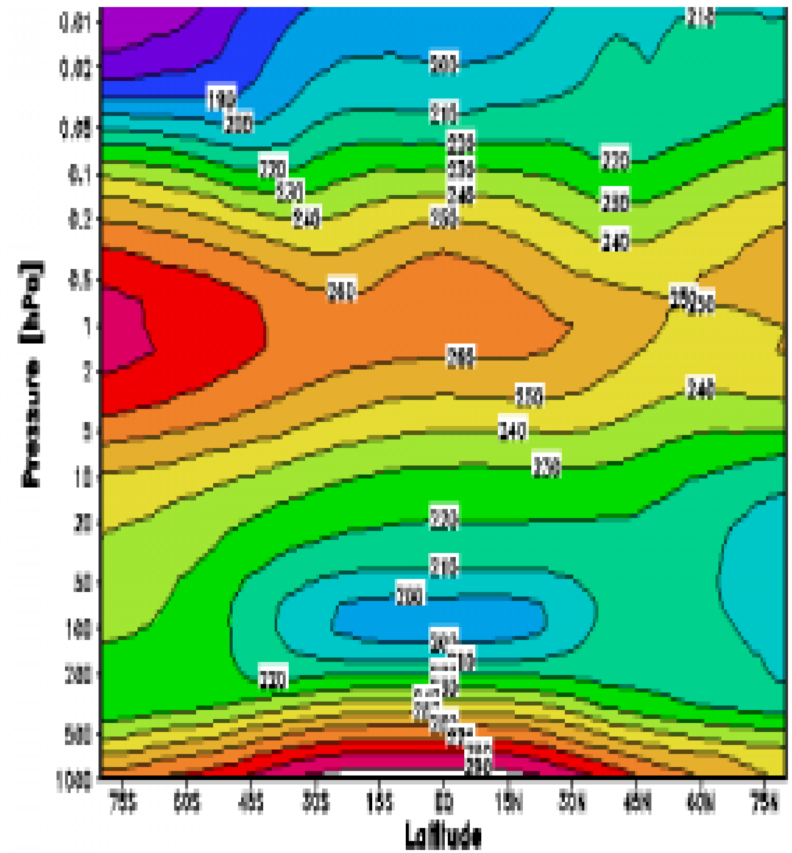


Zonal Mean Temperature

Jan 2018



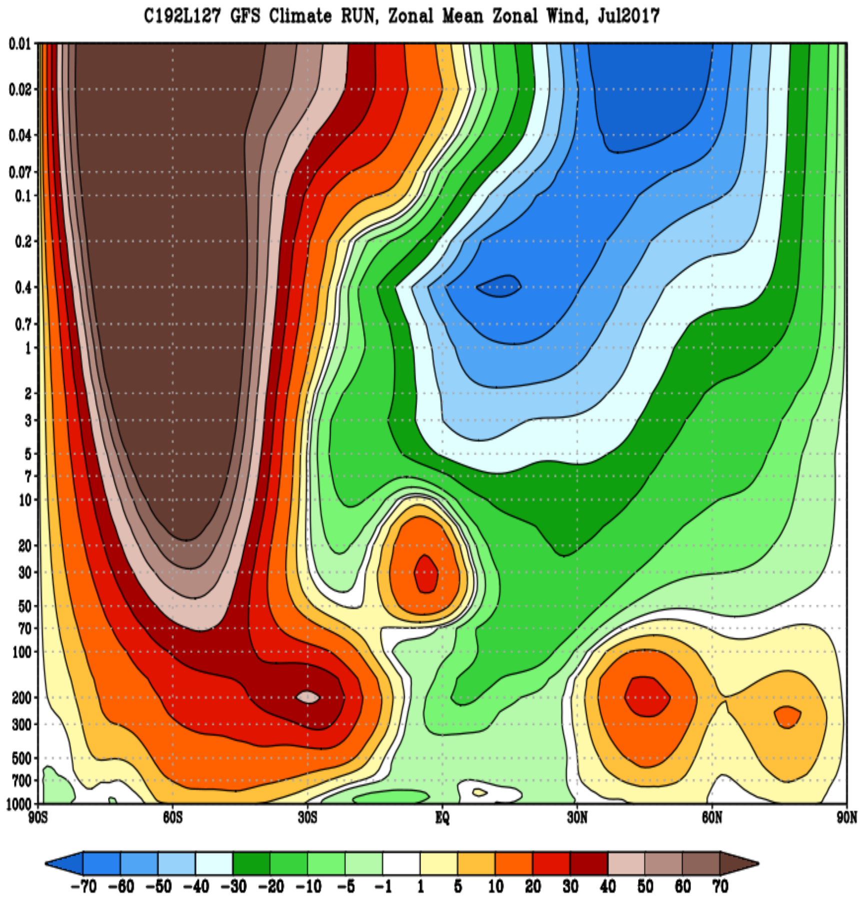
COSPAR Climatology



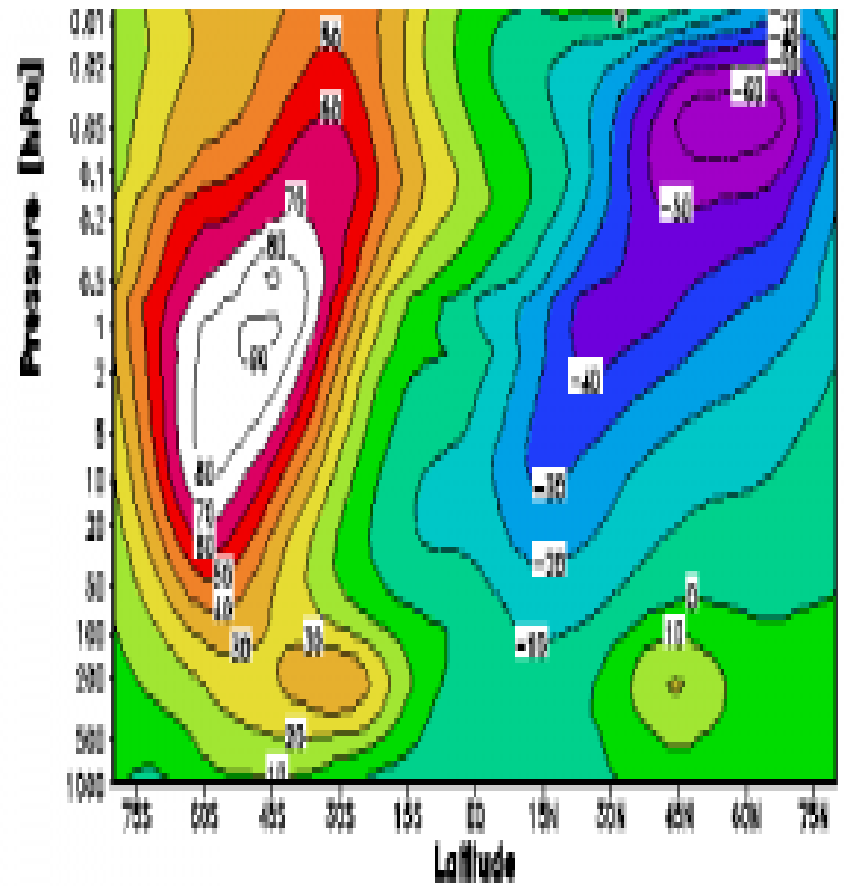
Too cold

Zonal Mean Zonal Wind

July 2017

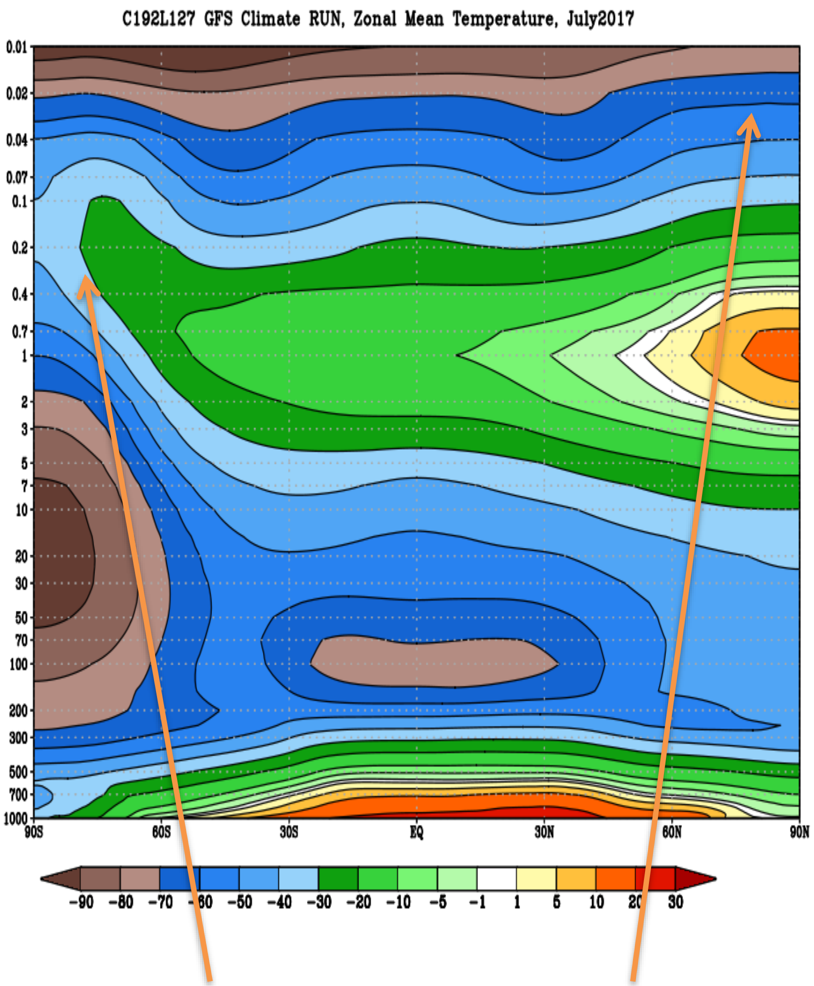


COSPAR Climatology



Zonal Mean Temperature

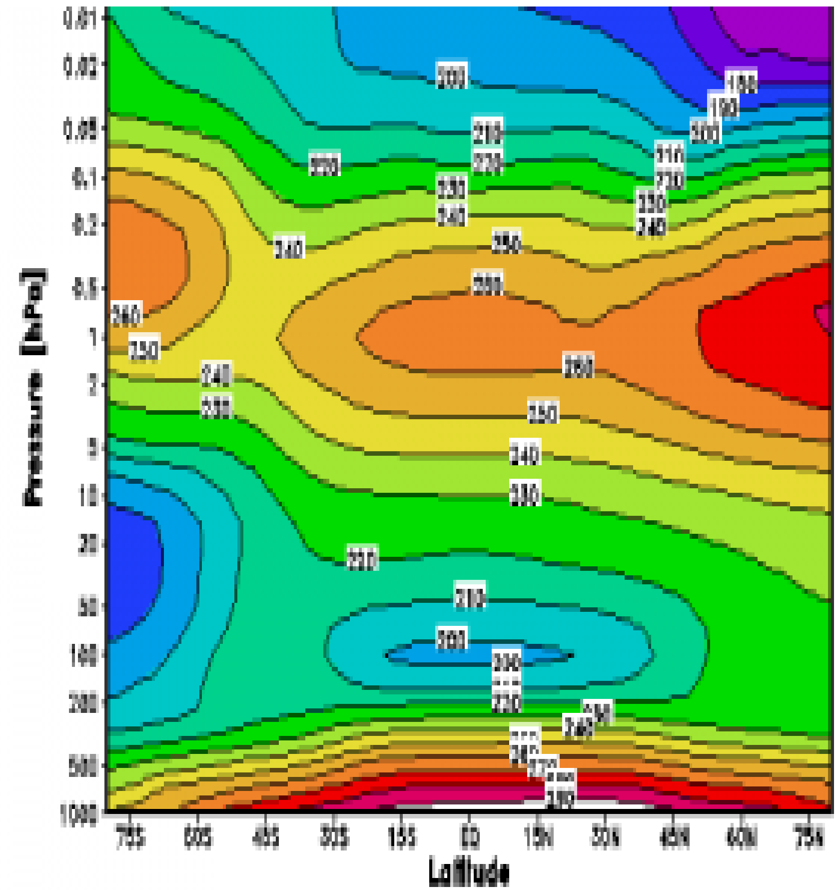
July 2018



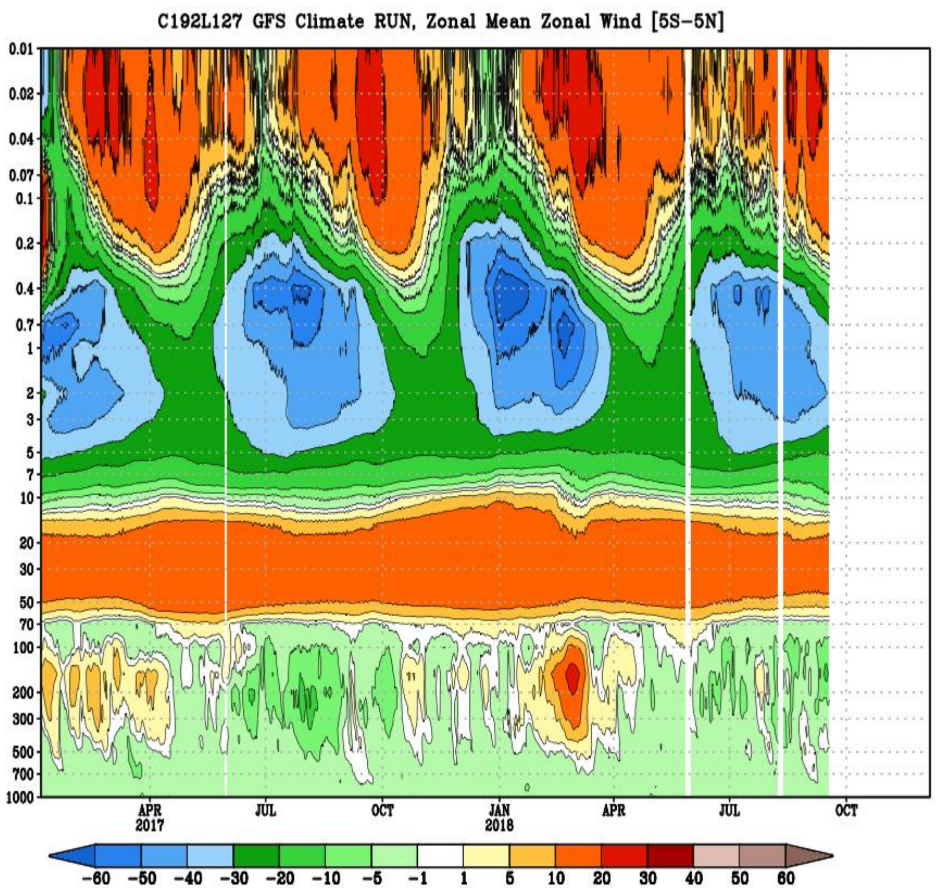
Model too cold

Model too warm

COSPAR Climatology

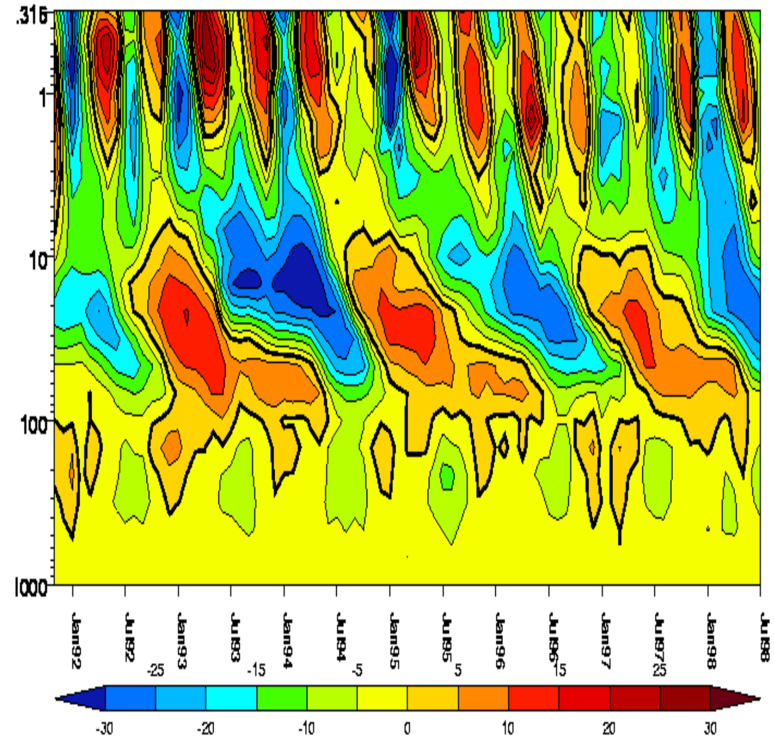


Climate Run (C192L127)



UKMO assimilated dataset

http://ugamp.nerc.ac.uk/hot/ajh/qbo.htm



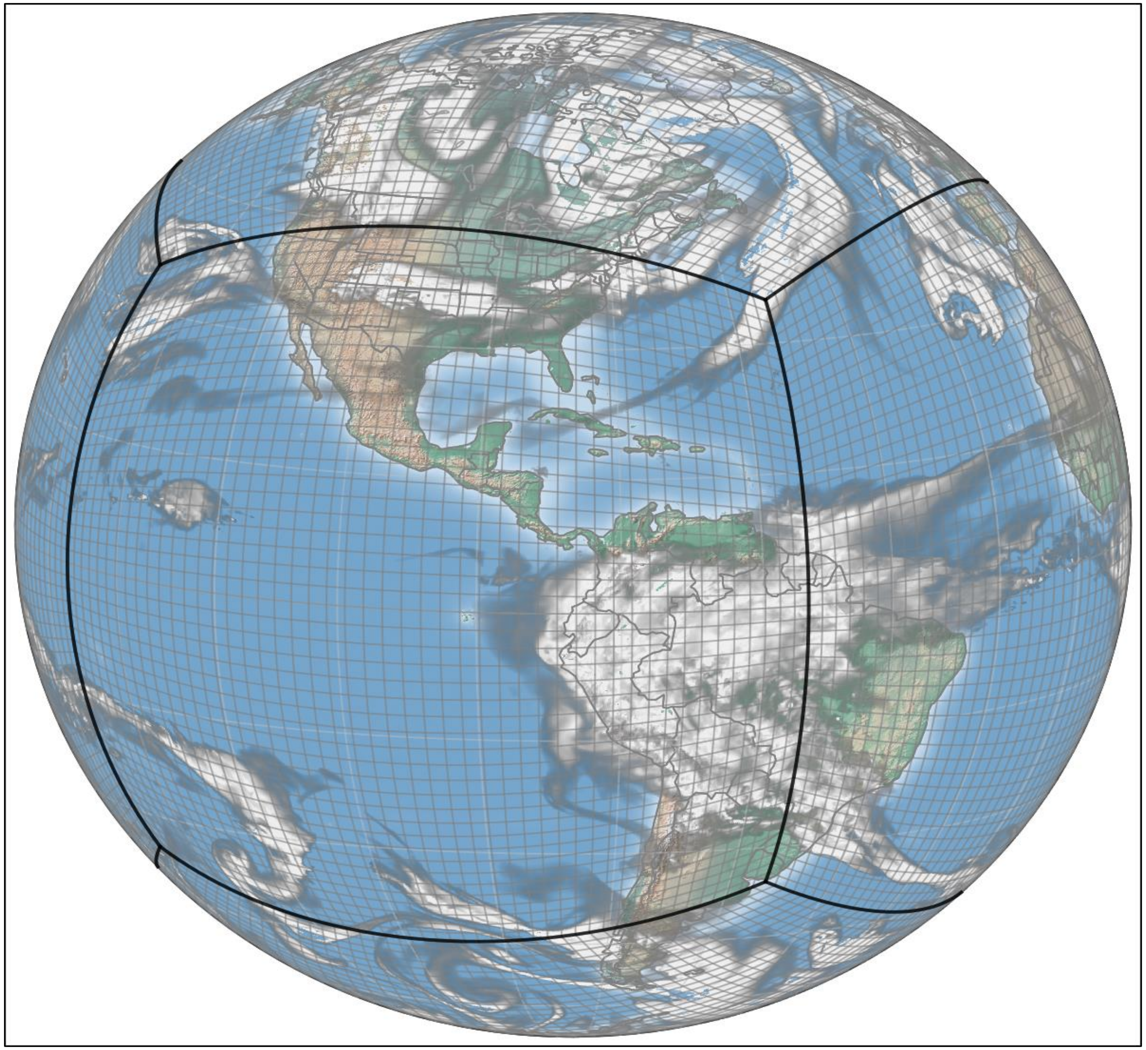
The Model failed to capture the QBO; SAO westerly phase is too weak.

Proposed PHYSICS OPTIONS for Preliminary GFSv16 Physics Testing

	P1: GFSv15+ sa-TKE-EDMF (control)	**P2 Radiation change**	**P3 LSM change**	**P4 GWD change**
Deep Cu:	sa-SAS	sa-SAS	sa-SAS	sa-SAS
Shallow Cu:	sa-MF	sa-MF	sa-MF	sa-MF
Microphysics:	GFDL	GFDL	GFDL	GFDL
PBL/TURB:	sa-TKE-EDMF	sa-TKE-EDMF	sa-TKE-EDMF	sa-TKE-EDMF
Radiation:	RRTMG	**Modified RRTMG**	RRTMG	RRTMG
Land:	Noah	Noah	**NOAH-MP**	Noah
O-GWD:	GFS Orog. GWD and Mtn Blocking	GFS Orog. GWD and Mtn Blocking	GFS Orog. GWD and Mtn Blocking	**UGWD**
C-GWD:	C-GWD	C-GWD	C-GWD	
O3/H2O:	NRL	NRL	NRL	NRL

PBL/turbulence: K-EDMF => sa-TKE-EDMF
Land surface: Noah => Noah-MP
GWD: separate orographic/non-orographic => unified gravity-wave-drag
Radiation: updates to cloud-overlap assumptions, empirical coefficients, etc. in **RRTMG**

Thank you



Back-up slides

Summary -- Benefits

- (significantly) Improved 500-hpa anomaly correlation
- Intense tropical cyclone deepening in GFS not observed in FV3GFS
- FV3GFS tropical cyclone track forecasts improved (within 5 days)
- Warm season diurnal cycle of precipitation improved
- Multiple tropical cyclone centers generated by GFS not seen in FV3GFS forecasts or analyses
- General improvement in HWRF and HMON runs
- New simulated composite reflectivity output is a nice addition
- Some indication that fv3gfs can generate modest surface cold pools from significant convection

Summary -- Benefits

Other Benefits

- FV3GFS with advanced GFDL MP provides better initial and boundary conditions for driving standard alone FV3, and for running downstream models that use advanced MP.
- Improved ozone and water vapor physics and products
- Improved extratropical cyclone tracks
- Improved precipitation ETS score (hit/miss/false alarm)
- Overall reduced T2m biases over CONUS

Summary -- Concerns

From MEG assessment

- FV3GFS can be too progressive with synoptic pattern
- Precipitation dry bias for moderate rainfall
- SST issues – North Pacific and lakes are too cold in the transition season
- Spurious secondary (non-tropical) lows show up occasionally in FV3GFS since the advection scheme change was made
- *Both GFS and FV3GFS struggle with inversions*
- *Both GFS and FV3GFS often has too little precip on the northwest side of east coast cyclones*

Other Concerns

- T2m over Alaska is too cold, likely caused by cold NSST and/or cloud microphysics issue in the Arctic region.
- NHC reported that FV3GFS degraded track forecast of hurricanes (initial wind > 65 kts) in the Atlantic basin

DA: Infrastructure Changes

- Improved GSI code efficiency

- The GSI does not currently have the capability to operate on a non-rectangular grid. Forecasts are therefore provided via the FV3 write-grid component on the Gaussian grid required by the GSI. **Increments are interpolated back on the cube-sphere grid** within the FV3 model itself.

- Both the analysis and EnKF components are now performed at **one-half of the deterministic forecast resolution** (increased from one-third in current operations) and is now C384 (~26km) instead of 35km. This reduced issues when interpolating between ensemble and control resolutions.

- **Tropical cyclone relocation** is **omitted** from the implementation, as is the full field **digital filter**.

- The current operational GDAS/GFS system uses a total (non-precipitating) cloud condensate, whereas the FV3-GFS has **five separate hydrometeor** variables.

From: DA Team

DA Infrastructure Changes – cont'd

- The initial FV3 data assimilation scheme retains the total cloud condensate control variable by **combining liquid water and ice amounts** from the model, but avoids issues with how to split the analysis increments into the component species by **not feeding the increment back** at all.
  - This approach (treating the cloud as a "sink variable") will **still update the other model fields to be consistent with the cloud increment** through the multivariate error correlation in the background error specification while also **mitigating "spin-down" issues** seen in current operations.

- **Only** the **SHUM** (Stochastically Perturbed Boundary Layer Specific Humidity) and **SPPT** (Stochastically Perturbed Physics Tendencies) are included as stochastic physics in the EnKF. The **SKEB** (Stochastic Energy Backscatter) **was not** available to be **used** at the time the code was frozen, and amplitude parameters for SHUM and SPPT were modified to compensate.

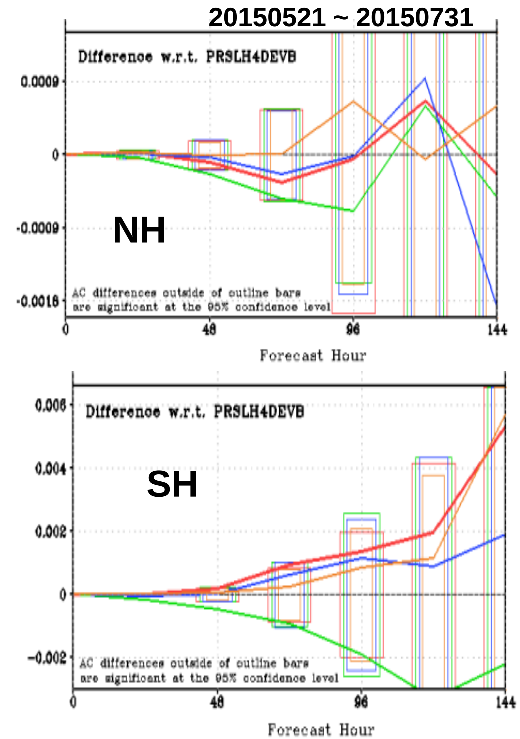
From: DA Team

DA: Observation Changes

- **ATMS** has been upgraded from **clear-sky to all-sky** assimilation to be consistent with the AMSU-A sensors.
- CrIS on Suomi-NPP was upgraded to use the full spectral resolution (FSR) data stream – consistent with CrIS on NOAA-20 (moisture and pressure).
- CrIS and ATMS on NOAA-20 as well as GOES-16 winds were made operational in 2018 and this is reflected in the FV3-GFS package. CrIS has slightly modified observation errors and thinning compared to operations.
- Turn on 10 water vapor channels for IASI.
- Turn on Megha-Tropiques Saphir (humidity)
- Monitor Suomi-NPP OMPS retrievals (ozone)

500hPa HGT ACC
ATMS Change to All-Sky

Cntl: Clear-Sky ATMS
All-Sky ATMS
(other curves are alternative configurations for all-aky)

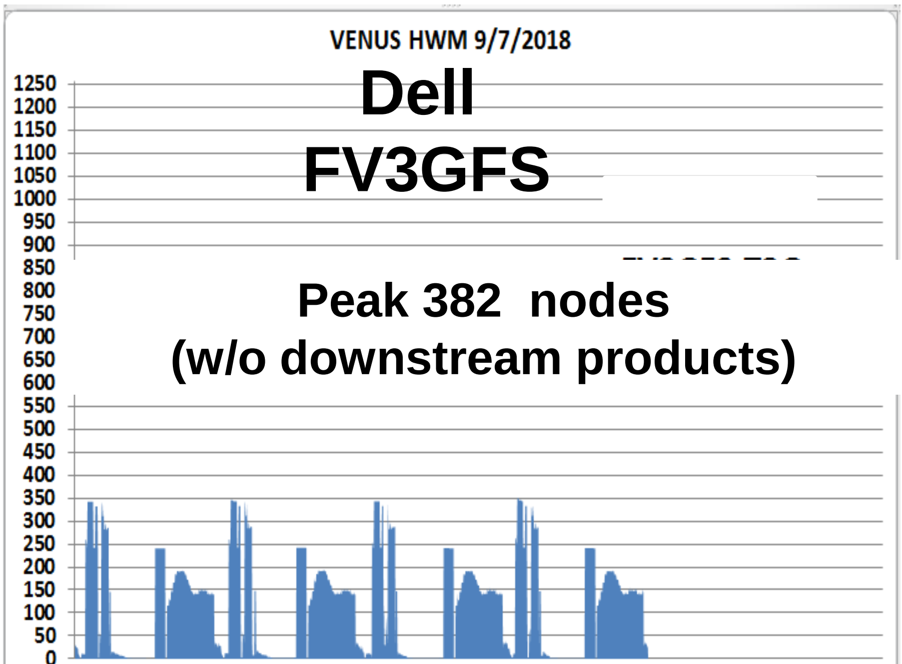


From: DA Team

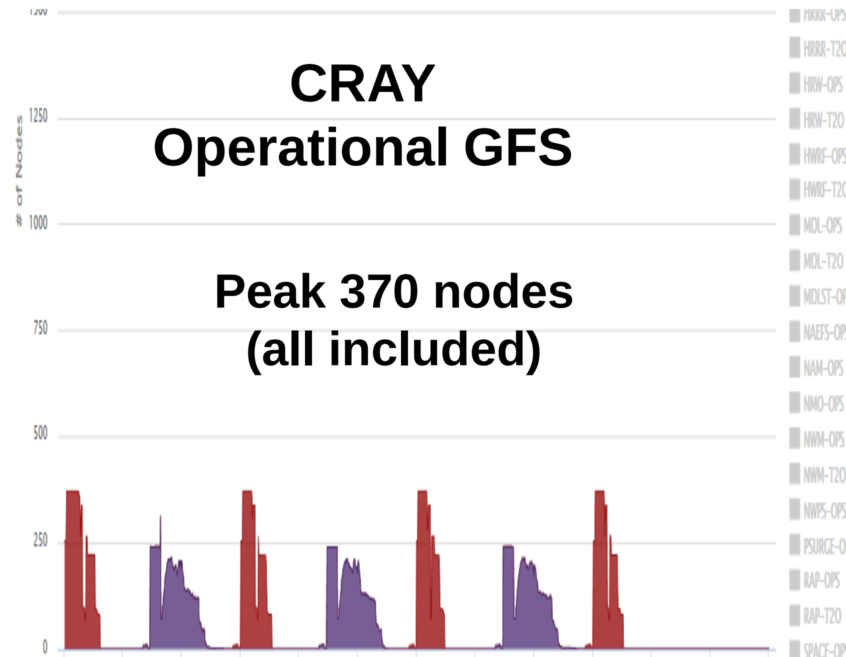
High Water Mark Test

With detailed node distribution

FV3 is more expensive to run than GSM



GFS fcst:	148 nodes
GDAS fcst:	28 nodes
Analysis:	240 nodes
ENKF fcst:	280 nodes



GFS fcst:	65nodes
GDAS fcst:	55 nodes
Analysis:	240 nodes
ENKF fcst:	200 nodes

Dell has 28 processors per node while Cray has 24 processors per node

From: Russ Treadon, Fanglin Yang, Matt Pyle

Timing Test and Forecast Configuration

RUN TIME (minutes)	J-Job prod	J-Job para	prod (minutes)	para (minutes)	para-prod
gfs_analysis	JGFS_ANALYSIS	JGLOBAL_ANALYSIS	22.9	26.8	4.2
gfs_forecast (0-10 days)	JGFS_FORECAST_HIGH	---	78.5	75.5	-3
gfs_forecast (11-16days)	JGFS_FORECAST_LOW	---	11.3	30.3	19
gfs_forecast (0-16 days)	---	JGLOBAL_FORECAST	89.8	120.8	31
gdas_analysis_high	JGDAS_ANALYSIS_HIGH	JGLOBAL_ANALYSIS	29.7	30.7	1.0
gdas_forecast_high	JGDAS_FORECAST_HIGH	JGLOBAL_FORECAST	12.3	11.7	-0.6

Highlights:

- current operational GFS runs at T1534 (13 km) for the 1st 10 days, then at T574 (35 km) up to 16 days
- V3GFS runs at the same C768 resolution (~13 km) up to 16 days
- Operational GFS write hourly output for the 1st 5 days, 3 hourly up to 10 days, then 12 hourly up to 16 days
- FV3GFS writes hourly output for the 1st 5 days, then 3 hourly up to 16 days

- **FV3GFS analysis will be 4.2 minutes slower than current operation; day-10 products will be delivered 3 minutes earlier; day-16 product will be delayed by 19 minutes.**
- **GDAS cycles remains almost the same in terms of timing (+/- 1.0 minutes)**

Changes in Online Disk Usage
Per Cycle

~160% increase

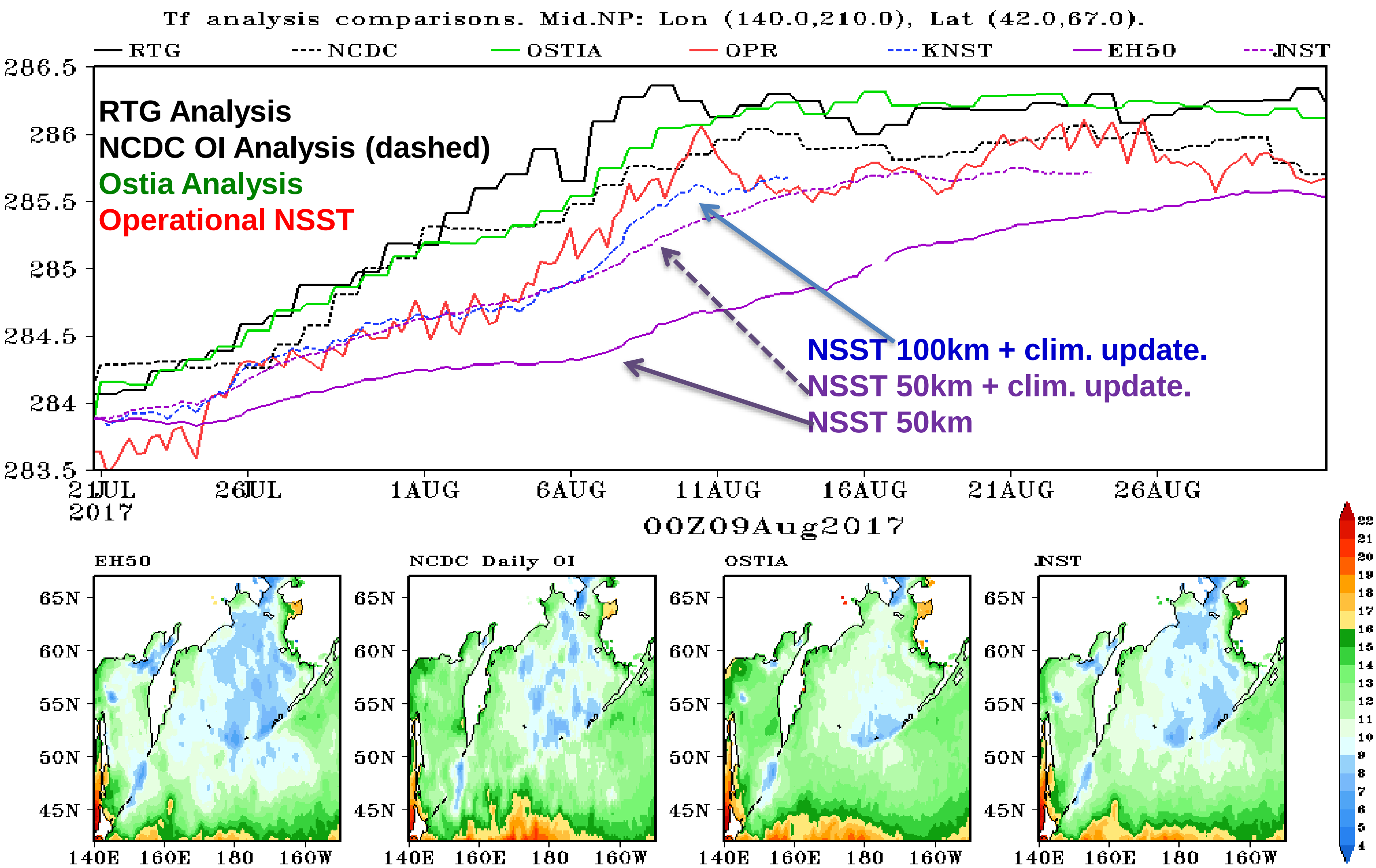
	anl+forecast	products & misc	total
ops gfs	1.70 TB	0.30 TB	2.0 TB
ops GDAS	0.157 TB	0.029 TB	0.186 TB
ops ENKF	1.831 TB	0.043 TB	1.874 TB
ops total			4.06 TB
FV3 GFS	4.0	0.70	4.7
FV3 GDAS	0.295	0.05	0.3
FV3 ENKF	5.4	0.3	5.7
FV3 total			10.7 TB

Ops GDAS and ENKF are run at T574 (1152x576), while FV3GFS is run at C384, e.g. T766 (1532x768). This is equivalent to a 77.7% increase in forecast file size. Factoring in the increase of output variables, ENKF and GDAS file size will increase by 200%.

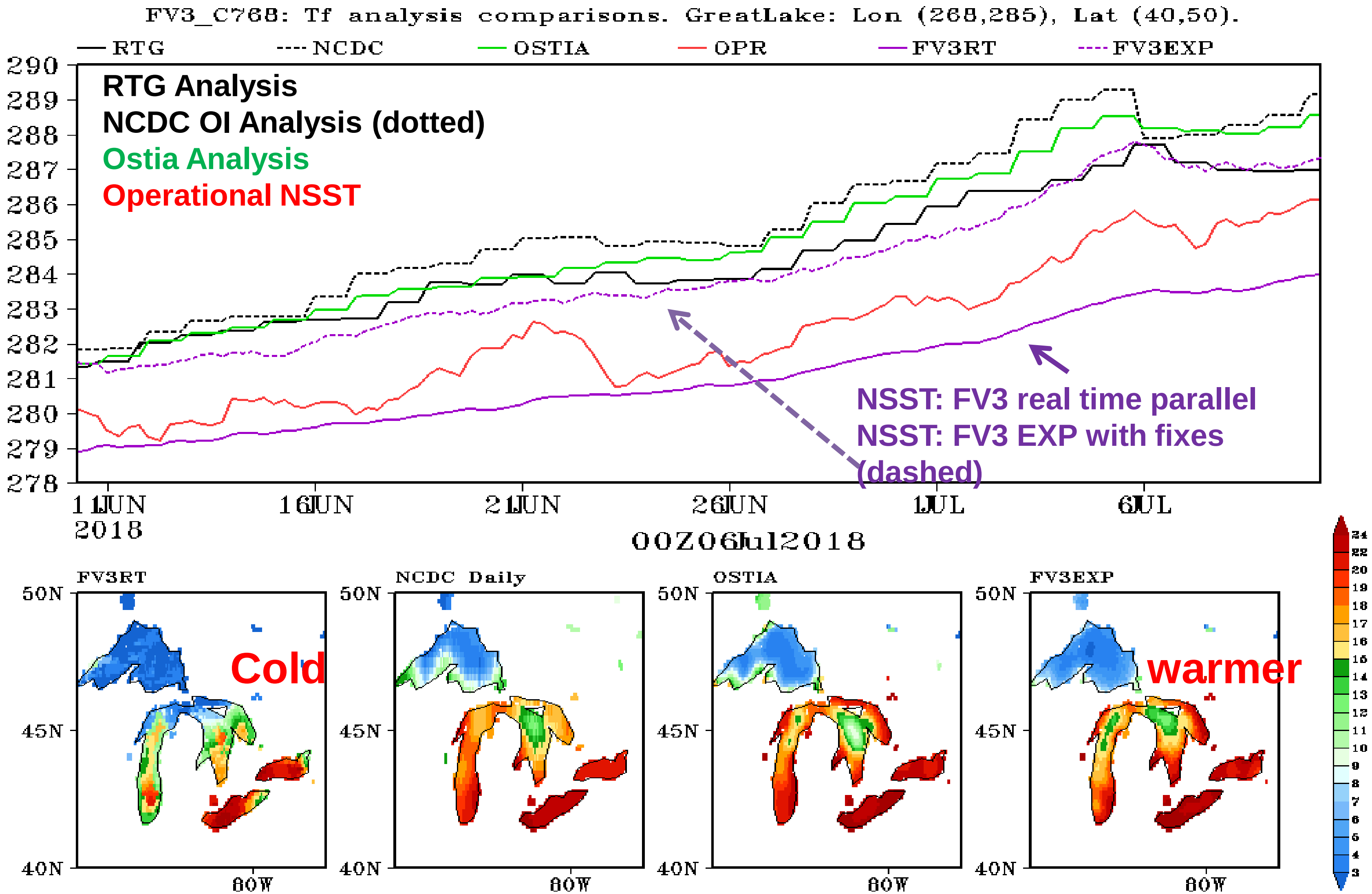
Changes in HPSS Archives
per cycle (link)

	Ops GFS	Proposed for FV3GFS
Tarball naming convention	gfs.yyyymmddhh.sigma.tar enkf.yyyymmdd_hh.anl.tar enkf.yyyymmdd_hh.fcs.tar enkf.yyyymmdd_hh.fcs03.tar enkf.yyyymmdd_hh.fcs09.tar enkf.yyyymmdd_hh.omg.tar gdas.yyyymmddhh.tar gdas.yyyymmdd_radmonhh.ieee.tar gfs.yyyymmddhh.anl.tar gfs.yyyymmddhh.pgrb2_0p25.targ fs.yyyymmddhh.pgrb2_0p50.tar gfs.yyyymmddhh.pgrb2_1p00.tar gfs.yyyymmddhh.sfluxgrb.tar	gfs.targfs_flux.tar gfs_nemsioa.tar gfs_restarta.tar gdas.targdas_restarta.targdas_restartb.targfs.pgrb2_0p25.targfs.pgrb2_0p50.targfs.pgrb2_1p00.tarenkf.gdas.tarenkf.gdas_grp01.tarenkf.gdas_grp02.tarenkf.gdas_grp03.tarenkf.gdas_grp04.tarenkf.gdas_grp05.tarenkf.gdas_grp06.tarenkf.gdas_grp07.tarenkf.gdas_grp08.tarenkf.gdas_restarta_grp01.tarenkf.gdas_restarta_grp02.tarenkf.gdas_restarta_grp03.tarenkf.gdas_restarta_grp04.tarenkf.gdas_restarta_grp05.tarenkf.gdas_restarta_grp06.tarenkf.gdas_restarta_grp07.tarenkf.gdas_restarta_grp08.tar
permanent	**1171 GB**	**1700 GB**
2-year	**55 GB**	**1320 GB**
total	**1226 GB**	**3020 GB**

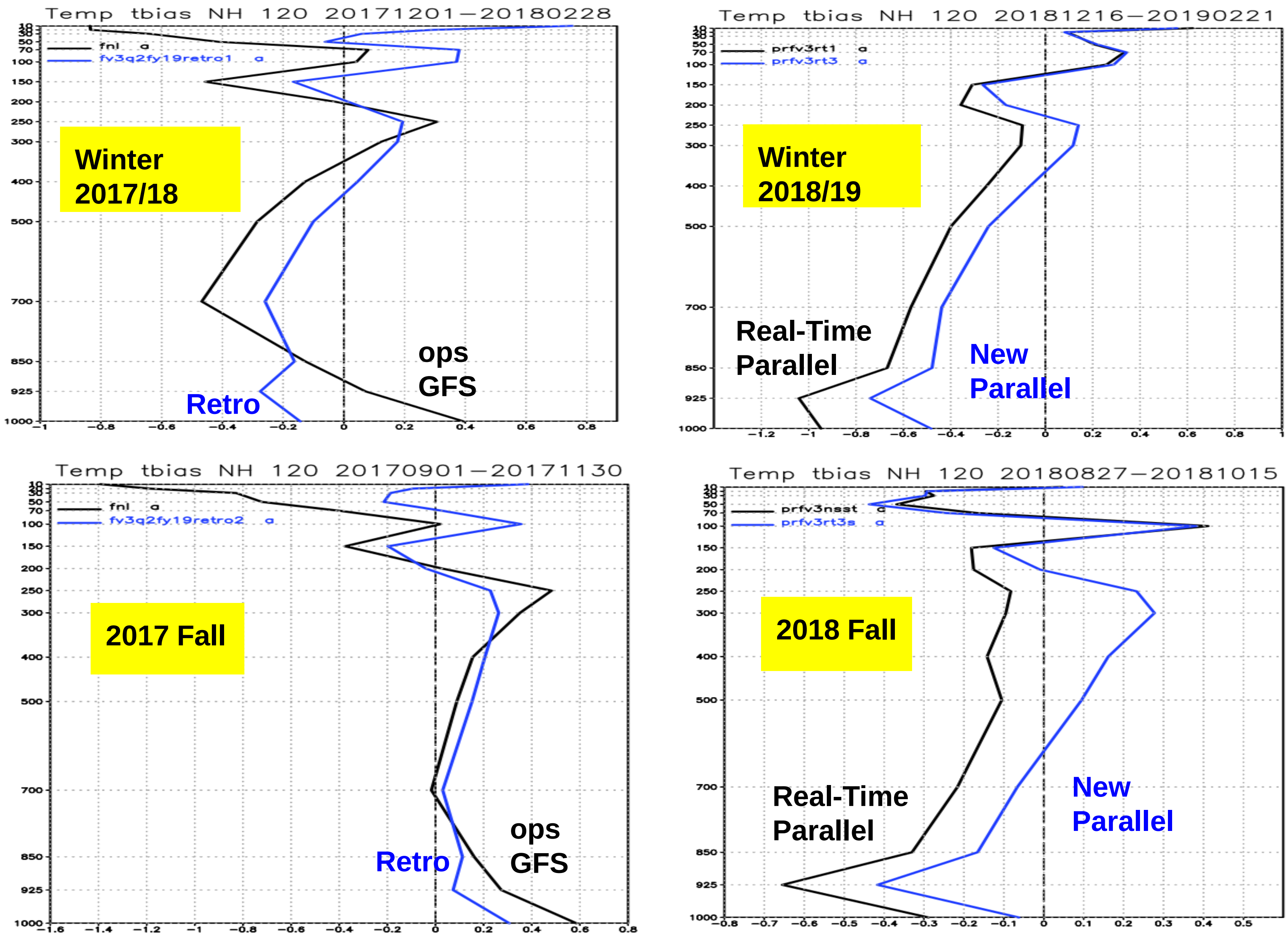
Fixing the N. Pacific Cold Bias



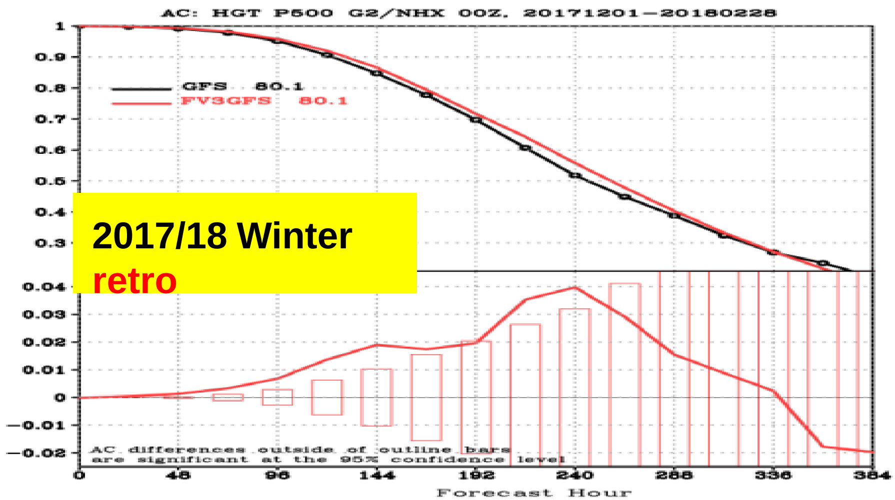
Fixing the Great Lakes Cold Bias

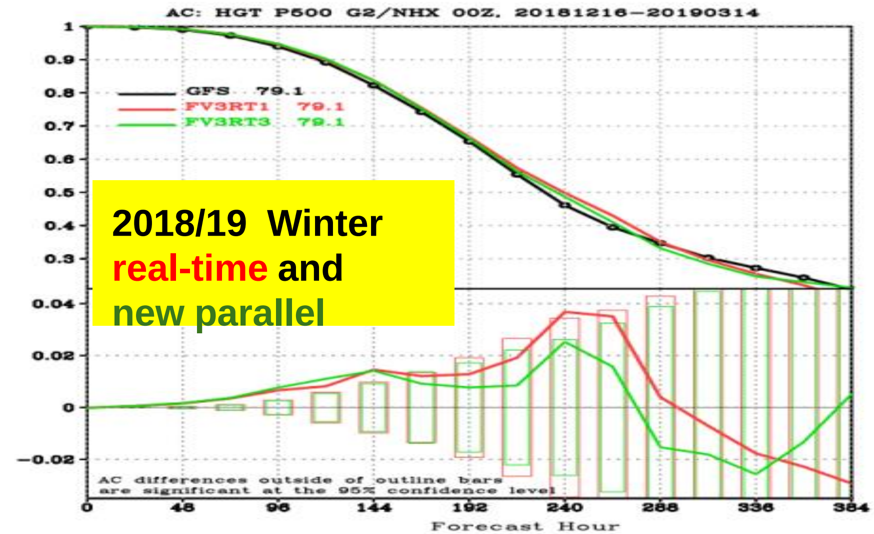


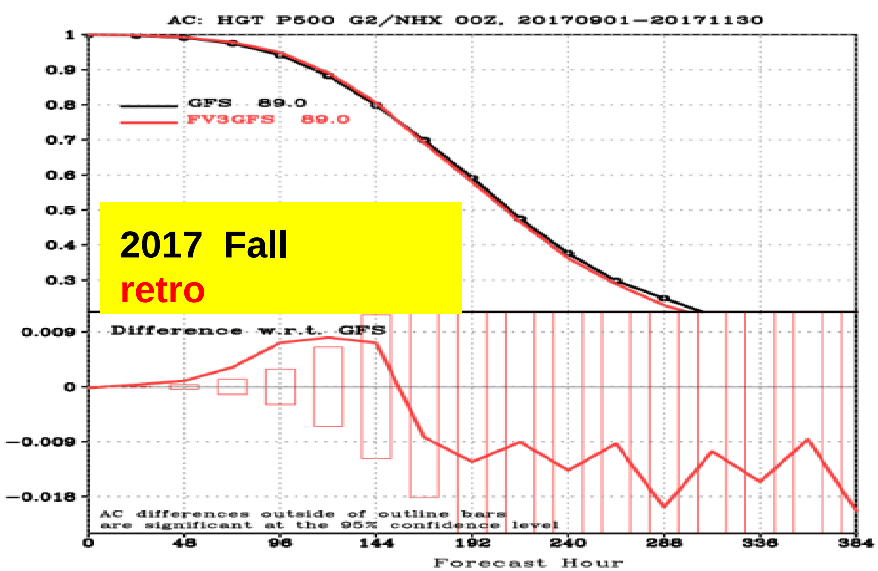
Comparison of NH day-5 fit-to-robs for the New Parallel with that for the "3-year retro" package

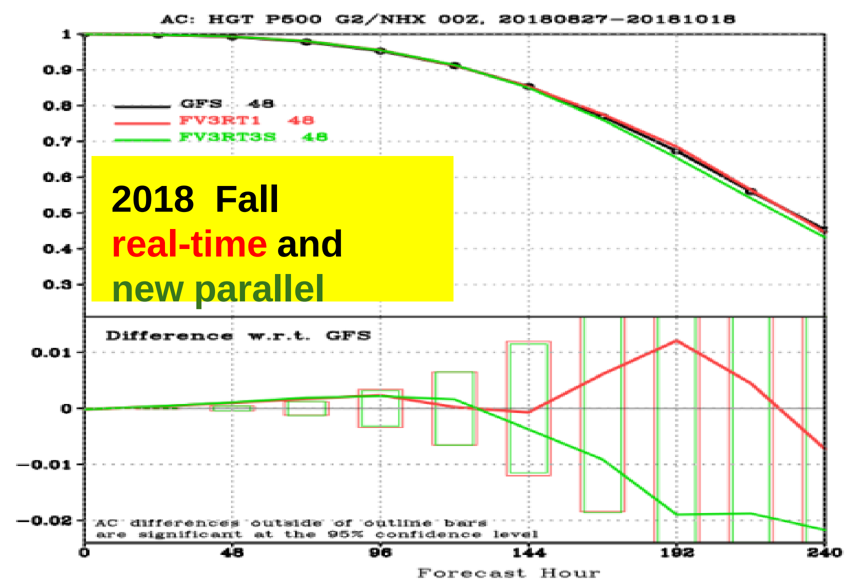


NH 500-hPa Height ACC
The improvement is seen in both the retros and new runs

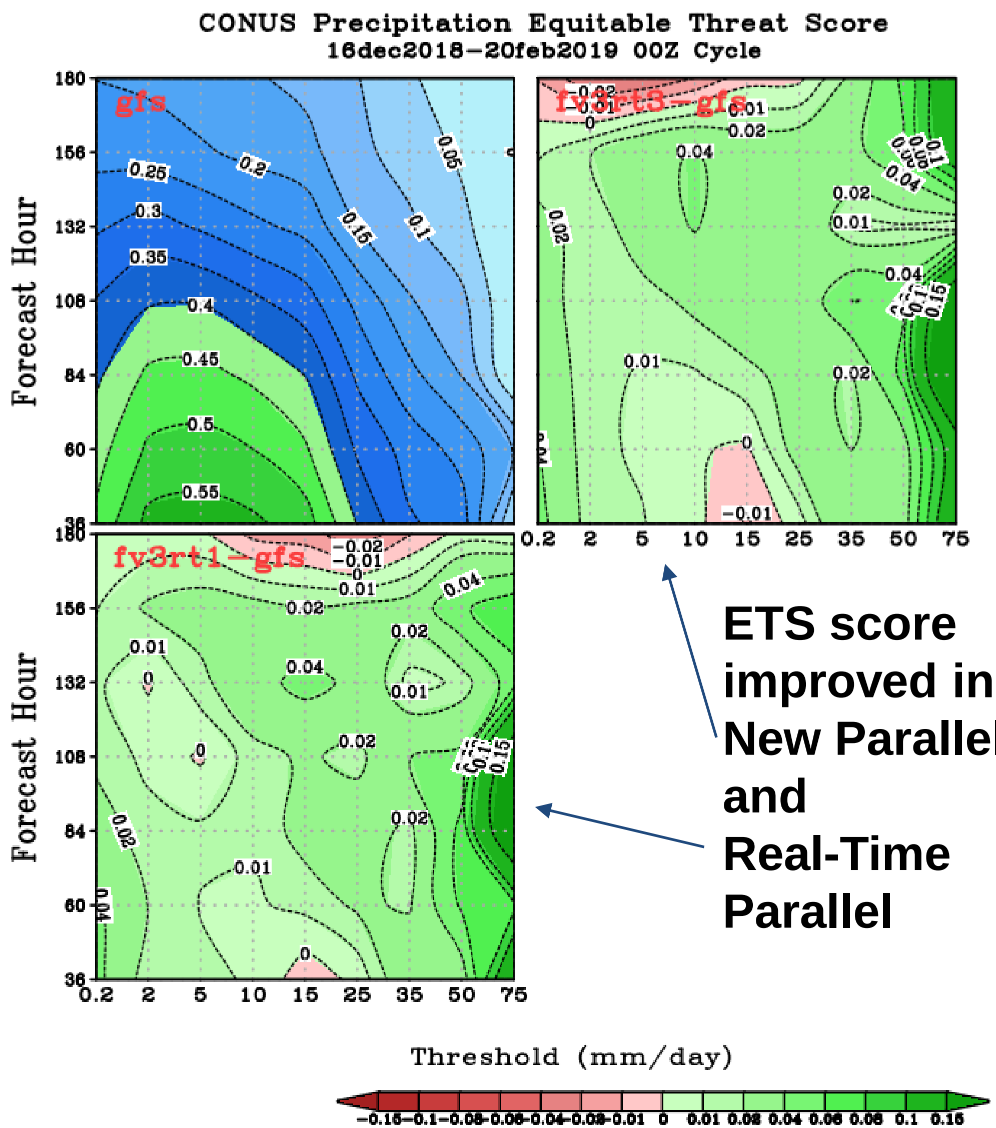




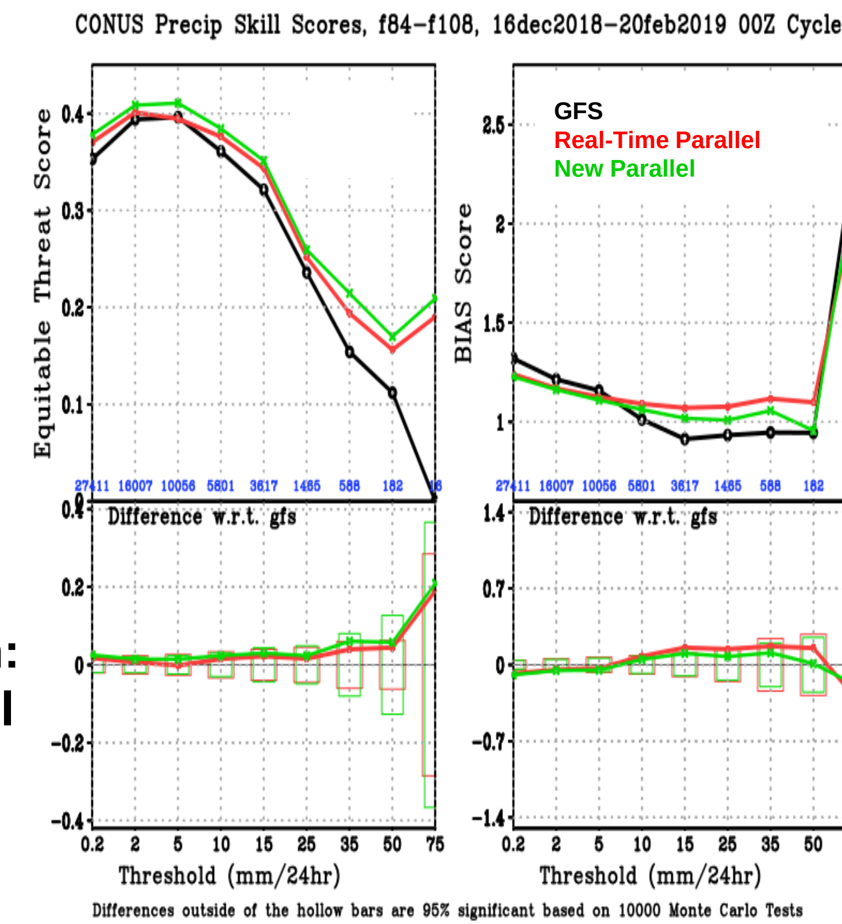




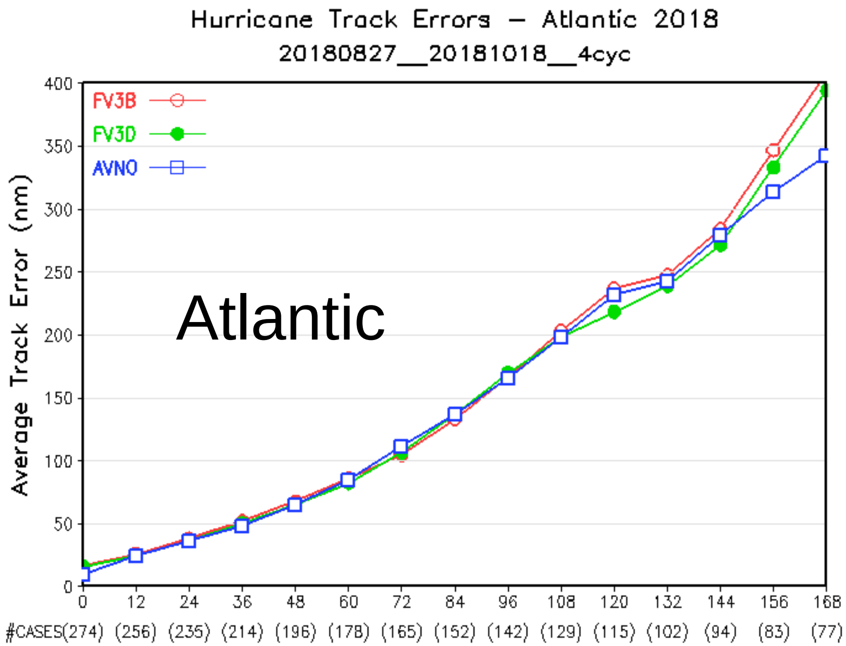
Precipitation ETS and BIAS Scores
Winter 20181216 ~ 20190220, Verified against Gauge Obs.



ETS score improved in: New Parallel and Real-Time Parallel

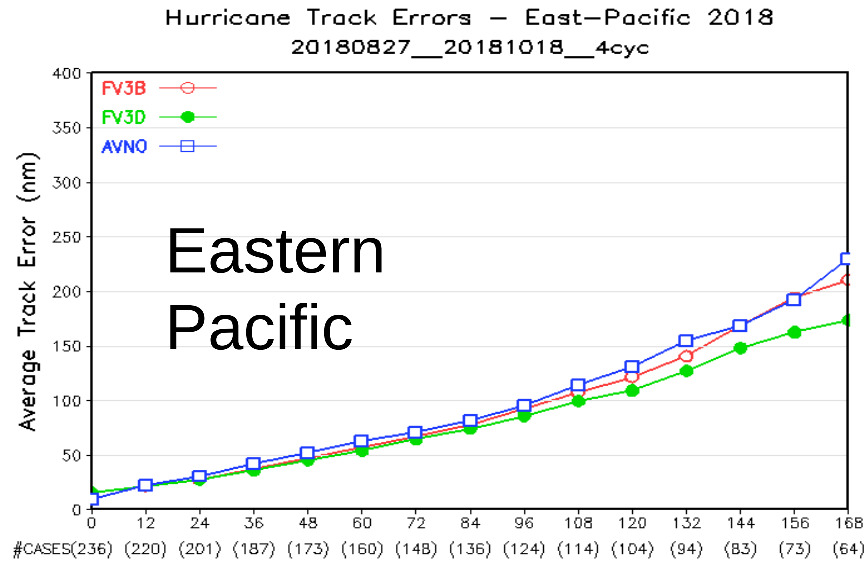


Mean Track Errors, 27Aug2018 ~ 18Oct 2018



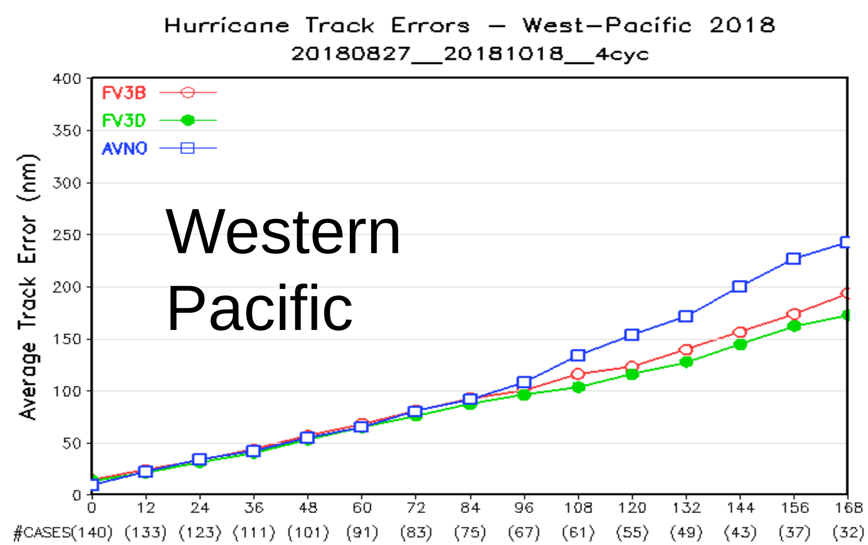
Confidence Level (%) of Student–t Tests

FV3B_FV3D	79	97	98	91	91	83	65	75	62	67	92	75	79	74	71
FV3B_AVNO	100	86	93	97	78	56	85	72	57	67	64	62	60	92	98
FV3D_AVNO	100	64	52	79	59	71	74	50	64	50	80	59	68	84	98



Confidence Level (%) of Student–t Tests

FV3B_FV3D	62	59	56	93	89	98	83	93	98	97	99	96	98	99	99
FV3B_AVNO	100	83	98	99	98	98	88	85	78	88	95	97	50	58	91
FV3D_AVNO	100	81	99	99	99	99	97	98	98	99	99	99	98	99	99



Confidence Level (%) of Student–t Tests

FV3B_FV3D	77	98	89	98	99	95	97	96	86	98	84	87	80	74	89
FV3B_AVNO	99	89	76	73	73	74	54	55	88	98	99	99	99	99	97
FV3D_AVNO	99	69	94	85	79	55	81	76	96	99	99	99	99	99	99

FV3B: Real-Time Parallel
FV3D: New Parallel
AVNO: Operational GFS