Briefing to EMC CCB
September 24, 2018

GDAS/GFS V15.0.0
Upgrades for Q2FY2019

Presented by:

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FV3GFS T2O Project Lead
EMC Modeling and Data Assimilation Branch

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

With Special thanks to NCO for securing computing resources for us to run a massive amount of experiments in a short period of time

Topics

Geoff Manikin, representing the VPPP Model Evaluation Group, gave a comprehensive evaluation of the FV3GFS forecast skills at the MEG weekly meeting on September 20th. Please refer to MEG Recording for Geoff's presentation.

This presentation will be focused on

- **Science changes**
- **Product changes**
- **System configuration and resource requirement**
- **General performances**
- **Downstream user and model evaluation**
- **Benefits and concerns**

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
JAN 2019	64	FV3 (13km)	Finite-Volume	NGGPS FV3 dycore, GFDL MP

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

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NGGPS FV3GFS-v1 Transition to Operations

FV3GFS is being configured to replace spectral model (NEMS GSM) in operations in Q2FY19

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:

- 3/7/18: code freeze of FV3GFS-V1 (GFS V15.0)
- 3/30/18: Public release of FV3GFS-V1
- 4/1 – 1/25/19: real-time EMC parallel
- 5/25 – 9/10/18: retrospectives and case studies (May 2015 – September 2018; three summers and three winters)
- 9/24/2018: Field evaluation due; EMC CCB
- 10/01/2018: OD Brief, code hand-off to NCO
- 12/20/2018-1/20/2019: NCO 30-day IT Test
- 1/24/2019: Implementation

Quad Chart

GDAS/GFS Version 15
Status as of September 20, 2018

G

Project Information & Highlights

Leads: Vijay Tallapragada & Fanglin Yang (EMC), Steven Earle (NCO)

Scope: FV3 based GFS with upgrades to GFS physics including GFDL microphysics, ozone and water vapor photochemistry parameterizations.

Expected benefits: Initial FV3 based operational GFS with improved forecast skills

Dependencies: NCO and satisfactory evaluation by stakeholders and downstream products

G Schedule

Milestones & Deliverables	Date	Status
EMC/NCO EE2 kick off meeting	1/4/18	Completed
Freeze model code and data assimilation system	3/15/18	Completed
Complete full retrospective/real time runs and evaluation	9/10/18	Completed
Field evaluation	9/24/18	In Progress
Conduct CCB and deliver final system code to NCO	9/24/18	In Progress
Deliver Service Change Notice to NCO	11/01/18	In Progress
Complete 30-day evaluation and IT testing	1/20/19	planned
Operational Implementation	1/24/19	planned

EMC	NCO	Red text indicates change from previous quarter

G Issues/Risks

Risk: Not enough computational resources to run the EMC parallels; **Mitigation**: Run the real time parallels on WCOSS prod, and run multiple streams of retrospective experiments on multiple machines such as CRAY and DELL. Entire DELL (prod+dev) were dedicated for running 10 streams of FV3GFS experiments in the summer of 2018.

Risk: Insufficient NWAVE bandwidth for archiving FV3GFS retrospective/real-time runs to HPSS; **Mitigation:**Options: (a) buy more bandwidth for NWAVE; (b) restrict archives to limited data (will have negative impacts on downstream evaluations); (c) rerun the cases with missing/reduced HPSS archives at a later time.

Risk: Increased forecast file size and output variables requires 160% increase in online disk and HPSS storage; **Mitigation**: TBD (need NCO to acquire more disks)

G Resources

Staff: 3 Fed FTEs + 10 contractor FTEs; including Dev (FV3, physics, DA, post processing, V&V, and infrastructure)

Funding Source: STI/NGGPS

Compute: EMC Dev: (+100%); **Parallels:** (+100%); **Ops**: 360 nodes HWM

Archive: Parallels: 7 PB HPSS for 3-year retros; **Ops**: 10.6TB online and 2.8TB HPSS per cycle (+160%)

R Management Attention Required	Y Potential Management Attention Needed	G On Target

On Target

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

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

Physics still runs at 64-bit precision

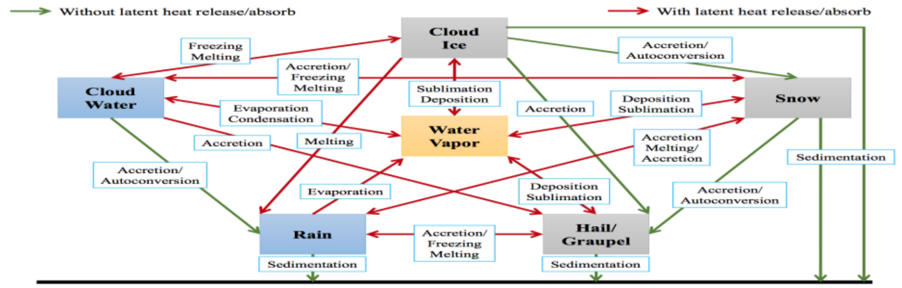
Zhao-Carr MP

Prognostic could species: one total cloud water

GFDL MP

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

more sophisticated cloud processes



Unique attributes of GFDL MP

1. Fast physics (phase changes ONLY, for now) between “Lagrangian-to-Eulerian” remapping in FV3

2. Time-split between warm-rain (faster) and ice-phase (slower) processes

3. Time implicit monotonic scheme for terminal fall of condensates

4. Thermodynamic consistency: exact moist energy conservation; condensates carry heat & momentum → heat and momentum transported during the sedimentation processes

5. “Scale-awareness” achieved by an assumed horizontal subgrid variability and a 2^{nd} order FV-type vertical reconstruction for autoconversions

From: SJ Lin

Revised Bare-Soil Evaporation For Reducing Dry and Warm Biases

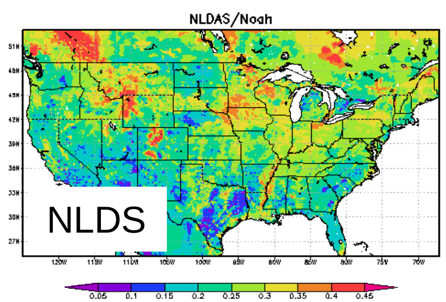
$$FX = (\Theta_1 - \Theta_{dry})/(\Theta_{sat} - \Theta_{dry})$$

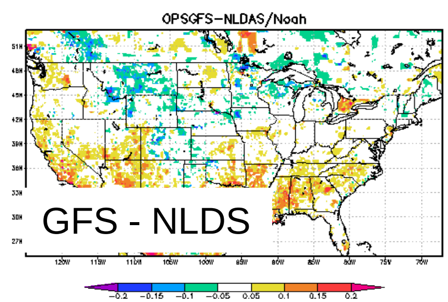
$$E_{dir} = (1 - \sigma_f)(FX)^{fx} E_p$$

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

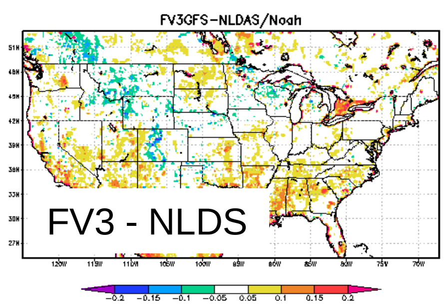
In the current model, θ_{dry} is set to the same as wilting point θ_{ref}. In reality, θ_{dry} is usually lower than θ_{ref}

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))

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

NEMS GSM
Includes reference tendency and dependence on O3 mixing ratio

FV3GFS
Additional dependences on temperature and column total ozone

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

χ_{O3} prognostic Ozone mixing ratio

T Temperature

c_{O3} column ozone above

From: Shrivinas Moorthi

Water Vapor Sources and Sinks in the Stratosphere/Mesosphere

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

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

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

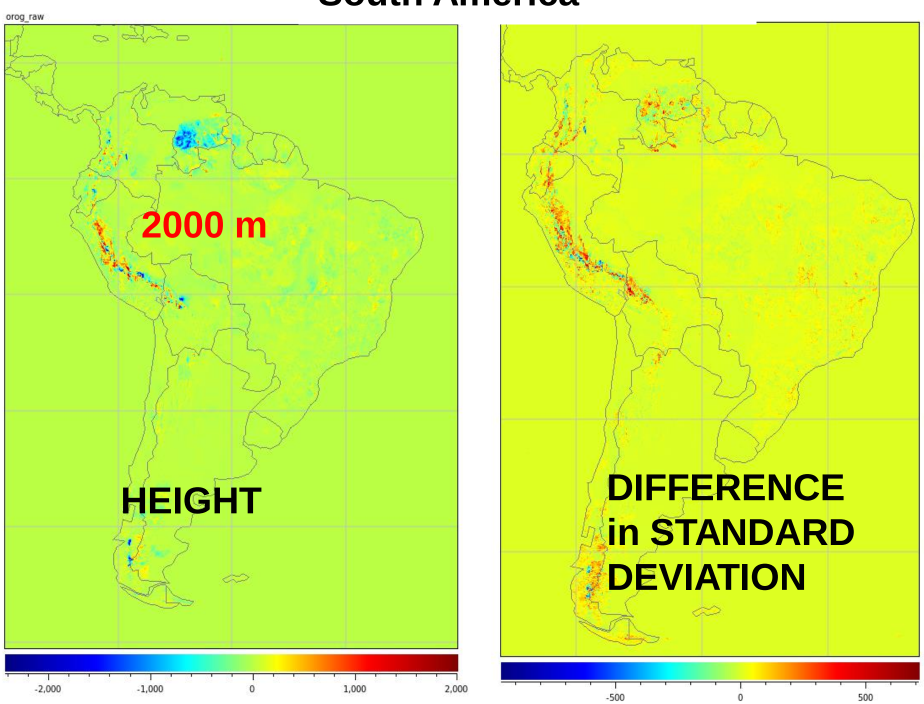
- The scheme mirrors that of ozone, with only production and loss terms.

From: Shrivinas Moorthi

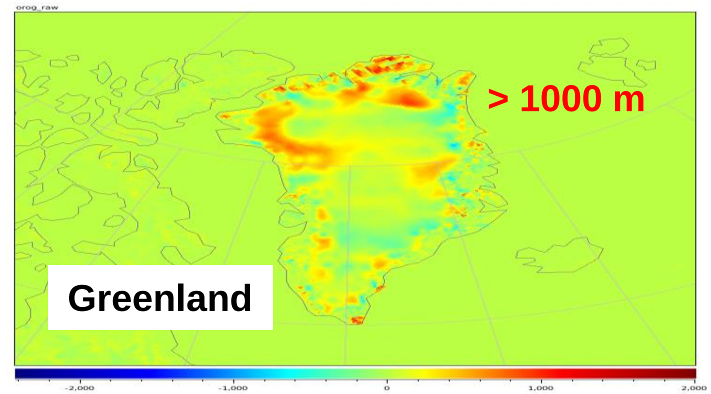
Terrain: GMTED2010 vs GTOPO30

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

South America

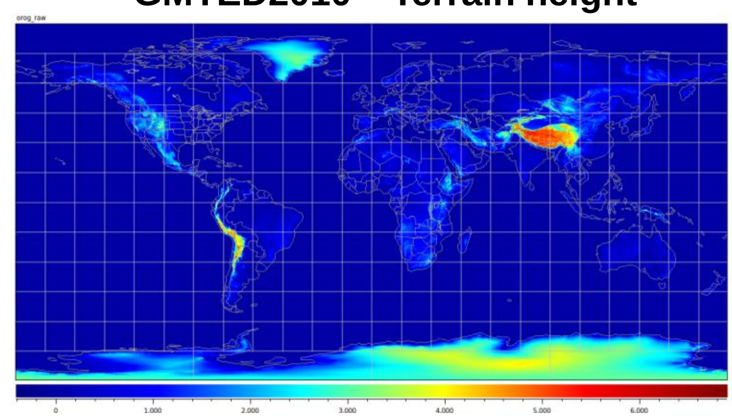


GMTED minus GTOPO30



DIFFERENCES IN GREENLAND ARE LARGE IN MAGNITUDE AND AREAL EXTENT.

GMTED2010 – Terrain height



From: George Gayno & Fanglin Yang

FV3GFS Stochastic Physics Update

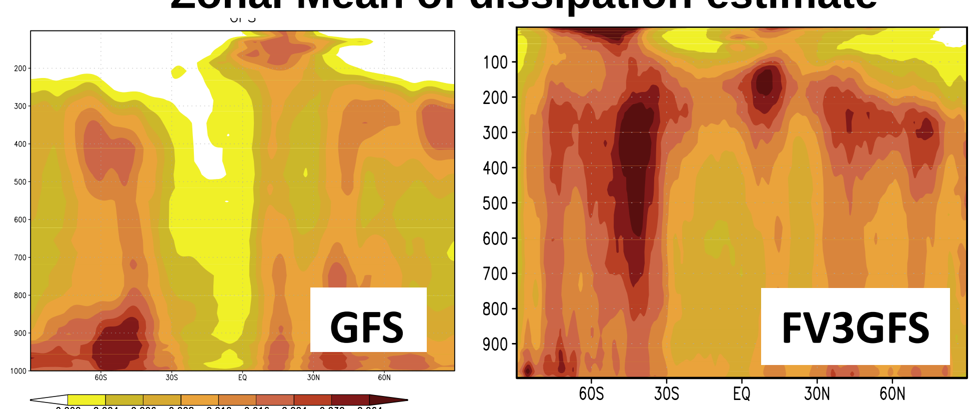
SKEB, SPPT, and SHUM were implemented into FV3GFS

- GFS generates random patterns in spectral space, and transforms patterns to a Gaussian grid
- FV3GFS still uses spectral patterns in spectral space, transforms them to a Gaussain grid, then interpolates to model's cubed-sphere grid. The spectral resolution of the random pattern is decoupled from the resolution of the model, but due to the way the spectral transforms are decomposed with MPI, there is a limit of the number of MPI tasks for a spectral resolution (this decomposition is taken from the GSM core).

Stochastic Kinetic Energy Backscatter

- GFS only uses the ***numerical dissipation*** estimate based on the ***vorticity gradient***, and smoothed in spectral space.
- FV3 core calculates ***Kinetic Energy*** loss at each time step in terms of a heat source that is added to the temperature equation. This loss smoothed in grid-point space for SKEB.

Zonal Mean of dissipation estimate



Vertical correlation of random patterns

- GFS produces a unique random pattern at every model level, then smoothed in the vertical using 40 passes of a 1-2-1 filter.
- Update to FV3GFS is to use the evolution of the random patterns over time to create vertical correlation. The pattern are saved on a independent vertical coordinate and interpolated to model levels. This allows for a **separation of vertical and temporal correlation** but only needing to carry one random pattern

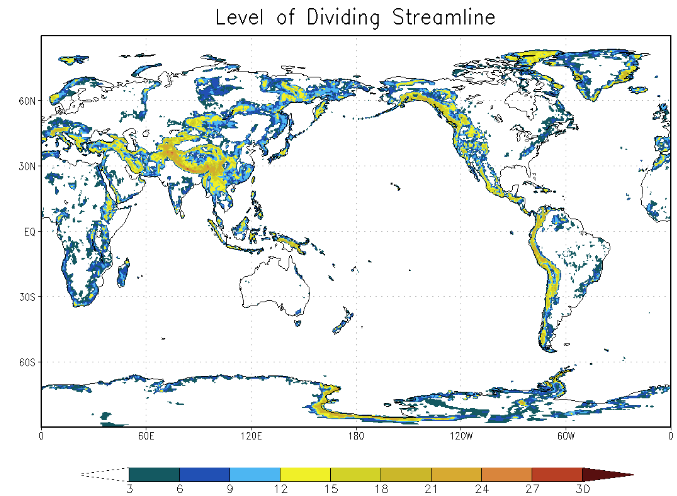
From: Phil Pegion

FV3GFS Stochastic Physics Update

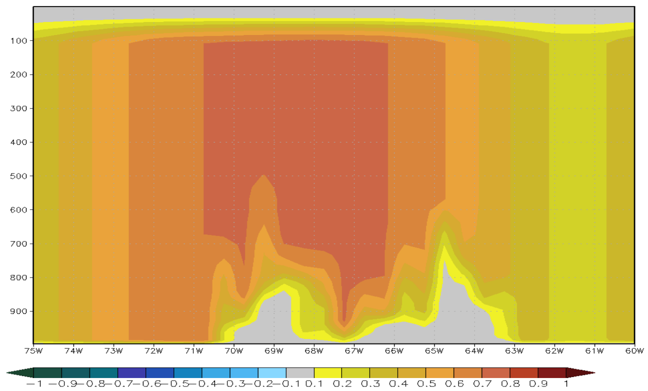
Modification to SPPT

Several crashes were traced back to an interaction of the PBL scheme and mountain blocking scheme with SPPT.
Gravity wave/mountain blocking scheme diagnoses a “dividing streamline” based on orography and kinetic energy (Lott and Miller 1997)
This fix is to not apply any SPPT perturbations where the model diagnoses the flow as blocked, then ramp up to full perturbations over 3 grid points in the vertical.

level of the dividing streamline

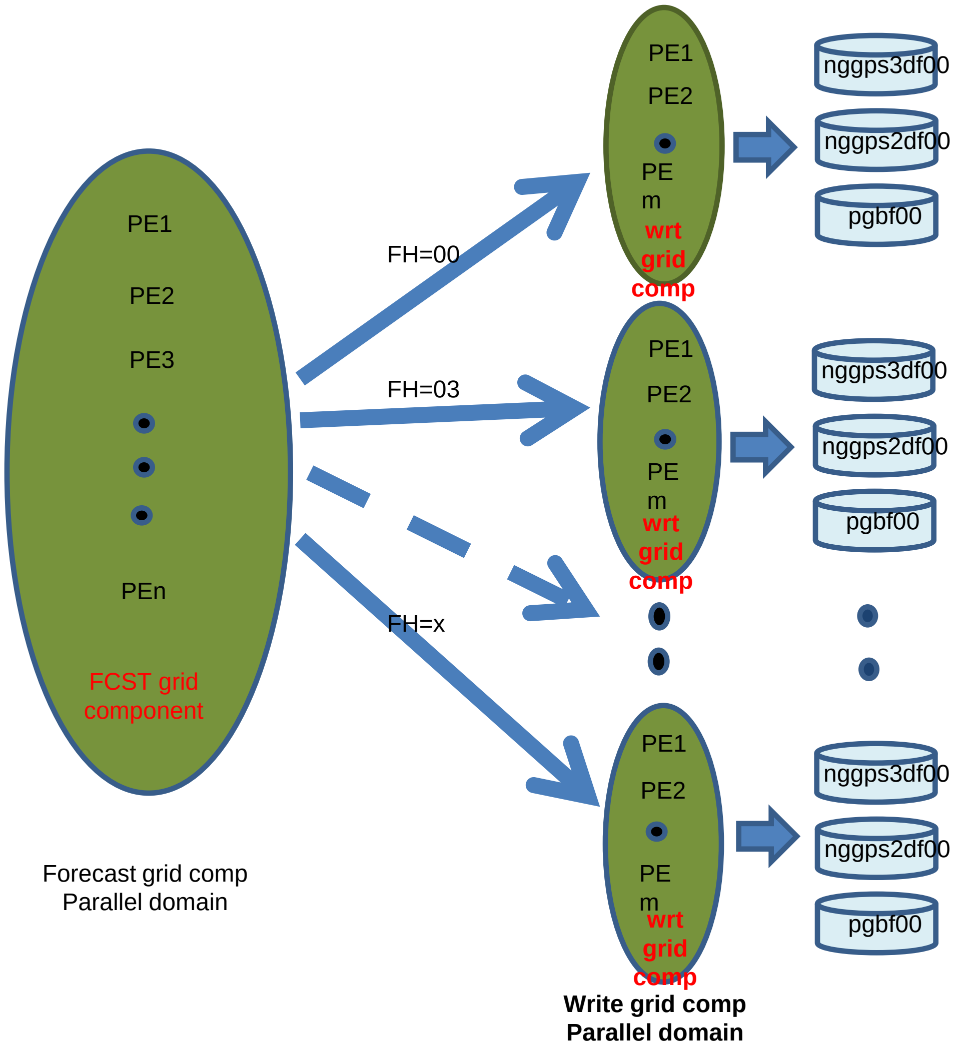


Cross section across the Andes



From: Phil Pegion

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

- 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.

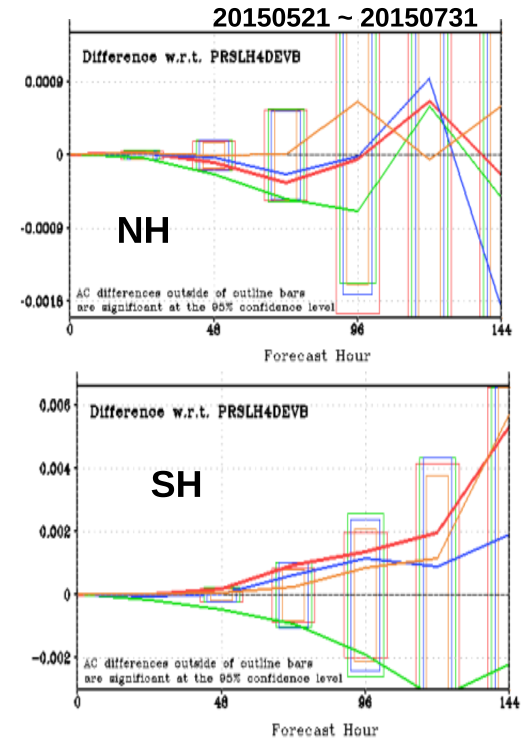
From: DA Team

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

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

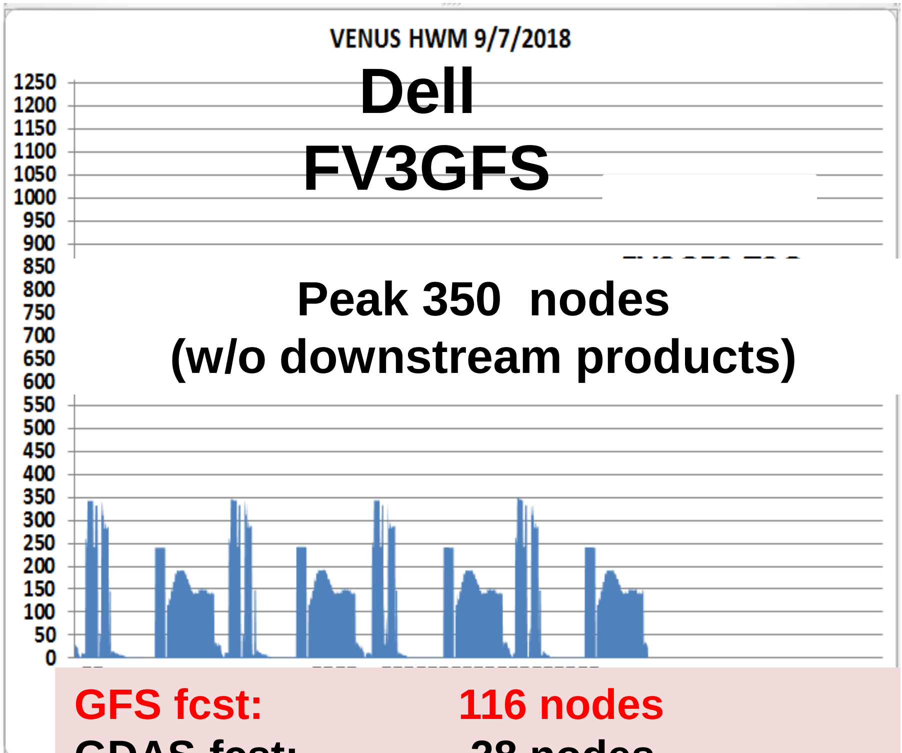
- ➢ **Almost all scripts adopted from the NEMS GFS were rewritten for the FV3GFS**
- ➢ **The old psub/pend job submission system is replaced by Rocoto drivers**
- ➢ **The 4-package superstructure workflow was merged into one package with a flat structure**
- ➢ **All JJOBS were rewritten. Both EMC parallels 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)

High Water Mark Test

With detailed node distribution

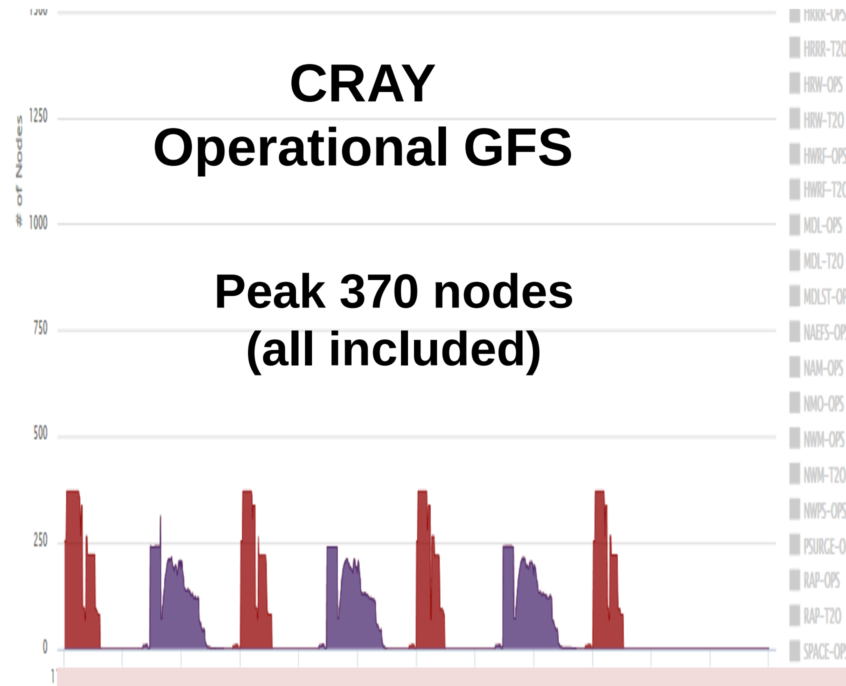
FV3 is more expensive to run than GSM



Dell FV3GFS

Peak 350 nodes (w/o downstream products)

GFS fcst:	**116 nodes**
GDAS fcst:	**28 nodes**
Analysis:	**240 nodes**
ENKF fcst:	**280 nodes**



CRAY Operational GFS

Peak 370 nodes (all included)

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	45.3	34
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 31 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**	**1858 GB**
2-year	**55 GB**	**991 GB**
total	**1226 GB**	**2849 GB**

- *All tarball names are changed*
- *nemsioa.tar: saving forecast history nemsio files 3-hourly up to 84 hours for running* ***standalone FV3***
- *2-year “991GB” : saving forecast history nemsio files 6-hourly from 90 to 384 hours. (optional)*

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.
- The real-time parallel was moved from CRAY to DELL in August.

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

With the support of MDL scientists, we included MDL GFSMOS in the real-time parallel and two retro runs. This effort streamlined MOS evaluation of GFS for current and future implementations.

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

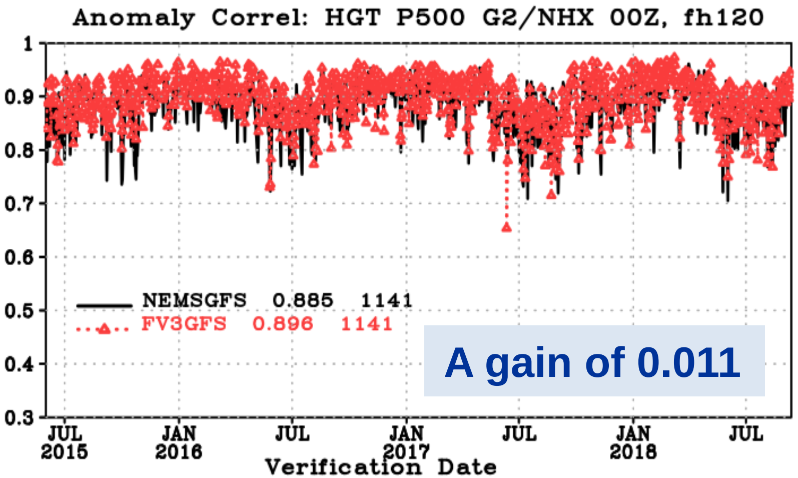
Verification & Evaluation

- **Geoff Manikin presented a comprehensive evaluation of the FV3GFS forecast skills at the MEG weekly meeting on September 20th.**
- **A few of the highlights will be repeated here.**
- **Additional verification and evaluation will be added.**
- **Benefits and concerns from both MEG's presentation and this briefing will be summarized at the end of this talk.**

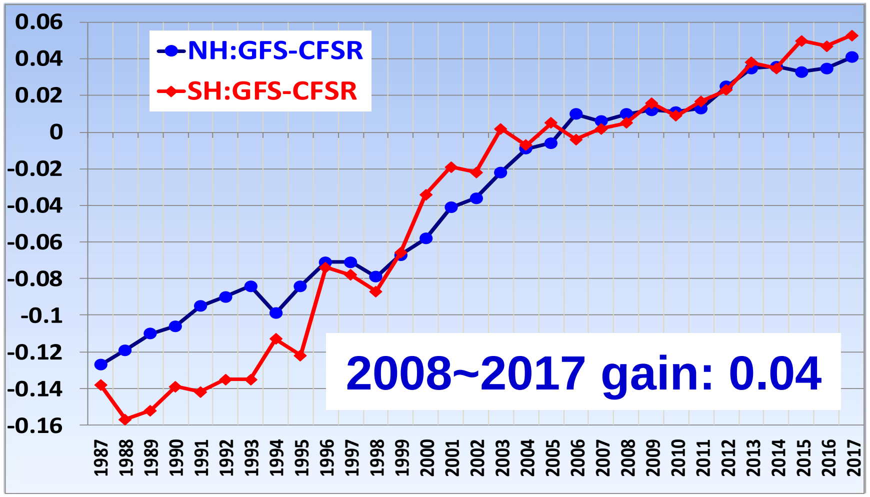
nomenclatures: ***ops GFS, NEMSGFS or GSM*** referred in this talk are the same spectral model

NH 500-hPa HGT Anomaly Correlation
(20150601 ~ 20180912)

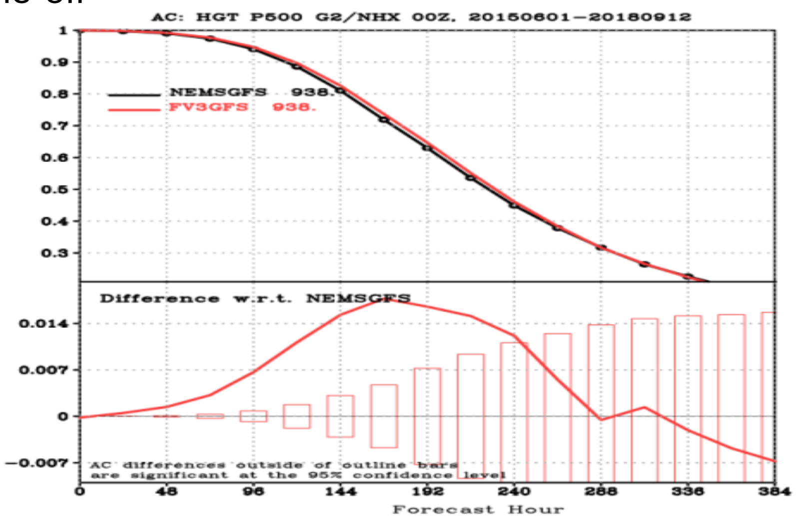
Day-5



Annual Mean day-5 ACC, GFS - CFSR

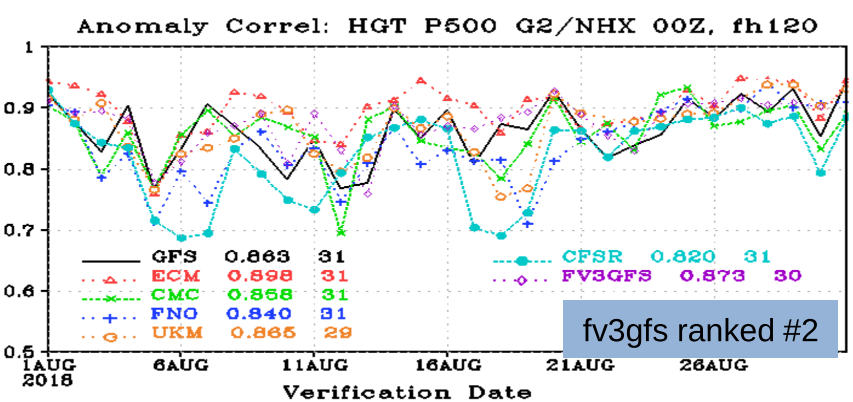


Die-off



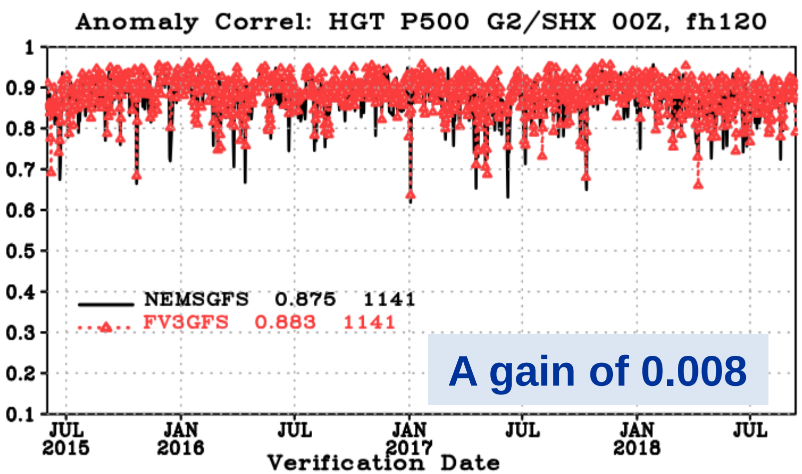
Increase is significant up to day 10

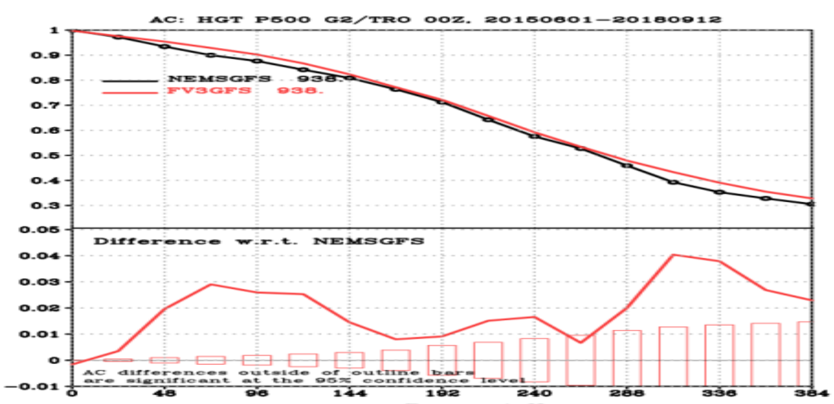
Major International NWP, August 2018 Mean



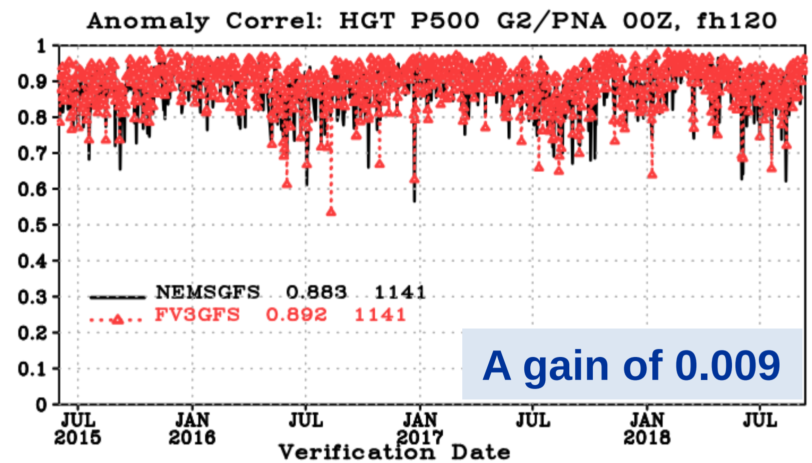
SH and N. America 500-hPa HGT ACC
(20150601 ~ 20180912)

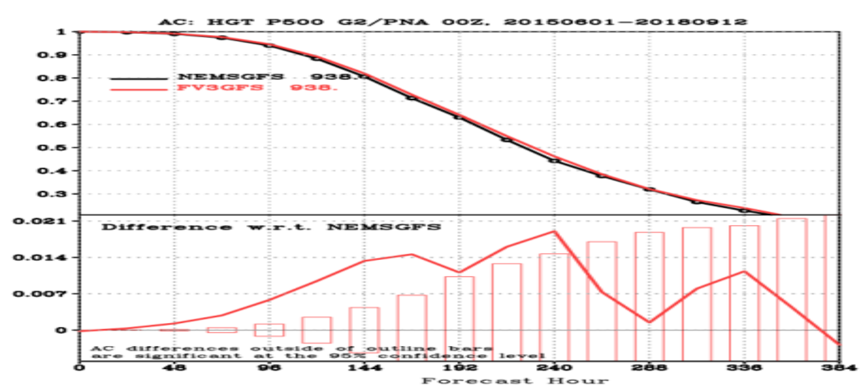
SH





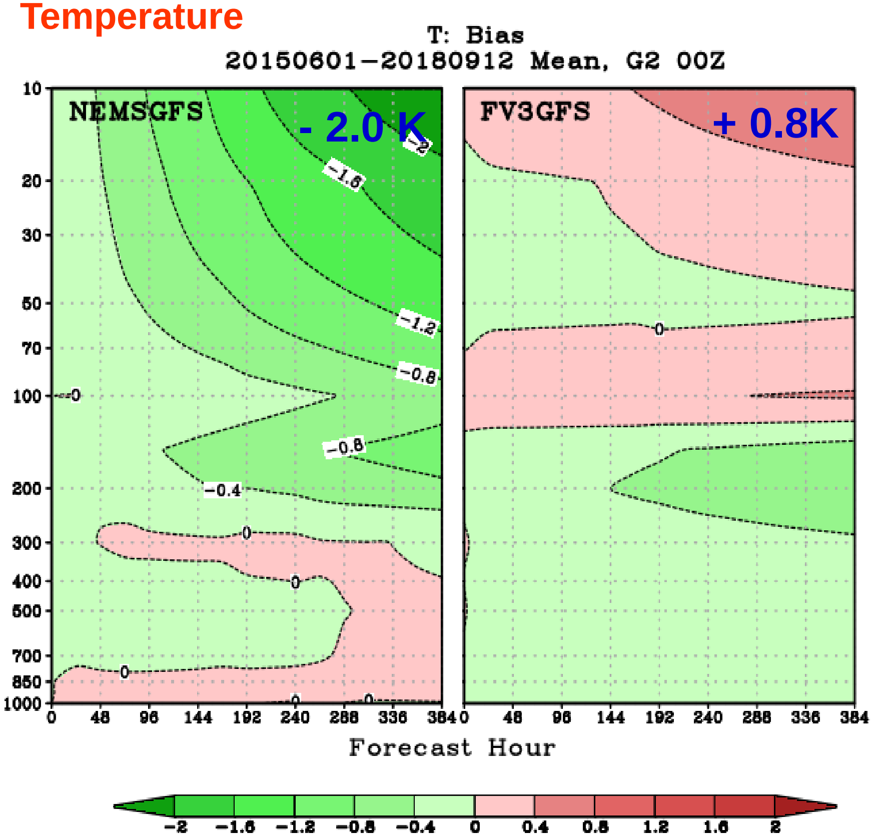
Pacific North America



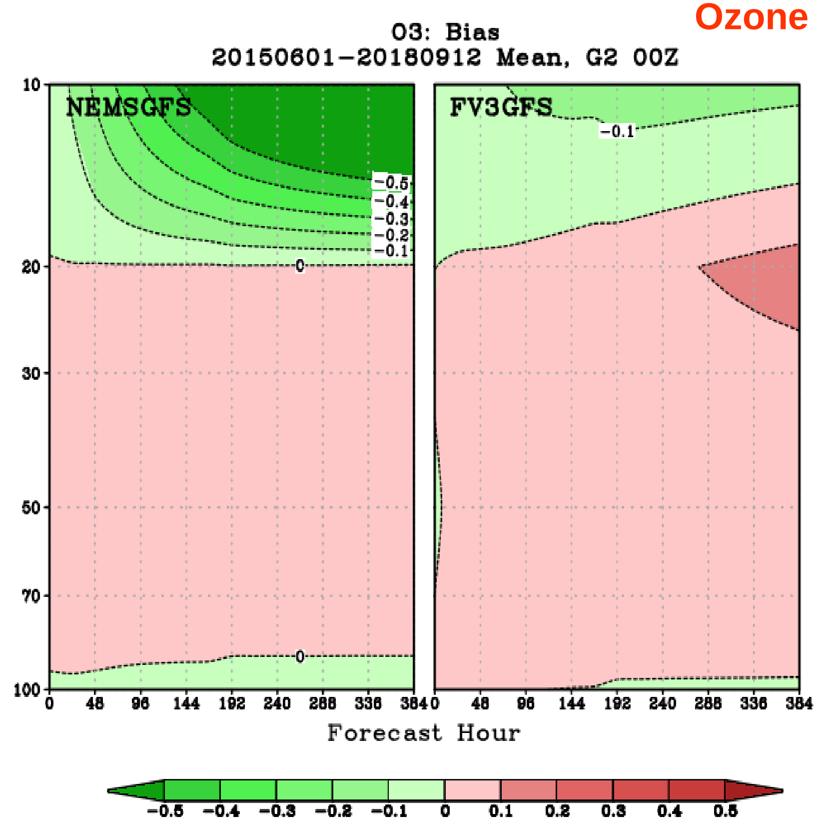


Global Mean Temperature & Ozone Bias
Verified against analyses

Temperature



Ozone

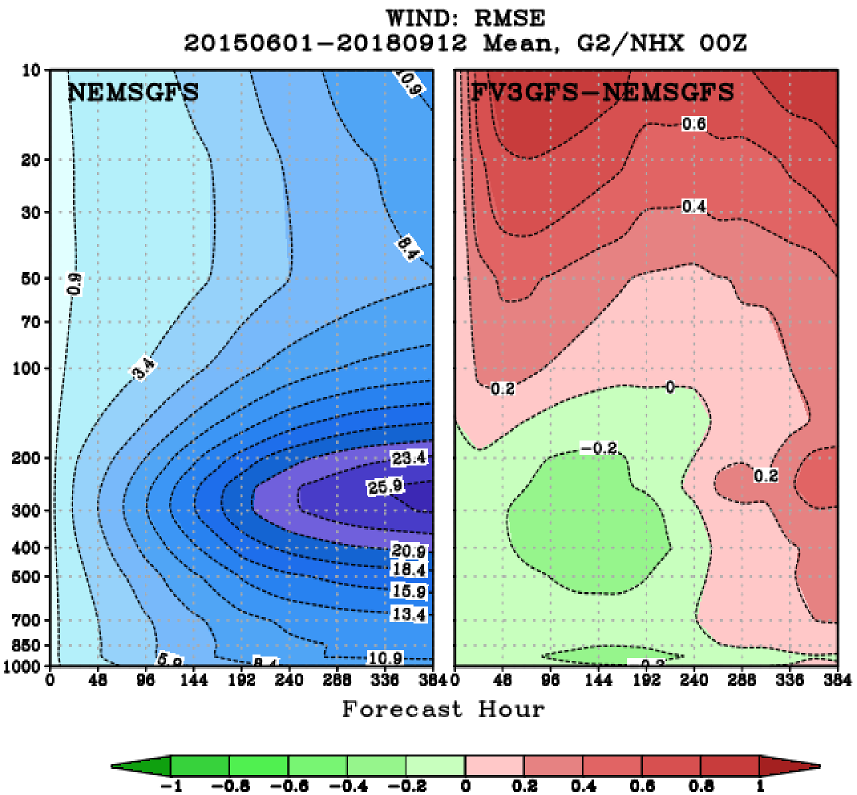


GSM has strong cold bias in the middle to upper stratosphere (- 2K).
FV3GFS warm bias (+0.8K) is caused by a radiation bug (more to come)

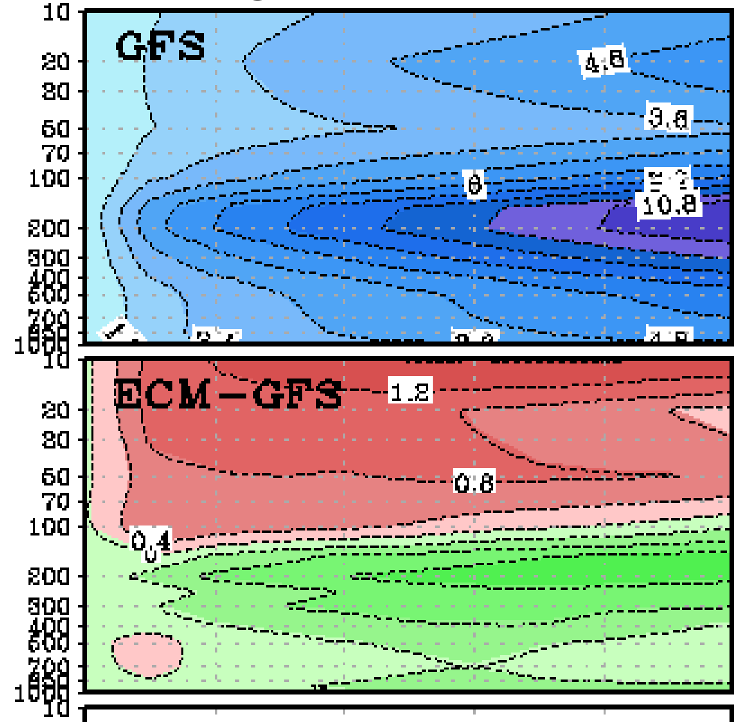
GSM loses ozone in forecast.
FV3GFS conserves better.

NH WIND RMSE

Verified against analyses



August 2018

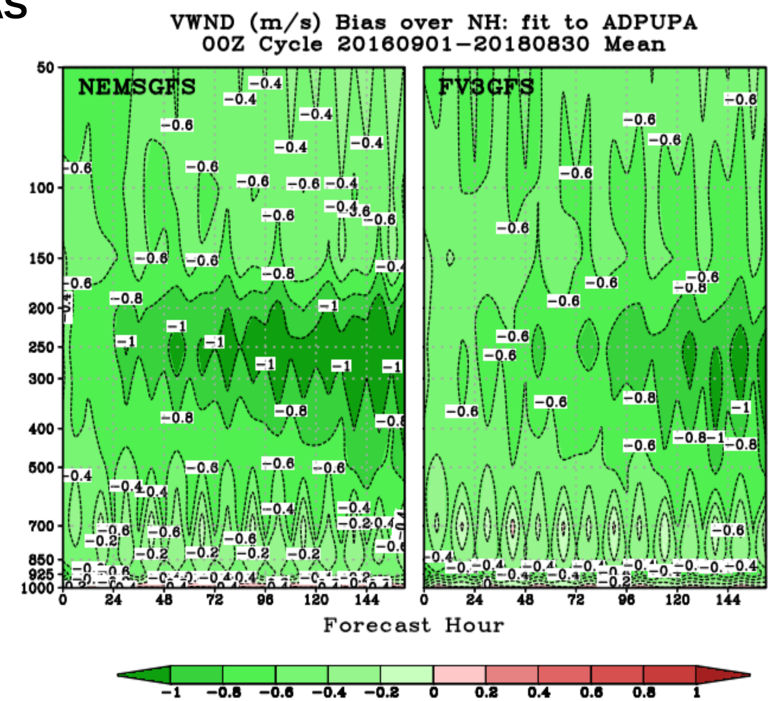


- FV3GFS has larger RMSE than GSM in the stratosphere
- FV3GFS RMSE is similar to ECMWF RMSE
- It is believed GSM winds in the stratosphere is too smooth due to strong damping

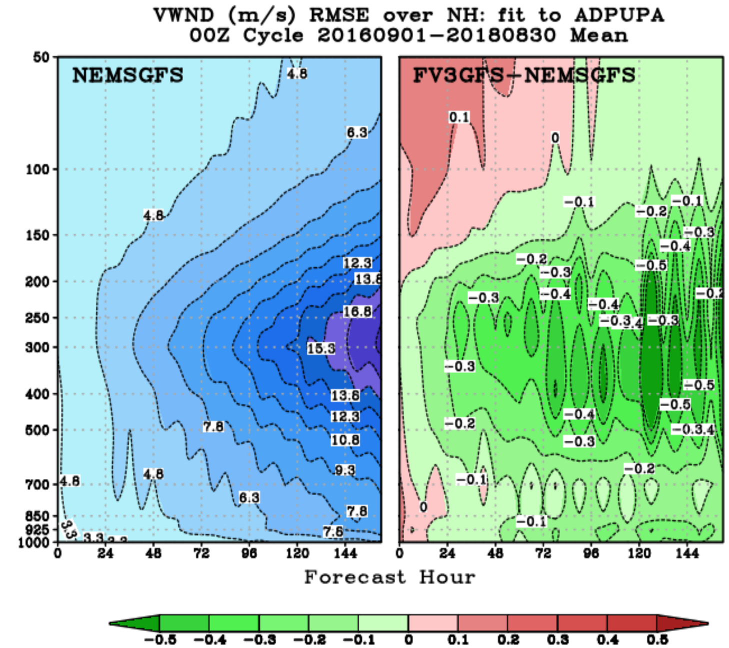
NH WIND BIAS and RMSE

Verified against ROBS, 20160901 ~ 20180831

BIAS



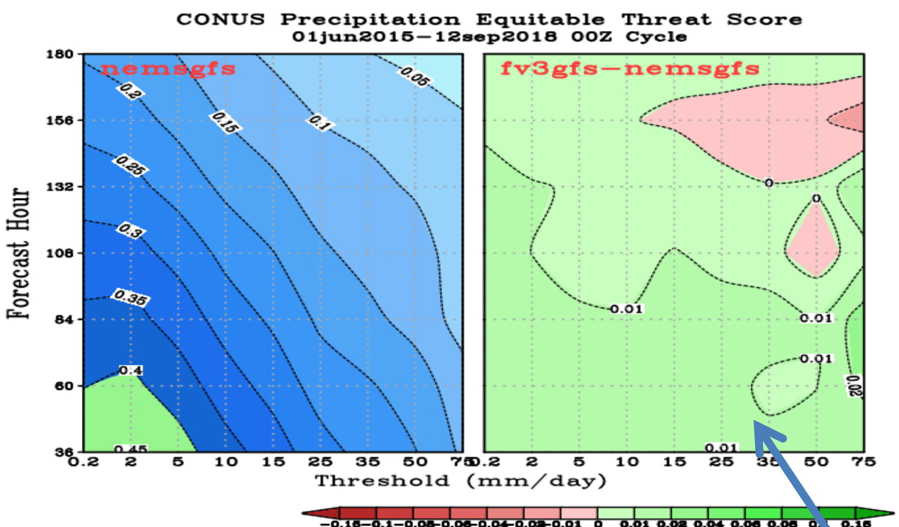
RMSE

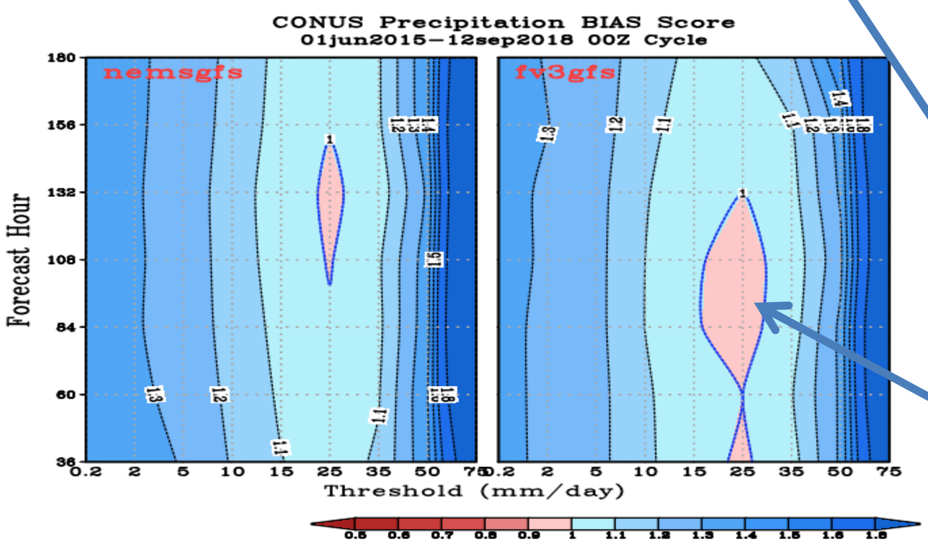


- Winds in both GSM and FV3GFS are weaker than observed, but **FV3GFS is closer to the observation**.
- FV3GFS has stronger winds at the jet level, **reduced RMSE in the troposphere**, but worse in the stratosphere

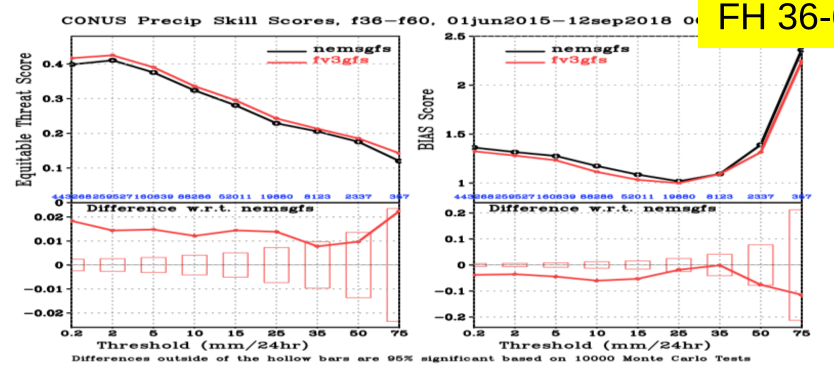
CONUS Precip ETS and BIAS SCORES

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

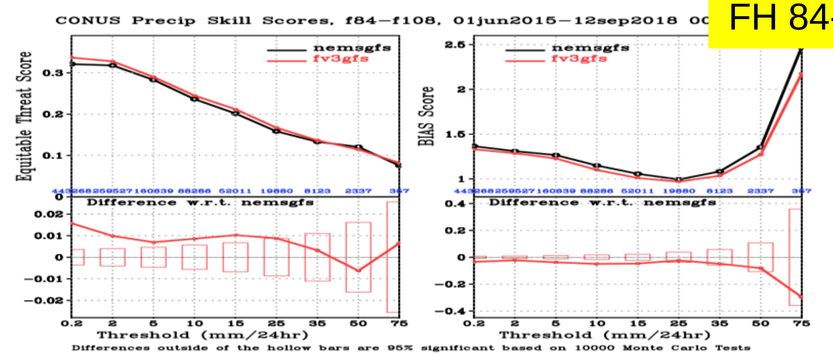




FH 36-60



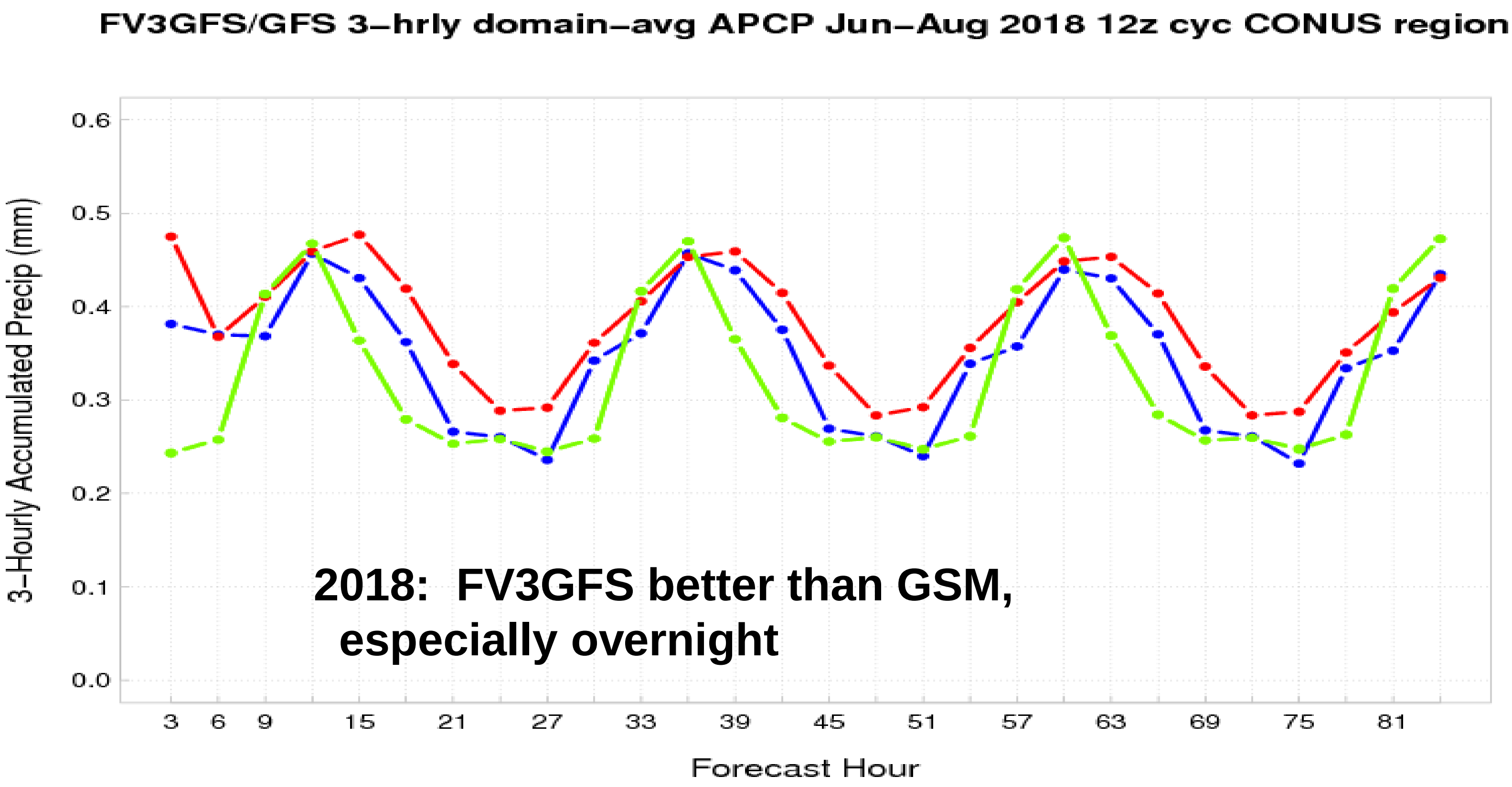
FH 84-108



- 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

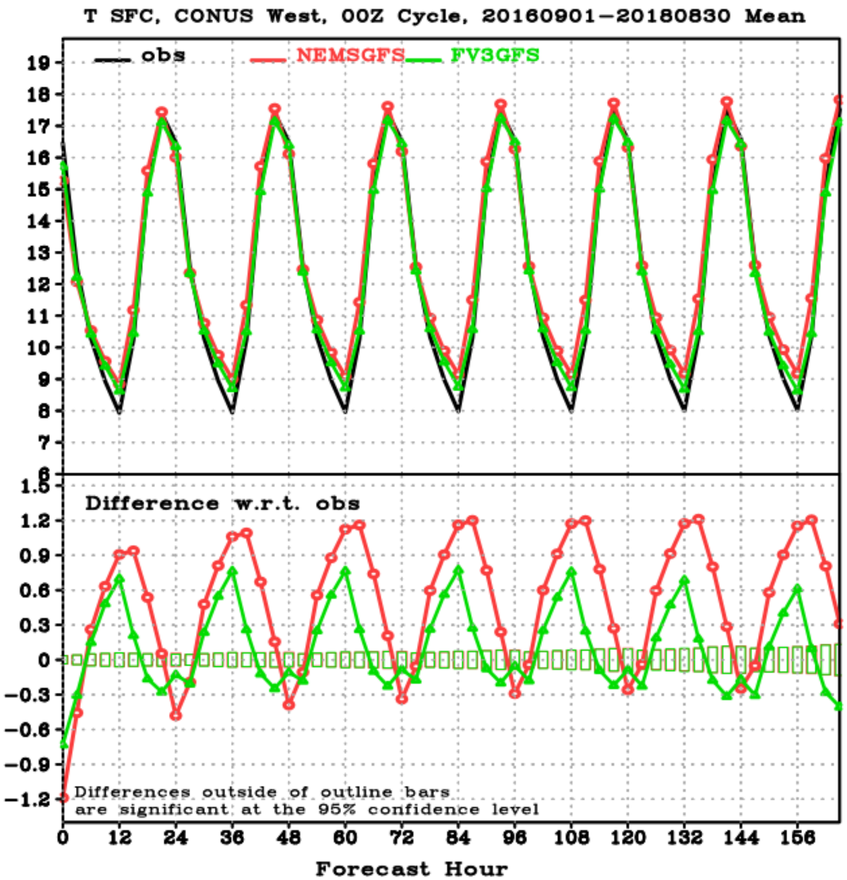
CONUS 2-m Temperature

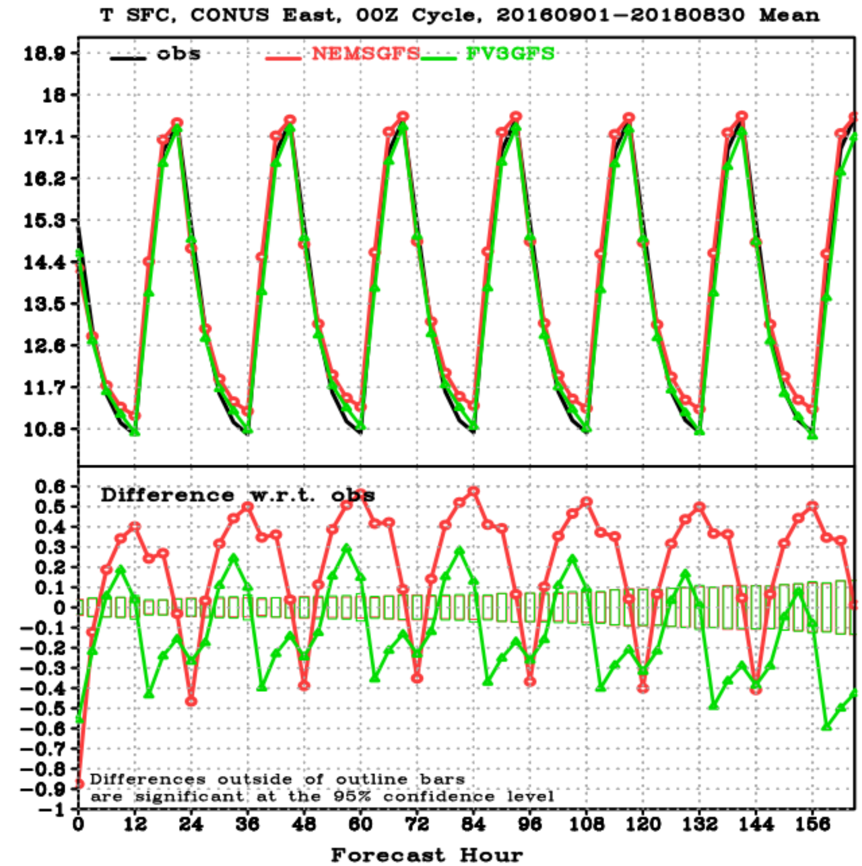
Verified against Station Observations, 3-year mean

WEST

OBS GFS FV3GFS

EAST



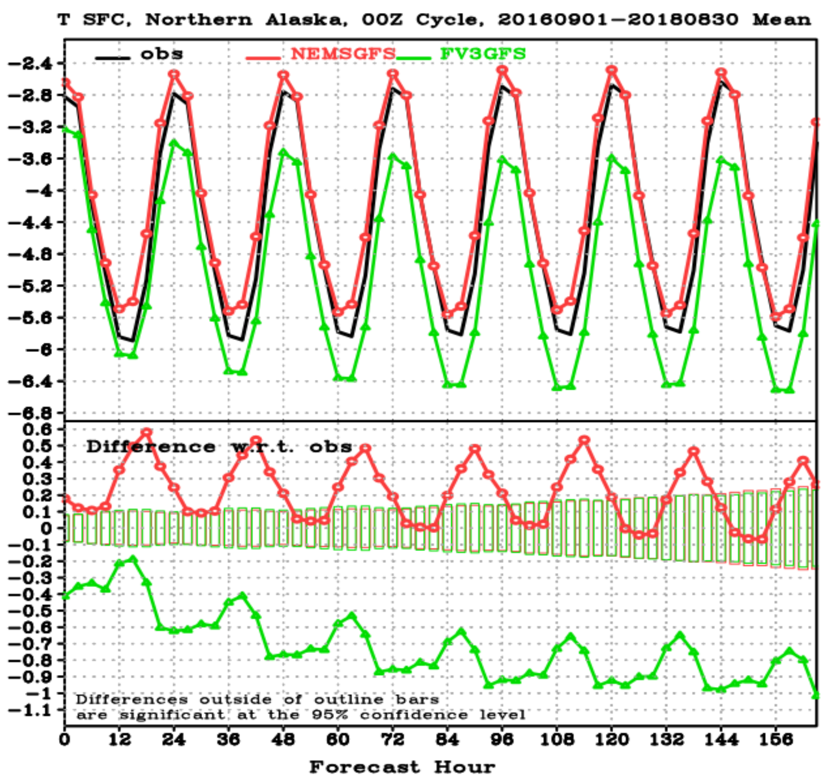


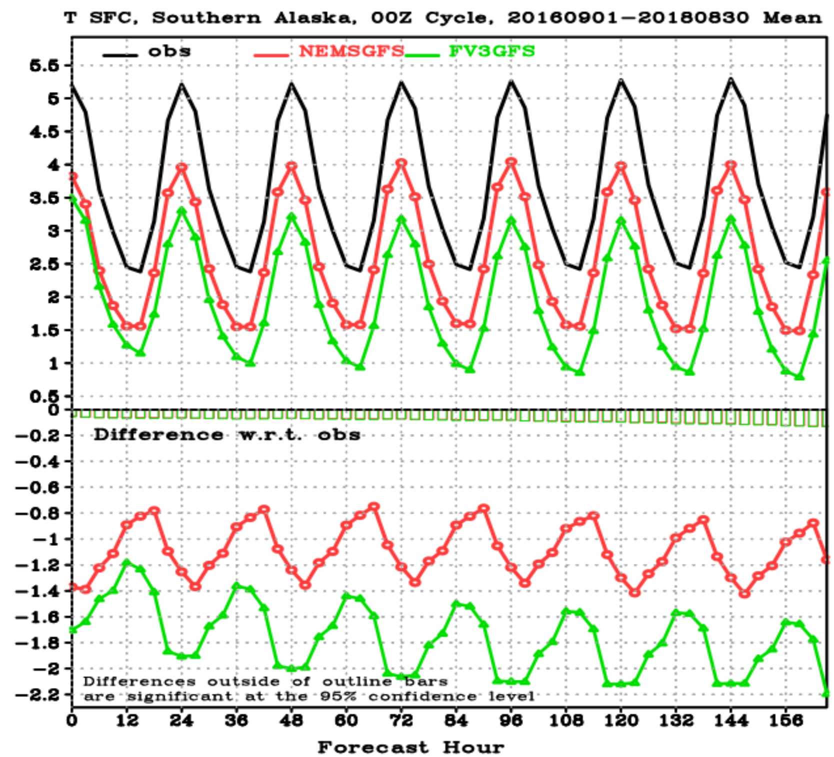
Slight FV3GFS improvement in both the min and the max

2-m Temperature over Alaska

Verified against Station Observations, 3-year mean

NORTH ALASKA **OBS GFS FV3GFS** **SOUTH ALASKA**





FV3GFS has large cold bias !

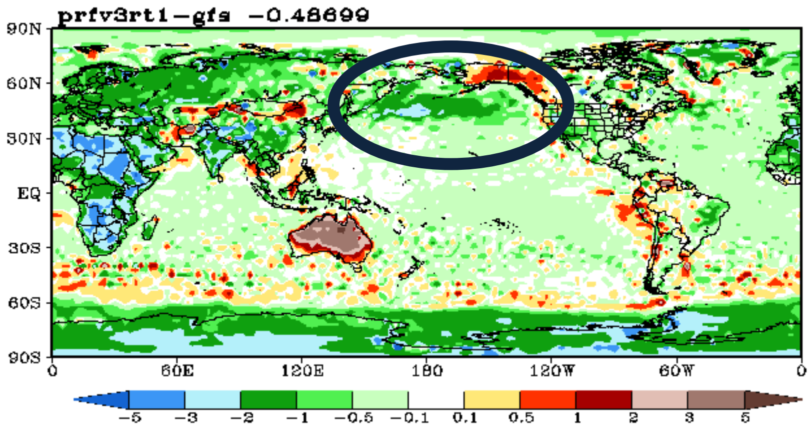
Likely caused by a cold NSST and an overestimate (underestimate) of cloud in summer (winter)

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.

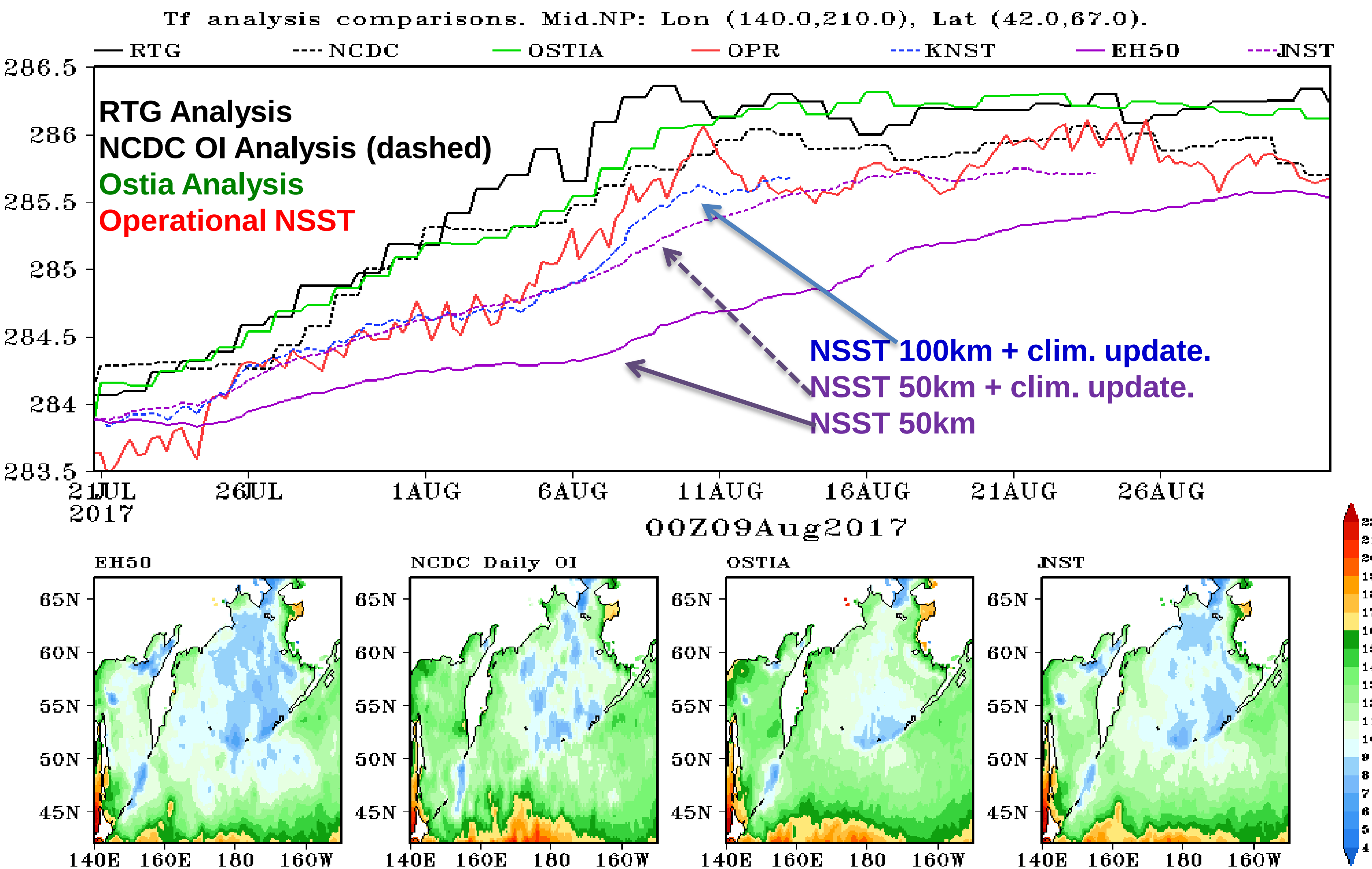
Tref, 26 May – 18 September 2018



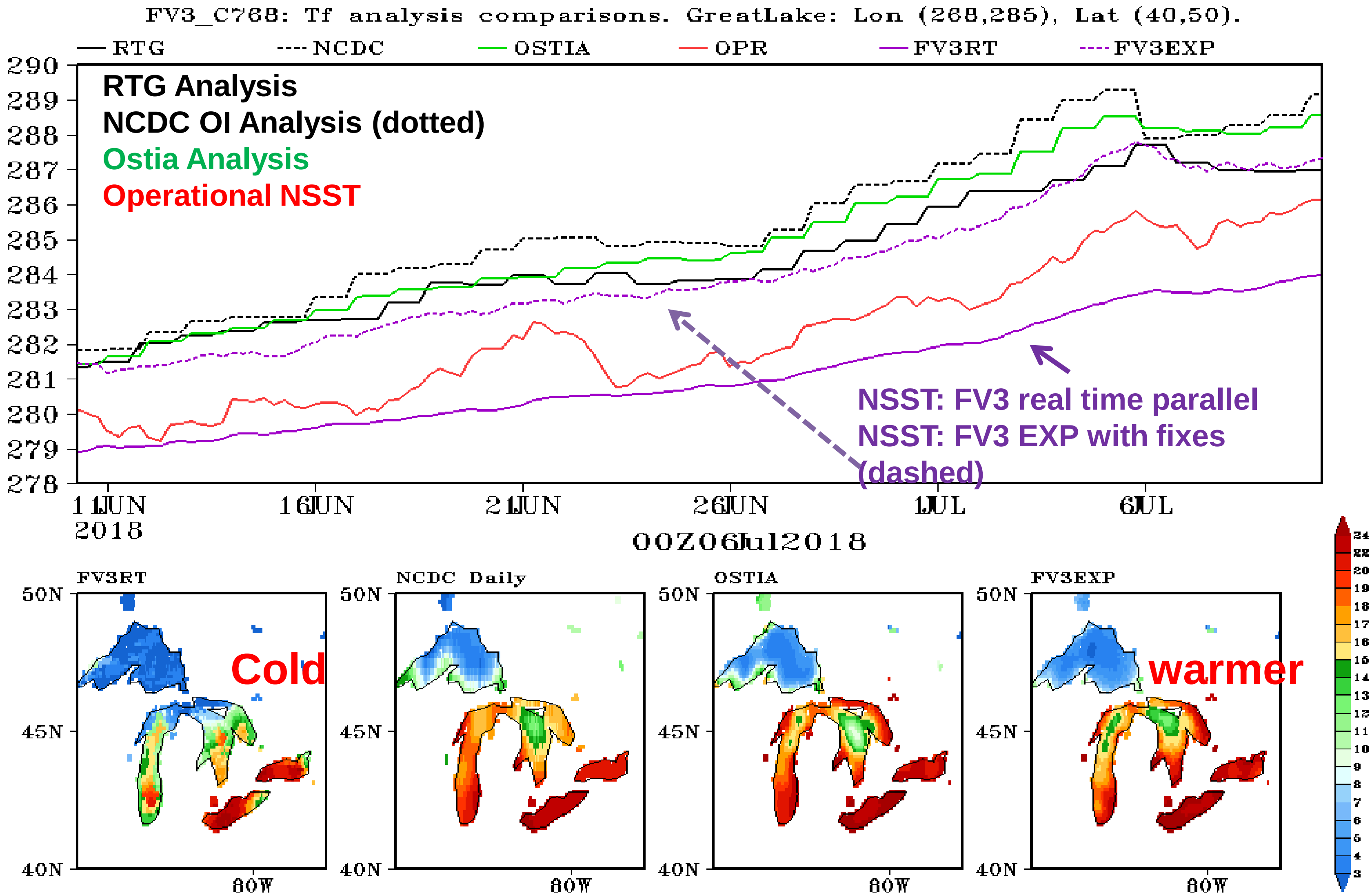
gcycle is now called hourly in GDAS forecast step

From: DA Team

Fixing the N. Pacific Cold Bias

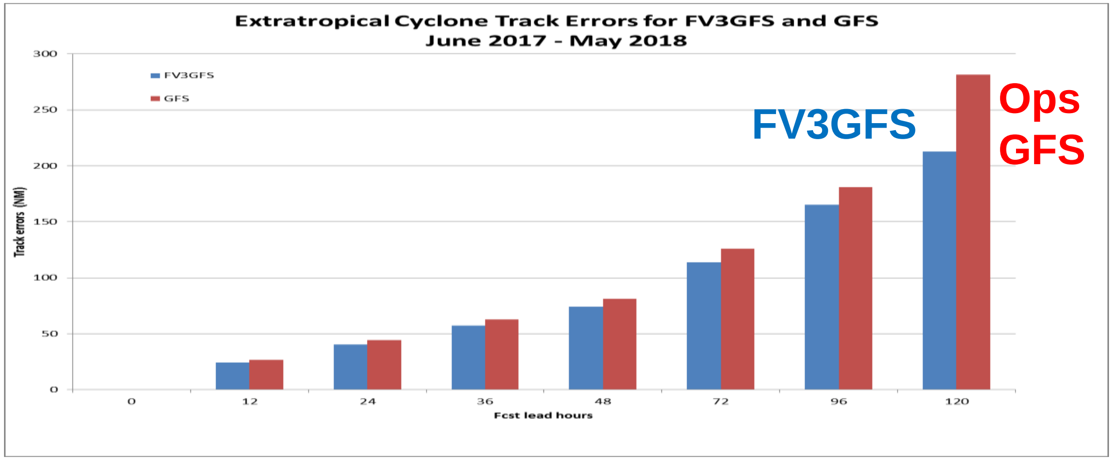


Fixing the Great Lakes Cold Bias



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.

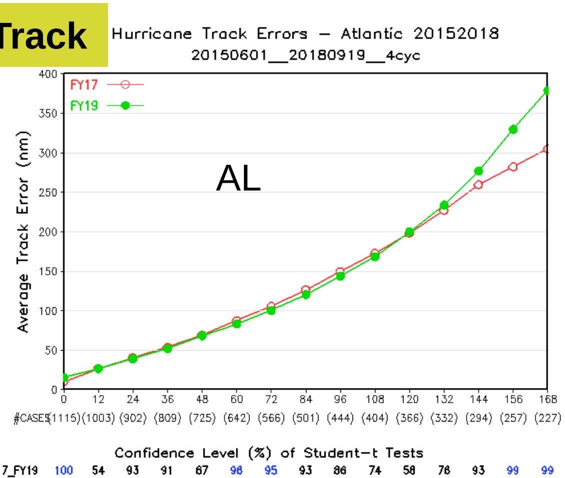
From: Jiayi Peng

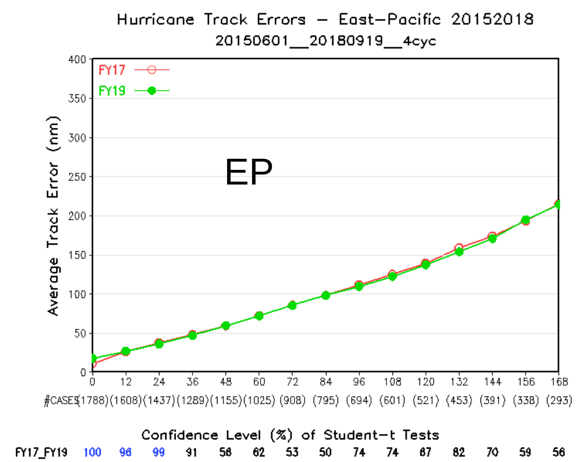
Hurricane Track and Intensity

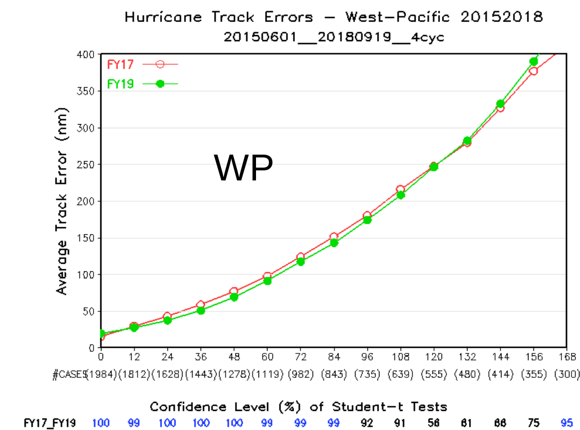
20150601 ~ 20180919

Red: NEMS GFS; Green FV3GFS

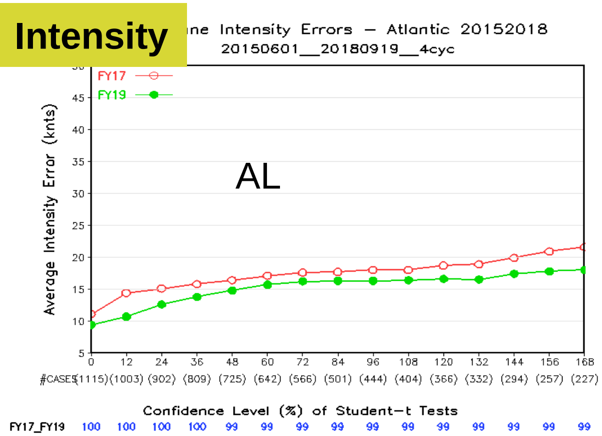
Track

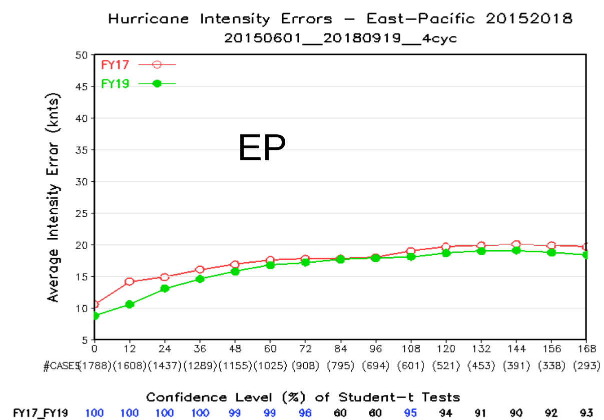


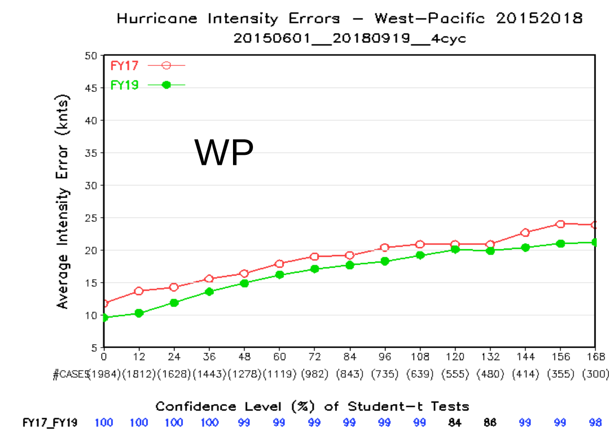




Intensity





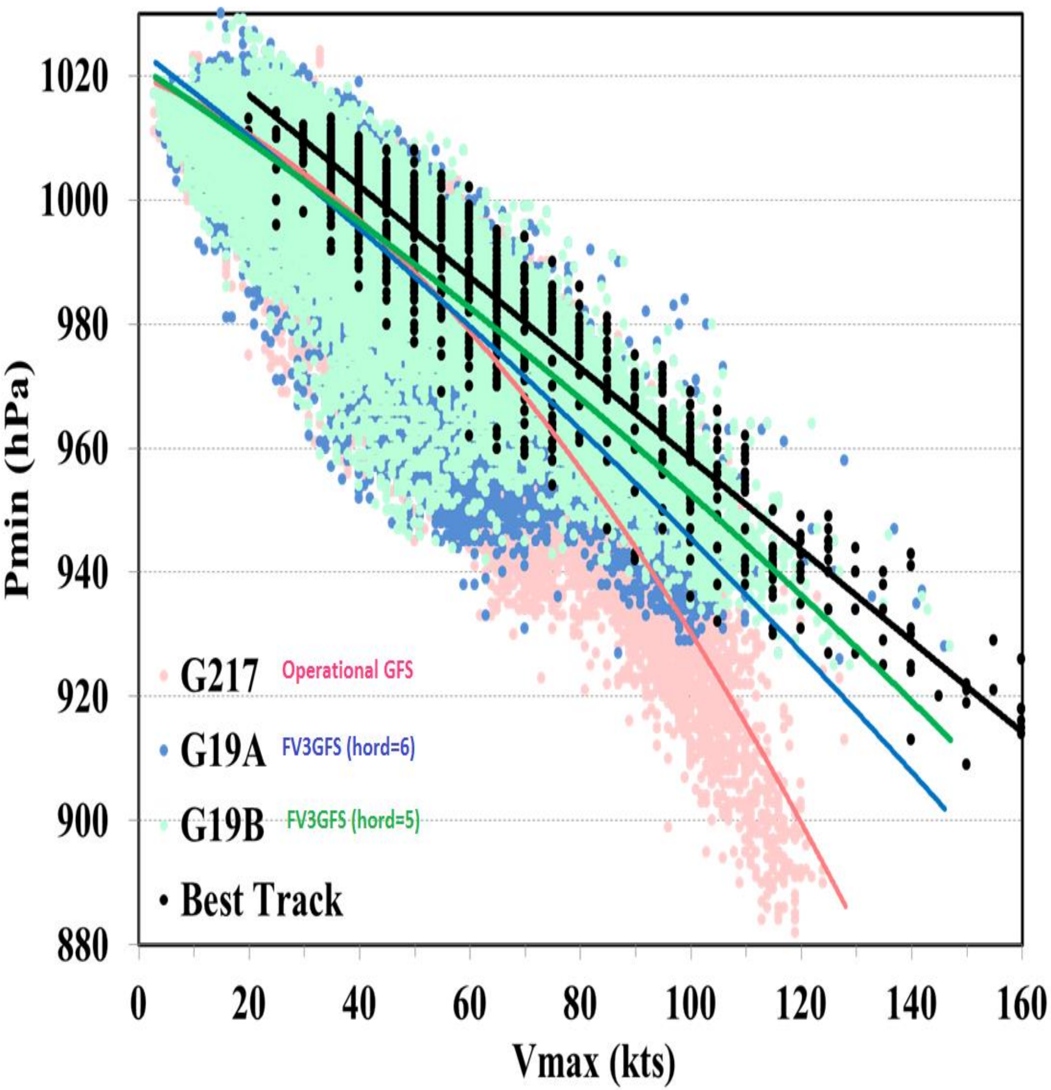


- **Intensity is improved over all basins**
- **Tracks in AL and WP are improved for the first 5 days except at FH00, and degraded in day 6 and day 7. Track in EP is neutral**

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

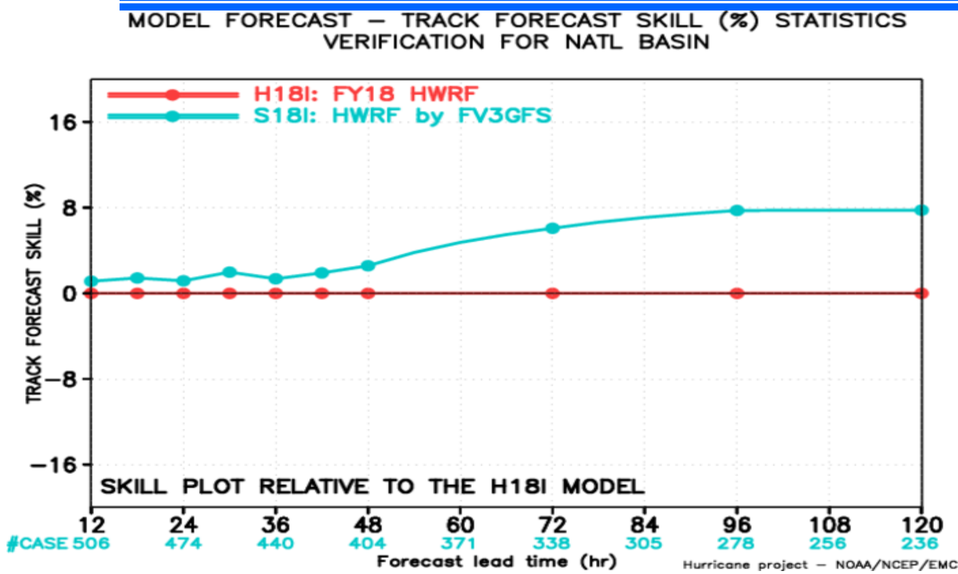


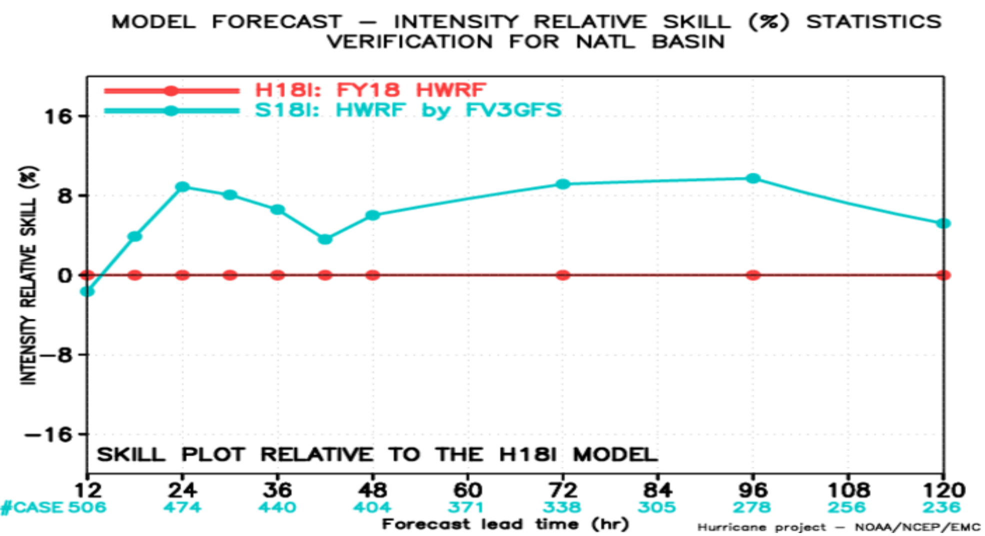
Graph made by HWRF group

Evaluation by downstream models and product users

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*

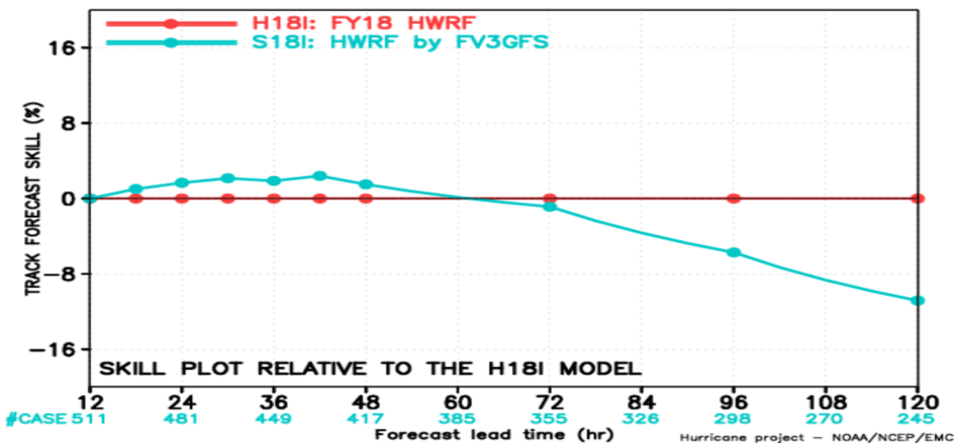
* This list was jointly devised by NHC and EMC based on criterion related to best representation of basins

From: Avichal Mehra

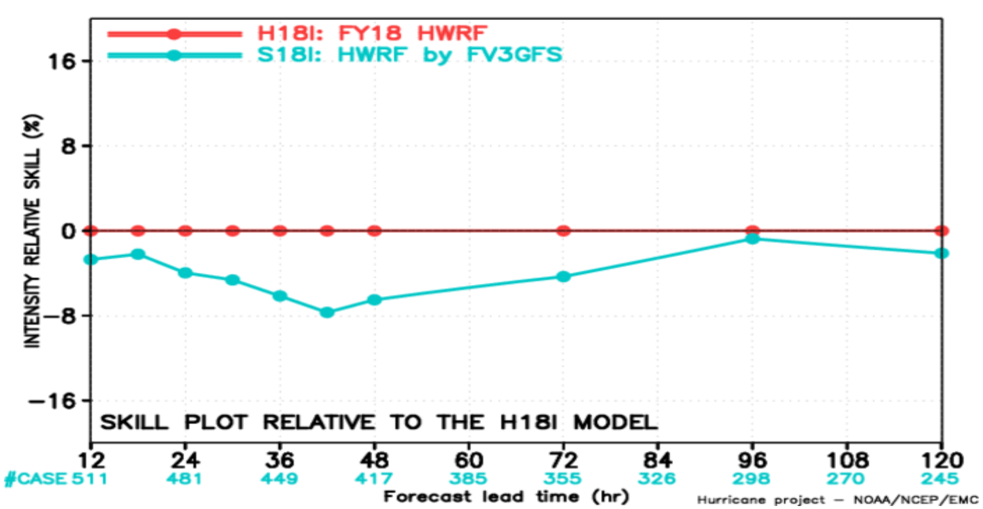
FY18 HWRF Testing with FV3GFS

Priority Storms, Early Model

MODEL FORECAST – TRACK FORECAST SKILL (%) STATISTICS
VERIFICATION FOR EPAC BASIN



MODEL FORECAST – INTENSITY RELATIVE SKILL (%) STATISTICS
VERIFICATION FOR EPAC BASIN



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

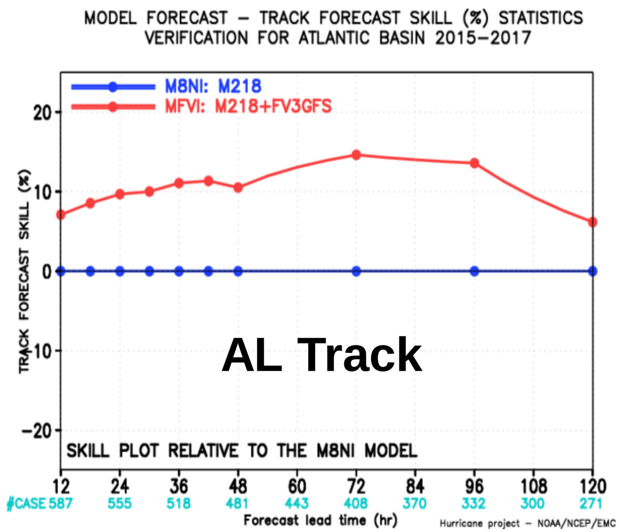
2016 15E Newton
2016 13E Lester
2016 11E Javier*
2016 07E Frank
2016 05E Darby
2016 04E Celia

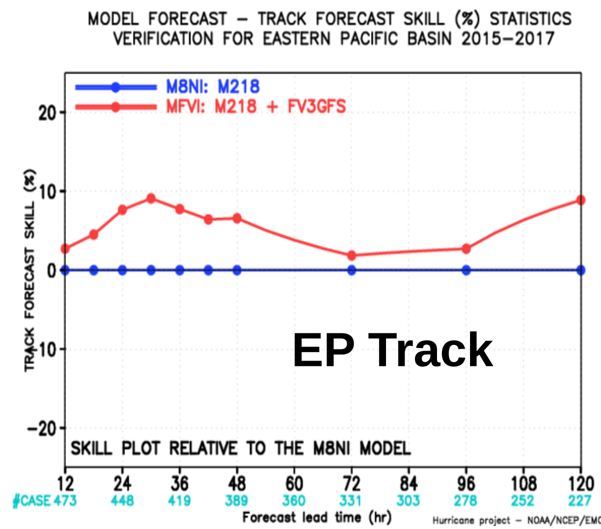
2015 20E Patricia*
2015 19E Olaf
2015 13E Jimena
2015 12E Ignacio
2015 06E Enrique

From: Avichal Mehra

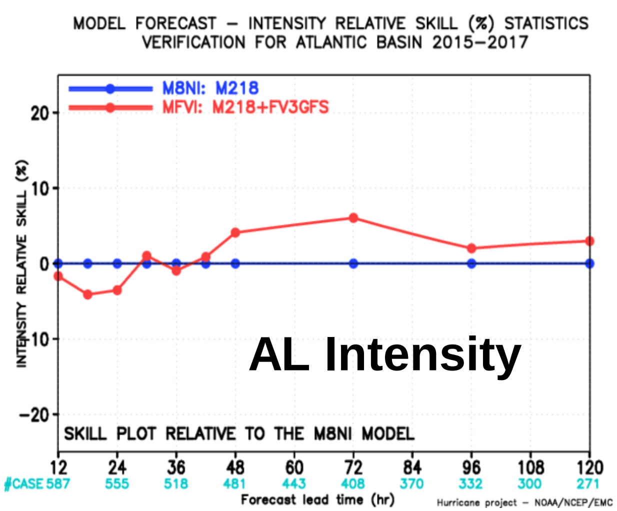
FY18 HMON Testing with FV3GFS

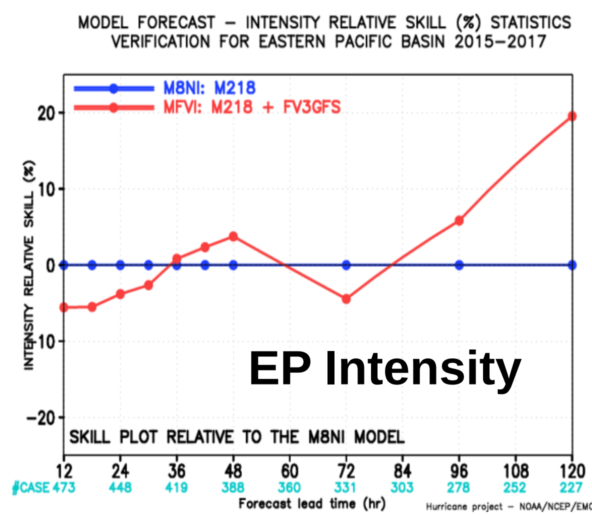
Priority Storms, Early Model





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.**





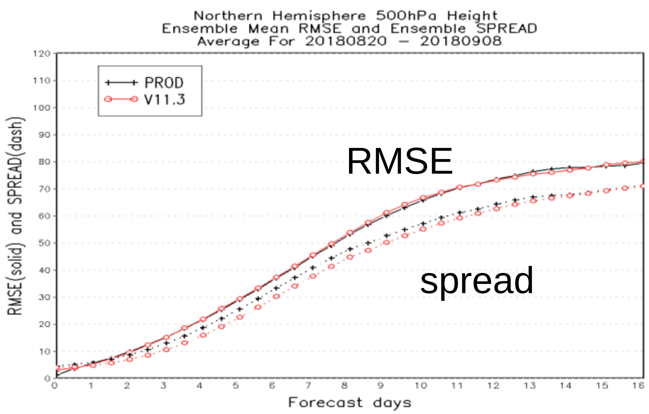
EP: improvement in track skill for early lead times peaking at around 10 % (at hr 30) and once again at Day 5 while giving improvement at **all lead times**. **Intensity** relative skills are **neutral till Day 3** and significantly **positive at Day 4 (6%) and Day 5 (20%).**

From: Avichal Mehra

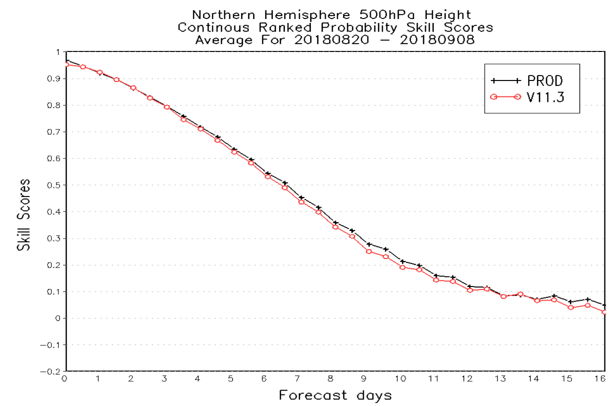
Operational GEFS initialized with FV3GFS

20180820 ~ 20180908

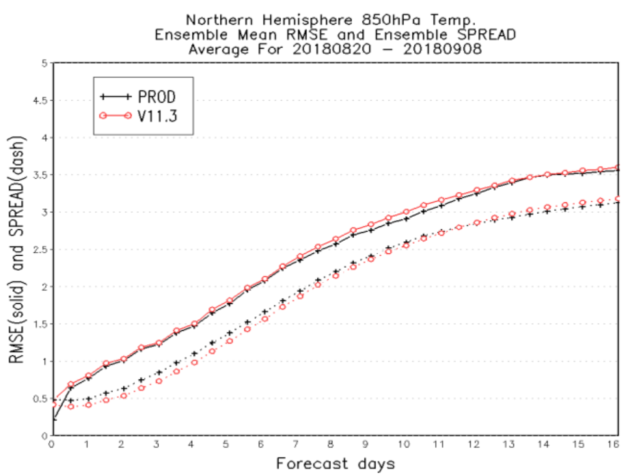
NH Z500 RMSE and Spread



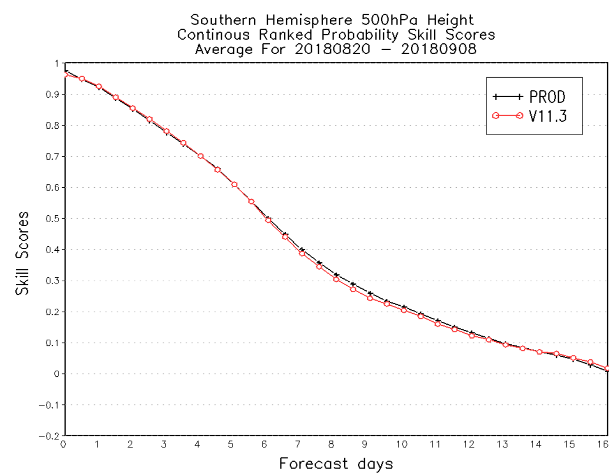
NH Z500 CRPSS



NH T850 RMSE and Spread



SH Z500 CRPSS



Slightly reduced ensemble spread

Minor degradation in CRPSS and RMSE.

Limited Sample size

Black: ops GEFS

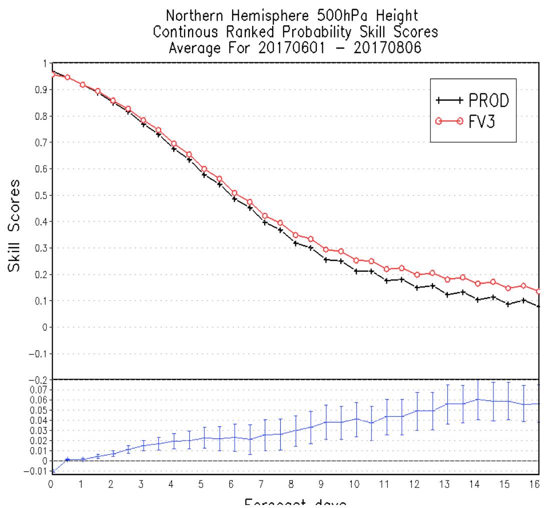
Red: ops GFS w/ FV3GFS ICs

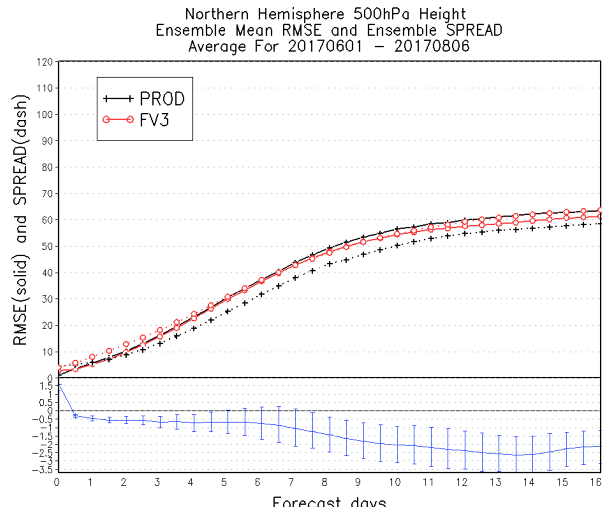
Experimental GEFSv12 Initialized with FV3GFS

20170601 ~ 20170806

Z500 CRPS

Z500 RMSE and Spread

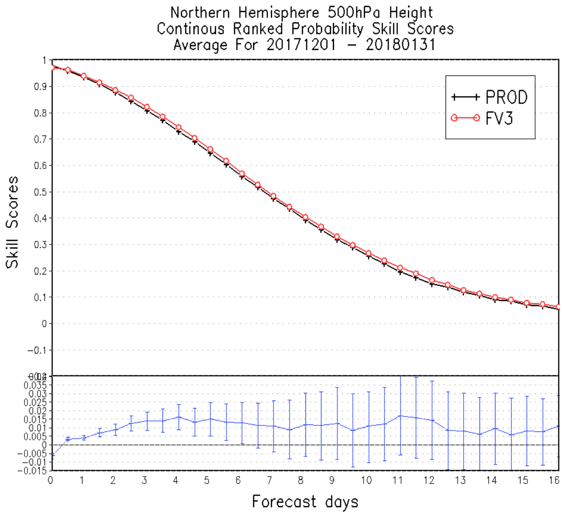


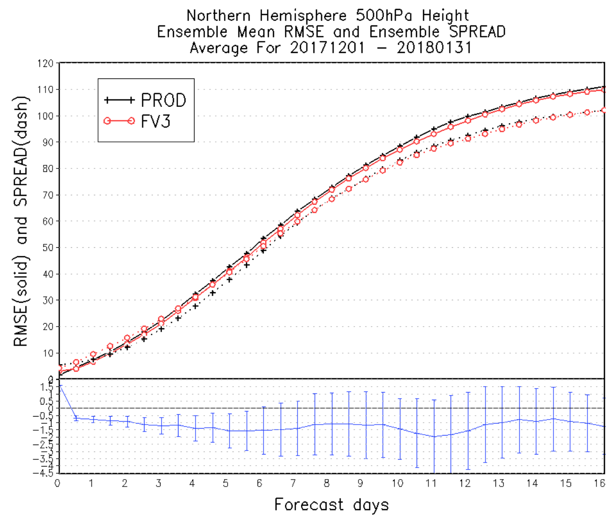


Warm Season

20170601 ~ 20170806

Experimental GEFS (v12 beta) overall outperforms OPS-GEFS (v11) in various standard verification scores





Cold Season

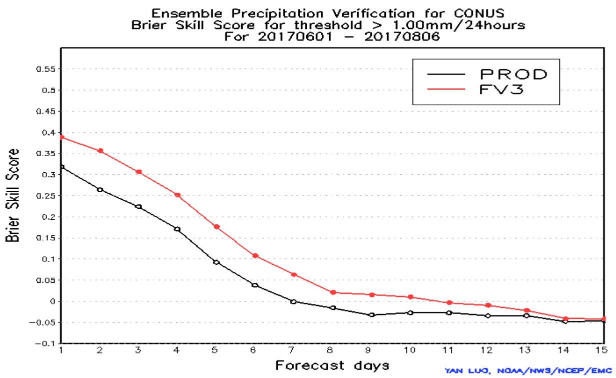
20171201-20180131

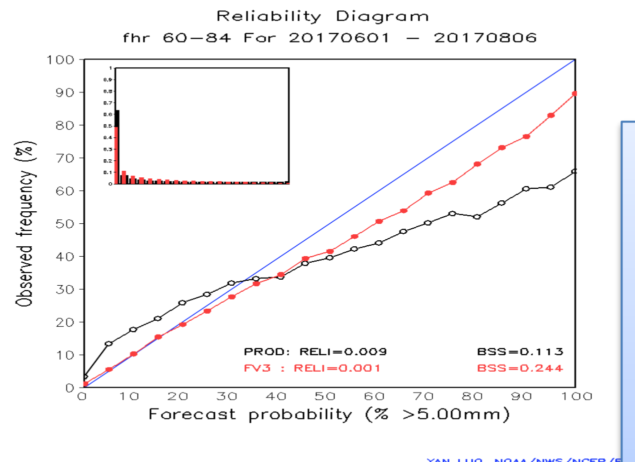
Experimental GEFSv12 Initialized with FV3GFS: CONUS Precipitation

>1mm BSS

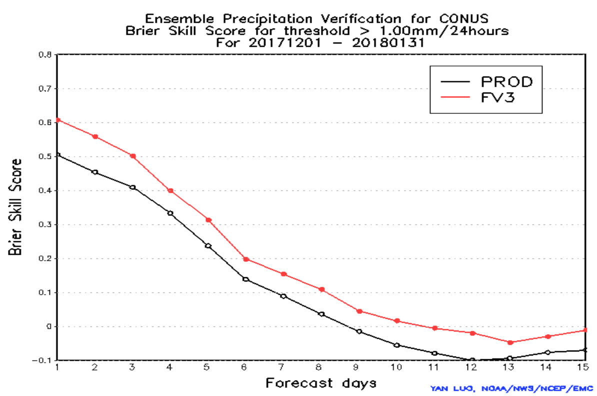
60-84hr forecast >5mm Reliability

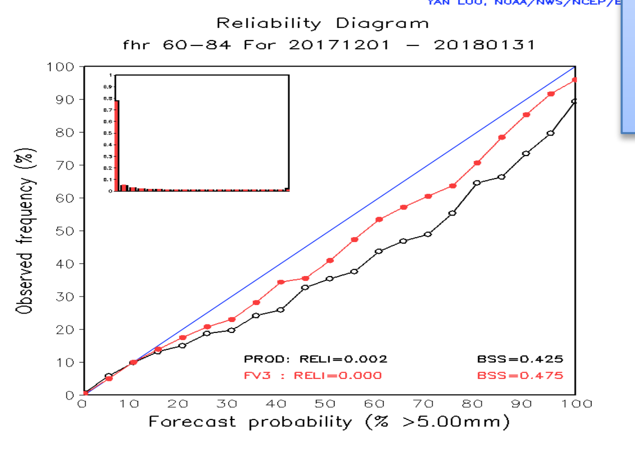
Warm Season
20170601 ~ 20170806





Precipitation forecast is improved compared with OPS-GEFS (v11), especially for reliability.



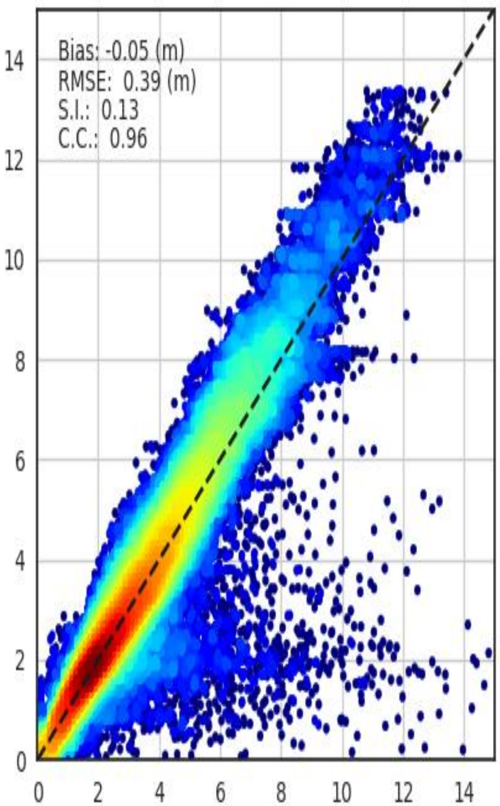


Cold Season
20171201-20180131

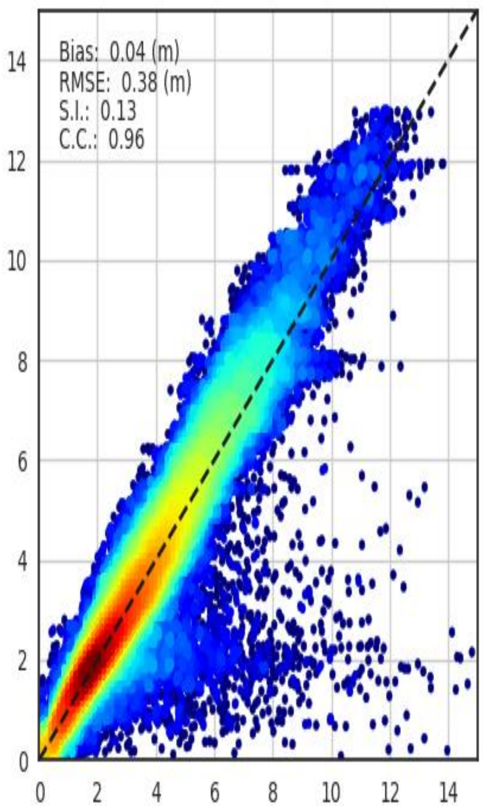
Global Wave Model Testing with FV3GFS

- Nowcast wave heights generated by NCEP's Global Wave Model
  - GSM forcing (left)
  - FV3 forcing (right)
- Retrospective: June 2017
- Relative to wave heights from ALTIKA altimeter
- **Consistent results for mean conditions at all ranges**
- **FV3-forced waves positive bias**
- **GSM negative bias of same magnitude**
- All other statistics, similar

GSM-forced Wave



FV3-forced Wave



From: Henrique Alves

CPC Assessment of FV3GFS Stratospheric Forecast

From Craig Long:

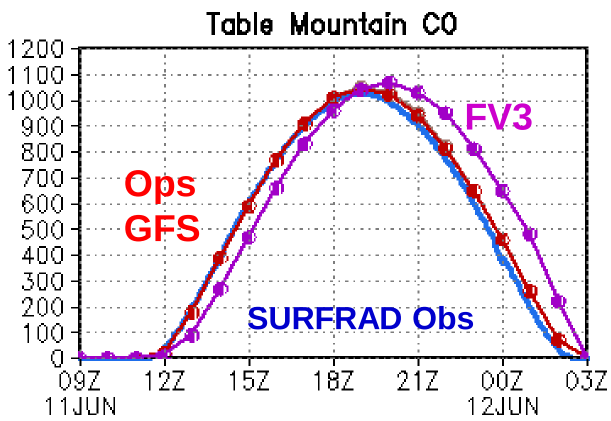
- FV3GFS Temps are similar to GFS in middle and lower stratosphere
- **FV3GFS Temps are warmer in upper stratosphere**
- FV3GFS Temp fcsts in winter hem upper strat high lats are colder
- Zonal Winds are slightly worse in FV3GFS at longer fcst times
- Ozone mixing ratio analyses and fcsts are similar
- **Total ozone** anal are diff at high lats, **FV3GFS fcsts are slightly better**
- **Specific Humidity is much more realistic**
- FV3GFS is similar to GFS forecasting the 2018 SSW

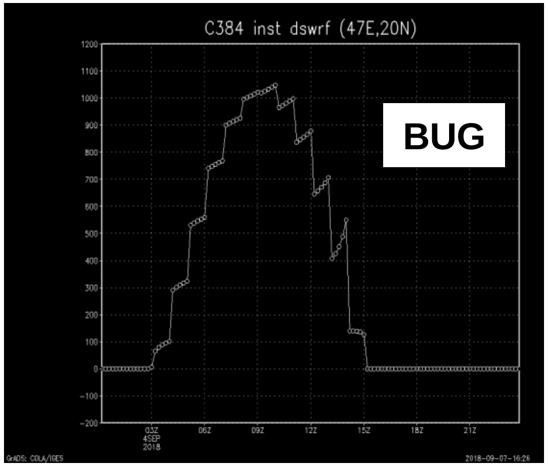
- **Most metrics are neutral**
- **Improvement in specific humidity is attributed to the newly added water vapor physics and the assimilation of 10 IASI water vapor channels.**

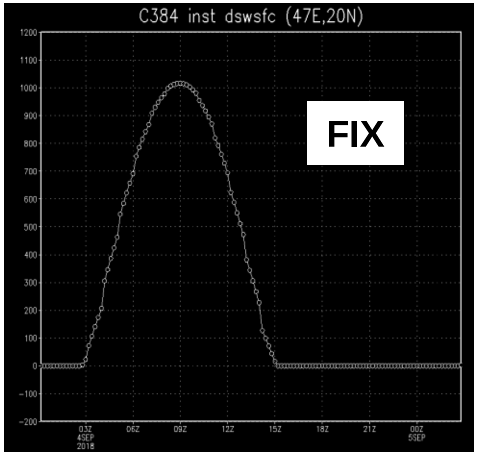
Radiation Bug Fix

A bug was found in the computation of short-wave radiation, and fixed

Hourly Surface Downward SW

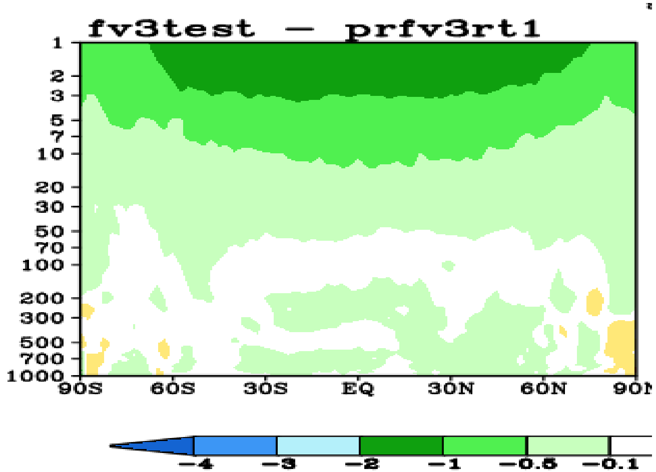






The Impact

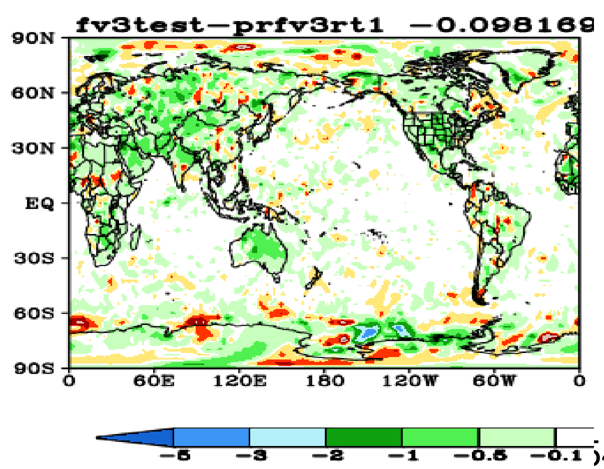
Day-5 Zonal Mean Temp



Cools the upper stratosphere by 1 to 2 degrees

Make the T2m slightly cooler

Day-5 T2m



Summary -- Benefits

From MEG Assessment

- (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

Final Thoughts

- It is understood that there are still certain science and technical issues with this new model that remain to be resolved. However, we believe the ***benefits greatly overweigh the concerns***.

- Some of the issues should be and could be addressed if there were a shorter GFS upgrading cycle. It has becoming increasingly unsustainable for us to run more than three years of retrospective parallels for every GFS implementation. There is not enough computing power and manpower. This practice is slowing down the improvement of the forecast system.

- **We hereby request EMC Director's approval for the implementation of Q2FY19 GFS/GDAS V15.0**

- **This implementation lays the foundation for building a unified national weather and climate forecast system**

Thank you