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
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

<table>
<thead>
<tr>
<th>Mon/Year</th>
<th>Lev</th>
<th>Truncations</th>
<th>Z-cor/dyncore</th>
<th>Major components upgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug 1980</td>
<td>12</td>
<td>R30 (375km)</td>
<td>Sigma Eulerian</td>
<td>first global spectral model, rhomboidal</td>
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<tr>
<td>Oct 1983</td>
<td>12</td>
<td>R40 (300km)</td>
<td>Sigma Eulerian</td>
<td>GFDL Physics</td>
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<td>Apr 1985</td>
<td>18</td>
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<td>Sigma Eulerian</td>
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<tr>
<td>Aug 1987</td>
<td>18</td>
<td>T80 (150km)</td>
<td>Sigma Eulerian</td>
<td>First triangular truncation; diurnal cycle</td>
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<tr>
<td>Mar 1991</td>
<td>18</td>
<td>T126 (105km)</td>
<td>Sigma Eulerian</td>
<td></td>
</tr>
<tr>
<td>Aug 1993</td>
<td>28</td>
<td>T126 (105km)</td>
<td>Sigma Eulerian</td>
<td>Arakawa-Schubert convection</td>
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<tr>
<td>Jun 1998</td>
<td>42</td>
<td>T170 (80km)</td>
<td>Sigma Eulerian</td>
<td>Prognostic ozone; SW from GFDL to NASA</td>
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<tr>
<td>Oct 1998</td>
<td>28</td>
<td>T170 (80km)</td>
<td>Sigma Eulerian</td>
<td>the restoration</td>
</tr>
<tr>
<td>Jan 2000</td>
<td>42</td>
<td>T170 (80km)</td>
<td>Sigma Eulerian</td>
<td>first on IBM</td>
</tr>
<tr>
<td>Oct 2002</td>
<td>64</td>
<td>T254 (55km)</td>
<td>Sigma Eulerian</td>
<td>RRTM LW;</td>
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<tr>
<td>May 2005</td>
<td>64</td>
<td>T382 (35km)</td>
<td>Sigma Eulerian</td>
<td>2L OSU to 4L NOAH LSM; high-res to 180hr</td>
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<td>May 2007</td>
<td>64</td>
<td>T382 (35km)</td>
<td>Hybrid Eulerian</td>
<td>SSI to GSI</td>
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<td>Jul 2010</td>
<td>64</td>
<td>T574 (23km)</td>
<td>Hybrid Eulerian</td>
<td>RRTM SW; New shallow cnvtion; TVD tracer</td>
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<tr>
<td>Jan 2015</td>
<td>64</td>
<td>T1534 (13km)</td>
<td>Hybrid Semi-Lag</td>
<td>SLG; Hybrid EDMF; McICA etc</td>
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<tr>
<td>May 2016</td>
<td>64</td>
<td>T1534 (13km)</td>
<td>Hybrid Semi-Lag</td>
<td>4-D Hybrid En-Var DA</td>
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<tr>
<td>Jun 2017</td>
<td>64</td>
<td>T1534 (13km)</td>
<td>Hybrid Semi-Lag</td>
<td>NEMS GSM, advanced physics</td>
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<tr>
<td>JAN 2019</td>
<td>64</td>
<td>FV3 (13km)</td>
<td>Finite-Volume</td>
<td>NGGPS FV3 dycore, GFDL MP</td>
</tr>
</tbody>
</table>

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 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

**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

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**Issues/Risks**

**Risk:** Not enough computational resources to run the EMC parallels; **Mitigation:** Run the real time parallels on WC OSS 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 NWARE bandwidth for archiving FV3GFS retrospective/real-time runs to HPSS; **Mitigation:** Options: (a) buy more bandwidth for NWARE, (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)

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**Milestones & Deliverables**

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

**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%)

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**On Target**
➢ 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

Zhao-Carr MP
- Prognostic cloud species: one total cloud water

GFDL MP
- Prognostics cloud species: five
  Liquid, ice, snow, graupel, rain
- More sophisticated cloud processes

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

Physics still runs at 64-bit precision
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 2nd order FV-type vertical reconstruction for autoconversions

From: SJ Lin
Revised Bare-Soil Evaporation For Reducing Dry and Warm Biases

\[ FX = \frac{(\Theta_1 - \Theta_{dry})}{(\Theta_{sat} - \Theta_{dry})} \]

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

where \( FX \) is the fraction of soil moisture saturation in the upper soil layer, \( \Theta_1 \), \( \Theta_{dry} \), and \( \Theta_{sat} \) 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, \( \Theta_{dry} \) is set to the same as wilting point \( \Theta_{ref} \). In reality, \( \Theta_{dry} \) is usually lower than \( \Theta_{ref} \).

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.

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))

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

Reference tendency \((P - L)_0\) and all partial derivatives are computed from odd oxygen (Ox ≡ \(O_3 + O\)) 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.

\(\chi_{O3}\)   prognostic Ozone mixing ratio
\(T\)      Temperature
\(c_{O3}\)   column ozone above

From: Shrivinas Moorthi
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$_2$O 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: 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 Gaussian 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.

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 an 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
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.

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)
Post Processing Upgrade and Changes

➢ Changes in products:
  • Vertical velocity from FV3GFS is \( \frac{dz}{dt} \) 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 \( \frac{dz}{dt} \) 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)

Cray
Operational GFS
Peak 370 nodes
(all included)

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

GFS fcst: 65 nodes
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

<table>
<thead>
<tr>
<th>RUN TIME (minutes)</th>
<th>J-Job prod</th>
<th>J-Job para</th>
<th>prod (minutes)</th>
<th>para (minutes)</th>
<th>para-prod</th>
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</thead>
<tbody>
<tr>
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<td>JGFS_ANALYSIS</td>
<td>JGLOBAL_ANALYSIS</td>
<td>22.9</td>
<td>26.8</td>
<td>4.2</td>
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<tr>
<td>gfs_forecast (0-10 days)</td>
<td>JGFS_FORECAST_HIGH</td>
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<td>78.5</td>
<td>75.5</td>
<td>-3</td>
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<td>gfs_forecast (11-16days)</td>
<td>JGFS_FORECAST_LOW</td>
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<td>11.3</td>
<td>45.3</td>
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<td>gfs_forecast (0-16 days)</td>
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<td>JGLOBAL_FORECAST</td>
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<td>120.8</td>
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<td>JGLOBAL_FORECAST</td>
<td>12.3</td>
<td>11.7</td>
<td>-0.6</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th></th>
<th>anl+forecast</th>
<th>products &amp; misc</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>ops gfs</td>
<td>1.70 TB</td>
<td>0.30 TB</td>
<td>2.0 TB</td>
</tr>
<tr>
<td>ops GDAS</td>
<td>0.157 TB</td>
<td>0.029 TB</td>
<td>0.186 TB</td>
</tr>
<tr>
<td>ops ENKF</td>
<td>1.831 TB</td>
<td>0.043 TB</td>
<td>1.874 TB</td>
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<tr>
<td>ops total</td>
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<td>4.06 TB</td>
</tr>
<tr>
<td>FV3 GFS</td>
<td>4.0</td>
<td>0.70</td>
<td>4.7</td>
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<tr>
<td>FV3 GDAS</td>
<td>0.295</td>
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<td>0.3</td>
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<tr>
<td>FV3 ENKF</td>
<td>5.4</td>
<td>0.3</td>
<td>5.7</td>
</tr>
<tr>
<td>FV3 total</td>
<td></td>
<td></td>
<td>10.7 TB</td>
</tr>
</tbody>
</table>

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%. 

~160% increase
# Changes in HPSS Archives per cycle

## Tarball naming convention

<table>
<thead>
<tr>
<th>Ops GFS</th>
<th>Proposed for FV3GFS</th>
</tr>
</thead>
<tbody>
<tr>
<td>gfs.yyyymmddhh.sigma.tar  enkf.yyyymmdd hh.anl.tar</td>
<td>gfs.targfs_flux.tar gfs_<strong>nemsioa.tar</strong></td>
</tr>
<tr>
<td>enkf.yyyymmdd hh.fcs.tar  enkf.yyyymmdd hh.fcs03.tar</td>
<td>gfs_restarta.tar</td>
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<tr>
<td>enkf.yyyymmdd hh.fcs09.tar  enkf.yyyymmdd hh.omg.tar</td>
<td>gdas.targdas_restarta.targdas_restartb.targfs.pgrb2_0p25.targfs.pgrb2_0p50.tar</td>
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<td>gdas.yyyymmddhh.tar gdas.yyyymmdd_radmonhh.ieee.tar</td>
<td>tarenkf.gdas grp01.tarenkf.gdas grp02.tarenkf.gdas _grp03.tarenkf.gdas grp04.tar</td>
</tr>
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<td>gfs.yyyymmddhh.anl.tar gfs.yyyymmddhh.pgrb2_0p25.tar</td>
<td>tarenkf.gdas grp05.tarenkf.gdas grp06.tarenkf.gdas grp07.tarenkf.gdas grp08.tar</td>
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<td>gfs.yyyymmddhh.sfluxgrb.tar</td>
<td>tarenkf.gdas_restarta_grp06.tar</td>
</tr>
</tbody>
</table>

### Permanent

- **1171 GB**

### 2-year

- **55 GB**

### Total

- **1226 GB**

### Proposed for FV3GFS

- **1858 GB**

### Observations:

- All tarball names are changed
- **nemsioa.tar**: saving forecast history nemsio files 3-hourly up to 84 hours for running **standalone FV3**
- 2-year “991 GB”: 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
http://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/fv3q2fy19retro1
http://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/fv3q2fy19retro2
http://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/fv3q2fy19retro3
http://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/fv3q2fy19retro4
http://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/fv3q2fy19retro5
http://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/fv3q2fy19retro6

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).
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
http://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/fv3q2fy19retro1c
http://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/fv3q2fy19retro2c
http://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/fv3q2fy19retro4c
http://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb/fv3q2fy19retro6c

real-time parallel
hord=5, Dec2017 ~ Aug2018
hord=5, Jun2017 ~ Nov2018
hord=5, Jun2016 ~ Nov2016
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.
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

Anomaly Correl: HGT P500 G2/NHX 00Z, fh120

A gain of 0.011

Die-off

AC: HGT P500 G2/NHX 00Z, 20150601-20180912

Increase is significant up to day 10

Annual Mean day-5 ACC, GFS - CFSR

2008~2017 gain: 0.04

Major International NWP, August 2018 Mean

fv3gfs ranked #2
SH and N. America 500-hPa HGT ACC
(20150601 ~ 20180912)

SH

Pacific North America

A gain of 0.008

A gain of 0.009
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.
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
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

• 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/GFS 3–hrly domain–avg APCP Jun–Aug 2018 12z cyc CONUS region

2018: FV3GFS better than GSM, especially overnight

From: Ying Lin
Slight FV3GFS improvement in both the min and the max
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.

gcycle is now called hourly in GDAS forecast step

Tref, 26 May – 18 September 2018

From: DA Team
Fixing the N. Pacific Cold Bias

RTG Analysis
NCDC OI Analysis (dashed)
Ostia Analysis
Operational NSST

NSST 100km + clim. update.
NSST 50km + clim. update.
NSST 50km
Fixing the Great Lakes Cold Bias

RTG Analysis
NCDC OI Analysis (dotted)
Ostia Analysis
Operational NSST

NSST: FV3 real time parallel
NSST: FV3 EXP with fixes (dashed)

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

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

FV3GFS captures slightly smaller number of cases.

From: Guang-Ping Luo
### Tropical Cyclone Genesis

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td># Cases</td>
<td>Ops GFS</td>
<td>139</td>
<td>145</td>
<td>119</td>
<td>210</td>
<td>234</td>
</tr>
<tr>
<td></td>
<td>FV3GFS</td>
<td>171</td>
<td>145</td>
<td>196</td>
<td>104</td>
<td></td>
</tr>
<tr>
<td>Hit (POD)</td>
<td>Ops GFS</td>
<td>63%</td>
<td>60%</td>
<td>92%</td>
<td>74%</td>
<td>65%</td>
</tr>
<tr>
<td></td>
<td>FV3GFS</td>
<td>65%</td>
<td>71%</td>
<td>77%</td>
<td>67%</td>
<td></td>
</tr>
<tr>
<td>False Alarm</td>
<td>Ops GFS</td>
<td>65%</td>
<td>49%</td>
<td>64%</td>
<td>49%</td>
<td>28%</td>
</tr>
<tr>
<td></td>
<td>FV3GFS</td>
<td>51%</td>
<td>49%</td>
<td>63%</td>
<td>68%</td>
<td></td>
</tr>
</tbody>
</table>

**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

- 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

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.

Atlantic

From: Avichal Mehra
FY18 HWRF Testing with FV3GFS
Priority Storms, Early Model

**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.

From: Avichal Mehra
FY18 HMON Testing with FV3GFS
Priority Storms, Early Model

From: Avichal Mehra

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%).**
Operational GEFS initialized with FV3GFS
20180820 ~ 20180908

NH Z500 RMSE and Spread

NH 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

From: Henrique Alves
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:
- Table Mountain CO
- Ops
- GFS
- FV3
- SURFRAD Obs

The Impact:
- Day-5 Zonal Mean Temp: Cools the upper stratosphere by 1 to 2 degrees
- Make the T2m slightly cooler

Day-5 T2m: Make the T2m slightly cooler
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
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
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 outweigh the concerns.

- Some of the issues should be and could be addressed if there were a shorter GFS upgrading cycle. It has become 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