GDAS/GFS V15.0.0
Upgrades for Q2FY2019

Presented by:

Fanglin Yang
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>
</tr>
<tr>
<td>Oct 1983</td>
<td>12</td>
<td>R40 (300km)</td>
<td>Sigma Eulerian</td>
<td></td>
</tr>
<tr>
<td>Apr 1985</td>
<td>18</td>
<td>R40 (300km)</td>
<td>Sigma Eulerian</td>
<td>GFDL Physics</td>
</tr>
<tr>
<td>Aug 1987</td>
<td>18</td>
<td>T80 (150km)</td>
<td>Sigma Eulerian</td>
<td>First triangular truncation; diurnal cycle</td>
</tr>
<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>
</tr>
<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>
</tr>
<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>
</tr>
<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>
</tr>
<tr>
<td>May 2007</td>
<td>64</td>
<td>T382 (35km)</td>
<td>Hybrid Eulerian</td>
<td>SSI to GSI</td>
</tr>
<tr>
<td>Jul 2010</td>
<td>64</td>
<td>T574 (23km)</td>
<td>Hybrid Eulerian</td>
<td>RRTM SW; New shallow cnvtion; TVD tracer</td>
</tr>
<tr>
<td>Jan 2015</td>
<td>64</td>
<td>T1534 (13km)</td>
<td>Hybrid Semi-Lag</td>
<td>SLG; Hybrid EDMF; McICA etc</td>
</tr>
<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>
</tr>
<tr>
<td>Jun 2017</td>
<td>64</td>
<td>T1534 (13km)</td>
<td>Hybrid Semi-Lag</td>
<td>NEMS GSM, advanced physics</td>
</tr>
<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

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

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

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)

Milestones & Deliverables

<table>
<thead>
<tr>
<th>Milestones &amp; Deliverables</th>
<th>Date</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMC/NCO EE2 kick off meeting</td>
<td>1/4/18</td>
<td>Completed</td>
</tr>
<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>1/20/19</td>
<td>planned</td>
</tr>
<tr>
<td>Operational Implementation</td>
<td>1/24/19</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%)

Management Attention Required

Potential Management Attention Needed

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

**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

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

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

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

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.

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)*)

\[
\frac{\partial \chi}{\partial t}(P - L) = (P - L)_0 + \frac{\partial(P - L)}{\partial \chi_{o_3}} \left( \chi_{o_3} - \bar{\chi}_{o_3} \right) + \frac{\partial(P - L)}{\partial T} \left( T - \bar{T} \right) + \frac{\partial(P - L)}{\partial c_{o_3}} \left( c_{o_3} - \bar{c}_{o_3} \right)
\]

**NEMS GSM**  
Includes reference tendency and dependence on O3 mixing ratio

**FV3GFS**  
Additional dependences on temperature and column total ozone

Reference tendency \((P-L)_0\) 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.

\(\chi_{o_3}\)  
prognostic Ozone mixing ratio

\(T\)  
Temperature

\(c_{o_3}\)  
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 H₂O 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
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

Greenland

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 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.
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

**GFSL 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
• 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 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)

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>
</tr>
</thead>
<tbody>
<tr>
<td>gfs_analysis</td>
<td>JGFS_ANALYSIS</td>
<td>JGLOBAL_ANALYSIS</td>
<td>22.9</td>
<td>26.8</td>
<td>4.2</td>
</tr>
<tr>
<td>gfs_forecast (0-10 days)</td>
<td>JGFS_FORECAST_HIGH</td>
<td>---</td>
<td>78.5</td>
<td>75.5</td>
<td>-3</td>
</tr>
<tr>
<td>gfs_forecast (11-16 days)</td>
<td>JGFS_FORECAST_LOW</td>
<td>---</td>
<td>11.3</td>
<td>45.3</td>
<td>34</td>
</tr>
<tr>
<td>gfs_forecast (0-16 days)</td>
<td>---</td>
<td>JGLOBAL_FORECAST</td>
<td>89.8</td>
<td>120.8</td>
<td>31</td>
</tr>
<tr>
<td>gdas_analysis_high</td>
<td>JGDAS_ANALYSIS_HIGH</td>
<td>JGLOBAL_ANALYSIS</td>
<td>29.7</td>
<td>30.7</td>
<td>1.0</td>
</tr>
<tr>
<td>gdas_forecast_high</td>
<td>JGDAS_FORECAST_HIGH</td>
<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>
</tr>
<tr>
<td><strong>ops total</strong></td>
<td><strong>4.06 TB</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FV3 GFS</td>
<td>4.0</td>
<td>0.70</td>
<td>4.7</td>
</tr>
<tr>
<td>FV3 GDAS</td>
<td>0.295</td>
<td>0.05</td>
<td>0.3</td>
</tr>
<tr>
<td>FV3 ENKF</td>
<td>5.4</td>
<td>0.3</td>
<td>5.7</td>
</tr>
<tr>
<td><strong>FV3 total</strong></td>
<td><strong>10.7 TB</strong></td>
<td></td>
<td></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  (link)

<table>
<thead>
<tr>
<th>Tarball naming convention</th>
<th>Ops GFS</th>
<th>Proposed for FV3GFS</th>
</tr>
</thead>
<tbody>
<tr>
<td>gfs.yyyymmddhh.sigma.tar</td>
<td>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.yyyymmddhh_radmonhh.ieee.tar gfs.yyyymmddhh.anl.tar gfs.yyyymmddhh.pgrb2_0p25.tar gfs.yyyymmddhh.pgrb2_0p50.tar gfs.yyyymmddhh.pgrb2_1p00.tar gfs.yyyymmddhh.sfluxgrb.tar</td>
<td>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</td>
</tr>
</tbody>
</table>

| 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
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

real-time parallel
hord=6, Dec2017 ~ May2018
hord=6, Jun2017 ~ Nov2018
hord=6, Dec2016 ~ May2017
hord=6, Jun2016 ~ Nov2016
hord=6, Dec2015 ~ May2016
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
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.

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

**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

---

**FH 36-60**

**FH 84-108**
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
CONUS 2-m Temperature
Verified against Station Observations, 3-year mean

Slight FV3GFS improvement in both the min and the max
2-m Temperature over Alaska
Verified against Station Observations, 3-year mean

NORTH ALASKA

SOUTH ALASKA

OBS  GFS  FV3GFS

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

From: DA Team

Tref, 26 May – 18 September 2018
Fixing the N. Pacific Cold Bias

TF analysis comparisons. Mid.NP: Lon (140.0,210.0), Lat (42.0,67.0).

- RTG
- NCDC
- OSTIA
- OPR
- KNST
- EH50
- NST

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)
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>
</tr>
</thead>
<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>
</tr>
<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>
</tr>
<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.
Tropical Cyclone Genesis

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td># Cases</td>
<td>Ops GFS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>139</td>
<td>145</td>
<td>119</td>
<td>210</td>
<td>234</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>FV3GFS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>171</td>
<td>145</td>
<td></td>
<td>196</td>
<td>104</td>
<td></td>
</tr>
<tr>
<td>Hit (POD)</td>
<td>Ops GFS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>63%</td>
<td>60%</td>
<td>92%</td>
<td>74%</td>
<td>65%</td>
<td>63%</td>
</tr>
<tr>
<td></td>
<td>FV3GFS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>65%</td>
<td>71%</td>
<td></td>
<td>77%</td>
<td>67%</td>
<td></td>
</tr>
<tr>
<td>False Alarm</td>
<td>Ops GFS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>65%</td>
<td>49%</td>
<td>64%</td>
<td>49%</td>
<td>28%</td>
<td>57%</td>
</tr>
<tr>
<td></td>
<td>FV3GFS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>51%</td>
<td>49%</td>
<td></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

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
**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

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

- 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

>1mm BSS
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 ALTIIKA 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

Day-5 Zonal Mean Temp

Cools the upper stratosphere by 1 to 2 degrees

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
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 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