HFIP Annual Meeting

UFS CAM Applications: FV3SAR Testing Update

5 November 2019
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NOAA/ESRL/GSD
NOAA/NCEP/EMC
NOAA/NSSL
NCAR/DTC
UFS Applications (draft)

CAM Application Team (AT)

Medium-Range/S2S Application Team (AT)

FOCUS

- local
- regional
- global

PREDICTIVE TIME SCALE

- hour
- day
- week
- month
- year

UFS APPLICATIONS

- weather and seasonal
- hurricane
- space weather
- marine and coastal
- air quality
- flood and hydrological

- Warn on Forecast System
- Rapid Refresh Forecast Systems
- Global Forecast System
- Sub-Seasonal Forecast System
- Seasonal Forecast System
- Hurricane Analysis and Forecast System
- Whole Atmosphere Model
- Coastal Modeling Systems
- Air Quality Systems
- National Water Model

Downstream CAM Applications
CAM High-Level Science Priorities

FV3 CAM Operational Readiness (SAR CAM Workshop Sep 2019)
- Dynamics Tuning
- IC/LBC processing
- Frequent-cycling DA

CAM Physics Unification (SAR CAM Workshop Sep 2019)
- Currently several operational CAM physics suites (NAMnest, HRRR, HWRF)
- Significant differences from medium-range weather applications and development priorities (GFS, GEFS)

CAM Application Unification (SAR CAM Workshop Sep 2019)
- Many proposed UFS CAM applications
- Are there overlaps that can be avoided?

- Currently support CAM initializations
- Currently provide mesoscale environmental information for hazard deterministic and ensemble prediction
- Plan being developed for acceleration of this process

CAM Ensemble Design Simplification (CLUE, HWT 2016-2019)
- Currently a multi-model (MME), multi-physics, multi-initialization CAM ensemble system (HREF)
- Experimental single-model single-stochastic physics CAM ensemble system (HRRRE)
- Experimental single-model multi-physics CAM ensemble system (WoFS)
CAM Technical Priorities

Test Plan Development (Metrics/Testing Workshop in July/Aug 2018)
  CAM verification metrics established
  How to use them for pre-implementation decision making?

SAR Workflow Unification (SAR Workflow Code Sprint July 2019)

Cloud Computing Tests (OAR Cloud Workshop Jul-Aug 2019, HU-1 Supplemental Project)

SAR Code Release (Release Teams)
  Scope
  Documentation
  User support
SAR CAM Workshop Outcome Themes

● Establish Dynamics Baseline Configuration
  ○ Established that SAR (one-way) and global nests (two-way) are producing statistically identical results
  ○ Select stable configuration including namelist options (shared document)
  ○ Tag CCPP version of model configuration
  ○ Select common 3-km CONUS “JP” horizontal grid (gnomonic projection)
  ○ Configure model top at 2 mb, ~8 m lowest level, 64 vertical levels

● Establish Physics Baseline Configuration
  ○ Transition to CCPP interface for all stakeholders
  ○ Separation of physics and dynamics for generalized physics relationship with model time step
  ○ Transparent test plan/selection process for CAM physics suite (HRRR, WoF, NAM, HWRF, GFS)
  ○ Process-level development of physics parameterizations and collaboration on components across org

● Establish Community Workflow
  ○ Continue merging workflows including build scripts with attention to NCEP libraries
  ○ Simplify of input files, in-model diagnostics, write component (native grid) and post-processing
  ○ Need operational configuration option, entry point for data assimilation and vertical level flexibility
  ○ Need NCO-compliant variable passing between scripts and more verbose error messages
  ○ Need to determine scope of supported top-level workflow manager options (Rocoto, ECFlow, Python, etc…)

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SAR CAM Workshop Outcome Themes

● Data Assimilation Challenges
  ○ GSI to JEDI transitions: WoF-JEDI in 2021?, RRFS-JEDI in 2023?, start with forward operators (UFOs)
  ○ Need data assimilation updates/increments in lateral boundaries
  ○ Coupled land-atmosphere data assimilation
  ○ Analysis increment balance options (DFI, IAU, etc…)
  ○ Non-linear/non-gaussian obs/operators
  ○ Ensemble localization and inflation schemes
  ○ GOES all-sky radiance assimilation
  ○ Continuously cycled system for physics evaluations

● Establish Common Cases
  ○ Need failure cases for stability testing and a mix of weather events for skill evaluation
  ○ Need scaling baseline for resource testing against operational CAMs
  ○ Need regression tests including non-NOAA machines for development testing
SAR CAM Community Support

- Leverage DTC UFS-CAM software support & community engagement efforts (deliverables include):
  - SAR-FV3 workflow repository transitioned to GitHub
  - Workflow review committee created as defined in the completed code management protocols
  - Full end-to-end regression test established for the community SAR-FV3 workflow repository
  - Enhanced community SAR-FV3 workflow with new tasks included as development of the full system matures
  - Updated documentation to support the initial release of the SAR-FV3 workflow to the community
  - SAR-FV3 users’ forum designed and made available to facilitate community support
CAM Verification Metrics

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Forecast Field</strong></td>
<td><strong>Application</strong></td>
<td><strong>Vertical Attribute</strong></td>
<td><strong>Temporal Attribute</strong></td>
<td><strong>Validation Source</strong></td>
<td><strong>Priority/Importance</strong></td>
<td><strong>Maturity/Readiness</strong></td>
<td><strong>emergent Methodology</strong></td>
<td><strong>Deterministic Scores</strong></td>
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<tr>
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<td><strong>Downstream Shortwave Radiation</strong></td>
<td>Quality(Energy Land Surf)</td>
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<td>RMSE, BIAS</td>
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<td>Aviation</td>
<td>Column</td>
<td>Instantaneous</td>
<td>METARs</td>
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<td>Grid-to-Point</td>
<td>POD, FAR, AUR, Perforn(500, 1000, 3000, 5000, 10000 m)</td>
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<td><strong>Echo Top Height</strong></td>
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<td>MRRS Echo Top</td>
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<td>POD, FAR, AUR, Perforn(20, 25, 30, 35, 40, kft), Scale [0, 200]</td>
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<td>POD, FAR, AUR, Perforn(5.5, 1.0, 3.0, 5.0, 10.0 mce MI)</td>
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<td><strong>CAPE/CIN</strong></td>
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<td>RAOB</td>
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<td>RMSE, BIAS [36 h], Diam[32-122]</td>
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<td>POD, FAR, AUR, Perforn(32-122), Diam[0, 100]</td>
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<td>RMSE, BIAS [36 h], Diam[32-122]</td>
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<td>Precip</td>
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<td>Stage IV</td>
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<td>SE, BIAS, Correlation, Std subregions, urban</td>
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<td>Precip</td>
<td>Composite</td>
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<td>Severe</td>
<td>Composite</td>
<td>Instantaneous</td>
<td>Upper from max, sonic anemometers</td>
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<td>Upper from max, sonic anemometers</td>
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<td>CSI, BIAS, [17.7 K], Scale [30, 40]</td>
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<td><strong>PIER Depth</strong></td>
<td>Environmental</td>
<td>Top of PIER</td>
<td>Instantaneous</td>
<td>METARs, NCAR, ACARS, Storm Reports</td>
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<td>POD, FAR, AUR, Perforn(36, 40, 65, 50, 125, % percentile)</td>
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<td><strong>Updraft Velocity</strong></td>
<td>Severe</td>
<td>2-5, 0-3 km AGL</td>
<td>Hourly Max, Min</td>
<td>Storm Reports</td>
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<td>2</td>
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<td>SE, BIAS, Correlation, Std subregions, urban</td>
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<td>Surface</td>
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<td>METARs</td>
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<td>POD, FAR, AUR, Perforn(36, 40, 65, 50, 125, % percentile)</td>
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<td>23</td>
<td><strong>Snow Water Equivalent</strong></td>
<td>Winter Weather</td>
<td>Surface</td>
<td>24-hr Totals</td>
<td>NORDS Snow Analysis (24-hr)</td>
<td>2</td>
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<td>POD, FAR, AUR, Perforn(36, 40, 65, 50, 125, % percentile)</td>
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<td>Air Quality</td>
<td>Column</td>
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<td>Scale adj mult</td>
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<td>RMSE, BIAS</td>
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<td>Air Quality</td>
<td>Surface</td>
<td>Instantaneous</td>
<td>Scale adj mult</td>
<td>3</td>
<td>3</td>
<td>Grid-to-Point</td>
<td>RMSE, BIAS</td>
</tr>
<tr>
<td>26</td>
<td><strong>Perfusion Meter</strong></td>
<td>Air Quality</td>
<td>Surface</td>
<td>Instantaneous</td>
<td>Scale adj mult</td>
<td>3</td>
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<td>RMSE, BIAS</td>
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<td>ARM, Surf: Sky ridge, albedo, UCSTRN</td>
<td>3</td>
<td>3</td>
<td>Grid-to-Point</td>
<td>RMSE, BIAS</td>
</tr>
<tr>
<td>28</td>
<td><strong>Cloud cover, (L,M,H,T)</strong></td>
<td>Environmental</td>
<td>Column</td>
<td>Instantaneous</td>
<td>Cimel Laser, AERONET, CLAUR, AFWA</td>
<td>3</td>
<td>3</td>
<td>Grid-to-Point</td>
<td>RMSE, BIAS, [36 h], Diam, Sub-regional spred</td>
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<tr>
<td>29</td>
<td><strong>Reflectivity</strong></td>
<td>Severe</td>
<td>-10°C</td>
<td>Hourly Max</td>
<td>NRMSS Mosaic</td>
<td>3</td>
<td>3</td>
<td>Grid-to-Point</td>
<td>CSI, BIAS, [30, 40]</td>
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<tr>
<td>30</td>
<td><strong>Snow Water Equivalent</strong></td>
<td>Winter Weather</td>
<td>Surface</td>
<td>1-hr</td>
<td>MetARs</td>
<td>2</td>
<td>3</td>
<td>Grid-to-Point</td>
<td>POD, FAR, AUR, Perforn(36, 40, 65, 50, 125, % percentile)</td>
</tr>
</tbody>
</table>

Metrics were collected from broad CAM stakeholder input (aviation, hydrology, severe, winter, air quality, etc...)

Only metrics classified by stakeholders as highest priority and maturity were selected for initial CAM evaluations and pre-operational implementation decisions.

Options for including future metrics exist as priority and maturity is increased.
Experience with Real Time Runs

- Running real time, continuously since May 1st 2018
- NEST: May 1st, 2018 - July 22nd 2019
  - Turned off to allow resources for other testing
- SAR: July 3rd, 2018 - Present
- SAR-DA: Fall 2018 - June 2019
  - LBC update issue
- SARX: June 19th, 2019 - Present
  - Sandbox for testing
  - Promising changes go into SAR
- Practical reasons drive need for SAR
  - more efficient
  - focused development
  - rapidly updating data assimilation, etc.
- Compare Nest and SAR
  - 60 hour forecasts
- FSS for 6-h precip in June 2019
- Results here are *WITHOUT* LBC Blending

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Enhanced LBC Treatment through Blending

- Nest vs. SAR statistically indistinguishable → good!
- Still need to address boundary issues
  - Standing waves with wavelength of 2-delta x occur adjacent to some parts of regional domain boundaries

23 km T - No Blend

- Layer 4
- 6 Hours
- C96 or ~ 23 km

*Slide courtesy of Tom Black

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LBC Blending

- Layer 4
- 6 Hours
- C96 or ~ 23 km

*Slide courtesy of Tom Black

Waves just displaced into the domain a little bit

Much more well behaved

Linear Blending - 10 Rows

Exponential Blending - 10 Rows
LBC Blending

Linear (dashed) and exponential (solid) blending - 10 Rows

*Slide courtesy of Tom Black*
● EMC Provided FV3 CAM runs rated near top of FV3 CAMs tested (*great*!)
  ○ EMC Nest and SAR
    ■ Noted that these were very similar (good thing)
● EMC runs tended to have “blobby” looking storms with less discernible structure

*Figure courtesy of HWT model comparison page*
Dynamics Tuning: Testing to improve storm structure

Results from prelim testing by E. Strobach

Current settings

Obs

hord=5

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Configuration Uncertainties with SAR

- SAR has many tunable parameters
- Part of challenge is that SAR solutions appear fairly sensitive to parameter changes - more than current CAMS.
- **Example of Sensitivity: Two Warn on Forecast cases**
  - Take hourly DA generated analyses from WRF-ARW WoFS and initialize the SAR with those analyses.
  - Run 4 hour forecasts with 18 members for both models
  - Use “same” physics in both ensembles-> HRRR suite
  - Simple test: Change the SAR time step
    - WoFs runs using dt=5 and 15 sec
    - SAR runs with 5, 15, 30, 60 sec time step
    - Mean values are generated from obj-based storm identification and represent the average W over 27 pts.
- **SAR updrafts are sensitive to choice in time step....**
- **Why are SAR updrafts 50-75% larger than current operational CAM with same mesoscale environment and same time step?**

![Graph showing 4 Hour FCST: 1 May 2018 Ensemble mean W's](image)

- 1 May 2018
  - Scattered supercells
- SAR dt= 5
- SAR dt=15
- SAR dt=30
- SAR dt=60
- WRF dt=15
- WRF dt= 5

![Graph showing 4 Hour FCST: 20 May 2019 Ensemble mean W's](image)

- 20 May 2019
  - Numerous storms + ~ dozen supercells

HFIP/HAFS
Less diffusive → less stable?

- Less diffusive advection has, so far, required adding additional damping elsewhere to keep model stable
  - Work is ongoing
- Cluster of range warnings/bad values occurs early in the forecast (f01-f06) and coincides with an MCS over eastern Texas

Bad range values tend to occur near model top. Some values are seen at mid-level and near surface

*Slide courtesy of Ed Strobach*
Coordinating with CAM developers and stakeholders across NOAA labs, EMC and universities and other collaborators

Providing suggested settings (stable) for controlled tests of SAR CAM

Documentation will be critical not only for what the namelist choices do but why certain options are preferred for certain applications.
Ensemble DA Updates

- Enhancements are needed to GSI EnVar code and EnKF code to handle FV3-SAR
  - GSI now has capability to read in FV3-SAR ensembles
    - Restart files
    - “cold start” files generated by CHGRES
  - EnKF to use the FV3SAR ensembles in the form of the restart files
  - Dual resolution is ready but testing with a case is TBD
  - Can run with a combination of regional and global ensembles
    - e.g. 3 km SAR members + GDAS members

- Capabilities have been preliminarily validated
  - Broader application, testing, and feedback is welcome
  - Can provide the branch info for anyone
Current DA Testing

- The GSI system has been developed to interface directly with the FV3 native grid for a tile or nest input
- Configuration similar to 3 km NAM CONUS nest, using hourly RAP obs
- Have switched this off due to LBC consistency issue
Regional DA Imbalance: Hours 0 to 6

Difference of cold start regional FV3 forecast from regional DA forecast with hourly spinup from T-06 to T-00.

500 mb Height (dam)
Current

Model writes fields into restart files \textit{without the boundary}:

GSI updates the integration domain:

New

Model writes fields into restart files \textit{with the boundary}:

GSI updates the entire domain \textit{including the boundary}:

*Thanks to Tom Black for this slide
CAM Physics Proposed Baseline

- This recommendation of physics closely resembles current operational CAM configurations/experience for various systems

<table>
<thead>
<tr>
<th>Parameterization</th>
<th>FV3CAM Baseline</th>
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<tbody>
<tr>
<td>Microphysics</td>
<td>Aerosol-aware, radiation-coupled Thompson</td>
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<tr>
<td>Longwave/Shortwave Radiation</td>
<td>RRTMG</td>
</tr>
<tr>
<td>Boundary and Surface Layer (PBL)</td>
<td>Scale-aware MYNN</td>
</tr>
<tr>
<td>Land Surface Model (LSM)</td>
<td>Noah MP (contingent upon changes to vertical levels to match existing CAM skill)</td>
</tr>
</tbody>
</table>

- CAM ensemble forecasts that use a multi-physics approach:
  Additional microphysics schemes such as Ferrier-Aligo and NSSL double-moment
  Additional PBL/surface layer schemes such as MYJ

- These selections should not be viewed as immutable if future testing and evidence dictates that changes are needed.
SAR-FV3 Community Workflow Tasks

1. **make_grid** – Generates grid (of GFDLgrid or JPgrid type) files.
2. **make_orog** – Generates filtered orography files.
3. **make_sfc_climo** – Generates surface climatology files (used if fields are not available in external model output).
4. **getExternFiles_ic** – Copies output files from the external model (for ICs) that are needed for generating ICs, surface fields, and the 0-th hour LBC on the native SAR-FV3 grid into experiment directory (either from disk or mass store).
5. **getExternFiles_bc** - Copies output files from the external model (for LBCs) that are needed for generating LBCs into experiment directory (either from disk or mass store).
6. **make_ic** – Regrids fields from the external model for ICs onto the native SAR-FV3 grid (including surface fields and the 0-th hour LBC).
7. **make_bc** – For each boundary update time, regrids the fields from the external model for LBCs to the SAR-FV3 grid.
8. **run_fcast** – Runs a forecast (cycle) with the SAR-FV3.
9. **post** – Processes the forecast output files (on the write-component grid) through UPP to generate grib2 files that can be used for verification.
Modification of the Gnomonic Grid

Through collaboration with EMC (Jim Purser):

- Concentrate model coordinates (great circles) near center of tile six to improve uniformity after stretching
- Added two plotting parameters (alpha and kappa) to the generation of the gnomonic grid
- Flares the corners of the grid to reduce grid variability

Blue represents the outline of the SAR grid (tile seven) with the sixth tile of the global FV3 in red.
Comparison of RAP/RAP-equivalent Grids

With Global “Parent” Grid

Original RAP-ARW Grid

No Global “Parent” Grid
(Best option!)

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Comparison of HRRR/HRRR-equivalent Grids

With Global “Parent” Grid

Original HRRR-ARW Grid

No Global “Parent” Grid
(Best option!)

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Development work planned before SAR release

- Incorporate DA into workflow
  - Include new workflow task for GSI
  - Introduce capability to start model from restart files
- Introduce a user-configurable vertical coordinate grid (work has already begun)
  - Model top pressure
  - Vertical distribution of coordinate surfaces
- Create a set of baselines to be used to test new commits to both the regional_workflow and external repositories (work has already begun)
  - Establish policy for cross-platform/repository regression testing
- Allow for submission of individual workflow tasks on the command line
- Include option to blend external model fields near the edges of the integration domain (code now available from EMC) to minimize spurious standing waves
- **Targeting summer 2020 release**
HFIP Summer Demo Experiments:

1. **HAFS v0.A** – A FV3 SAR configuration, analogous to the CAM FV3 SAR configuration, but for TC regions of interest. GFS physics and RAP/HRRR (continental CAM physics)

2. **HAFS v0.B** – A FV3 nest within the FV3 global model (as shown above)

Image courtesy of Andrew Hazelton (NOAA/AOML/HRD).
HAFSv0.A runs in the FV3-SAR community workflow

- Implemented HAFSv0.A as a pre-defined domain in the FV3-SAR community workflow (3-, 13-, and 25-km grid spacing options)
- Successfully ran eight HAFSv0.A cold-start cycles for Hurricane Dorian:
  - 8/30/19 to 9/2/19, both 00 and 12Z
  - 168-hour forecasts
  - 3-km resolution
  - GSD physics
  - 152 nodes on Hera, ~5 hour wall clock time per cycle
  - Used Lambert Conformal output grid
- Implemented GFDL tracker into workflow, but need data on regular lat/lon grid to run
- Working on modifying FV3-SAR post script to produce regional_latlon write component grid, then use wgrib2 transformation to regular lat/lon grid
- After tracker runs, plan is to process ATCF files for NHC stats
HAFSv0.A runs in the FV3-SAR community workflow

- Zonal winds at lowest model level for the 4-hr forecast from the 2019083112 cycle
- Max zonal winds during cycle: 66 m/s

05 Nov 2019
**FV3-CAM Timeline → Rapid Refresh Forecast System**

- **FY18/19**: Development underway standalone/regional, nesting, DA, physics, etc.
- **Q3FY20**: RAPv5/HRRRv4 Implementation
  - Freeze all non-FV3 CAM systems
- **Q4FY20**: HREFv3
  - Replace poorly performing members with FV3-CAM if justified via objective stats
- **FY21**: CAM Development Continues
  - Demonstration FV3-CAM ensemble DA + forecast system
  - Evaluate against HREF.
  - Continue physics testing/advancement.
- **~FY23**: RRFSv1
  - Implement RRFSv1 pending favorable evaluation

**Rapid Refresh Forecast System → To replace HREF, HRRR, NAM + nests, HiResWs**

*Timeline may be revised as development matures/progresses*
Unification of Regional Modeling Systems

Global (15-30 km, 4/day)
- GFS
- GEFS

Regional (12-15 km, 4-24/day)
- RAP
- SREF
- NAM
  - HRRR
  - HiResARW
  - HiResNMMB
  - NAMnest
  - HiResARW2
  - HREF

CONUS CAM (3-4 km, 2-24/day)
- HRRR
- HiResARW
- HiResNMMB
- NAMnest
- HiResARW2
- HREF

Sub-CONUS CRM (1-2 km, on-demand)
- FireWxNest

FY19 (now)
Unification of Regional Modeling Systems

FY20

Global (15-30 km, 4/day)
- GFS ➔ GEFS

Regional (12-15 km, 4-24/day)
- RAP ➔ SREF ➔ NAM

CONUS
- HRRR ➔ HiResARW ➔ SARFV3
- NAMnest ➔ HiResARW2
- HREF

Sub-CONUS
- CRM (1-2 km, on-demand)
- FireWxNest

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Unification of Regional Modeling Systems

FY23 and beyond

Global (10-15 km, 4-24/day)

GFS → GEFS

North American CAM (3 km, 2-24/day)

RRFS

Sub-CONUS CRM (1 km, on-demand)

WoFS

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