Expanding the UFS to Multiple Dynamical Cores

Opportunities and Challenges

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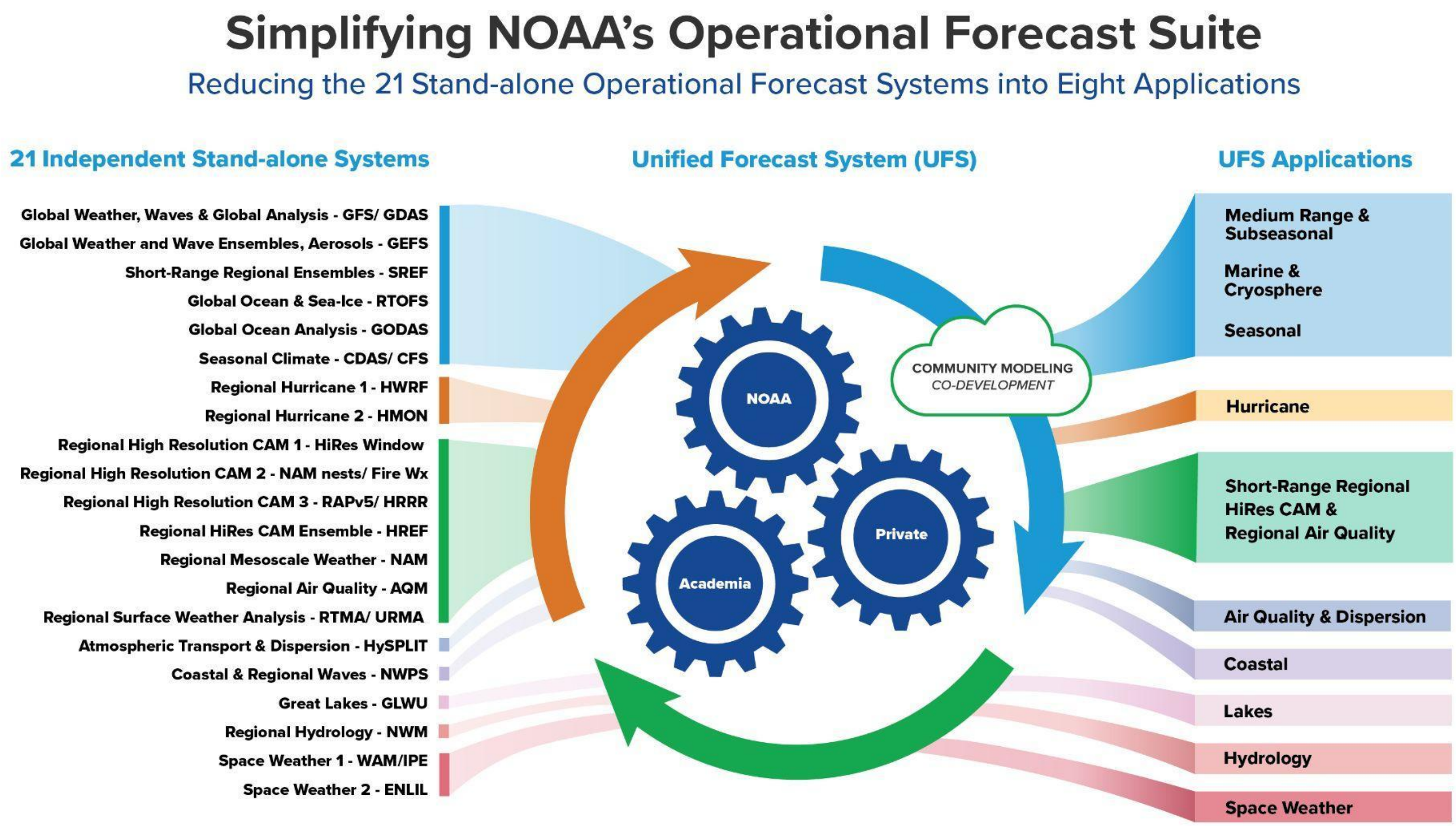
Slide adapted from Jacob Carley, UFS R2O meeting, Feb 6, 2024



Simplifying NOAA's Operational Forecast Suite

Reducing the 21 Stand-alone Operational Forecast Systems into Eight Applications

21 Independent Stand-alone Systems

- Global Weather, Waves & Global Analysis - GFS/ GDAS
- Global Weather and Wave Ensembles, Aerosols - GEFS
- Short-Range Regional Ensembles - SREF
- Global Ocean & Sea-Ice - RTOFS
- Global Ocean Analysis - GODAS
- Seasonal Climate - CDAS/ CFS
- Regional Hurricane 1 - HWRF
- Regional Hurricane 2 - HMON
- Regional High Resolution CAM 1 - HiRes Window
- Regional High Resolution CAM 2 - NAM nests/ Fire Wx
- Regional High Resolution CAM 3 - RAPv5/ HRRR
- Regional HiRes CAM Ensemble - HREF
- Regional Mesoscale Weather - NAM
- Regional Air Quality - AQM
- Regional Surface Weather Analysis - RTMA/ URMA
- Atmospheric Transport & Dispersion - HySPLIT
- Coastal & Regional Waves - NWPS
- Great Lakes - GLWU
- Regional Hydrology - NWM
- Space Weather 1 - WAM/IPE
- Space Weather 2 - ENLIL

Unified Forecast System (UFS)

UFS Applications

- Medium Range & Subseasonal
- Marine & Cryosphere
- Seasonal
- Hurricane
- Short-Range Regional HiRes CAM & Regional Air Quality
- Air Quality & Dispersion
- Coastal
- Lakes
- Hydrology
- Space Weather

From Uccellini et al. (2022)

Slide adapted from Jacob Carley, UFS R2O meeting, Feb 6, 2024

Implementation of UFS applications in last 5-7 years

Many successes, for example for UFS Global (GFS) and Hurricanes (HAFS)

For the Rapid Refresh Forecast System (regional convection allowing, HRRR successor), significant forecast issues remain

- Details of convective structure
- Excessive precipitation biases
- Does not meet operational requirements

Mitigation efforts in RRFS were unsuccessful. Two studies were requested by NOAA leadership:

1. A white paper describing the RRFS problems and mitigation strategies
2. A study to estimate the effort for adding another dynamical core to the UFS

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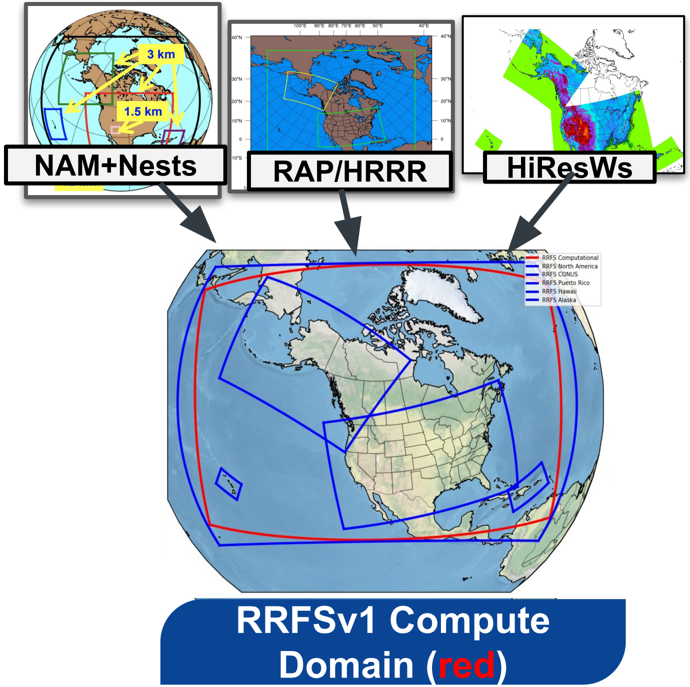
Rapid Refresh Forecast System (RRFS)

- FV3 dynamical core (limited area model)
- Hourly updated
- 3-km grid spacing over North America, 65 vertical layers
- Hybrid 3DEnVar data assimilation (30 members)
- Includes Smoke and Dust
- Deterministic forecast to at least 18 h every hour
- Deterministic+ensemble forecast to 60 h every 6 hours



RRFSv1 Compute Domain (red)

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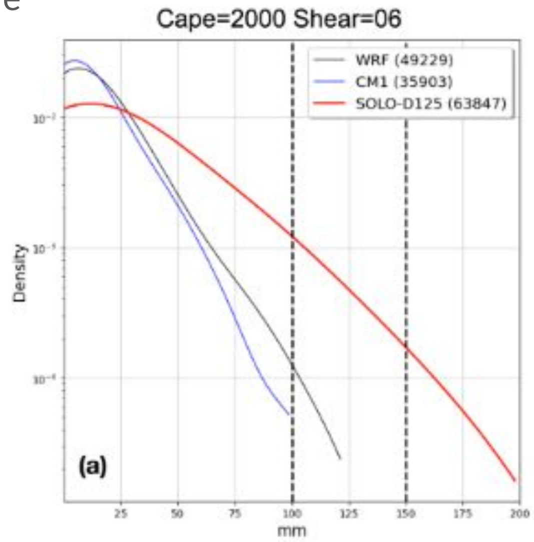
The culprit: C-D grid structure + necessary damping

- C-D grid structure of FV3 represents rotational modes better than C grid
- Requires enhanced damping to remove excess energy at/near gridscale
- Combination of grid choice and necessary damping leads to wider/stronger updrafts, stronger storms and more precipitation

QPF Kernel Density Estimate



Fixing the issue in FV3 or moving to another dycore?

- Addressing the issue in FV3 requires major code changes: "*It is important to realize that the changes needed for the FV3 dynamical core, as described below, are significant enough that the resulting code would effectively create a second dynamical core within the UFS*" (from the white paper)
- The alternative: Adding MPAS to the Unified Forecast System as a second dynamical core?
  - MPAS has established Limited-Area Model capability
  - MPAS-JEDI has demonstrated data assimilation capabilities
  - MPAS has demonstrated promising performance for RRFS convective applications

But which of the two options is cheaper, faster, more promising for the future?

White paper: Jacob Carley et al. (2023), Mitigation Efforts to Address Rapid Refresh Forecast System (RRFS) v1 Dynamical Core Performance Issues and Recommendations for RRFS v2 (https://doi.org/10.25923/ccgj-7140)

Tiger Team to scope out adding MPAS to UFS

- Team: Dan Rosen, Dom Heinzeller, Dustin Swales, Jun Wang, Kevin Viner, Ligia Bernardet
- Scope: Research technical work needed to bring a new dycore into the UFS
    - Be general but focus on the RRFS configuration
    - Be general but focus on MPAS
    - Provide an estimation of resources needed
- Collected feedback from UFS application leads, NCAR/MMM and NCAR/CGD

- Report: Jun Wang et al. (2023), Integration of MPAS Dycore into UFS (https://ufs.epic.noaa.gov/wp-content/uploads/2024/01/Integration-of-MPAS-Dycore-into-UFS.pdf)

How to integrate MPAS in the UFS (what part of it)?

MPAS Standalone (forecast model)

- Atmospheric model (MPAS–A: MPAS dycore, physics, … + infrastructure shared with MPAS-O/I/…)
- Ocean, sea ice, etc. model components (not part of public release)

MPAS in CESM/CAM (referred to as SIMA-MPAS)

- The MPAS dycore is integrated in CESM/CAM
- Dycore code comes from the same repo as MPAS Standalone

MPAS in UFS: Approach similar to CAM-SIMA, i.e. add a new dycore to UFS

- Single modeling system has many advantages for NOAA and the community

Generalizing the UFS atmospheric component

- The atmospheric component of the UFS, FV3ATM, is a coupling interface between dynamics, physics, atmospheric I/O, and external components
- Needs abstraction and generalization (FV3ATM -> UFSATM)
    - Facilitate introduction of a new dycore, such as MPAS
    - Opportunity to clean up and restructure

UFSATM
Code Mgmt
Pre-Proc
DA
Physics
Coupling
I/O
Post-Proc

Code Management

- MPAS will be a submodule under UFS Weather Model Atmospheric Component
- Code will point directly to the MPAS official repository (NCAR/MMM)
- MPAS - UWM interface will stay under UWM atmosphere repository
- This is similar to how MPAS is used in CESM/CAM / how FV3 is used in UFS
- Needs good relationship between UFS and MPAS teams - and also $$$?

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Pre-Processing

- There are existing tools to ingest GRIB2 and drive MPAS
- Work needed to use GFS (v16) analysis data available as netCDF files on native grid
- There are also existing tools to interpolate static datasets to MPAS grid
- These may need to be connected to existing UFS utility packages
- Need to develop code to generate input fields for some CCPP physics

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Data Assimilation (DA)

- JEDI DA algorithms and obs operators are model-agnostic
  - Allow for swapping the model interface
- JEDI uses grids provided by model interfaces
  - Native grid DA for both FV3 and MPAS can be used
- Ongoing JEDI-MPAS experiments by MMM and JCSDA
- Can leverage JEDI-UFS work and JEDI-MPAS work at JCSDA (w/ in-kinds)

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Physics-Dynamics Coupling

- The equivalent of the RRFS physics schemes in MPAS are different (older) than in UFS, and they are not connected via CCPP
- **Use CCPP Framework and Physics in UFSATM to connect MPAS dycore with physics**
  - Create MPAS-specific interstitial schemes in CCPP, new suite definition files
  - Parameterizations need to return tendencies
  - Different placement of calls to CCPP (before/after dycore)
  - Transformations: moist to dry, pressure levels to geometric height, (i,k) to (k,i)
  - Some of this functionality exists in MPAS-A/CCPP and needs to be reused
- Some work needed for mesh-dependent stochastic processes (not all of them are critical for short-range weather)

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Inter-Component Coupling: UFSATM NUOPC Cap

- Drive MPAS dycore through existing UFSATM NUOPC Cap
- Create connections between MPAS and the UFSATM NUOPC Cap
- Some of this functionality already exists in CESM/CAM and can be leveraged

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Input/Output

- Approach 1: Use MPAS I/O on native mesh, then use convert_mpas utility to interpolate to lat-lon
  - Sufficient for initial testing
- Approach 2: Develop asynchronous I/O (write component) capability for use in UFSATM
  - Needed to increase performance for operations
  - Ties in with plans to develop a generic write grid component for UFS components

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Post-Processing

- Run offline UPP from MPAS history files
  - UPP uses files created by convert_mpas
- MPAS directly outputs all the post-processing products
  - Integrate UPP code into MPAS to output in native mesh, then convert to lat-lon
- Run inline UPP in write grid component
  - Develop write grid component for all grids needed and call UPP

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Opportunities & challenges for MPAS dycore in UFS

Opportunities

- High chance to meet RRFS v2 operational requirements with MPAS cheaper/faster than with FV3
- Flexibility of having two dycores in UFS - choose what works best
- Recognition and impact of MPAS efforts, and funding for MPAS development/code management

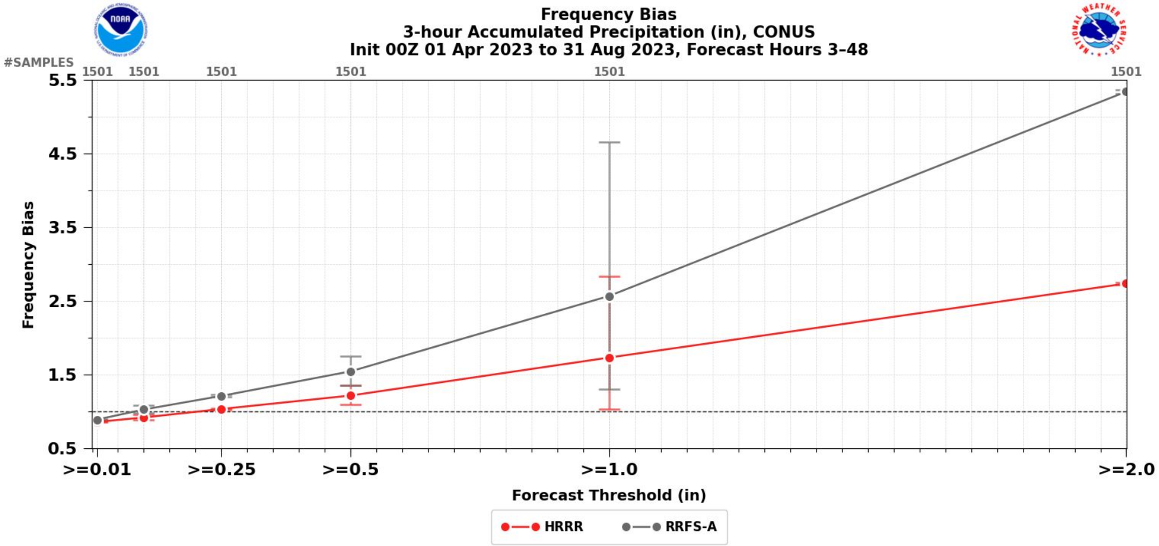
Challenges

- Implementing MPAS dycore in UFS requires a number of expert developers available for the job
- Maintaining two dycores requires more resources
- Being used in operations can impose constraints/priorities on development

Bonus slides

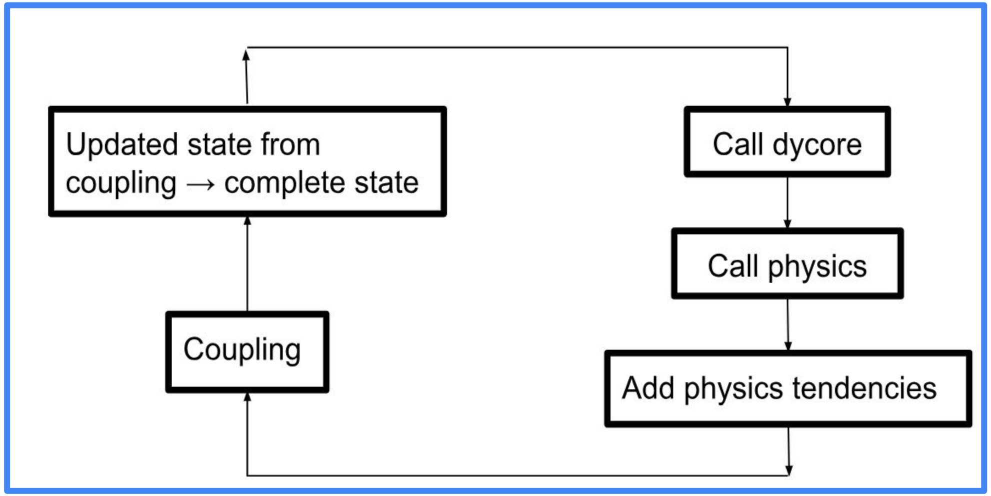
Convective Storm Intensity, High Precipitation Bias

Most obvious in convectively unstable environments with relatively weak forcing and vertical wind shear



Physics-Dynamics Coupling (continued)

FV3



Updated state from coupling → complete state

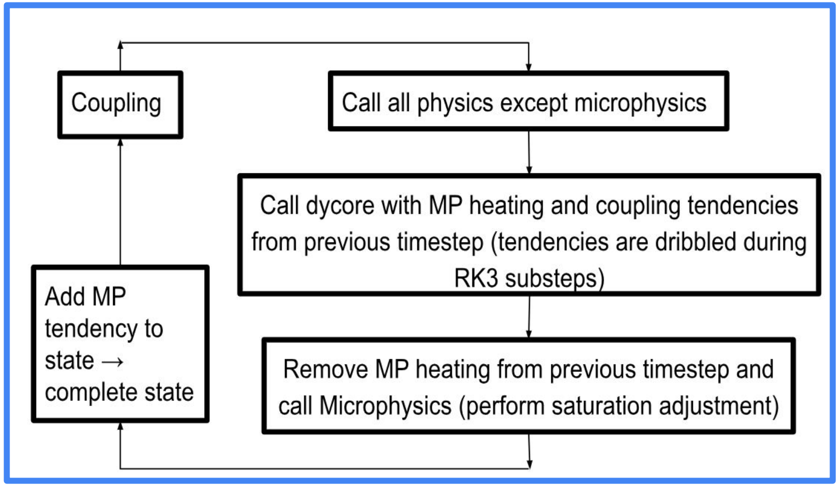
Call dycore

Call physics

Add physics tendencies

Coupling

MPAS



Coupling

Call all physics except microphysics

Call dycore with MP heating and coupling tendencies from previous timestep (tendencies are dribbled during RK3 substeps)

Add MP tendency to state → complete state

Remove MP heating from previous timestep and call Microphysics (perform saturation adjustment)