NATIONAL WEATHER SERVICE

Model infrastructure development in UFS weather model

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Presenters: Jun Wang, Arun Chawla, Denise Worthen, Dusan Jovic, Raffaele Montuoro, Gerhard Theurich, Dan Rosen, Ufuk Turuncoglu, Rocky Dunlap, Mariana Vertenstein, Brian Curtis, Sadegh Sadeghi Tabas, Rahul Mahajan, Jong Kim, Mark Potts, Alexander Richert, Hang Lei, Edward Hartnett, Dom Heinzeller, Jiande Wang, Matthew Masarik, Jessica Meixner, Bin Liu, Wen Meng, Jianping Huang, Anning Cheng, Michael Barlage, Helin Wei, Chunxi Zhang, George Gayno, Shan Sun, Ligia Bernardet, Rusty Benson, Lauren Chilutti, Thomas Robinson, Barry Baker, Tom Clune, Weiyuan Jiang

UFS Webinar

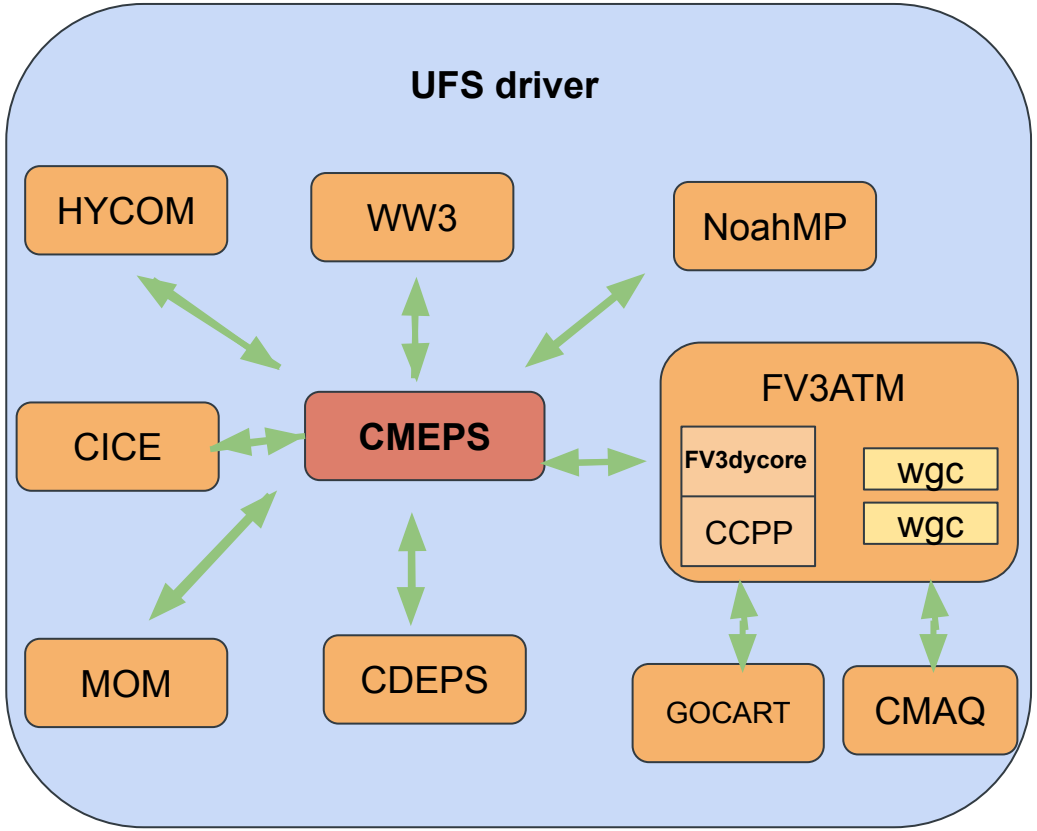
Overview

- Fully coupled capability
- Build system
- Computational performance
- Open source and open development with the community
- Present and planned work
- Key points

Fully coupled earth modeling system

Develop fully coupled ufs-weather-model with community

- The UFS weather model is **open source** software supporting both **research and operational** developments. It contains:
  - **17 authoritative** repositories
  - **9 major flagship** model components
  - **Community mediator** and 9 **sharable** NUOPC caps
- **Model infrastructure** has been developed as the foundation to build the unified system:
  - Coupled model prototypes
  - GFSv17/GEFSv13
  - RRFSv1
  - AQMv7
  - HAFSv1
  - FV3/JEDI
  - Marine DA forecast model



Coupling Infrastructure Development

- CMEPS - Community Mediator for Earth Prediction Systems
  - Community development and testing helps ensure robustness across multiple applications
  - Feature rich, easily extensible
- FV3ATM: Atmosphere model with FV3 dycore with CCPP physics
  - Developed FV3ATM NUOPC cap
  - Integrated CCPP physics
  - Developed write grid component and inline post capability
  - Developed coupling capability with other earth model components
- CICE6 - Community Sea Ice Model
  - Replaced CICE5
  - Code refactor and modernization, new column ice physics package (icepack)
- MOM6 - Community ocean model
  - Enabled CMEPS compatibility
  - Added ocean lag and Mesh options

Coupling Infrastructure Development

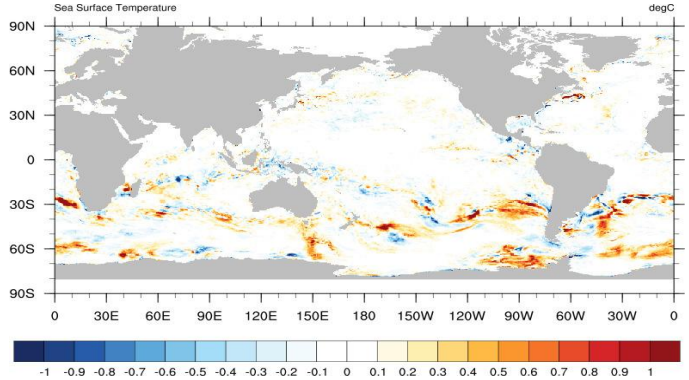
- CMAQ - The Community Multiscale Air Quality Modeling System
  - Integrated into UFS as the air quality component model (AQM)
  - Used Fengsha windblown dust emission scheme
- GOCART - The Goddard Chemistry Aerosol Radiation and Transport
  - Integrated into UFS through new FV3atm run phases and GOCART NUOPC cap
  - two-way coupling FV3atm <--> GOCART
  - Introduced NASA's MAPL infrastructure into UFS
- WW3 NUOPC cap
  - New mesh based NUOPC cap
  - Capable of coupling WW3 on an unstructured triangular mesh
- CDEPS - Community Data Models for Earth Predictive Systems
  - Feature rich, flexible data model replacement for any component
  - Leverages CMEPS for interoperability

CMEPS- Community Mediator for Earth Prediction Systems

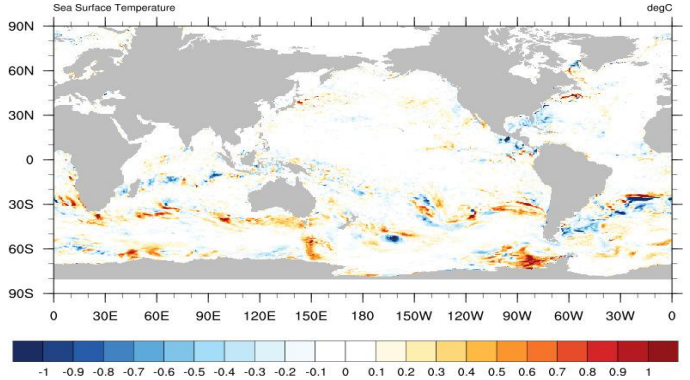
- **Transition** from in-house NEMS Mediator to CMEPS
  - Active development includes latest ESMF features
  - Contains diagnostic capabilities for water and energy budgets
  - Mapping between components is "expensive"; CMEPS uses multiple methods to reduce cost

- **Community development and testing** helps ensure robustness across multiple applications
  - Code structured as a set of reusable modules, with single system (UFS, CESM) dependent file
  - Provides for separation of concerns but also interoperability

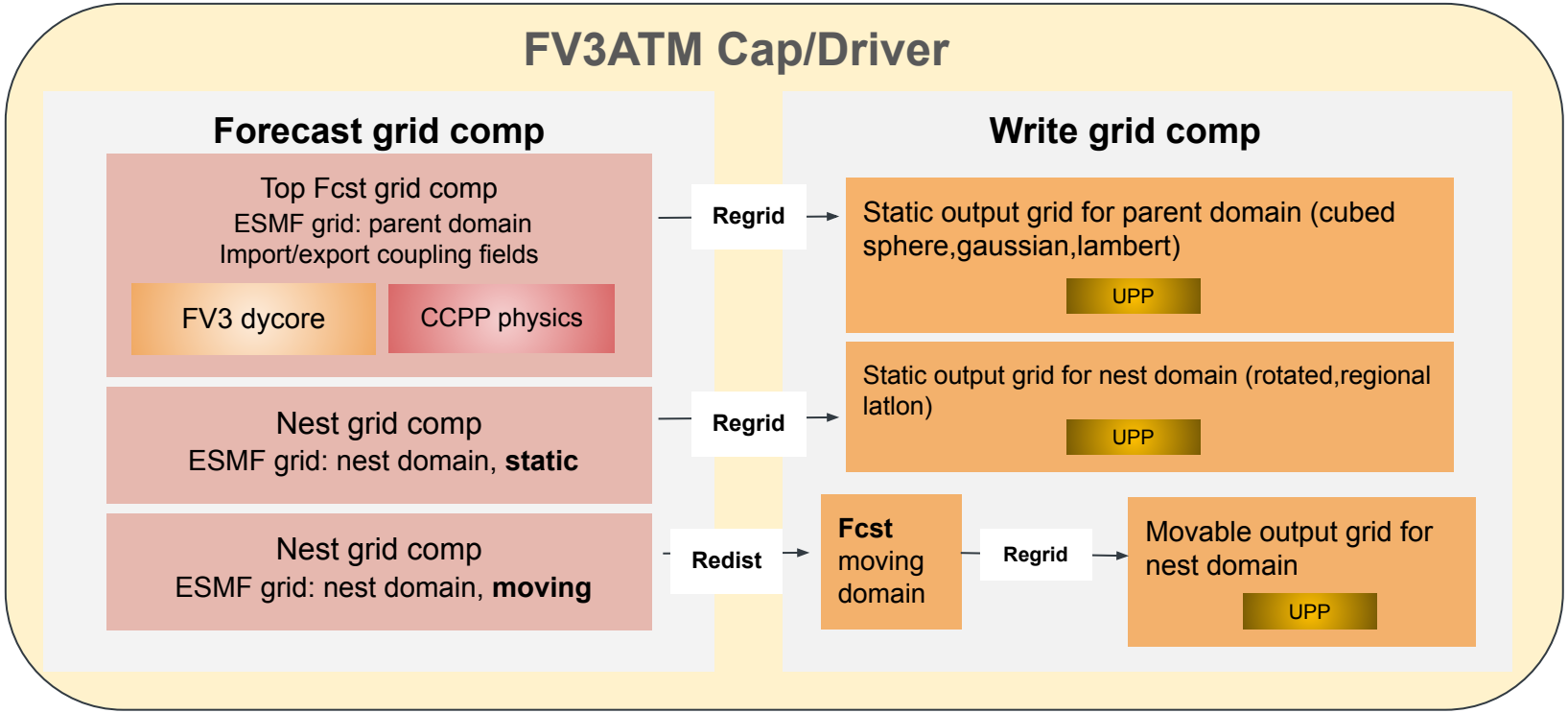
SST difference from NEMS on two platforms



SST difference between CMEPS and NEMS



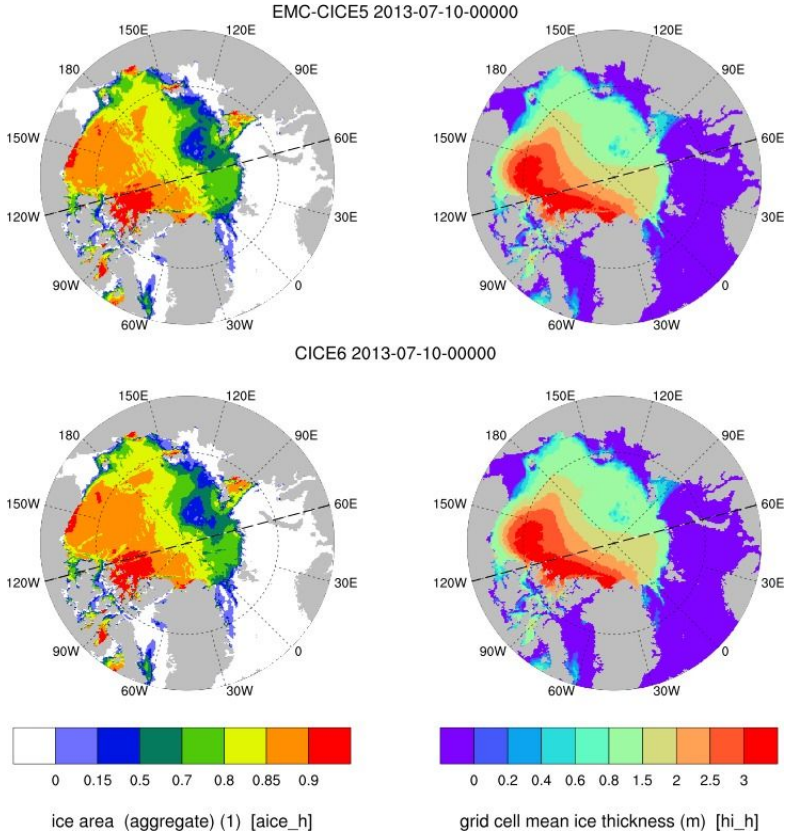
FV3ATM: atmosphere model with FV3 dycore and CCPP



UPP: unified Post processing
Fcst: forecast

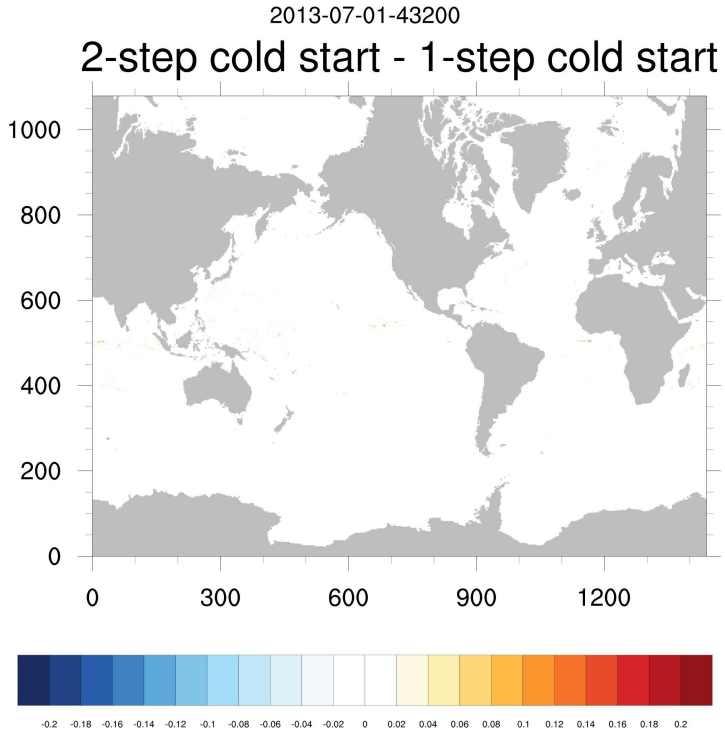
CICE6 - Community Sea Ice Model

- Replaced CICE5 in UFS
  - CICE6 released in 2018, no further development in CICE5
  - Code refactor and modernization
  - New column ice physics package (icepack)
- **Shared NUOPC Cap** implemented as part of transition to CICE6
- CICE6 and CICE5 **perform similarly** when both use the same variable freezing temperature method



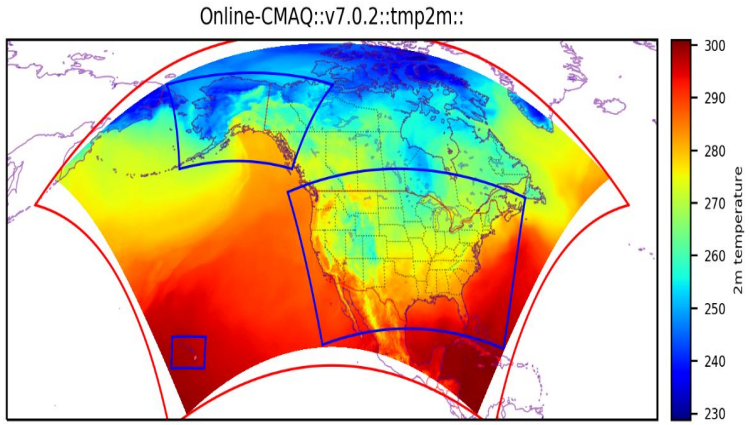
MOM6: community ocean model

- MOM6 cap was updated to use **CMEPS** mediator
- An **ocean lag** method was developed to allow ocean lag at the first time step so that atmosphere can send the required data to ocean to let it run at the second time step
  - The one step cold start simplifies the cold start process
  - Differences between two step cold start and one step cold start are nearly zero after 12 hours
- A **mesh option** is added for MOM6 cap to use mesh in coupled configuration



Air Quality Model (AQM) v7.0 Implementation

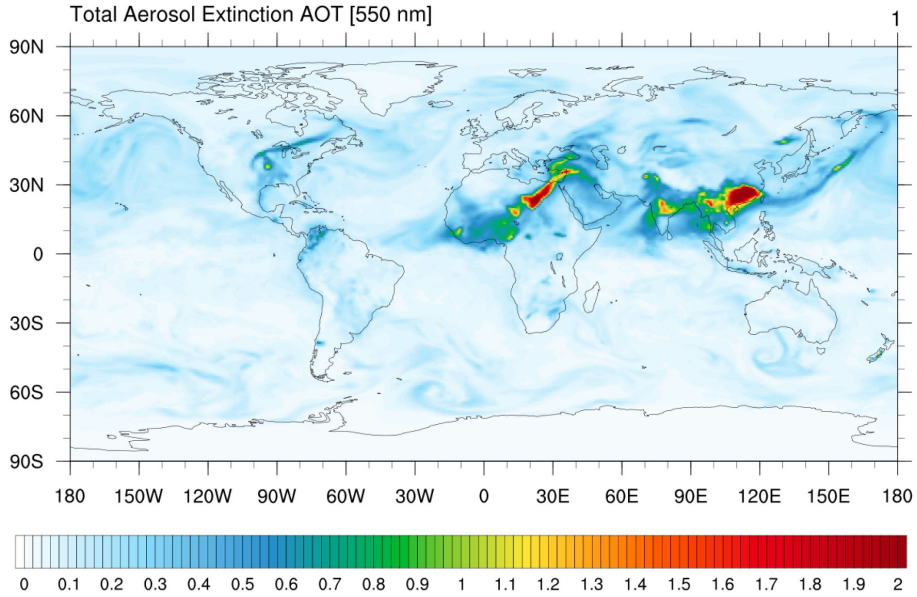
- FV3ATM-AQM coupled using ESMF connectors with **new AQM NUOPC Cap**
- Developed Fengsha windblown dust emission scheme
- Regional configuration added to UFS



Red box: AQM v7.0 computation domain; Shaded area: AQM v7.0 model output grid; Three blue boxes: operational model domains.

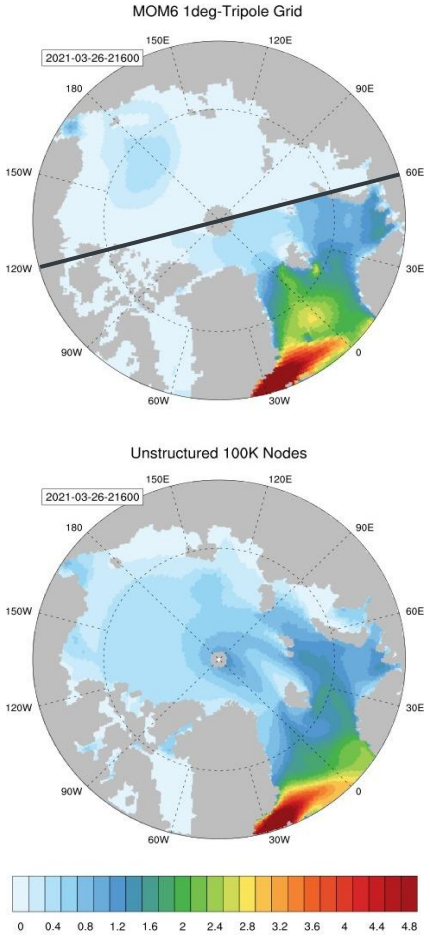
FV3atm-GOCART coupling

- Extension of both FV3ATM and GOCART NUOPC caps
- **FV3ATM coupled to GOCART** at each forecast time



Mesh-based NUOPC cap for WW3

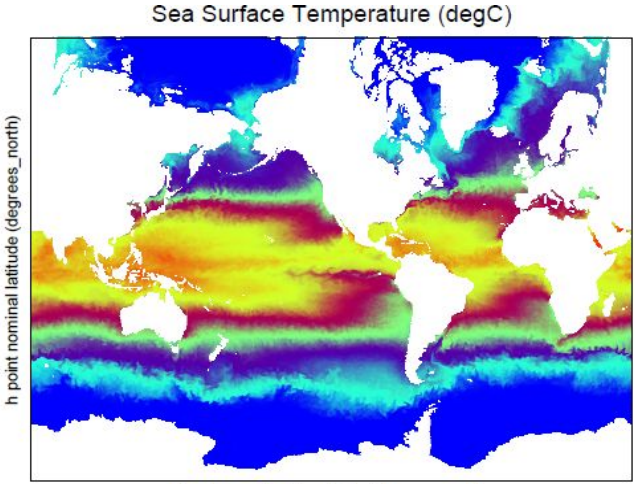
- Utilizes a **mesh** in place of a grid in Cap
  - Meshes can be either structured or unstructured, making them more flexible than grids
- **Coupled through CMEPS** instead of direct connectors
  - Provides restart reproducibility for WW3 coupled applications
  - Allows flexible run sequences since exchanged fields can be accumulated and averaged
- Mesh-based cap accommodates **unstructured** WW3 meshes
  - Unstructured WW3 meshes have significant advantages in scalability and coastal resolution
  - Allows wave fields to be continuous across MOM6 tripole seam (with PR3 scheme)



CDEPS - Community Data Models for Earth Predictive Systems

- **New data model** component
  - Feature rich, flexible data model replacement for ATM, OCN, ICE, WAV or LND component
  - CDEPS reads external observational data or model outputs at available time or resolution
  - Interpolates in time and space and sends the data to the CMEPS mediator as stand-in replacement for active component
- Allows **isolation of feedbacks** between components
- Allows capability of **hierarchical testing** of components models

DATM-MOM6-CICE6 configuration used for NG-GODAS



Forecast SST on day 20. The SST range is: -1.89-32.83C.

Build system

UFS-weather-model build system

- The **ufs weather model** supports applications with various levels of complexity and is used by operational implementations and research community developments
- CMake build
  - **CMake** provides **cross-platform support**, improves portability and requires less maintenance
  - cmake build capability is added to all the sub-components of ufs coupled model
  - ufs weather model was switched from gnu make to cmake build
- **Unified** UFS model code repository
  - ufs-weather-model, ufs-s2s-model and DATM-MOM6-CICE5 repositories are merged to one unified repository ufs-weather-model
  - The unified repository provides code base for short range regional weather and hurricane forecast, medium range global weather forecast and subseasonal to seasonal climate forecast. This is a critical step toward reducing the large number of operational models
- Porting
  - ufs-weather-model has been ported to several NOAA R&D and other platforms that can be accessed by research **communities and universities**
  - **Spack stack** library is integrated to to support multiple versions and configurations of libraries on a wide variety of platforms and environments

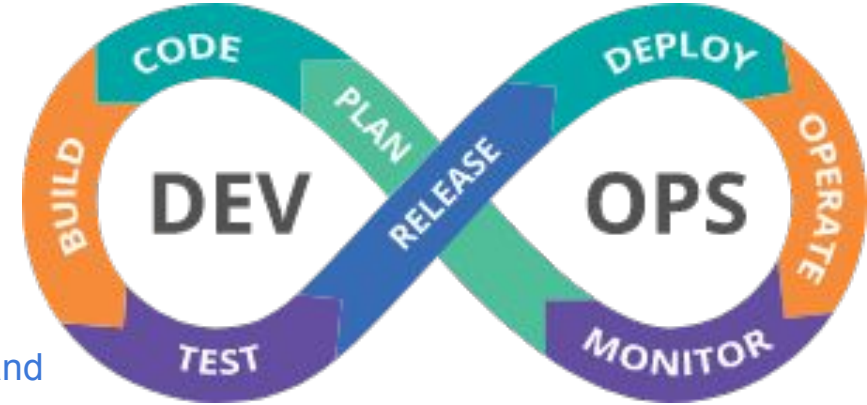
UFS-weather-model build system

- **Supported configurations** are: ATM, ATMAERO, ATMW, ATMWM, S2S, S2SW, S2SWA, HAFS, HAFSW, HAFS-ALL, NG-GODAS, and UFSAQM using cmake.
- Several **physics configurations** (CCPP physics suites) can be built and run with **same executable** for configuration comparison testing. Several executables can be **built simultaneously** with different configurations including different components

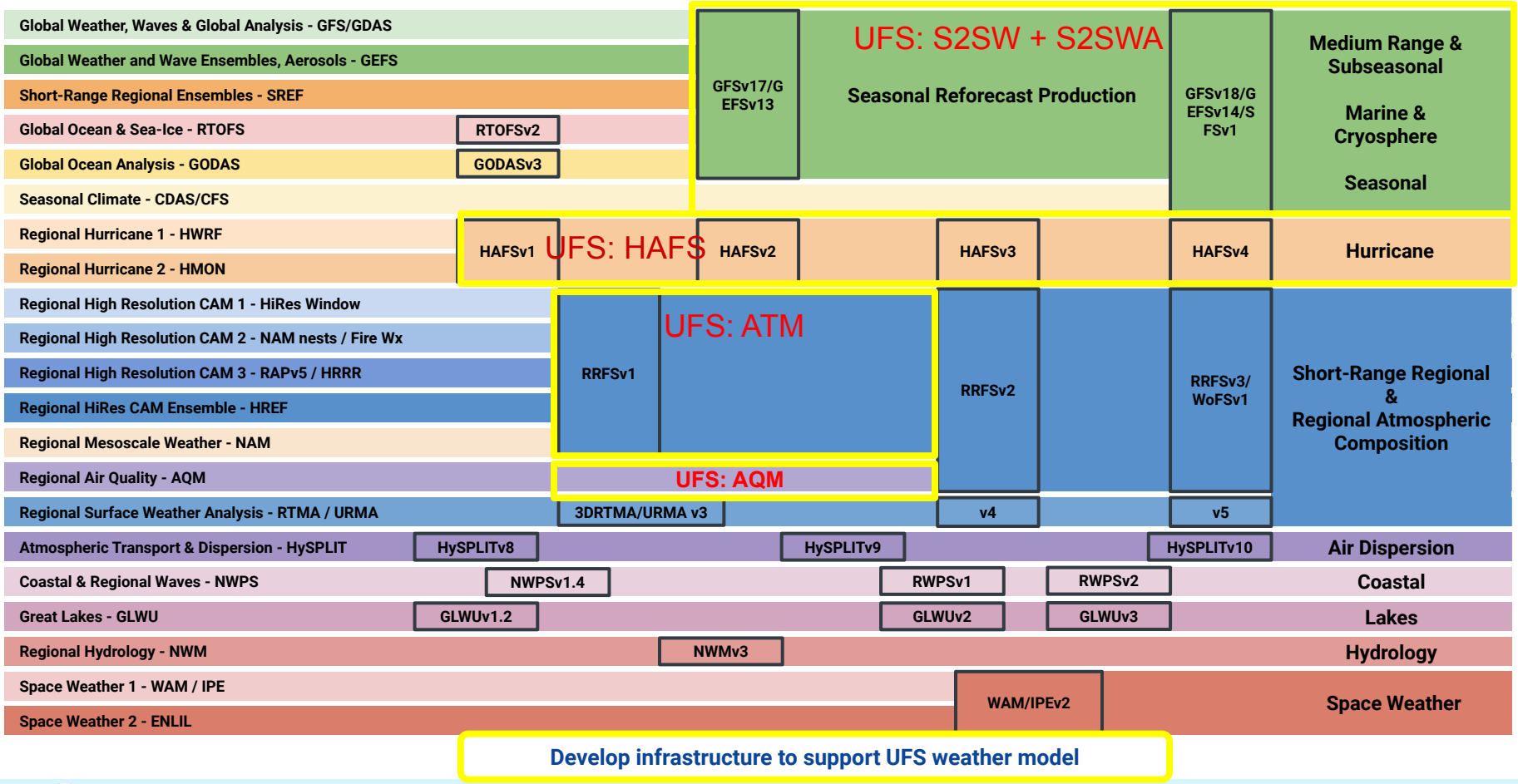
Configurations	FV3atm	MOM6	HYCOM	CICE6	WW3	AERO	AQM	CDEPS	CMEPS	Stochy Phys
ATM	●									●
S2SWA	●	●		●	●	●			●	●
HAFS	●		●		●			●	●	●
UFSAQM	●						●			●
GODAS		●		●				●	●	●

Regression test framework

- **Testing is critical to** maintain high standard code quality!!!
- Develop regression test framework to support **DevOps** in UFS development
  - Application tests
  - Resolution tests
    - C48, C96, C192, C384, C768
  - Feature tests
    - Consistent test procedure for new feature and combined new features.
  - Stability tests
  - Code quality: Operational requirement tests
    - Reproducibility: threading, decomposition, restart. MPI
    - Reliability test: debug test



Develop UFS weather model to simplify the NCEP operational suites



Computational performance

WW3 optimization

C96+full WW3 grids (without currents)

About 94% when tripling the number of MPI tasks

Code	Number of Pets	ModelAdvance	GetImport	FieldGather
Original Code	108	395.33	100.43(25%)	35.80
Original Code	292	371.29	257.18(70%)	192.42
FieldGather Update	108	374.07	77.30(20%)	12.52
FieldGather Update	292	194.84	73.45(38%)	8.70
OMP Update	108	322.61	17.77(6%)	13.33
OMP Update	292	141.31	14.72(10%)	10.36

WW3 run speeds up 18%

About 36% when tripling the number of MPI tasks

- Remove inefficient data collecting and implement threading

Data compression with parallelization in operations

C768L127 fcst output	Nemsio No compression	Netcdf No compression	Netcdf Lossless (deflate=1,nbit=0)	Netcdf Lossy (deflate =1, nbit=20)	Netcdf Lossy(deflate=1,nbit=14)	Netcdf Lossy (deflate=1, nbits=14),parallel writing, default decomposition chunksize	Netcdf Lossy (deflate=1, nbits=14),parallel writing Layer chunksize
A 3D file size, (total fcst)	33.6GB (7TB)	33.6GB (7TB)	23.6GB (5TB)	13.5GB (2.8TB)	6.3GB (1.3TB)	6.3GB (1.3TB)	6.3GB (1.3TB)
Write Time	79s	300s	960s	680s	400s	43s	34s

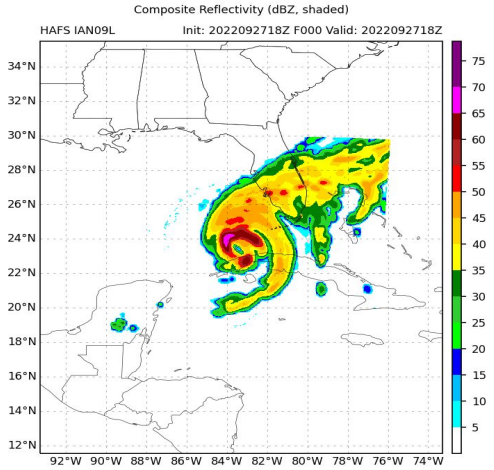
- **GFSv16 could NOT be implemented** without this feature!
- **Collaborated with Unidata and PSL**, testing, release and deployment in operations in under two months

Inline Post

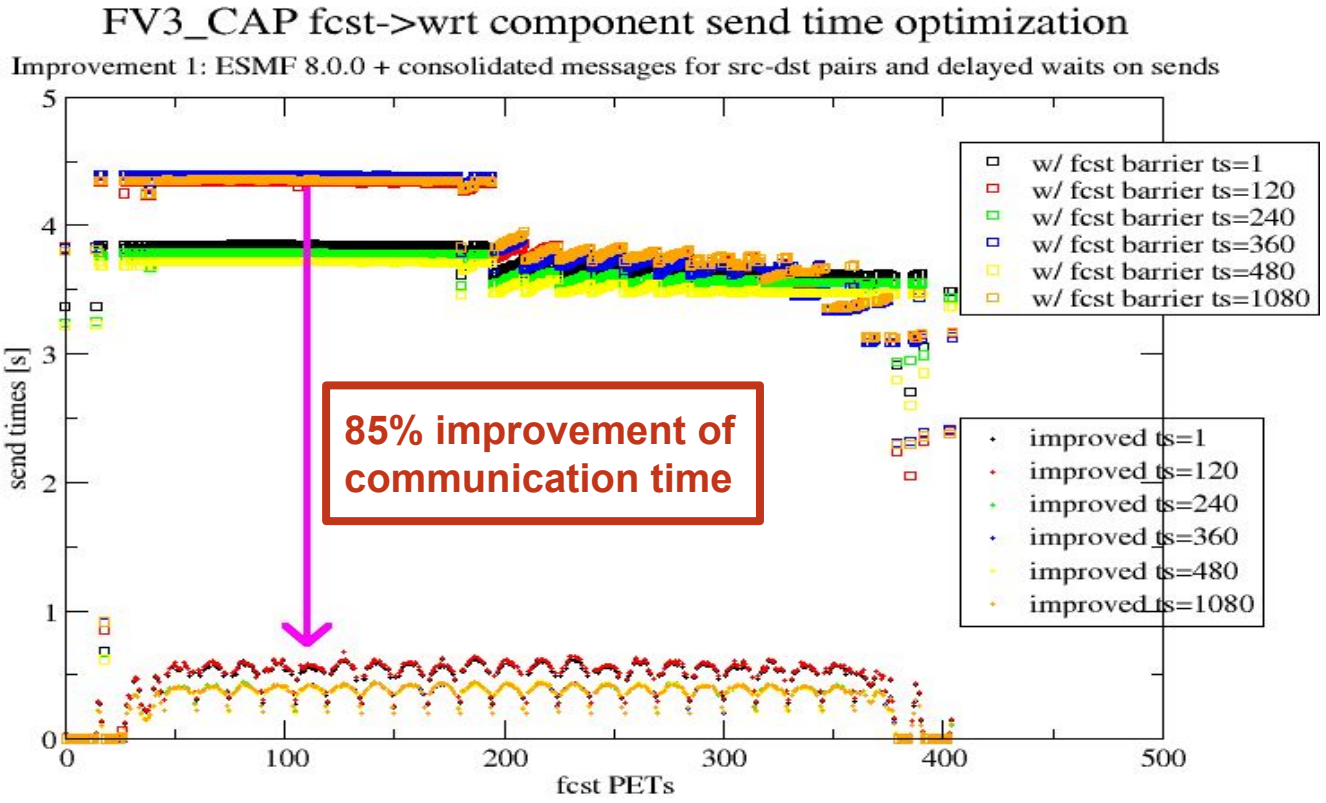
- Using the inline post **saves computational time (80% for high resolution runs)**

experiments	C96L64 (6 tasks)	C192L64 (12 tasks)	C768L127 (84 tasks)
Single master file size	51MB	180MB	2.5GB
Inline post time	4s	7s	39s
Offline post time	12s	17s	211s

- Inline post capability has been **extended to support multiple grid** moving nest applications
- The results have been verified in the **HAFS moving nest application**



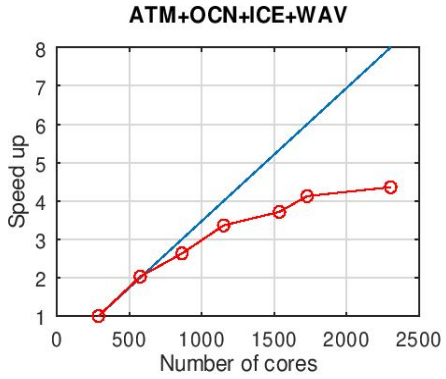
Improving data transfer between forecast and IO server

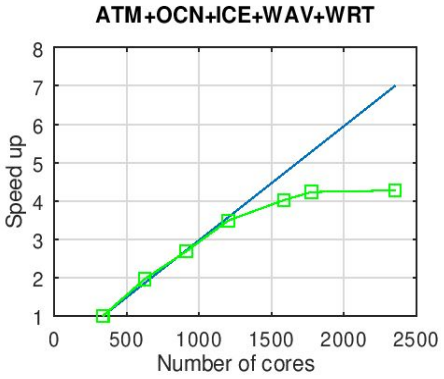


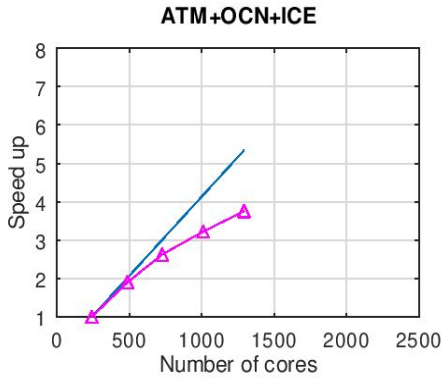
Collaborated with ESMF group

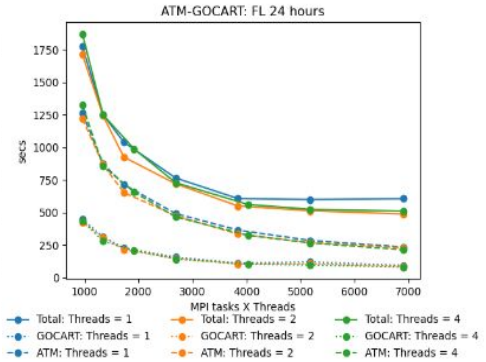
Monitoring coupled system load balance

- Identify the **scalability** issues in the code updates in the model components
- Monitor the **load balance** in the coupled system
- Monitor the **resource efficiency** in the coupled runs









Other code optimization

- Develop mixed mode data type in UFS coupled applications

experiments	C384L127mx025 (25km atm, ¼ ocn/ice/wav)	C768L127 mx025 (13km atm, ¼ ocn/ice/wav
With Mixed mode data type	9.8 m/d **(23%)**	23.2 m/d **(24%)**
Original setting	12.8 m/d	30.4 m/d

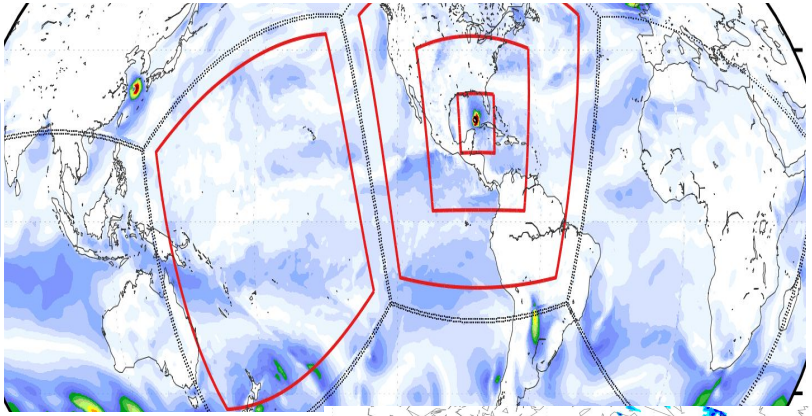
- Implement flexible threading configurations using ESMF managed threading
  - Cumulative performance gain **12%**
- Explore compiler options to speed up the computational speed (**5%**)

Open source and open development with the community

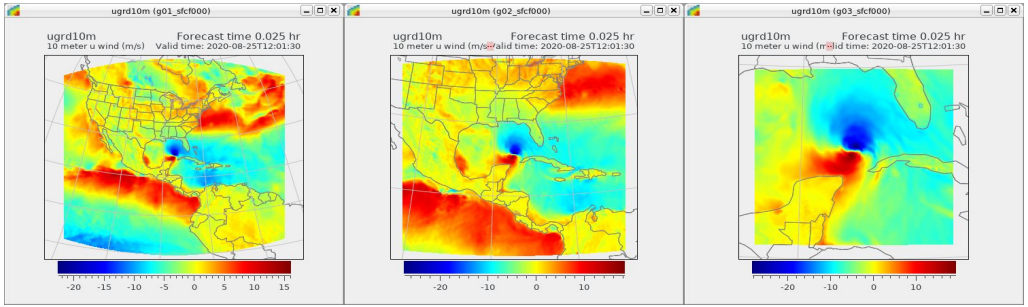
Moving Nests (HAFS)

- Collaboration of 4 Organizations

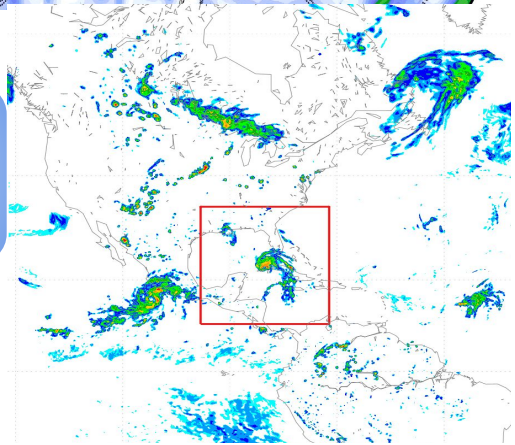
GFDL – Global Parent and Telescopic Nests



EMC & NCAR – Asynchronous I/O



AOML – Regional Parent and Moving Nests



Open Source and Open Develop with community

https://github.com/ufs-community/ufs-weather-model

- ~200 forks
- ~140 developers
- >1800 issues and pull requests
- >10K files
- 4.3M LoC
- Support **operational and R&D platforms** including laptops and Cloud
- **Close collaboration** with entities in UFS **community**

Courtesy: Sam Trahan

Present and planned work

- Implement **exchange grid** for coupling conservation
- Work with community to develop fully **coupled land** model component
- Explore **wave ice coupling** capability with unstructured WW3 mesh
- Develop component model configurations in coupled mode with **data models**
- Extend the write grid component to write out **restart files** for all the UFS configurations
- Apply **new data compression** algorithms in the write grid component NetCDF history files
- Design and implement **general IO server** that can be used by other model components

Present and planned work (continued)

- **Transitioned** code management, R&D platform support and user support to **EPIC,** continue supporting operational platforms
- Collaborate with EPIC and other teams to develop **hierarchical testing** framework
- Develop **regional coupling**
- Jointly with JCSDA, implement **JEDI** in UFS
- Integrate **new dycore MPAS** to UFS weather model
- Support **operational implementations**

Key Points

- UFS weather model is **built consistently** with various configurations and currently supports previous and upcoming operational models
- The **coupling infrastructure** capability has been developed to support earth components coupling including atmosphere, ocean, sea ice, wave, aerosol and chemistry and land on global and regional scales.
- A significant effort has been put into improving UFS weather model **computational performance**.
- The UFS weather model is **open source** and developed through **collaboration** with the community.

Questions???