Development of UFS Coupled Model Infrastructure

Jun Wang[1*], Denise Worthen[2], Bin Li[2], Minsuk Ji[2], Brian Curtis[2], Dusan Jovic[2], Dom Heinzeller[3], Linlin Pan[3], Shrinivas Moorthi[1], Shan Sun[4], Benjamin W. Green[45], Mariana Vertenstein[6], Anthony Craig[7], Gerhard Theurich[8], Rahul Mahajan[1], Arun Chawla[1]

[1]NOAA/NWS/NCEP/EMC, [2]IMSG@NOAA/NWS/NCEP/EMC, [3]DTC-NOAA/GSL-CIRES, [4]NOAA/OAR/GSL, [5]CIRES,University of Colorado, [6]NCAR, [7]STC, [8]ESMF/NRL/SAIC

[*]Jun.Wang@noaa.gov

Introduction:

The Unified Forecast System (UFS) is a community-based coupled Earth system model. It is designed to be the source system for NOAA's operational numerical weather prediction applications. Currently, the UFS can support a range of applications from a standalone atmosphere to several coupled configurations with different combinations of subcomponents at different resolutions. NCEP plans to use UFS coupled configurations in its next global forecast system (GFS) and sub-seasonal to seasonal prediction system (S2S) implementations. In this paper, we describe several major model infrastructure developments that enhance the UFS coupled model forecast capability.

Model description

The latest UFS consists of atmosphere, ocean, sea-ice, wave and data atmosphere models. The atmosphere component consists of the Finite-Volume Cubed-Sphere Dynamical Core (FV3), the Common Community Physics Package (CCPP) and the write grid components. The ocean component is the Modular Ocean Model (MOM6). The Consortium Model for Sea-Ice (CICE) version 6 was recently transitioned into the UFS. The wave model is NOAA's WAVEWATCH III (WW3). The data atmosphere (DATM) is the NEMS data atmosphere model (NEMSDATM). These components are coupled through the Community Mediator for Earth Prediction Systems (CMEPS) within the NOAA Environmental Modeling System (NEMS) infrastructure. Six coupled model benchmark experiments have been conducted at 0.25 degree resolution for a 35-day integration and the results have been verified against observations and analysis data.

Model infrastructure improvements

Three major infrastructure improvements have been made to the UFS coupled model. They are described below.

1. <u>Major model component development</u>

In the atmosphere component, the CCPP [CCPP documentation, 2021] was adopted. This gives the UFS coupled runs the flexibility to choose different atmosphere physics packages. New physics updates from the GFSv16 implementation were merged to the ufs-weather-model repository, which include an updated sa-TKE-EDMF planetary boundary layer scheme, new parameterization in the subgrid scale nonstationary gravity wave drag scheme, updated GFDL microphysics scheme for computing ice cloud effective radius and an updated Noah land surface model. To resolve the issue of inconsistent land/sea masks between atmosphere and ocean grids, a fractional land sea mask capability was added to the atmosphere component. The fractional grid allows water and land to coexist at coastline points. The coupling strategy was also extended so the model can represent air-sea interactions precisely.

The mediator component of the UFS coupled system was transitioned from the NEMS mediator to the Community Mediator for Earth Prediction Systems (CMEPS) [CMEPS documentation, 2020]. CMEPS was developed as a NUOPC-compliant mediator based on ESMF to couple earth sub-components. It extends the NEMS mediator coupling capabilities and is shared by several earth modeling systems, including the Community Earth System Model (CESM) and the Hurricane Analysis and Forecast System (HAFS). The UFS weather model was transitioned to CMEPS from the NEMS mediator to take advantage of the new features developed in CMEPS.

Until recently, the UFS used CICE5 as its sea ice subcomponent. The CICE version 6.0.0 [Hunke, *et al*., 2020] was released in March 2018 with new features including the new icepack version 1.1.0 [Hunke, *et al.*, 2020], enhanced rheology options, dynamic array allocation, and a simplified initialization procedure, etc. The UFS sea ice model was transitioned to CICE6 in August 2020. It was verified that CICE6 and CICE5 perform similarly when both use the same variable freezing temperature method.

A data atmosphere model was added to UFS to support the Global Ocean Data Assimilation System (GODAS). It was found that the SST was increasing during model integration when the DATM was first implemented in DATM-MOM6-CICE5 configuration. The issue was fixed by correcting the bulk formula flux calculations at open water grid points in the mediator. The updated model (DATM-MOM6-CICE6-CMEPS) runs stably in GODAS experiments.

Because the mediator initial conditions are missing in the coupled runs with a concurrent run sequence, a two-step cold start was adopted in the UFS coupled model early benchmarks. A new ocean lag approach was implemented that did not advance the ocean until the second coupling timestep, at which time it advanced two steps. This one step cold start simplifies the cold start process and the differences between the two step and the one step cold start are nearly zero after 12 hours.

2. Build system, repository update and porting

CMake is an open-source compilation tool that provides cross-platform support, improves portability and requires less maintenance. The UFS switched from GNU Make to CMake to take advantage of these new features in October 2020.

A unified repository can avoid issues of inconsistent subcomponents shared by several repositories. It also simplifies the testing process across all the applications. Three UFS application repositories ufs-weather-model, ufs-s2s-model and DATM-MOM6-CICE5 were merged to one unified repository (ufs-weather-model) in September 2020. The unified repository provides a code base for short-range regional weather forecasts, medium-range global weather forecasts and subseasonal to seasonal climate forecasts. This is a critical step toward reducing the number of operational models.

The UFS was ported to several NOAA RDHPCS and other HPC platforms that can be accessed by research communities and universities, and it can also be built and run on laptops and desktops.

3. Regression test update and performance tuning

Several different resolution coupled tests were set up in the UFS regression test suite including 0.25degree (C384MX025), 0.5 degree (C192MX050) and 1.0 degree (C96MX100) runs. In those tests, consistent land sea masks on atmosphere and ocean/ice grids were created in order for the model to run stably. In addition to the regression test, stability tests with benchmark cases of 35-day forecast runs were set up. These tests also work as templates to test new or different physics packages. Restart reproducibility is critical for long climate runs to maintain consistent results. Restart reproducibility without the wave component was maintained when new features were added to the coupled run. Experiments were conducted to tune the number of tasks assigned to each component to achieve load balancing in the coupled runs.

Future work

The model infrastructure development will continue to improve the couple model forecast capability for the next operational implementation at NCEP. Future work includes: 1) setting up a fully coupled system with atmosphere, ocean, sea ice, wave and aerosols through CMEPS; 2) transitioning to the Community Data Models for Earth Predictive Systems (CDEPS) to support other data models including ocean, sea ice and land; 3) merging the Hurricane Analysis and Forecast System (HAFS) application into the UFS repository; 4) updating and maintaining regression tests, setting up CI/CD and cloud support for the coupled model; and 5) improving coupled model computational performance to meet the operational requirements.

References

CCPP v5 technical documentation, 2021: https://ccpp-techdoc.readthedocs.io/en/v5.0.0/

CMEPS documentation, 2020: https://escomp.github.io/CMEPS/versions/master/html/index.html

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