The Inclusion of chemistry modules into the NOAA UFS weather model with CCPP

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1. Introduction

At NOAA GSL, in collaboration with scientists from the CSL and ARL, we developed an atmospheric composition suite (based on WRF-Chem) and coupled it online with FV3GFS through the NUOPC-based NOAA NEMS software. This modeling system has been operational since September 24th, 2020 as an ensemble member of the Global Ensemble Forecast System (named as GEFS-aerosols) for global aerosol predictions. When using the NUOPC coupler, there are two independent components for atmosphere and chemistry that communicate via the NUOPC coupler every time-step. Because of the interactive and strongly couple nature of chemistry and physics, it is natural to allow for some of the atmospheric composition modules to be called directly from inside the physics suite. This can be accomplished through the use of the Common Community Physics Package (CCPP). CCPP, designed to facilitate a host-model agnostic implementation of physics parameterizations, is a community development and will be used by many different organizations. All the physics parameterizations in the NOAA Unified Forecast System (UFS) Weather Model are CCPP-compliant. Here we broke up the chemistry suite used in GEFS-aerosols, and all the chemical modules were embedded into UFS Weather Model using CCPP as subroutines of physics. This newly developed model with CCPP has been running in real-time starting in the middle of November, 2020. Because of this development we were able to include the CCPP-compliant modules of sea salt, dust, and wild-fire emissions into the NWP model to provide input for the double moment Thompson microphysics parameterization. The inclusion of smoke and aerosol emission modules into the Rapid Refresh Forecast System (RRFS) with CCPP is also ongoing.

2. Model description of FV3/CCPP-Chem

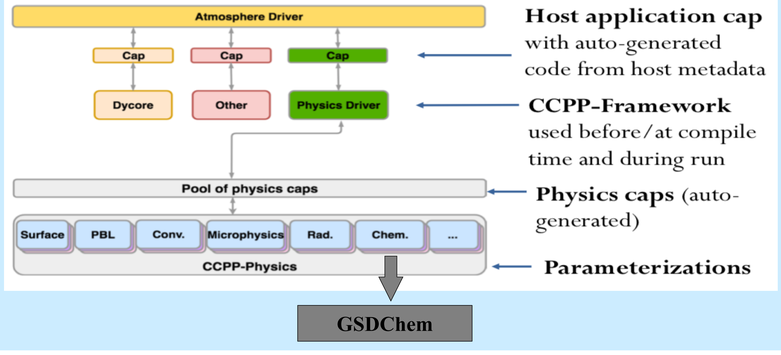
2.1). The host model: NOAA UFS Weather Model

Dynamics Core: Finite Volume Cubed-Sphere (FV3)
Physics: Common Community Physics Package (CCPP)
-- GFS physics package (GFDL MP, SAS convection, Hybrid EDMF PBL)
-- GSL physics suite (Thompson MP, GF convection, MYNN PBL)

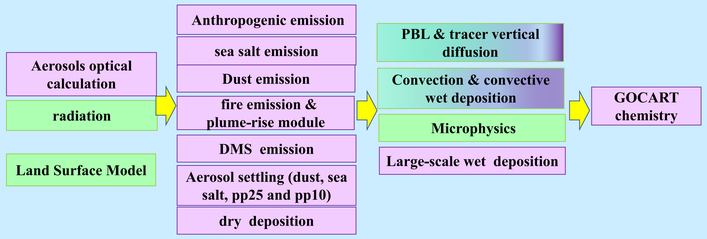
2.2). The GSL Chemical Model: GSDChem

- **Transport:** Grid-scale transport by microphysics scheme. Sub-grid transport by PBL and tracer convective transport and wet scavenging in convective scheme.
- **Chemistry:** simplified parameterization of sulfur/sulfate chemistry, hydrophobic and hydrophilic black and organic carbon, a 5-bin sea salt, 5-bin dust, volcanic ash.
- **Emission:** Global CEDS and HTAP anthropogenic emission. NESDIS Global Biomass Burning Emission Product (GBBEPx) and the 3BEM fires globally based on MODIS and WFABBA. 1D cloud model is used to calculate injection heights and plume rise emission rates online. MEGAN biogenic emissions. Volcanic ash.
- **Sea-salt and Marine Dimethyl Sulfide:** : NASA GEOS-5 GOCART sea salt scheme. GOCART w/ monthly values of marine dimethyl sulfide
- **Dust:** 2 options available; 5 size bins. FENGSHA dust scheme is used.

2.3). Coupling GSDChem into FV3 through CCPP

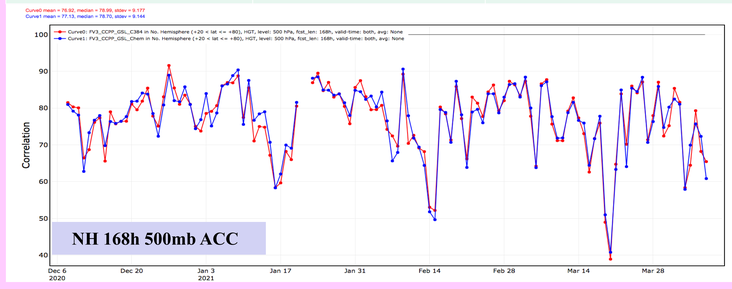


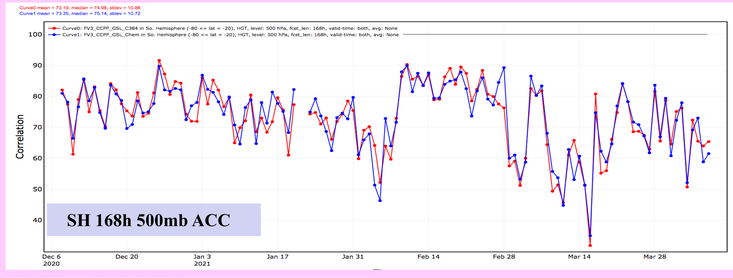
GSDChem was broken up and all the chemical modules were embedded into FV3 as subroutines of physics.

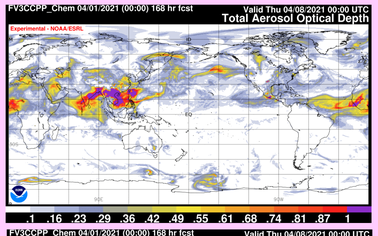


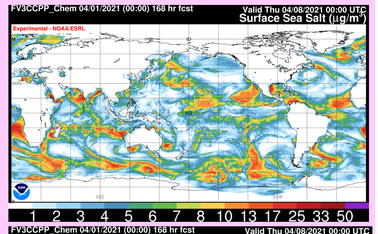
3. FV3/CCPP-Chem Real-time run with GFS physics

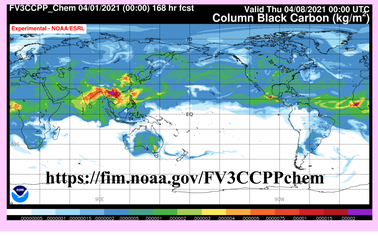
	FV3 _CCPP_GSL_C384	FV3_CCPP_GSL_Chem
Physics	GFS physics	GFS physics
Chemistry & feedback to Radiation	NO	YES
Resolution	C384 (~25km)	C384 (~25km)
Integration length	168 hours	168 hours

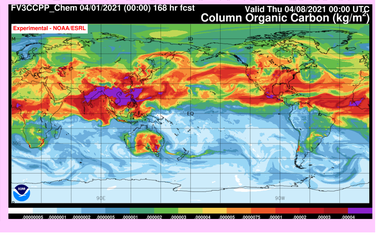








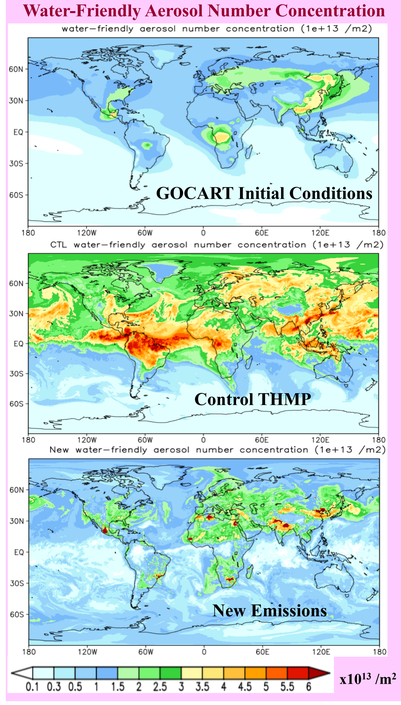




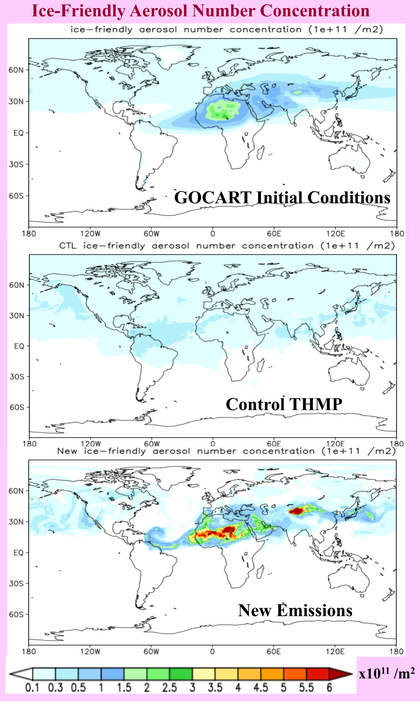
4. To provide aerosol emission for Double-Momentum Microphysics

- Three-week free running simulation at C384, L64 with GSL suite, May 1st 2020
- Control Thompson Microphysics (THMP)
  - Default water- and ice-friendly aerosol initial conditions (GOCART) and emissions.
  - Thompson v4.3
- New Emissions
  - No aerosol Initial conditions
  - CCPP implementation of emission routines
  - Sea salt, sulfate, organic carbon emissions grouped into water-friendly aerosols
  - Dust emissions for ice-friendly aerosols
  - Very little additional computational time
  - No additional tracer variables

Water-Friendly Aerosol Number Concentration



Ice-Friendly Aerosol Number Concentration



5. Summary

- The GSL Chemical model (GSDChem), which is based on GOCART from WRF-Chem with some updates, has been successfully implemented into the NOAA UFS Weather Model with CCPP.
- The FV3GFS/CCPP-Chem has been successfully run in real-time.
- Compared to the default Thompson MP free run, the free run with CCPP-compliant emissions produced more realistic water/ice friendly aerosols.
- The 13km global cycling run with CCPP-compliant emissions for water/ice friendly aerosols is ongoing.
- The development of RRFS-smoke with CCPP is ongoing.