A simple and realistic aerosol emission approach for use in a double moment aerosol-aware microphysics scheme in the NOAA UFS Weather Model

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1. Introduction

Aerosols play a significant role in the atmospheric precipitation physics of microphysics and convection. A physics suite, which includes the aerosol-aware double momentum Thompson microphysics scheme (Thompson MP), and the scale-aware and aerosol-aware Grell-Freitas (GF) convection scheme, was developed at NOAA Global System Laboratory (GSL). In the Thompson MP, the hygroscopic aerosol is referred as a "water friendly" aerosol (WFA), and the non-hygroscopic ice-nucleating aerosol is referred as "ice friendly" aerosol (IFA). For usual Thompson applications, WFA and IFA are derived using climatologies from NASA's Goddard Chemistry Aerosol Radiation and Transport (GOCART) model. The Common Community Physics Package (CCPP), which is designed to facilitate a host-model agnostic implementation of physics parameterizations, is a community development and is used by many model developers. All physics parameterizations in the NOAA Unified Forecast System (UFS) Weather Model must be CCPP-compliant. Here we embedded sea-salt, dust emission, and biomass burning and plumerise emission modules as well as anthropogenic aerosol emissions into the UFS by using CCPP. These aerosol modules are directly called within the physics package. The prognostic emission of sea-salt, sulfate, and organic carbon are combined to represent the WFA emission, while the prognostic emission of dust is used to represent IFA emission. Wet-scavenging is included in both, resolved and non-resolved precipitation physics. Dry deposition is also parameterized. Subgrid scale transport is included in PBL and convection. There are no additional tracer variables introduced in this simple approach. In the global forecast with C768 (~13km) horizontal resolution and 128 vertical levels, the initial results are promising.

2. Model description of the UFS Weather Model

2.1). The host model: NOAA UFS Weather Model

Dynamics Core: Finite Volume Cubed-Sphere (FV3)

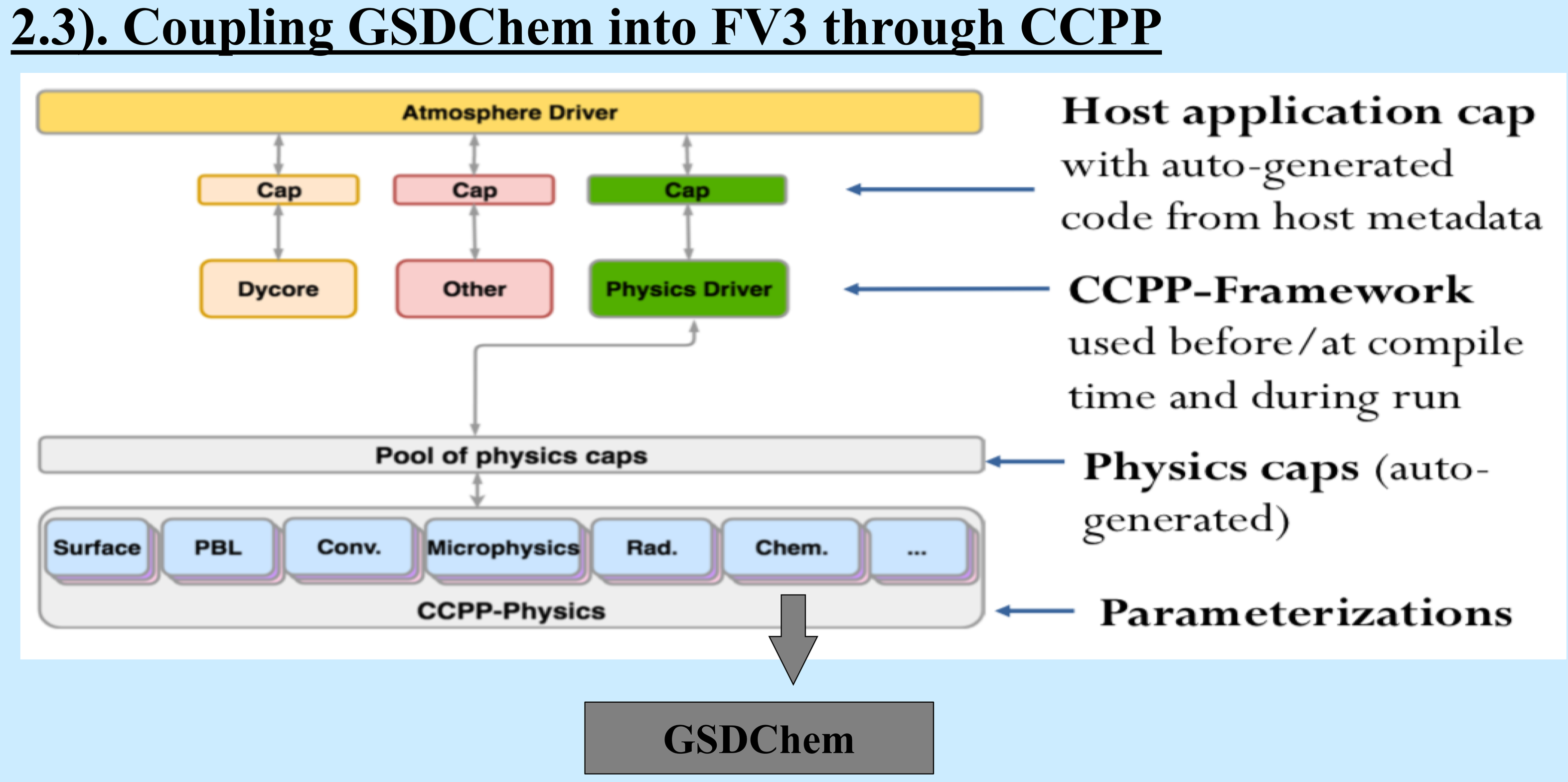
Physics: Common Community Physics Package (CCPP)

-- GSL physics suite (Thompson MP, GF convection, MYNN PBL)

2.2). The GSL Chemical Model: GSDChem

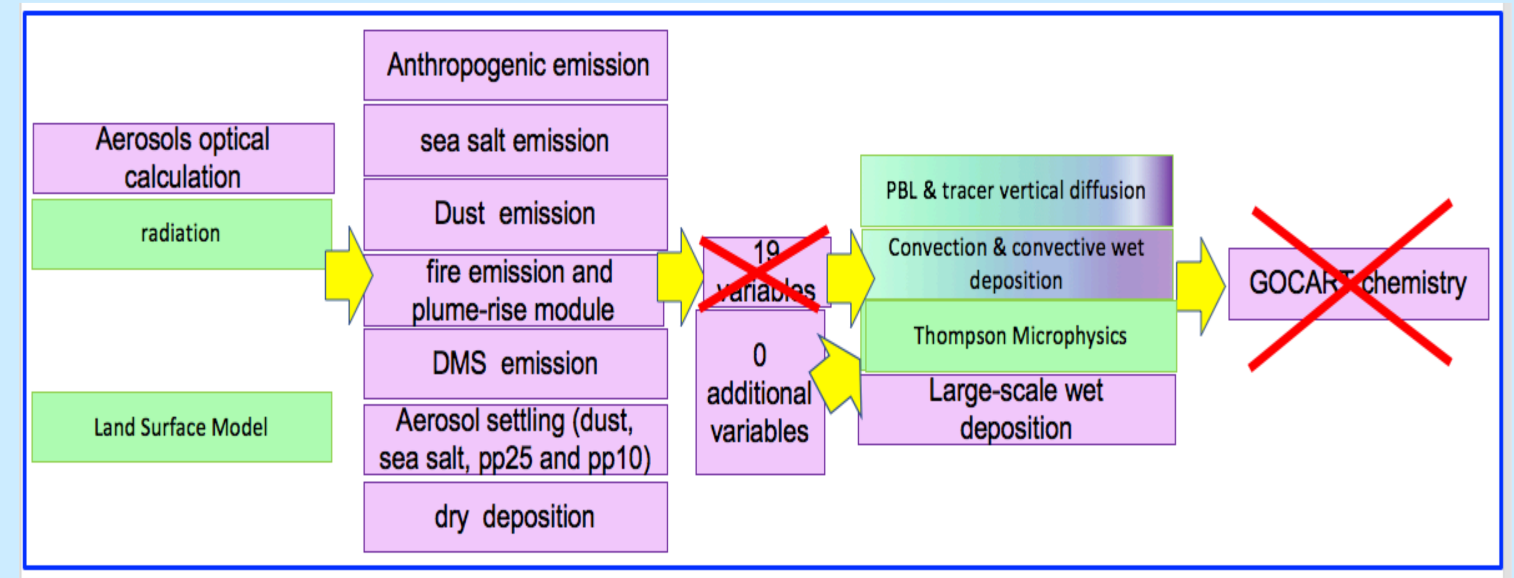
- **Transport:** Grid-scale transport by dynamics core. Sub-grid transport by PBL and tracer convective transport and wet scavenging implemented in convection scheme.
- **Chemistry:** simplified parameterization of sulfur/sulfate chemistry, hydrophobic and hydrophilic black and organic carbon, a 5-bin 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..
- **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



-- CCPP-Physics: a library of physics parameterizations that conforms to selected standards.
-- CCPP-Framework: enables connecting the physics to a host model.
-- GSDChem was broken up and all the chemical modules were embedded into the UFS Weather Model as subroutines of physics.

2.4). To provide aerosol emission for precipitation physics



- **In the Thompson MP, the hygroscopic aerosol is referred as a "water friendly" aerosol (WFA), and the non-hygroscopic ice-nucleating aerosol is referred as "ice friendly" aerosol (IFA).**
- **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**

3. Experiment design and Results

	CTL	New
physics	GSL physics	GSL physics
Emission for WFA/IFA	default empirical formular in Thompson microphysics	from sea-salt, dust, anthropogenic and wild-fire emission
FV3 Initial conditions	GFS (IC=2020120100)	GFS (IC=2020120100)
Resolution	C768 (~13km) L127	C768 (~13km) L127
Integration length	120 hours	120 hours
WFA/IFA initial condition	GOCART climatology	GEFS-Aerosols

Fig.1 Water-Friendly Aerosol number concentration ($10^{13}/m^2$) at 120h from (a) CTL, (b) New, and (c) the difference between New and CTL.

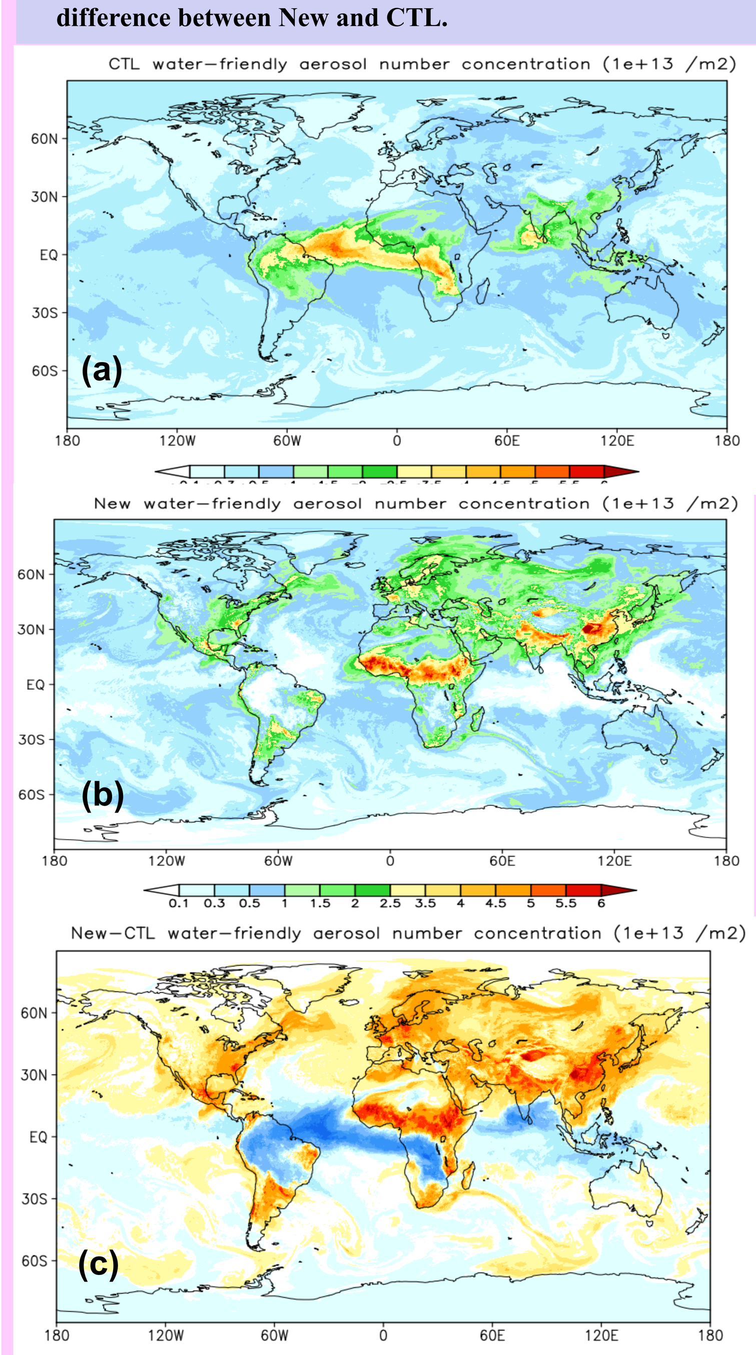


Fig.2 Aerosol optical depth at 120h from (a) MERRA2, (b) CTL, and (c) New.

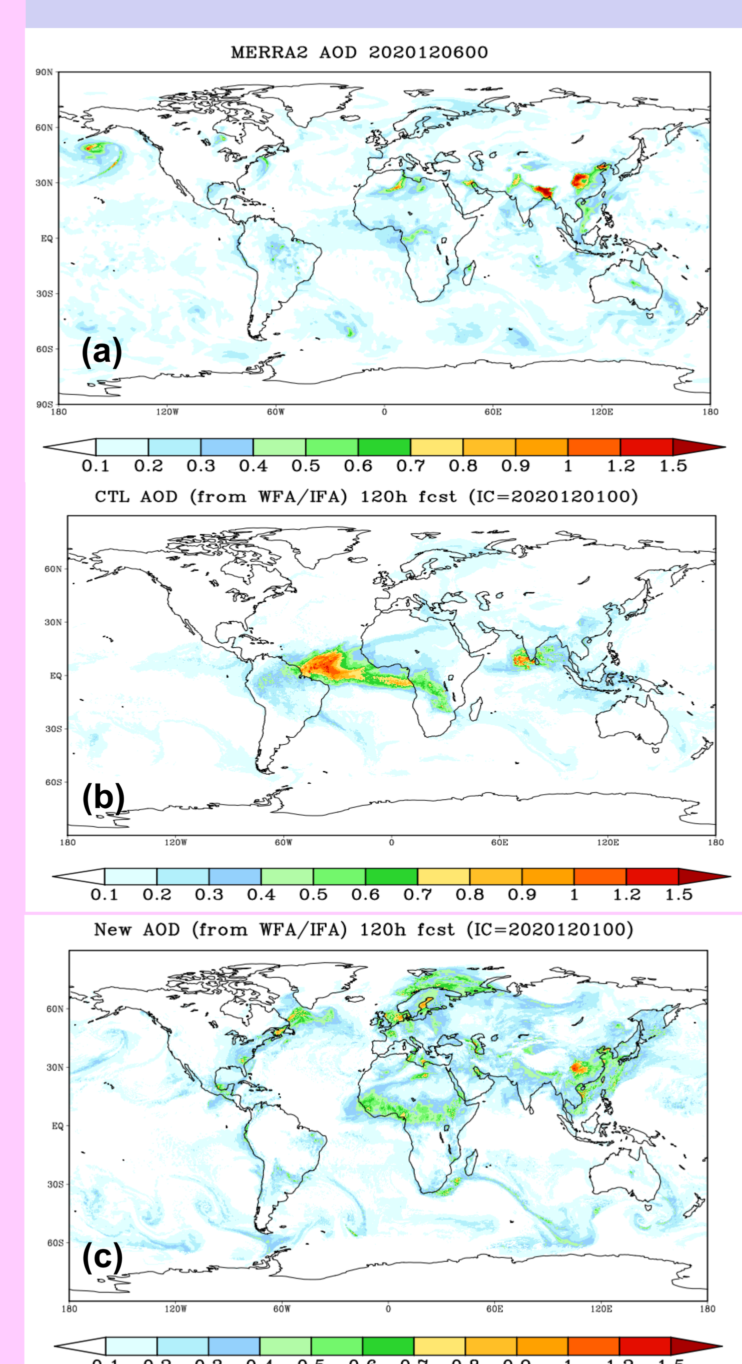


Fig.3 The difference between New and CTL runs of 120h averaged (a) convective precipitation (mm/day), and (b) resolved precipitation (mm/day).

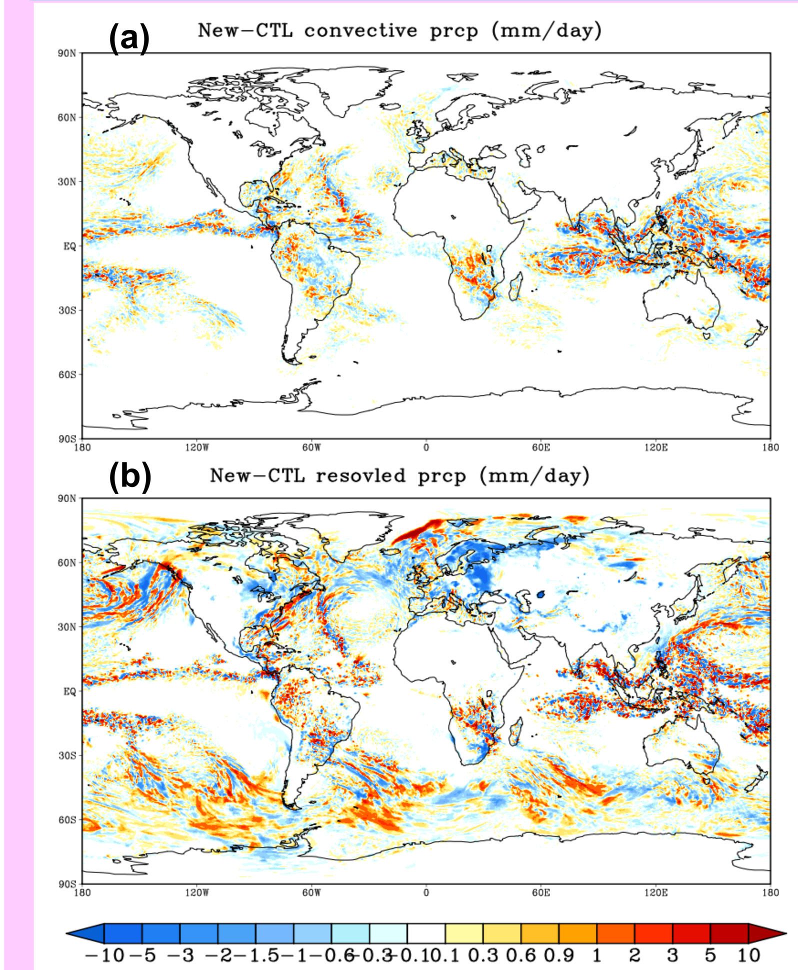


Fig.4 The 120h forecast tropical temperature bias (K) from CTL (in black) and New (in red) relative to GFS Analysis.

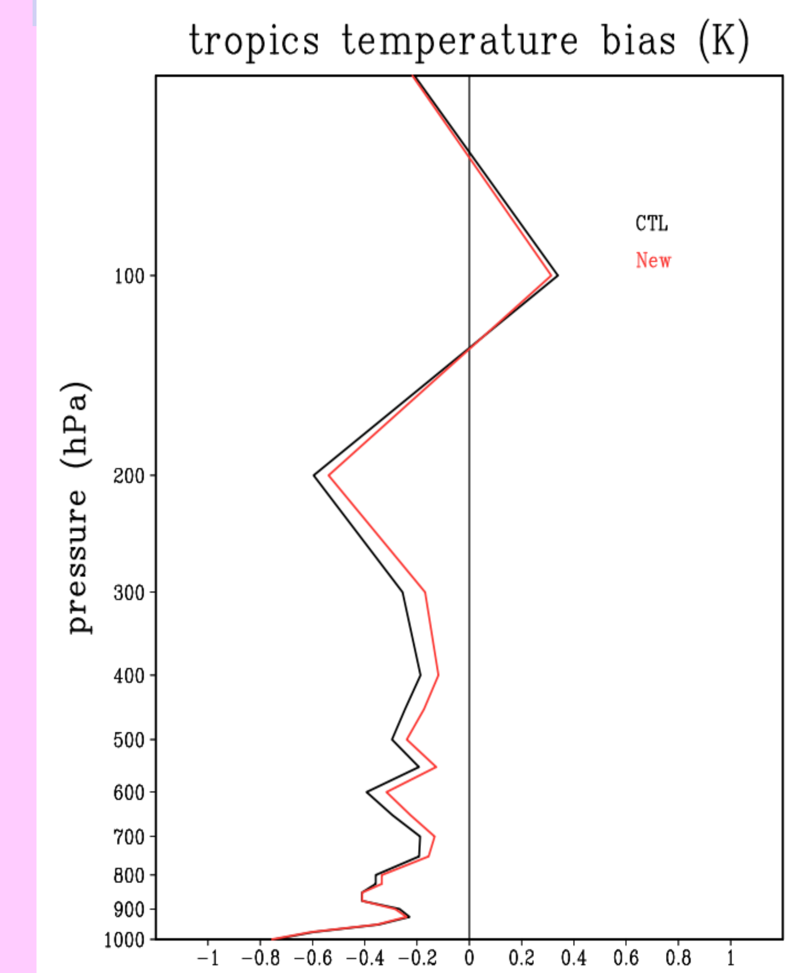


Fig.5 The difference between New and CTL runs of 120h averaged (a) high cloud fraction (%), and (b) middle cloud fraction (%), and (c) low-level cloud fraction (%).

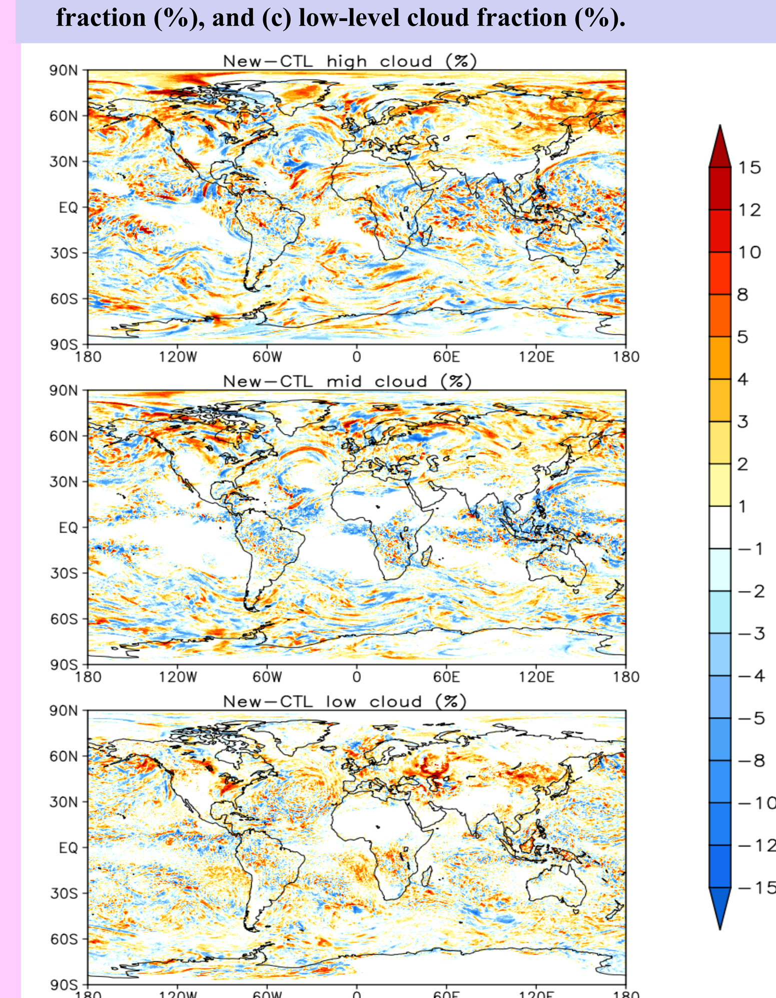
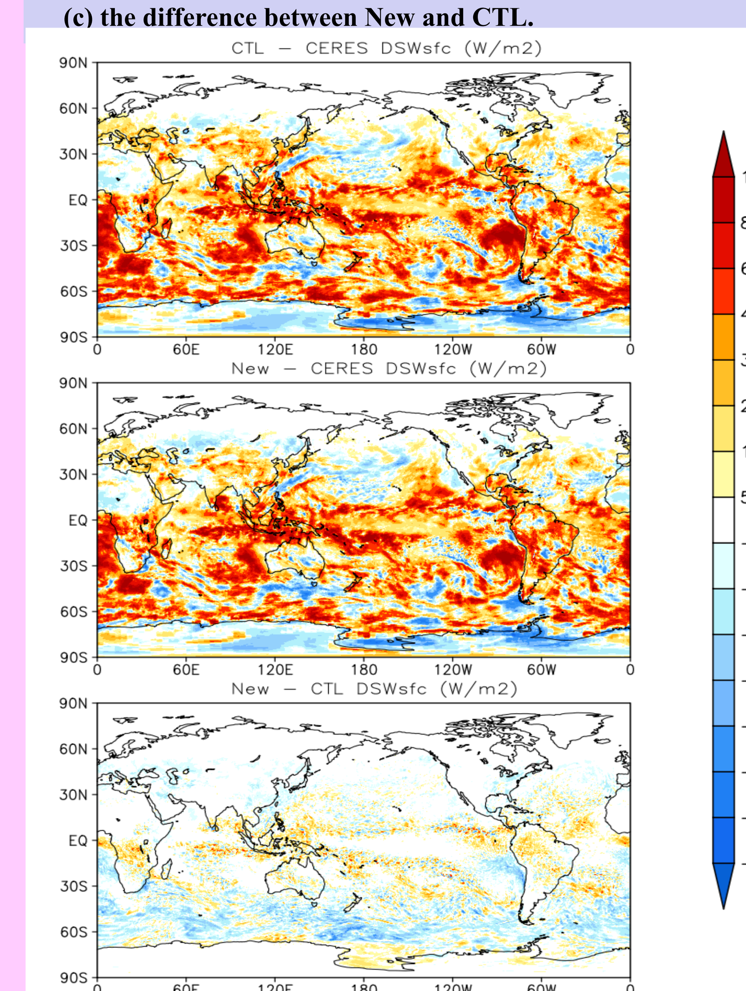


Fig.6 The bias of 120h averaged surface downward shortwave radiation (W/m^2) from (a) CTL, and (b) New, and (c) the difference between New and CTL.



4. Summary

- **A very simple approach, without introducing additional tracers, is developed to simulate two aerosol variables that the double momentum microphysics scheme needs with prognostic aerosol emissions, instead of using climatologies. This approach will be perfect for operational numerical weather predication as well as subseasonal-to-seasonal forecast.**
- **The initial results from a winter case (IC=2020120100), which used WFA/IFA initial conditions converted from GEFS-Aerosols chemical species, are promising. The microphysics responses are as expected (less resolved precipitation corresponds to an increase in water-friendly aerosols).**
- **A summer case (IC=2020060100), which used WFA/IFA initial conditions from cycling runs, has similar performance.**
- **We will also test the performance of the GF convective parameterization using the identical aerosol emission approach.**
- **A set of retro-run is running to evaluate the ACC skill.**