Aerosol Indirect Effects in the UFS in Global Cloud Permitting Simulations

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Introduction

Aerosols can impact the atmospheric energy budget directly by scattering, reflecting, and absorbing incoming solar radiation (aerosol direct effects, ADE). They can also indirectly influence weather and climate systems by acting as cloud condensation nuclei and/or ice nuclei, resulting in changes in cloud droplet number concentrations and sizes, modifying the microphysics, radiative properties, and even lifetime of clouds (aerosol indirect effects, AIE). The first indirect effects usually refer to the increase of droplet concentration and top of the atmosphere (TOA) albedo; the second involve changes of the microphysics, cloud life cycle, and surface precipitation, etc.

AIE are extensively studied in climate models by performing a control simulation with industrialized aerosol emissions and one with preindustrial emissions in order to study anthropogenic influences on climate. The indirect effects are mainly caused by sulfate related aerosols. The cloud radiation effect (CRE) from AIE (first and second) ranges from -1.1 to -3.7 W m^{-2} (Boucher et al. 2013). However, there are very few studies on the effects from turning on/off the whole aerosol indirect effects, the NonAll approach. In addition to the theoretical perspectives, the NoAll approach has more practical applications because most NWP models do not include any aerosol indirect effects. AIE on forecast skill is unknown.

In addition to factors such as poor understanding of physics and aerosol sources and sinks, model resolution is a major obstacle leading to uncertainties in modeling studies of AIE. Most models in the IPCC Intercomparison Studies have deep convection parameterization that does not include AIE. This study investigates AIE on cloud formation and the hydrometeorological cycle in UFS on a 3-km grid without parametrized deep convection and with a double-momentum microphysics scheme.

Experiment Design

The model used in this study is the atmosphere model of the NOAA Unified Forecast System (UFS), which has a 3 km horizontal resolution and 127 vertical levels extending to the mesopause (C3072L128 UFS). The Thompson microphysics, a double moment microphysics scheme, and the Rapid Radiation Transfer Model for GCM (RRTMG) are included in the physics package. MERRA2 (Modern-Era Retrospective analysis for Research and Applications, Version 2) aerosol climatology is used to drive the RRTMG radiation and activate the activation of ice nuclei (IN) or cloud condensation nuclei (CCN) of the microphysics scheme.

Four experiments were carried out with the same 2019100100 initial conditions and were run for 15 days 1) at 3-km resolution, no aerosol-cloud interaction, without parameterized deep convection (EXP ctl). The activation of IN/CCN in the microphysics scheme depends only on temperature. Therefore, only aerosol direct effect on radiation is activated in this experiment. 2) Same as (1) except the number concentrations of water friendly aerosol (NWFA) and ice-friendly aerosol (NIFA) are diagnosed from the Eidhammer-Thompson approach to activate IN/CCN using MERRA2 aerosol climatology (EXP aero). To investigate the effects of resolution, two more experiments at low resolution were performed: 3) same as (1) but using C768L127 with parameterized deep convection (13 km grid size, EXP ctl_low), and 4) same as (2) but using C768L127 and turning on deep convection (EXP aero_low).

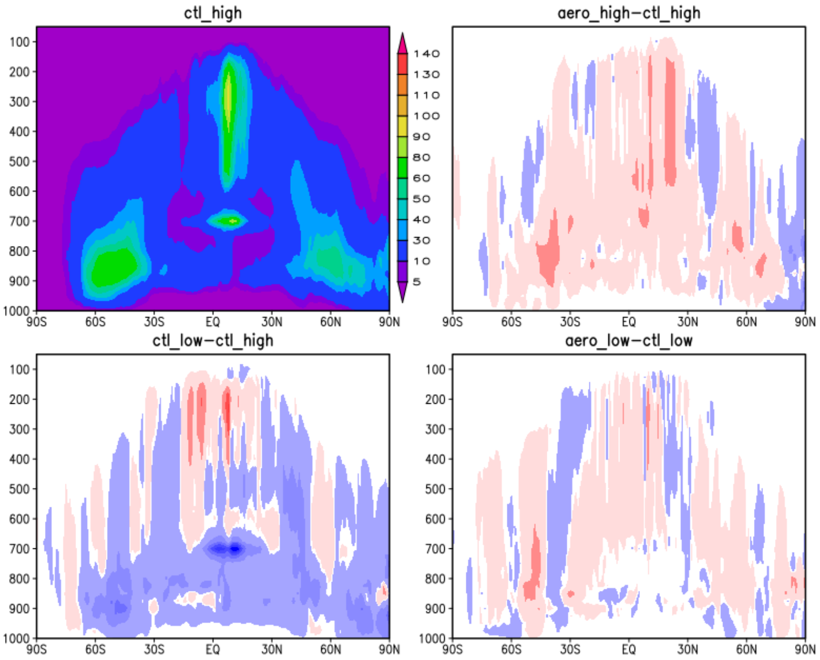

Figure 1. Vertical cross section of cloud liquid, cloud ice, and snow for the last 10 day mean from EXP ctl (a), diffrence between ctl and aero (b), EXP ctl_low (c), and the difference between aero_low and ctl_low (d)

Results

Aerosols provide more cloud condensation nuclei, so the cloud droplet number concentrations increase and cloud droplet sizes decrease (Twomey, 1974). This usually leads to more cloud liquid and ice in the atmosphere. This effect can be readily seen in Figure 1, which shows that the total cloud liquid, cloud ice, and snow are larger overall than in the control runs. This is more obvious in the cloud permitting runs in the Northern Hemisphere low latitudes and high troposphere. Note that the Thompson microphysics tends to treat ice as snow and this is one reason why snow is included. The coarse resolution runs tend to produce less hydrometers than the cloud permitting runs, especially for the low troposphere

(Figure 1c). Clouds with smaller particles and larger number concentrations should have higher albedo, and more TOA upward shortwave fluxes. The AIE effects represented by TOA upward SW differences between the control and aerosol is about -3.11 W m-2 and -0.65 W m-2 for the cloud permitting run and the low resolution run, respectively. Both are within the uncertainty range of the IPCC report. Large upward SW can be seen in the highly industrialized Eurasia region, central and north Africa, and storm track regime where sea salt serves as a main aerosol source. The AIE from the low resolution run is much smaller, probably because there is no aerosol parameterization in the deep convective scheme. The TOA SW differences caused by the resolution is nearly -14.38 W m-2, overwhelming the AIE. The large negative TOA SW near ITCZ where deep convection is active from the low resolution run relative to the high-resolution (Figure 2c) implies that less cloud ice and cloud water are produced in the deep convective parameterization.

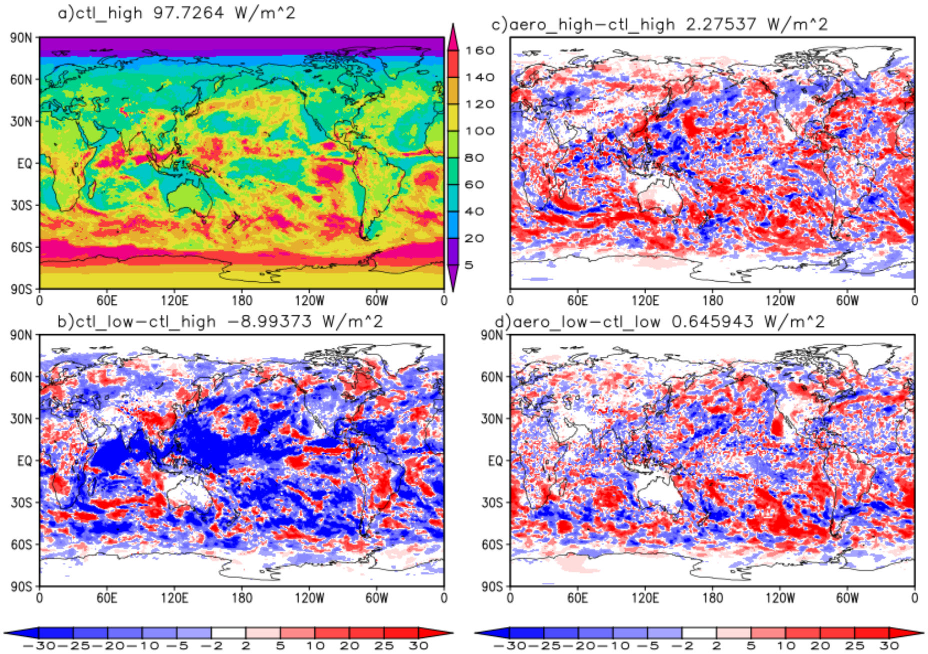

Figure 2. Same as Figure 1 except for mean global distribution of top of the atmosphere (TOA) upward shortwave radiation fluxes for the four experiments.

References

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