Indirect Effect of Aerosols on Numerical Weather Forecast
-- Coupling MERRA2 aerosol with Thompson microphysics

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1.Introduction

Aerosols and clouds continue to contribute the largest uncertainty in the climate and numerical weather modeling and predictions. Given our limited understanding of the aerosol indirect effect (AIE) and the complexity in both physics and computation to include AIE in numerical weather prediction (NWP) models, most NWP models use monthly mean aerosol climatology with a single-moment microphysics and neglects the aerosol indirect effects. This study investigates the AIE with a double-momentum microphysics and compares two computational efficient approaches to include AIE in an NWP model.

2. Experiment Design

The NWP model used in this study is The GFS version 17 (GFS.v17), which has a horizontal resolution of ~13 km and 127 levels in the vertical extending to the mesopause (C768L128 GFS). The Thompson microphysics, a double moment microphysics, and the Rapid Radiation Transfer Model for GCM (RRTMG) have been implemented in the GFSV17. MERRA2 (Modern-Era Retrospective analysis for Research and Applications, Version 2) aerosol climatology are used to drive the RRTMG radiation and to activate the activation of ice nuclei (IN) or cloud condensation nuclei (CCN) in one approach.

Three free forecasting experiments are performed from June 1st 2019 to September 1st 2019 for every five days: 1) There is no aerosol effects on microphysics (EXP noaero), The activation of IN/CCN are temperature dependent only. So there is only aerosol direct effect in this experiment. 2) Same as 1), except that the number concentration of water friendly aerosol (NWFA) and the number concentration of ice friendly aerosol (NIFA) are diagnosed from the Edhammer-Thompson approach to activate IN/CCN using MERRA2 (EXP mraero). and 3) Same as 1) except that NWFA and NIFA is advected and forecasted with sources and sinks (EXP ltaero). Because there are two more forecasted variables in EXP ltaero, it is about 10% more expensive than EXP mraero and noaero.

3. Results

3.1 Aerosol Indirect Effects

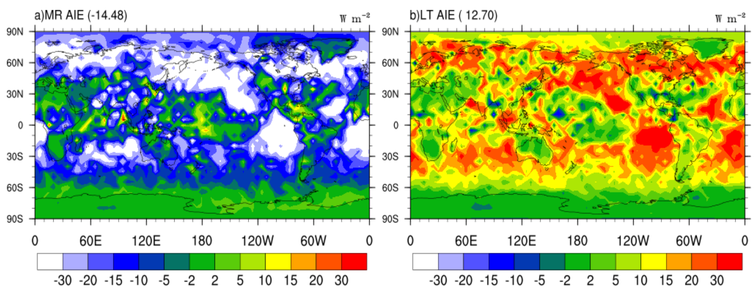

Fig. 1. Aerosol indirect effects (AIE) Calculated from the difference of cloud radiation forcing (CRE) between EXPs mraero and noaeros (a) and between EXPs ltaero and noaeros (b), respectively. Large difference can be seen in the regions where stratocumulus clouds exists.

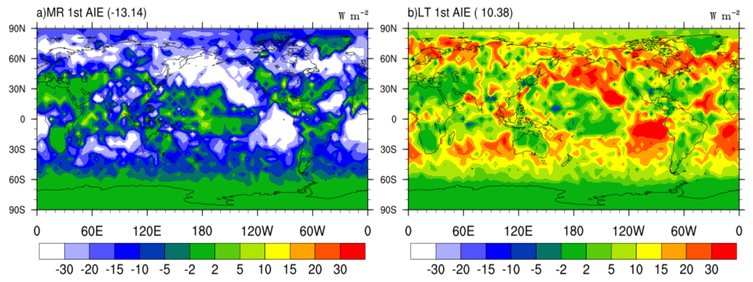

Fig. 2. The first AIE for EXPs mraero (a) and ltaero (b), respectively. The first AIE results in an increase in droplet/particle concentration due to the increase of aerosol. The albedo of clouds usually increase due to the increase of the effective radius.

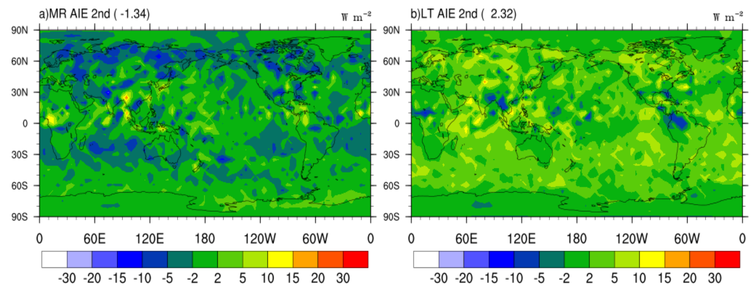

Fig. 3. The second AIE for EXPs mraero (a) and ltaero (b), respectively. The second AIE is related to the life cycle of clouds that might be modified by the aerosol indirectly, with variation of precipitation.

3.2 Impacts on rain water and precipitation

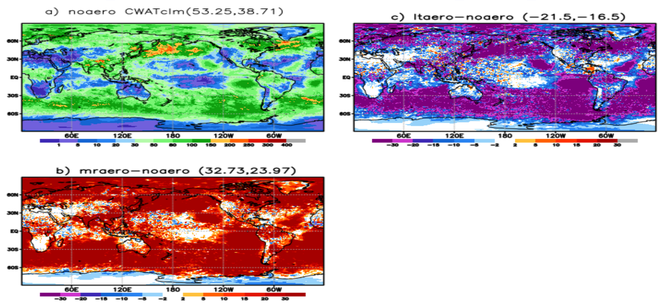

Fig. 4. Column mean cloud water (liquid and ice, g m^{-2}) for the 5th day from EXP noaero (a), diffrence between mraero and noaero (b), and that between ltaero and noaero (c). Notice that the increase of low bias of cloud water from EXP ltaero.

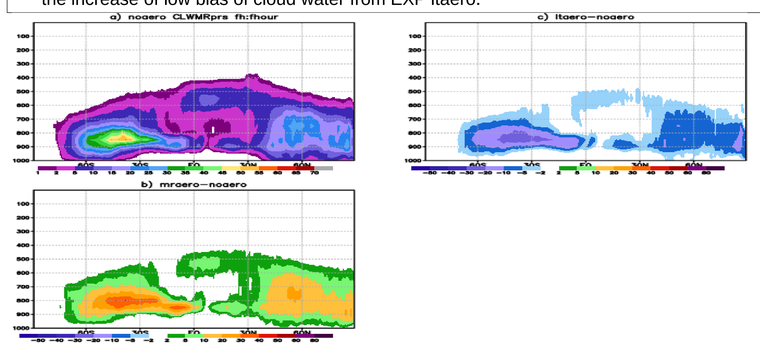

Fig. 5. Vertical cross section of liquid for the 5th day from EXP noaero (a), diffrence between mraero and noaero (b), and that between ltaero and noaero (c). The difference of ice between the EXPs mraero and ltaero is very small, so not shown.

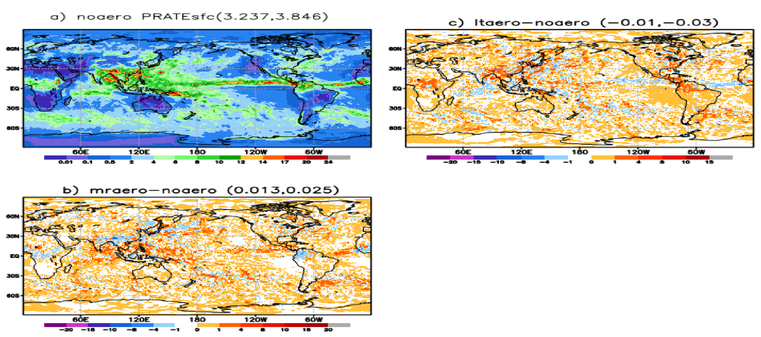

Fig. 6. Mean surface precipitation (mm day^{-1}) for the 5th day from EXP noaero (a), diffrence between mraero and noaero (b), and that between ltaero and noaero (c).

3.3 Water- and Ice-Friendly aersol and their effects

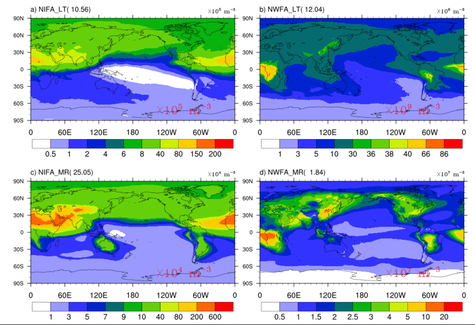

Fig. 6. Vertical weighted average of NWFA and NIFA from EXP ltaero (a and b) and from EXP mraero (c and d). Notice the scale factor differences among those plots (red fonts). NWFA from EXP ltaero is about two orders larger than EXP mraero, while NIFA is about one order larger.

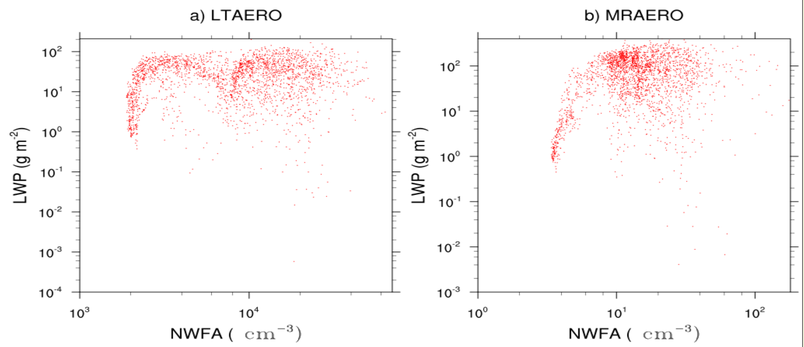

Fig. 7. Scattered plots for NWFA and LWP from EXPs mraero (a) and ltaero (b), respectively.

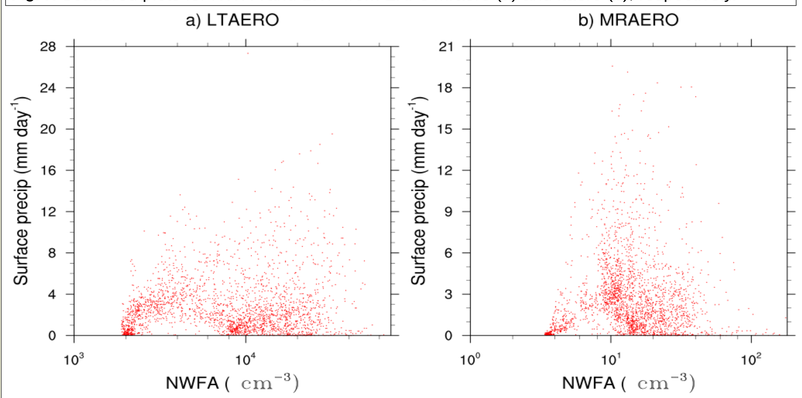

Fig. 8. As in Fig. 6, but for surface precipitation and NWFA

4. Summary

- The aerosol indirect effects (AIE) from the NWFA and NIFA forecasting approach (EXP ltaero) is opposite to the diagnosed approach (EXP mraero). The first indirect effect is dominated the second effects. The AIE is closely related to the cloud liquid differences.
- Large differences in cloud liquid are seen in the two approaches. The diagnostic approach decreases the low bias and the forecast approach increases it.
- NIFA and NWFA from forecast approach are about 5 times and 100 times of the diagnostic approach.
- The analysis of the relationship between NWFA and cloud liquid and surface precipitation find that there are weak positive correlations and there is a point for negative correlations.

5. Acknowlegement

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