Stochastic particle-resolved modeling of atmospheric aerosols and their climate impacts

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ABSTRACT

Here we present the development and application of particle-based methods to represent atmospheric aerosols in numerical weather prediction and air quality models. Measurements show that each atmospheric aerosol particle consists of a complex mixture of chemical species, such as soluble inorganic salts and acids, insoluble crustal materials (dust), trace metals, and carbonaceous materials. An aerosol particle population therefore constitutes a high-dimensional distribution in the space of possible compositions.

Aerosol particles influence the large-scale dynamics of the atmosphere and climate because they interact with solar radiation, both directly by scattering and absorbing light and indirectly by acting as cloud condensation nuclei (CCN). Their sizes range from nanometers to micrometers, and a major source of difficulty in understanding the climate impact of aerosols is due to scale interactions between nanoscale particles and global-scale weather and climate effects.

Limited by computational resources, previous modeling efforts have used simplifying assumptions regarding the aerosol composition, such as assuming that all particles of a given size have identical chemical composition. This can lead to significant errors in the prediction of aerosol climate impacts. To alleviate a priori assumptions regarding aerosol composition, particle-resolved techniques are advantageous because of their ability to simulate the high-dimensional distribution of particle compositions.

In this work, we present the development of the particle-resolved aerosol model PartMC-MOSAIC [1] coupled to the Weather Research and Forecast (WRF) model [2], a regional weather model with domains on the order of hundreds of kilometers. The WRF-PartMC-MOSAIC model uses a 3D Eulerian grid for the atmospheric fluid flow, while explicitly resolving the evolution of individual aerosol particles within a representative volume per grid cell. Particles are represented as vectors of composition and exact particle locations within a grid cell are not tracked. Since particle-resolved techniques have high computational cost, efficient stochastic sampling techniques are used to simulate coagulation, emission, dry deposition and advection-diffusion of particles. The cost to simulate coagulation is proportional to number of coagulation events. For dry deposition, cost is proportional to particle removal rates, and for transport it is proportional to advection-diffusion rates.

We use this new model to quantify the importance of aerosol composition for the aerosol impact on climate by determining the errors in simulated climate-relevant quantities, such as heating rates and CCN activity, that arise from the simplified aerosol representation.

REFERENCES

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