Geoscientific Model Development
An interactive open-access journal of the European Geosciences Union

Geosci. Model Dev., 4, 137-168, 2011
www.geosci-model-dev.net/4/137/2011/
doi:10.5194/gmd-4-137-2011

Volume 4, issue 1

Model description paper

03 Mar 2011

The multi-scale aerosol-climate model PNNL-MMF: model description and evaluation

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Received: 18 Sep 2010 – Published in Geosci. Model Dev. Discuss.: 08 Oct 2010
Revised: 12 Feb 2011 – Accepted: 21 Feb 2011 – Published: 03 Mar 2011

Abstract. Anthropogenic aerosol effects on climate produce one of the largest uncertainties in estimates of radiative forcing of past and future climate change. Much of this uncertainty arises from the multi-scale nature of the interactions between aerosols, clouds and large-scale dynamics, which are difficult to represent in conventional general circulation models (GCMs). In this study, we develop a multi-scale aerosol-climate model that treats aerosols and clouds across different scales, and evaluate the model performance, with a focus on aerosol treatment. This new model is an extension of a multi-scale modeling framework (MMF) model that embeds a cloud-resolving model (CRM) within each grid column of a GCM. In this extension, the effects of clouds on aerosols are treated by using an explicit-cloud parameterized-pollutant (ECPP) approach that links aerosol and chemical processes on the large-scale grid with statistics of cloud properties and processes resolved by the CRM. A two-moment cloud microphysics scheme replaces the simple bulk microphysics scheme in the CRM, and a modal aerosol treatment is included in the GCM. With these extensions, this multi-scale aerosol-climate model allows the explicit simulation of aerosol and chemical processes in both stratiform and convective clouds on a global scale.

Simulated aerosol budgets in this new model are in the ranges of other model studies. Simulated gas and aerosol concentrations are in reasonable agreement with observations (within a factor of 2 in most cases), although the model underestimates black carbon concentrations at the surface by a factor of 2–4. Simulated aerosol size distributions are in reasonable agreement with observations in the marine boundary layer and in the free troposphere, while the model underestimates the accumulation mode number concentrations near the surface, and overestimates the accumulation mode number concentrations in the middle and upper free troposphere by a factor of about 2. The overestimation of accumulation model number concentrations in the middle and upper free troposphere is consistent with large aerosol mass fraction above 5 km in the MMF model compared with other models. Simulated cloud condensation nuclei (CCN) concentrations are within the observational variations. Simulated aerosol optical depths (AOD) are in reasonable agreement with observations (within a factor of 2), and the spatial distribution of AOD is consistent with observations, while the model underestimates AOD over regions with strong fossil fuel and biomass burning emissions. Overall, this multi-scale aerosol-climate model simulates aerosol fields as well as conventional aerosol models.

Citation: Wang, M., Ghan, S., Easter, R., Ovchinnikov, M., Liu, X., Kassianov, E., Qian, Y., Gustafson Jr., W. I., Larson, V. E., Schanen, D. P., Khairoutdinov, M., and Morrison, H.: The multi-scale aerosol-climate model PNNL-MMF: model description and evaluation, Geosci. Model Dev., 4, 137-168, doi:10.5194/gmd-4-137-2011, 2011.

Discussion paper
Published on 08 Oct 2010