Spatial distributions and radiative effects of black carbon with MRI Earth System Model

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Most aerosol components have only the scattering property of solar radiation; however, black carbon (BC) aerosols efficiently absorb it and lead to heating of the atmosphere. Because of these effects, the role of BC particles in the climate system has been recognized to be particularly important. However, there remain large uncertainties in estimates of the spatial distributions of BC and its radiative effects in current climate models.
Recently, Meteorological Research Institute (MRI) developed a new version of MRI Earth System Model (MRI-ESM2) for participating in the Coupled Model Intercomparison Project Phase 6 (CMIP6). In this study, we modified treatments of BC in MRI-ESM2. We applied a new BC aging parameterization, which enables the representation of variations of the conversion rate from hydrophobic BC to hydrophilic BC depending on atmospheric conditions, although the original approach assumes the constant conversion rate of 1.2 days. We developed a new treatment of wet removal of aerosols in cumulus parameterization scheme, which enables a simultaneous treatment of vertical transport and wet removal of aerosols in cumulus convection in a consistent manner, although the original approach does not. We represented enhancement of BC light absorption due to coatings assuming internal mixing with sulfate, although the original approach does not take into account the coatings on BC.
We performed the MRI-ESM2 calculations for 2008-2015 with nudging towards the meteorological data (JRA-55) and sea surface temperature (not coupled with the ocean model in this study). Comparisons with the surface measurements showed that MRI-ESM2 improves the predictions of seasonal variations of BC over the Arctic, although the original constant-rate aging approach underestimates the BC concentrations and does not reproduce the seasonal variations. Comparisons with several aircraft measurements showed that MRI-ESM2 improves the vertical profiles of BC in the upper and middle troposphere, although the original wet removal approach largely overestimates BC mass concentrations. These results suggest that the seasonal variations of BC over the Arctic were primarily controlled by aging processes and wet removal by cumulus convection played an important role for BC concentrations in the upper and middle troposphere.
The annually and globally averaged direct radiative forcing by BC at the top of atmosphere was estimated to be approximately 0.2 W m^{-2} in this study. Comparisons with calculations using the original approaches suggest that the forcing increased by 40% due to enhancement of BC light absorption with coatings and increased by 20% due to improvement in representations of BC aging processes.

Keywords: Aerosol, Black carbon, Climate model, Aging process, Wet deposition, Radiative effects

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