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Aerosol-climate interactions in the NASA GEOS-5 atmospheric general circulation model

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Aerosols such as black carbon, dust, and some organic carbon species both scatter and absorb incoming solar radiation. This aerosol direct radiative forcing (DRF) redistributes solar energy both by cooling the surface and warming the atmosphere. As a result, these aerosols affect atmospheric stability and cloud cover (the semi-direct effect, or SDE). Furthermore, in regions with persistent high loadings of absorbing aerosols (e.g. Asia), regional circulation patterns may be altered, potentially resulting in changes in precipitation patterns. Many general circulation model (GCM) studies of the effects of absorbing aerosols on climate have taken a step-wise approach. First, aerosol distributions are simulated offline in a chemical transport model forced with assimilated meteorology. Then, in a second step, the aerosol distributions simulated a priori force the radiative transfer module of a GCM to drive a climate simulation. This stepwise approach therefore can not account for the changes in aerosol distributions that arise as the climate is perturbed. As GCMs have advanced, more have incorporated an online treatment of aerosols, in which the model aerosols are radiatively interactive and transported consistently with the underlying climate model hydrodynamics and physical parameterizations. An example of such a model is the NASA Goddard Earth Observing System model version 5 (GEOS-5) atmospheric GCM, in which we have implemented an online version of the Goddard Chemistry, Aerosol, Radiation and Transport (GOCART) model. GOCART includes representations of the sources, sinks, and chemical transformation of externally mixed dust, sea salt, sulfate, and carbonaceous aerosols. The GEOS-5/GOCART system provides us with an opportunity to examine the extent to which aerosol-climate coupling influences the response of regional climates and the hydrological cycle to the direct and semi-direct aerosol effects. Here we consider a series of ensemble simulations of the present-day period (2000-2009) forced by observed sea surface temperatures. In the control ensemble, there is no radiative forcing by aerosols. A second ensemble includes dynamically and radiatively interactive aerosols. We evaluate these simulated aerosol distributions for their representativeness by comparing to observations from satellite (MODIS, MISR) and ground-based (AERONET) remote sensing instruments. A final ensemble of model runs is composed by radiatively forcing the model with prescribed monthly and inter-annually varying aerosols calculated offline from our interactive aerosol simulations' ensemble mean. The SDE and response of each simulation is determined by differencing with respect to the control simulation. Globally, the climate response is not statistically different to interactive versus offline aerosol forcing. However, on regional scales, such as over southwest Asia during the pre-monsoon period, we do find statistically different changes in important climate parameters, such as precipitation. Regions most significantly impacted by aerosol-climate coupling included those regions influenced by dust radiative forcing, because in GOCART both dust emissions and loss processes depend on model meteorology.