Black carbon (BC) is a product of incomplete combustion of fossil fuel, biofuel and biomass burning (Bond et al., 2004; Forsstrom et al., 2013). It strongly absorbs visible light and has been ranked as the 2nd most important individual absorbing agent after CO2,with a climate forcing of +1.1Wm-2(Bond et al., 2013). Generally, BC aerosols can impact the global atmospheric radiative budget both as atmospheric aerosols, after mixing with other soluble organic materials, or as impurities in snow and ice after being transported to the polar regions and depositing onto their surfaces, resulting in a positive feedback on the surface albedo (Zuberi et al., 2005; Flanner et al., 2007). BC aerosols also have adverse impacts on air quality and human health (Highwood and Kinnersley, 2006).

Quantifying these impacts requires us to develop faithful model representations of BC burden and its climate-relevant properties such as CCN activities and optical properties. Currently, however, significant discrepancies in model simulated BC remain in most global climate models (GCMs) and large uncertainties of its climate forcing have been shown. For example, previous studies have implied a general overestimation of BC in the mid-upper troposphere in the mid-latitudes, and an underestimation of BC in the lower and middle troposphere at high latitude (Koch et al., 2009; Schwarz et al., 2010; Fan et al., 2012). The simulated BC aerosol absorption optical depth tends to be biased low compared to satellite observations (Koch et al., 2009). These model failures can result from the complex BC aerosol processes and properties that has not been well captured, such as its emissions, coagulation, condensation, dry deposition, wet scavenging, etc. (Hakami et al., 2005; Koch et al., 2009; Shindell et al., 2008). These processes in turn control the evolution of aerosol burden, size distribution, mixing states, and consequently its climate forcing (Schulz et al., 2006; Quaas et al., 2009).

Among them, one key process that contributes to the uncertainties and thus needs to be captured is the BC ‘aging’ process, the conversion of freshly emitted, hydrophobic BC to aged, hydrophilic BC through coating with sulfate and organics or coagulation (Langner et al., 1992; Parungo et al., 1994; Liousse et al., 1996). This process directly contributes to the CCN activation and wet removal, and also impacts black carbon’s optical properties by evolving the composition and mixing states of aerosols. Therefore, it plays a significant role in simulating the lifetime of BC, and hence its transport, distributions and climate effects (Croft et al., 2005; Riemer et al., 2004). In addition, previous studies have found that the parameterizations of the aging process can significantly affect model results (Liu et al., 2011).

Albeit its importance, the treatment of BC aging, however, is usually very simplified in global scale models, either by using fixed timescales or parameterized aging rates for the sake of computational limits. The most simplified bulk scheme assumes fully externally mixed populations and often use a fixed aging timescale (on the order of 1-2 days) for conversion of hydrophobic BC to hydrophilic BC (Cooke and Wilson, 1996). There are also more advanced and complicated schemes such as the modal aerosol model or sectional models, computing mechanic transfer rates by assuming aerosol size distributions and mixing levels (Wilson et al., 2001; Bauer et al., 2008, Huang et al., 2013).

The representation of BC aging in the Community Atmosphere Model with Chemistry (CAM-Chem), an atmospheric component of the Community Earth System Model (CESM), uses the latter scheme. It applies a 4-mode version of the modal aerosol model (MAM4), where BC is emitted to the primary carbon mode, and then is aged and transferred to the accumulation mode by condensation of sulfate, ammonia and SOA and by coagulation (Liu et al., 2012; Lamarque et al. 2012). In MAM4, a criterion of 8 monolayers of sulfate is used to compute the aerosol transfer rate from primary carbon mode to accumulation mode. It assumes that BC particle is aged after it is condensed by 8 monolayers of sulfate. However, previous study has shown that considerable sensitivities exist regarding the choices of the number of monolayers and other parameters, and significant model biases in BC burden have been found compared to HIPPO observations (Liu et al., 2015).

Furthermore, Laura et al has derived a parameterization that characterizes the aging rates of BC aerosols through gas condensation and particle coagulation from detailed simulations on the particle scale, based on the particle-resolved PartMC-MOSAIC model (Particle Monte Carlo Model for Simulating Aerosol Inter- actions and Chemistry) (Laura et al., 2016). PartMC-MOSAIC is a complex aerosol model that provides detailed information on aging processes at the micro-scale, by tracing the size, composition and mixing states of particles (Riemer et al., 2010). That parameterization can be applied to evaluate and to improve the treatment of BC aging in the global-scale models.

In this work, our aim is to assess the representation of BC aerosols in MAM4 of CAMChem model. We conduct several sensitivity runs of BC mixing ratio, mixing states and direct radiative forcing to its condensation criterion, in order to investigate the extent to which those quantities are sensitive to the choices of aging parameters. We also exploit the PartMC-MOSAIC parameterization as the reference to evaluate the performance of MAM4 aging scheme.

Our method and model specification are described in Sect.2. Sensitivity analysis of BC is presented in Sect.3. In Sect.4, we focus on process analysis of BC aging by comparing the CAMChem aging timescales with PartMC aging timescales. In Sect.5, we assess the comparability of modeled BC concentration with SP2 measurements. The results are shown in Sect.6.

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