

Response to Anonymous Referee # 1

(Note: Reviewer comments are listed in grey, and responses to reviewer comments are in black. Pasted text from the new version of the paper is in italics.)

The authors developed a wet removal scheme that explicitly describes the influence of cloud processes on BC in CESM. Compared to the original scheme in CESM (i.e., MAM7), the improved wet scavenging scheme greatly reduces bias against HIPPO 1-4 aircraft observations. Finally, the authors calculated global total annual mean BC conversion rates among different phases, quantified the contributions of different cloud processes to the conversion rates, and evaluated the influences of these processes on BC distribution and direct radiative forcing. Generally speaking, the paper is well written and documented, explanatory sections are interesting, and tables and graphics are well constructed. As a result, I am recommending the paper be accepted with minor revisions. The few questions and comments I have are listed below in the specific comments to the authors.

We really appreciate the thoughtful and valuable comments from the reviewer. These comments substantially help to improve our manuscript by addressing these issues.

Specific Comments

1. In the section 2.1, the parameterizations used in this study may be summarized in a table in order to make the paper more clear. In addition, the related information about the HIPPO campaigns (e.g., location, flight samples, time) is welcome.

Thanks for this great suggestion! In order to make the paper easy to read, we have inserted Table 1 to summarize all equations. Meanwhile, we have provided more background information of HIPPO campaigns in section 2.4:

“In order to evaluate our new parameterization, we compare model simulation results with aircraft measurements from HIAPER Pole-to-Pole Observation (HIPPO). The HIPPO observations provide extensive vertical profiles of 26 species from the surface to 14 km above the remote Pacific, spanning from 85°N to 67°S. Five deployments were conducted in periods of 8–30 January 2009, 31 October – 22 November 2009, 24 March – 16 April 2010, 14 June – 11 July 2011, 9 August – 9 September 2011 (Wofsy, 2011). BC Particles were measured using a single-particle soot photometer (SP2) (Schwarz et al., 2010). Because the aircraft both ascends and descends along each flight track, HIPPO generates vertical profiles of BC concentrations.”

Table 1. Cloud processes associated with our improved BC wet removal parameterization, BC conversion along with each cloud process, and corresponding conversion rate as described by Equations (1)-(11).

PROCESS	BC CONVERSION	BC CONVERSION RATE
Cloud activation	BC _{philic} to BC _{water}	$k_{\text{philic} \rightarrow \text{water}} = \frac{\text{CDNC}}{N_{\text{aerosol-CCN}}}$
Ice nucleation	BC _{philic} to BC ice	$k_{\text{philic} \rightarrow \text{ice}} = \frac{\text{ICNC}}{N_{\text{aerosol-IN}}}$
Contact freezing, immersion freezing, homogeneous freezing, riming splintering	BC _{water} to BC _{ice}	$k_{\text{water} \rightarrow \text{ice}} = \frac{\text{CONTACT} + \text{IMMERSION} + \text{HOMO} + \text{SPLINT}}{Q_{\text{liq}}}$
Melting	BC _{ice} to BC _{water}	$k_{\text{ice} \rightarrow \text{water}} = \frac{\text{MELT}}{Q_{\text{ice}}}$
Evaporation of the cloud, the Bergeron process and evaporation of cloud water sedimentation	BC _{water} to BC _{philic}	$k_{\text{water} \rightarrow \text{philic}} = \frac{\text{EVP_CLOUD} + \text{BERG} + \text{EVP_CSEDI}}{Q_{\text{liq}}}$
sublimation of cloud ice sedimentation	BC _{ice} to BC _{philic}	$k_{\text{ice} \rightarrow \text{philic}} = \frac{\text{EVP_ISED1}}{Q_{\text{ice}}}$
Autoconversion and accretion	BC _{water} to BC _{rain} s	$k_{\text{water} \rightarrow \text{rain}} = \frac{\text{PRAO} + \text{PRCO}}{Q_{\text{liq}}}$
Collision and coalescence	BC _{ice} to BC _{snow}	$k_{\text{ice} \rightarrow \text{snow}} = \frac{\text{PRAIO} + \text{PRCIO}}{Q_{\text{liq}}}$
Riming	BC _{water} to BC _{snow}	$k_{\text{water} \rightarrow \text{snow}} = \frac{\text{RIMING}}{Q_{\text{liq}}}$
Deep and shallow convection scavenging	Deposition of BC _{phobic}	$k_{\text{phobic} \rightarrow \text{convection}} = \frac{\text{RRDP} + \text{RRSH}}{Q_{\text{liq}} + Q_{\text{ice}}}$
Deep and shallow convection scavenging	Deposition of BC _{philic}	$k_{\text{philic} \rightarrow \text{convection}} = \frac{\text{RRDP} + \text{RRSH}}{Q_{\text{liq}} + Q_{\text{ice}}}$

2. One suggestion: Different cloud processes may affect the vertical profile of BC. Besides direct radiative forcing, I wonder that corresponding radiative heating rate profiles of BC caused by different cloud processes how to change??? I encourage the authors to perform related simulation in the current or further study.

Thanks for the reviewer's valuable suggestion. We will address this and perform related simulations in our future work to see how the influence of cloud processes on aerosols would modify the radiative heating rate.

References:

Schwarz, J., Spackman, J., Gao, R., Watts, L., Stier, P., Schulz, M., Davis, S., Wofsy, S. C., and Fahey, D.: Global-scale black carbon profiles observed in the remote atmosphere and compared to models, *Geophysical Research Letters*, 37, 2010.

Wofsy, S. C.: HIAPER Pole-to-Pole Observations (HIPPO): fine-grained, global-scale measurements of climatically important atmospheric gases and aerosols, *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences*, 369, 2073-2086, 2011.