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Interactive comment on "Enhancement of snow albedo reduction and radiative forcing due to coated black carbon in snow" *by* Wei Pu et al.

Anonymous Referee #1

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The authors investigated the coating effect of BC on BC-induced snow albedo reduction by using core/shell Mie calculations and SNICAR model. They found that BC coating can enhance snow albedo reduction by up to 80% and 30% for non-absorbing and absorbing coating, respectively. They further developed an empirical parameterization for BC coating effect on snow albedo and applied their calculations to different regions based on in-situ measured BC and OC concentrations in snow. This study could help advance our understanding of the role of BC in interacting with snowpack and potentially reduce the uncertainty in estimates of BC-snow albedo radiative effect. The manuscript is generally well-written in terms of language and structure. I have a few comments and suggestions for the authors to consider. Particularly, there are still some places that require more discussions and further clarifications.

Specific comments:

1. The authors assume BC coated by sulfate and OC in snow, which is fine for the purpose of theoretical calculations. However, one important issue related to the coated BC in snowpack is that in reality, many coating materials are soluble (e.g., sulfate and some organics) and will presumably dissolve into BC-containing hydrometeors during wet deposition onto snow surface. Hence, it may not be realistic to assume BC coated by sulfate (and even some OC) in snowpack. I understand this is a complicated problem, and the solubility of BC coating materials heavily relies on the chemical composition. I am not sure if the authors noticed any observations regarding BC coating in snow. If yes, this should be mentioned in the text. If there is no available observation, the authors could at least discuss this issue in the introduction.

2. The authors claimed that "This study is the first to explicitly resolve the optical properties of coated BC in snow . . ." in the abstract and main text. However, this is not true. An earlier study (He et al., 2014) has already explicitly resolved the effect of coated BC particles internally and externally mixed with snow grains of different shapes and applied it to the Tibetan Plateau, which is a pioneer study to look at this effect. This earlier study should be briefly discussed in the introduction section and compared with the results from the present study. But it's good to see that the authors here also explored the effect of an absorbing shell.

Reference: He, C., Q. Li, K.-N. Liou, Y. Takano, Y. Gu, L. Qi, Y. Mao, and L. R. Leung (2014), Black carbon radiative forcing over the Tibetan Plateau, Geophys. Res. Lett., 41, 7806–7813, doi:10.1002/2014GL062191.

3. Introduction and Methodology: One important piece that was not mentioned here is the mixing state of BC and snow grains (i.e., internal vs. external) and snow grain shape. Recent studies (e.g., Flanner et al., 2012; Liou et al., 2014; He et al., 2018b) have shown that the BC-snow internal mixing can significantly enhance snow albedo reduction compared with BC-snow external mixing, while nonspherical snow grains

have weaker albedo reduction than snow spheres. This can be briefly discussed in the introduction. Besides, the authors did not mention whether they assumed BC-snow external or internal mixing and whether they assumed spherical snow grains in their SNICAR simulations. By default, SNICAR assumes BC-snow external mixing and snow spheres (Flanner et al., 2007), but a recent study (He et al., 2018c) has extended the SNICAR model to account for BC-snow internal mixing and nonspherical snow grains. So which SNICAR version did the authors use in this study? More details need to be added in the methodology part.

References:

Flanner, M. G., Zender, C. S., Randerson, J. T., and Rasch, P. J.: Present-day climate forcing and response from black carbon in snow, J. Geophys. Res.-Atmos., 112, D11202, https://doi.org/10.1029/2006jd008003, 2007.

Flanner, M. G., Liu, X., Zhou, C., Penner, J. E., and Jiao, C.: Enhanced solar energy absorption by internally-mixed black carbon in snow grains, Atmos. Chem. Phys., 12, 4699–4721, https://doi.org/10.5194/acp-12-4699-2012, 2012.

He, C., Liou, K. N., Takano, Y., Yang, P., Qi, L., and Chen, F.: Impact of grain shape and multiple black carbon inter- nal mixing on snow albedo: Parameterization and radiative effect analysis, J. Geophys. Res.-Atmos., 123, 1253–1268, https://doi.org/10.1002/2017JD027752, 2018b.

He, C., Flanner, M. G., Chen, F., Barlage, M., Liou, K.-N., Kang, S., Ming, J., and Qian, Y.: Black carbon-induced snow albedo reduction over the Tibetan Plateau: uncertainties from snow grain shape and aerosol–snow mixing state based on an updated SNICAR model, Atmos. Chem. Phys., 18, 11507–11527, https://doi.org/10.5194/acp-18-11507-2018, 2018c.

Liou, K. N., Takano, Y., He, C., Yang, P., Leung, R. L., Gu, Y., and Lee, W. L.: Stochastic parameterization for light absorption by internally mixed BC/dust in snow

grains for application to climate models, J. Geophys. Res.-Atmos., 119, 7616–7632, https://doi.org/10.1002/2014JD021665, 2014.

4. Page 6, Line 12: The authors assumed a fixed MAC of 0.3 m2/g at 550 nm for OC. Is there any observation to support this assumption?

5. Page 6, Line 21: The authors seem to assume a fixed monodisperse BC size distribution instead of lognormal distribution, right? Please clarify. Also, what is the assumed shell diameter?

6. Page 9, Lines 4-6: It will be good if the authors can include some comments on how applicable their parameterization is for BC concentration > 1000 ng/g.

7. Page 9, Lines 9-12: The authors assumed an infinite snowpack when applying their calculations to in-situ measurements. Is it because there are no snow depth measurements? Also, what snow-LAP parameters were in-situ measured? Please provide more specifics here.

8. Section 3.1: How did the authors define the variable "Eabs"? A formula will be helpful. Similarly for Section 3.2, definitions of parameters like E_alpha need to be provided in terms of a mathematical expression.

9. Page 11, Line 7: Why does the BC concentration make a negative contribution to E_det(alpha) instead of positive contribution?

10. Page 11, Line 12: Note that the solar radiative flux is very small at wavelengths < 350 nm.

11. Section 3.5: Please include a clarification somewhere in this section to state that this parameterization is under the assumptions of semi-infinite snowpack, BC-snow external mixing, and spherical snow grains.

12. Section 3.6: More descriptions regarding the parameters from observations are needed. For example, did the authors assume semi-infinite snowpack or used mea-

sured snow depth in their calculations? Did the authors use time-varying downward solar radiation in the calculation of radiative forcing? How did the authors assume the snow grain size? Is it from observations?

13. It will be good if the authors can include a few sentences to briefly summarize the applicability of their parameterizations in terms of the range of BC concentration, snow condition, snow size, core/shell ratio, etc.

14. Another thing the authors did not mention is the direct and diffuse radiation they assumed in their calculations for both parameterization development and in-situ measurement application. If direct radiation was assumed, what was the value of solar zenith angle used? Clarifications need to be added.

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