Response to Reviewer #1:

General comments:

The authors systematically investigated the responses of dust emissions, transport, and deposition to dust direct and in-snow radiative effects over East Asia. This work could help to improve the understanding of dust radiative effects and feedbacks in this region. The manuscript is generally well written and particularly I like Figure 13 which concisely summarizes the possible dust-in-snow radiative feedback. I have a few comments for improving the manuscript. Although most of my comments are minor, they need to be addressed properly before the manuscript can be considered for publication.

Response: Thank the Reviewer very much for the positive comments.

1. Page 2, Lines 11-13: As the authors mentioned, Kok et al. (2017) showed that inaccurate dust size distribution could lead to nontrivial biases in modeled DRF. Is it accurate enough by using the Bulk Aerosol Model (BAM) scheme embedded in CAM to represent dust size distributions as done in the present study?

Yes, we used the improved CAM4-BAM model as described by Albani et al. (2014) and Xie et al. (2018) in the present study. This CAM4-BAM model has been improved in terms of three major aspects: (1) optimized soil erodibility maps through generating the specific scale factors to the macroareas, (2) updated dust optical properties based on more realistic absorption coefficients (Yoshioka et al., 2007), and (3) an improved size distribution for use in dust emissions provided by Kok (2011). It is noted that the accurate dust size distribution (Kok et al., 2017) is from the analytical results (Kok et al., 2011), which is absolutely same with the improved CAM4-BAM used in our study.

2. Page 2, Lines 24-34: A number of recent references on advancing the understanding of BC/dust-in-snow effects are missing here. For example, several studies (e.g., Flanner et al., 2012; Liou et al., 2014; Dang et al., 2016; He et al., 2017b, 2018a) have shown the significant impacts of snow grain shape (spherical vs.

nonspherical) and aerosol-snow mixing state (internal vs. external) on BC/dust-snow albedo forcing. Further studies also investigated the effects of snow grain packing (e.g., He et al., 2017a) and aerosol size distribution in snow (e.g., Schwarz et al., 2013; He et al., 2018b) on aerosol-snow interactions. Since the aerosol-in-snow effect is the focus of this study, I suggest including these recent references here. In addition, in terms of BC/dust deposition over the TP (Lines 32-34), some latest observational studies (e.g., Lee et al., 2017; Li et al., 2018; Zhang et al., 2018) can also be included here.

References:

Dang, C., Q. Fu, and S. Warren: Effect of Snow Grain Shape on Snow Albedo, J. Atmos. Sci., 73, 3573–3583, doi: 10.1175/JAS-D-15-0276.1, 2016.

Flanner, M. G., X. Liu, C. Zhou, J. E. Penner, and C. Jiao: Enhanced solar energy absorption by internally-mixed black carbon in snow grains, Atmos. Chem. Phys., 12(10), 4699–4721, doi:10.5194/acp-12-4699-2012, 2012.

He, C., Y. Takano, and K.-N. Liou: Close packing effects on clean and dirty snow albedo and associated climatic implications, Geophys. Res. Lett., 44, doi:10.1002/2017GL072916, 2017a.

He, C., Takano, Y., Liou, K.-N., Yang, P., Li, Q., and Chen, F.: Impact of snow grain shape and black carbon-snow internal mixing on snow optical properties: Parameterizations for climate models. Journal of Climate, 30, 10,019–10,036, doi:10.1175/JCLI-D-17-0300.1, 2017b.

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

He, C., Liou, K.-N., and Takano, Y.: Resolving size distribution of black carbon internally mixed with snow: Impact on snow optical properties and albedo. Geophysical Research Letters, 45, 2697–2705, doi:10.1002/2018GL077062, 2018b.

Lee, W.-L., K. N. Liou, C. He, H.-C. Liang, T.-C. Wang, Q. Li, Z. Liu, and Q. Yue: Impact of absorbing aerosol deposition on snow albedo reduction over the southern Tibetan plateau based on satellite observations, Theor. Appl. Climatol., 129(3-4), 1373-1382, doi:10.1007/s00704-016-1860-4, 2017.

Li X., S. Kang, G. Zhang, B. Que, L. Tripatheea, R. Paudyal, Z. Jing, Y. Zhang, F. Yan, G. Li, X. Cui, R. Xu, Z. Hu, C. Li. Light-absorbing impurities in a southern Tibetan Plateau glacier: Variations and potential impact on snow albedo and radiative forcing. Atmospheric Research, 200, 77-87, doi:10.1016/j.atmosres.2017.10.002, 2018.

Liou, K. N., Y. Takano, C. He, P. Yang, R. L. Leung, Y. Gu, and W. L. Lee: 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, doi:10.1002/2014JD021665, 2014.

Schwarz, J. P., Gao, R. S., Perring, A. E., Spackman, J. R., & Fahey, D. W. (2013). Black carbon aerosol size in snow. Scientific Reports, 3(1), 1356.

Zhang, Y., Kang, S., Sprenger, M., Cong, Z., Gao, T., Li, C., Tao, S., Li, X., Zhong, X., Xu, M., Meng, W., Neupane, B., Qin, X., and Sillanpää, M.: Black carbon and mineral dust in snow cover on the Tibetan Plateau, The Cryosphere, 12, 413-431, doi:10.5194/tc-12-413-2018, 2018.

Thank the Reviewer's comments for providing a number of recent references on advancing the understanding of BC/dust-in-snow effects. In the revised manuscript, we have added these references and the corresponding descriptions according to the comments: *"Recent studies have shown the significant impacts of snow grain shape (spherical vs. nonspherical) and aerosol-snow mixing state (internal vs. external) on BC/dust-in-snow radiative forcing (e.g., Flanner et al., 2012; Liou et al., 2014; Dang et al., 2016; He et al., 2017b, 2018a). Further studies were also conducted to investigate the effects of snow grain packing (He et al., 2017a) and aerosol size distribution in snow (Schwarz et al., 2013; He et al., 2018b) on aerosol-snow interactions."* And we also added *"There exists a larger amount of deposition on snow of black carbon and dust aerosols over the TP due to the high industrial and natural emissions in Asia from observational studies (Xu et al., 2009; Ming et al., 2013; Qu et al., 2014; Lee et al., 2017; Li et al., 2018; Zhang et al., 2018)."*

3. Page 3, Line 9: Please remove "by" before "to explain".

Taken.

4. Page 4, Lines 2-4: A recent study (He et al., 2018c) has updated a number of new features into the SNICAR model, including the effects of snow grain shape and aerosol-snow mixing state based on a set of new parameterizations (He et al., 2017b), which showed important impacts on aerosol-in-snow forcing. It seems that the authors here assumed external mixing between aerosols and spherical snow grains, which may not represent the realistic snowpack situation. It would be better if the authors could add some discussions on this important issue.

References:

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. Discuss., doi:10.5194/acp-2018-476, in review, 2018c.

We have added these references and the corresponding descriptions according to the comments: "Note that a set of new parameterizations including the effects of snow grain shape and aerosol-snow mixing state has been coupled into the SNICAR model, which may represent the realistic snowpack situation (He et al., 2018c). It is interesting to check the difference in radiative forcing over East Asia between these two models in the future. "

5. Page 4, Lines 6-7: The authors focused on dust over the Tibetan Plateau by using a model spatial resolution of ~1 degree. However, this resolution may not be able to resolve the complex topography of the Tibetan Plateau and may cause some uncertainty in the simulations. Could the authors add some discussions on this aspect?

Yes，we have added some discussions in the revised manuscript: "Due to the complex topography of the TP, higher-resolution simulations can resolve more details of the deep valleys and high mountains over and around the TP and make some significant improvements in the simulated climate (Li et al., 2015). Hence, it is necessary to conduct the higher-resolution simulations to address this issue."

6. Page 4, Lines 12-13: The authors neglected the radiative properties of other aerosols, which may cause some biases in estimating dust-in-snow forcing. For example, Flanner et al. (2009) suggested that co-existing BC and dust may lead to smaller albedo reduction/forcing caused by dust (or BC) compared with dust (or BC)-only situation. Could the authors elaborate a little on this?

Yes, I believe the Reviewer's point is exactly right. Generally, (A+B) effect = A effect + B effect + AB nonlinear interactions in the model. Hence, in the revised manuscript, we have added "It is noted that black carbon (BC) deposited on snow over the TP mainly from South Asia and East Asia (Xu et al., 2009; Wang et al., 2015) also displays a significant positive forcing over this region (Flanner et al., 2009; Qian et al., 2011). Here, we only consider the radiative forcing of the dust-in-snow over the TP ignoring the radiative forcing of the BC-in-snow in our study. Due to neglecting the nonlinear interactions between BC and dust, the dust-in-snow radiative forcing might not be accurate. Additionally, the overestimated SCF in the MAM may also artificially increase the dust-in-snow radiative forcing. The overestimated radiative forcing may amplify its feedbacks on the East Asian climate and dust cycle."

7. Page 4, Line 24: Please change "is" to "are".

Taken.

8. Page 4, Lines 27-28: Could the small wet deposition of dust be due to the weak solubility of dust?

Figure S1 shows the percentage of the dust wet deposition to the total deposition in the MAM. Over Northwest China, it has the smallest percentage of dust wet deposition and it has larger percentage of dust wet deposition over the Ocean. Hence, we can conclude that the less rain determines the small wet deposition over Northwest China based on the spatial distribution of the percentage.

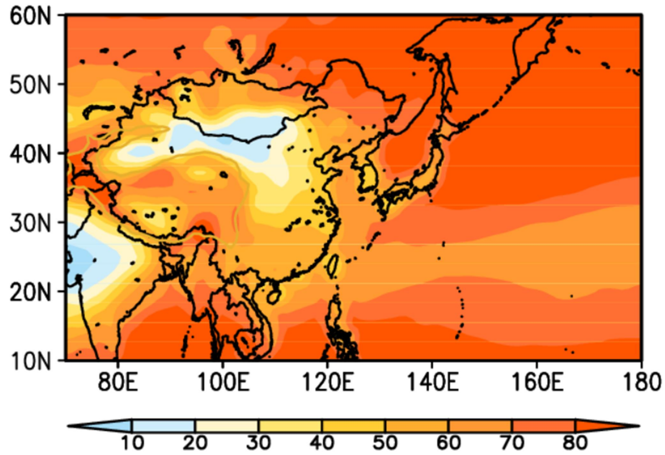

Figure S1, Percentage of dust wet deposition to the total deposition (wet+dry deposition) in the MAM.

9. Section 2.2: (1) In terms of dust AOD, the authors only showed model results but no evaluation against observations, which seems not consistent with the section title "Model evaluation". It would be better if the authors could show some model evaluations on dust AOD (e.g., compare with satellite AOD during dust events). If this would take too much additional work, at least the authors could provide some references showing the evaluation of dust AOD using this model. (2) The authors showed some biases in modeled SCF, which may directly translate into biases in dust-in-snow forcing. How would this bias affect the final results/conclusions? Could the authors add some discussions on this?

Yes, I have added the descriptions about comparisons with observed AOD and deposition and the corresponding references (Albani et al., 2014; Xie et al., 2018). In the revised manuscript, we have added "This improved CAM4-BAM has been evaluated against measurements such as AOD, and dust deposition over the East Asia (Albani et al., 2014; Xie et al., 2018), showing a better simulation of dust cycle." We also added the overestimated SCF: "Additionally, the overestimated SCF in the MAM may also artificially increase the dust-in-snow radiative forcing. The overestimated radiative forcing may amplify its feedbacks on the East Asian climate and dust cycle."

10. Section 3.1: The authors showed that the change in dust emissions induced by SRF+DRF is 5.98 Tg/season, which is contributed by two competing effects (-8.8 Tg/season caused by DRF and 14.78 Tg/season caused by SRF). It seems that the response of dust emissions to dust radiative effects is linear (5.98= -8.8+14.78), which may not be very intuitive, since some nonlinear processes (e.g., transport, deposition, circulation, etc.) are involved in this radiative feedback (Fig. 13). Could the authors add some comments on this?

Yes, the Reviewer's point is exactly right. The total change in dust emissions induced by SRF+DRF is 5.98 Tg/season (Case1-Case3), which is resulted from the two competing effects. However, the changes caused by DRF (-8.8 Tg/season) and SRF (14.78 Tg/season) are included the nonlinear interactions between SRF and DRF. Hence, the values of dust emissions caused by DRF and SRF can be altered when removing the nonlinear interactions between SRF and DRF. Hence, in the revised manuscript, we have added "It is noted that the total change in dust emissions induced by SRF+DRF is 5.98 Tg/season, which is absolutely exact. However, the changes caused by DRF (-8.8 Tg/season) and SRF (14.78 Tg/season) are included the nonlinear interactions between SRF and DRF. Hence, the values of dust emissions caused by DRF and SRF can be altered when removing the nonlinear interactions between SRF and DRF."

11. Page 6, Lines 13-14: Another element in this positive feedback process is that increasing surface temperature leads to stronger snow aging and hence larger snow grain sizes, and finally reduces snow albedo.

Yes, we have added this element in the positive feedback process in the revised manuscript "Another element in this positive feedback process is that increasing surface temperature results in stronger snow aging and hence larger snow effective grain sizes, and finally reduces snow albedo (Flanner et al., 2009)."

12. Page 7, Lines 1-10: Could the authors put their SRF effects into the context? For example, are the results and conclusions shown here different from previous studies?

If so, how different are they and why?

Yes, we have added the descriptions "It is noted that SRF significantly increases the surface temperature, reduces the SCF and enhances the surface total heat flux (LHF and SHF) over the TP, which is absolutely same as the previous results (Qian et al., 2011). Due to the higher horizontal resolution of ~1 degree in this study, our result shows the finer spatial distribution of changes in these properties, especially over the TP compared to Qian et al. (2011)."

13. Page 8, Line 11: Another reason for the largest SRF in MAM could be that the snow cover/depth reaches the maximum over TP in early spring, along with the largest dust deposition, leading to the largest SRF.

Yes, we have added "This is mainly because the larger snow cover in MAM, along with the largest dust deposition exerts a significant radiative forcing, climatic feedbacks, and changes in dust emissions in this season."

14. Page 8, Line 21: It seems that the authors did not show results for the expansion of dust source region area caused by SRF in this manuscript.

As we know, dust emissions are primarily a function of surface wind speed, vegetation (and snow) cover, and soil erodibility. The decreases in vegetation and snow cover in the modeled grids can enhance the dust emissions by expanding the dust source area of the corresponding grids. Additionally, Figure S2 also shows that the total dust source area in our simulations is also expanded, due to the decreased snow cover by SRF. Hence, SRF can results in the expansion of dust source region area by reducing snow cover evidently.

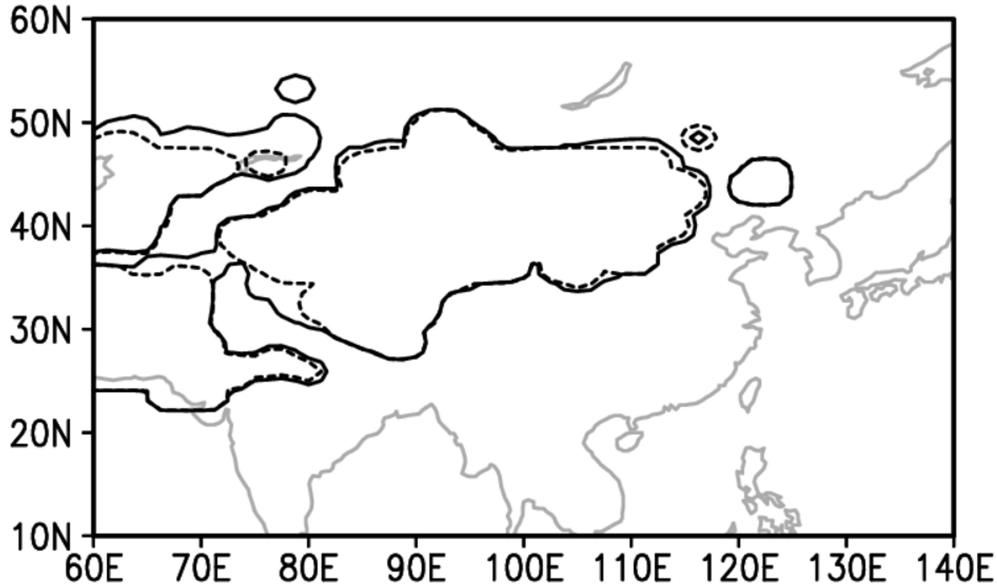

Figure S2, Dust source area defined as emission flux>0 kg/m2/s with Case 1 (Real line) and Case 2 (dotted line).