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The revised manuscript entitled "Modulation of springtime surface sensible heating over the Tibetan Plateau on the interannual variability of East Asian dust cycle" by Xiaoning Xie, Anmin Duan, Zhengguo Shi, Xinzhou Li, Hui Sun, Xiaodong Liu, Xugeng Cheng, Tianliang Zhao, Huizheng Che, and Yangang Liu

We thank the ACP Handing Editor (**Professor Kari Lehtinen**) for his hard work and the two anonymous referees for their constructive suggestions to improve our manuscript significantly. We greatly appreciate the generally positive comments from both the two Reviewers (Reviewer #1 and Reviewer #2), and have addressed all the concerns, with point-by-point responses detailed below (reviewers comments in red color and our responses in blue color). We have uploaded the file of "Response to reviewers.pdf".

Best wishes,

Xiaoning Xie

Response to Reviewer #1:

General comments:

Dust has important effects on TP and Asian regional climate, while the change in TP climate can feed back to dust generation and lifecycle. The authors conducted model simulations combined with analysis of observations and reanalysis datasets to quantify the effects of TPSH on the interannual variability of dust life cycle in East Asia. This would potentially enhance our understanding of the interactions between dust aerosols and Asian/TP climate, and hence regional climate change. The manuscript is generally well-structured, and the methodology is also sound. Before it can be considered for publication, I have a few comments and suggestions to potentially improve the quality of the manuscript. Particularly, more clarifications and discussions are needed in the modeling and analysis parts. Please see my specific comments below.

Response: Thank the Reviewer #1 very much for the positive comments. According to the comments, we have added some descriptions in the modeling and analysis parts, and some discussions in Section 5 in responses to the specific comment below.

1, Title: The authors mainly focused on MAM TPSH, so I suggest including "Springtime" in the title to avoid any confusion.

Taken. According to the Reviewer's comment, we have changed the title as **"Modulation of springtime surface sensible heating over the Tibetan Plateau on the interannual variability of East Asian dust cycle"**

2, Introduction: It would be good if the authors could explicitly highlight the difference and novelty of this study compared with their previous study (Xie et al., 2018b), since there are some overlaps between the two studies.

Yes, I agree with the Reviewer' comment. Based on the sensitivity of the GCMs, the enhanced surface sensible heat flux can enhance the Asian dust cycle through the dust-in-snow radiative forcing in Xie et al., 2018b. Hence, we want to know, in the interannual variability of observations and models, whether the springtime surface sensible heating over the Tibetan Plateau can affect the variability of East Asian dust cycle to further confirm this mechanism. Hence, in our manuscript, we have added "More recently, based on sensitivity of GCM simulations, Xie et al. (2018b) revealed that the dust-in-snow radiative forcing over TP significantly increases the eastern Asian dust emissions and the regional dust cycle through enhancing the TPSH, indicating a positive feedback loop. However, the detailed relationships between TPSH and the East Asian dust cycle remain elusive, especially for interannual variability. Therefore, we should check the relationship with springtime TPSH and Asian dust cycle Asian dust cycle to further confirm this mechanism, based on the interannual variability of observations and models." in Section Introduction.

3, Section 2: (1) The website links for the observation and modeling data used in this study need to be provided if they are publicly accessible. (2) For the model, I suggest the authors use CAMchem/MAM in the future study, which includes more realistic aerosol representations. Besides, the assumption of aerosol external mixing and/or simplified (i.e., spherical) particle structure/morphology in CAM4-BAM can lead to uncertainty/bias in DRF (e.g., He et al., 2015: https://doi.org/10.5194/acp-15-11967-2015; Scarnato et al., 2015: https://doi.org/10.5194/acp-15-6913-2015). This issue needs to be discussed to some extent in the manuscript. (3) Was the aerosol-cloud interaction included in the model? The authors did not mention this. (4) I am not quite convinced that it is a good idea to fix the emissions in year 1850. As the authors mentioned, the anthropogenic emissions could serve as a confounding factor for the perturbation of the MAM TPSH impact. If removing the anthropogenic emissions, then the resulting effect of TPSH on dust cycle would not be realistic. If so, the authors need to make some clarifications in the title, abstract, and introduction sections to state that this study only considers the scenario without anthropogenic emission effect. This issue is particularly important when considering that the observations used to evaluate model actually reflect both the natural dust emissions and anthropogenic emissions of other species throughout the study period.

Yes, I believe that the reviewer's comments are very constructive for improving our manuscript. Firstly, all the website links for data of CAM4-BAM, MERRA-2 reanalysis, and the surface sensible heating flux of 73 meteorological stations of the China Meteorological Administration over TP used in this study have been shown in **Section Data availability**. We have added the corresponding descriptions as "The surface sensible heating flux of 73 meteorological stations of the China Meteorological Administration over TP is available in the personal hompage of Anmin Duan, at http://staff.lasg.ac.cn/amduan/index/article/index/arid/11.html. The MERRA-2 reanalysis are developed by the GMAO with support from the NASA Modeling, Analysis and Prediction program, acquired from https://goldsmr5.gesdisc.eosdis.nasa.gov/data/ (last access: 14 Sept. 2018). Simulated data of CAM4-BAM can be made accessible on request to the corresponding author (xnxie@ieecas.cn).”

Secondly, according to the Reviewer’s comments about (2) and (3), we have added the description in Section 5 “The CAM4-BAM model assumed a subbin fixed size distribution of externally mixed aerosols and spherical particle structure/morphology of dusts (Neale et al., 2010). This simplified assumption of aerosols lead to uncertainty or bias in evaluating dust direct radiative forcing (Yang et al., 2007; He et al., 2015; Scarnato et al., 2015). In microphysical processes of the model, the cloud droplet number concentration and ice number concentration are fixed as constant, ignoring aerosol-cloud interactions (Neale et al., 2010). The model cannot evaluate dust effects on warm, mixed or ice phase clouds. Additionally, the assumed dust-snow external mixing underestimates the dust-in-snow feedbacks in CAM4-BAM, and the new parameterization in dust-snow internal mixing enhances the radiative feedbacks (He et al., 2019). Hence, exact parameterizations with dust optical properties, dust-cloud processes and dust-in-snow interactions will reduce the model uncertainty and can effectively evaluate dust-climate interactions in the future.”

Finally, we agree with the Reviewer’s comments about effects of anthropogenic aerosols. The anthropogenic aerosols (especially black carbon aerosols) can deposit on TP, which affects the TP surface albedo and the surface sensible heat flux (e.g., Qian et al., 2011; Shi et al., 2019). Additionally, according to the Reviewer’s comments, we also conducted the experiment with the anthropogenic aerosol and precursor gas emissions at the year of 2000 (PD). Figure S1 shows the spatial distribution of the correlation coefficients between the TPSH and the anomalies of surface dust concentration in the new experiment with PD aerosol emissions. It is shown that the spatial pattern is very similar with Figure 3 in our manuscript. Therefore, the relationship between TPSH and surface dust concentration in interannual variability is exactly true, although the anthropogenic aerosols can affect the TPSH. Hence, we believe that the experiment with fixed PI aerosols is suitable to investigate the effect of springtime TPSH on the interannual variability of East Asian dust cycle.

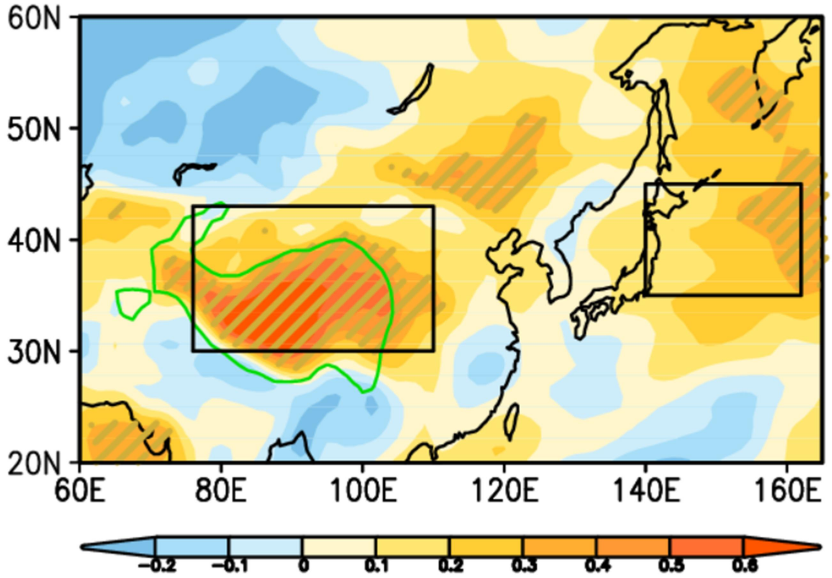

Figure S1. Spatial distribution of the correlation coefficients between the index of sensible heat over the TP (TPSH index) and the anomalies of surface dust concentration in MAM for the 30 year CAM4-BAM simulation. Here the slanted lines in the grey (a, d) represent the grid points where the changes pass the two-tailed t test at the 5% significance level and the green-contour area indicates the plateau above 2500 m.

4. Section 3.1: (1) Some more discussions on the reasons of the spatial patterns and biases of TPSH need to be provided. Currently, the authors mainly described the results without many explanations of the physics behind in this section. (2) A particularly interesting question is that dust also feeds back to the TP climate and affect TPSH. For example, column dust leads to surface dimming and reduce TPSH, while dust in snow enhances surface warming and increase TPSH. So how does this dust feedback contribute to the variation of TPSH under the effects of other influential factors? The authors mainly discussed the effect of TPSH on dust in the following sections, but it will be interesting to see the effect of dust on TPSH too. (3) The authors seem to focus on evaluating modeled surface dust concentrations only. Why not also evaluate the column property such as AOD? This at least will be meaningful

over dust source regions. This is also important for the discussions on dust loading in the following sections.

Yes, I agree with the Reviewer' comments and have added the corresponding descriptions. Firstly, we have added the corresponding explanations about the spatial distribution and interannual variations of TPSH in the manuscript. We have been added "The spatial patterns of the MAM TPSH are basically consistent with the ground measurements, reanalysis, and satellite data (Shi and Liang, 2014). There exist persistent snow cover over the western TP and several mountains (Pu et al., 2007; Xie et al., 2018b), which increases surface albedo and modulates the radiative energy balance, and then leads to lower sensible heat fluxes (Xie et al., 2005; Wang et al., 2014)." and "The result indicates a significant interannual variation of the MAM TPSH, which are mainly account for that of surface wind speed, ground-air temperature, and snow cover/depth in winter-spring (Duan et al., 2011; Shi and Liang, 2014; Wang et al., 2014)." Secondly, the point about dust effect on TPSH from the Reviewer is very good. I have added the corresponding discussions about dust direct and dust-in-snow effect (Figure S2 in the followings) on TPSH in the Section 5. "Over the TP, the dust-in-snow forcing is dominated compared with dust direct forcing, which determines the TP warming and regional dust cycle (Qian et al., 2011; Xie et al., 2008b). A significant feature of dust-in-snow effect over the TP creates a positive feedback loop enhancing the East Asian dust cycle. Our results show that, compared to the weakest TPSH years, the MAM dust cycle in the strongest TPSH years are much more vigorous over East Asia. In the strongest TPSH years, much more dusts deposited on snow over TP (Figure 12a) show larger dust-in-snow forcing (Figure 12b) and then further enhance the regional dust cycle through the above positive feedback loop of dust-in-snow." Finally, the modeled dust AOD of CAM4-BAM has been evaluated against Measurements from global in Figure 4 (Albani et al., 2014) and eastern Asian region in Figure 3 (Xie et al., 2018a). Hence, the corresponding description has been added in the manuscript "For the dust aerosol optical depth (AOD), the CAM4-BAM has been evaluated against ground-based measurements from global scale (Albani et al., 2014) and eastern Asian region (Xie et al., 2018a), showing strong and positive correlations with observational sites on seasonal and annual means.”

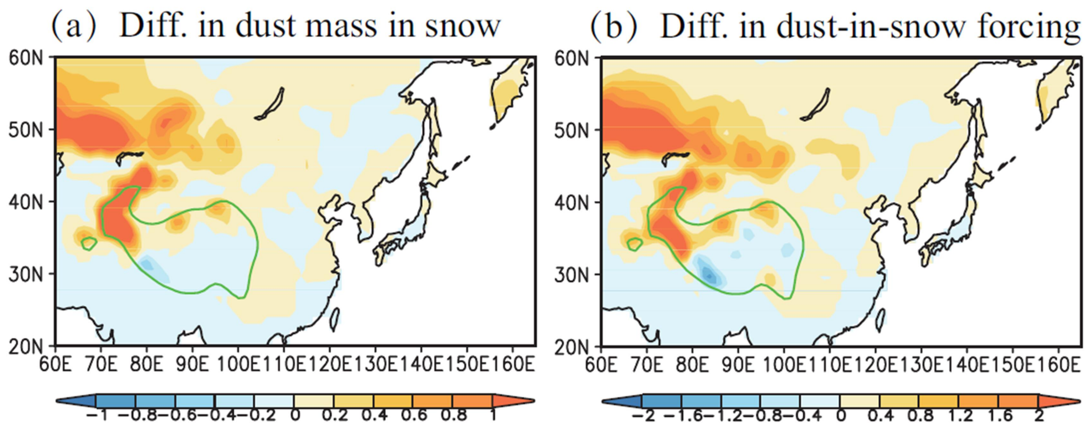

Figure S2. Spatial distribution of the MAM composite difference between the strongest and weakest TPSH years (strongest-weakest) for the model in (a) dust mass in snow column (g m^{-2}) and (b) dust-in-snow forcing (W m^{-2}). The green-contour area indicates the plateau above 2500 m.

5. Section 5: (1) The authors made the argument that the dust-in-snow feedback plays an important role, but without any quantitative analysis and/or figures. The dust-in-snow feedback is actually an interesting point, so it would be good to see some quantitative results, figures, and discussions to back up the argument. Besides, a recent study (He et al., 2019: https://doi.org/10.1029/2019MS001737) showed that the dust-snow albedo effect/feedback can be significantly enhanced by dust-snow internal mixing compared with external mixing (presumably assumed in CAM4-BAM model). This could potentially enhance the importance of the dust-in-snow feedback in modulating TPSH. Some discussions on this aspect would be useful. (2) Since a number of potential uncertainty factors (some of them have been mentioned in my comments above) could be involved in the model simulations and analysis, I suggest including a paragraph or two to specifically discuss the uncertainties of this study in this section.

Yes, the constructive suggestions have been provided from the Reviewer about Section 5. Firstly, we have added Figure 12 (Figure S2 in the followings) about dust-in-snow forcing and the corresponding discussions about dust-snow external mixing in CAM4-BAM. Secondly, according to the Reviewer's comments, we have added a paragraph about potential uncertainty factors of the CAM4-BAM in Section 5 as "The CAM4-BAM assumed a subbin fixed size distribution of externally mixed aerosols and spherical particle structure/morphology of dusts (Neale et al., 2010). This simplified assumption of aerosols lead to uncertainty or bias in evaluating dust direct radiative forcing (Yang et al., 2007; He et al., 2015; Scarnato et al., 2015). In microphysical processes of the model, the cloud droplet number concentration and ice number concentration are fixed as constant, which ignoring aerosol-cloud interactions (Neale et al., 2010). The model cannot evaluate dust effects on warm, mixed or ice phase clouds. Additionally, the assumed dust-snow external mixing underestimates the dust-in-snow feedbacks in CAM4-BAM, and the new parameterization in dust-snow internal mixing enhances the radiative feedbacks (He et al., 2019). Hence, exact parameterizations with dust optical properties, dust-cloud process and dust-in-snow interactions will reduce the model uncertainty and effectively evaluate dust-climate interactions in the future."

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