The authors developed a glacier mass and energy balance model to estimate the impact of atmospheric deposited BC on glacier melting at the the Laohugou Glacier No. 12, Western Qilian Mountains. They found that the BC deposition particularly from industrial emissions significantly accelerates the glacier melting on top of the global warming. The findings are interesting. However, I have a few concerns and suggestions for the authors to address before the manuscript can be considered for potential publication.

Major comments:

1. My major concern is that the measurements used to constrain and drive model simulations are collected in different years. This temporal inconsistency can lead to substantial uncertainties in the model simulations and parameter optimization, unless there is very small interannual variability for those measured quantities. The authors need to either justify the negligible impact from interannual variability or quantify the associated uncertainty due to this temporal inconsistency and report it along with the results.

Answer: We thank the reviewer for the comment.

This are no homochromous measurements of BC in snow pit, surface ice, and atmosphere on the Laohugou No. 12 Glacier, and there are non-existent in any other glaciers as far as I know, because of the difficulty in data acquisition in glacier regions. The aim of this study is to construct a model consisting of deposition, process of post-deposition of LAPs, and access the rough order of LAPs effect on glacier melt. It must be different of LAPs depositions between different years, but we believe that they are in the same order of magnitude, and could support our study. In addition, we replenished uncertainties analyses according to measured LAPs concentrations, which is shown in the following responses.

2. Lines 107-110: This part is not quite clear to me. How did the authors measure the BC lost in melted snow and then add it to compute the total BC content in snow pit? Particularly, it seems that the authors need to quantify/estimate the amount of BC scavenged by snow meltwater out of the snow pit to compute the total deposited BC in snow. Also, the authors mentioned a little bit about computing the BC lost amount based on removal efficiency in Line 127. However, the removal efficiency has quite large uncertainty (Qian et al., 2014: https://doi.org/10.1088/1748-9326/9/6/064001). This estimation method seems

to have large uncertainty for the lost amount of BC. Did the authors conduct any uncertainty analysis to quantify this?

Answer: We thank the reviewer for the comment.

The lost BC was obtained by multiplying amount of melted snow and average concentration of BC in snow pit and removal efficiency. We have changed this paragraph as following. The removal efficiency indeed has large uncertainty, according to range of removal efficiency provided by Qian et al., 2014 文献, we have implemented uncertainty analysis, which is shown in discussion.

Line 107-110: "we assumed that adding the lost BC lost by melted snow to the total content of BC in the snow pit reflected the total content of BC deposited by the atmosphere in a year, the lost BC was obtained by multiplying amount of melted snow and average concentration of BC in snow pit and removal efficiency."

3. Section 5.1: The relative importance/contribution of different types of BC (e.g., from meltout ice, wet deposition, dry deposition) is essentially dominated by the vertical distribution of these BC particle concentrations. The glacier melting caused by BC is mostly driven by the albedo reduction, which is most sensitive to the BC concentration in the top few centimeter snowpack. Thus, physically speaking, the small contributions of BC from meltout ice and wet deposition are probably because the BC locating in the deeper snow layers and BC concentration is relatively low (compared to dry deposition), respectively. Some discussions related to these physical insights need to be added or clarified. Also, the timing of these different BC particles occurring could also have an impact since spring and summer typically lead to the strongest impacts from BC-driven melting.

Answer: We thank the reviewer for the comment. BC from wet deposition firstly falls in the top layer, it experiences enrichment and removal just like BC from dry deposition. The biggest difference between wet deposition and dry deposition is, all of BC from dry deposition in surface influences surface albedo while part of wet deposited BC in top few centimeter of snowpack and BC from melted snow influences the surface albedo, we have indicated this in the revised manuscript. BC from meltout ice participates in calculation of albedo when glacier ice exposes.

We calculated albedo reduction caused by BC in surface snow, the contribution of BC to glacier melting is a comprehensive result of different types of BC. In this study, we try our best to physically simulate different types of BC effect on glacier melting, if all of BC from wet deposition and BC from meltout ice always participates in calculation of albedo, they will have bigger contribution to glacier melting than that we simulated, while it is not in line with the real situation.

The contribution of different types of BC to glacier melting is an accumulated value of a year or melt season. Our model physically simulated BC deposition and process of post-deposition, so those contributions could actually reflect existence or nonexistence of a type of BC effect on glacier melting.

4. This glacier modeling adopted many assumptions, simplifications, and approximations. Thus, a section specifically discussing and/or quantify the uncertainties involved in the model simulations will be very helpful. Some of my comments have touched a little bit on several uncertainty sources.

Answer: We thank the reviewer for the constructive comment.

The main aim of this study is to explore how much on earth effect of BC and increased BC on current glacier melting. For this purpose, we collected data of BC in atmosphere, snow and ice, which could represent current concentration level of BC. We used them in a mass balance year and explored how much on earth effect of increased BC on current glacier melting. Those assumptions used in this study indeed took many uncertainties to the results. We thank the reviewer again for careful and valuable comments and suggestions. We will provide a profound discussion about uncertainties caused by the model parameters in the revised manuscript.

Minor comments:

1. Lines 44-45: “have generally been retreating slowly.” Is this relative to the mean retreating rate over the global cryosphere?

Answer: the slow retreating rate is relative to retreating rate after 1990s. For example, the retreat rate of glacier area increased from 4.43 km^2/a during 1979 - 1991 to 7.04 km^2/a during 1991 – 2011 in the western part of Nyainqentanglha (Bolch et al., 2010; Zhang et al., 2018), the rate of glacier mass loss in the Himalayas from 2000 to 2016 is −0.43±0.14 m w.e./a, is two times of the loss rate during 1975 to 2000 (−0.22±0.13 m w.e./a) (Maurer et al., 2019).

Bolch T, Yao T, Kang S, et al. A glacier inventory for the western Nyainqentanglha Range and the Nam Co Basin, Tibet, and glacier changes1976–2009. Cryosphere, 2010, 4: 419–433.

Zhang Z, Jiang L, Liu L, et al. Annual glacier-wide mass balance (2000–2016) of the interior Tibetan Plateau reconstructed from MODIS albedo products. Remote Sens, 2018, 10: 1031.

Maurer J M, Schaefer J M, Rupper S, et al. Acceleration of ice loss across the Himalayas over the past 40 years. Sci Adv, 2019, 5: eaav7266.

2. Lines 57-60: This statement is not accurate because there are several previous studies using the simultaneous direct deposition of atmospheric BC from model simulations (including BC emitted from human activities) to estimate the associated BC effects on snow and ice over the Tibetan Plateau (e.g., He et al., 2014: https://doi.org/10.1002/2014GL062191; Ji et al., 2015: https://doi.org/10.1007/s00382-015-2509-1; Gul et al., 2021: https://doi.org/10.5194/acp-22-8725-2022).

Answer: we thank the reviewer for the comment. We have emphasized on researches of BC effect on glacier melt in this sentence, He et al. 2014 and Ji et al. 2015 focused on BC effect on snow melt over the Tibetan Plateau, Gul et al. (2022) calculated radiative forcing of BC based on collected snow samples from glaciers rather than direct deposition of atmosphere. In addition, post-deposition process of BC in glacier surface profoundly influences concentration of BC, which causes important effect on glacier melt. While BC effect on large-scale snow cover was not considered the process in the atmospheric models, it may cause limited uncertainty for large scale snow cover, but is inapplicable to glacier melt.

3. Line 148: This is a little confusing. The first/top snow layer was never depleted by ablation?

Answer: we have changed the sentence to…

Line 148-151: "The top layer always kept 2 cm until the total snow dept was less than 2 cm. The second snow layer firstly replenished ablated snow amount of top layer, then third layer. The concentration of BC and water content in top layer were recalculated by uniformly mixing the replenished snow and rest snow of top layer. To avoid infinite increase of the LAPs concentration, the LAPs in the snow layer were gradually mixed with LAPs in the ice surface when the total snow layer was less than 2 cm."

4. Section 3.4: The authors assumed BC externally mixed with (likely spherical) snow grains in the calculations. However, several previous studies have pointed out that BC-snow internal mixing and non-spherical snow grain shape can have large impacts on the BC-induced snow albedo changes (e.g., Dang et al., 2016: https://doi.org/10.1175/JAS-D-15-0276.1; He et al., 2018: https://doi.org/10.1002/2017JD027752). At least some discussions should be provided regarding the uncertainty related to this aspect.

Answer: We thank the reviewer for the comment. We will discuss the related uncertainty caused by the assumption of externally mixture of BC with snow grains.

Section 3.4: It seems that the glacier melting is only for snowpack, right? How about the glacier ice component? Is there an ice layer in the model? Note that ice layer treatment (in terms of albedo calculation) will be different from that of snowpack.

Answer: In this study, ice albedo was calculated by the same albedo method with snowpack, in which the SSA for ice was specified as 1.6 $cm^2\ g^{-1}$ as suggested by Goelles and BØggild, 2017 (Line 234-235). The sources of LAPs in glacier ice included meltout of englacial LAPs besides atmospheric deposition. The enrichment and removal of LAPs in glacier ice was used same method with that in snow.

5. Figure 3a: It seems that the model results are consistently higher than observations during winter and spring. What could be the reason(s)?

Answer: the wind was very strong and snow was dry in winter and spring on the glacier, under the influence of strong wind, the fresh snow quickly packed together to a hard layer and partly mixed with old snow layer, thus the surface albedo would quickly reduce from albedo of fresh snow to albedo of firn. This process is hard to be expressed by the model and not considered by the albedo model. However, there were no melts in winter and spring, thus the overestimation did not influence results of melt.

6. Figure 4: Although the simulated mass balance agrees with observations, the simulated snow height is consistently lower than measurements. What are the implications? Is this only the issue with snow density simulation? Would this snow height bias affect the optimization of other model parameters?

Answer: low catching rate of rain gauge to snowfall and partly influence from snowdrift in windy winter together caused the underestimation of snow height. The parameters were calibrated by the measurements at site of 4550 m, so it did not affect the optimization of model parameters.

7. Figure 5: I am a little confused here. Are the BC and MD concentrations shown here both from measurements or model simulations? If they are from model results, how do they compare with measurements?

Answer: the BC and MD concentrations in Fig. 5 were from model simulations. We did not directly compare the simulated BC and MD concentrations with measured in Fig. 5, because all measurements were single-point and discrete. In the content, we mentioned measured concentrations of BC and MD, they had a similar magnitude with our simulated concentrations.

8. Figure 6: The albedo by removing all MD and BC is much higher than that by removing either of them particularly in the low-elevation areas. This nonlinearity seems to suggest the strong impacts from the snow grain growth induced albedo reduction during melting along with the MD/BC induced albedo reduction.

Answer: the sum of concentrations of BC alone and MD alone to glacier melt is much lower concentration of BC and MD together in the low-elevation areas, this is because there is an approximate logarithmic relationship between the concentration of LAPs and albedo reduction (formula 5), i.e., albedo declines rapidly with increase of LAPs in the case of low concentration of LAPs, whereas it declines slowly with increase of LAPs in the case of high concentration of LAPs (Line 326-329). In the low-elevation areas, the glacier ice always exposes in the ablation season. The glacier ice contains both BC and MD in high concentration, hence removal BC or MD alone causes limited impact on glacier albedo, because the remaining one of LAPs still could greatly reduce glacier albedo and increase of LAPs on this concentration could cause limited impact on glacier albedo.

9. Section 5.2: Is there any observation to validate the glacier mass change in model results? For example, the GRACE satellite data?

Answer: section 5.2 mainly expressed potential contributions of increased BC emission and temperature to current glacier melting. This contribution can't be obtained by observations, only can be obtained by melting methods.