A point-by-point response to the reviews

Dear Reviewers:

Thank you for your comments and the reviewers' comments concerning our manuscript entitled " Different responses of CO_2, CH_4, and N_2O fluxes to seasonally asymmetric warming in an alpine grassland of Tianshan Mountains" (MS No.: bg-2020-396). Those comments are all valuable and very helpful for revising and improving our paper, as well as the important guiding significance to our researches. We have studied those comments carefully and have made a point to point reply and correction. Revised portion are marked in red color in this manuscript. Specific corrections and responds to the reviewer's comments are listed as follows:

Comments to the Author:

 # the comment by Y.G. Du

This manuscript describes the response of GHGs emissions to seasonally asymmetric warming in an alpine grassland of Tianshan Mountains. It is an interesting topic to understand carbon and nitrogen cycles with increasing temperature. The manuscript is well written and concise. The experiment is well designed and conducted. I suggest this manuscript could be accepted after some minor revisions.

Introduction: the research advances of responses of CO_2, CH_4 and N_2O fluxes to seasonally asymmetric warming is very limited, more contents could be added especially in grassland ecosystem. Authors quoted many IPCC results about warming and its effect on GHGs fluxes, which need to be summarized.

Response: Thank you for your precise comment for the Introduction. We have added to the latest research on the effect of warming on greenhouse gas flux in grassland ecosystems. Add the following: "A recent study showed that seasonal variations in carbon flux were more closely related to air temperature in the meadow steppe (Zhao et al., 2019). Another study found that experimental warming enhanced CH_4 uptake in the relatively arid alpine steppe, but had no significant effects on CH_4 emission in the moist swamp meadow (Li et al., 2020). Furthermore, soil CH_4 uptake was not significantly affected by warming in the alpine meadow of the Tibetan Plateau (Wu et al., 2020). In contrast, a global meta-analysis showed that experimental warming stimulates C fluxes in grassland ecosystems, and the response of C fluxes to warming strongly varies across the different grassland types, with greater warming responses in cold than in temperate and semi-arid grasslands (Wang et al., 2019). Across the data set, Li et al. (2020) demonstrated that N_2O emissions were significantly enhanced by whole-year warming treatments. In contrast, no significant effects on soil N_2O emissions were observed by in short-season warming." See L321-333 of the revised manuscript.

We also summarized the IPCC results about warming and its effect on GHGs fluxes. The revised content is as follows: "The 3rd and 4rd Assessment Report of the Inter-Governmental Panel on Climate Change (IPCC) proposed that, against the backdrop of global warming, the temperature change shows that the warming amplitude in the winter is greater than that in the summer, with the warming amplitude at high latitude being greater than that at low latitude, and confirmed that the warming shows asymmetric trends on a seasonal scale (Easterling et al., 1997; IPCC, 2001, 2007)." See L124-210 of the revised manuscript.

Materials and methods: air temperature and precipitation data of growing season and non-growing season could not be found, which are important to explain the effect of seasonally asymmetric warming on GHGs flux.

Response: Thank you for your comment for the Materials and methods. We have presented air temperature and precipitation data through tow figures. And described the Figure S3 and S4 in the Appendix for the revised manuscript.

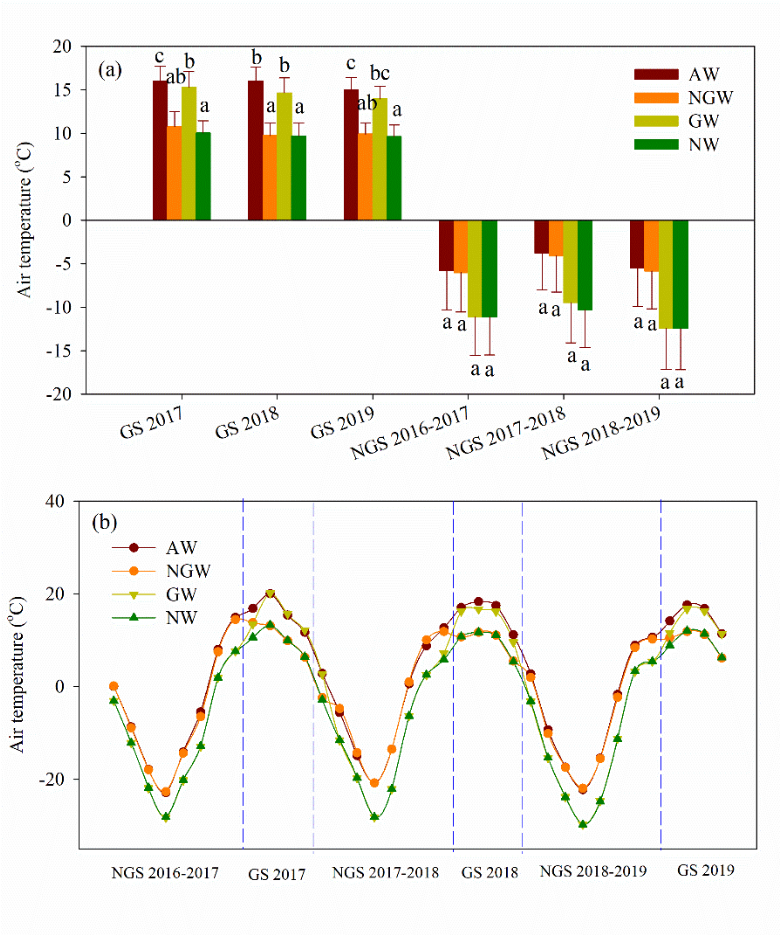

Figure S3 Variation in air temperature (inside the open-topped chamber, OTC, 50 cm above the ground) under four treatments in alpine grassland from October 2016 to September 2019. GS, growing season; NGS, non-growing season; AW, warming throughout the year; NGW, warming in non-growing season only; GW, warming in growing season only; NW, non-warming. No significant differences among AW, NGW, GW and NW from analysis of variance (ANOVA) are denoted as bars within the same season with a common lowercase letter, *P* < 0.05; data points are the mean ± standard error.

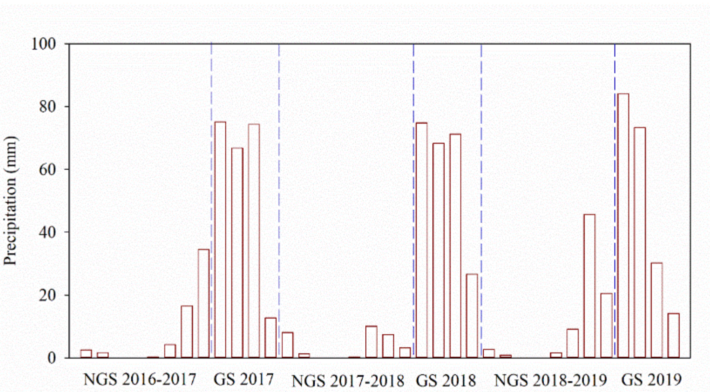

Figure S4 Variation in precipitation in the alpine grassland from October 2016 to September 2019. GS, growing season; NGS, non-growing season.

Discussion: please delete figure 2 and $P < 0.05$ or $P > 0.05$. The manuscript do not research the response of GHGs to daytime, nighttime or short-season warming, please delete it.

Response: Thank you for precise comment for the Discussion. However, we disagree with this comment. Figure 2 shows the highlights of this manuscript: "Response of variations in CO_2, CH_4, and N_2O fluxes to changes in soil temperature under AW, NGW and GW conditions in the alpine grassland, from 2016 to 2019." Figure 2 does not mention what the comments suggest: "the response of GHGs to daytime, nighttime or short-season warming".

Conclusions: please add the responses of CH_4 and N_2O fluxes to warming in the study.

Response: Thank you for your precise comment for the Conclusions. We have revised the conclusion as "In summary, the effect of seasonally asymmetrical warming on *Re* and N_2O emission was obvious, unlike the situation with CH_4 uptake. The *Re* and N_2O emission were able to adapt to continuous warming, resulting in a reduced response rates of the *Re* and N_2O emission to temperature increase. Warming in the non-growing season increased the temperature dependence of the *Re*. Thus, we believe that the study of climate change should pay greater attention to warming in the non-growing season, to avoid underestimating the greenhouse effect on *Re* in alpine grasslands." See L1090-1096 of the revised manuscript.

Anonymous Referee #1

I have reviewed this paper by Gong et al. This study revealed the effect of seasonally asymmetric warming on greenhouse gas fluxes in alpine grassland, and it advances our understanding of warming effects on greenhouse gas fluxes. I think there are a few minor issues that could be improved Before it could be accepted for publication.

1) The authors should focus more on the mechanisms behind the different responses of greenhouse gas fluxes to seasonally asymmetric warming.

Response: Thank you for your precise comment. We revised the manuscript.

L820-832, “Ecosystem CH_4 flux is the net result of CH_4 production and consumption, occurring simultaneously under the action of methanogenic archaea and methane-oxidizing bacteria (e.g., Mer and Roger, 2001). In addition, our results demonstrated that warming increased CH_4 uptake in the growing season, but decreased CH_4 uptake in the non-growing season in the alpine grassland, findings similar to those from other grassland ecosystems (Lin et al., 2015; Wu et al., 2020; Zhu et al., 2015). Our results also demonstrated that seasonally asymmetric warming did not significantly affect the response rate of CH_4 uptake (Figure 3 d-f, $P > 0.05$). CH_4 flux depended on temperature, pH, and the availability of substrate (e.g., Treat et al., 2015). The CH_4 uptake observed during the three growing season and non-growing season implied that the alpine grassland soil could act as an atmospheric CH_4 sink, a finding which agrees with the results of many previous studies in similar regions (Wei et al., 2015; Zhao et al., 2017).”

L947-949, “Unlike CH_4 flux in alpine grasslands, Treat et al. (2018) confirmed that wetland was a small CH_4 source in the non-growing season, whereas uplands varied from CH_4 sinks to CH_4 sources.”

L960-966, “However, our results displayed N_2O emission peaks during the freeze–thaw periods (e.g., May 2017, June 2018 and April 2019). Warming increased N_2O emissions in the thawing period due to disruption of the gas diffusion barrier and greater C and N availability for microbial activity (Nyborg et al., 1997). Wagner-Riddle et al. (2017) also demonstrated that the magnitude of the freeze/thaw-induced N_2O emissions was associated with the number of days with soil temperatures below 0^oC.”

2) There are a few minor things needed to be revised throughout the manuscript.

For example, Line 16: ”greenhouse gas flux” should be changed to ”greenhouse gas fluxes”; Line 154: ”Figure 2” should be ”Fig. 2” to be consistent with other places.

Response: Thank you for your precise comment. Line 16: we revised as “greenhouse gas fluxes”. See L108 of the revised manuscript.

Anonymous Referee #2

General comments

The manuscript “Different responses of CO2, CH4, and N2O fluxes to seasonally asymmetric warming in an alpine grassland of Tianshan Mountains” by Gong et al. describes the effects of seasonal warming (growing season warming, non-growing season warming, annual warming) on CO2, CH4, and N2O fluxes during 3 years at an alpine grassland site in the southern Tianshan mountains, China.

I value the authors efforts to collect multi-year, and year-round data with manual chamber measurements. While I find evaluating the response of GHG fluxes to changes in temperature during different seasons highly important (especially the non-growing season), the manuscript in its current state has several shortcomings, which I have outlined in my specific comments and line edits below.

Specific comments

1) The authors discuss CO2 fluxes, however, it is unclear which component of the CO2 flux has been measured. It would seem that ecosystem respiration was measured, which should be stated clearly throughout the manuscript. Temperature is a well known control on respiration, but based on this study the authors can not draw conclusions on the effect of temperature on net CO2 exchange without accounting for photosynthesis. I suggest revising the manuscript text accordingly.

Response: As the anonymous referee’s comment, we're measuring ecosystem respiration. We revised the manuscript text accordingly. See the revised manuscript.

2) To understand the observed interannual variations in GHG exchange in response to temperature it would be important to include information on other climate parameters as well, especially interannual variations in precipitation, soil moisture and

or water table. If this data is available, I highly recommend including it and to add discussion on this topic.

Response: Thank you for your precise comment. We plot the changes of precipitation, air temperature and soil moisture, and analyze the influence of soil temperature and moisture on greenhouse gas fluxes and their association effect through variance decomposition. we do not have the monitoring data of the groundwater level in Bayinbuluk Grassland. We will carry out the work in the future. It was discussed and analyzed in the revised manuscript. As shown in the figure below:

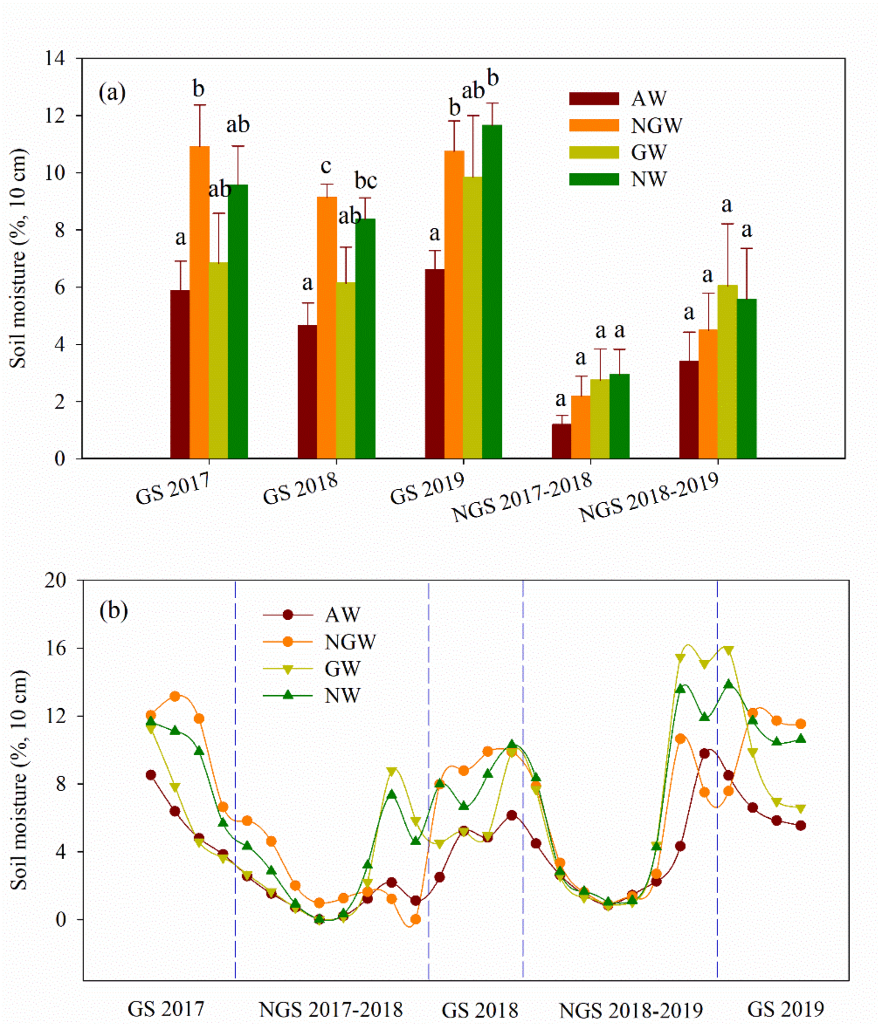

Figure S2 Variation in soil moisture (at 10-cm depth) under four treatments in alpine grassland from June 2017 to September 2019. GS, growing season; NGS, non-growing season; AW, warming throughout the year; NGW, warming in nongrowing season only; GW, warming in growing season only; NW, non-warming. Significant differences among AW, NGW, GW and NW from analysis of variance (ANOVA) are denoted as bars within the same season with different lowercase letters, $P < 0.05$; data points are the mean ± standard error.

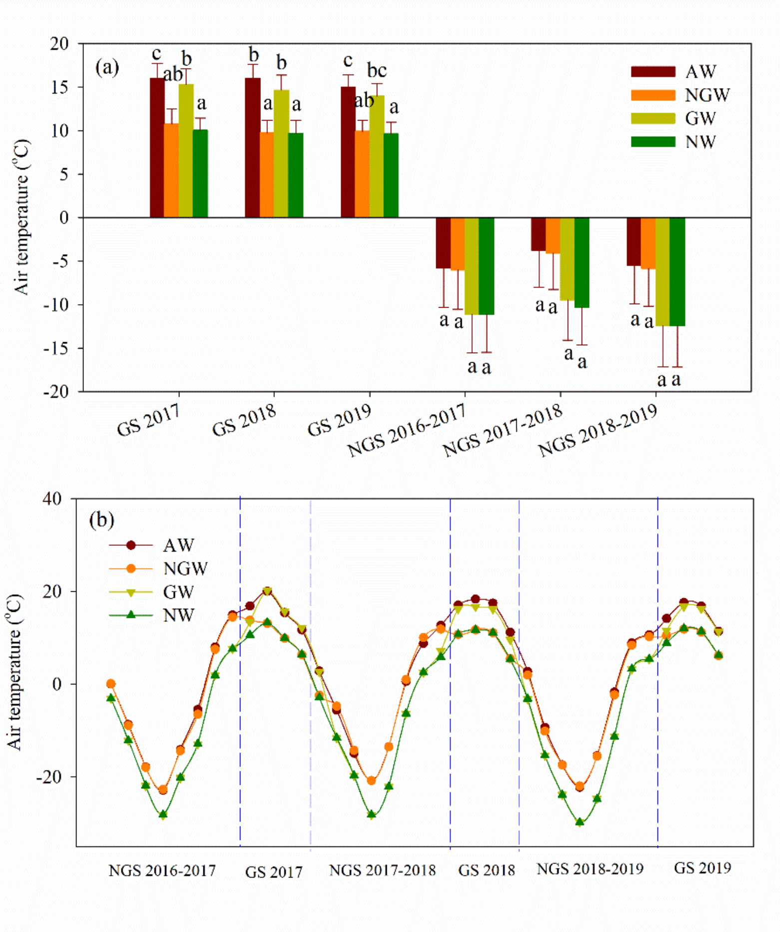

Figure S3 Variation in air temperature (inside the open-topped chamber, OTC, 50 cm above the ground) under four treatments in alpine grassland from October 2016 to September 2019. GS, growing season; NGS, non-growing season; AW, warming throughout the year; NGW, warming in non-growing season only; GW, warming in growing season only; NW, non-warming. No significant differences among AW, NGW, GW and NW from analysis of variance (ANOVA) are denoted as bars within the same season with a common lowercase letter, $P < 0.05$; data points are the mean ± standard error.

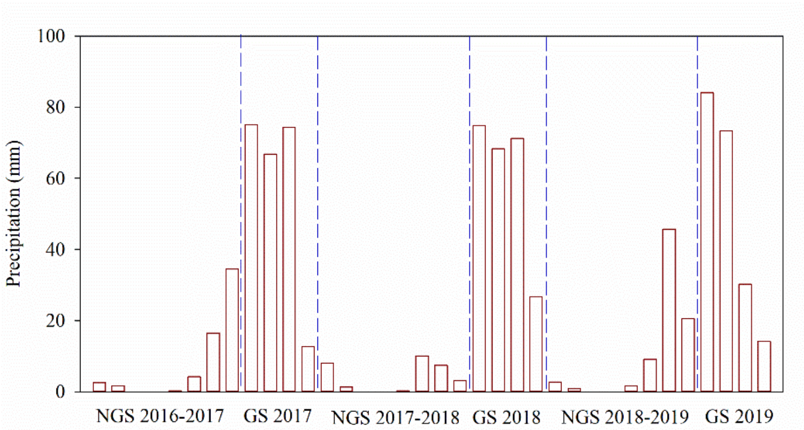

Figure S4 Variation in precipitation in the alpine grassland from October 2016 to September 2019. GS, growing season; NGS, non-growing season.

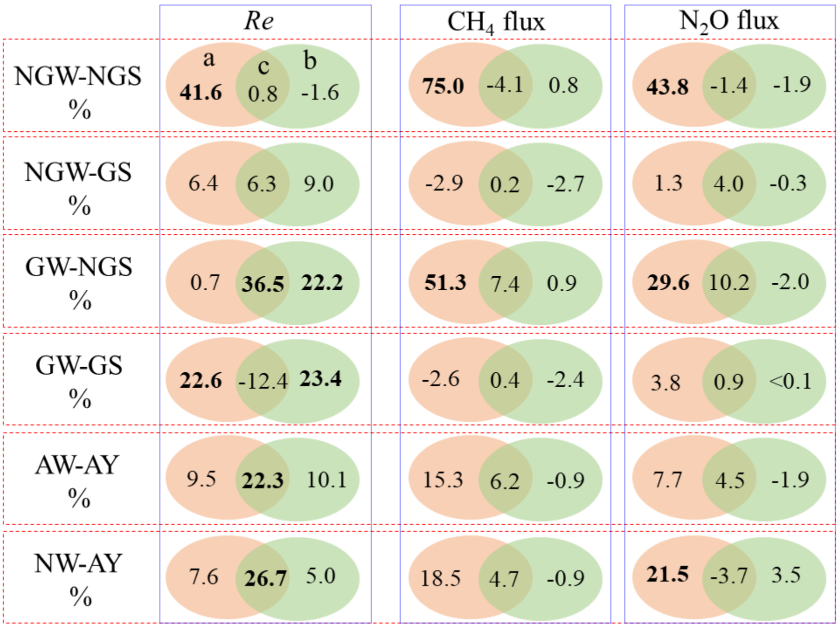

Figure 4 Influence of soil temperature and soil moisture on ecosystem respiration (*Re*), CH_4 uptake, and N_2O emission by variation-partitioning analysis under four treatments in the growing season and non-growing season. a, Single effect of soil temperature (%); b, single effect of soil moisture (%); c, joint effects of soil temperature and moisture (%); NGW-NGS, greenhouse gas fluxes in non-growing season under non-growing season warming treatment; NGW-GS, greenhouse gas fluxes in growing season under non-growing season warming treatment; GW-NGS, greenhouse gas fluxes in non-growing season under growing season warming treatment; GW-GS, greenhouse gas fluxes in growing season under growing season warming treatment; AW-AY, annual

greenhouse gas fluxes under annual warming treatment; NW-AY, annual greenhouse gas fluxes without warming.

3) Adding discussion on whether the warming treatment with OTCs impacted other environmental variables (such as soil moisture, snow depth) would be needed in order to assess the effectiveness of the warming treatment and validity of results. Shortly reporting results on the achieved temperature increase in the warmed plots compared to control treatments in the results section would be helpful as well (this is only shown in the supplementary material Fig S1).

Response: Thank you for your precise comment. Yes, warming treatment with OTCs impacted soil moisture and snow depth. The change of snow depth mainly affects the soil moisture, therefore, we focused on the analysis of how warming affects the greenhouse gas flux by affecting soil moisture (Figure 4). We added the information in the revised manuscript.

4) Introduction as well as discussion and conclusion remain rather superficial. This manuscript would greatly benefit from some streamlining, clearly stating the objectives and relevance of this study, and a more thorough literature review and comparison to other studies. For example, this study reports rather large CH4 uptake rates. How do these rates compare to what is observed in other studies from similar ecosystems? Based on the findings of this study, can larger-scale conclusions be drawn on what impact warming will have on CH4 uptake in these ecosystems? The study also reports all three GHGs, which is a strength of this study, as measurements of N2O fluxes in particular are rare in colder climates. The authors could highlight this in their study, and provide some comparison to other studies. And while investigating the effect of temperature on fluxes was clearly the aim of this study, some acknowledgement of drivers of GHG fluxes other than temperature would be useful to include.

Response: Thank you for your precise comment. We revised the manuscript and added the information of your comments. For example, L124-210, "The 3rd and 4rd Assessment Report of the Inter-Governmental Panel on Climate Change (IPCC) proposed that, against the backdrop of global warming, the temperature change shows that the warming amplitude in the winter is greater than that in the summer, with the warming amplitude at high latitude being greater than that at low latitude, and confirmed that the warming shows asymmetric trends on a seasonal scale (Easterling et al., 1997; IPCC, 2001, 2007)."

L214-219, "Experimental warming is known to influence ecosystem respiration (*Re*), CH_4 uptake, and N_2O emission (Pärn et al., 2018; Treat et al., 2018; Wang et al., 2019). Information on *Re*, CH_4 uptake, and N_2O emission and their sensitivity to warming, will enhance our understanding of ecosystem C and N cycling processes and improve our predictions of the response of ecosystems to global climate change (Li et al., 2020; Wang et al., 2019)."

L223-228, "A study of the Alaskan tundra found that summer warming (using open-top chambers to increase air temperatures in the growing season) significantly increased *Re* in the growing season by about 20 % (Natali et al., 2011). Compared with the slight effect of winter warming on the CO_2 fluxes in the growing season, warming increased CO_2 fluxes during the snow-covered non-growing season by more than 50% (Natali et al., 2011)."

L321-333, "A recent study showed that seasonal variations in carbon flux were more closely related to air temperature in the meadow steppe (Zhao et al., 2019). Another study found that experimental warming enhanced CH_4 uptake in the relatively arid alpine steppe, but had no significant effects on CH_4 emission in the moist swamp meadow (Li et al., 2020). Furthermore, soil CH_4 uptake was not significantly affected by warming in the alpine meadow of the Tibetan Plateau (Wu et al., 2020). In contrast, a global meta-analysis showed that experimental warming stimulates C fluxes in grassland ecosystems, and the response of C fluxes to warming strongly varies across the different grassland types, with greater warming responses in cold than in temperate and semi-arid grasslands (Wang et al., 2019). Across the data set, Li et al. (2020) demonstrated that N_2O emissions were significantly enhanced by whole-year warming treatments. In contrast, no significant effects on soil N_2O emissions were observed by in short-season warming."

L398-402, "For example, over longer time periods of warming, accelerated carbon decomposition and increased plant N uptake may decrease soil organic C and N pools (Wu et al., 2012), and the microbial community with variable C use efficiency may reduce the temperature sensitivity of heterotrophic respiration (Zhou et al., 2012)."

L406-409, "Therefore, we hypothesize that warming in the non-growing season will stimulate GHG flux (especially during the non-growing season) in the alpine steppe. However, continuous warming throughout the year and during the growing season will reduce the sensitivity of GHG flux to warming."

L820-832, "Ecosystem CH_4 flux is the net result of CH_4 production and consumption, occurring simultaneously under the action of methanogenic archaea and methane-oxidizing bacteria (e.g., Mer and Roger, 2001). In addition, our results demonstrated that warming increased CH_4 uptake in the growing season, but decreased CH_4 uptake in the non-growing season in the alpine grassland, findings similar to those from other grassland ecosystems (Lin et al., 2015; Wu et al., 2020; Zhu et al., 2015). Our results also demonstrated that seasonally asymmetric warming did not significantly affect the response rate of CH_4 uptake (Figure 3 d-f, $P > 0.05$). CH_4 flux depended on temperature, pH, and the availability of substrate (e.g., Treat et al., 2015). The CH_4 uptake observed during the three growing season and non-growing season implied that the alpine grassland soil could act as an atmospheric CH_4 sink, a finding which agrees with the results of many previous studies in similar regions (Wei et al., 2015; Zhao et al., 2017)."

L947-949, "Unlike CH_4 flux in alpine grasslands, Treat et al. (2018) confirmed that wetland was a small CH_4 source in the non-growing season, whereas uplands varied from CH_4 sinks to CH_4 sources."

L960-966, "However, our results displayed N_2O emission peaks during the freeze–thaw periods (e.g., May 2017, June 2018 and April 2019). Warming increased N_2O emissions in the thawing period due to disruption of the gas diffusion barrier and greater C and N availability for microbial activity (Nyborg et al., 1997). Wagner-Riddle et al. (2017) also demonstrated that the magnitude of the freeze/thaw-induced N_2O emissions was associated with the number of days with soil temperatures below 0^oC."

5) The discussion is rather short and exclusively focuses on the reponse rate of the three gases to temperature, while some of the rather interesting key findings of this study are not addressed (such as for example increasing annual CH4 uptake with warming, or increasing N2O emissions with warming during the non-growing season). It also looks like the site displayed emission peaks of N2O during the shoulder periods, especially spring, which might be an important point to mention in the discussion (see for example: Wagner-Riddle et al. (2017). Globally important nitrous oxide emissions from croplands induced by freeze–thaw cycles. Nature Geoscience 10(4):279-83).

Response: Thank you for your precise comment. We revise the sections according to your comments. See the revised manuscript, L820-832, "Ecosystem CH_4 flux is the net result of CH_4 production and consumption, occurring simultaneously under the action of methanogenic archaea and methane-oxidizing bacteria (e.g., Mer and Roger, 2001). In addition, our results demonstrated that warming increased CH_4 uptake in the growing season, but decreased CH_4 uptake in the non-growing season in the alpine grassland, findings similar to those from other grassland ecosystems (Lin et al., 2015; Wu et al., 2020; Zhu et al., 2015). Our results also demonstrated that seasonally asymmetric warming did not significantly affect the response rate of CH_4 uptake (Figure 3 d-f, $P > 0.05$). CH_4 flux depended on temperature, pH, and the availability of substrate (e.g., Treat et al., 2015). The CH_4 uptake observed during the three growing season and non-growing season implied that the alpine grassland soil could act as an atmospheric CH_4 sink, a finding which agrees with the results of many previous studies in similar regions (Wei et al., 2015; Zhao et al., 2017)."

L947-949, "Unlike CH_4 flux in alpine grasslands, Treat et al. (2018) confirmed that wetland was a small CH_4 source in the non-growing season, whereas uplands varied from CH_4 sinks to CH_4 sources."

We also revised the sections about "Our results suggested that the response of N_2O emission to temperature increase was limited by the warming that occurred throughout the year. However, our results displayed N_2O emission peaks during the freeze–thaw periods (e.g., May 2017, June 2018 and April 2019). Warming increased N_2O emissions in the thawing period due to disruption of the gas diffusion barrier and greater C and N availability for microbial activity (Nyborg et al., 1997). Wagner-Riddle et al. (2017) also demonstrated that the magnitude of the freeze/thaw-induced N_2O emissions was associated with the number of days with soil temperatures below 0^oC." See L958-966 of the revised manuscript.

Line edits

Abstract: L13-14: specify whether CO2 fluxes are ecosystem respiration or net ecosystem exchange, not clear if the reported numbers are net CO2 losses to the atmosphere. Also, do these numbers represent the total range of fluxes between 2016 and 2019? It might be more meaningful to present growing season as well as annual mean or median fluxes in the abstract, as fluxes, especially for CH4 and N2O, are highly variable.

Response: Thank you for your precise comment. CO2 fluxes are ecosystem respiration, we defined it exactly in the revised manuscript. For example, L12 "An experiment was conducted to investigate the effect of seasonally asymmetric warming on ecosystem respiration (*Re*), CH_4 uptake, and N_2O emissions in alpine grassland…"

We agree with this comment, and we revised as "…annual mean of *Re*, CH_4, and N_2O fluxes in growing season were 42.83 mg C m^{-2} h^{-1}, −41.57 μg C m^{-2} h^{-1}, and 4.98 μg N m^{-2} h^{-1}, respectively." See L14-16.

L14-15: this is counter intuitive and does not match with what is shown in supplementary figure S3 (where CO2 and N2O fluxes show a clear positive correlation with soil temperature, and CH4 uptake increases with increases temperature). Please rephrase.

Response: Thank you for your precise comment. We have revised this section as "The *Re*, CH_4 uptake, and N_2O emissions were positively correlated with soil temperature." See L19-20 of the revised manuscript.

L16-18: "the variation in GHG flux under seasonally asymmetric warming was different between the growing season and the non-growing season": this statement is vague, please be more specific and state clearly what was observed.

Response: Thank you for your precise comment. We revised this sentence as "Furthermore, warming during the non-growing season increased *Re* and CH_4 uptake in both the growing season and non-growing seasons. However, the increase in N_2O emission in the growing season was mainly caused by the warming during the growing season." See L16-19 of the revised manuscript.

L18-24: a short explanation of the term "response rate" might be needed in this context.

Response: We added a sentence to illustrate the term "response rate", the sentence is "In addition, the response rate was defined by the changes in greenhouse gas fluxes driven by warming." See L22-108 of the revised manuscript.

L24-27: A clear summary statement with the specific implications of this study would be needed here.

Response: we revised the sentence as "we observed the stimulatory effect of warming during the non-growing season on *Re* and CH_4 uptake. In contrast, the response rates of *Re* and N_2O emissions were gradually attenuated by long-term annual warming, and the response rate of *Re* was also weakened by warming over the growing season." See L109-112 of the revised manuscript.

Introduction: L38: daytime/nighttime differences are not addressed in this study. Consider removing from the introduction or add results and discussion to address this issue.

Response: we removed "and between daytime and nighttime" from the introduction. Relevant references were also deleted.

L34-36: Yes, but I would advise caution with this statement (considering the larger than average warming in higher latitudes and Arctic amplification).

Response: We accepted the comment and removed the sentence. Relevant references were also deleted.

L39: 3rd assessment report.

Response: we revised the term as "3rd". See L124 of the revised manuscript.

L48: delete "in the atmosphere"

Response: we deleted "in the atmosphere".

L47-49: some rephrasing might be needed (considering that water vapour is a major GHG present in Earth's atmosphere as well).

Response: we revised the sentence as "Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are three of the major greenhouse gases (GHGs) in the atmosphere". See L211-212 of the revised manuscript.

L47-50: a general statement with some background information on the influence of temperature on GHG production and emissions would be useful for the reader in this context.

Response: we added the statement as “Experimental warming is known to influence ecosystem respiration (*Re*), CH_4 uptake, and N_2O emission (Pärn et al., 2018; Treat et al., 2018; Wang et al., 2019). Information on *Re*, CH_4 uptake, and N_2O emission and their sensitivity to warming, will enhance our understanding of ecosystem C and N cycling processes and improve our predictions of the response of ecosystems to global climate change (Li et al., 2020; Wang et al., 2019).” See L214-219 of the revised manuscript.

L50: Please check those % numbers (radiative forcing of CO2 is larger than that of CH4).

Response: we checked those % numbers, and revised as “with their contributions to global warming being 60 %, 20 %, and 6 %, respectively (IPCC, 2007, 2013).”. See L213 of the revised manuscript.

L50-52: Not sure whether this statement is correct. At least in northern or high-elevation regions with less accessible sites, warming treatments are often conducted during the summer months. Some rephrasing might be needed.

Response: we revised this statement as “At present, most studies focus on the influence of warming on GHG flux in terrestrial ecosystems during the summer months (Keenan et al., 2014; Li et al., 2011; Yang et al., 2014).”. See L220-222 of the revised manuscript.

L55: please specify whether “CO2 flux” in this context refers to increased CO2 emissions or increased net uptake, and under what conditions this increase occurred (warming treatment or naturally warmer summer?).

Response: In light of this comment, we have revised this sentence as “A study of the Alaskan tundra found that summer warming (using open-top chambers to increase air temperatures in the growing season) significantly increased *Re* in the growing season by about 20 % (Natali et al., 2011).” See L223-226 of the revised manuscript.

L56-57: for simplicity, replace “the effect of increased temperature in winter” with “the effect of winter warming”.

Response: we replaced “the effect of increased temperature in winter” with “the slight effect of winter warming”. See L226 of the revised manuscript.

L56-58: This sentence is not quite clear. Does this mean winter warming did not affect growing season CO2 fluxes, but winter warming did increase CO2 fluxes during the nongrowing season? Consider rephrasing.

Response: we revised the sentence as “Compared with the slight effect of winter warming on the CO_2 fluxes in the growing season, warming increased CO_2 fluxes during the snow-covered non-growing season by more than 50% (Natali et al., 2011).” See L226-228 of the revised manuscript.

L58-60: replace “absorption” with “uptake.

Response: we replaced “absorption” with “uptake”. See L229 of the revised manuscript.

L62: start sentence with “A study by xx (2012) in an alpine grassland ecosystem showed: : :”

Response: Thank you for your accurate comments. We have revised them. See L316-317 of the revised manuscript.

L69: consider added examples for biotic and abiotic factors here.

Response: Thank you for your accurate comments. We added the sentence as “For example, over longer time periods of warming, accelerated carbon decomposition and increased plant N uptake may decrease soil organic C and N pools (Wu et al., 2012), and the microbial community with variable C use efficiency may reduce the temperature sensitivity of heterotrophic respiration (Zhou et al., 2012).” See 398-402 of the revised manuscript.

Wu, Z., Dijkstra, P., Koch, G. W., & Hungate, B. A. (2012). Biogeochemical and ecological feedbacks in grassland responses to warming. Nature Climate Change, 2, 458–461. https://doi.org/10.1038/nclimate1486

Zhou, J., Xue, K., Xie, J., Deng, Y. e., Wu, L., Cheng, X., … Luo, Y. (2012). Microbial mediation of carbon-cycle feedbacks to climate warming. Nature Climate Change, 2, 106–110. https://doi.org/10.1038/nclimate1331

L75-81: This is rather vague and I suggest to be more specific and clearly state the overall aim of this study.

Response: we revised as "Therefore, we hypothesize that warming in the non-growing season will stimulate GHG flux (especially during the non-growing season) in the alpine steppe. However, continuous warming throughout the year and during the growing season will reduce the sensitivity of GHG flux to warming. This current short communication will help to assess this variation with respect to GHG flux response to increasing temperatures against the backdrop of global climate change, by carrying out seasonally asymmetrical warming studies in alpine grasslands." See 406-412 of the revised manuscript.

Methods: L87: Is permafrost present at the site? If yes, it would be useful to add this information.

Response: Yes, permafrost is present at the site. We added the information as "Permafrost is present in the Bayinbuluk alpine grassland, with the average maximum frozen depth (from 2000 to 2011, Zhang et al., 2018) being more than 250 cm." See L418-443 of the revised manuscript.

L93: in addition to soil, vegetation and temperature it would be useful to add some information related to typical soil moisture/water table levels at the site, since that is important for discussing GHG exchange and observed interannual differences.

Response: Thank you for your comments, we added the sentence as "and the average annual soil moisture was 5.9 % (2017-2019)". See L451 of the revised manuscript.

L95: please provide description and dimensions of open-top chambers.

Response: we added the description and dimensions of open-top chambers as "The open-top chambers (OTCs) were made of 5 mm thick tempered glass. To reduce the impact of precipitation and snow, the OTC was constructed with a hexagonal round table which was 100 cm high, and the diagonals of the bottom and top were 100 cm and 60 cm, respectively." See L452-455 of the revised manuscript.

L101-108: please provide some more details regarding flux measurement and analysis. E.g., were pre-installed collars used for the flux measurement? Were the chambers equipped with a fan and pressure equilibration tube? Were chambers transparent or opaque? Please also mention the sign convention in this context (i.e. positive fluxes = emissions?).

Response: we revised these sentences as "Gas samples were taken 0, 10, 20 and 30 minutes after the lid of the static chamber was sealed in between 12:00 and 14:00 (GMT + 8) every day. The rates of ecosystem respiration, CH_4 and N_2O fluxes were calculated based on the change in concentration of CO_2, N_2O and CH_4 in each chamber over time by a linear or non-linear equation ($P < 0.05$, $r^2 > 0.95$) (the positive flux values represent emission, and the negative flux values represent uptake; Liu et al. 2012; Wang et al. 2013)." See L508-513 of the revised manuscript.

Wang K, Zheng X, Pihlatie M, Vesala T, Liu C, Haapanala S, Liu H (2013) Comparison between static chamber and tunable diode laser-based eddy covariance techniques for measuring nitrous oxide fluxes from a cotton field. Agric For Meteorol 171:9–19.

Liu C, Wang K, Zheng X (2012) Responses of N2O and CH4 fluxes to fertilizer nitrogen addition rates in an irrigated wheat-maize cropping system in northern China. Biogeosciences 9:839–850.

L105: please add the total number of sampling times. L105-108: What quality criteria were used to accept or reject fluxes? E.g. r2, RMSE, minimum number of sampling points during one flux measurements? This information is not provided in the cited reference (Chen et al 2013).

Response: we added the total number of sampling times as “A total of 232 samples were taken, collecting once or twice a week.” And revised L105-108 as “Gas samples were taken 0, 10, 20 and 30 minutes after the lid of the static chamber was sealed in between 12:00 and 14:00 (GMT + 8) every day. The rates of ecosystem respiration, CH_4 and N_2O fluxes were calculated based on the change in concentration of CO_2, N_2O and CH_4 in each chamber over time by a linear or non-linear equation ($P < 0.05$, $r^2 > 0.95$) (the positive flux values represent emission, and the negative flux values represent uptake; Liu et al. 2012; Wang et al. 2013).. See L508-513 of the revised manuscript.

Results: L124-125: In addition to the range, it would be useful to provide mean/median values here. I also suggest to add a few sentences describing the general pattern of fluxes as this site, before presenting the treatment results, to provide the reader with a general overview (for example stating that the site acted as a net CH4 sink, with negligible CH4 emissions, and small N2O source).

Response: Thank you for your precise comment. We revised the sentences as “Our study showed that the Bayinbuluk alpine grassland exhibited a low *Re*, was a net CH_4 sink, and a negligible N_2O source. The annual mean values of *Re*, CH_4 uptake, and N_2O emissions in the growing season were 42.83 mg C m^{-2} h^{-1}, 41.57 μg C m^{-2} h^{-1}, and 4.98 μg N m^{-2} h^{-1} , respectively, from October 2016 to September 2019 (Figure 1).” See L570-573 the revised manuscript.

L131-136: talking about an increase and decrease in CH4 flux is slightly confusing in this context, as the authors mainly observed CH4 uptake. The 6.4% increase in CH4 flux in the AW treatment that the authors report here is in fact an increase in CH4 uptake, according to Fig. S2. This would mean a decrease in CH4 from an atmospheric point of view, and I suggest to rephrase this whole section accordingly. To avoid confusion, it might be useful to refer to uptake and emissions, rather than fluxes, throughout the manuscript.

Response: Thank you for your precise comment. we rephrased this whole section accordingly. “The AW temperature change induced a 6.4% increase in CH_4 uptake in the growing season and a 3.8% decrease in the non-growing season. The GW treatment resulted in 7.1% and 10.2% increases in CH_4 uptake in the growing season and non-growing season, respectively. On the contrary, the NGW generated a 10.6% and 9.2 % decrease in CH_4 uptake in the growing season and non-growing season, respectively (Figure 2 b).” See L579-584 the revised manuscript.

L126-140: are all these reported %changes significant (standard errors seem rather large)? It would be useful to add information regarding statistical significance in Fig S2 and manuscript text.

Response: Thank you for your precise comment. One-way ANOVA results of *Re*, CH_4 uptake and N_2O emissions among the four warming treatments were not significant ($P > 0.05$). We added this information in the revised manuscript, “One-way ANOVA results of *Re*, CH_4 uptake and N_2O emissions among the four warming treatments were not significant, with the exception that the soil CH_4 uptake in the growing season 2019 under GW treatment was significantly higher than that of the AW and NGW treatments ($P < 0.05$).”. See L589-697 of the revised manuscript.

L126 and throughout: please specify which CO2 flux component is discussed (see specific comments above).

Response: Thank you for your precise comment. We revised “CO_2 flux” as “ecosystem respiration” and abbreviation for *Re* in the whole manuscript.

L143: delete “extremely”.

Response: Thank you for your precise comment. We deleted “extremely”.

L141-144: Do the authors mean interannual differences between growing seasons?

Response: Yes, Ecosystem respiration (*Re*), CH_4 uptake, and N_2O emissions were distinguished between growing seasons and non-growing seasons in interannual and intertreatment two-way repeated-measure ANOVA. The interannual differences in *Re*, CH_4 uptake, and N_2O emissions were all due to the growing season, except for significant differences in N_2O emissions during the non-growing season. (Figure 1)

L141-145: Generally, this section is not very clear and would benefit from some rephrasing. It would be important to state that interannual differences were larger than impact of warming treatment (for CO2 and N2O) according to Fig. 1, whereas warming treatment had a significant impact on CH4 fluxes.

Response: Thank you for your precise comment. We have added the sentences as "Therefore, interannual variation was larger than the impact of the warming treatment (for *Re* and N_2O emissions, Figure 1), whereas the warming treatment had a significant impact on CH_4 uptake." in order to better express the meaning of this section. See L703-705 of the revised manuscript.

L147-148: I suggest simplifying "CH4 flux showed significantly decreasing trends with increasing soil temperature" to something like "we observed increasing CH4 uptake with increasing soil temperature".

Response: Thank you for your precise comment. We revised as "we observed increasing CH4 uptake with increasing soil temperature", See L707 of the revised manuscript.

Discussion and conclusion: Please see my specific comments above regarding the discussion section, as well as:

L166-171: It would be useful to include some background information on mechanisms behind CH4 fluxes for the reader, i.e. when do emissions occur, what conditions promote CH4 uptake, why would temperature increase CH4 uptake, etc.

Response: Thank you for your precise comment. We revised this section as

“Ecosystem CH_4 flux is the net result of CH_4 production and consumption, occurring simultaneously under the action of methanogenic archaea and methane-oxidizing bacteria (e.g., Mer and Roger, 2001). In addition, our results demonstrated that warming increased CH_4 uptake in the growing season, but decreased CH_4 uptake in the non-growing season in the alpine grassland, findings similar to those from other grassland ecosystems (Lin et al., 2015; Wu et al., 2020; Zhu et al., 2015). Our results also demonstrated that seasonally asymmetric warming did not significantly affect the response rate of CH_4 uptake (Figure 3 d-f, $P > 0.05$). CH_4 flux depended on temperature, pH, and the availability of substrate (e.g., Treat et al., 2015). The CH_4 uptake observed during the three growing season and non-growing season implied that the alpine grassland soil could act as an atmospheric CH_4 sink, a finding which agrees with the results of many previous studies in similar regions (Wei et al., 2015; Zhao et al., 2017). Hu et al. (2016) suggested that asymmetrical responses of CH_4 fluxes to warming and cooling should be taken into account when evaluating the effects of climate change on CH_4 uptake in the alpine meadow on the Tibetan plateau. Unlike CH_4 flux in alpine grasslands, Treat et al. (2018) confirmed that wetland was a small CH_4 source in the non-growing season, whereas uplands varied from CH_4 sinks to CH_4 sources. The latest research confirmed that warming in the Arctic had become more apparent in the non-growing season than in the typical growing season (Bao et al., 2020). Hereby, Bao et al. (2020) found that the CH_4 emissions during the spring thaw and the autumn freeze contributed approximately one-quarter of the annual total CH_4 emissions. That experimental warming is stimulating soil CH_4 uptake in the growing season implies that the grasslands of the Bayinbuluk may have the potential to remove more CH_4 from the atmosphere under future global warming conditions.” See L822-958 of the revised manuscript.

L176-177: for the nongrowing season contribution of CH4 fluxes a comparison to other ecosystems would be useful; see for example Treat, C.C., Bloom, A.A. and Marushchak, M.E., 2018. Nongrowing season methane emissions–a significant component of annual emissions across northern ecosystems. Global change biology, 24(8), pp.3331-3343.

Response: Thank you for your precise comment. We added the sentences as "Unlike CH_4 flux in alpine grasslands, Treat et al. (2018) confirmed that wetland was a small CH_4 source in the non-growing season, whereas uplands varied from CH_4 sinks to CH_4 sources." See L949-951 of the revised manuscript.

L178-186: please see my specific comment regarding discussion of other environmental variables besides temperature. N2O in particular is rarely depend on just on variable, and the effect of temperature may often be masked by other variables such as water table, and mineral nitrogen availability. This may require at least short mention in the discussion section. See for example Pärn, J. et al. 2018. Nitrogen-rich organic soils under warm well-drained conditions are global nitrous oxide emission hotspots. Nature communications, 9(1), pp.1-8.

Response: Thank you for your precise comment. We added the sentences as "Pärn et al. (2018) found that N_2O emission from organic soils increases with rising soil NO_3^-, follows a bell-shaped distribution with soil moisture." See L969-971 of the revised manuscript.

Figures: Fig. 2: please add r2 and P-values for all figure panels (even for nonsignificant relationships). Fig S2: please add number of measurement times for growing season / non-growing season mean. Also, please specify in y-axis or figure caption which component of the CO2 flux is shown (ER?). As panel b shows CH4 uptake, I suggest to flip the y-axis, showing zero on top and negative values at the bottom. Overall, I would suggest to use boxplots (including quartile ranges and outliers) rather than barplots in this figure, to capture the full range of fluxes, as it would be important to show e.g. also the occurrence of emissions (for CH4) or uptake (for N2O). The authors may also consider moving this figure into the main text.

Response: Thank you for your precise comment. We added r^2 and *P*-values for all figure panels of the Fig. 3 in the revised manuscript. Based on these comments, we redrew Fig. S2 using boxplots (Now switch to Figure 2 in the revised manuscript), added number of measurement times for growing season / non-growing season mean.