Response to review comments

MS No.: BG-2021-193

Interactive comment on "Effects of soil water content on carbon sink strength in an alpine swamp meadow of the northeastern Qinghai-Tibet Plateau"

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January 2nd, 2022

Associate Editor Decision: Publish subject to minor revisions (review by editor) (16 Dec 2021) by Trevor Keenan

Comments to the Author:

Dear authors,

Thank you for your revisions to the manuscript in response to the points earlier raised by the reviewers. As you can see from their assessment, your response has addressed the majority of their concerns, though both has some outstanding questions and suggestions. Reviewer #2 in particular raises concerns regarding the title, the description of the novelty, and the identified effect of radiation. I understand that in the title you mean the effect on the carbon cycle, rather than interactive effects between the different drivers and the carbon cycle (which is what the reviewer understands the title to imply). I suggest clarifying this by changing the title to "Radiation, soil water content, and temperature effects on carbon cycling in an alpine swamp meadow of the northeastern Qinghai-Tibet Plateau", which is less ambiguous. Their second point about novelty should be addressed by following their suggestion to improve the introduction section. Their third point regarding variability in radiation deserves some thought, and I look forward to your response to this issue.

Given the additional suggestions from the reviewers, I would like to invite you to submit a

revised manuscript and response to their reviews, which I will review once submitted.

Thanks and best wishes,

Trevor

Dear Editor,

We appreciate editor and reviewers very much for your positive and constructive comments on our manuscript. The valuable suggestions and comments are of great help to us. We have studied every comment carefully and revised the manuscript according to your suggestions. Meanwhile, we have checked the format and punctuation marks. Point-by-point responses to the comments are listed below this letter. Please find attached the revised version and a marked-up manuscript version showing the differences to the last submitted version. Please note that the line numbers point to the non-marked manuscript. We hope the revised manuscript is satisfactory to your journal's standards and scope.

Please contact us freely if you need any further information. Thank you very much for your consideration and we look forward to hearing from you.

We wish you a Happy New Year.

Yours sincerely,

Junqi Wei

Response to Comments of Referee #1

I read the revised MS of "Radiation, soil water content, and temperature interactions with carbon cycling in an alpine swamp meadow of the northeastern Qinghai-Tibet Plateau", and found that the authors tried to address my previous comments by editing text and providing

some supplementary data. However, I am afraid that three of my concerns still remain to be addressed as following.

We thank Reviewer 1 (REF#1) for taking the time to assess again our manuscript and for providing general comments and main concerns. We believe your comments have helped to improve the manuscript and we carefully considered them. Here specifically we clarify 1) the title of the manuscript, 2) the innovation of our study explicitly in the introduction, and 3) the mechanisms underlying temporal variability of NEE and GPP.

(1) The title of the MS emphasizes the interactions among radiation, soil water content and temperature effect, but the main text of the MS did not mention the interaction effects among temperature, moisture and radiation at all.

Many thanks to REF#1 for further comments concerning the title. We indeed do not study the interactions among radiation, soil water content and temperature effect, but we intend to identify the controlling factors and highlight the effects of radiation, soil water content, and temperature on the carbon cycle. Therefore, based on your comment and also following the advice from the associated editor, we changed the title to:

> "Radiation, soil water content, and temperature effects on carbon cycling in an alpine swamp meadow of the northeastern Qinghai-Tibetan Plateau"

(2) The authors explained the novelty of this study in the response to my previous comments that "The experimental site is located at Haibei in the northeastern Tibetan Plateau. According to Wei et. al (2021), there are at least six eddy covariance sites at Haibei, including alpine swamp CO2 fluxes monitoring site. Haibei is the most densely distributed area of eddy covariance sites on the Tibetan Plateau. The strength of CO_2 sink and its diurnal, seasonal and interannual characteristics in alpine swamp at Haibei have been reported in previous publications, such as Zhao et al. (2005) and Zhao et al. (2010), yet it is also the first objective of this study. Thus, the innovation of the objective is not clear to me." However, in the revised

MS, the novelty of this study has not been clearly mentioned the Introduction section. It would be better if the authors' response regarding the novelty of this study could be summarized and added into the Introduction section.

Thanks for your suggestions regarding the novelty of this study. The REF#1 is right, we did not clearly express the novelty explicitly in the text (and just gave a detailed explanation in the response letter). Following REF#1's suggestion we complemented several of these points in the revised text to highlight the novelty of this study and improve the introduction section (L75-106):

> "However, the existing studies concerning ecosystem C dynamics on the QTP mainly focused on alpine meadows (Saito et al., 2009; Zhao et al., 2005, 2010; Zhu et al., 2015b), only a few analyses have been conducted to specifically characterize C dynamics in alpine swamp meadows (Zhao et al., 2010; Qi et al., 2021; Liu et al., 2020; Zhu et al., 2020). The magnitudes and interannual variations of net ecosystem exchange (NEE) in alpine wetlands from the QTP are proved to be closely related to radiation, precipitation, and temperature (Cao et al., 2017; Niu et al., 2017). Temperature has been identified as an important driver for ecosystem respiration (Re) in alpine swamp meadows, and Zhao et al. (2005, 2010) found that Re follows an exponential relationship with soil temperature. Other studies also noticed that rainfall is an important determinant of the interannual C sink/source strength in alpine swamp meadows (Liu et al., 2019; Zhu et al. 2020). For example, CO_2 emissions were reported to decrease notably after rain events (Zhao et al., 2010). Even though alpine swamp meadow ecosystems are characterised by high SWC, the role of SWC on C cycling has often been neglected or assumed to be less important. Compared to other factors, the effects of SWC on the net C uptake in alpine swamp meadows are still unclear. Climate warming and the associated enhanced evapotranspiration and permafrost degradation may change soil hydrology dramatically (Andresen et al., 2020; Zhao et al., 2019). Considering the critical role that SWC played in regulating C uptake and soil respiration of other ecosystem types (Ganjurjav et al. 2016; Peng et al., 2014; Quan et al., 2019; Taylor et al., 2017; Wu et al., 2019), it is important to understand whether the change of SWC would aggravate the saturated water stress or trigger drought effects on net C uptake in the alpine swamp meadow ecosystem under future climate warming.

These uncertainties require a detailed investigation to understand wetland C source/sink processes and their potential future C sink strength variations (sign and magnitude). In addition, as compared with alpine meadows, there still needs long-term continuous observations for the alpine swamp meadow to investigate C dynamics during dry and wet years. So a four-year field observation dataset is provided in this study to characterize and quantify the importance of SWC in addition to temperature and net radiation on the C sink strength of an alpine swamp meadow. Therefore, the objectives of this study are to (i) quantify the diurnal and seasonal variations of net ecosystem exchange (NEE), gross primary productivity (GPP), and ecosystem respiration (Re), (ii) identify and quantify the relative importance of different key environmental drivers contributing to the variability observed of NEE, Re, and GPP, and (iii) analyse how these C fluxes respond to soil water availability, temperature, and radiation variation in a QTP alpine swamp meadow. This study would provide new insights into better understanding of the complex C cycle dynamics in the Tibetan Plateau driven by the almost certain future intensified climate warming."

Section 4.3 and Table 2 show that the alpine swamp meadow studied by Zhao et al. (2005) and (2010) is a net C source, whereas the alpine swamp meadow in our study is a persistent and strong C sink. Such different results demonstrate that exist a substantial heterogeneity of net C uptake in alpine swamp meadows and thus further long-time observational studies are still needed to characterize its response to climate change. This is now also noted in section 4.3 (L394-402):

"The NEE observations from this study were within the NEE ranges of previous studies in similar ecosystems located across the QTP (-255.5 – 173.2 g C m^{-2} y^{-1}) (Table 2). According to Wei et al. (2021), there are six observational studies about C flux around our study site, three of them are focused on alpine swamp meadows. Among them, one study had one-year dataset (Zhang et al., 2008), and the other two characterized the same location (Zhao et al., 2005, 2010). The three studies were reported as a net C source, while our 4-year dataset revealed that this alpine swamp meadow functioned as a net C sink of -168.0 ± 62.5 g C m^{-2} y^{-1} at a 3571 m asl.. The different directions of C exchange suggest that there are still uncertainties in our understanding of C exchange in alpine swamp meadows, and further efforts are still needed to improve our projection of C balance change of this ecosystem under changing climate.”

(3) In the revised MS, the authors concluded that “The interannual variability of NEE and GPP were controlled more clearly by Rn” (Lines 252-253) based on machine learning approaches. However, there is no apparent change in Rn during the observational period according to the Rn data provided by the authors in this round of revision. In the MS, this is clearly mentioned as “there is no significant difference in net radiation between the four years we studied” (Lines 273-274). Thus, why interannual variability of NEE and GPP is dominated by Rn that has not apparently changed during the observational period. The mechanism underlying interannual variability of NEE and GPP still needs to be more rigorously analyzed.

Thank you for pointing out this confusing part and we apologize for making few semantic mistakes. Figure 5(c) first aggregated hourly data across the growing season of each year, and then calculated the importance of environmental variables for each growing season, independently. Figure 5(c) represents the contributions of environmental variables to seasonal variation of C fluxes in each specific year. Therefore, Figure 5(c) is consistent with the seasonal analysis where Rn has the largest impact on NEE and GPP (while experiencing a minimal variable importance difference between seasons).

We intended to use the results in Figure 5(c) to demonstrate the large and consistent contributions of Rn to GPP and NEE in all the observational years. The referee made us realize that it was not appropriate to use the word “*interannual*” to refer to the comparison of contributions in different years. Instead, in the revised manuscript, we modified the word “*interannual*” to “*inter-seasonal variability*” in Figure 5(c) and corresponding text.

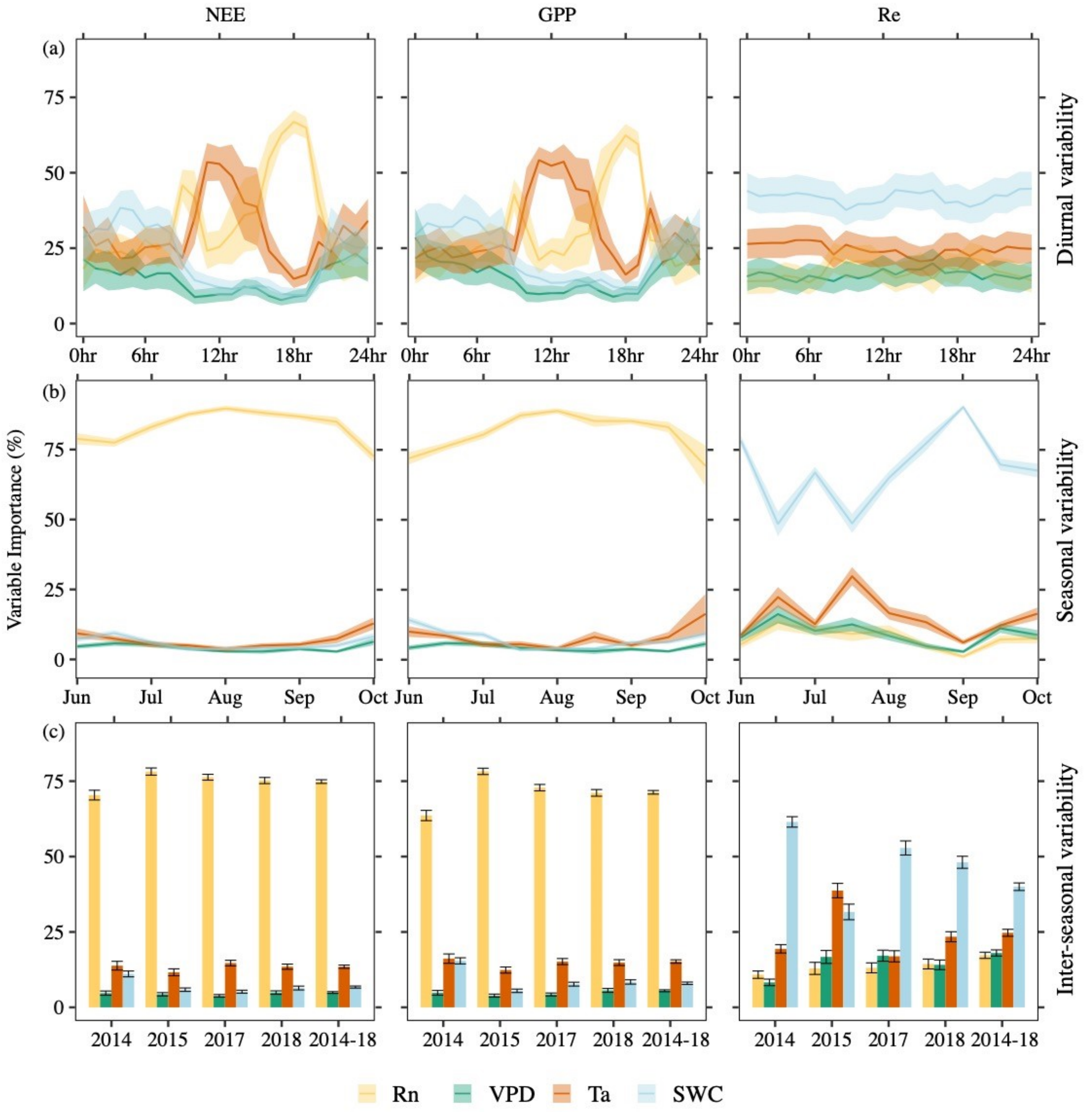

Figure 5. Contribution to diurnal and seasonal variation of NEE, GPP, and Re from different environmental drivers (Rn (yellow), Ta (orange), SWC (blue), and VPD (green)). Solid lines with shades (diurnal and seasonal variability) and bars with error bars (inter-seasonal variability) both illustrate the average ± standard deviation of the importance across 1000 decision trees. Inter-seasonal variability refers to the variability of the integrated growing season of 2014, 2015, 2017, and 2018.

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Response to Comments of Referee #2

I'm satisfied with how the authors have addressed all my comments in this improved version. I only have some minor concerns on this version:

We are thankful for the reviewer's insightful comments that substantially contributed to improve our manuscript. We have carefully considered the reviewer's remarks and clarified the manuscript accordingly.

1. Line 38–41: I don't think this manuscript analyzes the impact of climate warming on soil hydrological conditions of alpine swamp meadow. The authors can argue that C exchanges could be affected by changing soil hydrological conditions due to climate warming, but can not state the change of soil hydrological conditions in the future, which you did not study. Please clarify the difference.

Thank you for this comment. We agree and revised the sentence as follows (L38-41):

> "We argue that soil respiration and subsequent ecosystem C sink magnitude in alpine swamp meadows could likely be affected by future changes in soil hydrological conditions caused by permafrost degradation or accelerated thawing-freezing cycling due to climate warming."

2. Line 281–282: Is there any reference relating to alpine swamp meadow ecosystems to support these statements, that is, microbial activities were suppressed by the anaerobic environment due to saturated soil water conditions?

Thank you for pointing this out. We added the corresponding references in the text (L305-307) and to the reference list:

> "Therefore, microbial activity, and thus heterotrophic respiration were likely suppressed by the anaerobic environment due to saturated soil water condition (Chimner and Cooper, 2003; Sun et al.,

2021).”

3. Line 293–299: The explanation of the comparison between two specific time periods here is much clearer here than in the Method part (Line 177–183). But it’s better to merge Line 293–299 into the Method part to give a clear explanation there other than too late here. A brief introduction of the comparison is enough here.

Many thanks for this comment – following your advice we merged the old Line 293-299 into the Method part (old Line 177-183). Now the text in the Method section is as follows (L195-206):

> “Since C fluxes are affected by plant phenology and climate factors, including temperature, soil moisture, and radiation simultaneously, to analyze the effect of a single factor, ideally, other factors need to be identical or at least closed (no significant differences). In each comparison, data of the same period in each year were selected to exclude the influence of plant phenology. To further analyse the effect of soil moisture, radiation, and temperature on C fluxes, we selected a specific group of data for further evaluation other than the entire observation time. The group of data contains two late growing season periods: periods with a significant difference in SWC but almost identical Ta and Rn (i.e., late growing season of 2014 vs 2015) and periods with a significant difference in Ta but almost identical SWC and Rn (i.e., late growing season of 2014 vs 2018). Additionally, in order to analyse the effect of annual temperature on C fluxes, we selected a group of time stamps with significant differences in Ta but almost identical SWC and Rn (i.e., 2017 vs 2014, and 2018 vs 2014). The magnitude of the differences between C fluxes in the same group were analysed by the independent-sample T-test method.”

And we condensed the old Line 293-299 as follows (L313-315):

> “To better understand the underlying mechanisms around how SWC interacts with the C fluxes in the studied alpine swamp meadow ecosystem, we selected two late growing season periods, which have significant differences in SWC but no significant difference in Ta (Fig. 6(a); Table S2). ”

4. Line 388–389: I would suggest moving this sentence to the beginning of the next paragraph.

Thank you for this insightful comment. We modified and merged the old lines 380-387 and moved them right after old lines 388-389. Now the new paragraph is (L394-402):

> "The NEE observations from this study were within the NEE ranges of previous studies in similar ecosystems located across the QTP (-255.5 – 173.2 g C m^{-2} y^{-1}) (Table 2). According to Wei et al. (2021), there are six observational studies about C flux around our study site, three of them are focused on alpine swamp meadows. Among them, one study had one-year dataset (Zhang et al., 2008), and the other two characterized the same location (Zhao et al., 2005, 2010). The three studies were reported as a net C source, while our 4-year dataset revealed that this alpine swamp meadow functioned as a net C sink of -168.0 ± 62.5 g C m^{-2} y^{-1} at a 3571 m asl.. The different directions of C exchange suggest that there are still uncertainties in our understanding of C exchange in alpine swamp meadows, and further efforts are still needed to improve our projection of C balance change of this ecosystem under changing climate."

5. Line 417: Which flux?

Thanks. We specified the C exchange as Re. The sentence reads as follows (L428-431):

> "Soil moisture, however, has the largest influence over Re variability on diurnal and seasonal scales, suggesting that SWC is a key control on Re. In addition, air temperature played a less important role in regulating Re. "

6. Ecosystem respiration is sometimes abbreviated to Re, but sometimes not. The same goes for soil water content. Please make them consistent throughout the text.

Thanks – these have been revised.

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