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

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Response to Comments of Referee #1

Wei et al. reports that "Effects of soil water content on carbon sink strength in an alpine swamp meadow of the northeastern Qinghai-Tibet Plateau". This study investigated the diurnal, seasonal and annual variability of CO_2 fluxes and their drivers in an alpine swamp on the northeastern Tibetan Plateau. This helps to more clearly understand the role of alpine swamp in alpine ecosystem carbon (C) cycling in Tibetan Plateau, because alpine swamp cycling in Tibetan Plateau is less focused at regional scale, compared with alpine steppe and alpine meadow. The text is well-written and clear. Nevertheless, I have reservations about the innovation of scientific questions and the reliability of some results that need to be addressed before the publication of this manuscript.

We thank Reviewer #1 for taking the time to assess our manuscript and for providing general positive comments and main concerns. We believe the comments have helped to improve the manuscript and we carefully considered them. Here specifically we clarify the innovation of our scientific questions addressed in this study. As REF#1 pointed out, alpine swamps in Tibetan Plateau are less focused at regional scale than alpine steppes and alpine meadows. This study highlights among other things the importance of soil water availability regulating carbon sink strength of an alpine swamp, which is characterized by saturated water condition and high soil water content (SWC). The role of soil water has often been neglected or assumed to be less important relative to other factors for carbon (C) cycling. This study provides a four-year field observation dataset to characterize and quantify the importance of soil water controlling the C sink strength of an alpine swamp – one key finding is that a 15% decrease in soil water can induce 25% higher respiration and therefore weaken C sink strength by 20%, and an additional 44% increase of temperature at annual scale can also weaken the C sink strength by about 50% (see answer to comment number 4). These new insights will help us to better understand, model and predict the complex C cycle dynamics in the Tibetan Plateau driven by the almost certain future intensified climate warming.

(1) 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.

We appreciate REF#1 for sharing this very useful information about other existing eddy covariance sites and related references. We have now cited these previous studies in the revised manuscript see L76 and L77. According to Wei et. al (2021), there are six observational studies about C fluxes at Haibei. However, only three of the them focused on alpine swamp meadows (or wetland in Wet et. al (2021)). Among them, one study only focused on a 1-year dataset (Zhang et al., 2008), and the other two characterized the same location (Zhao et al., 2005, 2010). Moreover, these alpine swamp meadows were reported as a net C source while we our site showed a consistent C sink. The different directions of C exchange suggest that there are still uncertainties in our understanding of C exchange in this alpine swamp meadows, and further insights are obtained from studying multiple years of observations. Therefore, further efforts are still needed to improve our projection of C balance change of this ecosystem under changing climate.

Additionally, as mentioned before, previous studies focusing on C fluxes in alpine swamp meadows did not give enough consideration to the effects of soil water content on C fluxes given their nearly saturated nature. A number of previous studies have shown that temperature is an important driver of ecosystem respiration in similar alpine swamp meadows. For example, in the papers from Zhao et al. (2010) and Zhao et al. (2005), the authors showed that ecosystem respiration follows the exponential variation of soil temperature without considering soil water content. Zhu et al. (2020) also suggested that soil temperature plays the most important role in the change of monthly ecosystem respiration in the alpine wetland at Luanhaizi, northeastern

Qinghai-Tibet Plateau. Therefore, in this study, we wanted to characterize and estimate the terrestrial C exchange while considering the potential effects of soil moisture. Meanwhile, it should be noted that Zhao et al. (2010) also noticed that the CO_2 emission rates decrease notably after rain events, and Zhu et al. (2020) confirmed that annual precipitation exhibits significant impact on variation of annual net C uptake. All these existing studies have suggested that C fluxes are related to water availability condition, but few studies have found that soil moisture explicitly affects respiration, and its decrease further reduces net C uptake in alpine swamp meadows, this finding could be an important factor for carbon modelling in the future.

Finally, the addition and further analysis of multiple years of data from new sites is always very important also in a more regional/global context - there is a generalized sparsity of in situ observations where their temporal and spatial coverage is very limited. We believe that any effort and addition to this generalized lack of in situ data will be useful for both flux communities such as FLUXNET and ASIAFLUX and modelling community in general.

(2) The main drivers of NEE variation based on the different approaches are contradictory in this study. Net radiation is the leading factor affecting seasonal and annual variability of NEE based on machine learning approach (Fig. 5, Lines 231-250). However, the combined effect of temperature and soil moisture change is the main factor influencing the annual variation of NEE in Section 4.3 and Table 2. The title of this manuscript only emphasizes the effect of soil moisture. Therefore, there are three different descriptions of the dominant factor of CO_2 sink in this manuscript. The mechanism underlying NEE variation needs to be more rigorously analyzed.

Thank you for this insightful comment. Our first draft didn't present the findings clearly and it was somewhat misleading. First of all, we should acknowledge that the original title did not fully reflect our conclusions, therefore we revised it as follows:

> *"Radiation, soil water content, and temperature interactions with carbon cycling in an alpine swamp meadow of the northeastern Qinghai-Tibet Plateau".*

In the S4.3, we intend to put our results into a broader context by comparing with other surrounding alpine swamp meadow sites to highlight the effects of the complex interactions between temperature and soil water content on carbon fluxes. In this section, we did not intend to explicitly disentangle the most important drivers for the NEE at annual scales among these different sites, given that detailed observations for net radiation are lacking for other sites. Such comparison highlights the importance of SWC (precipitation as a proxy for SWC as explicit SWC is not present in these either) in controlling NEE. This further validates our Random Forest (RF) findings regarding the drivers for the Re in our site (Figure 5). We should keep in mind that NEE is the difference between Re and GPP, environmental variables affecting Re and GPP could affect NEE indirectly (Song et al. 2011).We revealed that the main drivers for the GPP, Re and NEE are remarkably different. Net radiation is a key driver of seasonal and annual NEE and GPP, while soil water content is most important for Re at diurnal, seasonal and annual scales. Therefore, our findings from the RF analyses are not contradictory to the discussions regarding the difference in NEE and the potential influence factors among different sites.

However, your constructive comments point out an interesting scientific issue regarding the divergent drivers for the NEE dynamics at different time scales across different alpine swamp meadow sites. This will be an excellent point to be addressed in our future study.

(3) A key conclusion of this study is that ecosystem respiration (Re) increases with decreasing soil water content (SWC). This is based on the comparisons of Re and SWC observations in the late growing seasons of 2014 and 2015 (Section 4.1). However, both SWC and Re in the late growing season are largest in 2017 during the observational period (2014-2017) (Figs. 2 and 4). Thus, the conclusion of "Section 4.1 Low soil moisture is associated with enhanced ecosystem respiration" (Lines 262-312) is likely to be unreliable. All observational years (2014, 2015, 2017 and 2018) are recommended to be considered in the analyses, rather than only two years (2014 and 2015).

Many thanks for this comment - we have not clearly described the comparisons in S4.1 between years in the text. Since C fluxes are affected by plant phenology and climate factors including temperature, soil moisture, and radiation simultaneously (Figure 5), in order to analyze the effects of single factor, ideally, other factors need to be identical or at least close (no significant differences). Based on this theory, we made our comparisons of specific time periods other than all the observation time. We now explicitly implemented the following text in S4.1, L288-293:

> *"Since C fluxes are affected by plant phenology and climate factors including temperature, soil moisture, and radiation simultaneously (Fig. 5), to analyze the effects of single factor, ideally, other factors need to be identical or at least close (no significant differences). Based on this theory and to better understand the underlying mechanisms around how SWC interacts with the C fluxes in the studied alpine swamp meadow ecosystem, we selected a specific group of data for further evaluation other than the entire observation time. "*

As described in S2.4, L177-184, we chose explicitly 2014 and 2015 for comparison in S4.1 because there was not a significant change in temperature (<1%) between these two periods, while soil water content decreased significantly more (15.4%) in 2015 (see Table S2). Therefore, within this set of conditions we can compare the influence of soil water content reduction on Re, and its influence further over NEE. Similarly, in S4.2, we also chose 2014 and 2018 for comparison, because the temperature difference between these two periods was greatest (25%) while there was no significant difference in soil water content (0.1%) (see again Table S2), so we could isolate and study the impact of temperature increase over the C fluxes.

Although the soil water content and ecosystem respiration in 2017 were at their highest, the temperature was also higher than in 2015, so we cannot compare it with 2015 to study separately the influence of soil water content change on ecosystem respiration and further net C uptake. To clarify this, we included a more detailed explanation about this comparison in the revision, see S2.4, L177-184:

> *"To further analyse the effect of soil moisture, radiation, and temperature on C fluxes, we selected two groups of time stamps with significant difference in SWC but almost identical Ta and Rn (i.e. late growing season of 2014 vs 2015) and 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 difference in Ta but almost identical SWC and Rn (i.e. 2017 vs 2014, and 2018 vs 2014). We made the comparison in each group to exclude the influence of plant phenology,*

which can influence C fluxes significantly. The magnitude of the differences between C fluxes in the same group were analysed by the independent-sample T-test method."

Please note also that we included a new column with net radiation to complement the comparison and expand the discussion in order to improve the manuscript's clarity and align better with RF findings, this is including also radiation as suggested by REF#1 indirectly in the earlier point but also explicitly suggested by REF#2 later on.

Table S2. Seasonally aggregated environmental drivers and C fluxes in the late growing season of 2014, 2015, and 2018 and their relative difference between years.

Period	Ta (°C)	Rn (W m^{-2})	SWC (%)	NEE (g C m-2)	Re (gC m-2)	GPP (g C m-2)
2014 Late GS	6.8±2.6	93.2±49.4	80.7±4.1	-175.6	152.7	328.3
2015 Late GS	6.8±2.5	93.2±43.6	68.3±4.3	-141.6	191.9	333.5
2018 Late GS	8.5±3.4	97.7±47.6	80.8±3.8	-134.3	225.4	359.7
2015 - 2014	0.8%	-0.1%	-15.4%	-19.4%	25.7%	1.6%
2018 - 2014	25%	4.8%	0.1%	-23.5%	47.6%	9.6%

Note: late GS represents late (Aug. - Sep.) growing season.

(4) Another key conclusion of this study is that warming leads to higher C losses rather than enhanced C uptake. This is based on the comparisons of Re and GPP observations in the late growing seasons of 2014 and 2018 (Section 4.2). Warming decreases NEE in late growing season but this does not indicate that warming decreases annual NEE. Recently, Wei et al. (2021) found that "plant uptake of CO2 outpaces losses from permafrost and plant respiration on the Tibetan Plateau" at annual scale based on 32 eddy covariance sites

in the Tibetan Plateau. Thus, the authors should more rigorously examine whether warming decreases net C sink of alpine swamp on the Tibetan Plateau.

This is a great point, thanks for bringing this up. In the revised manuscript, we added a new Table S4 to characterize the effect of temperature increase on net C uptake at annual basis and added more discussion accordingly. Based on a new variance analysis, soil water content in 2015 was significantly lower than in 2014, 2017, and 2018 ($p < 0.05$), while there was no significant difference in soil water content between 2014, 2017, and 2018, and there was also no significant difference in net radiation between these four years either. Therefore, we chose 2014, 2017, and 2018, when there was no significant difference in moisture conditions, to study the impact of temperature increase on C fluxes at an annual scale in the alpine swamp meadow. In fact, according to our data there was a reduction of net C uptake in warmer 2017 and 2018, and an increase of GPP and Re in 2017 and 2018 compared with 2014 (the increase of GPP is relatively lower than Re in warmer 2017 and 2018). Therefore, these extended results indicate that a temperature increase can decrease the net C uptake on an annual scale in this site. We added a new Table S4 in the supplement material:

Table S4. Daily aggregated environmental drivers and C fluxes in 2014, 2017, and 2018.

Year	Ta (°C)	Rn (W m^{-2})	SWC (%)	NEE (g C m^{-2})	Re (g C m^{-2})	GPP (g C m^{-2})
2014	-0.9 ± 8.2	72.2 ± 52.9	47.8 ± 32.0	-240.3	561.1	801.4
2017	-0.5 ± 8.3	73.4 ± 53.7	50.2 ± 32.8	-117.6	959.3	1076.9
2018	-0.5 ± 9.1	74.7 ± 54.9	49.8 ± 31.6	-113.4	788.4	901.8
2017-2014	44.4%	1.7%	5.0%	-51.1%	71.0%	34.4%
2018-2014	44.4%	3.5%	4.1%	-52.8%	40.5%	12.5%

We further added the following text in Section 4.2, L330-336:

> *"To evaluate if this finding is also consistent at an annual scale, we further analyzed annual aggregated data. An annual comparison was made between the 2014, 2017, and 2018 when SWC were found insignificantly different while temperatures in 2017 and 2018 were 44.4%*

higher than in 2014 (Table S4). Additionally, this 44.4% increase in Ta in 2017 and 2018 both led to stronger GPP and Re (Table S4). Although both GPP and Re increased, the intensity in Re was greater than GPP, indicating that warmer temperatures have a stronger impact on ecosystem respiration in this site, resulting in an approximately 50% decrease of the net C uptake (Table S4).”

We thank REF#1 for pointing us towards this nice paper by Wei et al., 2021 *“Plant uptake of CO_2 outpaces losses from permafrost and plant respiration on the Tibetan Plateau”*. We benefited a lot from this paper. The conclusion from Wei et al. (2021) are based on data of 32 eddy covariance sites during 2002 to 2020, while our study only covers 4-years of year-round observations. Differences in time and space scales may help to explain the differences we found. In fact, in the figure 4 from Wei et al. (2021) there are specific sites from Haibei where RR_{NEP} (Response ratio of NEP to the warming rate) is smaller than 1.0, indicating a negative effect of warming on the NEP. Potential site-specific differences together with the particularity of water condition in of alpine swamp ecosystem could be the possible reason. We have added more text in the discussion section S4.2, L347-353.

“Wei et al. (2021) also found that the uptake of C by plants will exceed the amount of C release under warmer and wetter climate conditions at annual scale based on manipulative experiments and model simulations focused on the Tibetan Plateau. Their study is based on a longer-term trend while our study only covers 4-years of year-round observations thus site-specific differences in time and space scales may explain this variability. Nevertheless, such results indicating inconsistent ecosystem responses suggest that there are still large uncertainties in the responses of C flux components to temperature variation and further work is still crucial.”

Specific comments

(1) Line 26, “-168.0 ±-62.5” may should be “-168.0 ± 62.5”.

Typo, thanks for picking it up. Changed accordingly.

(2) Lines 75-76, "only a few experiments have been conducted to specifically characterise alpine swamp meadow ecosystem C dynamics.", but no study focusing on alpine swamp C cycling is mentioned at here. The previous studies focusing on alpine swamp CO2 fluxes in the Tibetan Plateau are recommended to be mentioned, such as alpine swamp CO2 fluxes observations at Haibei (Zhao et al., 2005, 2010), Shenzha (Qi et al., 2021), Nam Co (Liu et al., 2020), and Huanhaizi (Zhu et al., 2020).

References

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Qinghai-Tibetan Plateau. Journal of Geophysical Research-Biogeosciences, 125 (11). 10.1029/2020jg006011.

Thank you very much for this very useful information concerning previous studies including sites focusing on alpine swamp CO_2 fluxes. Following the recommendation from REF#1 we have cited these previous studies and updated the description in the revised manuscript to further highlight the novelty of this study, S1, L75-78:

> *"Although many studies concerning ecosystem C dynamics on the QTP have focused on alpine meadow ecosystems (Saito et al., 2009; Zhao et al., 2005, 2010; Zhu et al., 2015b) and alpine swamp meadow ecosystems (Zhao et al., 2005, 2010; Qi et al., 2021; Liu et al., 2020; Zhu et al., 2020), the effect of SWC on the C uptake is still unclear as compared to that of temperature for alpine swamp meadow ecosystems."*

Interactive comment on Biogeosciences Discuss., https://doi.org/10.5194/bg-2021-193