Responses to Reviewers

Responses to reviewer#1

General Comments

Yun et al. present in this paper eddy covariance based observations of landatmosphere methane exchanges in concert with environmental data, such as climate and soil temperature or water content. The data shows that the site at the Tibet plateau is a net annual methane sink, which is an important finding for better constraining bottom-up estimates of the methane balance. Most semi-empirical models so far do not allow any methane sink but assume a methane source of soils. Interestingly, this ecosystem, if uniform in soil properties and vegetation, seems to act as methane source during winter and spring while acing as a methane sink in summer and autumn. These findings are interesting and important, and the paper is in general well written. Still, I do have some questions and comments that should be addressed thoroughly prior to any publication.

Response: Thank you very much for your insightful comments and great suggestions, which are tremendously helpful for us to improve the manuscript. Following your comments, we have revised the manuscript. Detailed responses to each of your comment and suggestion can be found in the following point-to-point responses.

1. i)*: This is a good introduction into the topic and knowledge gap. However, I request to state the research questions addressed here more precisely. I can see at least three questions: - What is the long-term annual methane budget of the study site? - What is the seasonal methane budget of the study site? - Which environmental factors control the seasonal methane budget and why? - Is a classical vegetation productivity based definition of growing season useful for defining the methane flux seasonality? The manuscript tries to address all these questions but it is useful to*

state them precisely in the introduction, and then they can be addressed with respective methods and presentation of results.

Response: Thank you for the suggestion of clearly stating the research questions in the Introduction. Following these suggestions, we have included explicit statements on research goals in the revised manuscript (lines 69 – 77).

"The primary aims of this investigation are to understand (1) the long-term annual and seasonal variation of the methane budget for a typical alpine permafrost site in the QTP, and (2) the environmental factors controlling these CH_4 variations and possible underlying mechanisms. In addition, while the consumption and production of ecosystem methane are known through microbial activities, conventional investigations on seasonal methane fluxes usually used climate or vegetation defined "seasons". Therefore, a third research goal of this current study is to investigate if the classical vegetation productivity-based definition of growing season will be useful for defining the methane flux seasonality."

2. ii) Cryoturbation is a collective term for many soil transport processes based on freezing and thawing that lead to a subduction of topsoil horizons down to the transition zone. This term is wrongly used in this manuscript. I think what the authors mean is freezing and thawing instead. Please, correct this.

Response: Thanks for pointing out the unclear use of the term cryoturbation. We have replaced "cryoturbation" with "freezing and thawing" throughout the manuscript, following your suggestion.

3.iii) In addition to eddy covariance based observations of methane fluxes, this study presents a lot of observations of environmental factors, such as climate and soil properties. This is really interesting because this allows addressing the question on why do we see this strong seasonality with methane sources (summer, autumn) and sinks (winter, spring). However, the data presented does not explain these seasonal differences. The attempts of explanation in the discussion section with several hypotheses are important but please include into this discussion how these hypotheses could have been proven by your data or which other measurements were required.

Response: Thanks for your constructive comments. We completely agree with the reviewer on the importance of bringing the measured environmental data to explain results and test hypotheses in the discussions of the seasonal CH_4 flux difference. In this revised work, we tried to use our field measured environmental data in the discussion section for hypothesis testing and explanations.

Following this suggestion, we have revised the related discussions by emphasizing the explanation and hypotheses of seasonal CH_4 fluxes with environmental data. In particular, we also supplied a new table of seasonal soil water content variation (Supplementary Table 1) and a new figure of soil temperature data of spring_ and autumn_ (Supplementary Figure 10), which are important for explaining the observed seasonal variations in CH_4 fluxes. Other major revisions that make connections between our field observation data and hypothesis testing are summarized below.

(1) To explain the hypothesis of different soil hydrothermal conditions will greatly influence CH_4 cycles in permafrost regions, we supplemented data of the snow-cover time and SWC of 0-40cm (Supplementary Table 1) within footprint when discussed the CH_4 flux during winter. The data showed that the QTP alpine steppe generally has little to no snow

cover during winter. And this relative dry soil could facilitate the oxidation of CH_4, and therefore reduce the size of the winter CH4 source when compared to other permafrost regions, in this revised manuscript, on lines 461-463.

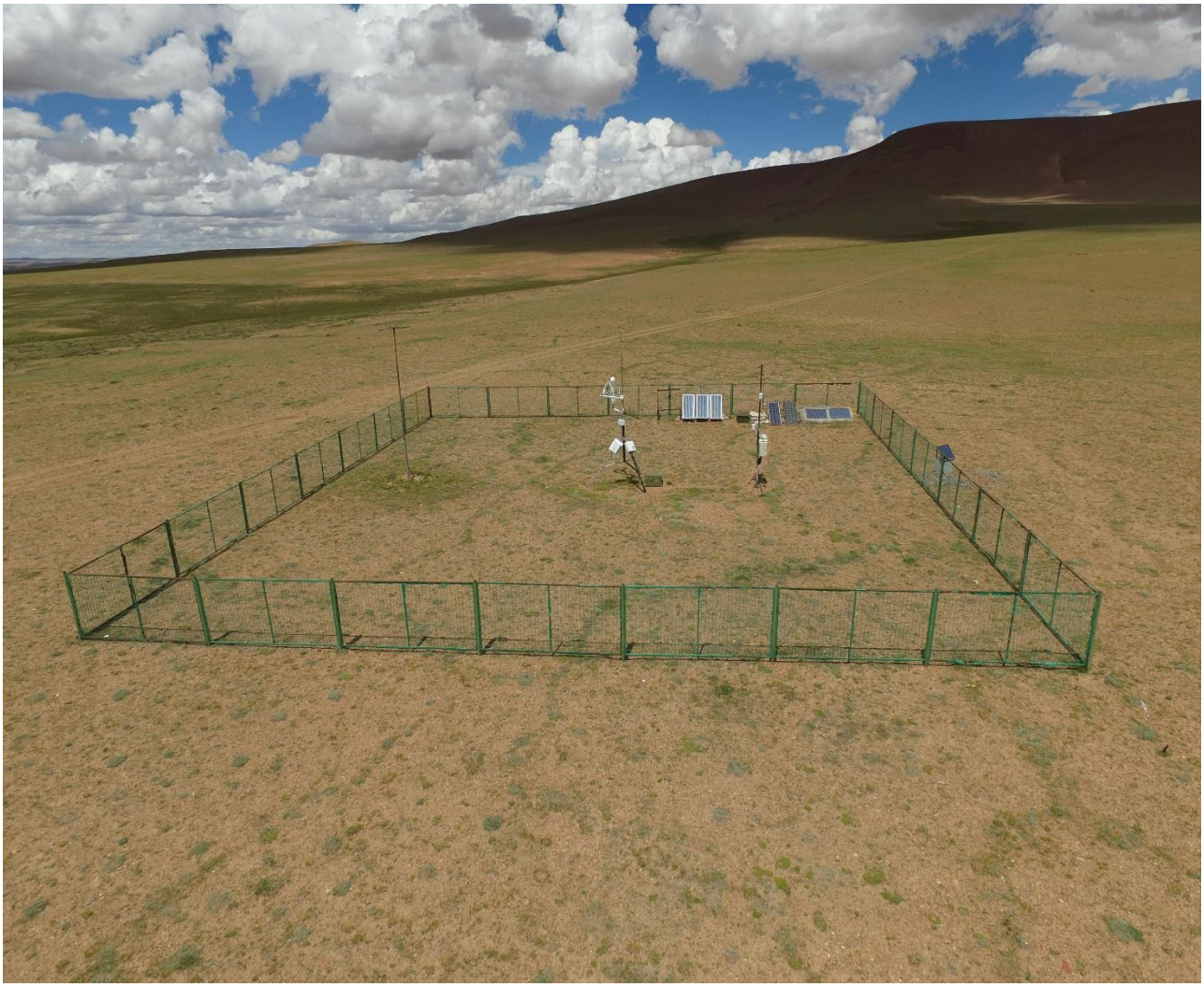
(2) Before we invoked the hypothesis of *seasonal* variations in soil thawing and freezing dynamics to explain observed spring_ and autumn_ CH_4 flux variation, we first ruled out the possible cause from *spatial* variation in vegetation species, soil type and soil water content by providing data and a new photo of the footprint of the eddy covariance tower (Supplement Figure 11). This photo clearly shows the spatial composition of the entire footprint is relatively homogeneous; and therefore, indirectly support our hypothesis that the observed seasonal CH_4 flux variations are likely caused by seasonal differences in soil thawing and freezing dynamics. On lines 501 -508 and 969 - 970.

(3) We also provided some freezing-thawing process details with pointing-to-data in explaining observed CH_4 patterns. For example, on lines 490 - 496.

Finally, the new discussion of seasonal variations in CH_4 fluxes can be found in Lines 451 - 527 of the revised manuscript.

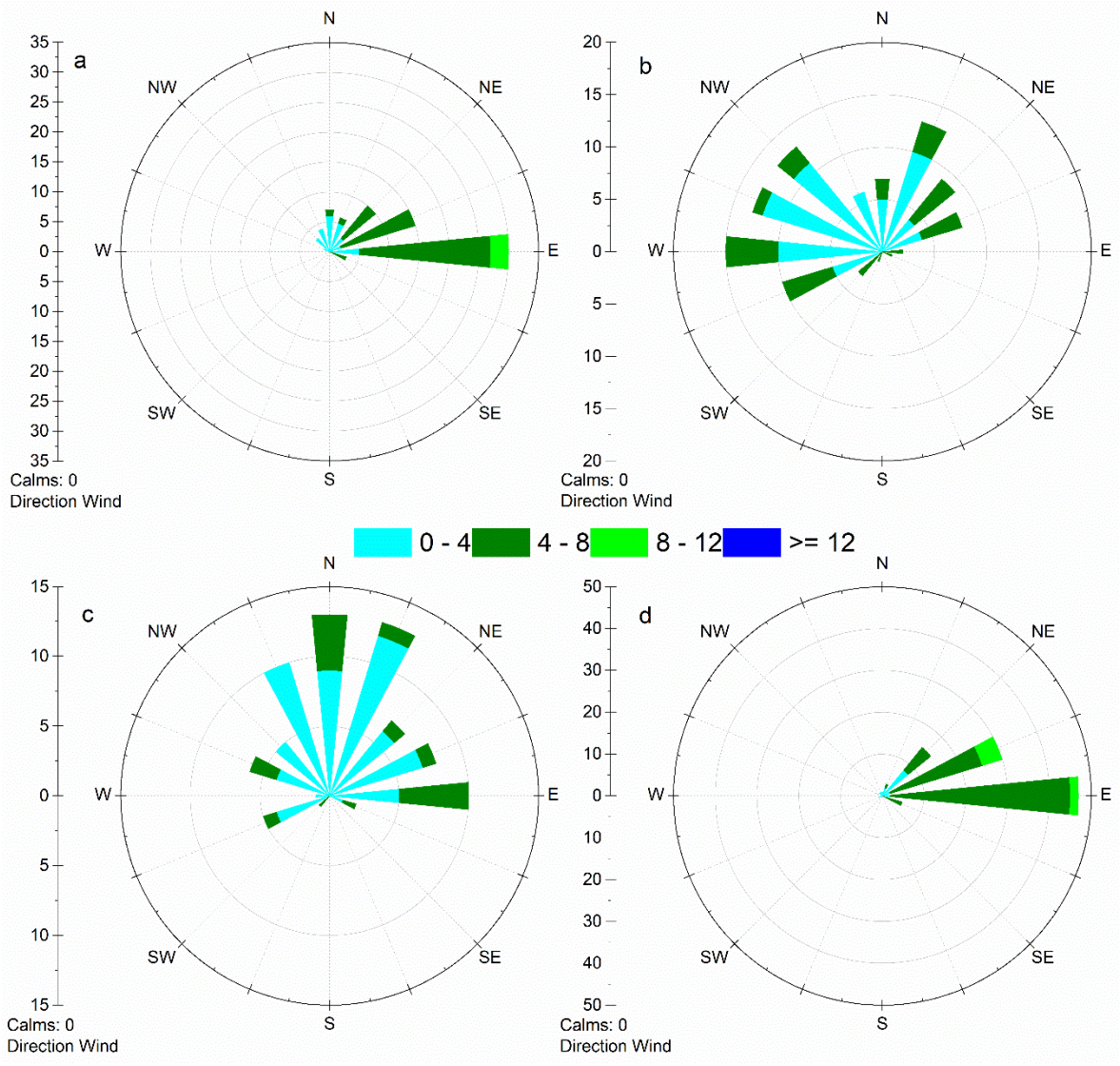
4. *In general, the temporal differences in eddy cov CH_4 time series could have been due to either temporal differences in soil processes or spatial differences of the footprint. I strongly suggest to first rule out the latter case before discussing all kind of soil processes leading to the seasonality of methane fluxes: Are there more wet or dry soil areas in the footprint and do we see methane flux dynamics due to changes in the footprint? Please, analyze wind direction and wind speed together with methane fluxe in Fig. 5. Also, the main wind direction can be displayed in color scale in fig 9.*

Response: Thank you for your constructive comments. We fully agree with the reviewer that because of the changing prevalent wind directions among different seasons, the spatial variation of the measured footprint may have affected the seasonal interpretation of methane fluxes. As our field picture (Supplementary Figure 11) showed, the footprint was generally spatially homogeneous in terms of vegetation and soil types. We have added the content of the spatially homogeneous vegetation and soils in the discussion of the seasonal methane fluxes variations (Lines 501 - 508 of the revised manuscript), and we supplemented the seasonal soil water content data in the revised manuscript (Supplementary Table 1).



Supplementary Figure 11. A bird's eye view of the eddy covariance in Beilu'he station

Furthermore, we also followed your suggestion to analyze wind direction and wind speed together with methane fluxes in the original Figure 5 (new Figure 3 in the revised manuscript). However, the visualization effect of this combined figure is not ideal. Therefore, we re–plotted footprint area seasonal variation of wind speed and direction between 2012 and 2016 (Supplementary Figure 4 in the revised manuscript, which is copied below). Thank you for your understanding



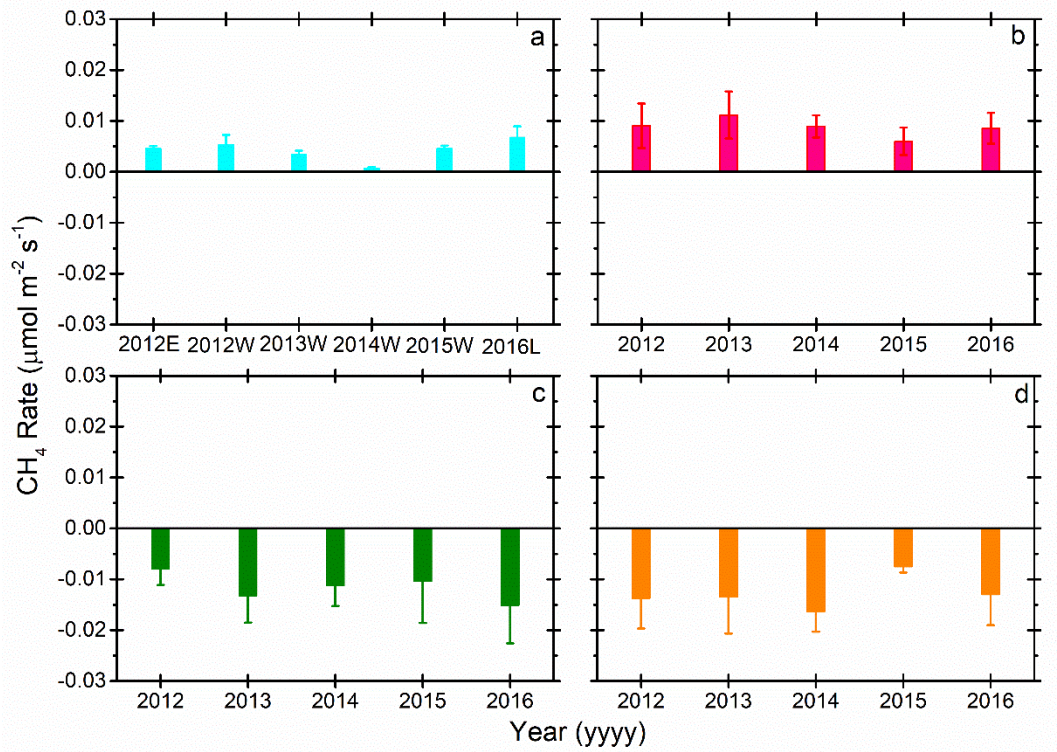
Supplementary Figure 4. Diel mean of wind speed and direction between 2012 and 2016.

5. One more idea that could be tested is the importance of vegetation activity for an oxygen flux into the soil. You could analyze your GPP data from the tower in concert with methane fluxes to prove this hypothesis.

Response: We appreciate your valuable comments; and we agree that the GPP data as a proxy of vegetation activities may provide important insights on oxygen fluxes. However, our crew are still in the very early stage of compiling and analyzing the raw data for GPP estimates, which may take many months to half year or even longer to finish. Therefore, unfortunately currently we are unable to use the GPP data in concert with methane fluxes for hypothesis test, which will be an open question for future investigations. Thank you very much for your understanding!

6. Minor comments - I would place fig 13 and 14 directly after fig 5. Fig 14 should have the same order of seasons than fig 13 and a uniform y-axis scale.

Response: Follow your comment, we corrected the seasons order and y-axis scale for the then Figure. 14 (now is Supplementary Figure 9 in the revised manuscript, copied below). We also followed the suggestion from another reviewer to move non-essential figures to the supplementary materials. Therefore, Figures 13 and 14 are now Figures 5 and Supplementary 9 in the revised manuscript, on lines 955 - 962:



Supplementary Figure 9. Seasonal CH_4 rate mean value from 2012 to 2016: (a) is winter, (b) is spring, (c) is summer, and (d) is autumn. In the (a), 2012E is started from January 1st, 2012 and ended on February 17th, 2012; 2012W is started from 19th November, 2012 to 4th February, 2013; 2013W is started from 1st December, 2013 to 17th February, 2014; 2014W is started from 6th November, 2014 to 4th February, 2015; 2015W is started from 9th November, 2015 to 15th February, 2016; 2016L is started from October 26th, 2016 and ended on December 31st, 2016. All data are presented as mean values with standard deviations (mean ± standard deviation).

7.Minor comments: Most of section 3.2 should be part of the methods section.

Response: Thanks for the suggestion. In this revision, we removed most of section 3.2 to the methods section, on line 277 – 287 and on line 434 – 448.

Responses to reviewer#2

General Comments

This paper entitled "Consumption of atmospheric methane by the Qinghai-Tibetan Plateau alpine steppe ecosystem" describes a study of methane dynamics determined with a rich, multi-year microbial and eddie-covariance data set. The authors observed an interesting shift in the ecosystem from a CH4 source to a sink over the season and propose a new seasonal separation based on soil and microbial conditions rather than air temperature. The modeling effort was not terribly successful (only describing a small portion of the observed variation), but given the high temporal frequency and multi-year nature of the data, this seems like a very compelling contribution to this journal.

My main two critiques are about the paper's structure and number of figures. On the first point, there are many grammatical errors that distract from the message of the paper. Starting from the first lines of the abstract through the end of the paper, a thorough, line-by-line treatment is needed. More generally, the paper would greatly benefit from a thorough revision at the paragraph and section levels. Making sure there are clear topic sentences for each paragraph and that each section has a logical progression would help readers appreciate the importance of these findings. On the second point, there are many figures that are better suited for the supplementary information. Currently, including the background meteorological figures before getting to the response variable of interest (CH4 flux) reduces the focus and punch of the findings. Focusing on a few key figures (for example 5, and 11-14) would improve the paper.

Response: We are very grateful to the reviewer for the insightful comments on our manuscript! Following the reviewer's comments, we had the manuscript thoroughly checked for grammatical

and wording errors by a native English speaker; we also re-organized the content to make sure every section and paragraph had a clear topic sentences and that each section has a logical progression. Furthermore, we re-organized all the figures by only keep some significant figures in main text and putting other non-essential figures into supplementary materials. As a result, we have five figures in the main text and ten figures in the supplementary.

Major comments

1. On the first point, there are many grammatical errors that distract from the message of the paper. Starting from the first lines of the abstract through the end of the paper, a thorough, line-by-line treatment is needed. More generally, the paper would greatly benefit from a thorough revision at the paragraph and section levels. Making sure there are clear topic sentences for each paragraph and that each section has a logical progression would help readers appreciate the importance of these findings.

Response: Very valuable comments! Thank you! In the revised manuscript, we had the manuscript thoroughly checked for grammatical and wording errors by a native English speaker; we also re-organized the content to make sure every section and paragraph had a clear topic sentences and that each section has a logical progression. For example, on the first paragraph of the Results section, we now started with the topic sentence "We first reported the statistics of environmental factors at the Beilu'he Permafrost Weather Station based on meteorological records from 2012 to 2016." (Lines 310 - 311) The Discussions section now also started with a topic sentence "Our results suggested that the alpine steppe ecosystem in Beilu'he was a CH_4 sink of about -0.86 ± 0.23 g $CH_4 - C\ m^{-2}\ yr^{-1}$ during the study period of 2012-2016." (Lines 451 - 452)

2. On the second point, there are many figures that are better suited for the supplementary information. Currently, including the background meteorological figures before getting to the response variable of interest (CH4 flux) reduces the focus and punch of the findings. Focusing on a few key figures (for example 5, and 11-14) would improve the paper.

Response: In this revision, we re-organized all the figures by only keep some significant figures in main text and putting other non-essential figures into supplementary materials. As a result, we have five figures in the main text and eleven figures in the supplementary.