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Interactive comment on "Model estimates of climate controls on pan-Arctic wetland methane emissions" *by* X. Chen et al.

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"The authors use a land-surface process-based model to identify the dominant climate drivers of northern high-latitude wetland methane (CH4) emissions, and to estimate present-day and future CH4 emissions from Arctic wetlands. The authors quantify the model CH4 emission sensitivity to precipitation, temperature, radiation and CO2. The process-based model and the sensitivities are both used to derive 21st century methane emissions based on CMIP5 climate driver projections. The study results show that CH4 emissions will be 42% higher in the 21st century, relative to 1997-2006. The manuscript is clearly written: the methodology is well documented, and the results are clearly presented."

We thank the reviewer for the detailed comments that helped improve our manuscript,

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especially regarding uncertainties. Our responses to all the comments are listed below.

"A major shortcoming of the work presented in this manuscript is that the wetland CH4 emission climate sensitivity and 21st century predictions are wholly contingent on the model used in this study. However, the authors do not attempt quantify or explore the structural and/or parametric model uncertainty. Given that model parameters are a major source of uncertainty in future flux projections in the carbon cycle (e.g. Booth et al., 2012), I strongly recommend that the authors quantify or characterize the sensitivity of their results to model parameters controlling methane emissions. "

To quantify the uncertainties in our results, we performed several new runs that take the uncertainties of methane model parameters into consideration, following a similar approach to the experiments in Bohn et al. (2013). The details of the uncertainty analyses are now included in a new section, section 2.7. We have updated figure 9 to include a new set of panels that show ranges in climate sensitivity values at 95% confidence level. We also performed uncertainty analyses on our future projections, and have updated our figure 10 to include the 95% confidence bounds. While the parameter uncertainty added uncertainty to our estimates of total emissions, it did not change the nature of T- or P-limitation in any substantial way. However, we recognize that our results are still contingent on our model formulation. We address this in the Discussion section.

"It is also unclear whether the model can adequately simulate the inter-annual variability of wetland CH4 emissions: although the authors have compared the mean annual model wetland CH4 emissions against a range estimates, the temporal variability of modeled wetland CH4 fluxes has not been compared against other bottom-up/topdown estimates or in-situ measurements. Given that the seasonal and inter-annual variations of the model's wetland CH4 emissions - and their response to climatic variability - are a fundamental component of the work presented in this manuscript, the authors should compare the temporal variability of CH4 emissions against at least one (if not all) of the following: in-situ measurements, atmospheric inversion CH4 estimates, other model

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results (e.g. Melton et al., 2013)."

Interannual variability is an important metric of simulation quality. Unfortunately, there are very few in situ observations in the domain that have sufficiently long record lengths (>= 10 years) that could help constrain model interannual variability. In terms of comparisons with inversions and other large-scale models, Bohn et al. (2015) compared the time series of annual emissions over the Western Siberian Lowland (part of the pan-Arctic area) from 21 models, including our model formulation (UW-VIC), to those of three atmospheric inversions (two from Bousquet et al., 2011 and one from Bloom et al., 2010) over the period 1993-2010, and found that, while none of the models had high correlations with the inversions, UW-VIC was among the few models that shared similar behavior with the inversions (namely, low correlations with either summer inundated area or summer air temperature). Those models with higher correlations with inundation or temperature tended to do so as a result of flaws in their model formulations. Further, the inversions themselves showed some suspicious behaviors, with one of the Bousquet inversions reaching net negative emissions over all of boreal Asia in some years, and the Bloom inversion showing almost no interannual variability. Therefore, we argue that our model has already been sufficiently evaluated in terms of interannual variability. We have added a short discussion of this point to the Discussion section.

"Finally, the authors categorize the sensitivity of wetland CH4 emissions with respect to June-August precipitation (P) & temperature (T), however both observations and models suggest substantial wetland CH4 emissions in September/October (Chang et al., 2014, Mastepanov et al., 2008, Melton et al., 2013), and hence September/October P and T undoubtedly play an important role. The authors should either extend this period to include September, or should explicitly state why September/October T and P were omitted."

Our sensitivity estimates do include the September/October P and T influence, because we calculated the sensitivities of annual CH4 to annual P, T and CO2 (the control runs affected climate year-round). What may have confused the reviewer is that we averaged these sensitivities over all grid cells that had similar JJA P and JJA T. I.e., we computed the average sensitivity to annual climate as a function of JJA climate. The reason for this is that CH4 emissions occur primarily during the growing season, and are therefore much more highly correlated with JJA T and P than with annual T and P. We have updated section 2.4 in our text to make this clearer. Also, we highlight this again in the notation of figure 9.

Specific comments

"Throughout the manuscript: The term “Arctic” is misleading, given that the study region includes all wetland CH4 emissions at latitudes >45N. Please consider revising."

It is true that the domain contains land that is outside of the Arctic Circle. However, several studies (e.g., Su et al., 2006; Slater et al., 2007; Zhu et al., 2013) have used the term “pan-Arctic” to refer to the Arctic terrestrial drainage basin, i.e., all land that drains into the Arctic Ocean. Our domain is similar to that domain, with the exception that it also contains Tibet. We have added an appropriate clarification to Section 2.1.

P5942 L15-L18: “Over the entire period 1948–2006, our reconstructed CH4 emissions increased by 20%, over 90% of which can be attributed to climate change. An increasing trend in summer air temperature explained the majority of the climate-related variance”. Climate change is a broad term. Please rephrase and/or be more specific.

This is now rewritten as “Over the entire period 1948–2006, our reconstructed CH4 emissions increased by 20%, over 90% of which can be attributed to changes in air temperature, precipitation and atmospheric CO2 concentration. An increasing trend in summer air temperature explained the majority of the climate-related variance”.

P5951 L6: “two-dimensional matrices”; it is unclear what the two dimensions of the sensitivity matrices are here. Please clarify.

We have rewritten this sentence as “Then, we computed the average sensitivities in each group, and plotted them as a function of JJA T and P. This gave us two-dimensional matrices of sensitivities".

P5951 L7-L9: Argument is hard to follow, please consider revising.

This is now rewritten as "Grid cells with same JJA T and P conditions typically came from quite different locations in the study domain, thus the resulted averaged sensitivities were not overly influenced by the wetland characteristics of a single region".

P5957 L24: "these sensitivities"; presumably these are climate sensitivities. Please be more specific, given that this is the first sentence in this subsection.

The sentence has been rewritten as "To create a projection of future CH4 emissions based on the climate sensitivities (Sections 2.4 and 3.2.2), we computed matrices of the sensitivity of aggregate annual emissions to each annual driver as a function of JJA T and P (Fig. 9), similarly to the earlier correlation matrices (Fig. 6)".

P5963 L23-L24: "This is slightly higher than (but within the range of) previous estimates." The two statements are mutually exclusive, please clarify.

We have rewritten this as "This is on the slightly higher end, but still within the range of previous estimates".

P5963 L25: Conclusion 2 is wholly contingent on the model used in this study. The authors should make this clear.

We have rewritten this as "Based on our model, climate change over the last $\sim$ half century has led to a substantial (20%) increase in total emitted CH4, with increases in air temperature (and associated downward longwave radiation) being the dominant driver".

Technical corrections

Figure 6: The "4" in CH4 not aligned correctly with text.

Fixed

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