Note: in the following document, the original comments made by the reviewer are copied in black, while the authors' responses to these comments follow in blue.

Authors' response to comments submitted by Reviewer #1

The importance of methane balance for Earth System modelling is beyond question. Modelling methane emission and oxidation in the context of Earth System studies is a very complicated task, and accordingly, relatively little progress has been made over the years in this direction. The situation is probably even worse for high latitudes, where very specific processes and phenomena need to be taken into account. Therefore, the work presented here is of importance, and it is clearly a timely effort that must be pursued. In my point of view, it is only a first step towards a really useful methane scheme for periglacial landscapes in JSBACH, but it is a necessary step, and it is a sufficiently large one to warrant publication, provided some revisions detailed below.

The authors appreciate the positive evaluation of the reviewer and the support on the publication of this manuscript. We also agree that the presented work represents only a first step towards the establishment of a process-based methane module for JSBACH, and that further improvements will be necessary to upgrade the presented model version for application at larger scales.

The model is tested only at one single site, for very short periods. There are quite some other usable sites which would have provided a useful, more general picture of the performance and applicability of the model. I would really encourage the authors to consider using some other sites, such as Zackenberg (e.g. Juncher Jørgensen et al., Nat Geosci 2015, doi:10.1038/NGEO2305) or Barrow (e.g. Zona et al., PNAS 2016, doi:0.1073/pnas.1516017113). In particular, it would be useful to extend the temporal coverage (in terms of seasons, covering shoulder seasons and winter). Late-season processes (see, e.g. Mastepanov et al., Nature 2008, doi:10.1038/nature07464) should also be looked at.

The authors agree with the reviewer that testing and application of a newly developed model at a single site, using a dataset that exclude large parts of the full annual cycle, can only provide limited insight into the comprehensive applicability of our model. We also agree that both Zackenberg and Barrow would be suitable candidate sites to test the model under different environmental conditions, since both have been studied intensively for a long time, and therefore should be capable to provide the diverse input datasets we require for our model tests. Still, to document the model applicability across sites in the Arctic domain falls out of scope of the presented manuscript. Instead, it is intended here to present the description of the process-based methane module for JSBACH, including a demonstration of model performance using observational datasets from at a single Arctic monitoring site (Samoylov island). Although adding more sites might strengthen the results, it would require investing a large amount of time into observational data collection, quality checks, and additional model runs. Furthermore, it would considerably increase the length of the presented manuscript. The interpretation of model-data-intercomparison would also require many additional paragraphs since it cannot be assumed that we can work with uniform datasets from different sites. Because we also see the need to demonstrate model performance at different Arctic monitoring sites and scales, these steps will be taken for future experiments, and we plan to present them in a follow-up manuscript. Still, the lack of presentation of more sites to evaluate the applicability of the methane model does not undermine the scientific contribution of the presented manuscript. The shortcomings of using just one single site for model performance evaluation will be clearly highlighted in the Discussions section of the revised manuscript. In there, we will also clearly state that further model evaluation at various spatial and temporal scales are required prior to any large-scale application of the model.

- In the same vein, the paper here talks a lot about springtime emission bursts after snow-melt. Can this actually be seen somewhere?

In our response to reviewer #2, we present a list of references where springtime outburst emissions of methane have been documented. Please refer to that letter for details.

- I understand that you limited methane exchanges in winter (i.e. when snow > 5 cm) because you had strong methanotrophy. But wouldn't that be naturally limited at very cold temperatures? Why isn't it? As is, your modelled impact of snow is not much more that voluntary error compensation.

Actually, our simulations yielded cold-season methanotrophy at a very limited level, but continuously lasting throughout the winter. This can be attributed to a suboptimal carbon decomposition routine in the current model implementation. Furthermore, in this model implementation, freezing of relatively dry soils also leads to oxic soil conditions that facilitate methane transport into the soil. Since this process at the found size is not realistic, we used the limited methane exchange as a mechanism to regulate corresponding emissions.
Still, the authors agree that the chosen mechanism that prevents methane release once the snow cover reaches a depth of 5 cm is a very crude approximation of the snow cover influence. The next iteration of the model development will therefore include a more sophisticated, process-based representation of methane diffusion through snow. This upgrade, however, needs to be coupled to a major restructuring of several model components, and therefore cannot be reconciled with the model version presented within the context of this manuscript. We will highlight this shortcoming in the discussion.

- I do not understand why you talk about a 0.5 degree resolution here. Isn't the model setup a site setup? In that case, "spatial resolution" does not make much sense.

Even though we run the model at 'site level' in theory, the general structure of the JSBACH model is still set up for spatially explicit model runs at global scales. In particular, many assumptions behind model structures are exclusively valid at large spatial scales. One prominent example here is the hydrology scheme which works exclusively vertically. This assumption is violated at pedon scale where lateral fluxes from rim to polygon centre dominate soil water content. This is the reason why we split the model experiments into two runs: one for rim and one for centre, in order to mimic this lateral flow. However, there are many more of such assumptions in the model, e.g. for the radiation scheme and energy balance (no south versus north-facing slopes etc.). Since our ultimate target is to provide a new methane module that can be integrated into global scale JSBACH runs, accordingly the structure of our methane module also needs to target spatially explicit runs, and site level runs in fact are landscape-scale spatial runs using input data representing a very small domain. This kind of site-level model evaluation has a long history in land surface modelling, e.g. Sitch et al. (2003); Morales et al. (2005); Beer et al. (2007). We added some new text passages to the revised manuscript to make this clear.

- More generally, I would have really liked to see a sensitivity study concerning the parameters of the model, such as in Khvorostiyanov et al. (Tellus, 2008; part 2 of a paper of which you cite part 1. doi:10.1111/j.1600-0889.2007.00336.x). In particular in your case, this would be very useful - you already state that many model parameters are quite uncertain.

This is a very good point and we completely agree with the reviewer. We reviewed the list of user-defined parameter settings that are required to run the new methane module of JSBACH, and categorized them by relevance and available information to support the chosen settings. Based on this survey, we identified a shortlist of 10 parameters, and defined an uncertainty range of +/- 10 % for their settings. For the resulting maximum and minimum values of this range for each parameter an individual model run was performed, and model sensitivity towards the setting of the chosen parameters was evaluated through changes in the cumulative methane emissions within the study period (Jul 2003 – Oct 2005) that followed the variation of the parameter. Results will be summarized in a new table in the revised manuscript.

- I am not totally convinced that a large-scale evaluation of the model would not make any sense yet, as you state. One could probably gain some understanding of the sensitivity of the model, and possibly see if orders of magnitude of methane fluxes of large scales are OK.

The authors agree with the reviewer that spatially explicit simulations of methane processes could provide new insight into the performance of the new algorithms, since larger grids would cover a range of environmental conditions (climate, land cover, hydrology, freeze-thaw status, etc.). However, this extension again will require a major restructuring of the model algorithms, particularly related to conflicts of the new methane algorithms with the existing hydrology implementation in JSBACH. This goes beyond the scope of the presented manuscript. A larger scale evaluation of the model, based on spatially-explicit runs in a regional setting, is therefore planned for a follow-up study, see also the discussion above.

- This scheme is designed by Earth System modelling applications, or at least, it is implemented in a land surface module that was designed for such applications. As for now, you need to run it twice for rims and polygon centers. Clearly, in an ESM context, this is not a practical solution. I encourage you to discuss ways forward to solve that issue.

The authors agree with the reviewer that separate model runs for polygon rims and polygon centers can only be a work-around when the target is to evaluate a newly developed methane module for JSBACH that ultimately can be applied in global simulations. Still, we believe that this solution is very effective for the purpose of the presented manuscript, i.e. to demonstrate the performance of the algorithm under strongly different soil moisture regimes. For future applications, we are already in the process of adopting the methane module to large-scale models of water-logged conditions (TOPMODEL approach). These upgraded model versions will be presented in a follow-up manuscript.

- I'm not a native speaker, but to me the use of the English language in the manuscript seems to deserve some improvement.

We plan to have the revised version of the manuscript reviewed by a native speaker before resubmission.

References

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