Response to reviews

We very much thank both reviewers for their very thoughtful comments on our manuscript. We incorporated their suggestions to the best of our abilities.

In revising the manuscript, we made the following major changes:

1. We rewrote the abstract
2. We extended Section 2 (Model and development) by adding a paragraph to the subsection on Wetlands and rewriting the subsections on wetland methane emissions and drainage of croplands
3. We extended the experiment description (Section 3)
4. We extended the results section 4.4
5. We extended the discussion of wetland area estimates and added a short section on offline versus online experiments
6. We exchanged Figure 4

In addition, we made numerous small changes, especially with regard to wording and spelling.

In the following, we will give a detailed response to the two reviews. The reviewers' comments are shown in blue, while our response is shown in black.

Review 1

I have several minor, editorial comments:

You say "interactive" as a key feature of your model, but I am almost sure that you mean "iterative"

An interactive model requires some back and forth response of the user, whereas iterative model uses a calculation that repeats estimating the solution until convergence to an accurate solution.

You did not describe any interface for collecting interactive user response. I therefore assume that you mean "iterative".

On second reading, I think that by "interactive" you mean that the atmosphere is driving and getting feedback from the surface emission model. That will make it a "coupled atmosphere-land surface model". You do use the term "coupled model" in the discussion. I still don't think "interactive" is the best term to use here.

We very much thank the reviewer for pointing out this potential source of misunderstanding, which we had overlooked completely. In the land surface modelling community, one commonly distinguishes between "standalone" and "interactive" models. Here, the former means a land surface model that is driven by imposing atmospheric boundary conditions from an external source, implying that the land surface cannot affect the atmospheric conditions. The latter, in contrast, applies to a modelling setup where the land surface model is run coupled to an atmospheric model, with both models exchanging fluxes of energy, water and other tracers, thus the land surface and the atmosphere interact. Since this is common usage in our community, we overlooked the potential for misunderstanding.

In order to remedy this problem, we exchanged "interactive model" for "coupled model", a term that should lead to fewer misunderstandings.

Abstract

As your main goal is stated “to test the sensitivity of the wetland methane emissions”, and especially because your model is not globally validated to the methane emissions, please provide more information on what you found in that regard to sensitivity to different anthropogenic effects, and less details about what the exact numbers for methane emission were as determined by the model.
We completely rewrote the abstract, focusing more on the specific results of our experiments.

General editing

In L68 and everywhere else in the manuscript, correct “wetland extend” to “wetland extent”. “Extend” is a verb. The noun is “extent”.
You need a comma before every “e.g.”, and before most “which”, after “therefore”, and around “however”.
We carefully proof-read the manuscript, improving wording, correcting several typos, and making sure commas exist where required. Among those changes, we also corrected these issues the reviewer mentioned.

Methods

L66 – what do you mean by “5”? (“...presented in Marthews et al. (2015) and 5.”)
Unfortunately, that was a very dense statement. Meant was that we used the value from Marthews et al, unless it was smaller than 5, in which case we would use 5 as a minimum value, and we will reformulate to make it clear.

Subsection 2.2 – were these parameters constant EVERYWHERE? That is highly unrealistic

L97 “via diffusion, ebullition and plant aerenchyma”. Where did you come up with the diffusion parameters, and especially the aerenchyma transport parameters?
Parameter values were mainly taken from Riley et al. (2011), who based them on measured values from the literature. Also, many parameters aren't actually constant everywhere, but rather dependent on local temperature and /or moisture conditions. We reformulated the section, extended the process description, improved clarity, and especially clarified sources for parameter values.

Discussion

L268-278 this sentence is way too long. I got lost. Please break it to shorter statements.
We reformulated the entire paragraph, hopefully making it much clearer.

Review 2
General comments: In this study, the authors incorporated wetlands and wetland methane emissions into the ICON-XPP model to estimate global methane emissions. They tested the sensitivity of the results using a coupled model simulation and identified some dependencies with the atmosphere. Although there have been some studies that have estimated wetland methane emissions using models, these are mostly carried out offline. Therefore, this study is an interesting addition to our

current knowledge. However, some aspects need improving before publication. One of the main concerns is that the method requires more detail. For example, the processes of methane production, oxidation and transport, and the model simulation setups. Without these details, the results were difficult to understand. Specific comments follow:

We thank the reviewer for her/his interest and encouragement, as well as the constructive criticism. We extended and rewrote the sections on model description and experimental setup, hopefully making them easier to understand.

As mentioned in the introduction, human activities significantly modify surface hydrology (line #32). Incorporating all these activities will be a huge challenge, but would it be possible to include wetland drainage? For example, could we include the percentage of the wetland area that has been drained each year since 1900, if this better represents the wetland area?

Thanks very much for this excellent suggestion. This will, however, be very difficult for two reasons: 1) The coupled atmosphere - land surface experiments we have conducted thus far are rather expensive in terms of required computation time, making it very difficult to repeat them. 2) We are lacking data: A few years ago, we looked into the drainage history of peatlands, first on the global scale, and then on the national (Germany) scale. Even on this very limited scale, records were extremely difficult to obtain, and neither comprehensiveness of coverage nor representativeness could be ensured. Thus this is an excellent suggestion, but we were not able to do this for the revision of our manuscript.

Line #198: Could you add the number from Saunois et al. (2016)?

Saunois et al. (2016) do not give a number for the standard deviation of annual mean emissions that we could find, therefore we did not add it. However, Saunois et al. do give a number for the ensemble mean wetland emissions, which we compare to our model results.

Figure 4: Could you extend the axis range to make the ends of the bars more visible?

We redrew the Figure with longer axes.

DrySurf experiment: The SWR scheme changed the surface water dynamics as well as the precipitation patterns. Did including SWR in the model lead to more realistic wetland extent and precipitation patterns?

This is very difficult to say. The changes due to SWR occur in regions where the precipitation difference to observations is relatively small, and neither the “Base” nor the “DrySurf” experiment is clearly better. The same goes for wetland extent. In the revised manuscript, we discuss this in section 5.1.

I find the WetCrop setup a bit confusing: it could be due to the experiment name, the definition of wetlands or the lack of detailed information. Switching off the drainage means that croplands can be converted to wetlands (with a change in vegetation), increasing both the area of wetlands and their methane emissions. However, what does it mean when you say there are no effects of drainage on the basic soil hydrology below the crops in line #103 and no changes in the carbon cycle compared to the 'Base' in line #259? Are croplands kept wet without any vegetation change from crops to wetland plants? If the croplands are 'wet', why does the wetland area increase together with methane emissions from wetlands?

I fear there is a basic misunderstanding of what we (and other global wetland/methane modellers) mean by the term “wetland”, as this is, of necessity, different from what people who are working

empirically consider. While a wetland in the ecological sense is an ecosystem that is characterised by wet conditions, as well as specific plant assemblages, this level of detail cannot, at present, be represented in global land surface models. Here, a “wetland” is defined purely hydrologically as an area where the water table is at or above the surface, leading to anaerobic conditions in the soil, and thus methane production. Vegetation, on the other hand, is prescribed from remote sensing in our experiments, and thus does not react to the hydrological conditions in the soil.

Thus, in a sense, global modellers tend to use the term “wetland” inappropriately, and in writing our manuscript we made the mistake of not clarifying this sufficiently.

Therefore, if we “switch off” the drainage in the model, the croplands in the model can now be inundated (and thus generate methane, if inundated for long enough for conditions to become anaerobic), but they do not become wetlands in the ecological sense, as vegetation does not change.

In the revised version of the manuscript, we added a paragraph to Section 2.1, explaining the term “wetland” as used in land-surface modelling, and rewrote most of section 2.3, explaining what it means to “switch off” the drainage of croplands.

The same applies to ConstVeg: is the land cover of 1855 kept constant throughout the simulation despite changes to surface water? If so, how do wetland area and methane emissions change?
This is similar to the previous issue: In our model experiments, vegetation is prescribed and independent of surface water. If hydrological conditions change, inundation changes (in our manuscript, it would be called a change in wetland area), leading to methane changes.

In the revised manuscript, we tried to clarify this issue by clearer describing the model setup and extending section 4.4.

Section 2.1: What were the temporal and spatial resolutions used to calculate the wetland area fraction? Was the resolution high enough to capture the heterogeneity of permafrost areas such as polygonal tundra or palsa?
We extended section 2.1, adding a paragraph clarifying these issues.

Section 2.2: What are the exact processes of methanogenesis? SOM decomposes to 100% CO_2 in aerobic conditions and to 50% CO_2 and 50% CH_4 in anaerobic conditions with 35% efficiency. What is the proportion between acetoclastic methanogenesis and hydrogenotrophic methanogenesis? Do you assume that acetoclastic methanogenesis is dominant? A more detailed description of methanogenesis could be provided.
We significantly extended section 2.2, better describing methanogenesis.

Section 4.1: To what extent are the wetlands comparable with those in global and regional inventories? If not, what could be causing the uncertainty? Despite the wetland extent potentially being underestimated, global methane emissions are comparable with those in other syntheses. Is methane emission per area then overestimated? A more detailed description of methane production and transport processes would help us to understand this issue.
We extended the discussion of wetland extent and how it compares to literature estimates in section 5.4. We also significantly extended sections 2.1 and 2.2, better describing methane production and transport, also mentioning the uncertain parameters that allow model calibration.

Line #269: I would be careful with the comment that offline simulations can lead to the wrong conclusion. Depending on the purpose and how the model works, offline and online simulations can have different strengths and weaknesses. For example, interactions between wetlands and the

climate can only be observed through online simulations. However, if the area of wetlands and wetland methane emissions, as well as their interaction with the climate, are not simulated well, there can be higher errors in online simulations than in offline simulations, where the extent of wetlands and the climate are well constrained.
Thanks for this reminder, we added a short section to the discussion and phrased more carefully

Section 5.4: Could you add the numbers of wetland extent from each reference?
We did just that, extending the discussion of wetland area estimates.

There are many typos. These are the ones I found, but there may be more. Please read through the manuscript carefully and correct them.

1980'ies to 1980s in line #18

CO2 to CO_2 in line #20

wetland extend to wetland extent in line #68

it's to its in line #98

were to where in line #112

in creasing to increasing in line #123

1940'ies to 1940s in line #165

the paragraph needs to be organized better to avoid two sentences in parenthesis in line #196
We carefully proofread the entire manuscript, correcting all of these typos, as well as several others, checked punctuation and typesetting, and reworded several sections in order to make them easier to read and understand.
We hope we succeeded in this, although I am sure Copernicus will find additional errors when they do the final typesetting.