

Our replies to the comments of Referee #2 are given below *in Italics*.

Schuldt et al. describe in their manuscript the implementation of peat accumulation and methane emissions in the JSBACH land surface model of the MPI-ESM. This is an important step forward in Earth System modelling that is missing in other models. I thus encourage the authors to consider the general and specific points below, and strongly support the publication of the paper after a revision. The MS is very well written and structured in a concise way.

Firstly, we thank the 2nd reviewer of our paper, for very constructive comments.

General:

The authors apply their peat and methane model to boreal wetlands. I presume that wetlands include here specifically peatlands (bogs and fens), but also seasonally inundated areas. While the peat model in JSBACH is tailored to peat C accumulation in peatlands, methane emissions from all kind of wetlands are important. It is thus needed to define the ecosystem represented by the model more specifically.

In the scientific literature dealing with wet- and peatlands, there is a rather unfortunate tendency to use these terms synonymously, which is a source of considerable confusion (Rydin and Jeglum 2006). “Wetland” refers to the hydrological properties of a certain location, i.e., an area where the water table is at or above the surface for any length of time, while “peatland” refers to an ecological system, i.e. a system dominated by certain plant species in which anaerobic conditions lead to a large accumulation of organic matter in the soil (minimum depth of peat: 30-40cm). While the terms often are used synonymously, they certainly aren't – all peatlands are wetlands, but only permanent wetlands can accumulate peat.

We understand boreal wetlands as peat moss dominated ecosystems. Their common features are waterlogged conditions, slow decomposition and slow rates of subsurface flow that allow the partly decayed organic matter to accumulate in place (Dise, 2009). The processes of anaerobic decomposition that allow carbon to accumulate also produce the greenhouse gas CH₄. Boreal wetlands commonly are further subdivided into bogs and fens, according to their nutrient regime. Further subdivisions according to their moisture regime, soil or substrate are also common. As the key features of these ecosystems, carbon accumulation and CH₄ emission, will be investigated in this study, these ecosystems will be referred to hereinafter as boreal wetlands as the generic term or peatlands, indicating the accumulation of carbon in the soil.

Our term “boreal wetlands” only refers to permanent wetlands of the northern latitudes, i.e., peatlands, but not to seasonally inundated areas. We will discuss this issue in the paper.

This has consequences for the verification of simulated peat C densities and methane emissions in the selected regions of HBL and WSL. In this study the map of Kleinen et al., 2012 is used for the distribution of wetlands. It is based on a TOPMODEL approach and agrees well with observation based inundation area (Kleinen et al., 2012; Prigent et al., 2007). However, Melton et al., 2012 highlight in their wetland intercomparison that inundation and TOPMODEL simulated areas differ quite considerably from peatland area from soil maps

(Tarnocai et al., 2007). The latter is based on soil surveys and maps areas where actually peat layers exist.

As an example the map used in this study has very small area fractions in the HBL; maximum fractional wetland area is further east in Quebec and New Fundland (Fig. 3). As a consequence maximum emissions are in the same region (Fig. 7). This region is known for very large lake systems, but main peatland area is further east in the HBL (Tarnocai et al. 2007).

I understand that for an Earth System Model this small mismatch plays only a minor role. Nevertheless, the peatland distribution matters for the calibration of total peat C accumulation and methane emissions, which is then applied globally.

I thus suggest to additionally use the peatland distribution map by Tarnocai et al. 2007, and recalculate peat C content and methane emissions. This sensitivity test would certainly strengthen the quantitative conclusions.

At the time when the model was developed and simulations were carried out, the Northern Circumpolar Soil Carbon Database (NCSCD) by Tarnocai et al. (2007) was available. This dataset provides an estimate of the size of carbon pools in soils of the northern circumpolar permafrost region. Their area estimates are of rather variable quality, though, especially their estimated area for the Eurasian permafrost region is twice the size of other estimates (Tarnocai et al., 2009). In addition their data only cover permafrost regions, therefore completely ignoring peat deposits in non-permafrost areas, for example in central and eastern Europe, as well as southern Canada.

The NCSCD was updated by Hugelius et al. (2012), who account for fractional coverage of different soil types, representing peatlands as well. However, this dataset has a major shortcoming with regard to application in our study: The NCSCD gives no information on the water table height within the peatland fraction, which is required to determine the degree of anoxia (i.e., the amount of methane emitted) within the soil column. Since the Kleinen et al. (2012) approach to determine the water table within the wetland fraction of a grid cell redistributes the grid cell mean water table according to a distribution function based on topography, it is not possible to prescribe a wetland area incompatible with the topographic distribution function and still determine a consistent water table position.

Even if we omit the areas that are not included in the NCSD, there is no consistent way of combining the Tarnocai peatland extent data with hydrology. Prescribing the wetlands fraction and water table based on different approaches would lead to inconsistencies and incalculable errors that might propagate further to peat accumulation and CH₄ emission.

Using the presented modelling approach, imperfections in the peatland distribution are clear limitations of the study which can only be improved with a completely new modelling setup. We therefore kindly ask the reviewer to accept the imperfections that come along with the approach chosen and consider this in the review of the revised paper.

Specific:

- p. 12676, line 2: Please spell out LAI or refer to Table 2.

We will spell out LAI as 'leaf area index'.

- p. 12676, equation 3: To my understanding there is a C_L missing as the carbon flux scales with the litter C pool. It should read $dC_S/dt = \beta_L R_L C_L - R_S C_S$.

This also applies to eq. 8 on page 12677. Is this correct?

This is correct. The term C_L is missing in the equations (3) and (8). We will correct these equations as suggested.

- p. 12676, equation 4: What is γ_G ? Couldn't find it in Table 2 nor the entire text. Also an introduction of C_G , sla and LAI in this equation would be helpful for the reader here.

γ_G is a factor relating leaf carbon to the carbon content of the whole pool (20th entry in table 2). Unfortunately the Greek symbol gamma was changed to a Y in the type setting. We will ask the illustrator to change it. We will further introduce C_G , sla and LAI in the text.

- p. 12677, line 10: add h_A symbol for height

We will add the symbol h_A

- p. 12677, line 13ff: How are turnover times estimated?

The turnover times for the acrotelm are derived from studies showing that SOC turnover is a short-term process, operating in yearly to decadal timescales (Malmer et al., 1993, Schimel et al., 1994; Clymo et al., 1998) and catotelm turnover times are long-term processes that operate on millennial time scales (Clymo et al., 1998). We will elaborate on this in the text.

- p. 12678, equation 14: Are CH₄ emissions from litter possible?

Yes, CH₄ emissions from litter are possible but not considered in our model.

- p. 12679, line 4ff: What thresholds are used for concentration to form bubbles and pressure for ebullition? Is CO₂ partial pressure also calculated and can it trigger an ebullition event?

Since we use the original Walter and Heimann (2000) model for methane transport, we can only refer to their original publication. Ebullition occurs, when the methane concentration in a layer exceeds a threshold concentration C_{thres} . They assume that C_{thres} is lower at vegetated than at unvegetated sites, and therefore calculate C_{thres} as $C_{thres} = C_{min} \left(1 - \frac{P_{unveg}}{100}\right)$ with P_{unveg} the percentage of the grid cell that is not vegetated and $C_{min} = 500\mu M$. CO₂ partial pressure is not considered in their approach.

- p. 12679, line 15: So 2 layers, where "layer" means acrotelm and catotelm, each with 1cm resolution? Please clarify.

In our peatBALANCE model "layer" means acrotelm and catotelm respectively. The methane transport model, however, has a vertical resolution of 1cm. We clarify this point in the text.

- p. 12680, line 26: What are the initial conditions for the catotelm pool? As the size of C_C

matters for the respiration and the net C balance in eq. 9, it is important for the peat C accumulation. Does it matter for your simulations (beginning at 6kyr BP) whether you have a C stock accumulated over 10kyr or if you start from scratch?

In principle the peatBALANCE model can start to allocate carbon from scratch. The simulations presented in this paper start at 6,000 years BP. Analysis of peat cores indicate that at that time significant amounts of peat had been accumulated already. In order to mimic this development we allowed the model to accumulate 40 GtC prior to the 6,000 year long simulation.

The total respiration flux certainly depends on the size of the catotelm pool. The accumulation of peat is the balance of respiration and organic matter addition through litter input. Therefore, as pool size increases, respiration increases until the respiration flux is as large as the input flux. The model approaches this equilibrium state asymptotically, and in the high northern latitudes this equilibrium will be reached after roughly 50000 years. Peat accumulation therefore still is in a rather linear regime where the exact size of the catotelm pool does not matter. On the other hand, the model implicitly assumes a well-developed structure of acrotelm and catotelm, requiring a minimum size of the catotelm C pool.

- p. 12681, line 12ff: So does your comparison only include sites which are younger than 6000 years or did you run the model for the time period according to the basal date of the individual peat-core data? Please clarify.

As described in Kleinen et al., 2012, we convert the measured peat height and basal date into a peat accumulation rate (long term apparent rate of carbon accumulation, LORCA) by dividing the basal depth by the basal date in years BP and converting the height accumulation rates into a carbon accumulation rate by using the C fraction and density of catotelm peat. These rates of carbon accumulation are then compared to model results, removing the need to run the model for an exactly specified period.

- p. 12682, line 20ff: Is the emission area between model and data comparable?

The area is well comparable. For comparison the area was chosen as defined by Pickett-Heaps (2011): 50° N–60° N, 75° W–96° W.

- p. 12683, line 17ff: In Fig. 11 did you plot average soil C density for peatland C or all soils including permafrost C? The NCSCD data set also includes a sub-set for peatland C density only (Tarnocai et al., 2007), which should be shown.

We will plot the sub-set for peatland C density, in order to allow a better comparison between estimated and modelled peatland C.

- p. 12684, line 23ff: I agree that simulated wetland area might be an equivalent alternative to wetland maps from observations. But I suggest to differentiate in the text between "wetlands" and "peatlands" (see my general comment). Since your model is actually simulating peat accumulation, a comparison with surveys showing the location of soil containing peat layers is better suited than maps or estimates of inundated areas.

See our reply to the general comment.

- p. 12684, line 18: repetition of "mostly"

The double word "mostly" will be deleted.

- p. 12688, line 6: Does the model have an N cycle, and if yes do you apply N deposition to peatlands? In the literature it is highly discussed topic as how strong anthropogenic N deposition can affect the mostly N limited peatlands.

We are aware of the strong influences of Nitrogen on the carbon cycling of boreal ecosystems. At the current state our model does not include any nutrient cycles. The development branches of the land surface module of the MPI-ESM however do have Nitrogen and Phosphorous cycles included.

- p. 12697, Table 1: Wania et al. 2009a,b does actually include peat accumulation rate calculations. The description of methane emissions is described in a later paper: Wania et al., 2010.

We will update table 1 and mention the peat accumulation rate calculations as well as CH₄ emissions.

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