Biogeosciences Discuss.,
doi:10.5194/bg-2016-319-AC3, 2017

Biogeosciences
Discussions
Open Access

Interactive comment on "Modelling Holocene peatland dynamics with an individual-based dynamic vegetation model" *by* Nitin Chaudhary et al.

Nitin Chaudhary et al.

nitin.chjj@gmail.com

Received and published: 21 March 2017

We appreciate the time and effort spent by the reviewers in reviewing this manuscript. We have addressed all the issues indicated in the review reports and believe that the revised version will meet the journal's publication requirements.

General comments: Looking at figure 8, it is apparent that the modelled peat depth vs. the observed peat depth is not great. This I can understand, the climate of the holocene when these peatlands were forming is not likely to be well captured with climate and conditions as they were able to produce. My main issue is the NEE estimates from the model are also not corresponding well to observations. In this instance the conditions at the sites are well known and reasonable climate should be possible. The problem

Printer-friendly version

Discussion paper

with the NEE values being off significantly is that it is difficult then to trust when the model predicts the peat depth at sites should grow significantly or shrink since the NEE is how that is controlled in essence.

I also feel that many of the model outputs are not compared to observations when they should be. For e.g., the active layer depth is only compared at one of the 10 sites simulated. Do any of the other sites have information about ALD? Do any have ALD timeseries for comparision? What about the PFT distribution. The PFT distribution is shown in Table 5 but is just a presence or absence. Is there any more quantitative values that can be used to compare the model to obs here? Given the productivity differences between PFTs, it could be instructive for interpretation of model-obs differences. For the WTP, could there be some comparisons not just of some mean annual value but of the timeseries? Is the water table correct at the different times of the year? In general, much of the model performance is sort of dumped into tables, since this is the first paper describing this peatland version of LPJ-GUESS I believe more effort has to be put into demonstrating that the model doesn't get things 'sort of ok' for the wrong reasons.

Response: We agree with the reviewer's point that we need to give a better demonstration of the skill of our model. We have therefore clarified and improved these aspects of the paper, and here we provide a summary of our changes.

Net Ecosystem Exchange (NEE)

We ran the model with the observed dataset for the Stordalen site from the year 2001-2012 and our model predicts reasonable NEE values for the Stordalen site (see Fig. 11 in the revised manuscript (RM)). NEE outputs for the other three sites are almost within the range of observed NEE values (see Table 5 in the RM), albeit with some differences. Fajemyr and Degerö Stormyr are disturbed (i.e. subject to anthropogenic influence), which we have haven't accounted for in the model but relatively less influenced sites (Stordalen and Siikaneva) showed close match with the observed values. Furthermore,

Printer-friendly version

Discussion paper

water borne carbon fluxes are not included in the model and that is also one of the potential causes of this discrepancy.

Peatlands are heterogeneous ecosystems and the carbon fluxes vary spatially and temporally within the landscape. Ecosystem scale NEE can be obtained using eddy flux towers, but previous studies have highlighted that peatland short-term NEE fluxes show a lot of variability and may not be indicative of long-term peatland behavior (Lafleur et al., 2003; Aslan-Sungur et al., 2016). We believe that it is equally important for models to capture the long-term carbon accumulation rate (LARCA). We find our LARCA values are quite close to the Fajemyr and Siikaneva sites and in our companion paper (Biogeosciences Discuss., doi:10.5194/bg-2017-34, 2017) we have demonstrated that the model was able to capture the right LARCA values in almost all the major peatland regions across the Arctic.

Active Layer Depth (ALD)

We have compared the simulated annual ALD with the observed values (1990-2011) for the Stordalen site (see Fig. 9 in the RM) and even analysed the hummocks and hollow ALD separately. We found that the magnitude, variability and trend of the simulated annual ALD are close to the observed values (see Fig. 9 in the RM). ALD is shallow in drier, elevated areas while deeper in wetter hollows, a phenomenon observed in many permafrost peatland sites (Johansson et al., 2013). The ALD trends over the observed period are also similar. Observed ALD trends are 69.2 cm/year, whereas the modelled ALD trend is 68.2 cm/year over the same period.

Furthermore, in our companion paper we produced a permafrost extent map (see Fig. 5 on the page 28 in the companion paper) that captures the main features of the permafrost distribution map developed by Tarnocai et al. 2009 (see their Fig. 1 on page 3), highlighting the robustness of the model in predicting the existence of permafrost in other areas besides the sites discussed in this paper.

Water Table Position (WTP) and PFT distribution

We have compared the observed annual and monthly WTP for a semi-wet patch in Stordalen to the simulated result with our model's semi-wet patches for the period 2003-12. The results were quite consistent with observed values (see Figs. 8 and A5 in the RM).

For majority of Stordalen peatland history, different species of mosses occupied the mire. The model predicted correctly the dominance of wet PFT during 4000-3000 cal. BP (see Fig. 6a in the RM). However, there was a certain period between 700-1700 cal. BP when graminoids were again the dominant PFT, but we could not reproduce that period due to the climate forcing used here, as explained in the text. See lines: 527-533 in the RM.

We have given further responses to each of the reviewer's comments on WTP, plant distribution, bulk density and ALD below.

line 10: Change 'current' to 'many' in the start of the second sentence. Other models do indeed have peatlands, e.g.

Response: We agree with the reviewer on this but many current models do not have a multiple peat layer representation with permafrost functionality and we wanted to highlight such functionality in current dynamic global vegetation models (DGVM), not in other models. Only Kleinen et al. (2012) and Stocker et al. (2014) have introduced initial representations of peat formation in a DGVM framework but both of them lack permafrost functionality. The papers by Wu et al. (2016) and Alexandrov et al. (2016), however, describe quite recent model developments but both were published last year when this study was being submitted, so we couldn't refer them. Also, these two models are not DGVMs (see Table S1 on page 45 (line: 793) in the RM- there are many other models apart from the one mentioned in this table). In Table S1, comparison of the functionality and scope of a representative set of current peatland models have been mentioned. So, although we think current is a more appropriate word than many, we have modified the earlier sentence and clarified the above points for the readers.

Printer-friendly version

Discussion paper

Revised text (lines: 11-13 in the RM) - However, most DGVMs do not yet have detailed representations of permafrost and non-permafrost peatlands, which are an important store of carbon particularly at high latitudes.

l. 30: Do you really mean Wania et al here? That was a modelling study... If you are talking about the mask used for the peatland regions that was Tarnocai, not Wania. Cite the true reference please.

Response: We have now modified the sentence and added that reference (see lines: 30-31 in the RM).

Revised text: Around 19% (3556 × 103 km2) of the soil area of the northern peatlands coincides with low altitude permafrost (Tarnocai et al., 2009; Wania et al., 2009a).

l. 38: Could add some of the refs I gave above to this list.

Response: We have added a reference to Stocker et al. (2014) (see lines: 37-39 in the RM). Here we are referring specifically to DGVMs.

Revised text: Only a few DGVMs include representations of the unique vegetation, biophysical and biogeochemical characteristics of peatland ecosystems (Wania et al., 2009a, b; Kleinen et al., 2012; Tang et al., 2015).

l. 40: See the Stocker ref along with Alexandrov to see if this statement is correct still.

Response: Many models described in these references did not have multiple annual layer representations of peat accumulation and decomposition so we haven't included them in this sentence (see Table S1 in the RM (line: 793)). However, we have reformulated the sentence for more clarity (see lines: 35-45 in the RM) and added a separate sentence to acknowledge the work done by other modelling groups. Revised text- Dynamic global vegetation models (DGVMs) are used to study past, present and future vegetation patterns from regional to global scales, together with associated biogeochemical cycles and climate feedbacks, in particular through the carbon cycle (Smith et al., 2001; Friedlingstein et al., 2006; Sitch et al., 2008; Strandberg et al., 2014;

Zhang et al., 2014). Only a few DGVMs include representations of the unique vegetation, biophysical and biogeochemical characteristics of peatland ecosystems (Wania et al., 2009a, b; Kleinen et al., 2012; Tang et al., 2015). Model formulations of multiple peat layer accumulation and decay have been proposed and demonstrated at the site scale (Frolking et al., 2010; Heinemeyer et al., 2010) but have not yet, to our knowledge, been implemented within the framework of a DGVM. However, peatland processes are included in some other types of model frameworks (Morris et al., 2012; Alexandrov et al., 2016; Wu et al., 2016) and been shown to perform reasonably for peatland sites. Large area simulations of regional peatland dynamics have been performed by (Kleinen et al., 2012; Schuldt et al., 2013; Stocker et al., 2014; Alexandrov et al., 2016) (see Table S1).

l. 43: 'northern high latitudes, ... , could' - suggest adding some commas.

Response: Thank you, we have done this (see lines: 47-49 in the RM)

Revised text: Current climate models predict that the northern high latitudes, where most of the peatlands and permafrost areas are present, could experience warming of more than 5°C by 2100 (Hinzman et al., 2005; Christensen et al., 2007; IPCC, 2013).

l. 70: By soil resources, you mean water right? nutrients are not simulated in this version, correct? Response: Yes, by soil resources we mean water, not nutrients, and we have clarified this in the text (see lines: 76-79 in the RM)

Revised text: Vegetation structure and dynamics follow an individual- and patch-based representation in which plant population demography and community structure evolve as an emergent outcome of competition for light, space and soil water among simulated plant individuals, each belonging to one of a defined set of plant functional types (PFTs) with different functional and morphological characteristics (see below).

l. 80: So how many soil layers? This description in this paragraph is different than the figure. Please make them more congruent. I am still not sure how many layer were truly simulated.

Response: For Stordalen, 4739 + 100 peat layers were simulated, i.e. one peat layer for each of the 4739 years after inception until year 2000, followed by a 100-year projection from 2001 to 2100. For Mer Bleue, it was 8400 + 100 layers. We can't show that many layers in a figure so we simplified the representation in schematic representation of the model (see Fig. 1 in the RM and lines: 91-98).

Revised text: A one-dimensional soil column is represented for each patch (defined below), divided vertically into four distinct layers: a snow layer of variable thickness, one dynamic litter/peat layer of variable thickness corresponding to each simulation year (e.g. 4739 + 100 layers by the end of the simulations, described in Section 2.4 below, for Stordalen), a mineral soil column with a fixed depth of 2 m consisting of two sublayers: an upper mineral soil sublayer (0.5 m) and a lower mineral soil sublayer (1.5 m), and finally a "padding" column of 48 m depth (with 10 sublayers) allowing the simulation of accurate soil thermal dynamics (Wania et al., 2009a). The insulation effects of snow, phase changes in soil water, precipitation and snowmelt input and air temperature forcing are important determinants of daily soil temperature dynamics at different depths.

l. 95 : based on what studies?

Response: We added the references after the second sentence but now we have moved it a little further in the text for clarity (see lines: 104-105 in the RM)

Revised text: Woody litter mass from shrubs decomposes relatively slowly because it is made up of hard cellulose and lignin (Aerts et al., 1999; Moore et al., 2007).

l.97: I don't understand the 'fresh litter debris decomposes through surface forcing until the last day of the year'. Surface forcing?

Response: When the litter (leaves and stems, where appropriate) is dropped on the ground surface it doesn't become a part of peat column (formed of multiple layers –

Printer-friendly version

Discussion paper

see above) instantaneously. This litter then decomposes at rates depending on the surface conditions in that year, i.e. surface temperature and moisture, becoming the top layer in the peat layer of the soil column the following year. So, in our framework, we decompose the litter mass present on the peat surface for the first year before it transforms into a peat layer. However, for dead roots, we add them directly to the peat layers where they belong (see lines: 106-110 in the RM).

Revised text: Fresh litter debris decomposes on the surface through exposure to surface temperature and moisture conditions until the last day of the year. The decomposed litter carbon is assumed to be released as respiration directly to the atmosphere while any remaining litter mass is treated as a new individual peat layer from the first day of the following year, which then underlies the newly accumulating litter mass.

l 117 : Please put the values of all these constants in the text and not just the table. It was confusing until I found the table since the table is not really mentioned until much later.

Response: We have included constant values at all the appropriate places and also referred earlier to Table 2 in the revised manuscript. See lines: 150-153, 156-158, 166-168, 219, 222, 231 and 234 and Table 2 in the RM.

l 117: How does K relate to K_o or K_i?

Response: We use K in general terms to refer to an overall decomposition rate of the entire peat column. ki, however, is the decomposition rate of an individual peat layer (i) (see Eq. 2 and 3 in the RM) and ko is the initial decomposition rate. This distinction was introduced by Clymo (1984) and is also used in the Frolking et al. (2010) and some other publications on peatland modelling. We explain these variables just below the equations where they were first defined and there we also referred to these papers (see lines: 129-140 and 144 in the RM)

Eqns 4 and 5 - would be nice if these were plotted, easier than trying to imagine in the head...

Response: We agree with the reviewer. We have now included them as a new figure (Fig. A1 in the RM; see lines: 152, 158 and 728 in the RM)

In Fig. A1 (in the RM), we presented assumed decomposition dependency on (a) soil temperature and (b) soil water content.

All eqns - be consistent between 1.0 and 1 etc. in the equations.

Response: Agreed. We have changed all equations to use 1 consistently

Eqn 6 - units?

Response: kg m-3 (Included in the text see lines: 166-167 in the RM)

l. 153 - value of the min and max bulk densities? Calculated somewhere?

Response: Minimum bulk density – 40 kg m-3 and maximum bulk density - 120 kg m-3 They are prescribed values and inspired by the work of Frolking et al. (2010) (see their Fig. 3 and Table 2 on page 6) where they used a similar range of 30-120 kg m-3. Heinemeyer et al. (2010) prescribed a range of 50-100 kg m-3 (see their section 2.3.5 on page 214). Similar ranges can be found in the majority of peatlands (see the explanation below).

pg 7 - choose one: cm or mm and please stick to whichever is chosen.

Response: Agreed. We have changed it to cm throughout.

Eqn 8 - Did I miss how F was found?

Response: We gave the reference in the beginning but now we have placed it right next to F (see line: 216 in the RM). F is the fraction of the modelled area subject to evaporation (i.e. bare soil fraction) calculated by LPJ-GUESS, and explained in Gerten et al. (2004) – see Eq. 9 on Page 254 in their paper. Revised text: Evaporation can only occur when the snowpack is thinner than 1 cm and is calculated following the approach of Gerten et al. (2004), as in the standard version of LPJ-GUESS:

ET= 1.32 .E .W_cˆ2. F

where E is the climate-dependent equilibrium evapotranspiration (cm), Wc is the water content on the top 10 cm of the peat soil and F is the fraction of modelled area subject to evaporation, i.e. not covered by vegetation (Gerten et al., 2004).

Eqn 12: Are you sure this is a change of porosity? This looks more like a fraction of original porosity. Change to me implies something like flux.

Response: Porosity, the volume of empty spaces over the total volume, varies between 0-1. In our implementation, porosity is a function of bulk density and it decreases from (1-40/800 = 0.95) to (1-120/800 = 0.85) as bulk density increases. Frolking et al. (2010) used a similar function (see their Eq. 18 on page 7) and we have given a reference to it. Ryden et al. (1980) found a similar observed range of 0.97-0.88 in depressed patches and 0.93-0.87 in elevated areas in Stordalen (see their Tables 2 and 3 on page 37-39).

L 227: So moss can get water from 50 cm mineral + peat depth until peat => 50 cm? This seems strange and would greatly advantage moss for quite a while. Is there any indication that moss can access water almost 1 m down? I find this difficult to believe.

Response: In our representation, moss can only take up water from the top 50 cm of the soil. It can take up water from the top 50 cm of the mineral soil during the spin up phase, after which it starts taking up the water from the peat soil (but again only the top 50 cm). We have clarified this in the text. See lines: 243-249 in the RM.

Revised text: In the beginning of the peat accumulation process, plant roots are present both in peat and upper and lower mineral soil layers but their mineral soil root distribution declines linearly as peat grows (see Fig. 2) and the corresponding mineral layer reduction is used to access water from the peat layers. Mosses are assumed only to take up water from the top 50 cm of the mineral soil in the beginning but once the peat depth exceeds 50 cm they only take water from the peat layers (top 50 cm of the peat layer). Other PFTs can continue to take up water both from the mineral and peat soils until peat depth reaches 2 m, and from only from the peat soil thereafter.

l. 253: How are the heights done? Is this peat height or actual elevation?

Response: It is the cumulative peat height minus the initial elevation.

l. 316: Sure it conserves the IAV - but it also then pegs the IAV as the same for the whole simulation instead of perhaps changing through time.

Response: We agree with the reviewer on this point but it is a common technique used for reconstruction of palaeo climate forcing when there are no proxy based climate data available from which one could infer a change in IAV. We have clarified the text to explain the effects of not capturing the IAV, see lines: 507-515 and 527-533.

Revised text: Studies of the influence of GCM-generated climate uncertainty (i.e. variations in climate output fields among GCMs) on carbon cycle model prediction, underline the high prediction error that can arise, for example in present-day biospheric carbon pools and fluxes (Ahlström et al., 2013; Anav et al., 2013; Ahlström, 2016). Potential bias and errors in the predicted climate may be expected to be even higher in palaeoclimate simulations, not least due to the absence of instrumental observations for validating the models. Furthermore, in this study additional bias could arise due to the interpolation procedure used to transform GCM output fields into monthly anomalies, required to force our model. These were generated by linearly interpolating between the climate model output, which is only available at 1000-year intervals. As such, the applied anomalies do not capture decadal or centennial climate variability that can contribute to climate-forced variable peat accumulation rates and vegetation dynamics on these timescales (Miller et al., 2008).

Mosses emerged as the dominant PFT at the beginning of the simulation, while 300-400 years after peat inception shrubs started establishing in the higher elevated patches as a result of a lowering of WTP. Graminoids were not productive during the entire simulation period apart from the period 4-3kyr cal. BP (Kokfelt et al., 2010). The model predicted correctly the dominance of graminoids, characteristic of wet conditions, during 4-3kyr cal. BP. However, a period of graminoid dominance between 700-1700 cal. BP was not accurately captured. One explanation can be the absence of decadal and centennial climate variability in the adopted climate forcing data, resulting in an “averaging out” of moisture status over time that elminates wet episodes needed for graminoids to be sufficiently competitive.

l. 318: No, it is really reanalysis or interpolated climate. There are no ’observed’ gridded products available.

Response: Yang et al. (2012) developed an observed climate time series (50 m resolution) from 1913-2006 for the Stordalen catchment. We used the first 30 years (1913-1942) mean (μ) and standard deviation (σ) and drew randomly generated climate data assuming a normal distribution. The randomly generated climate data is then applied to the relative anomalies derived from the gridcell nearest to the location of the site from millennium time-slice experiments using the UK Hadley Centre’s Unified Model. Explained in detail between lines – 350-362.

Existing Text: The high spatial resolution (50 m), modern observed climate dataset was developed by Yang et al. (2012) for the Stordalen site. In this dataset, the observations from the nearest weather stations and local observations were included to take into account the effects of the Torneträsk lake close to the Stordalen catchment. The monthly precipitation data (1913-2000) for Stordalen at 50 m resolution were downscaled from 10 min resolution using CRU TS 1.2 data (Mitchell and Jones, 2005), a technique quite common for cold regions (Hanna et al., 2005). The precipitation data was also corrected by including the influences of topography and also by using historical measurements of precipitation from the Abisko research station record. Finally, monthly values of Holocene temperature were interpolated to daily values, monthly precipitation totals were distributed randomly among the number (minimum 10) of rainy days per month from the climate dataset and the monthly CRU values of cloudiness for the first 30 years from the year 1901-1930 were repeated for the entire simulation period. We added random variability to the daily climate values by drawing random values from a normal distribution with monthly mean (μ) and standard deviation (σ) of the monthly observed climate were used for Stordalen from the period of 1913-1942 and for Mer Bleue, 30 years of monthly CRU values from the period of 1901-1930 were used.

l. 341: Can you please expand more on why you needed to keep the mineral and peat layers saturated during initialization. This to me would imply that your model was out of equilibrium at the start of your runs and thus the transient behaviour would be influenced by the model initial conditions. This is a bit worrying. Once you released the saturated conditions the model could then over-react to dry conditions as mentioned.

Response: We adopted this model initialisation strategy partially to avoid any sudden collapses of the peat column in very dry conditions because young, shallow peat can become drier or wetter within a very short time span and continuous dry periods would increase temperature dependent decomposition rates and reduce the accumulation rate markedly. Furthermore, peatlands develop due to the complex processes of terrestrialisation or plaudification that are not fully captured by our model in its current form. We agree that keeping the patches wet enough during the initialization phase is a limitation of our model, but it is one that corresponds to allowing peat growth in locally, low-lying saturated ecosystems in each gridcell.

l. 349 : This comment about adjusting to the local WTP really drives my request for comparing timeseries of WTP since it is then apparent that we cannot put too much stock in the mean WTP values matching reasonably.

Response: We forced the model with observed climate from 2001-2012 and found modelled annual and monthly WTP for semi-wet patches are quite close to the observed annual WTP from the year 2003 to 2012 (see Figs. 8 and A5 in the RM and lines: 538-548 in the RM).

Revised text: The modelled annual and monthly WTP from 2003-2012 in semi-wet patches and modelled annual ALD 1990-2012 is in good agreement with the observed values for the Stordalen region (Figs. 8, 9 and A5) supporting the ability of model to capture hydrological dynamics that further drive peatland dynamics. For the additional evaluation sites, modelled dominant vegetation cover, LARCA and WTP were in good agreement with the observed values for the three selected sites at which this information was available. Under the present climate, Stordalen was simulated to be a small sink for atmospheric CO2, in agreement with observed NEE (see Fig 11). NEE interannual range is likewise close to observations for the other Scandinavian sites (Table 5). However it is uncertain whether recent annual observations of NEE necessarily reflect the long-term peatland carbon balance, in view of high variability on multiple timescales. For example, Fajemyr has switched between source (14.3-21.4 g C m-2 yr-1 in 2005-2006; 23.6 g C m-2 yr-1 in 2008) and sink (-29.4 g C m-2 yr-1 in 2007; -28.9 g C m-2 yr-1 in 2009) conditions in recent years, and this variability has been attributed to disturbances and intermittent drought conditions (Lund et al., 2012).

In Fig. 8 (RM) (a) the total sum of precipitation (in cm) and (b) a comparison between observed and simulated mean annual WTP for semi-wet patches in Stordalen for the period 2003-2012 was presented In Fig. A5 in the RM a comparison between observed and simulated monthly mean WTP (JJA) for semi-wet patches in Stordalen for the period 2003-2012 have been shown.

l. 400: ’lower than 50 kg m-3’ - higher meant? l. 416: Any obs to compare with here?

Response: Simulating bulk density is a challenge. In some peatlands, it may increases with depth due to compaction (Clymo, 1991; Novak et al., 2008) but other studies have shown no net increase in the bulk density with depth in some other locations (Tomlinson, 2005; Baird et al., 2016). In our study, the simulated bulk density is a function of the total mass remaining and in the peat profile it varies between 40-102 kg m-3 for Stordalen. Ryden et al. (1980) given a range of 45-230 kg m-3 (see page 41 and Table 5 and 6 in their paper) and our values are well within this range. We also find bulk density doesn’t decline with depth and it is highly variable down the profile.

Since the lower layers were frozen, they didn't decompose significantly and their bulk densities remain higher relative to other partially frozen or unfrozen layers. The value referred to by the reviewer is the mean value of the entire simulated peat profile and it was lower than 50 kg m-3 since the majority of peat layers are not highly compacted as a result limited decomposition due to permafrost or high water contents (see lines: 429:440 in the RM).

Revised text: When the peat layers had decomposed sufficiently and lost more than 70% of their original mass (Mo), their bulk density increased markedly. The observed monthly and annual WTP for the semi-wet patches and mean annual ALD were very near to the simulated values (see Figs. 8, 9 and A5). The simulated bulk density varies between 40-102 kg m-3 and the mean annual bulk density of the full peat profile was initially around 40 kg m-3, increasing to 50 kg m-3 as the peat layers grew older. Some studies (Clymo, 1991; Novak et al., 2008) noted a decline in bulk density with depth due to compaction. However, the simulated peat column does not exhibit such a decline with depth, instead being highly variable down the profile as found in other studies (Tomlinson, 2005; Baird et al., 2016). Freezing of the lower layers inhibited decomposition, with the result that bulk densities remained higher relative to other partially frozen or unfrozen layers. The pore space and permeability are linked to the compaction of peat layers. Therefore, when the peat bulk density increased, pore space declined from 0.95 to 0.93 reducing the total permeability of peat layers that in turn reduced the amount of percolated water from the peat layers to the mineral soil.

l. 421: Are there any vegetation reconstructions available for these sites? Pollen cores that can help determine if the model successional sequence is reasonable?

Response: For majority of its peatland history, different species of mosses occupied the Stordalen mire. The model predicted correctly the dominance of wet PFT during 4000-3000 cal. BP. However, there was a certain period between 700-1700 cal. BP when graminoids were again the dominant PFT, but we could not reproduce that period due to the climate forcing used here, as explained in the text. See lines: 527-533 in the

Printer-friendly version

Discussion paper

RM.

Revised text: Mosses emerged as the dominant PFT at the beginning of the simulation, while 300-400 years after peat inception shrubs started establishing in the higher elevated patches as a result of a lowering of WTP. Graminoids were not productive during the entire simulation period apart from the period 4-3kyr cal. BP (Kokfelt et al., 2010). The model predicted correctly the dominance of graminoids, characteristic of wet conditions, during 4-3kyr cal. BP. However, a period of graminoid dominance between 700-1700 cal. BP was not accurately captured. One explanation can be the absence of decadal and centennial climate variability in the adopted climate forcing data, resulting in an “averaging out” of moisture status over time that elminates wet episodes needed for graminoids to be sufficiently competitive.

Fig 1: why are the mosses all different colours? Can this diagram be simplified - like only a couple grass instead of that dark mat? Should permafrost maybe be ’frozen soil’ or maybe distinguish seasonally frozen soil from perenially frozen? Why is the permafrost bubble circular? Would the model really have a different bottom permafrost depth between its tiles in the same gridcell? I can understand a different top depth but not really a bottom.

Response: Our moss colours are different because they depict different stages of the moss growth cycle. However, for simplicity we have changed it to single colour. Graminoids numbers are also reduced. We have changed the text from permafrost to frozen soil and removed the circularity (see Fig. 1 in the RM). In principle, our model can have different ALD values in each patch based on the soil temperature and soil water content in that patch. Wet patches can have greater ALD than dry patches (see Fig. 9 in the RM).

Fig 2: Perhaps choose a different acronym than UM since that is also used in the MS to talk about a model.

Response: We have changed it to UMS (Upper mineral soil). See Fig. 2 in the RM.

Revised caption: Fig. 2 in the RM - Root fractions in the upper (UMS) and lower mineral soil (LMS) layers as a function of peat depth (m). The broken lines represent root fractions in UMS and solid lines indicate fractions in the LMS.

Fig. 6 I find the acronym choice non-sensible. Why does the final S of deciduous shrubs be S and not a D? Not a big deal but it makes it harder to quickly remember what the acronym stands for. Response: We used HSS in the paper since it is the acronym for High Summergreen Shrubs and LSS for Low Summergreen Shrubs (see Table 1 in the RM). These are the most common acronyms used in LPJ-GUESS publications (Wolf et al., 2008; Miller and Smith, 2012). We have revised the figure (see Fig. 6 in the RM).

Fig 7: No description of the X and Z in the caption. What do Top, Middle, and Bottom really correspond to? This gets back to my earlier comment that I don't understand how your soil layers were divided.

Response: We have now explained X and Z in the caption. There are 4739 peat layers and they were aggregated in to number of sublayers for the soil temperature calculation. We start with three sublayers of equal depth and add a new sublayer for every half a meter peat depth increment. We adopted this scheme for soil temperature because over the time these individual layers become so thin and numerous that they slow down the numerical soil temperature calculations. In total, seven sublayers formed at the Stordalen site and in figure the three sublayers are shown as top (average of layers 6+7), middle (average of layers 3+4+5) and bottom (average of layers 1+2). See lines: 172-181 in the RM. Revised text: To simulate permafrost, peat layer decomposition and cycles of freezing and thawing, the soil temperature at different depths must be calculated correctly. In the Arctic version of LPJ-GUESS as described by Miller and Smith (2012), mineral soil layers (i.e. below the peat layers added in this study) are subdivided into 20 sublayers of 10 cm thickness to calculate soil temperature at different depths. In our implementation, new peat layers are added on top of these mineral soil layers. To overcome computational constraints for millennial simulations we aggregate the properties of the individual annual peat layers into thicker sublayers for the peat temperature calculations, beginning with three sublayers of equal depth and adding a new sublayer to the top of previous sublayers after every 0.5 m of peat accumulation. This resulted, for example, in seven aggegate sublayers for the Stordalen simulations described in Section 2.4. The result is a soil column with a dynamic number of peat sublayers, 20 mineral soil layers and multiple “padding” layers to a depth of 48 m. A single layer of snow is included, as in existing versions of the model.

Revised Caption: Fig. 7. (a) Total simulated peat ice fraction (10-year moving average) over 4700 years at Stordalen. Peat layers corresponding to annual litter cohorts were aggregated to top (top 1 m), middle (middle 1 m) and bottom (lower 1.5 m) for display. (b) Total simulated ice fraction for 1900-2100 following the RCP8.5 scenario (see Fig. A6 for the RCP2.6 scenario results), (c) Total simulated mean September active layer depth for the last 4700 years and (d) for 1900-2100 at Stordalen following the RCP8.5 scenario (FTPC8.5) and RCP2.6 scenario (FTPC2.6).

Fig 8: As I said in the general comments, this figure does not give much confidence when combined with the NEE results.

Response: As mentioned earlier, NEE outputs for the other three sites are almost within the range of observed NEE values (see Table 5 in the RM), albeit with some differences. The recent short-term NEE values are not the right criteria to judge whether the model is doing the right job or not because they vary a lot spatially as well as temporally and since the peatland landscape is such a heterogeneous site, the NEE values vary between each points. Though, large-scale fluxes can be obtained from eddy flux tower but they also showed high variability (Lafleur et al., 2003; Aslan-Sungur et al., 2016). In this study, some sites (Fajemyr and Degero Stormyr) are relatively disturbed sites with high N deposition which might have influenced their NEE fluxes (Lund et al., 2007). The other factor of large uncertainty in NEE in Fajemyr is non-inclusion of trees. Also, water borne carbon fluxes (DOC) and CH4 are not yet considered in our model (but are under development; e.g. Tang et al., 2015b). Inclusion of these factors would minimize the uncertainty. This is the reason we didn't do any future predictions for these sites. However, comparatively less disturbed sites showed reasonable simulated NEE values (see Fig.11 in the RM). We believe, the right evaluation for the peat carbon balance can be extracted from long-term carbon accumulation values (LARCA) and we find a close match between modelled and observed LARCA values. In our companion paper, we have found the model is able to capture the right LARCA value across many regions. See lines: 540-548 in the RM.

In Fig. 11 of the RM, we presented (a) annual simulated NEE (kg C m-2 yr-1) for Stordalen and (b) relationship between observed and modeled annual NEE (kg C m-2 yr-1) for three Scandinavian peatland ecosystems (Table 5; observed NEE data from (Aurela et al., 2007; Lund et al., 2007; Sagerfors et al., 2008; Aslan-Sungur et al., 2016)). EC = eddy covariance (flux tower) data; CH = chamber flux measurements.

Revised text: For the additional evaluation sites, modelled dominant vegetation cover, LARCA and WTP were in good agreement with the observed values for the three selected sites at which this information was available. Under the present climate, Stordalen was simulated to be a small sink for atmospheric CO2, in agreement with observed NEE (see Fig 11). NEE interannual range is likewise close to observations for the other Scandinavian sites (Table 5). However it is uncertain whether recent annual observations of NEE necessarily reflect the long-term peatland carbon balance, in view of high variability on multiple timescales. For example, Fajemyr has switched between source (14.3-21.4 g C m-2 yr-1 in 2005-2006; 23.6 g C m-2 yr-1 in 2008) and sink (-29.4 g C m-2 yr-1 in 2007; -28.9 g C m-2 yr-1 in 2009) conditions in recent years, and this variability has been attributed to disturbances and intermittent drought conditions (Lund et al., 2012).

Also, see Table 5 in RM where observed dominant vegetation cover, long-term apparent rate of carbon accumulation (LARCA), short-term net ecosystem exchange (NEE), and annual water table position (WTP) compared with mean modelled values (1990-2000) for the 3 grid points in Scandinavian region were included

Printer-friendly version

Discussion paper

Fig A1 - perhaps add total water (liquid and frozen) so we can see if the total content was changing and it wasn't just changing phase.

Response: We have added a new panel showing the total water and ice in cm (see Fig. A4 in the RM). In the figure, total water is the melted water and total ice is the frozen water.

Table 2: density is needing the o as an subscript. Also please bring these all into the main text, it is annoying to have to search out the table when one is reading the text (and it is often not mentioned that one needs to search for a table...)

Response: We have added a subscript to the density parameter. We have also included all the parameter values in the text and we also now refer to Table 2 in RM when a new constant is first mentioned See lines: 150-153, 156-158, 166-168, 219, 222, 231 and 234 and Table 2 in the RM.

Table 5: WTP units? Please put in proportions of the veg so we can tell if the proportions modelled are in any way correct rather than just presence/absence.

Response: The WTP unit is cm and we have included in the text (see Table 5 in the RM). However, we unfortunately couldn't find total vegetation proportion data for these sites.

References:

Aerts, R., Verhoeven, J. T. A., and Whigham, D. F.: Plant-mediated controls on nutrient cycling in temperate fens and bogs, Journal, 80, 2170-2181,doi: 10.1890/0012-9658(1999)080[2170:pmconc]2.0.co;2, 1999. Ahlström, A., Schurgers, G. & Smith, B. : The large influence of climate model bias on terrestrial carbon cycle simulations, Environmental Research Letters, in press., 2016.2016. Ahlström, A., Smith, B., Lindström, J., Rummukainen, M., and Uvo, C. B.: GCM characteristics explain the majority of uncertainty in projected 21st century terrestrial ecosystem carbon balance, Biogeosciences, 10, 1517-1528,doi: 10.5194/bg-10-1517-2013, 2013. Alexandrov,

G. A., Brovkin, V. A., and Kleinen, T.: The influence of climate on peatland extent in Western Siberia since the Last Glacial Maximum, Sci Rep, 6,doi: ARTN 24784 10.1038/srep24784, 2016. Anav, A., Friedlingstein, P., Kidston, M., Bopp, L., Ciais, P., Cox, P., Jones, C., Jung, M., Myneni, R., and Zhu, Z.: Evaluating the Land and Ocean Components of the Global Carbon Cycle in the CMIP5 Earth System Models, J. Clim., 26, 6801-6843,doi: 10.1175/Jcli-D-12-00417.1, 2013. Aslan-Sungur, G., Lee, X. H., Evrendilek, F., and Karakaya, N.: Large interannual variability in net ecosystem carbon dioxide exchange of a disturbed temperate peatland, Science of the Total Environment, 554, 192-202,doi: 10.1016/j.scitotenv.2016.02.153, 2016. Aurela, M., Riutta, T., Laurila, T., Tuovinen, J. P., Vesala, T., Tuittila, E. S., Rinne, J., Haapanala, S., and Laine, J.: CO2 exchange of a sedge fen in southern Finland - The impact of a drought period, Tellus Ser. B-Chem. Phys. Meteorol., 59, 826-837,doi: 10.1111/j.1600-0889.2007.00309.x, 2007. Baird, A. J., Milner, A. M., Blundell, A., Swindles, G. T., and Morris, P. J.: Microform-scale variations in peatland permeability and their ecohydrological implications, Journal of Ecology, 104, 531-544,doi: 10.1111/1365-2745.12530, 2016. Christensen, J. H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, I. Held, R. Jones, R.K. Kolli, W.-T. Kwon, R. Laprise, V. Magaña Rueda, L. Mearns, C.G. Menéndez, J. Räisänen, A. Rinke, Sarr, A., and Whetton, P.: Regional Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA., 2007.2007. Clymo, R. S.: The limits to peat bog growth, Philos. Trans. R. Soc. Lond. Ser. B-Biol. Sci., 303, 605-654,doi: 10.1098/rstb.1984.0002, 1984. Clymo, R. S.: Peat growth, Quaternary Landscapes. Eds Shane LCK, Cushing EJ. Minneapolis, University of Minnesota Press., 1991. 76-1121991. Friedlingstein, P., Cox, P., Betts, R., Bopp, L., Von Bloh, W., Brovkin, V., Cadule, P., Doney, S., Eby, M., Fung, I., Bala, G., John, J., Jones, C., Joos, F., Kato, T., Kawamiya, M., Knorr, W., Lindsay, K., Matthews, H. D., Raddatz, T., Rayner, P., Reick, C., Roeckner, E., Schnitzler, K. G., Schnur, R., Strassmann, K., Weaver, A. J., Yoshikawa, C., and Zeng, N.: Climate-carbon cycle feedback analysis: Results from the (CMIP)-M-4 model intercomparison, J. Clim., 19, 3337-3353,doi: 10.1175/jcli3800.1, 2006. Frolking, S., Roulet, N. T., Tuittila, E., Bubier, J. L., Quillet, A., Talbot, J., and Richard, P. J. H.: A new model of Holocene peatland net primary production, decomposition, water balance, and peat accumulation, 1 Article, Earth System Dynamics, 1-21 pp., 2010. Gerten, D., Schaphoff, S., Haberlandt, U., Lucht, W., and Sitch, S.: Terrestrial vegetation and water balance - hydrological evaluation of a dynamic global vegetation model, Journal of Hydrology, 286, 249-270,doi: 10.1016/j.jhydrol.2003.09.029, 2004. Hanna, E., Huybrechts, P., Janssens, I., Cappelen, J., Steffen, K., and Stephens, A.: Runoff and mass balance of the Greenland ice sheet: 1958-2003, Journal of Geophysical Research-Atmospheres, 110, 16,doi: 10.1029/2004jd005641, 2005. Heinemeyer, A., Croft, S., Garnett, M. H., Gloor, E., Holden, J., Lomas, M. R., and Ineson, P.: The MILLENNIA peat cohort model: predicting past, present and future soil carbon budgets and fluxes under changing climates in peatlands, Climate Research, 45, 207-226,doi: 10.3354/cr00928, 2010. Hinzman, L. D., Bettez, N. D., Bolton, W. R., Chapin, F. S., Dyurgerov, M. B., Fastie, C. L., Griffith, B., Hollister, R. D., Hope, A., Huntington, H. P., Jensen, A. M., Jia, G. J., Jorgenson, T., Kane, D. L., Klein, D. R., Kofinas, G., Lynch, A. H., Lloyd, A. H., McGuire, A. D., Nelson, F. E., Oechel, W. C., Osterkamp, T. E., Racine, C. H., Romanovsky, V. E., Stone, R. S., Stow, D. A., Sturm, M., Tweedie, C. E., Vourlitis, G. L., Walker, M. D., Walker, D. A., Webber, P. J., Welker, J. M., Winker, K., and Yoshikawa, K.: Evidence and implications of recent climate change in northern Alaska and other arctic regions, Clim. Change, 72, 251-298,doi: 10.1007/s10584-005-5352-2, 2005. IPCC: Climate Change 2013: The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 2013. NY, USA2013. Johansson, M., Callaghan, T. V., Bosio, J., Akerman, H. J., Jackowicz-Korczynski, M., and Christensen, T. R.: Rapid responses of permafrost and vegetation to experimentally increased snow cover in sub-arctic Sweden, Environmental Research Letters, 8,doi: 10.1088/1748-9326/8/3/035025, 2013. Kleinen, T., Brovkin, V., and Schuldt, R. J.: A dynamic model of wetland extent and peat accumulation: results for the Holocene, Biogeosciences, 9, 235-248,doi: 10.5194/bg-9-235-2012, 2012. Kokfelt, U., Reuss, N., Struyf, E., Sonesson, M., Rundgren, M., Skog, G., Rosen, P., and Hammarlund, D.: Wetland development, permafrost history and nutrient cycling inferred from late Holocene peat and lake sediment records in subarctic Sweden, J. Paleolimn., 44, 327-342,doi: 10.1007/s10933-010-9406-8, 2010. Lafleur, P. M., Roulet, N. T., Bubier, J. L., Frolking, S., and Moore, T. R.: Interannual variability in the peatland-atmosphere carbon dioxide exchange at an ombrotrophic bog, Glob. Biogeochem. Cycle, 17,doi: 10.1029/2002gb001983, 2003. Lund, M., Christensen, T. R., Lindroth, A., and Schubert, P.: Effects of drought conditions on the carbon dioxide dynamics in a temperate peatland, Environmental Research Letters, 7,doi: Artn 045704 10.1088/1748-9326/7/4/045704, 2012. Lund, M., Lindroth, A., Christensen, T. R., and Strom, L.: Annual CO2 balance of a temperate bog, Tellus Ser. B-Chem. Phys. Meteorol., 59, 804-811,doi: 10.1111/j.1600-0889.2007.00303.x, 2007. Miller, P. A. and Smith, B.: Modelling Tundra Vegetation Response to Recent Arctic Warming, Ambio, 41, 281-291,doi: 10.1007/s13280-012-0306-1, 2012. Mitchell, T. D. and Jones, P. D.: An improved method of constructing a database of monthly climate observations and associated high-resolution grids, Int. J. Climatol., 25, 693-712,doi: 10.1002/joc.1181, 2005. Moore, T. R., Bubier, J. L., and Bledzki, L.: Litter decomposition in temperate peatland ecosystems: The effect of substrate and site, Ecosystems, 10, 949-963,doi: 10.1007/s10021-007-9064-5, 2007. Morris, P. J., Baird, A. J., and Belyea, L. R.: The DigiBog peatland development model 2: ecohydrological simulations in 2D, Ecohydrology, 5, 256-268,doi: 10.1002/eco.229, 2012. Novak, M., Brizova, E., Adamova, M., Erbanova, L., and Bottrell, S. H.: Accumulation of organic carbon over the past 150 years in five freshwater peatlands in western and central Europe, Science of the Total Environment, 390, 425-436,doi: 10.1016/j.scitotenv.2007.10.011, 2008. Ryden, B. E., Fors, L., and Kostov, L.: Physical Properties of the Tundra Soil-Water System at Stordalen, Abisko, Ecological Bulletins, 1980. 27-541980. Sagerfors, J., Lindroth, A., Grelle, A., Klemedtsson, L., Weslien, P., and Nilsson, M.: Annual CO2 exchange

Printer-friendly version

Discussion paper

between a nutrient-poor, minerotrophic, boreal mire and the atmosphere, Journal of Geophysical Research-Biogeosciences, 113, 15,doi: 10.1029/2006jg000306, 2008. Schuldt, R. J., Brovkin, V., Kleinen, T., and Winderlich, J.: Modelling Holocene carbon accumulation and methane emissions of boreal wetlands - an Earth system model approach, Biogeosciences, 10, 1659-1674,doi: 10.5194/bg-10-1659-2013, 2013. Sitch, S., Huntingford, C., Gedney, N., Levy, P. E., Lomas, M., Piao, S. L., Betts, R., Ciais, P., Cox, P., Friedlingstein, P., Jones, C. D., Prentice, I. C., and Woodward, F. I.: Evaluation of the terrestrial carbon cycle, future plant geography and climate-carbon cycle feedbacks using five Dynamic Global Vegetation Models (DGVMs), Global Change Biology, 14, 2015-2039,doi: 10.1111/j.1365-2486.2008.01626.x, 2008. Smith, B., Prentice, I. C., and Sykes, M. T.: Representation of vegetation dynamics in the modelling of terrestrial ecosystems: comparing two contrasting approaches within European climate space, Glob. Ecol. Biogeogr., 10, 621-637,doi: 10.1046/j.1466-822X.2001.t01-1-00256.x, 2001. Stocker, B. D., Spahni, R., and Joos, F.: DYPTOP: a cost-efficient TOPMODEL implementation to simulate sub-grid spatio-temporal dynamics of global wetlands and peatlands, Geosci. Model Dev., 7, 3089-3110,doi: 10.5194/gmd-7-3089-2014, 2014. Strandberg, G., Kjellstrom, E., Poska, A., Wagner, S., Gaillard, M. J., Trondman, A. K., Mauri, A., Davis, B. A. S., Kaplan, J. O., Birks, H. J. B., Bjune, A. E., Fyfe, R., Giesecke, T., Kalnina, L., Kangur, M., van der Knaap, W. O., Kokfelt, U., Kunes, P., Latalowa, M., Marquer, L., Mazier, F., Nielsen, A. B., Smith, B., Seppa, H., and Sugita, S.: Regional climate model simulations for Europe at 6 and 0.2 k BP: sensitivity to changes in anthropogenic deforestation, Climate of the Past, 10, 661-680,doi: 10.5194/cp-10-661-2014, 2014. Tang, J., Miller, P. A., Crill, P. M., Olin, S., and Pilesjo, P.: Investigating the influence of two different flow routing algorithms on soil-water-vegetation interactions using the dynamic ecosystem model LPJ-GUESS, Ecohydrology, 8, 570-583,doi: 10.1002/eco.1526, 2015. Tarnocai, C., Canadell, J. G., Schuur, E. A. G., Kuhry, P., Mazhitova, G., and Zimov, S.: Soil organic carbon pools in the northern circumpolar permafrost region, Glob. Biogeochem. Cycle, 23,doi: Artn Gb2023 10.1029/2008gb003327, 2009. Tomlinson, R. W.: Soil carbon stocks and changes in the Republic of Ireland, Journal of Environmental Management, 76, 77-93,doi: 10.1016/j.jenvman.2005.02.001, 2005. Wania, R., Ross, I., and Prentice, I. C.: Integrating peatlands and permafrost into a dynamic global vegetation model: 1. Evaluation and sensitivity of physical land surface processes, Glob. Biogeochem. Cycle, 23,doi: Gb3014 10.1029/2008gb003412, 2009a. Wania, R., Ross, I., and Prentice, I. C.: Integrating peatlands and permafrost into a dynamic global vegetation model: 2. Evaluation and sensitivity of vegetation and carbon cycle processes, Glob. Biogeochem. Cycle, 23,doi: Gb3015 10.1029/2008gb003413, 2009b. Wolf, A., Callaghan, T. V., and Larson, K.: Future changes in vegetation and ecosystem function of the Barents Region, Clim. Change, 87, 51-73,doi: 10.1007/s10584-007-9342-4, 2008. Wu, Y. Q., Verseghy, D. L., and Melton, J. R.: Integrating peatlands into the coupled Canadian Land Surface Scheme (CLASS) v3.6 and the Canadian Terrestrial Ecosystem Model (CTEM) v2.0, Geosci. Model Dev., 9, 2639-2663,doi: 10.5194/gmd-9-2639-2016, 2016. Yang, Z., Sykes, M. T., Hanna, E., and Callaghan, T. V.: Linking Fine-Scale Sub-Arctic Vegetation Distribution in Complex Topography with Surface-Air-Temperature Modelled at 50-m Resolution, Ambio, 41, 292-302,doi: 10.1007/s13280-012-0307-0, 2012. Zhang, W., Jansson, C., Miller, P. A., Smith, B., and Samuelsson, P.: Biogeophysical feedbacks enhance the Arctic terrestrial carbon sink in regional Earth system dynamics, Biogeosciences, 11, 5503-5519,doi: 10.5194/bg-11-5503-2014, 2014.

Interactive comment on Biogeosciences Discuss., doi:10.5194/bg-2016-319, 2016.

Printer-friendly version

Discussion paper