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Interactive comment on "The limits to northern peatland carbon stocks" *by* Georgii A. Alexandrov et al.

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We are pleased to see that Referees agrees that the results of the study are worth publishing. We also acknowledge the importance of Referee's comments to strengthen the presentation of the results. Below is our response to the Referee's questions and recommendations.

Response to the questions asked by Referee:

1. (1) P1 L18: How did you define northern peatlands (> 40N or 45 N)?

(2) Here we refer to the article of Loisel et al. (2017) and keep in mind the peatlands located north of 45 N.

(3)"... northern peatlands, namely the peatlands distributed across the northern mid- and high-latitude regions located north of 45°N, ..."

2. (1) P1 L19: "The variations are explained by..." Which variations?

(2) Here we keep in mind the variation in the carbon sink magnitude mentioned in the previous sentence (P1 L19).

(3) "The variations in the sink magnitude..."

3. (1) P1 L22: "However, during the last 5000 years, the area of peatlands remained relatively stable ..." Peat basal ages are used as proxies to identify new peatland areas and expansion rate. From figures 1 and 3 in MacDonald et al. 2006, we can see that around 30-40

(2) Here we cited the estimates of Bog/Swamp area given in the "Table 1. Reconstructed surface area of ecosystems" in the Adams and Faure (1998) article: 1.85 Mkm2 by 8000 BP, 2.35 Mkm2 by 5000 BP, 2.45 Mkm2 by present. The cumulative curve of 1516 radiocarbon dates of basal peat deposits shown at the at the Figure 3 in the article of MacDonald et al. (2006) also show that major part (70 percents) of the studied peatlands was initiated before 5000 BP. Moreover, MacDonald et al. (2006) wrote, "new peatland initiation was relatively modest in the late Holocene", that seemingly had the same meaning as the phrase "the area of peatlands remained relatively stable in the late Holocene", and led to conclusion that the growth in the peat depth was responsible for the major part of the carbon uptake in the late Holocene, whereas peatland expansion was responsible for the minor part of the carbon uptake in the late Holocene.

(3) Taking into account considerable uncertainty over peatland area at any particular time of the past, we agree that it would be more correct to say, "Since the area of peatlands remained relatively stable in the late Holocene, the major part of the carbon sink provided by northern peatlands during this period could be attributed to the growth

in peat depth, not to the growth of the area occupied by the northern peatlands".

4. (1) P1, L.25: "the northern peatlands may accumulate 864-2200 PgC ... " This is a very high value, how did you calculate this range. From where did you find this information? What about the peatland distribution area and sink capacity, will they remain the same in the future? Studies indicated that many peatlands would lose their carbon sink capacity while some may enhance

(2) This range was calculated as follows. "The average rate of carbon accumulation associated with peat growth is estimated at 18-28 gC m-2 yr-1 (Yu, 2001)" (P1, L.24). Northern peatlands occupy 2.4-4 million km2 (Yu, 2011) (P1, L.25). Hence, during the 20000 $(2*10^4)$ years, the northern peatlands may accumulate from $(18*2.4*10^{12})*(2*10^4) = 86.4*10^{16} = 864*10^{15}$ gC to $(28*4*10^{12})*(2*10^4) = 224*10^{16} = 2240*10^{15}$ gC. This is an estimate of cumulative carbon uptake that could be provided by peatlands under the present peatland area and the present average carbon accumulation rate. Our research, in fact, is based on the hypothesis that average carbon rate must decline in the future.

(3) "This rate suggests that northern peatlands, occupying 2.4-4 million km2 (Yu, 2011), may accumulate during the next 20,000 years the amount of carbon comparable to the expected cumulative anthropogenic carbon emissions corresponding to a 2.5oC warming (Raupach et al., 2014), namely from 864 PgC (18 gC m-2 yr-1 *$2.4*10^{12}$ m2 * $2*10^4$ yr) to 2240 PgC (28 gC m-2 yr-1 * $4*10^{12}$ m2 * $2*10^4$ yr)." We also move the next paragraph to the end of Introduction, to start the discussion of changes in the rate of carbon accumulation immediately after these estimates.

5. (1) P2 L6: How did you estimate this range – see my previous comment. (2) See the response to the question No. 4.

6. (1) P2 L11: "at least a small portion of the organic matter that enters the acrotelm always reaches to the catotelm ..." Is this a plausible argument – do you think, acrotelm always passes organic matter in the catotelm? Even when peatland experiences con-

tinuous dry conditions?

(2) Here we keep in mind an accumulating peatland, not a degrading peatland: "at least a small portion of the organic matter that enters the acrotelm always reaches the catotelm in an accumulating peatland".

(3) We may put more accent to the context of this phrase by adding the sentence, "This is, of course, not true in the case of a degrading peatland, but degrading peatlands do not fall within the scope of this study".

7. (1) P2 L 13-15: In which study, did you find this information?

(2) This conceptual scheme summarizes and generalizes a number of studies, but the closest source is the article of Alexandrov, Brovkin, and Kleinen (Sci. Rep., 6, doi:10.1038/srep24784, 2016)

(3) The maximum height of the water table, and thus the potential peat depth, is determined by the amount of effective rainfall, drainage system density and the hydraulic conductivity of peat and mineral materials below the peat (Alexandrov et al., 2016).

8. (1) P2 L27: How did you determine where to form a cluster in a grid cell?

(2) The location of a peatland cluster in a grid cell does not affect the estimate of the potential amount of carbon that could be accumulated in the grid cell, therefore it is not determined.

(3) To avoid possible misunderstanding, we change "clustered distribution "to "non-uniform distribution", "The conservative estimate assumes uniform distribution of peatlands over all grid cells ($f_{PW} = f_{P,obs}; f_{WP} = 1$), the non-conservative estimate assumes non-uniform distribution over all grid cells ($f_{PW} = 0.75; f_{WP} = f_{P,obs}/0.75$), and the less-conservative estimate is derived using a rule-based algorithm categorizing the grid cells into those where peatland distribution is uniform and those where peatland distribution is non-uniform."

9. (1) P3, L.3: What is the density of draining system?

(2) The density of draining system is the length of draining streams per unit area.

(3) "...the potential peat depth, is determined by the amount of effective rainfall, drainage system density (the length of draining streams per unit area) and the hydraulic conductivity ..."

10. (1) P3 L4: "The impeded drainage model approach" – Give more details about this approach and model. What it is and where this approach has been used before?

(2) The details of the impeded drainage model approach are given in the Supplement (https://www.biogeosciences-discuss.net/bg-2019-76/bg-2019-76-supplement.pdf). The basic idea of the approach is that the maximum peat depth is equal to the maximum height of water table above the level of draining system calculated using the impeded drainage model plus the maximum depth of acrotelm.

(3) "To calculate the potential peat depth, we apply an equation derived (see Supplement) from the impeded drainage model used in our previous study (Alexandrov et al., 2016)?.".

11. (1) P3 eqn 1 - From where this equation comes from? Any previous applications?

(2) This equation was derived from the equations of the impeded drainage model, see equations (S1-S17) in the Supplement (https://www.biogeosciences-discuss.net/bg-2019-76/bg-2019-76-supplement.pdf).

(3) This part of the text is rewritten.

12. (1) P3 L10: There are many peatlands in the southern latitude region between 45-55N, particularly in China, U.S and Mongolia. Have you considered them in your calculation?

(2) Yes, we considered the peatlands located north of 45 N.

(3) " ... sink provided by northern peatlands, namely the peatlands distributed across the northern mid- and high-latitude regions located north of 45°N, ..."

13. (1) P3 L18: Did you check the recent study by Xu et al. 2018 where the authors have refined the global and regional estimates of peatland distribution area? How your dataset (WISE30sec) is different or better than Xu et al. 2018 (PEATMAP)?

(2) The WISE30sec data set (Batjes, 2016) of soil properties is based on Harmonised World Soil Database (HWSD). The differences in the estimates of peatland area between HWSD and PEATMAP are reported in the Table 2 of the article published by Xu et al (2018): 1.327 vs 1,339 Mkm2 for North America, 0. 879 vs 1.180 Mkm2 for Asian Russia, 0.634 vs 0.528 Mkm2 for Europe. It does not seem that these differences may dramatically affect our conclusion that it might be reasonable to agree that the estimate of 875 ± 125 PgC, as obtained from two completely independent methods, is the most expedient estimate of the potential carbon stocks in northern peatlands. At the same time, we agree that it is important to trace the effect of input data updates. Therefore, we are going to publish the source code of the computer programs that were used in calculations. This source code could be employed by anyone for updating our estimate in response to the updated information on peatland area.

(3) "Analyzing the uncertainty in the data on present-day peatland extent goes beyond the scope of this study. Improving the accuracy of these data is a well known task tackled by ISRIC, the International Soil Reference and Information Centre, (Batjes, 2016; Hengl et al., 2014), and by networks of peatland scientists such C-Peat (Treat et al., 2019) and PeatDataHub (Xu et al., 2018). Hence, it might be more important to update the estimates of potential carbon stocks on a regular basis to keep pace with improvements in the accuracy of the data on present-day peatland extent."

14. (1) P4 L: How accurate are these conservative and non-conservative estimates? From Table 1, one can see that both estimates fail to capture the observed peatland carbon density. In fact, in some cases, the conservative estimates are higher than the

observed values. Based on this information, do you think we can rely on your modelled limits?

(2) Both the conservative and non-conservative estimates are not the estimates of the present peat carbon density: they are estimates of the maximum peat carbon density that could be achieved in the future, under given climatic and geomorphological conditions. Therefore, they should not capture the observed peatland carbon density. The fact that the non-conservative estimates are significantly higher than the observed carbon densities allows the following interpretation: the sites listed in the Table 1 are far from equilibrium and could accumulate a large amount of carbon by the end of the current interglacial. As to the conservative estimates, which are lower than the actual peat carbon density at the sites that fall within the grid cells where fP,obs is less than 20

(3) This part of text is rewritten.

15. (1) P5 L15: There are other methodologies which have been developed to estimate total carbon stocks (see Yu et al. 2012). How your approach is different or better than these methodologies and what are its limitations?

(2) These methodologies are to estimate present carbon stocks. We estimate the carbon stocks that could be achieved in the future. Our approach for estimating the future carbon stocks is similar to peat volume approach, but the estimate of the mean peat depth in a given region is replaced by the estimate of the maximum mean peat depth that could be achieved in the given region. We also compare our estimate of the future carbon stocks with those we derived from the time history approach.

(3) "The results of our study suggest that even the conservative estimate of the potential carbon stocks (665 PgC) is still higher than Gorham's (1991) estimate of 455 PgC in the actual carbon stocks of northern peatlands. Gorham's estimate, based on peat-volume approach, . . ." . . . "The conservative estimate is also higher than the Yu's (2011) estimate of actual carbon stocks, 547 ± 74 PgC, based on the time history approach,

suggesting that northern peatlands in total would accumulate in the future more carbon than they store now.

16. (1) P5 L16: "We adapted this methodology for use at the global scale . . ." Global or regional because you have considered only the northern peatlands?

(2) It may be more correct to say, that we adapted this methodology for use in the studies of the Earth climate system, as we found that northern peatlands are the important element of the Earth climate system affecting the length of the current interglacial.

(3) "We adapted this methodology for use at the Earth system scale . . ."

17. (1) P6 L7: "If there were no limits to their growth . . ." In the introduction, you have mentioned that peatlands can reach to steady state and do not grow or accumulate carbon after that. Do your analysis shows in which regions peatlands have already reached to steady state?

(2) If there would be a map of carbon stocks in peatlands, the comparison of this map to the map displayed at the Fig.3 (the less-conservative estimate of the potential carbon stocks) would show in which regions peatlands have already reached to steady state. At the moment, only the grid cells where $p_{C,max}/(A * f_{P,obs}) \leq 45$ KgC m-2 could be categorized as the grid cells where peatlands already reached the steady state.

Response to recommendations made by Referee:

1. (1) P2 L 1-15: Support your arguments with previously established knowledge. Include references. (2) Done

2. (1) P2 L5: Define what a steady state is for your readers. (2) Done (3) " . . . the closer the peatland ecosystem is to its steady state, that is, to the equilibrium between organic matter production and decomposition, the lower is the carbon sink magnitude."

3. (1) P2 L9: Remove this expression – "the so called" (2) Done

4. (1) P2 L 16: Could you explain a bit about your model. What it does and other

relevant information briefly and give more details in the methods section. (2) Done (3) This part of the text is rewritten.

5. (1) P2 L 22: "The gridded data on soil properties give the fraction of a grid cell covered by peatlands : : :" Include reference. (2) done

6. (1) P2: I think a paragraph needs to be added in the end which explains the purpose of your study. (2) done

7. (1) Methods: You could start with an equation for the maximum depth of peat before introducing the maximum carbon stock in a grid cell (2) Done

8. (1) Methods. Perhaps subheadings could be helpful to improve and clarify the structure of the methods. I also suggest you to add a model description section.

(2) done

(3) We divided the Methods section into: "Equations", "Input data", and "Uncertainty associated with peatlands distribution over a grid cell"

9. (1) P3 L7-8: it is better to include the value of constants in the equation or under it. (2) done

10. (1) P3 L11: Include a brief write up about the SoilGrid dataset and what it contains.

(2) We use only the depth to bedrock from this dataset and give reference to the paper where this data set is described in detail.

11. (1) P3 L22: If you have the dataset then you can easily estimate how much area is occupied by northern peatlands. According to Xu et al., around 3.12 million km2 area is occupied by peatlands above 45N and Yu et al. 2010, used 4.0 million km2.

(2) Yes. We corrected this phrase.

(3) "These data allow us to estimate the values that fP may take at the cells of the 0.1°*0.1° geographic grid (Figure 2) and the total area, $2.86 * 10^6 km^2$, that peatlands

occupy in the land north of 45N."

12. (1) P4 Results: This looks like a part of the discussion. I recommend you to explain your results and what you see in your figures before comparing them with the previously established knowledge.

(2) done

13. (1) P4 L27: You can also include the eqn used by Gorham 1991- Cpeat = Pi (Ai $\times Di \times BDi \times CCi)$

(2) We did not find this equation in the cited Gorham's paper. Therefore, we supposed that it might be better to explain the Gorham's version of the peat-volume approach through an indirect quotation of his words. Here is the direct quotation, "... we can then estimate readily the total carbon in the dry mass of boreal and subarctic peat, subtracting the mined area, as $(3.42 \times 10^{12} m^2) \times (2.3m) \times (112 \times 10^3 g/m^3) \times (0.517) = 455 \times 10^{15} g$, or 455 petagrams (Pg)."

14. (1) P4 L29: 112×10^3 g m-3 - Change it to 112 kg m-3

(2) This is a part of an indirect quotation; therefore, we suppose that it might be better to keep the units in the same format as they were in Gorham's paper.

15. (1) P5 L4: Explain what time history approach is.

(2) Since it is difficult to explain this approach in few words, we suppose that it might be better to give a reference to the publication, where this approach is explained in detail.

16. (1) P5 L18-22: No references.

(2) References are inserted.

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