Associate Editor Decision: Reconsider after major revision by Sebastiaan Luyssaert
Comments to the Author:
Dear authors,
Based on the referee comments and the subsequent discussion, I would like to invite you to prepare and upload a revised version of the manuscript. In addition to addressing the main comments of the referees the revision should address the following:

A. *Ensure that the knowledge gain in biogeochemical processes is stressed throughout the manuscript.*
B. *Given the scriticism of both referees on section 5.3 of the discussion, the discussion should be balanced towards biogeochemical processes.*
C. *Other model approches(OrCHIDEE, JULES,…) should not simply be mentioned in the manuscript but the key differences between those approaches and yours should listed. The readers will want to understand what makes your approach unique.*

Thank you very much for encouraging us to revise the manuscript and good comments.

A. We first improve our model to include non-vascular plants and then use the updated model to explore the treatment responses, including different warming levels under both elevated and ambient atmospheric CO2 concentration conditions. Our main goal is to explore how the carbon dynamics of the peatland system will change under the treatment conditions. Knowledge about biogeochemical processes is gained by including the moss plant functional type and investigating its impacts on simulated carbon, energy and water cycling in this important peatland ecosystem under conditions approximating future climate.
B. We agree that the section 5.3 is more focusing on future model development and was detached from the discussion. Followed the comments, we merged section 5.3 to section 5.1 and 5.2 to make the manuscript more coherent with a focus on biogeochemical processes and clearer structure.
C. Thank you for your good comment about this point. We added those model approaches to the Introduction section (L137-146), and also pointed out how they differ from our model approach.

Reviewer 1

Even though, mosses are ubiquitous part of boreal vegetation, especially so in peatlands, mosses and their contribution to ecosystem functions are overlooked. The study introduces new plant functional type (PFT) with Sphagnum-specific processes that can be in some extent to be used to describe mosses in other boreal and arctic environments, e.g. upland forests and wet tundra. Manuscript consists, sensitivity analysis of updated land model component and validation part that takes place in boreal ombrotrophic, raised-dome bog peatland with warming and CO_2 enrichment experiment. Authors have stated that drier and warmer future climates can lower water table and it has implications on growth of Sphagnum. In the study, capillary rise is a function of peat water content in 10 cm, but it is not clearly stated that if measured or modelled values of peat water content is used in sensitivity analysis and in case study and how water table fluctuations affect functions (e.g. gross primary production) of Sphagnum mosses?

We use modeled values of peat water content in both the forward simulations and the sensitivity analysis. The modeled water table (WT) has a direct effect on the sphagnum GPP in our model when WT is above the soil surface, through submergence effects (manuscript Eq 7). WT also has an indirect effect on sphagnum GPP, through total conductance to CO_2 (g_{tc}), as follows: g_{tc} increases with total Sphagnum water content (manuscript Eq. 6) while GPP increases with g_{tc} (manuscript Eqs. 5 and 4). Total sphagnum water content includes a component from Sphagnum internal water (manuscript Eq 3) which is an empirically derived function of soil water nearest the 10cm soil horizon (manuscript Eq 2). As WT drops below the 10cm soil horizon the water content in that layer declines, leading to lower sphagnum internal water, lower sphagnum total water, lower g_{tc}, and lower GPP.

If there is more Larix and taller shrubs growing on the site, does it drain more or less the site? Do you see effect of warmer climate on water table depth in higher temperatures and how this will affect Sphaghnum mosses?

From manuscript Fig.6, we can see the relative biomass changes of Larix, shrub and hollow Sphagnum increase with temperature, the hummock Sphagnum biomass decreases with warming and is more dependent with water table height, and the water table generally decreases with temperature. We have added "We plotted the predicted canopy evaporation for hummock and hollow Sphagnum responses to warming and found that both hummock and hollow Sphagnum canopy evaporation increase with warming for both ambient and elevated atmospheric CO_2 conditions despite the Larix and shrubs are growing with warming. Moreover, the hollow Sphagnum canopy evaporation warming response is stronger than that of the hummock Sphagnum (Fig. S2)." to the text (L619-624).

What I am after is that which kind of hydrological feedbacks there are and how it affects ecophysiology of Sphagnum PFT if temperature will increase +9.0 degrees of Celsius. This is something to think about especially if capillary connection of Sphagnum is described through a simple relationship between capitulum water content and peat water content at 10 cm depth. This could be answered simply by studying hydrological balance of Sphagnum PFT and showing how large part capillary rise plays in Sphagnum hydrological balance. Is it even necessary or which kinds of implications it has to photosynthetic capacity or other ecophysiological processes? In my opinion, authors have not clearly showed or discussed underlying assumptions and consequences of made choices and it should be improved.

To make how the hydrological cycle affects the Sphagnum ecophysiology clear, we have added "One key feedback is if the water table declines, there can be enhanced decomposition and subsidence of the peat layer, which brings the surface down closer to the water table again. But we currently did not consider the peat layer elevation changes in our model and this will be one of the future development directions. The capillary rise plays into the Sphagnum hydrological balance, which varies depending on water table depth and evaporative demand. At short timescales or under rapidly changing conditions, there may not be equilibration between the Sphagnum water content and the peat moisture. Generally, the Sphagnum water content will equilibrate with the peat on a daily basis outside the plot since the dew point is often reached at

night. But inside the warmer plots since the VPD does not go to zero some disequilibration could remain. High-frequency latent heat flux data from the site are currently lacking, but could help to constrain these effects in the future. The current phenology observations also include if sphagnum hummock and hollow are wet or dry, and we could look at the relationship with soil water content sensors in future work." to the text (L 672-686).
We also added one more reference " Druel et al., 2017" to L701", "Thus, for the Sphagnum mosses desiccation occurs and the time needed before recovery to optimum photosynthetic capacity should be taken into account in our future work" to L 705-707, and "Larmola et al. (2014) also reported that the activity of oxidizing bacteria provides not only carbon but also nitrogen to peat mosses and, thus, contributes to carbon and nitrogen accumulation in peatlands, which store approximately one-third of the global soil carbon pool. We currently didn't consider this kind of CH4 associated carbon and nitrogen uptake by Sphagnum" to L713-720. We will eventually treat the Sphagnum mosses as the "top" soil layer with a lower thermal conductivity and higher hydraulic capacity than a mineral soil layer.

Sphagnum mosses are sitting on top of high CO2 (and water vapor) sources and experiencing naturally higher concentrations of CO2. How this affects to gross primary production of mosses and which kind of differences there possibly are between mosses that are located to hollows and hummocks? How does this fit to CO2 enrichment study?

To clarify the elevated CO_2 concentration responses of Sphagnum, we add the following text (L828-843): "Sphagnum mosses are sitting on top of high CO_2 sources. CH_4 can be a significant carbon sources of submerged Sphagnum (Raghoebarsing et al., 2005; Larmola et al, 2014); refixation of CO_2 derived from decomposition processes also is an important source of carbon for *Sphagnum* (Rydin and Clymo, 1989; Turetsky and Wieder, 1999). The effects of the elevation of atmospheric CO_2 on Sphagnum moss are currently disputed, with studies indicating an increase in growth rate (Jauhiainen and Silvde 1999; Heijmans et al. 2001a; Saarnio et al. 2003), decreases in growth rate (Grosvernier et al. 2001; Fenner et al. 2007) and no response (Van der Hejiden et al. 2000; Hoosbeek et al. 2002; Toet et al. 2006). Norby et al. (2019) indicated that no growth stimulation of both hummock and hollow *Sphagnum* under elevated CO_2 condition, but significant negative effects of elevated CO_2 on *Sphagnum* NPP in year 2018 at the same study site. Contrasting responses between Sphagnum species are thought to be coupled with the water availability. In contrast, our model results showed that both hummock and hollow *Sphagnum* growths were stimulated by the elevated CO_2 concentration, which may be attributed to the fact that we did not consider the light competition between the PFTS (shrub and tree shading effects) and use a fixed cover fraction of Sphagnum."
Is CO2 concentration profile assumed to be uniform throughout the canopy profile? Does this have effects on results of simulations?

We added the following text (L844-860): "The CO_2 vertical concentration profile is assumed to be uniform in the simulations. In the experiment, the enclosure's regulated additions of pure CO_2 are distributed to a manifold that splits the gas into four equal streams feeding each of the four air handling units (Hanson et al., 2017 Fig. 2a), and is injected into the ductwork of each furnace just ahead of each blower and heat exchanger. Horizontal and vertical mixing within each enclosure homogenizes the air volume distributing the CO_2 along with the heated air. The horizontal blowers in the enclosures together with external wind eddies ensure vertical mixing.

We do not have routine automated CO_2 concentration data below 0.5m. The moss layer may well be experiencing higher concentrations than assumed by the model, but such an impact will be minimized during daylight hours. Preliminary isotopic measurements imply a significant fraction of carbon assimilated by the moss may come from subsurface respired CO_2 (i.e., CO_2 with older ^{14}C signatures predating bomb carbon that can only be sourced from deeper peat, Hanson et al. 2017). We will consider this effect in future assessments of the isotopic C budgets for the SPRUCE study."

In Chapter 5.3 authors raise important issues and future directions. To me problem is that now it seems to be detached from the model description and discussions. Could this be embedded better in discussions to make the manuscript more coherent and structure clearer?

Thank you for your good suggestion. We embedded the context of 5.3 Section to Section 5.1 and 5.2 and changed Section 5.2 from "Predicted warming response uncertainties" to "Predicted warming and elevated CO_2 concentration response uncertainties".

L183: Are measurements of Sphagnum water contents from Sphagnum growing on hollows and hummocks? Were there any differences between these microtopograpichal features on water content in moss? Even though, this is clever way to solve capillary rise issue of mosses in simple manner but is this method applicable in both microtopographical positions? My main concern is that does this approach mask the effects of hydrology that is quite important for Sphagnum ecophysiology (main source of water in hollows and hummocks). How about self-cooling (enhanced evaporation) of Sphagnum covered surfaces due to capillary rise? Does the static approach fail especially in sunny days and which kinds of implications it has to Sphagnum ecophysiology?

The measurements of *Sphagnum* water content during sensor calibrations were primarily on hummock species but included some hollow species. They were not separated during measurements since we needed an integrated measurement for reference against the automated subsurface sensors. We have added this information to the water content dynamics of Sphagnum mosses Section (L219-224). "Currently, we apply the same method for the hummock and hollow Sphagnum water content prediction and can test the model against the measured data when more data are available. Our model still can predict Sphagnum water content differences between these microtopographies as expected, with the water content of hollows greater than that of hummocks. In addition, our model is able to represent the self-cooling effect, although we do not yet have measurements available to validate the model. The relationship of the differences between vegetation temperature (TV) and 2m air temperature (TBOT) (TV-TBOT) and canopy evaporation for both hummock and hollow Sphagnum demonstrated that the differences of TV-TBOT was negative and the canopy evaporation had a negative relationship with TV-TBOT (Fig. S3). " has been added to L724-734.

L589-L591 This is not only in case with submerged Sphagnum, but it seems that Sphagnum utilizes CH4 as an indirect source of CO2 (e.g. Larmola et al., 2014: DOI: 10.1073/pnas.1314284111)

We added “Larmola et al. (2014) also reported that the activity of methane oxidizing bacteria provides not only carbon but also nitrogen to peat mosses and, thus, contributes to carbon and nitrogen accumulation in peatlands, which store approximately one-third of the global soil carbon pool.” to the manuscript text and cited this literature (L713-719). We also cited it as reference in L829-830.

L614-618: Can it be that model parameters of hollow and hummock Sphagnum can differ from each other? How this could affect outcome of simulations? I would quess that Sphagnum growing on hummocks are more drought tolerant and resistant than those species growing in hollows. This could be seen i.e. in different slatop -value and, as discussed by authors, in base rate for maintenance respiration.

To clarify these aspects we added the following text (L 787-795) “We currently used the same parameters for both hummock and hollow, but could consider species differences in the future. Norby et al. (2019) investigated different Sphagnum species at the same site and reported there was no support for the hypothesis that species more adapted to dry conditions (e.g., S. magellanicum and Polytrichum mainly on hummocks) would be more resistant to the stress and would increase in dominance, and both hummock and hollow sphagnum are declining with warming despite the differences between them. This declining trend may be in part due to increased shading from the shrub layer, which is expanding with warming.” ELM is currently not able to represent this shading effect and we will address this in future model development.

L684: Is N fixation somehow represented in a model. Should that be mentioned in a model description? In my opinion, this is quite interesting and important part why moss PFTs should be included in models handling boreal and arctic regions.

We added “Inputs of new mineral nitrogen of ELM are from atmospheric deposition and biological nitrogen fixation. The fixation of new reactive nitrogen from atmospheric N2 by soil microorganisms is an important component of nitrogen budgets. ELM follows the approach of Cleveland et al. (1999) that uses an empirical relationship of biological nitrogen fixation as a function of net primary production to predict the nitrogen fixation” to Section 2.1(L177-183). We also added “We are measuring Sphagnum associated N2 fixation at the SPRUCE site and found that rates decline with increasing temperature (Carrell et al. 2019 Global Change Biology). We are continuing these measurements to see if they correlate with the GPP empirical relationship from Clevand (1999), or if temperature disrupts that association. Once finished, results will be used to represent N fixation by the Sphagnum layer and testing with measurements.” to L870-873 and L890-891.

Reviewer 2

In this study, new plant functional type (PFT) describing Sphagnum –moss, abundant in boreal and arctic peatlands, is incorporated into the land model component ELM of the Earth System model E3SM to better represent carbon, water and nutrient cycling in boreal and arctic regions.

The ELM with the newly proposed Sphagnum-PFT was parameterized and evaluated against data collected under ambient conditions and under climate-change experiment conducted at an ombrothrophic bog in Minnesota, US. Further, the model is used to predict changes in moss and vascular plant productivity, biomass accumulation and water table level for combined temperature and CO2 increase scenarios.

The article is well written and fits topically under the scope of BG. However, the relevance for larger scientific community is limited as the study is centered on development of a specific land model and testing for a specific site. I therefore consider the study as border line case for BG and maybe fits better into a more specific model development journal such as Geoscientific Model Development. However, this is up to the Editor to decide.

The primary goal of the SPRUCE project is to test how vulnerable an important Carbon-rich terrestrial ecosystem is to atmospheric and climatic change by warming the entire soil profile and measuring whether large amounts of CO_2 and CH_4 are emitted The regression design allows the derivation of key temperature response functions for mechanistic ecosystem processes that can be used for model validation and improvement. In this study, we introduce a moss PFT into the land model component (ELM) of the Energy Exascale Earth System Model (E3SM). Then, we evaluate our updated model against numerous measurements. We also apply the updated ELM to explore how an ombrotrophic, raised-dome bog peatland ecosystem will respond to different scenarios of warming and elevated atmospheric CO_2 concentration. The model development is only part of our goal, and we mainly focus on using the model to investigate the peatland ecosystem responses to changing climate and the feedbacks. Our model development work at SPRUCE in this manuscript is a first step to a broader peatland model in E3SM that can predict key climate feedbacks from these important ecosystems. The broader representativeness of the ecosystem responses at SPRUCE for other peatland systems was considered in the design of the experiment and will be further assessed using ELM-SPRUCE in future work at additional sites.

In recent years there has been strong interest on including Sphagnum as well as feather mosses and other bryophytes into land-surface models. In addition to the references listed in the Introduction the authors should take a look and cite the recent works of Philip Porada and colleagues (Porada et al., 2013, 2016), as well as note the inclusion of moss-PFT into ORCHIDEE-model (Druel et al., 2017). The authors should also be more explicit how their study builds on and improves the existing knowledge and methods to describe Sphagnum mosses in land surface models. If the study is to be published in BG, the results and methods should in my opinion be generalized and better interpreted against existing literature. Currently, the discussion, in particular Section 5.3, reads more as a research plan for future development of a specific land surface model.

Thank you for the suggestion to place our work in the context of existing literature. We added the following text and citations to the introduction (L137-146): "Druel et al. (2017) investigated the vegetation-climate feedbacks in high latitudes by implementing the nonvascular plants including bryophytes and lichens to the global land surface model ORCHIFEE. Porada et al. (2016) integrated a stand-alone dynamic non-vascular vegetation model LiBry (Porada et al.,

2013) to land surface scheme JSBACH, but LiBry and JSBACH mainly represent bryophyte and lichen growth on upland forest floor sites, not for wetland sites. Chadburn et al. (2015) introduced a new moss PFT to JULES land surface model and treated the thermal conductivity of moss depending on its water content

We also added a new section '2.2 Non-vascular plants: Sphagnum mosses' to Section 2 Model description to describe more details how we implement our Sphagnum mosses into our model (L189-202). For the future model development Section 5.3, we embedded it into Section 5.1 and 5.2 as the other reviewer also suggested.

My general comments are as follows:
1) Modeling Sphagnum water content
Sphagnum total water content is sum of two pools: Wtot = Winternal + Wsurface There are few remarks / comments that should be made. First, Winternal is described as non-linear function of top soil water content and thus immediately adjust to changes in soil water content (or water table). This approach thus assumes that in Sphagnum, Winternal is at hydrostatic equilibrium with soil water potential (or water content) as defined through water-retention characteristics of the peat-Sphagnum continuum. Moreover, it assumes that hydraulic conductivity is sufficiently large so that Sphagnum water content is never decoupled from soil water content. Such assumptions may not hold in case water table (WT) drops deep during prolonged dry periods, more propable in future climat

We added the following text (L686-691)"Moreover, the equilibration time between peat moisture and moss water content is reasonably fast, but the timescales for rewetting should change as the peat dries since the cross section for capillary rise will decline and thus the maximum flux to the surface will decline. So, at some point, between gravity potential and reduced hydraulic conductivity the capillarity will not satisfy evaporative demand."

But for the simplicity, we currently used the empirical representation of water content in our model for both hummock and hollow Sphagnum (as we responded above for the first viewer's comment).

We also added "Moreover, Walker et al., (2017) reported that the function of Sphagnum water content to soil water content or to water table depth they used for the SPRUCE site was empirical and may not be representative for peatland ecosystem. To better represent the peatland ecosystem in our model, we will eventually treat the Sphagnum mosses as the "top" soil layer with a lower thermal conductivity and higher hydraulic capacity." L734-739.

What is author's conclusion on generality of Winternal – soil water content relationship (Fig. 1) among Sphagnum species (hummock vs. hollow –preferences)? And how Winternal and Wexternal pools were separated from the gravimetric measurements of water content in Sphagnum to derive relationship between Winternal and soil water content?

During the calibrations, we used intact monoliths collected from multiple locations. The monoliths included both hummock and hollow species, but they were not separated during destructive measurements, since we needed an integrated measurement for comparison against the subsurface soil water content sensors. We have clarified this information to the water content dynamics of Sphagnum mosses Section (L219-224).

Second, the Wsurface is filled by interception of rainfall (how about condensation?) and drained by evaporation. I wonder how the surface storage capacity is described and parameterized and whether Wsurface and Winteral are completely independent water pools? See also Porada et al. (2018).

Surface storage of Sphagnum is described in Eq. 2 (the ELM default algorithms for representing canopy water, details as described by Oleson et al., 2013). The Sphagnum moss canopy water (canopy_water) is simulated by a function of interception, canopy drip, dew (was added to L244) and canopy evaporation.We treat Wsurface and Winternal as independent pools. Porada et al. (2018) used a process-based numerical simulation model to show that non-vascular vegetation contributes substantially to global rainfall interception and it was an interesting paper.

Third, the authors should describe how evapo(transpi)ration from Sphagnum-PFT is modeled and how it differs from vascular-PFT's. From which water pools evaporation takes place and how evaporation rate or surface conductance depend on Sphagnum characteristics and near-ground microclimate. How and whether evaporation is restricted with decreasing water content? This is required to understand e.g. how SLA and leaf C:N ratio can affect evapotranspiration and interpret the results of sensitivity analysis in Fig 2.

We use the same framework as for vascular PFTs (as described in the new Section 2.2 Non-vascular plants: Sphagnum mosses, L189-202), but the Ball-Berry slope term is assumed to be zero and the intercept term is the conductance term as a function of water content. Drying impacts the conductance and affects evaporation of the internal water. The SLA and leaf C:N ratio parameters are strong controls on Vcmax, and therefore overall productivity and Sphagnum moss LAI. The high sensitivities occur because LAI is a strong control on evapo(transp)iration.

2) Modeling Sphagnum photosynthesis
Standard Farquhar-approach is used to simulate Sphagnum net CO2 demand given air chloroplast conductance described as non-linear function of Wtot (eq. 6, from Williams and Flanagan, 1998). In addition, submerging of Sphagnum is assumed to 'kill' CO2 diffusion and thus a restriction to photosynthetic uptake is applied and described as linear function of submerged to total photosynthesizing height (here 0.05m) of the moss. Does the implementation of moss photosynthesis follow Walker et al. (2017)?

Walker et al. also uses the conductance equation from Williams and Flanagan but has a different implementation of the Farquhar model and did not calculate evaporation from the Sphagnum surface. We have added "Submergence in Walker et al. (2017) was expressed as photosynthesising stem area index (SAI) as a logistic function of water table depth. A maximum SAI of 3 was used and the parameter combination that most closely described the GPP data gave a range of water table depth from -10 cm for complete submergence and SAI of ~2.5 at 10 cm. This allowed for a range of processes such as floatation of Sphagnum with the water table, and adhesion of water to the Sphagnum capitula." to main text L312-317.

I like the approach but wonder whether the relatively poor match between modeled and 'measured' moss GPP (Fig 3) can be due i) to ill-represented or omitted temperature response *or seasonal acclimation of Vcmax etc., ii) biased Sphagnum temperature (how was it modeled – from surface energy balance?) or ii) too strong submerge-impact. As Sphagnum moss has high leaf (or shoot) area, radiation decays rapidly with canopy depth and thus the top centimeter(s) of the shoot system are responsible of majority of photosynthetic activity. For instance, Niinemets and Tobias (2014) and Zotz and Kahler (2007) show light attenuation profiles and photosynthesis profiles for some moss species. Considering typical characteristics (color) of Sphagnum-canopy, assuming CO2 uptake is evenly distributed across top 5cm may lead to overestimated submerge-impact.*

We added the following text to discussion Section 5.1 L 656-666 "In addition, we use the default formulation for acclimation of Vcmax in ELM which is based on a 10-day mean growing temperature. At this point we don't have sufficient measurements to test this assumption,but we can prioritize these measurements in the future. Sphagnum temperature is computed from surface energy balance but because the current model doesn't have the capacity to estimate shading effects from trees and shrubs, this may be overestimated. Moreover, biases in predicted water table height contribute to errors in the calculated submergence effect. Improving these biases and assuming an exponential rather than a linear CO_2 uptake profile may improve representation of the submergence effect. All these aspects may be attribute to the biases of simulated Sphagnum GPP. We can consider this in the future when we have more detailed measurements."

I also wonder whether the soil-respired CO2 leads the Sphagnum to operate in CO2 enriched atmosphere already in current conditions and whether this would lead to over-estimated increase of GPP at 900 ppm as photosynthetic CO2-response curve has saturating shape?

"Preliminary isotopic measurements imply a significant fraction of carbon assimilated by the moss may come from subsurface respired CO_2 (i.e., CO_2 with older ^{14}C signatures predating bomb carbon that can only be sourced from deeper peat, Hanson et al. 2017). However, the observed elevated CO_2 response is smaller than simulated (Hanson et al., 2020). Understanding the drivers of elevated CO_2 response or lack thereof is a key topic for future work and we will consider this effect in future assessments of the isotopic C budgets for the SPRUCE study." was added to L854-860.

In results L530-534 it is stated that modeled Sphagnum biomass correlates with water table and best correlation is found at with 3-month timelag. For GPP and NPP the instantaneous dependence on WT is from Fig 1. and eq. 6. Please describe how NPP is allocated into biomass and how the growth dynamics of Sphagnum-PFT is modeled; can this explain the timelag?

"NPP is allocated instantaneously into biomass. A positive NPP anomaly caused by water table shifts leads to higher LAI, which also increases future productivity for some amount of time even if the water table returns to normal. Sphagnum biomass has a 1-year turnover time in the simulation. This combination of effects leads to a roughly 3-month timelag." has been added to L610-614.

3) Modeled carbon cycle components and responses to warming and elevated CO2
For the reader to understand the modeled carbon cycle responses, it is necessary that ELM 'tiling scheme', pathway from NPP to biomass growth and between-PFT competition are better described in Section 2.1 and/or 3.3. That is, present information such as L627-634 earlier in the manuscript. Are shrubs and Sphagnum present as independent tiles or do they occur below the overstory trees?

The default ELM has 16 PFTs and bare ground. For this study, we only included 4 PFTs which are the dominant PFTs for our study site, including boreal evergreen needleleaf tree (Picea), boreal deciduous needleleaf tree (Larix), boreal deciduous shrub (representing several shrub species), and the newly introduced Sphagnum moss PFT (we already mentioned in 3.3 Section, L367-370). Based on the reviewer's suggestion, we moved the related content 'Currently ELM_SPRUCE does not include light competition among multiple PFTs, and thus does not represent cross-PFT shading effects. Our model also allows the canopy density of PFTs to change prognostically, and their fractional coverage is held constant.' from the original L 627-634 to Section 3.3 L 370-373.

4) Title: "Modeling the hydrology and physiology of Sphagnum moss in a northern temperate bog" should be revised to match the manuscript content. The study is on extending the land-surfacemodel with Sphagnum-PFT and simulating response of moss and vascular vegetation productivity to warming and increasing atmospheric CO2.

We plan to use this as the title "Extending a land-surface model with Sphagnum moss to simulate responses of a northern temperate bog to whole-ecosystem warming and elevated CO_2".

Specific comments:
L98: water and exchanges within peatland and between peatland and atmosphere?

we already modified the related content to 'water and exchanges within peatland and between peatland and atmosphere (L100-101).'

L 146-147: new chapter – study Aims.

A new paragraph to show the study objective starts with L160 'In this study, we introduce a new Sphagnum moss PFT into the model…' as suggested.

L178-179: Evaporation depends on evaporative demand (VPD; available energy), moss-atmosphere conductance (moss canopy structure, roughness and flow characteristics) and available water pool.
The latter is then depends on capillary rise from water table.

We rewrote the related content to 'Since evaporation at the Sphagnum surface depends on atmospheric water vapor deficit, moss-atmosphere conductance and available water pool which depends on capillary wicking of water up to the surface' (L215-217)

L196: canopy_water _ can_water

Thank you for catching this point. We changed canopy_water to can_water (L243).

L211: eq. 6 uses total water content, not Winternal

Yes, we used the total water content to calculate the total conductance to CO_2 in equation 6, which is consistent with Williams and Flanagan (1998) and Goetz and Price (2015). Thus, we removed 'The internal water content of Sphagnum mosses is observed to affect photosynthesis by constraining the length of the diffusive path for CO_2 through the variably-hydrated external hyaline cells to the carbon fixation sites (Robroek et al., 2009; Rydin and Jeglum, 2006)'.

L238-239: this assumes boundary-layer conductance >> moss surface – chloroplast conductance;
assumption is ok but could be mentioned. Note also that maximum g_tc may vary among Sphagnum species?

We added the related content "To be noted that we assume that the boundary layer conductance is greater than moss surface layer conductance, and the moss surface layer conductance is greater than chloroplast conductance." to the manuscript to L306-308.

L284: what is pre-treatment data?

Pre-treatment data is the data which was collected prior to initiation of the warming and CO_2 treatments, and this was added to L353-354.

L363-367: please elaborate whether the data used in parameter optimization is independent of data used in model testing (Fig. 3-4)

The sphagnum GPP in Fig. 3 was not used in the parameter optimization. For the Fig.4, the sphagnum NPP of year 2015-2017 is independent of the optimization, and only above biomass of trees and stem carbon of shrub for year 2012 and 2013 was used for the optimization. We added the years for the data which were used to constrain the model (L437-441), and also added the explanation to Fig.3 and 4 legend.

L393: point should be (*)

Thank you for pointing this out. We changed from point to * (L467).

L479-480: Just curious - why year 2012 was an exception? Were env. drivers different?

Sphagnum production in 2012 was high primarily because of especially high productivity in the hollows during the summer.We double checked the climatical forcing data and did not find the temperature and precipitation were abnormal for year 2012.

L522: Fig. 5: what is driving the strong inter-annual variability of Sphagnum and shrub NPP (annual variability has different sign among these PFT's). Is this mainly due to WT height and does root zone water content affect vascular PFT photosynthesis (O2-stress in wet conditions)?

There are strong inter-annual variabilities of Sphagnum and shrub NPP. For example， the variabilities of Sphagnum and shrub have different signs for predicted years 2020 and 2021 (Fig.5). We compared the BTRAN (a scalar representing soil water stress) of shrub for these two years and found that BTRAN may be the driving factor of shrub's variability. The hummock Sphagnum inter-annual variability is mainly driven by water table height with about 3-month lag (Fig.6). The hollow Sphagnum NPP of year 2020 for +0.00ºC, +2.25ºC, + 4.5ºC and +6.75ºC temperature levels is lower than the corresponding NPP of year 2021, but it is the opposite way for the +9.00ºC condition. The water table is higher for year 2020 than that of year 2021.This implicated that the submerge effect influences the inter-annual variability of hollow Sphagnum NPP. But many complex factors drive the inter-annual variability, and it is out of our scope for this study. Thus, we do not plan to include this content to the manuscript text. In addition, we don't currently model the effects of O_2 stress in the root zone.

L616-618: this is quite trivial result as Sphagnum water content was made proportional to soil water content (and hence WT).

We changed "Sphagnum growing on hummocks, on the other hand, showed negative warming responses and strong dependency on water table height" to "Sphagnum growing on hummocks, on the other hand, showed negative warming responses that are related to the strong dependency on water table height." (L776-778).

L659: The question is that to which extent the parameterization from S1-Bog be generalized to other peatlands?

The algorithms used to represent moss (e.g. Williams and Flanagan) are transferable to and have been applied by other modeling groups in other peatlands. However, we expect that certain parameters will vary, for example, the microtopographic parameters, the relationship between peat moisture and internal water content, and moss properties such as C:N ratio. The parameter sensitivity analysis informs us as to the most important parameters responsible for prediction uncertainty, and can inform how to prioritize these measurements. Collecting these measurements from a variety of sites will be a necessary preliminary exercise (L 913-920).

L667: See e.g. Beringer et al. (2001) and Porada et al. (2016) who have already done this.

Thanks for pointing these two literatures. We added them to the text and listed as references (L739).