Biogeosciences Discuss.,
https://doi.org/10.5194/bg-2020-90-AC1, 2020

Biogeosciences Discussions

Interactive comment on "Modeling the hydrology and physiology of *Sphagnum* moss in a northern temperate bog" *by* Xiaoying Shi et al.

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Received and published: 29 August 2020

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 CO2 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)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 CO2 (gtc), as follows: gtc increases with total sphagnum water content (manuscript Eq. 6) while GPP increases with gtc (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 gtc, 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 CO2 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 (L615-620).

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 changes in our model and this will be one of the future development directions. The capillary rise plays in Sphagnum hydrological balance, which varies depending on water table depth and evaporative demand. The sphagnum water content will equilibrate with the peat on a daily basis outside the plot since the dew point is reached. But inside the plots since the VPD does not go to zero there could remain some disequilibration. The current phenology observations include if sphagnum hummock and hollow are wet or dry, and we could look at the relationship with soil water content sensors at some point." to the text (L 668-679). We also added one more reference " Druel et al., 2017" to L693", "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 697-699, 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 L705-709. 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 CO2 concentration responses of Sphagnum, we add "Sphagnum mosses are sitting on top of high CO2 sources. CH4 can be a significant carbon sources of submerged Sphagnum (Raghoebarsing et al., 2005; Larmola et al, 2014); refixation of CO2 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 CO2 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 CO2 condition at the same study site. There are, however, significant negative effects of elevated CO2 on Sphagnum NPP in year 2018. 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 CO2 concentration, which may attribute to we did not consider the light competition between the PFTS (shrub and tree shading effects) and use the fixed cover fraction of Sphagnum." to the main text L831-846.

Is CO2 concentration profile assumed to be uniform throughout the canopy profile? Does this have effects on results of simulations?

We added “The CO_2 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 14C 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.” to L 847-863.

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 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 (L215-220). “Currently, we apply the same method for both hummock and hollow Sphagnum water content prediction, and can test the model against the measured data when more data are available. We do see the model predicted Sphagnum water content differences between these two microtopographies as expected, with the water content of hollows greater than that of hummocks. ELM is able to represent the self-cooling effect, although we do not yet have measurements available to validate the model. We looked at vegetation temperature (TV) - 2m air temperature (TBOT) as a function of canopy evaporation for both hummock and hollow Sphagnum, the differences of TV-TBOT is negative and the canopy evaporation has a negative relationship with TV-TBOT (Fig. S3).” has been added to L718-739.

L589-L591 This is not only in case with submerged Sphagnum, but it seems that Sphagnum utilizes CH_4 as an indirect source of CO_2 (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 (L705-709). We also cited it as reference in L832-833.

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 "We currently use the same parameters for both hummock and hollow, but could consider species differences in the future. Norby et al. (2019) investigated the same site Sphagnum species and reported the decline in Sphagnum cover affected both S. angustifolium/fallax and S. magellanicum, but the relative loss of S. magellanicum was greater, S. magellanicum, which was present primarily on hummocks and has morphological adaptations generally favorable for drier conditions, comprised a smaller fraction of the Sphagnum community in enclosures exposed to the warmer temperatures. However, the dominant response was a sharp decline in abundance of both species, and there was no evidence that S. angustifolium/fallax was replacing S. magellanicum. There was no support for the hypothesis that species more adapted to dry conditions (e.g., S. magellanicum and Polytrichum) would be more resistant to the stress and would increase in dominance. Despite these differences, both hummock and hollow sphagnum are declining with warming. This declining trend may be in part due to increased shading from the shrub layer, which is expanding with warming." to text L 787-801. 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 simply follows Cleveland et al. (1999) suggested empirical relationship that biological nitrogen fixation is a function of net primary production to predict the nitrogen fixation" to Section

2.1(L173-178). 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 L889-894

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