Review of bg-2020-90 Shi et al: Modeling the hydrology and physiology of Sphagnum moss in a northern temperate bog

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 CO_2 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 borderline 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.

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.

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 climate.

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?

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).

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.

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)?

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.

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?

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?

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?

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-surface model with Sphagnum-PFT and simulating response of moss and vascular vegetation productivity to warming and increasing atmospheric CO_2.

Specific comments:

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

L 146-147: new chapter – study Aims.

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.

L196: canopy_water → can_water

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

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?

L284: what is pre-treatment data?

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

L393: point should be (*)

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

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 (O_2-stress in wet conditions)?

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

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

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

References:

Beringer, J., Lynch, A.H., Chapin III, F.S., Mack, M. and Bonan, G.B., 2001. The representation of arctic soils in the land surface model: the importance of mosses. Journal of Climate, 14(15), pp.3324-3335.

Druel, A., Peylin, P., Krinner, G., Ciais, P., Viovy, N., Peregon, A., Bastrikov, V., Kosykh, N. and Mironycheva-Tokareva, N., 2017. Towards a more detailed representation of high-latitude vegetation in the global land surface model ORCHIDEE (ORC-HL-VEGv1. 0). Geoscientific Model Development, 10(12), p.4693.

Niinemets, Ü. and Tobias, M., 2014. Scaling light harvesting from moss "leaves" to canopies. In Photosynthesis in Bryophytes and Early Land Plants (pp. 151-171). Springer, Dordrecht.

Porada P, Van Stan II J, Kleidon A (2018) Significant contribution of non-vascular vegetation to global rainfall interception. Nature Geoscience, doi: 10.1038/s41561-018-0176-7

Porada P, Ekici A, Beer C (2016) Effects of bryophyte and lichen cover on permafrost soil temperature at large scale The Cryosphere 10, 2291-2315

Porada P, Weber B, Elbert W, Pöschl U, Kleidon A (2013) Estimating global carbon uptake by Lichens and Bryophytes with a process-based model. Biogeosciences 10, 6989-7033

Walker, A. P., Carter, K. R., Gu, L., Hanson, P. J., Malhotra, A., Norby, R.J., Sebestyen, S. D., Wullschleger, S. D., Weston, D. J.: 2017. Biophysical drivers of seasonal variability in Sphagnum gross primary production in a northern temperate bog, J. Geophys. Res.-Biogeo, 122, 1078-1097, https://doi.org/10.1002/2016JG003711, 2017.

Zotz, G. and Kahler, H., 2007. A moss "canopy"–Small-scale differences in microclimate and physiological traits in Tortula ruralis. Flora-Morphology, Distribution, Functional Ecology of Plants, 202(8), pp.661-666.