

Discussion of “Seasonal dynamics of vegetation effect on peatland surface energy balance”

By Flemming et al.

Author Response to Review #2

(Reviewer’s comments are marked in black and author’s responses are marked in blue.)

Flemming and others study heat fluxes in a temperate peatland. The study makes some interesting points but needs heavy revision before the analysis is publishable.

Response: We thank the reviewer for their constructive feedback. We will carefully consider the points that were raised and adjust the methodology, as well as write a more understandable and detailed explanation of why we chose our methodology.

We believe that all of the comments are feasible to address, and we are happy to submit a point-by-point response in which we outline how we will revise the manuscript in accordance with the reviewer’s comments.

The authors are basically asking when a temperate peatland shifts from being energy limited to water limited, but use a nonlinear equation (3) after having averaged data to daily time steps, which introduces a Jensen’s inequality. The ecosystem limitation index (ELI) might be more useful to explore (<https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2019JD031672>, <https://www.nature.com/articles/s41558-022-01403-8>)

Response: The ecosystem limitation index incorporates soil water content (SWC), incoming shortwave radiation, and evapotranspiration (ET), and is thus used to study soil dryness. Our focus here is on stomatal response to atmospheric dryness which can be a regulating mechanism under a wide range of soil water conditions (see for example Fu et al., 2022 or Li et al., 2025). While this regulation is more widely tested in forests and grasslands, its quantification in drained peatland ecosystems with shrubby vegetation remains untested

To avoid misunderstandings regarding the limitation type, we will revise the research questions (see our answer to Reviewer #1 please) and formulate our third research objective as to "Identify physiological thresholds at which canopy conductance (g_c) limits latent energy (LE) due to an increase in atmospheric dryness (measured as VPD)," where VPD denotes vapor pressure deficit.

In the revised manuscript, we will calculate g_c at 30-minute resolution using the modified Penman-Monteith equation, and additionally filter the values by time of day, and compare them against VPD. In addition, we will include soil heat flux (SHF) in the modified Penman-Monteith equation, as this improves modeling with both daily and 30-minute data.

Some opportunities to explore high frequency flux partitioning to explore transpiration and evaporation separately (<https://www.sciencedirect.com/science/article/pii/S0168192321004767>) were missed but likely less important if the question focuses more clearly on the shift between energy and water limitation. The problem is that ecosystem and canopy conductance

are frequently confused; the analysis as written deals with the former rather than the latter, albeit with careful high frequency flux partitioning the canopy term can be isolated.

Response: This is a valid point which we were fully aware of. If not carefully treated, the transpiration (T) component of g_c is confounded by evaporation (E) fluxes (which would be surface conductance (g_s) rather than g_c). To avoid this issue, we only included days with no precipitation (P) and <2 mm total P within the past 48 hours. This criteria was put in place to minimize the effect of surface E on g_c (see Gharun et al. 2020; Matos et al., 2025). We will ensure this approach and the reasoning for it is clarified in the revised version of the manuscript.

The analysis also needs to separate the role of soil moisture vs. VPD on controlling surface fluxes as the latter may become important as things dry out apart from WTD.

Response: Following the suggestion of the Reviewer #1 and since in the meantime additional fluxes have been measured and processed for this site, we have decided to increase the analysis period of our study from one year (2023) to three years (2023, 2024, 2025). In the updated analysis we will include SWC and update the manuscript in all sections accordingly.

A careful read for usage and errors (like on line 11, superscripting on 102, subscript on 126, etc) would improve readability.

Response: The manuscript will be carefully checked for abbreviations, typos, and other stylistic errors, and these will be corrected to ensure that the text remains clear (see also our response to Review 1 please).

29: also methane even when (partially) drained

Response: The passage in lines 27-29 discusses the consequences of anthropogenic drainage on fluxes from the peat. Drainage increases mineralization of peat, and leads to the release of a significant amount of CO₂ into the atmosphere. CH₄ emissions (from the peat) do not increase as a result of drainage as lowering the water table increases oxygen availability and reduces methanogenesis. The drainage ditches can become hotspots of CH₄ emission but here the statement is about the effect of drainage on greenhouse gas fluxes from the peat.

On 33, are you referring specifically to shrubification and or woody vegetation including trees in general or is there a reason why *Betula* in particular is noted? Or does rooting depth play a key role?

Response: The sentence in line 33 is indeed misleading and will be reworded.

The growth of *Betula* spp. in degraded bogs was intended as a representative example of broader vegetation changes, particularly shrubification and the general increase in woody vegetation, which can lead to changes in T. To avoid implying a specific focus on *Betula*, the sentence will be revised to refer more generally to shrubification and increasing woody vegetation.

40: I would somewhat disagree that Central European peatlands are unexplored, but upon a brief review it's true that there have been few to no studies on energy fluxes. What's more important to me is that it's described why it's important given the research that's gone on. In boreal and tropical systems.

Response: Peatland management is widely adopted in temperate peatland regions as a climate mitigation measure. The effectiveness of management for climate mitigation depends on the understanding of greenhouse gas fluxes as well as energy fluxes. Therefore how climate and vegetation impact LE fluxes is of direct importance for managing peatlands as a natural climate solution. We will make sure that the importance of our research topic is clarified in the Introduction.

46: this is very unsurprising as it's easy to see why peatlands are characteristically energy limited

Response: Here our intention was not to suggest novelty in the role of net radiation (R_n) itself, but rather to highlight that, despite this general energy limitation, the influence of other drivers such as WTD and vegetation composition remains variable and not fully resolved, particularly in Central European peatlands where energy flux measurements are scarce. To clarify this point, we will revise the paragraph to better emphasize on the remaining uncertainties, and highlight the relevance of investigating additional controls beyond R_n .

80: not sure what the own data processing is meant to refer to

Response: The phrasing was misleading. We will write "data processing" instead of "own data processing".

103: there's actually a reference by Loscher et al. on this https://journals.ametsoc.org/view/journals/hydr/10/5/2009jhm1148_1.xml

Response: Thank you for this suggestion. We will add this reference to support the statement regarding the psychrometric constant.

No reason to use dots in equations

Response: We will remove the dots from the equations.

What literature source does 2a come from?

Response: Dingman (2015). We will add this reference to the revised manuscript.

2e is unconventionally annotated, using e would be more common, or $\exp()$ rather than $\exp^{\text{superscript}}$

Response: We will correct the formatting of the equation.

117: this isn't true because the Penman-Monteith equation is derived from the energy balance expression which includes soil and other heat fluxes. It also doesn't assume

that conductance comes through the stomata because it is the result of the original Penman equation for open water.

Response: We agree that the wording of this sentence is misleading. The “Penman-Monteith method” refers to our methodology for calculating g_c by inverting the Penman-Monteith equation. We will rephrase the paragraph to make it clear that it refers to the assumptions of the methodology used in the manuscript. This will also include a more thorough explanation of why the selected conditions are necessary to make sure ET is closest to T and thus calculate g_c rather than g_s .

131: how was growing season defined?

Response: The growing season was defined as the period between March 15 and October 15, based on a visual inspection of continuous digital images from the site. However, the growing season can be defined based on different observation data (including eddy covariance fluxes, see for example Krebs et al. 2025; Körner et al. 2023). In the revised version of the manuscript, we will use gross primary production (GPP) to define the growing season and will explain this in the Methods section.

In this approach, start and end of the growing season will be determined by fitting a double sigmoid function to the partitioned GPP. The start and end will be determined as the first maximum and last minimum of the third derivative of the double sigmoid (Beck et al. 2006).

I don't understand in equation 3 why g_c would need to be further modeled

Response: g_c is further modeled because, in the previous step using the inverted Penman-Monteith equation, not all days could be included due to P. This resulted in a time series with systematic gaps. Because these gaps occur under specific conditions (e.g., mainly during rainy periods) they could introduce statistical bias into our driver analysis. Therefore g_c is subsequently modelled to fill these gaps and generate a continuous time series suitable for further analysis. We will make sure this point is clarified in the methods section.

134: there are more robust ways of doing this using a nonlinear modeling approach

Response: We apologize that the explanation was not clear enough. We did indeed apply a statistical model to analyze the relationship between g_c and VPD. We performed a local polynomial regression analysis using a nonparametric breakpoint detection and defined the global maximum as the regime change of g_c . We will clarify our approach better in the revised version. We will also mark the detected change point in the revised version of the manuscript with a vertical dashed line in the figure.

Fig. 1 are these daily averages?

Response: Yes, these are daily averages. The new caption will read:

“Figure 1: Test of the energy balance closure in DE-Amv during 2023–2025. The x-axis shows the difference of daily mean net radiation (R_n) and soil heat flux (SHF). The y-axis shows the daily means of latent energy (LE) and sensible energy (H). Dashed line marks the 1:1 relationship.

Throughout, the role of VPD vs. soil moisture should be separated to understand demand vs supply controls.

Response: In the revised version of the manuscript, we will also examine the relationship between g_c and SWC, using a local polynomial regression analysis.

298: mismatches in observational footprints are unlikely the cause of lack of energy balance closure (on average) and advective water flow will be a non-trivial component of lack of closure in this peatland. Also, large eddies that exceed the eddy covariance measurement period are certainly turbulent with high Reynolds number. They're just turbulent atmospheric motions that look like advection to the eddy covariance system.

Response: We will revise this statement to provide a more comprehensive explanation for the observed energy balance closure amount, incorporating the suggestions of the reviewer. We will write:

“In our experimental setup, part of the residual imbalance likely arose from several well-known limitations of the eddy covariance method. In peatland environments, advective transport of heat and water can represent a non-negligible component of the energy balance residual. In addition, large turbulent eddies with time scales exceeding the eddy covariance averaging period may contribute to the imbalance, as these motions are not fully captured by standard flux calculations. Further sources of imbalance include low-pass filtering of water vapor by the intake tube of the gas analyser, general measurement uncertainties, unaccounted energy storage (e.g., in soil or biomass), and errors introduced during data processing (Mauder et al., 2024). Despite these limitations, the observed closure indicates that the energy flux measurements are of sufficient quality to support robust analysis and interpretation.”

337: it wasn't shown here that vegetation contributes 1/3 to LE in the present study (if this is what is being referred to here).

Response: Thank you for flagging this error. This statement will be removed.

346: from the analysis, the ecosystem conductance rather than the canopy conductance was studied. Transpiration was never partitioned from the ET data. Per the point in this passage, the relationship above about 10 hPa in Fig. 7 would be constrained by an exponentially-decreasing function. This won't be quite as apparent if the data are averaged, which they were, and I'm not sure why they were. Averaging VPD results in a Jensen's inequality and I don't know why people use daily VPD averages. In Fig. 7 and throughout the manuscript, half-hourly values should be used to understand the functional relationship between fluxes and VPD. VPD is relatively unimportant (usually below 10 hPa) until it becomes important (above that), and averaging these two things obscures the true response.

Response:

In order to estimate g_c , only the growing season and days with less than 2 mm of total P within the past 48 hours were used. Under these conditions, $g_s \approx g_c$. Please see our response to your previous comment, for more detail.

Daily values for g_c , and thus also for VPD, are necessary in order to be able to neglect energy storage effects. These energy storage effects consist of various components. Soil stores energy that cannot be measured above the SHF sensor (-5 cm). Above-ground fluxes (LE, H) are measured only at the sensor level. If humidity increases in the canopy, it may be transported away with a time delay, and LE is thus measured with a time delay. The air mass between the ground and the canopy can potentially temporarily store energy (H) before turbulent exchange occurs, due to its heat capacity. Plant biomass can also temporarily store energy when it heats up. These effects occur particularly in the morning, when short-wave radiation increases rapidly and soil and biomass can absorb a large amount of energy. We will incorporate SHF into the modeling in the revised version of the manuscript, as this will allow us to better account for storage effects.

As described above, we will attempt to calculate g_c using the modified Penman-Monteith equation at a 30-minute resolution. To minimize the aforementioned energy storage effects and also to minimize higher uncertainties at night, due to the violation of the assumption that $g_s \approx g_c$, these results are additionally filtered to a reasonable time of day in which no unrealistic values occur. If possible, both results, the daily resolution and the 30-minute resolution, will be presented side by side.

With this higher-resolution approach, VPD thresholds throughout the day can be preserved. Since the daily values are modeled more robustly and, to the best of our understanding, contain potential information regarding the response of g_c to longer-term dry periods, we will also retain this approach. Both approaches will be compared and discussed in the revised version of the manuscript in terms of their strengths and weaknesses.

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