Dear Editor and Reviewers,

We appreciate the time and effort the editorial board and reviewers have dedicated to evaluating our manuscript. Your feedback has permitted us to enhance the quality and clarity of our work. In response to the constructive comments received, we have thoroughly revised our manuscript to address each point raised. Below, we provide detailed responses to the comments, highlighting the changes made and how they contribute to the overall improvement of our manuscript.

We look forward to your feedback on the revised submission.

Best regards,

Yanfei Li

On behalf of all co-authors

Below you will find:

- The reviewers' comments in black, normal font
- Our answers are in blue, normal font

All the line numbers in comment refer to the original manuscript.

Reviewer 1

I. General comments

The work presented in this manuscript is an impressive culmination of data informing models of the spatiotemporal variations in CO_2 flux in temperate peatlands. While the study is rich in data with a compelling model, the current state of the manuscript does not acknowledge two of the most well documented sources of carbon respiration in peatlands. Further, I question the use of UAS TIR imagery to effectively determine soil temperature in a peatland that is so richly covered in vegetation. These concerns are reflected in my two main comments below:

We thank the reviewer for the positive comments and valuable feedback. We have now incorporated the suggested changes and provided a deeper exploration of our study.

1. Main Comment 1

I am very happy to see the use of UAS thermal infrared imagery in this study. However, the details into how this method effectively captures the soil temperature of the peatland are not described. Flight conditions of the UAS were not described in the methods (clear, cloudy, after-rain, etc.) which could significantly impact the data. The TIR imagery would also need a thermal emissivity value to be calibrated and ensure accurate temperatures of the surface of the peatlands. This leads me to my issue with the vegetation cover of the peatlands interfering with the soil temperatures. Vegetation cover would have significantly higher thermal emissivity values compared to soils along the peat surface. In the article cited below, Harvey et al. (2019) describes a calibration for the thermal emissivity of water. I believe you should do something similar for vegetation versus soil along the surface of the peatland at the very least. If you can upscale this further by vegetation type, which has already been mapped in your 2024 publication, this would yield even more novel results for your study. Another route with this is offered by calibration in TIR image processing software, where you can apply a static thermal emissivity value based on other published values. This could further improve the model by breaking up the peatland into subsections and again ensuring the accuracy of your temperature values.

Harvey, M. C., Hare, D. K., Hackman, A., Davenport, G., Haynes, A. B., Helton, A., ... & Briggs, M. A. (2019). Evaluation of stream and wetland restoration using UAS-based thermal infrared mapping. Water, 11(8), 1568.

Thank you for your constructive comments and valuable suggestions regarding the calibration of UAV-based thermal infrared (TIR) imagery. We have now included a detailed description of the methodology and calibration steps in the revised manuscript.

During each UAV TIR flight, the camera emissivity was set to the default value (100%). To calibrate the raw land surface temperature (LST) data, we placed two reference panels (i.e., one hot and one cold, with temperature sensors underneath) on the ground for every flight. The raw LST data were first calibrated using the linear regression between the recorded panel temperatures and corresponding pixel values in the imagery. This initial calibration procedure is now described in the main text (Section 2.6 UAV imagery processing). Following your suggestions, we further refined the LST calibration by incorporating spatially upscaled thermal emissivity maps based on the land cover map of our previous work (Li et al., 2024). The emissivity values for each land cover class were obtained from published literature and applied during image processing to generate double-calibrated LST datasets:

The raw thermal infrared video streams were converted into RJPG images using ThermoViewer version 3.0.26 (TeAX, 2022). Subsequently, the thermal images were processed with the Pix4D mapper to generate land surface temperature (LST) maps (resolution: 12 cm). To calibrate the LST of each date (Figure 2a), we first applied linear regressions of temperature obtained by camera and temperature of 2 targets on the ground (Text S1) to create a correction formula. Next, we mapped the spatial variations of surface emissivity using the classification-based approach (Li et al., 2013; Snyder et al., 1998), based on land cover data from our previous work (Figure 1b; Li et al. (2024)) and emissivity values of each class from literature (Snyder et al., 1998). Finally, we converted the LST to thermal radiance using Planck's law, applied an emissivity-based correction, and then converted the radiance back to obtain calibrated LST.

References

Li, Y., Henrion, M., Moore, A., Lambot, S., Opfergelt, S., Vanacker, V., Jonard, F., Van Oost, K., 2024. Factors controlling peat soil thickness and carbon storage in temperate peatlands based on UAV high-resolution remote sensing. Geoderma, 449, 117009. https://doi.org/10.1016/j.geoderma.2024.117009.

Li, Z.-L., Wu, H., Wang, N., Qiu, S., Sobrino, J.A., Wan, Z., Tang, B.-H., Yan, G., 2013. Land surface emissivity retrieval from satellite data. International Journal of Remote Sensing, 34, 3084-3127. 10.1080/01431161.2012.716540.

Snyder, W.C., Wan, Z., Zhang, Y., Feng, Y.Z., 1998. Classification-based emissivity for land surface temperature measurement from space. International Journal of Remote Sensing, 19, 2753-2774. 10.1080/014311698214497.

The updated coefficients and contributions of double-calibrated LST data (i.e., contributions increased by 5% after the second calibration) in the model for mapping soil temperature are now provided in the support material (Table 1 below):

Table 1. *Coefficients and relative contributions of three input variables of linear mixed-effects regression models for modelling soil temperature. Random effects were evaluated by ICC and model performance was evaluated by Marginal R^2, Conditional R^2, AIC, RMSE, and KGE.*

Fixed effects: Coefficients (contributions)	*Air temperature*	*0.32*** (39.31 %)*
	NDVI	*5.76*** (22.05 %)*
	LST	*0.21*** (26.85 %)*
Random effects	*ICC (contributions)*	*0.21 (3.00 %)*
Model performance	*Marginal R^2*	*0.88*
	Conditional R^2	*0.91*
	AIC	*16977.4*
	RMSE	*1.26*
	KGE	*0.93*

*Note. Significance level: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.*

In addition, details of UAV flight conditions have been added to the Supplementary Material (Text S1: UAV Campaigns):

The UAV flight missions were carried out between 10 h 00 and 14 h 00, at a frequency of every two weeks in summer and monthly interval in other seasons. The flight patterns and altitudes used for UAV missions were similar to our previous work (Li et al., 2024). The RGB images were captured at a flight height of 100 m. The side and frontal overlap ratios were set to 70 % and 80 %, respectively, resulting in a spatial resolution of 2.05 cm. The multispectral and thermal infrared flights were conducted at above take-off point altitude of 90 m and a speed of 7.1 m/s simultaneously using a dual gimbal connector. Both side and frontal overlap ratios were set to 80 %. In this case, the spatial resolutions of the multispectral and thermal infrared images are approximately 6 cm and 12 cm, respectively. A MicaSense calibrated reference panel with known reflectance values was used immediately to calibrate the multispectral camera before and after each flight. The TeAX thermal infrared camera combines FLIR Tau2 cores and ThermalCapture hardware that allows the user to store raw infrared video streams directly on a local USB memory stick, together with additional information like position and time from GPS. In addition, TeAX technology makes heated shutters provide evenly a uniform temperature across the shutter and maintains this temperature throughout the duration of its operation. During the flight mission, the emissivity setting of the thermal infrared camera was set to 100 %. To further correct the differences between the true surface temperature of the ground and that measured by the sensor due to emissivity effect, two homemade thermal calibration panels (50 cm x 100 cm, one hot and one cold that fills with ice) were used on the ground with a known temperature to adjust any offsets in the thermal images and to understand the temperature changes throughout the duration of the flight. To enhance the LiDAR signal penetration, we chose the triple-echo mode with a sampling frequency of 160 kHz, maintaining a flight height of 50 m above the take-off point at a speed of 6 m/s. During the flight mission, the ground sampling distances varied between 1.16 cm and 2.18 cm per pixel. The IMU calibration procedures were conducted automatically at the beginning, during the mission, and after flight routes to ensure inertial navigation accuracy.

The RGB and LiDAR flights were conducted in RTK positioning mode using a D-RTK 2 base station (DJI, Shenzhen, China). The base station was set up at a known point and was used to provide real-time positional corrections throughout the flight. For the multispectral and thermal infrared cameras, nine ground control points (GCPs) were *used (50 cm × 50 cm targets). The GCPs were made of white laminated board stuck with aluminum foil in the diagonal area and were distributed across the study site during the flight mission. Their position was measured using an Emlid Reach RS2 GPS device, utilizing a post-processing RTK solution with the Belgian WALCORS network.*

We believe these improvements address your concerns regarding calibration accuracy and vegetation cover effects on TIR measurements, and they strengthen the robustness of our soil temperature mapping approach.

2. Main Comment 2

This manuscript in its current form does not describe the importance of hydrology or atmospheric pressure on carbon respiration in peatlands.

Depths of the water table are well documented in numerous articles to impact carbon respiration, with drier climates and lower water tables leading to enhanced carbon production. This deserves its own paragraph in the introduction and needs to be discussed in the methods in the background of the site. No details are provided about the hydrologic setting of the peatland study site and the difference between minerogenous groundwater contributions versus ombrogenous precipitation contributions are not clarified. The peatland needs to be described in some way (as either a bog, fen, heath, etc.) to understand the expected flows within the peat matrix that change how CO2 is released and generated. I would also point to Figure 2 as the CO2 respiration modeled parallels the rise in the water table of the peatland mid-year, which would be expected in these environments.

Thank you for your comments. Our study site is an ombrogenous bog hillslope, characterized by distinct SE-NW oriented topographic units (i.e., summit, topslope, shoulder, backslope, and footslope). Additional details about the landscape have been added to the revised manuscript (section 2.1 study site).

We agree that the water table plays an important role in regulating soil respiration in peatlands, and we have included this in both the *introduction* and *discussion*. Annual water table dynamics of the study site are now presented in the results (Table 2 below). Five water table sensors were installed along the middle transect of the landscape (i.e., five slope positions (summit, topslope, shoulder wet, backslope, footslope), 5 sites in total), close to locations where we conducted soil respiration measurements. However, water table data were only available from June 2023 to October 2024, whereas our soil respiration measurements (i.e., the Licor system, at 6 slope positions (summit, topslope, shoulder dry, shoulder wet, backslope, and footslope), 33 sites in total) were conducted from February 2023 to March 2024. Including water table as a model variable would therefore reduce the number of CO_2 observations by approximately half (from 666 to 336) and will not capture a full annual cycle.

As an alternative, we have reported the model performance (including water table) in the support material of the revised version (Table 3 below). In this model, we found that water table explained 10 % of seasonal variation in CO_2 fluxes, while NDVI and soil temperature were the most important variables, contributing 22 % and 21 %, respectively. The relatively small contributions from water tables might reflect (i) the limited number of monitoring locations, (ii) the shorter monitoring period, (iii) the generally low water table across the year (Table 2 below), particularly at the footslope, backslope, and summit, where maximum water tables remained > 9 cm below ground surface. This maintained aerobic layers that support soil respiration, thereby reducing the influence of their fluctuations on CO_2 fluxes. Increasing spatial coverage and temporal resolution of water table observations across the landscape would likely improve our ability to examine its influence on CO_2 emissions.

Table 2. Water table (i.e., June 2023 to May 2024) at different slope positions. The results are presented as the mean ± one standard deviation and values in brackets indicate the minimum and maximum values. The *Kruskal-Wallis* and *Dunn's* tests were conducted within each class with different superscript letters indicating significant differences (p < 0.05).

Slope positions	Footslope	Backslope	Shoulder wet	Topslope	Summit
Water table (cm)	-27.15 ± 8.31^{e} (-49.14, -18.53)	-21.07 ± 7.51^{b} (-35.91, -9.68)	-2.17 ± 5.62^{a} (-20.21, 4.17)	-21.76 ± 25.17^{d} (-77.41, 0.38)	-20.18 ± 11.80^{c} (-49.23, -9.20)

Table 3. Coefficients and relative contributions of three types of input variables (static, semi-dynamic, dynamic) of mixed linear regression models for modelling seasonal patterns of CO_2 flux at five slope positions (i.e., summit, topslope, shoulder wet, backslope, and footslope). Random effects were evaluated by *ICC* and model performance was evaluated by *Marginal* R^2, *Conditional* R^2, *AIC, RMSE,* and *KGE*.

	Input variables		Model 1	Model 2	Model 3
Fixed effects: coefficient (contribution)	Static	SOC stock (t ha^{-1})	0.004* (2 %)	0.004* (2 %)	0.004* (2 %)
		C/N ratio	0.04 (2 %)	0.05 (2 %)	0.05 (2 %)
	Semi dynamic	root biomass (g 100g^{-1})	0.04 (0.16 %)	0.07 (0.07 %)	0.07 (0.08 %)
		NDVI	2.29*** (25 %)	2.18*** (22 %)	2.18*** (22 %)
	Dynamic	Soil temp. (°C)	0.06*** (24 %)	0.06*** (21 %)	0.06*** (21 %)

		VWC (cm^3 cm^{-3})	-1.17*** (17 %)	-0.90*** (13 %)	-0.90*** (13 %)
		Water table (cm)	\	-0.01** (10 %)	-0.01*** (10 %)
		Atmospheric pressure (kPa)	\	\	-0.002 (1 %)
Random effects	*ICC* (contribution)		0.21 (7 %)	0.23 (6 %)	0.23 (6 %)
Model performance	*Marginal R^2*		0.69	0.70	0.70
	Conditional R^2		0.76	0.76	0.76
	AIC		590.00	581.30	583.30
	RMSE		0.52	0.51	0.51
	KGE		0.82	0.82	0.82

Note. Significance level: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$. All CO2 fluxes (μmol m^{-2} s^{-1}), soil temperature, and VWC data for spatial and seasonal patterns were from the LI8100 A system. The water table data was from the Solinst probes at five slope positions and atmospheric pressure data was from the meteorological station. The number of observations for modeling is 336.

The role of atmospheric pressure also needs to be addressed by the authors in the manuscript in the introduction and discussion sections. I would like to highlight the carbon respiration occurring in Figure 3 that could be attributed to shifts in atmospheric pressure prior to precipitation. The model appears to fail to quantify the change in atmospheric pressure transitioning from the winter to the spring in the northern hemisphere. This period is also well documented to release carbon rapidly in peatlands due to the thaw occurring and seasonal change in pressure locally. Pressure would be a great variable to incorporate with this model. I believe your correlation with temperature would be secondary to this new variable, if included.

We appreciate your suggestion addressing the role of atmospheric pressure in peatland CO_2 fluxes and have now included relevant discussion in both the *introduction* and *discussion* of the revised manuscript.

Atmospheric pressure can influence gas fluxes via pressure pumping by three mechanisms: (i) atmospheric turbulence, (ii) longer-period barometric changes associated with frontal passages, and (iii) quasi-static pressure fields induced by wind over irregular topography (Ryan and Law, 2005). In our study, when atmospheric pressure was included as a predictor in the model (Table 3, Model 3), it explained only 1 % of seasonal variability in soil respiration, whereas NDVI and temperature were dominant contributors. Examination of high-frequency time series data (i.e., hourly CO_2 flux from the eosFD probes) showed that at the daily scale, the diurnal pattern of CO_2

fluxes did not follow atmospheric pressure fluctuation (Figure 1). At longer time scales, the two variables displayed only weak correlations. Instead, the CO_2 flux showed clear correlation with temperature dynamics. Moreover, we observed that declines in atmospheric pressure were often followed by precipitation events, which in turn were associated with decreases in both air temperature and CO_2 flux, or slight CO_2 fluxes increases (Figure 1).

This suggests that atmospheric pressure may indirectly influence soil respiration by affecting precipitation patterns, rather than exerting a strong direct control. This limited direct effect of atmospheric pressure in our study area is likely due to (i) the absence of abrupt winter–spring thaw events which are typical of high-latitude peatlands, and (ii) the predominantly aerobic status of the surface peat in this hillslope bog, where maximum water tables remained below the surface most cases of the year (Table 2). In saturated peatlands, falling atmospheric pressure has been shown to trigger methane (CH_4) ebullition by releasing trapped gas bubbles (Baird et al., 2004; Tokida et al., 2005; Tokida et al., 2007), while in our study site, such bubble formation and ebullition are likely minimal. Consequently, the potential for direct pressure-driven CO_2 release is relatively low. Another contributing factor maybe the limitations of our observations: (i) the lower temporal resolution of biweekly chamber measurements (i.e., the li8100 A system) and (ii) high temporal frequency but short monitoring period at each slope position (i.e., the eosFD sensors) along the middle transect may have limited our ability to detect short-lived CO_2 flux responses to atmospheric pressure fluctuations.

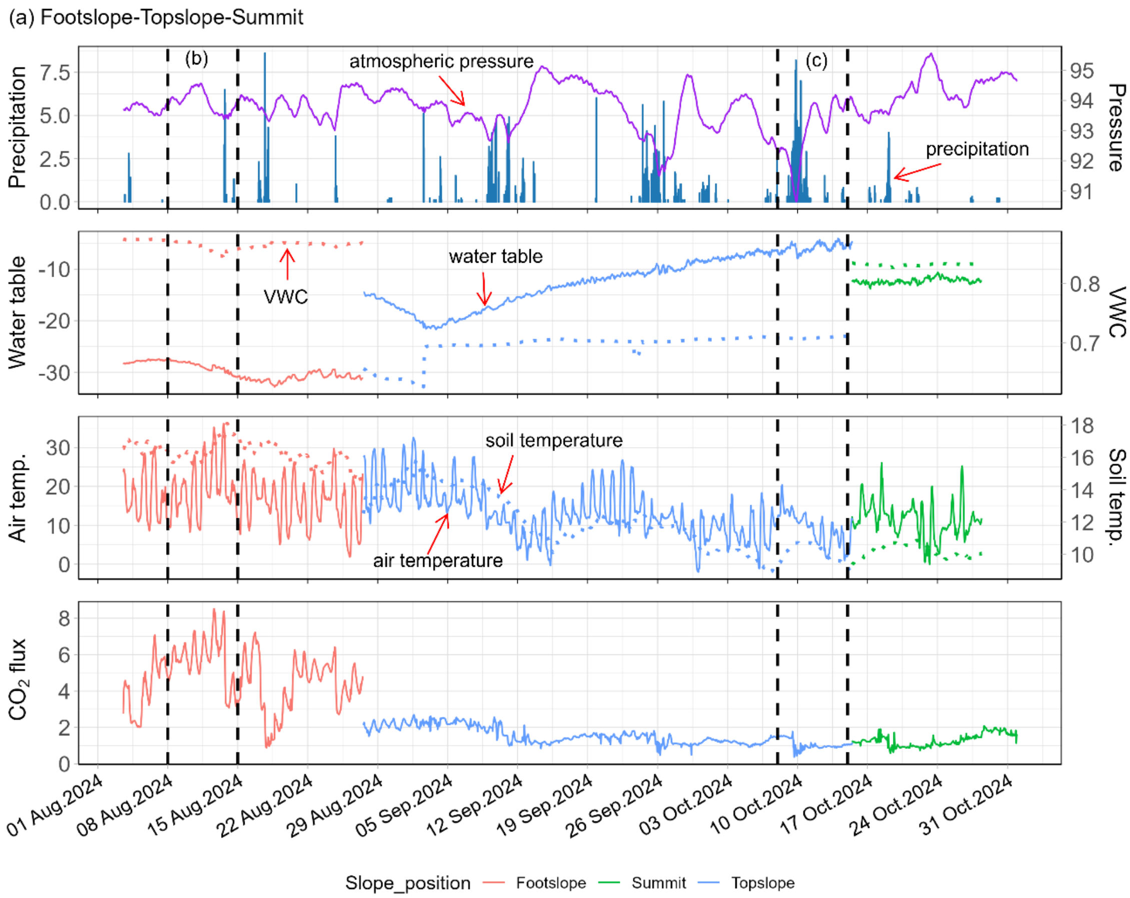
References

Ryan, M., Law, B. Interpreting, measuring, and modeling soil respiration. Biogeochemistry 73, 3–27 (2005). https://doi.org/10.1007/s10533-004-5167-7.

Baird, A.J., Beckwith, C.W., Waldron, S., Waddington, J.M., 2004. Ebullition of methane-containing gas bubbles from near-surface Sphagnum peat. Geophysical Research Letters, 31. https://doi.org/10.1029/2004GL021157

Tokida, T., Miyazaki, T., Mizoguchi, M., 2005. Ebullition of methane from peat with falling atmospheric pressure. Geophysical Research Letters, 32. https://doi.org/10.1029/2005GL022949

Tokida, T., Miyazaki, T., Mizoguchi, M., Nagata, O., Takakai, F., Kagemoto, A., Hatano, R., 2007. Falling atmospheric pressure as a trigger for methane ebullition from peatland. Global Biogeochemical Cycles, 21. https://doi.org/10.1029/2006GB002790



(a) Footslope-Topslope-Summit
(b)
(c)
atmospheric pressure
precipitation
Precipitation
Pressure
water table
VWC
Water table
soil temperature
air temperature
Air temp.
Soil temp.
CO_2 flux
01 Aug.2024
08 Aug.2024
15 Aug.2024
22 Aug.2024
29 Aug.2024
05 Sep.2024
12 Sep.2024
19 Sep.2024
26 Sep.2024
03 Oct.2024
10 Oct.2024
17 Oct.2024
24 Oct.2024
31 Oct.2024
Slope_position
Footslope
Summit
Topslope

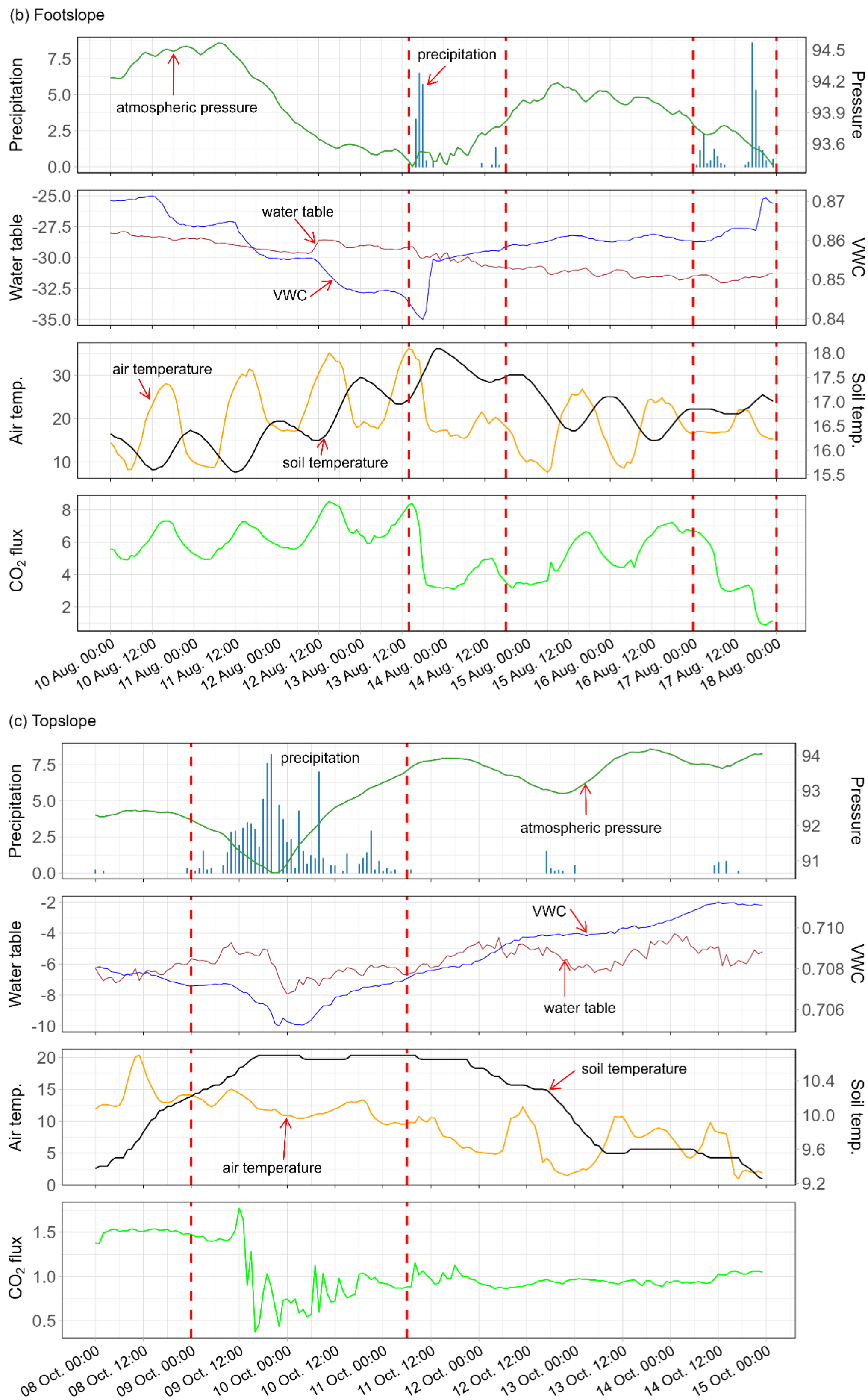


Figure 1. Examples showing time series data of air pressure (kPa), precipitation (mm), soil volumetric water content (VWC, cm^3 cm^{-3}), water table (cm), soil temperature (Soil temp., °C), air temperature (Air temp., °C), and CO_2 flux

(µmol m^{-2} s^{-1}, measured by eosFD probes) from 1 August 2024 to 31 October 2024 (a), from 8 August 2024 to 15 August 2024 at the footslope (b), and from 8 October 2024 to 15 October 2024 at the topslope slope position (c).

II. Specific comments

We thank the reviewer for all the specific comments and suggestions.

1) shorten "spatial and temporal" and "spatial-temporal" to "spatiotemporal" throughout this manuscript.

We have replaced all "spatial and temporal" and "spatial-temporal" to "spatiotemporal" throughout this manuscript.

2) line 14, new sentence here for clarity.

We have revised the sentence from "*CO_2 emissions from peatlands exhibit substantial spatial and temporal variability due to their heterogeneous nature, presenting challenges to identify their underlying drivers and to accurately quantify and model CO_2 fluxes*" to "*CO_2 emissions from peatlands exhibit substantial spatiotemporal variability, presenting challenges for identifying the underlying drivers and for accurately quantifying and modeling CO_2 fluxes*".

3) line 28, this needs a definition as it currently reads as though the reader is assumed to already know what this is.

We have defined the term "hot moments" in the abstract: "*hot moments (i.e., periods of time which have a disproportional high (> 90th percentile) CO_2 fluxes compared to the surrounding)*".

4) line 29, same issue with lack of a definition.

We have defined the term "hot spots" in the abstract: "*hot spots (i.e., locations which CO_2 fluxes higher than 90th percentile)*".

5) line 31, separate into two sentences.

We have separated the sentence "*Our study demonstrates that integrating UAV-based remote sensing with field surveys improves the understanding of soil respiration mechanisms across timescales in complex landscapes, providing insights into carbon dynamics and supporting peatland conservation and climate change mitigation efforts*." into two sentences: "*Our study demonstrates that integrating UAV-based remote sensing with field surveys improves the understanding of soil respiration mechanisms across timescales in complex landscapes. This will provide insights into carbon dynamics and supporting peatland conservation and climate change mitigation efforts*".

6) line 37, there are more recent estimates of these values than 2010, I suggest Page and Baird 2016 and/or Loisel et al. 2017 as more applicable citations.

Thank you for your recommendation, but we found a more recent citation and we also made corresponding revisions for the sentence: *Peatlands are globally distributed ecosystems that cover an area of 6.75 million km^2 and store approximately 942.09 ± 312 Gt of carbon (Widyastuti et al., 2025)*.

Reference: Widyastuti, M.T., Minasny, B., Padarian, J., Maggi, F., Aitkenhead, M., Beucher, A., Connolly, J., Fiantis, D., Kidd, D., Ma, Y., Macfarlane, F., Robb, C., Rudiyanto, Setiawan, B.I., Taufik, M., 2025. Digital mapping of peat thickness and carbon stock of global peatlands. CATENA, 258, 109243. https://doi.org/10.1016/j.catena.2025.109243

7) line 50, Important to note here that hydrology dominates these factors, yet is only listed as "moisture".

We have added more descriptions of biotic and abiotic factors that control soil respiration as the second paragraph in the introduction:

Soil respiration, a key ecological process that releases CO_2 from peatlands into the atmosphere, is influenced by a combination of biotic and abiotic factors. Among abiotic controls, soil temperature and moisture play a crucial role in driving microbial activity and root respiration, influencing CO_2 fluxes across daily to annual scales (Evans et al., 2021; Fang and Moncrieff, 2001; Hoyt et al., 2019; Juszczak et al., 2013; Swails et al., 2022). Water table fluctuations alter oxygen availability and distribution within the soil profile, directly affecting microbial processes and carbon emissions (Evans et al., 2021; Hoyt et al., 2019). Atmospheric pressure affects the transport of gases between the soil surface and the atmosphere, thereby modulating the CO_2 fluxes (Lai et al., 2012; Ryan and Law, 2005). Vegetation, as a key biotic factor, influences the spatiotemporal variations of soil respiration through phenology, structure, and community (Acosta et al., 2017; Wang et al., 2021). In addition, soil organic matter provides essential substrates for microbial activity, with previous studies suggesting that the quality of organic material, rather than its quantity, primarily regulates CO_2 fluxes in peatlands (Hoyos-Santillan et al., 2016; Leifeld et al., 2012).

8) line 53, I would stick with "hummocks and hollows" per conventional literature.

We revised the term "*soil benches and depressions*" to "*hummocks and hollows*".

9) line 58, Is this suggesting an inherent correlation between temperature and carbon release? From the literature cited there is no one who has correlated these variables.

The literature reported high heterogeneity in soil temperature at small scales; indeed, they did not analyze its correlation with soil respiration. So, we deleted the sentence and cited literature in the revised manuscript.

10) line 61, Atmospheric pressure needs to be listed and cited here, it is the dominant driver of such events.

We have listed and cited the atmospheric pressure in the revised manuscript.

11) line 67, Does this consider the chemical link between CO2 and CH4 release? Most folks care a lot about the CH4 release but these processes are inherently tied together in the peat soils. It would be good to address this here.

We have revised the sentence from "*Most studies have examined the mechanisms and contributions of hot spots and hot moments of other greenhouse gases (N_2O, CH_4) in agricultural and forestry ecosystems (Krichels and Yang, 2019; Anthony and Silver, 2021; Kannenberg et al., 2020; Leon et al., 2014; Fernandez-Bou et al., 2020), while research on CO_2 emission hot spots and hot moments in peatlands remains limited (Anthony and Silver, 2021, 2023)*." to "*Most studies have examined the mechanisms and contributions of hot spots and hot moments of other greenhouse gases (N_2O, CH_4) in agricultural and forestry ecosystems (Krichels and Yang, 2019; Anthony and Silver, 2021; Kannenberg et al., 2020; Leon et al., 2014; Fernandez-Bou et al., 2020). However, research on CO_2 emission hot spots and hot moments in peatlands remains limited (Anthony and Silver, 2023), even though both CO_2 and CH_4 originate from organic matter decomposition under different redox conditions*".

12) line 68, Just 2023 here.

We only kept the literature published in 2023 in the revised manuscript.

13) line 73, Not sure this truly "hinders" but rather limits the effective understanding of these zones.

We have revised the sentence from "*the spatial-temporal limitation hinders the effective detection of hot spots*" to "*the spatiotemporal limitation constrains the effective understanding of hot spots*".

14) line 80, Can this be worded to more directly correspond to the aims of the research in bogs? This reads as a methods statement.

We have simplified the sentences from "*Eddy covariance towers measure net ecosystem exchange over large areas by recording high-frequency CO2 concentrations and air turbulence, providing insights into temporal variations at the ecosystem level (Rey-Sanchez et al., 2022; Abdalla et al., 2014). However, the underlying controlling factors and mechanisms at the process level are difficult to infer due to the large spatial footprint. In addition, they may not accurately represent the spatial heterogeneity of peatlands (Lees et al., 2018)*" to "*Eddy covariance towers can continuously measure net ecosystem exchange over large areas (Abdalla et al., 2014; Rey-Sanchez et al., 2022), but they are less effective in capturing the spatial heterogeneity of peatlands (Lees et al., 2018)*".

15) line 85, Highlight the need for spatially robust measurements here. This needs to be rephrased with the past couple of sentenced for clarity.

We rephrased the sentence from "*These limitations highlight the need for complementary approaches to estimate CO_2 fluxes at the landscape scale with methods adapted for heterogeneous peatland ecosystems*" to "*These limitations highlight the need for spatially robust, high-resolution methods that can characterize CO_2 fluxes across heterogeneous landscapes*".

16) line 92, Heterogenous by what standard here? (Vegetation?, topography?, water origin?)

We have explained the heterogeneous in the revised manuscript: "*heterogeneous (e.g., complexity in topography, diverse vegetation, varying thermal-hydrological conditions)*".

17) line 100, Groundwater-surface water interactions as well here, could be integral to such CO2 releases: Moore, H. E., Comas, X., Briggs, M. A., Reeve, A. S., & Slater, L. D. (2024). Indications of preferential groundwater seepage feeding northern peatland pools. Journal of Hydrology, 638, 131479.

We have cited this literature in the revised manuscript.

18) line 104, These last two studies should be combined with the last sentence for brevity.

We have combined the two studies in the revised manuscript: "*some studies (e.g., Pajula and Purre (2021); Walcker et al. (2025)) employed UAV-based xxx*".

19) line 109, Is this a bog, fen, or heath? It would be good to determine the expected water contribution as this will directly influence carbon dynamics.

We have explained it is a bog peatland in the revised manuscript.

20) line 110, Reword "most ancient".

We reword "most ancient" to "oldest".

21) line 112, Again, this is where the water origin matters

We agree and we have added the details in *section 2 study area*.

22) line 113, Can you define what environmental factors you are targeting exactly?

We have defined the environmental factors in the revised manuscript: "*environmental factors—such as thermal-hydrological conditions, vegetation, carbon stock and quality— across complex peatland landscapes*".

23) line 114, Still not sure about this word choice as it implies a relationship with temperature which is not referenced.

See the response below.

24) line 119, I would combine these objectives in relation to your research questions directly.

We have revised the description of these objectives and research questions:

(1) What controls the nature and strength of the relationship between soil respiration and environmental factors— such as thermal-hydrological conditions, vegetation, carbon stock and quality— across complex peatland landscapes and across spatiotemporal scales? To address this, we first identify the factors driving seasonal and spatial variations in soil respiration and then assess the potential for linking environmental factors to CO_2 flux at high spatiotemporal resolutions.

(2) How do spatial and temporal peaks (i.e., hot spots and hot moments) of biogeochemical processes influence landscape-level carbon fluxes? For this purpose, we analyze the locations and timing of hot spots and hot moments, and assess their contributions to overall CO_2 flux budgets.

25) line 125, It would be good to know how many raised bogs are present in the system and what the assumed ombrogenous vs minerogenous water areas of the peatland are.

The peatlands in Haugtes Fagnes cover an area of 37.50 km^2, which primarily consists of raised bogs formed since the Late Pleistocene and grown under both oceanic and continental influences. But we are not sure exactly how many raised bogs. Our research site (i.e., ombrotrophic bog) is mainly fed by precipitation. We have revised the description of the study site in this section.

26) line 132, Is there additional work that has examined the impact of draining this peatland? It would profoundly impact carbon cycling as a whole and would likely not be comparable to a natural peatland. This is important to recognize.

We do not have additional work that has examined the impact of draining this peatland. Our research project mainly focusses on this landscape, where we explored the peat thickness, carbon storage, hydrology, dissolved nutrients, soil respiration etc. We did not find other studies that compare carbon cycling between natural and drained peatlands in this region.

27) line 134, It would be good to state the vector direction here rather than just Lat/Long coordinates in parentheses.

We have added the vector direction of the meteorological station in the revised manuscript "*An observation station of the Royal Meteorological Institute of Belgium (Mont Rigi, 50.51 N, 6.07 E) situated 3.07 km from northeast of the study site, records rainfall data every 10 minutes*".

28) Figure 1, These land cover labels are difficult to read, it would be good to perhaps reorient the figure with the two maps stacked on top of one another for reader comprehension.

We have modified the positions of two maps with two maps stacked on top of one another for reader comprehension (Figure 2 below).

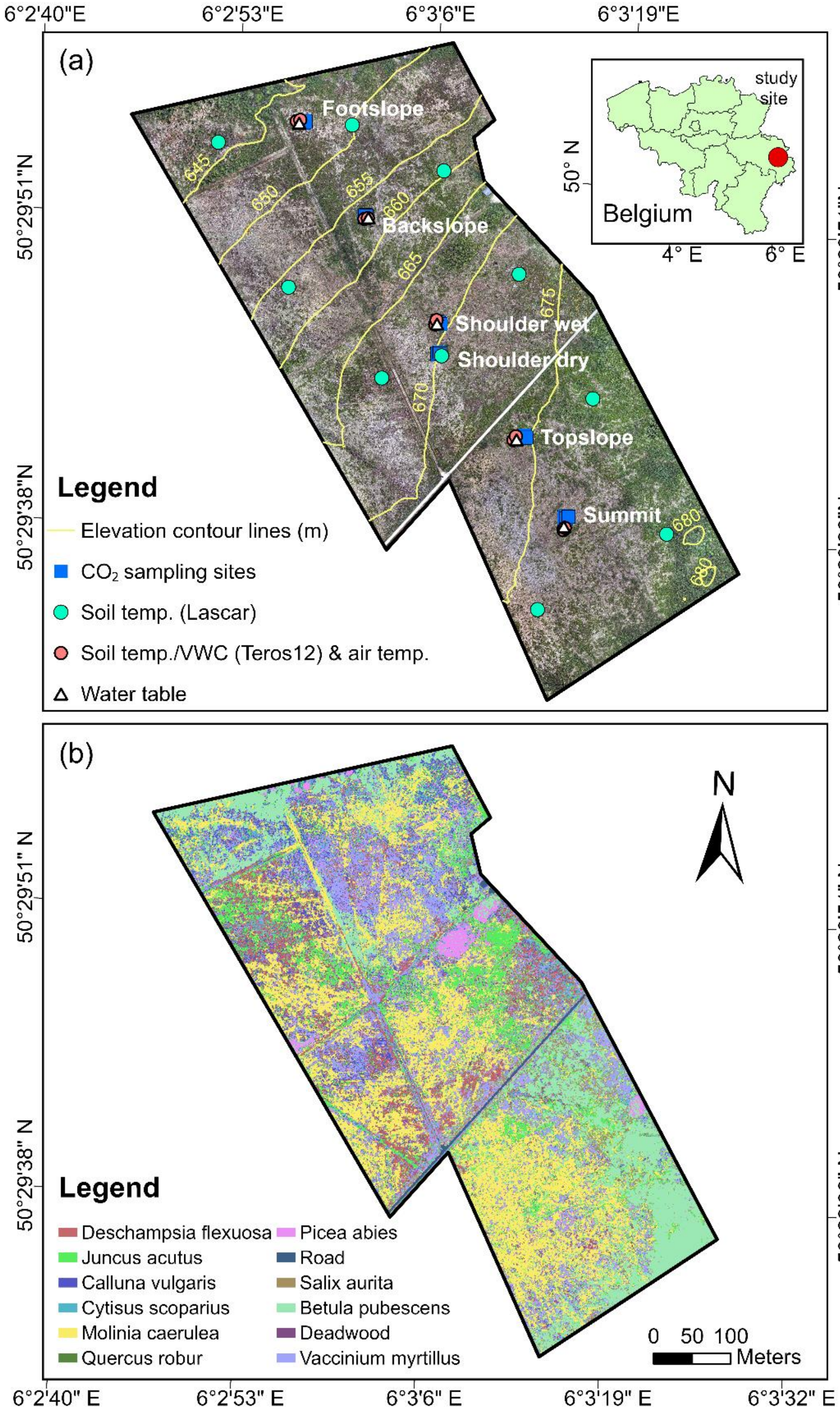


Figure 2. Maps showing the field-sampling locations (a) and land cover types (b) in the study area. Details on the land cover map are provided in our previous work (Li et al., 2024).

29) line 140, Would elevations be a better term here? The sampling locations appear to fall along the elevation gradient.

We think the term "slope position" is more appropriate than 'elevation', as it captures not only the relative height but also the specific terrain units along the hillslope.

30) line 144, Confused by this wording here, are you discussing the boundary of the peatland?

It is not the boundary of the peatland, but the shoulder slope position of the hillslope. For clarity, we have revised the sentence from "*While at the shoulder, considering the heterogeneous soil water conditions, six collars were installed in drier areas and another three in wetter areas*" to "*Given the high variability in soil water content at the shoulder position (Henrion et al., 2025), six collars were installed in drier areas (i.e., Shoulder dry) and another three in wetter areas (i.e., Shoulder wet)*".

31) line 151, It would be helpful to have resolution/accuracies listed for these instruments.

We have added the accuracy of all listed instruments we utilized in the field.

32) line 157, Again, I think you should focus on the elevation wording here.

See the response at above comment 29.

33) line 167, Again, would be useful to have resolution/accuracies listed here.

See the response at above comment 31.

34) line 172, Can you state the precision quantitatively?

We have added the precision in the manuscript "*resulting in a mean lateral positioning error of 1.84 cm across all sites*".

35) line 199, How was thermal emissivity accounted for? Without accounting for the thermal emissivity properly here, you don't know if you're truly getting the soil temperature, vegetation, or water temperature properly

See the response for Main comment 1.

36) line 202, LiDAR data cannot determine air temperature. This needs to be reworded.

We have reworded the sentence from "*The raw LiDAR data was processed in DJI Terra to provide a Digital Terrain Model (DTM; .tif file) with a resolution of 15 cm, which was used for generating daily air temperature maps*" to "*For mapping purposes, daily air temperature was statistically downscaled by incorporating the relationship between daily air temperature and elevation, followed by downscaling using a Digital Terrain Model (DTM) derived from LiDAR data*".

37) line 218, What coding language is this run through?

Our data analysis was conducted in RStudio and we have added the information in the sentence.

38) line 237, NDVI maps?

Yes, NDVI maps. We have added this information in the revised manuscript.

39) line 244, Would a KGE analysis be useful here given you have a number of independent variables to compare against?

We added KGE analysis for all models and also added the methodology description in the revised manuscript.

40) line 299, It would be important to describe where the vegetation types came from in the text and not just Figure 1.

We did a vegetation survey for each slope position where we installed instruments, and we have added the description in the revised manuscript.

41) Figure 2, Does this take into account the effects of atmospheric pressure on CO2 release in peatlands? I would have expected to see a spike during the melting of snow in the region, prompting carbon release...

We did not take into account the effects of atmospheric pressure on CO_2 release. See our explanation in response to Main comment 2.

42) Figure 2, This distribution models an expected water table change in a peatland nicely, it would be good to note this.

We agree that water table might play an important role, but since we do not have enough water table observations spatially and temporally, we did not include this variable in the model. See more explanation in the response to Main comment 2.

43) Table 1, I again question here if this is truly soil temperature as you would have effects on the TIR imagery from vegetation.

This is the soil temperature measured by the temperature sensor attached to the LI8100 system when we were measuring CO_2 fluxes, not from the map.

44) line 348, this statement implies bias to the model, I would be wary of this.

Thank you for your consideration. We have deleted this statement from the revised manuscript.

45) Figure 3, These plots show hot moments dominantly changing near precipitation events implying changes in atmospheric pressure. This would be a useful variable to include in your model based on prior literature instead of the questionable temperature data.

See our response to Main comment 2.

46) Figure 4, These are biased scales and should be plotted on a linear colormap rather than binned like they currently are.

We have replotted the maps with a linear colormap in the revised manuscript.

47) line 389, Are these really consistent? I worry significant hot moments are not captured by the model during periods of significant change in atmospheric pressure.

Yes. These literatures listed here indicated that soil temperature is an important variable driving the seasonal variability in soil respiration. Our results show that atmospheric pressure exerted indirect influence on soil respiration by changing the precipitation patterns. See more details in our response to Main comment 2.

48) line 393, I would again say that the CO2 respiration pattern modeled is in line with an expected water table response in peatlands. This needs to be looked at again.

We have added the discussion of water table fluctuations in the revised manuscript:

Numerous studies have demonstrated that water table levels play a crucial role on soil respiration (Berglund and Berglund, 2011; Evans et al., 2021; Hoyt et al., 2019; Knox et al., 2015). For example, Knox et al. (2015) demonstrated that a declining water table caused by drainage increases oxygen penetration into the peat, resulting in higher CO_2 flux compared to restored peatlands. Our study also observed negative correlations between the water table and CO_2 fluxes (Figures 1), whereas the water table accounted for only 10 % of CO_2 flux seasonal variations (Table 3 above). This relatively modest contribution may be attributed to (i) the limited number of observation sites (i.e., 5 sites along the hillslope), (ii) short duration of water table monitoring that matched the CO_2 flux measurement periods, and (iii) the generally low water table throughout the year (Table 2 above), particularly at the footslope, backslope, and summit, where maximum water tables remained > 9 cm below the ground. This maintained aerobic layers that support soil respiration, thereby reducing the influence of water table fluctuations on CO_2 fluxes. Increasing spatial coverage and temporal resolution of water table observations across the landscape would likely improve our ability to examine its influence on CO_2 emissions.

References:

Berglund, Ö., Berglund, K., 2011. Influence of water table level and soil properties on emissions of greenhouse gases from cultivated peat soil. Soil Biology and Biochemistry, 43, 923-931. https://doi.org/10.1016/j.soilbio.2011.01.002

Evans, C.D., Peacock, M., Baird, A.J., Artz, R.R.E., Burden, A., Callaghan, N., Chapman, P.J., Cooper, H.M., Coyle, M., Craig, E., Cumming, A., Dixon, S., Gauci, V., Grayson, R.P., Helfter, C., Heppell, C.M., Holden, J., Jones, D.L., Kaduk, J., Levy, P., Matthews, R., McNamara, N.P., Misselbrook, T., Oakley, S., Page, S.E., Rayment, M., Ridley, L.M., Stanley, K.M., Williamson, J.L., Worrall, F., Morrison, R., 2021. Overriding water table control on managed peatland greenhouse gas emissions. Nature, 593, 548-552. 10.1038/s41586-021-03523-1

Hoyt, A.M., Gandois, L., Eri, J., Kai, F.M., Harvey, C.F., Cobb, A.R., 2019. CO2 emissions from an undrained tropical peatland: Interacting influences of temperature, shading and water table depth. Global Change Biology, 25, 2885-2899. https://doi.org/10.1111/gcb.14702

Knox, S.H., Sturtevant, C., Matthes, J.H., Koteen, L., Verfaillie, J., Baldocchi, D., 2015. Agricultural peatland restoration: effects of land-use change on greenhouse gas (CO2 and CH4) fluxes in the Sacramento-San Joaquin Delta. Global Change Biology, 21, 750-765. https://doi.org/10.1111/gcb.12745

49) line 453, This again is contrary to most literature.

We have revised the discussion about influence of precipitation events on hot moments in the revised manuscript now:

In water-limited ecosystems or during the dry season of tropical peatlands, precipitation pulses can trigger hot moments of CO_2 gas emissions, as precipitation regulates soil moisture and infiltrating water physically displaces CO_2 from soil pores (Fernandez-Bou et al., 2020; Leon et al., 2014; Wright et al., 2013). This occurs when rainwater rapidly infiltrates dry soil, filling air-filled pores and forcing CO_2-rich air out due to hydraulic pressure. In this study, CO_2 fluxes showed both decreases and increases in response to precipitation events (Figure 1 above). The observed decreases may be attributed to the high-water content of the surface peat, and prolonged and intense rainfall led to lower temperatures, and increased soil moisture, and higher water table (Figure 3 below), thereby suppressing microbial and root respiration (Hoyt et al., 2019). Consequently, a few hot moments were captured during late July and early August during the heavy rainfall events (Figure 3 below).

References:

Fernandez-Bou, A.S., Dierick, D., Allen, M.F., Harmon, T.C., 2020. Precipitation-drainage cycles lead to hot moments in soil carbon dioxide dynamics in a Neotropical wet forest. Global Change Biology, 26, 5303-5319. 10.1111/gcb.15194

Leon, E., Vargas, R., Bullock, S., Lopez, E., Panosso, A.R., La Scala, N., 2014. Hot spots, hot moments, and spatio-temporal controls on soil CO2 efflux in a water-limited ecosystem. Soil Biology and Biochemistry, 77, 12-21. https://doi.org/10.1016/j.soilbio.2014.05.029

Wright, E.L., Black, C.R., Turner, B.L., Sjögersten, S., 2013. Environmental controls of temporal and spatial variability in and fluxes in a neotropical peatland. Global Change Biology, 19, 3775-3789. https://doi.org/10.1111/gcb.12330

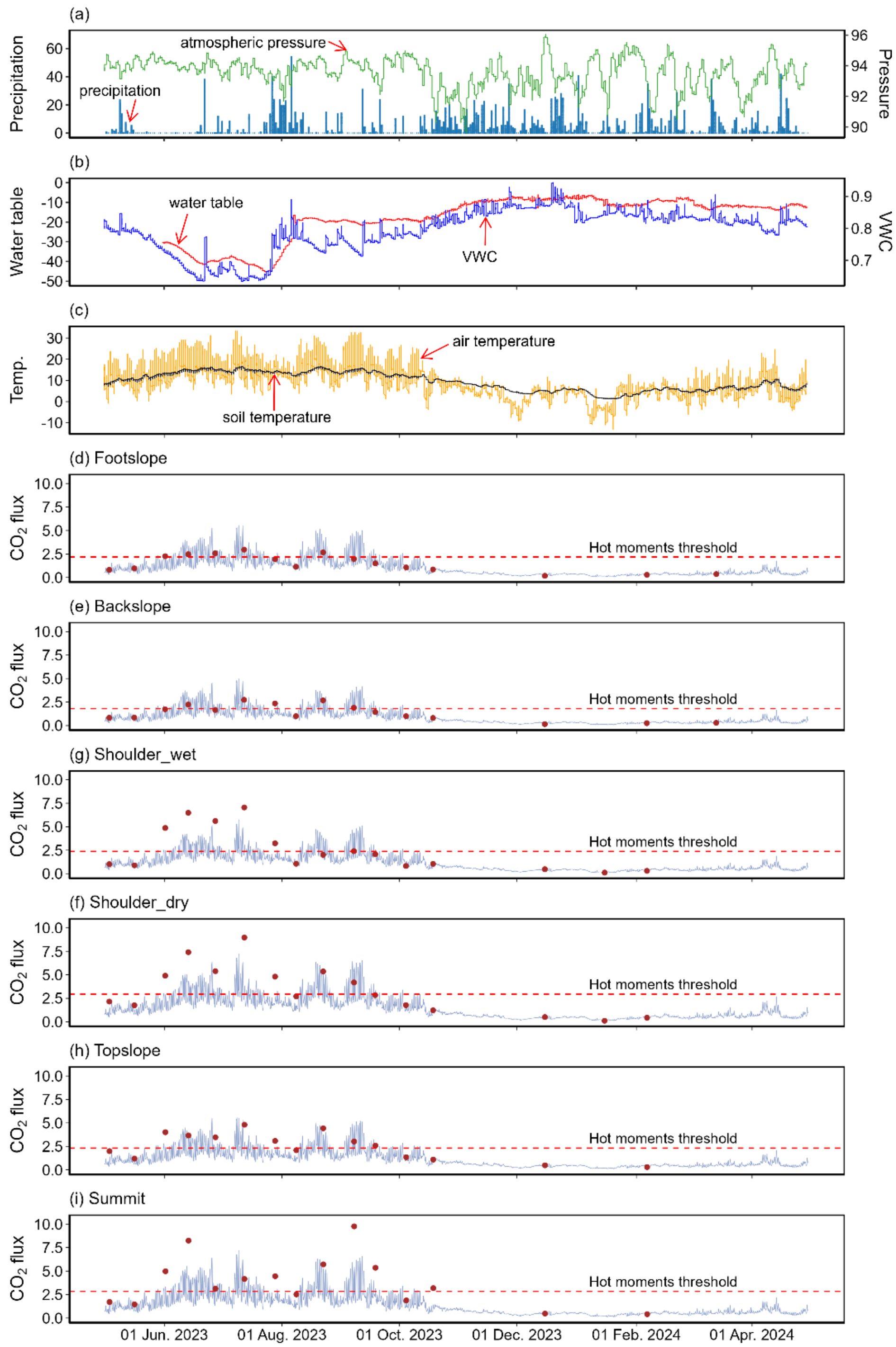


Figure 3. Time series of hourly rainfall (blue bar) and atmospheric pressure (light green line) (a), hourly mean VWC (blue line) and water table (red line) (b), hourly mean air temperature (orange line) and soil temperature (black line) (c), modelled hourly CO_2 flux (purple lines) and in-situ measurements (brown dots) at different slope positions (d-i). Precipitation(mm) data and atmospheric pressure (kPa) were from the nearby meteorological observation station (50.51 N, 6.07 E). The water table (cm) data was derived from the Solinist probes. The VWC (cm^3 cm^{-3}) and soil temperature (°C) were mean values from five slope positions monitored by Teros12 sensors at a depth of 10 cm. Air

temperatures (°C) were mean values from 5 stations at 1.4 m height above ground. Measured CO_2 fluxes (µmol m^{-2} s^{-1}) were from the LI8100A system.

50) line 483, Please check the entire document to ensure that "spatiotemporal" is used throughout rather than the several different word(s) used currently.

The “spatiotemporal” is now utilized in the entire document now.

51) line 490, Is there some metric you could use to show how this improved the estimates? Perhaps a confidence interval comparison of some sort?

The modeled annual mean CO_2 flux (mean ± SD: 1.78 ± 0.78 µmol m^{-2} s^{-1}) of the entire landscape is about 16% lower compared to the average field measurements (mean ± SD: 2.11 ± 2.38 µmol m^{-2} s^{-1}; 95% confidence interval: 1.93-2.30 µmol m^{-2} s^{-1}) at six slope positions. These similar average estimates indicate the representativeness of in-situ measurements and the robustness of modeling approach based on UAV data. Moreover, these maps provided high spatial resolution data, enabling the identification of CO_2 flux hot spots, which accounted for 10 % of the area but contributed to around 20 % of total CO_2 emission.

52) line 499, This section fails to recognize the important role of hydrology and changes in atmospheric pressure in these respiration dynamics.

We discussed the CO_2 emission hot spots in this section. We agree that hydrology is important for the spatial distribution of hot spots, so we added more related discussion in the revised manuscript: “the persistent hot spots that occurred at the shoulder might be due to their relatively drier conditions and higher carbon stocks compared to other areas (Li et al., 2024)”. However, we do not think that atmospheric might be a crucial role in regulating the occurrence of hot spots across this landscape (covering an area 33 ha), given the relatively small area.

References:

Li, Y., Henrion, M., Moore, A., Lambot, S., Opfergelt, S., Vanacker, V., Jonard, F., Van Oost, K., 2024. Factors controlling peat soil thickness and carbon storage in temperate peatlands based on UAV high-resolution remote sensing. Geoderma, 449, 117009. https://doi.org/10.1016/j.geoderma.2024.117009

53) line 533, Do you have a comparison of air temperature to soil temperature showing the soil temperatures are reasonable and not amplified due to the vegetation?

Air temperature is also important in explaining seasonal variability and diurnal trends in CO_2 fluxes. We measured CO_2 fluxes (measured by LI8100 system) and soil temperature (measured by temperature probes, not TIR data) at 33 sites, but we do not have site specific data for air temperature. Hence, only the soil temperature was considered in the seasonal model. In modeling the hourly CO_2 fluxes at six slope positions, both soil temperature and air temperature are considered.

54) line 543, I'd encourage you to make this data public in a repository such as Hydroshare (https://www.hydroshare.org/home/)

The field measurements of CO_2 flux will be available at *Hydroshare*. The UAV data will be made available on request due to their large size.

Reviewer 2

I. General comments

This manuscript presents a comprehensive multi-annual dataset on peatland carbon dynamics, combining UAV-based spatial observations with ground-based temporal CO_2 flux measurements. Overall, the paper is clearly written and well-structured, with the main findings effectively highlighted. The integration of spatio-temporal information via UAV surveys is a notable strength and adds interesting insights. However, there are three major issues that should be addressed before considering publication.

We appreciate your positive comments and suggestions. We believe these changes will enhance the clarity and accuracy of our manuscript.

1. Representativeness and definition of key terms:

The study site, while referred to as a "landscape," seems to comprise several hectares — yet no clear definition of what landscape scale entails is provided. The authors should clarify whether and how this site is representative of a broader peatland landscape or region in Belgium, and discuss the limitations if not. Similarly, the notion of a "complex" landscape is repeatedly invoked without explanation; if this adjective refers to the spatio-temporal variability of CO_2 flux patterns, this should be explicitly defined early on. Crucially, the type of peatland studied is not described, substantially limiting the transferability of the findings to other regions. The introduction should provide clearer context and definitions to justify the representativeness of the study.

Thank you for your constructive suggestions. Our study site is a bog hillslope, covering an area of 33 ha in the Belgian Hautes Fagnes, which represents an important ecosystem for studying peatland carbon fluxes due to its sensitivity to climate change and hydrological dynamics, as we mentioned in the last paragraph of the introduction. We now have added more context about the study area and defined the landscape scale and explained the complexity in section 2.1 Study area of the revised manuscript:

This ombrotrophic bog is mainly fed by precipitation and covers an area of approximately 32 hectares. The landscape exhibits complex structures, characterized by distinct SE-NW oriented topographic units (i.e., summit, topslope, shoulder, backslope, and footslope), along with diverse microtopographic features, spatiotemporal varying thermal-hydrological conditions, differences in peat thickness and carbon storage, and a range of vegetation types (Henrion et al., 2024; Li et al., 2024; Sougnez and Vanacker, 2011). More specifically, the summit is a low-relief, southeast-facing plateau at 675 - 680 m elevation, which transitions downslope into the topslope and concave shoulder slope positions (Figure 2a above). The northwest-facing backslope is relatively steeper (average slope grade: 4.98°; elevation range: 645 - 670 m) compared to these upper units, while the footslope lies in the northwestern hillslope adjacent to Hoëgne River. The peat thickness varies spatially from 0.20 to 2.10 m across the landscape, with deeper *deposits in the footslope and shallower peat at the topslope (Henrion et al., 2024; Li et al., 2024). The estimated soil organic carbon (SOC) stocks (i.e., top 1 m layer) range from 176.13 t ha^{-1} to 856.57 t ha^{-1}, with significantly higher storage at the summit, shoulder, and footslope (Li et al., 2024). Due to the pronounced topographic gradients and microtopography, the landscape exhibits great spatiotemporal variability in rootzone soil volumetric water content (range: 0.1 – 1 cm^3 cm^{-3}) and water table dynamics (range: -80 – 5 cm) (Henrion et al., 2025). The study site was drained and planted with spruces in 1914 and 1918, while the plantations were progressively cleared between 2000 and 2016. Since 2017, the site has been under restoration and now primarily covered by Vaccinium myrtillus, Molinia caerulea, Juncus acutus, and native hardwood species (e.g., Betula pubescens and Quercus robur) (Figure 2b above).*

Because we utilized the UAV remote sensing to monitor the surface environmental dynamics, extending coverage to a larger area would require substantial additional resources and time. Our study focused on demonstrating UAV-based mapping of soil respiration with high spatial resolution down to centimeter level, whereas this comes at the expense of spatial coverage. We now have discussed this limitation in the discussion part of the revised manuscript:

In addition, the key environmental variables used for mapping soil respiration were estimated by UAV data, which inevitably introduce uncertainties into the prediction processes. For instance, because daily UAV imagery was unavailable, the predictors (i.e., air temperature, LST, and NDVI) for modelling the spatiotemporal dynamics of soil temperature were linearly interpolated between acquisition dates, potentially adding uncertainty to the model results. Moreover, flight conditions and preprocessing of the raw UAV data (e.g., georeferencing, resampling, the calibration of LST, downscaling air temperature) may have further introduced errors into the soil temperature estimates. The corrected daily TWI maps were also subject to uncertainty, as they relied on in-situ soil VWC observations, which were only available in the middle transect of the landscape. Similarly, uncertainties in SOC stock mapping arose from the peat thickness estimation and soil sampling strategy, as discussed in our previous work (Li et al., 2024).

2. UAV methods and robustness of spatial thermal data:

The UAV-based thermal campaign is insufficiently described and omits discussion of common limitations (e.g. emissivity settings, light conditions, flight altitude, duration). Without any comparison to in-situ temperature data and evaluation of the resulting LST, the robustness of the spatial thermal dataset is highly questionable. While the spatial approach remains valuable for identifying relative patterns and hotspots across the site, the derivation of absolute CO_2 budgets from UAV-derived LST seems unjustified in its current methodological description. The authors should therefore refine the methods and expand the discussion to include these uncertainties and assumptions.

Thank you for your comments. We now have refined the methods and expanded related discussion of these uncertainties. Please see our response to the Main comments 1 of reviewer 1.

3. Clarity and accessibility of methods

The workflow is currently difficult to follow due to key methodological details being split between the main text and supplementary materials. For example, the use of the TWI to infer VWC is only explained in the supplement. I strongly recommend consolidating essential information in the main text and providing a clear workflow diagram — ideally one for the spatial and one for the temporal modelling approach — to improve clarity.

Thank you for your suggestions. We now have placed the methodology about mapping soil temperature and corrected daily TWI in the main text (Section 2.7 & 2.8). We also added one new section about model performance evaluation in the revised manuscript (Section 2.9). Besides, we provided two workflow diagrams for clarity (Figure 4 below):

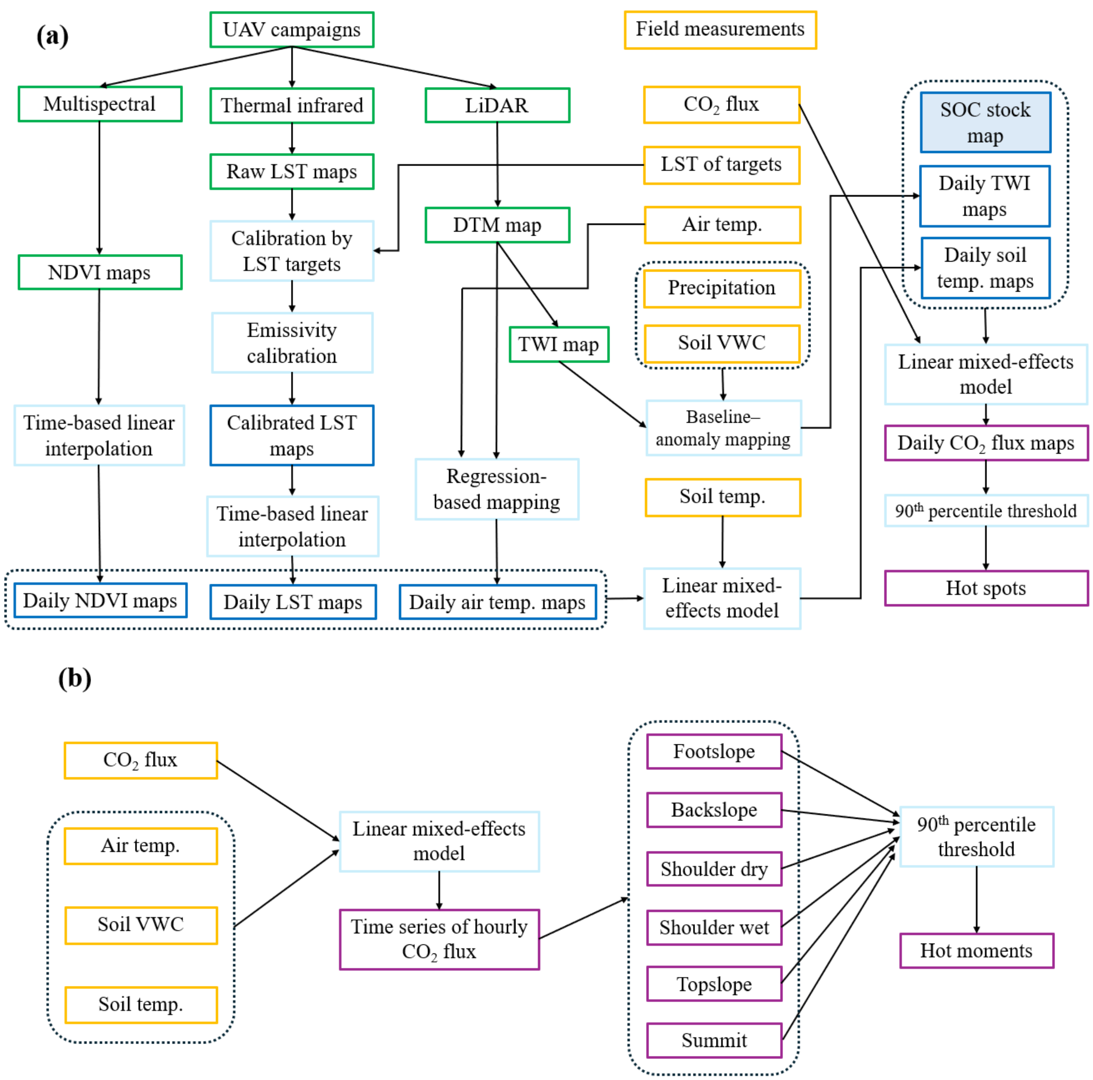


Figure 4. Workflow diagram of daily CO_2 flux spatial mapping (a) and hourly CO_2 flux temporal modeling (b).

II. Specific comments

1) l. 46-47 the two paragraphs are poorly linked- you should introduce the term soil respiration already in the first paragraph

Thank you for your suggestion. We now introduce the term "soil respiration" at the beginning of the second paragraph "Soil respiration, a key ecological process that releases CO_2 from peatlands into the atmosphere, is influenced by a combination of biotic and abiotic factors.".

2) l. 59 this statement is misleading, because the weather conditions in peatland are not more variable than elsewhere; you should rather refer to the higher sensitivity to meteorological variability regarding CO2 fluxes compared to other land cover types

Thank you for your correction. We now revised the sentence "*In addition, peatlands exhibit a high sensitivity to meteorological variability, which can trigger …*".

3) l. 68 shortly define hot moments and hotspots here (not only in the methods)

Thank you for your suggestion. We defined the hot spots at line 73 and hot moments at line 78. We now add double quotation marks for the two terms for emphasizing.

4) l. 202 should be presumably "used for generating daily mean soil temperature", at least when referring to Text S1

Thank you for your correction. We now revised the methodology structure and explain how air temperature is utilized in soil temperature mapping "*For mapping purposes, daily air temperature was statistically downscaled by incorporating the relationship between daily air temperature and elevation, followed by downscaling using a Digital Terrain Model (DTM) derived from LiDAR data*".

5) l. 272 unclear, why and how TWI is in the model- see my general comments

Thank you for your correction. We now revised the methodology structure. The calculation of TWI is explained in section 2.8 and Table 1.

6) l. 291-294 names for the different slope positions should be marked in the map or at least explained in the methods

Thank you for your suggestion. The names for the different slope positions are marked in the map (Figure 2a above) now and also explained in the study site section (see details in response to *1. Representativeness and definition of key terms*).

7) l. 295-302 unclear whether the species were retrieved from the UAV orthomosaics (Figure 1b) or determined in-situ at the measurement locations

The vegetation types at different slope positions were not derived from the UAV-derived vegetation map (Figure 2b above). We did a vegetation survey for each slope position, and we now add the description in section 2.2.

8) l.312 should be rewritten the other way around (different letters refer to significant differences)

Thank you for your correction. The sentence has been rewritten "*with different letters on top of boxes indicating significant differences among groups*".

9) l. 323 there is an interesting finding about NDVI that is currently not mentioned: the sign of the coefficient is positive for the seasonal patterns and negative for the spatial patterns; should be explained and discussed

We now added discussion for the NDVI in the revised manuscript:

The monthly/biweekly NDVI is the second-most influential predictor for CO_2 seasonal fluctuations (Table 3 in the manuscript), explaining 18 % of variability, as NDVI reveals vegetation phenology during the monitoring period. Accordingly, positive correlation was observed between CO_2 flux and NDVI at the seasonal scale. In the spatial-pattern model, however, the annual mean NDVI explained 12 % of the spatial variability in CO_2 fluxes (Table 3 in the manuscript) and the relationship became negative ($r = -0.29$, $p = 0.11$). This shift in correlation may be due to differences in vegetation structure and composition across the landscape. Slope positions with higher mean NDVI values (i.e., topslope and backslope) are mainly covered by dwarf shrubs (i.e., Vaccinium myrtillus), which exhibit lower CO_2 fluxes compared to other vegetation types. The lower CO_2 fluxes in dwarf shrub areas are likely associated with their lower root biomass.

10) l. 355 mention this station with coordinates in the methods

The coordinates of the station now are added behind.

11) l. 389-391 not clear whether water table remained stable; there are feedbacks between soil temperature and soil moisture- they are not completely independent from each other)

We have revised our discussion about the influence of water table fluctuation on soil respiration. Please see more details in our response to the Main comment 2 and Specific comment 48 of Reviewer 1.

12) l. 523-541 I missed any implications for peatland restoration from these findings; Can the success of the restoration be monitored with this methodology? It would be good to write 1-2 final sentences as an outlook in this perspective

We now added an outlook in the conclusion "*These high-resolution CO_2 flux maps enable us to locate hot spots as well as providing a valuable tool for assessing peatland management strategies, such as evaluating conditions before and after restoration*".

13) l. 540-541 this is an interesting point (high-frequency hotspots vs. sporadic hotspots), but I could not find this being mentioned or presented elsewhere in the manuscript which is a requirement for a conclusion to be drawn

We added the formation of high-frequency hotspots vs. sporadic hotspots in the revised manuscript:

We found that most of the hot spots occurred to the west of shoulder areas and to the east of the summit which is covered by dense vegetation. Some sporadic hot spots were found at the backslope and footslope positions. Spatial variability in the factors controlling biogeochemical processes, such as soil temperature, moisture, water table depth, vegetation type, and substrate quality, is likely driving these differences (Anthony and Silver, 2023; Kuzyakov and Blagodatskaya, 2015; McNamara et al., 2008). For instance, the persistent hot spots that occurred at the shoulder might be due to their relatively drier conditions and higher carbon stocks compared to other areas (Li et al., 2024). The tree-covered areas at the summit likely contribute substantial root respiration, which could sustain hot spot formation, in turn, trigger the formation of consistent hot pots throughout the year. Besides, litterfall beneath trees insulates the peat soil and provides an abundant resource for microbial activity even during the non-growing season. While at other places, such as the footslope and backslope, which are mainly covered by dwarf shrubs and Molinia caerulea with pronounced seasonal phenology, they potentially form sporadic soil respiration hot spots at specific times of the year. Furthermore, surface peat beneath relatively short vegetation can receive higher direct solar radiation in summer, leading to elevated soil temperatures and the emergence of carbon emission hot spots.

References:

Anthony, T.L., Silver, W.L., 2023. Hot spots and hot moments of greenhouse gas emissions in agricultural peatlands. Biogeochemistry. 10.1007/s10533-023-01095-y

Kuzyakov, Y., Blagodatskaya, E., 2015. Microbial hotspots and hot moments in soil: Concept & review. Soil Biology and Biochemistry, 83, 184-199. https://doi.org/10.1016/j.soilbio.2015.01.025

McNamara, N.P., Plant, T., Oakley, S., Ward, S., Wood, C., Ostle, N., 2008. Gully hotspot contribution to landscape methane (CH4) and carbon dioxide (CO2) fluxes in a northern peatland. Science of The Total Environment, 404, 354-360. https://doi.org/10.1016/j.scitotenv.2008.03.015

III. Technical comments

l. 52 please check grammar of this sentence

Thank you for your correction. We now replaced “partial” to “partially”.