#Response to RC2 :

We thank the reviewers for their careful reading of the manuscript and for their constructive and insightful comments, which helped improve the clarity and quality of the paper.
Please note that several figures referenced in the reviewer comments, including Figures 4 and 6, have been updated to the final version for improved clarity and consistency. These updates do not affect the results, analyses, or discussion presented in the manuscript. All updated figures, including those with minor modifications, are provided at the end of this document.

General comments :

There should be more care taken, however, to explain how the model is being validated against a different model of in-situ data rather than the site data in its rawest form. This often cannot be helped, but it warrants more discussion after presenting the model validation results to ensure readers are not misled.

We thank the reviewer for pointing this out. The ISBA model was validated against the statistical model derived from the in-situ chamber data because the raw measurements are monthly and sparse, while the ISBA model outputs daily fluxes. The statistical model allows reconstruction of daily NEE and associated fluxes for comparison with the model outputs. We have added a clarification in the Methods and Discussion sections to ensure that readers understand that the validation is performed against a derived statistical model rather than the raw measurements, and that this approach does not compromise the reliability of the comparison.

Lines 81–84 are now revised as follows:
« *These time series were derived from statistical models based on monthly CO2 flux measurements using the static chamber technique. The use of the statistical model allows reconstruction of daily fluxes, enabling direct comparison with the ISBA model outputs at the same temporal resolution. In the following sections, these reconstructed datasets are used as a reference for model validation, and readers should note that the validation is performed against the derived statistical model rather than the raw measurements.* »

Formatting figures should be checked for colour-blindness suitability. If any of your figures were in black & white, they would be very difficult to read – especially in Figure 3, where the mean and maximum air temperatures are only differentiated by the axis label colours, and Figure 5, were line thickness and colour intensity are similar such that they cannot be distinguished in black and white.

We thank the reviewer for this comment. Figures 3 and 5 have been updated to improve clarity and colour-blindness accessibility. Line types and thicknesses have been adjusted, and colours have been chosen to be easily distinguishable both in colour and in black & white reproduction. We have carefully checked all figures to ensure they remain legible and interpretable under these conditions.

Line-by-line comments :

43: another citation here would be useful, unless you are citing Turunen (2003) consistently throughout the paragraph – in that case, present that work more formally to better indicate that it informs multiple lines in the paragraph.

We thank the reviewer for this suggestion. We have added another citation regarding the definition and use of ARCA (Chaudhary et al., 2017) to complement Turunen (2003) and make it clear that both sources inform the discussion in this paragraph.

68: specify that 'average depth' refers to peat deposits.

We thank the reviewer for this comment. We have clarified that the average depth refers specifically to the peat deposits : *« The peatland has an average peat depth of 2 m »*

73: it would be useful to have some indication about the positioning of the piezometers within the site – nearby specific vegetation types? Placed randomly? Placed in a grid?

We thank the reviewer for this comment. We have clarified the manuscript : *« Piezometer wells are 50 mm diameter PVC tubes, distributed across the peatland to cover the full spatial extent of the site (Figure 1 from Garisoain (2024)), and their placement corresponds to the locations where chamber measurements were conducted. Water table depth (WTD) data were recorded at 1-hour intervals, and the mean value from the nine piezometers is used throughout the study. »*
Vegetation composition is described earlier in the Methods section.

76: the 'Couserans massif' phrase is unclear to those not familiar with French geography and may be worth introducing in section 2.1.

We thank the reviewer for this comment. We have clarified in Section 2.1 that the Couserans massif is a mountainous region in the central Pyrenees, southwestern France, to provide geographic context for international readers.

78-79: the sentence "The vertical resolution ... carefully considered" does not make sense. Reword.
79: by 'this', are you referring to the model, the model's resolution, or something else? Be more specific.

Thank you, we rephrase with : « *The S2M model has a vertical resolution of 300 m and provides hourly outputs. The topographical features of the peatland, including altitude, slope, and aspect, were carefully accounted for to ensure that the atmospheric variables extracted for the site accurately represent local conditions. »*

81: the 'see also' phrase should be expanded to a full sentence to claim how the vegetation is portrayed in your 2023 paper's figure.

« The vegetation comprises species typical of both ombrotrophic areas, such as Sphagnum palustre and Sphagnum capillifolium, and minerotrophic areas, including Carex demissa and Equisetum fluviatile (Henry et al, (2014). This distribution is illustrated in Figure 1 of Garisoain et al (2023), which shows the spatial arrangement of vegetation types across the study site. »

123: you have inconsistencies with naming equations compared to page 4. This continues throughout the paper.

Thank you.

167: explain more. Vertical distribution? Is this constant throughout the simulation or an initial condition? You get into it more by line 205, but it would be better to make it clearer here too.

Thank you, we've hadded some clarifications.
« The brown Sphagnum biomass (Bbrown) is uniformly distributed over the top 10 cm of the soil profile, and this vertical distribution is maintained throughout the simulation .»

225: cite the CENTURY model for thoroughness.

Thank you, see (Parton et al., 1997).

332: R_2 values below 0.5 warrants more explanation for their inclusion. Also, in the referenced Figure A4, you do not define subfigures (e) and (f).

Some r^2 values are below 0.5, but are presented to provide a complete overview of model performance across all conditions.

364: it would be useful to re-state that reported values are coming from ISBA in this section even if it seems redundant. This recurs in line 413 when discussing the dryness index – it may be useful to re-state that this is/isn't an ISBA output as it's not easy to keep track.

We thank the reviewer for this comment. We have updated the figure legends for Figures 4 and 7 to clearly indicate the origin of the data displayed, specifying which values are direct outputs from ISBA and which are derived (e.g., the dryness index), to improve clarity and help readers track the data sources.

367-369: you present the results qualitatively. It could be useful to put a number to the acceleration in NEE decline by comparing simple linear regressions for the two periods you describe. The same could be said for year-to-year variability; you could compare average change year-to-year for the two periods. This may not be statistically significant, but will make the point more concrete.

We thank the reviewer for this constructive suggestion. Following this recommendation, we have quantified both the acceleration in NEE decline and the evolution of year to year variability using simple and transparent metrics.
Specifically, we fitted linear regressions to cumulative NEE over three successive 22-year periods (1959–1980, 1980–2001, and 2001–2022). The resulting slopes show a clear intensification of the carbon sink, with mean slopes changing from −6.7 gC m^{-2} yr^{-1} (1959–1980) to −23.2 gC m^{-2} yr^{-1} (1980–2001), and further to −31.9 gC m^{-2} yr^{-1} (2001–2022). We also examined the associated p-values of these slopes, indicate that the linear trends are statistically significant for the two most recent periods, while the trend over the earliest period is weaker. Comparison of slopes shows that the strongest acceleration occurs between the first two periods, while the increase in sink strength slows down after the early 2000s. These values are now explicitly reported and illustrated in Figure 4.
In addition, year to year variability was quantified as the standard deviation of annual NEE for each period. Variability is highest during the early period (82.7 gC m^{-2} yr^{-1}), decreases substantially during the phase of strongest sink intensification (66.8 gC m^{-2} yr^{-1}), and slightly increases again during the most recent period (72.2 gC m^{-2} yr^{-1}). Although these differences are not formally tested for statistical significance, they provide a concrete comparison of interannual variability across periods, as suggested by the reviewer.
These additions have been incorporated into the Results section and Figure 4, making the interpretation of both acceleration and variability more quantitative and explicit.

375: How did you pick the time 'several time periods' displayed in the figure? You kind of explain in line 386, but it is unclear if this selection was intentional to show this point, or if the finding occurred organically from blocking out the three periods of time blindly.

We thank the reviewer for this important clarification. The subdivision of the time series into three successive periods of approximately 22 years was defined a priori, based on minimum temporal lengths commonly used in climatology (WMO, 2017 ; https://www.agroorbi.pt/livroagrometeorologia/DocsProg/Temas&ExercíciosExtraPorCapítulo/Cap1_Introdução/Docs/WMO%20Guidelines%20on%20the%20Calculation%20of%20Climate%20Normals_en.pdf). This duration ensures a sufficient number of observations for robust linear trend estimation while reducing the influence of short-term variability. Given the 64-year length of the record, a slight overlap was allowed so that each period remained long enough for trend calculation while maintaining three comparable intervals. The periods were selected based on this criterion and data availability, rather than on the evolution of the NEE time series itself, so that differences in slopes and variability emerged organically from the analysis rather than from intentional tuning.
This clarification has been added to the manuscript to make the rationale for the period selection explicit.

411: 'or contribution of 48% Figure 6' in the parentheses does not make sense. Do you mean to use the previous figure to contribute to the point that summer NEE 'drives' cumulative NEE? If so, give his its own sentence.

Thank you, we've rephrased with :
« The cumulative summer NEE tends to "drive" the cumulative annual NEE almost always sharing the same sign, except in years near equilibrium (cumulative annual NEE = 0). This

relationship is supported by a strong correlation between summer and annual cumulative NEE (r2 =0.71, Figure A7) and by the fact that summer NEE contributes approximately 40 % of the interannual variability of cumulative NEE (Figure 6). »

510-511: the sentence 'Over the long term … carbon sources' deserves a citation, or more notes on where you've seen this in your data. If van der Woude et al. (2023) is the citation, you can connect the previous phrase with this one using a semicolon to make this abundantly clear.

We thank the reviewer for this comment. We have clarified this section in the manuscript to distinguish between observations from our data and relevant literature. In our peatland, greening and higher summer GPP fluxes, together with increasing contributions from spring and autumn, currently buffer summer carbon losses, although some years show a partial imbalance. To contextualize this pattern, we cite van der Woude et al. (2023), who report similar mechanisms in European forest ecosystems under extreme droughts, where compensatory processes were insufficient to maintain carbon balance. This reference is provided as a useful analogy, illustrating how extreme events can challenge compensatory mechanisms; it complements our observations without implying that the same effect has been directly measured in peatlands. The revised text now explicitly conveys that prolonged or intensified droughts could potentially challenge the peatland's long term carbon sink function.

Table A1: The inclusion of the value for SWI_c is confusing if not given more context. Does this mean SWI for C3 herbaceous plants? This is specified in the main body of the paper. Where did you get this value?

We thank the reviewer for this comment. The value for SWIc was removed from Table A1, as it did not add relevant information and its inclusion without context could be confusing. All necessary context for soil water content is already provided in the main text.

More nitpicky formatting notes:

Note that before the text begins, you need to capitalise the second name of the Correspondence Author.

Thank you.

20: change 'most' to 'more' to avoid superlatives.

Done.

27-32: consider abbreviations for the models you describe, especially those you repeat later. The phrase "developed as offline tools … framework" is awkward and could be rephrased.

Thank you, we have rephrased : *« Dynamic vegetation and ecosystem models, developed as offline tools without atmospheric, climate, or carbon feedbacks, have since incorporated these processes into their frameworks. »*

40-41: I do not believe "Average" should be capitalised, and you should capitalise the components of LORCA contributing to its acronym.

Thank you.

49: abbreviate 'continental surface models' to CSMs in tandem with changes from lines 27-32.

Done.

58: do not separate objective with full stops. Rather, use semicolons.

Thank you.

80: italicise all Genus and species names for plants.

Thank you.

95: fix citations - Goudriaan (1986) and Jacobs (1994).

Thank you.

96: it's a bit confusing to introduce eq 2 before eq 1. It makes sense for (1) to be first, so restructure the sentence to match this order.

Thank you.

100: 'That's to say' is a clunky phrase; use 'meaning' instead. I think it would read better for *Ci* and *CO2* to have separate units despite being the same.

Thank you.

104: you have 'et' instead of 'and'. You need an 'is' after *Ia.*

Thank you.

106: add *Rd* in the beginning of the phrase like you do for the previous eqs.

Thank you.

107: ‘type of PFT (plant type)’ is clunky. Reword – maybe ‘PFT parameters’?

Thank you.

117: instead of a comma, connect your two references (Shi et al and Walker et al) with an ‘and’.

Thank you.

121: ‘Although they are not the same physical quality’ is either incomplete, or should be connected to the prior statement with a comma. Maybe restate the year (1994) rather than just
saying ‘Jacobs’’ as it’s on a new page from the original citation.

Thank you.

124: fix citation – Gong et al. (2020).

Thank you.

128: you do not define ω_{opt}.

Thank you.

132-133: italicise *Sphagnum*.

Thank you.

136: rather than ‘a day’, say ‘one day’ or ‘a timestep of one day’

Thank you.

142: ‘SLA (constants e and f)’ is ambiguous.

Thank you.

156: change ‘grass/herbaceous’ to ‘grass/herbaceous PFTs’

Thank you.

158: change ‘plant functional type (PFT)’ to simply ‘PFT’ or ‘the selected PFT’

Thank you.

162: ‘B’ is missing formatting. Add a comma after B_{brown}.

Thank you.

174-178: make this more concise; it does not flow well.

We’ve rephrased :
« The precipitation interception reservoir is considered negligible. Consequently, Sphagnum mosses receive water primarily through capillary action from the soil within 10 cm of the surface. Although direct interception of rainfall also contributes in reality, this process is not explicitly modeled here. Instead, we account only for the effect of capillarity by relating the water content of Sphagnum to that of the upper 10 cm of soil. Precipitation that would otherwise be intercepted bypasses the moss canopy and infiltrates directly into the soil, thereby influencing both soil and Sphagnum water content. »

193: the line would read better as: ‘Below a threshold value, as the *Sphagnum* mosses dry out, the resistance of the *Sphagnum* increases linearly, allowing the retention of a minimal threshold of water in the mosses. As such, we define:’ Omit space before colon.

Thank you.

198: define SWI_{sp} on line 195. You replace ‘Water’ with ‘Wetness’ on page 8 – make consistent.

Thank you.

206-208 : Move the sentence ‘Beyond 10 cm … SWI_{sp}=0’ after the sentence following.

Thank you.

212: no need for a new line here in my opinion.

Thank you.

228: no need for ‘see’, you can just cite using (Gibelin et al., 2008).

Thank you.

233 : the word ‘set’ is unclear. Reword more explicitly. Is this an initial condition ? Default ?

Thank you.
« In our simulations, the SOC fraction in each layer is fixed at 1, reflecting the assumption of a completely organic soil. »

243 : missing subscript for O_2.

Thank you.

256 : italicise *i* and *j.*

Thank you.

258: fix citation - (Morel et al., 2019).

Thank you.

259 : remove contraction.

Thank you.

262: ‘potentially *a* limiting reaction’

Thank you.

265: rather than saying gas transport by plants, you could say plant-mediated transport, which explains the abbreviation better.

Thank you.

267: rather than saying vegetation type, you shold say PFT to stay consistent.

Thank you.

277: no need for period after ‘summation’.

Thank you.

281: fix citation – Garisoain et al. (2024).

Thank you.

283: add ‘the’ between ‘use’ and ‘daily’. Put a period after *dif(t).*

Thank you.

287: no need for period after ‘A3’.

Thank you.

289 : I do not believe you define the dryness index as DI explicitly anywhere. Equations 18 and 19 seem not to be well explained, even if they are simple.

We’ve changed this paragraph to be more explicit :
The dryness index is based on the work Garisoain (2024) (see Figure A3 (b)). We first define the daily soil water deficit dif(t): …

To consider only periods of positive water deficit, we define the function f(t) as:…

The Dryness Index (DI) is then calculated by integrating f(t) over the summer period: …
This formulation ensures that only days with a positive soil water deficit contribute to the DI, providing a simple and physically meaningful measure of summer dryness.

295 : you begin to introduce unnecessary extra spaces here.

Thank you.

308-309: omit sentence ‘In other words … are introduced’. You are clear enough in this paragraph without over-explaining.

Thank you.

320-321 : capitalise Section.

Thank you.

323 : two full stops here by accident.

Thank you.

326 : capitalise Carbon. In the Figure 1 below, put y-axis units in parentheses.

Thank you.

332 & 344: missing a comma before 'Figure'.

Thank you.

Figure 5: using 'minus' to mean negative sounds clunky – I would simply say 'gross primary productivity' and explain it is negative to visually demonstrate it in balance with ER to create NEE. You should omit the space between 'periods' and the colon.

Thank you. We've changed the Figure and the captions :
« Seasonal evolution of cumulated (a) gross primary productivity (shown with negative sign by convention), … »

386: omit 'the'.

Thank you.

Figure 7: omit 'the' and 'one' on either side of 'annual'.

Thank you.

411: comma after R_2 before figure A7.

Thank you.

444 : make singular –'the black curve represents…'

Thank you.

455: the opening phrase is clunky and could likely be said in fewer words.

We've rephrased and changed the discussion paragraph :
« *The primary objective of this study was to evaluate the newly implemented Sphagnum PFT in the ISBA land surface model. Sphagnum photosynthetic activity is linked to water content in the top 10 cm of soil. While the model reproduces site scale carbon fluxes reasonably well, a more detailed validation of the water cycle would require eddy covariance data and multi-site evaluations to assess parameter transferability. The aim was not to optimize parameters, but to test whether realistic behavior could be reproduced at a well instrumented site using literature derived values.*

The mixed representation, combining Sphagnum and herbaceous PFTs, accounts for contrasting responses to soil moisture. theta(z) was removed for Sphagnu, allowing the moss layer to maintain microbial activity under dry conditions, while it was retained for herbaceous layers to preserve the soil moisture sensitivity of heterotrophic respiration. Model dynamics further support this choice, as herbaceous layers withdraw more water from the topsoil than Sphagnum, increasing the sensitivity of soil respiration to moisture fluctuations. Although respiration from the herbaceous component alone is not improved, retaining theta(z) is consistent with previous validations of the ISBA model for herbaceous vegetation, ensuring the parameterization remains grounded in established formulations (Gibelin et al., 2008)
*Importantly, the combination of PFTs captures contrasting responses to soil moisture, introducing functional diversity that likely increases the robustness of ecosystem carbon fluxes. This mechanism is reflected in the observed improvement of NEE on the mixed vegetation dataset, even if GPP and respiration alone do not always show large gains. These results also highlight the broader uncertainty in representing heterotrophic respiration as a function of soil moisture: classical formulations derived from mineral soils may not adequately capture responses in organic soils, as noted in other peatland modeling studies (Guenet et al., 2024), emphasizing the need for further research on moisture/respiration parameterizations. *

By combining PFTs with contrasting functional responses, the model captures compensatory dynamics across vegetation types: herbaceous layers respond strongly to moisture deficits, while Sphagnum maintains near surface moisture and microbial activity. This functional diversity improves site scale carbon flux estimates and suggests increased model robustness under variable hydrological conditions, which could be further enhanced by including interactive dynamics between Sphagnum mosses and herbaceous following the work of Kim and Verma (1996) but also competition and coupled carbon/water processes (Lippmann et al., 2023; Heijmans et al., 2008; Wu and Blodau, 2013a; Gong et al., 2020).»

494-495: restructure the sentence as so –'Despite some differences in seasonal representation, both ISBA and the statistical model by Garisoain et al. (2024) agree that …'

Thank you.

520-521: italicise *Sphagnum*.

Thank you.

Figure A6: 'Hourly' misspelled.

Thank you.

Table A1: 'functional' misspelled in title. No need for a space between Notes 1 and 2. Semicolon would be better after D_{xmax} = 0.4. You haven't properly formatted g_m or D_{max}. Page number for p.38 is the wrong font.

Thank you.

Bibliography

Chaudhary, N., Miller, P. A., and Smith, B.: Modelling Past, Present and Future Peatland Carbon Accumulation across the Pan-Arctic Region, Biogeosciences, 14, 4023–4044, https://doi.org/10.5194/bg-14-4023-2017, 2017.

World Meteorological Organization: WMO Guidelines on the Calculation of Climate Normals, Wmo-no. 1203, World Meteorological Organization, Geneva, Switzerland, https://library.wmo.int, 2017.

Parton, W. J., Scurlock, J. M. O., Ojima, D. S., Gilmanov, T. G., Scholes, R. J., Schimel, D. S., Kirchner, T., Menaut, J.-C., Seastedt, T., Garcia Moya, E., Kamnalrut, A., and Kinyamario, J. I.: Observations and Modeling of Biomass and Soil Organic Matter Dynamics for the Grassland Biome Worldwide, Global Biogeochemical Cycles, 7, 785–809, https://doi.org/10.1029/93GB02042, 1993.

Guenet, B., Orliac, J., Cécillon, L., Torres, O., Sereni, L., Martin, P. A., Barré, P., and Bopp, L.: Spatial Biases Reduce the Ability of Earth System Models to Simulate Soil Heterotrophic Respiration Fluxes, Biogeosciences, 21, 657–669, https://doi.org/10.5194/bg-21-657-2024, 2024.

This part presents the figures that have been updated following the reviewers' comments.

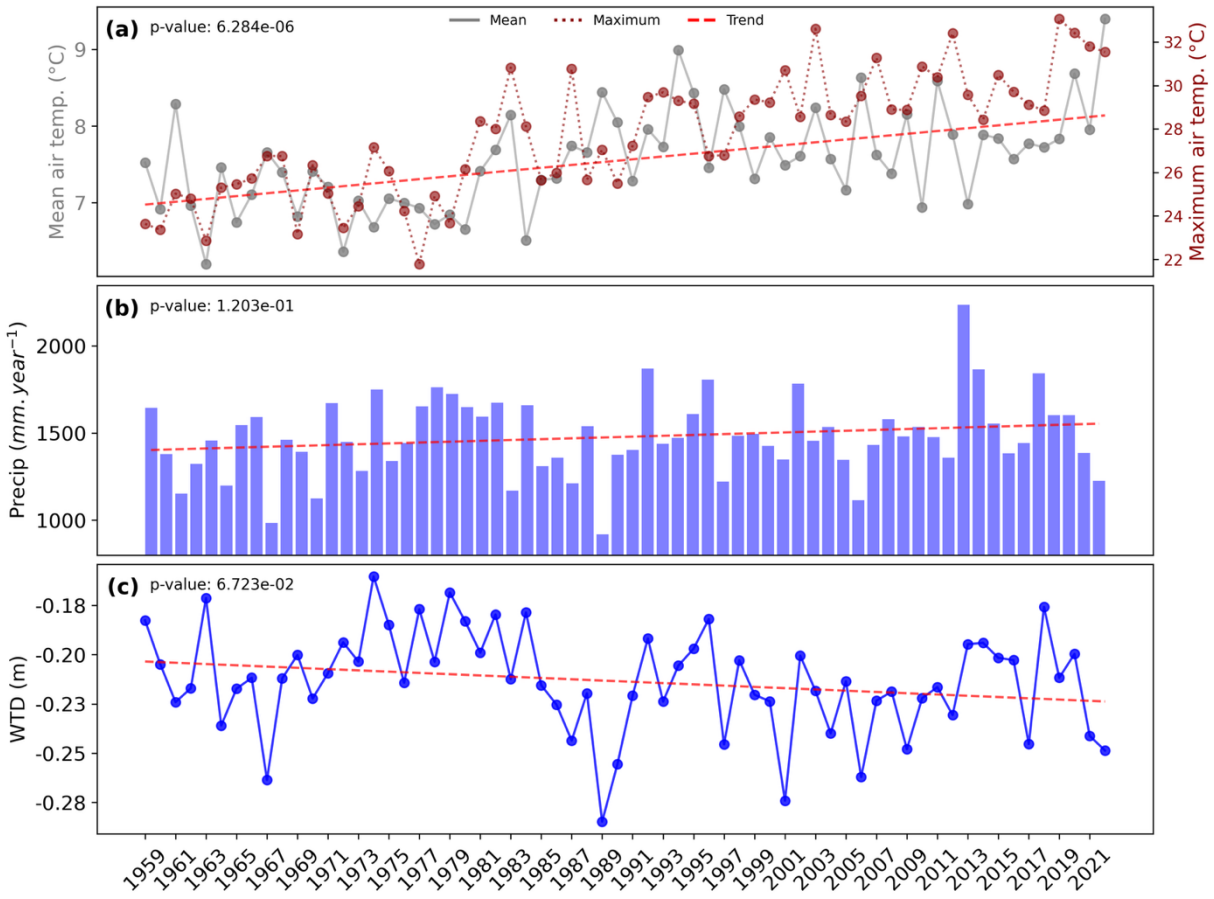

Figure 3. ***(a) Mean and maximum annual air temperature*** $^\circ$ ***C and (b) annual cumulate precipitation*** $mm.year^{-1}$ ***both from the S2M reanalysis and (c) mean water table depth*** m ***diagnosed from ISBA outputs, along with their trends as red dashed lines and corresponding p-values.***

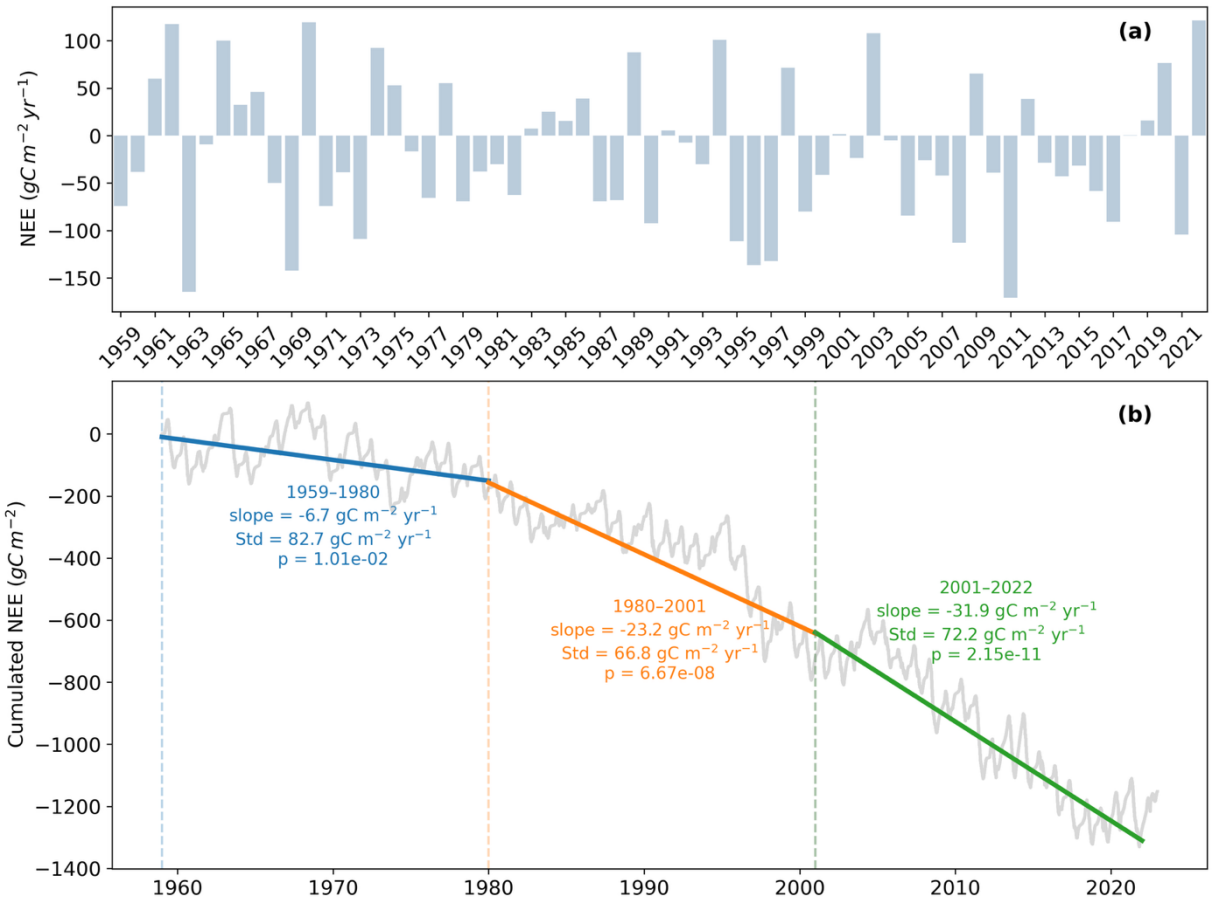

Figure 4. ***(a) Annual net ecosystem exchange*** $(gC.m^{-2}.year-1)$ ***from 1959 to 2022, as simulated by ISBA. (b) Hourly cumulated net ecosystem exchange*** $(gC.m^{-2})$ ***from 1959 to 2022, also from ISBA. The pannel additionally reports the linear trend (slope), its p-value, and the standard deviation of annual NEE for three distinct periods: 1959–1980, 1980–2001, and 2001–2022.***

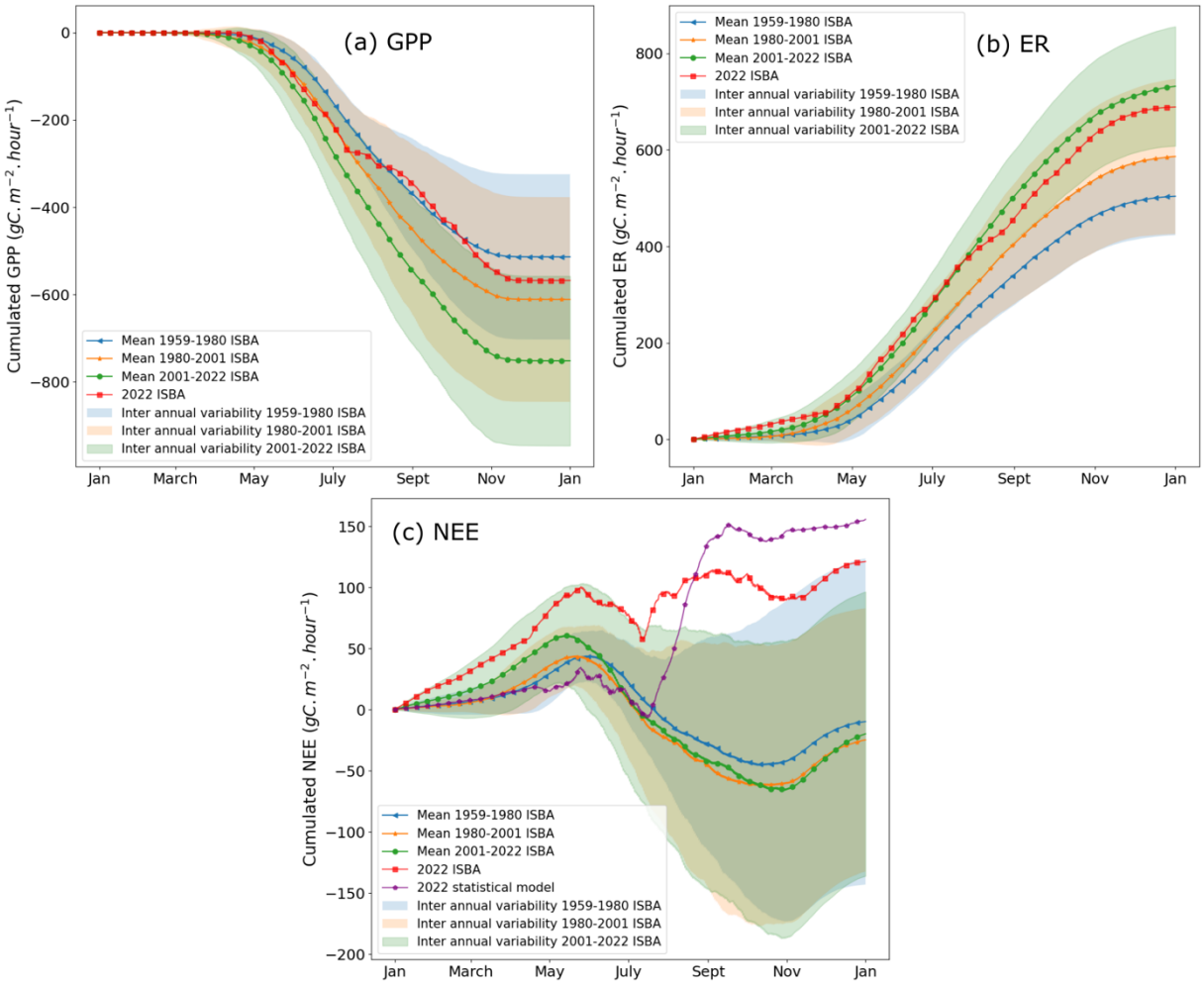

Figure 5. ***Seasonal evolution of cumulated (a) gross primary productivity (shown with negative sign by convention), (b) ecosystem respiration, (c) net ecosystem exchanges from ISBA over several time periods: 1959-1980 in blue, 1980-2001 in orange, 2001-2022 in green with interannual variability represented as a 90% confidence interval. Superimposed, the 2022 NEE seasonality simulated by ISBA (red curve) and the statistical model (purple curve).***

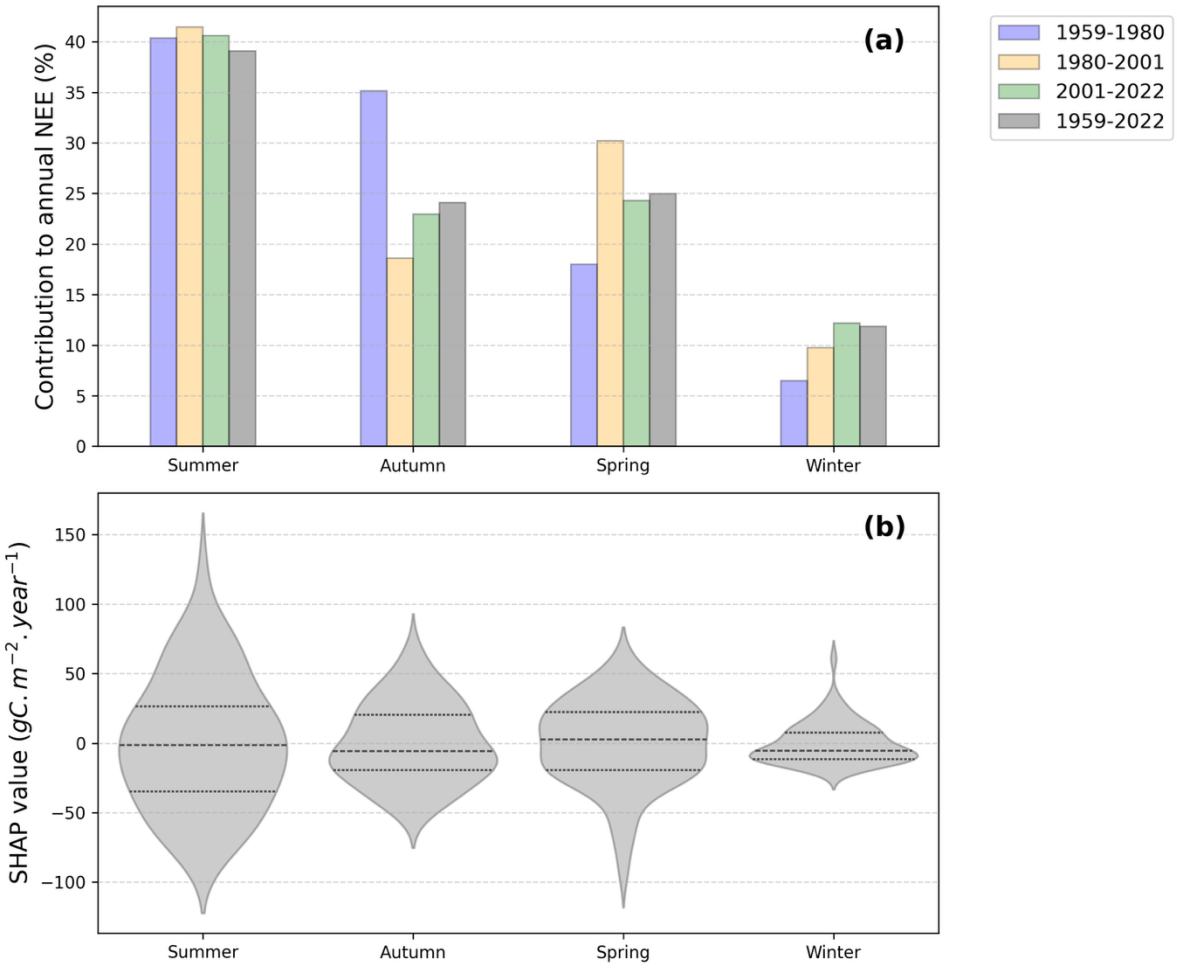

Figure 6. ***(a) Seasonal contributions to annual NEE across four time periods : 1959-1980 in blue, 1980-2001 in orange, 2001-2022 in green, 1959-2022 in grey. Each bar represents the relative importance of a season in explaining the total NEE, as determined by Shapley regression coefficients. Seasons are defined as winter (December–February), spring (March–June), summer (July–August), and autumn (September–November). (b) Distribution of SHAP values by season for 1959–2022. Positive or negative SHAP values indicate the direction of each season's contribution to annual NEE, showing whether a season increases or decreases the yearly flux.***

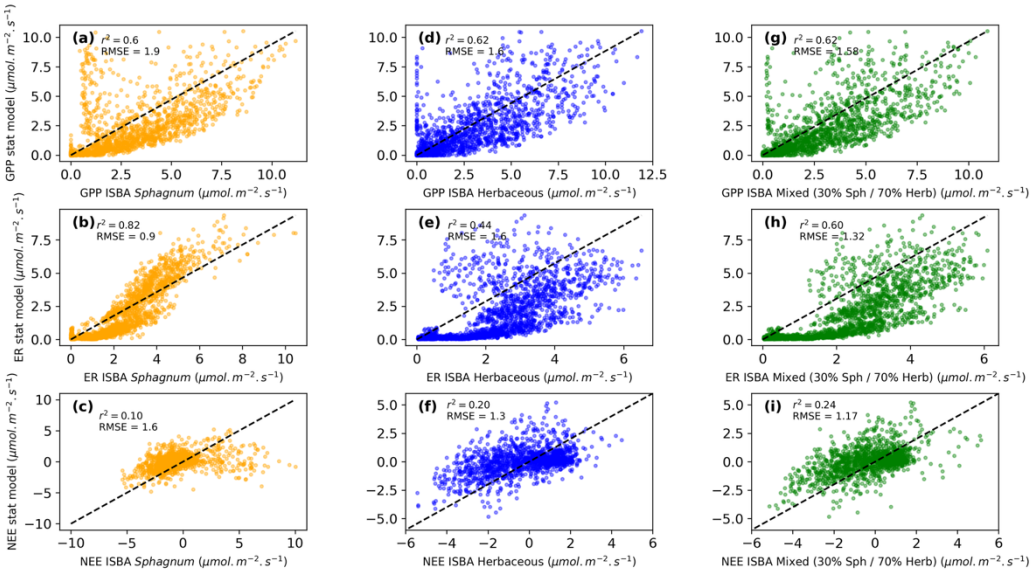

Figure A4. ***Comparison of daily ecosystem photosynthesis, respiration and net ecosystem exhange from the statistical model with: (a) the new Sphagnum photosynthesis, (b) the new Sphagnum ecosystem respiration, (c) the new Sphagnum net ecosystem exchange, (d) the previous herbaceous photosynthesis, (e) the previous herbaceous ecosystem respiration, (f) the previous herbaceous net ecosystem exchange, (g) the mixed vegetation photosynthesis, (h) the mixed vegetation ecosystem respiration, (i) the mixed vegetation net ecosystem exchange.***

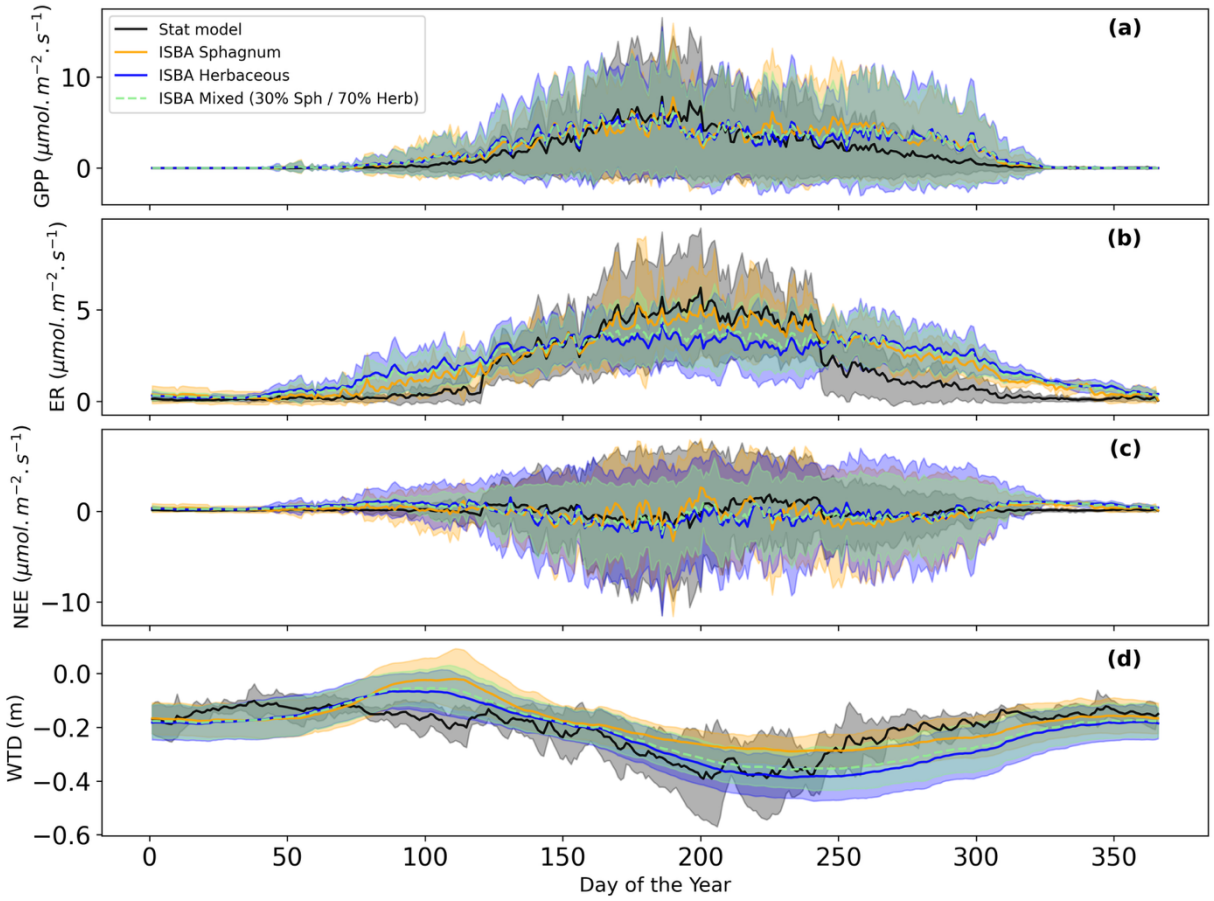

Figure A5. ***Daily annual cycle (2017-2022) of (a) Gross Primary Productivity, (b) Ecosystem Respiration, (c) Net Ecosystem Exchange, (d) Water Table Depth from the statistical model in black, the ISBA Sphagnum model in orange, the ISBA herbaceous model in blue, and the ISBA mixed vegetation in green.***

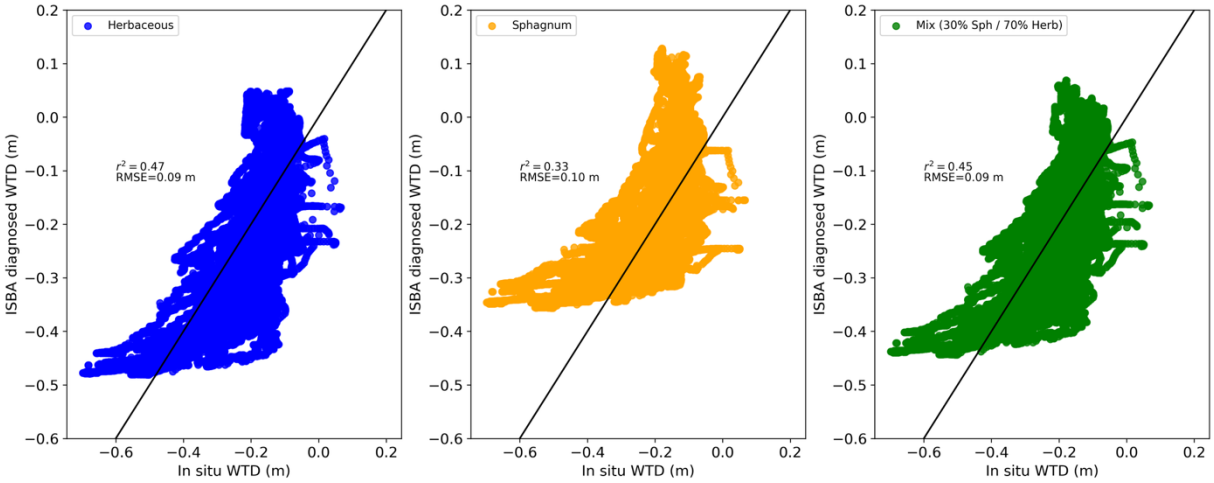

Figure A6. ***Hourly ISBA-diagnosed water table depth (WTD) with herbaceous vegetation as the dominant cover is compared to hourly in situ WTD in the left panel, while the right panel presents ISBA-diagnosed WTD with Sphagnum as the dominant vegetation versus in situ WTD.***

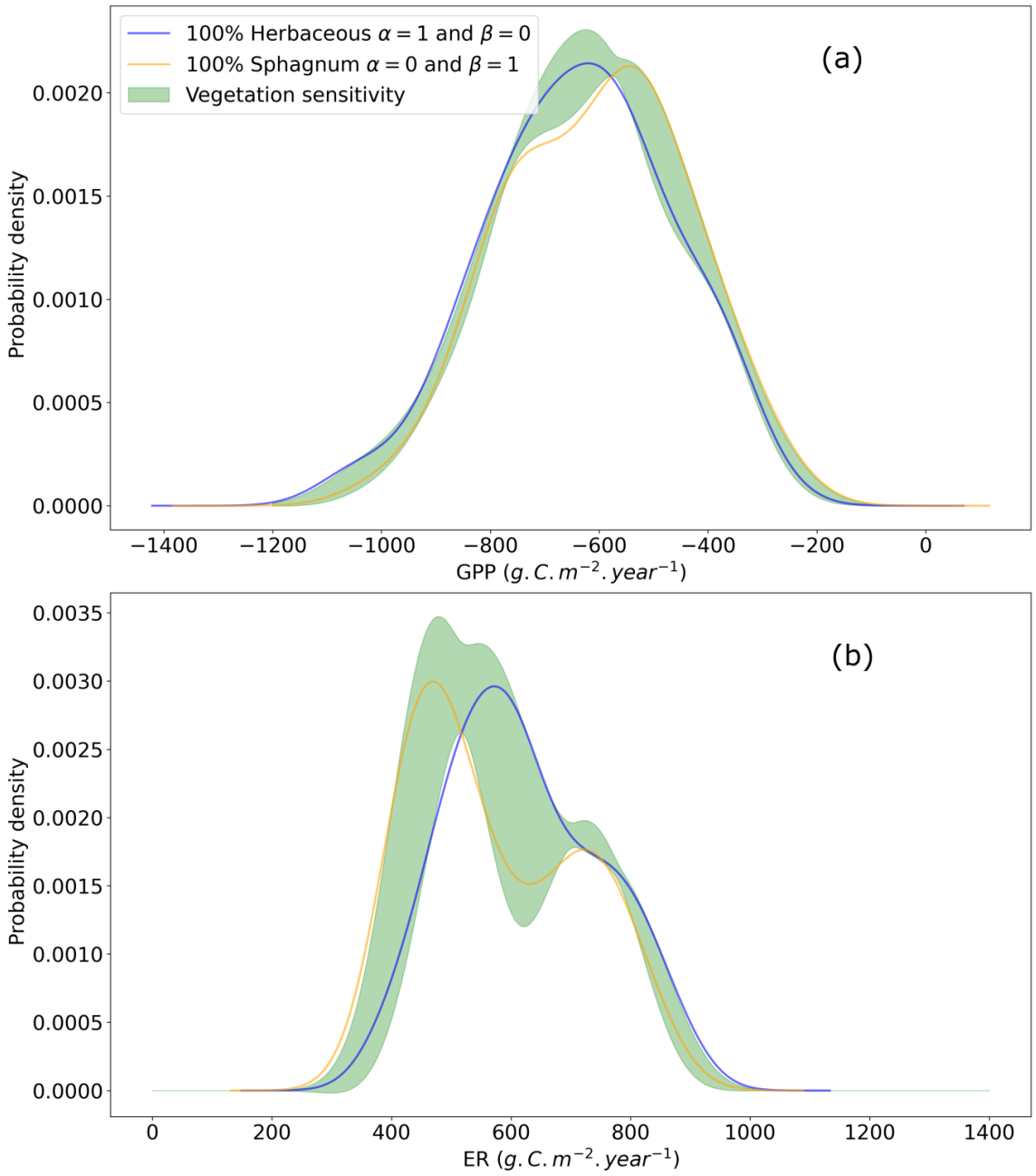

Figure A10. ***Probability density function of annual cumulated (a) GPP and (b) ER over 1959-2022. In black, the vegetation mix corresponds to 70% herbaceous and 30% Sphagnum. In orange a 100% Sphagnum mix and in blue a 100% herbaceous mix. In shaded areas, the 95% confidence intervals corresponding to the variation of the vegetation mix in the form*** $\alpha \times Y_{Sphagnum} + \beta \times Y_{herbaceous}$ ***with*** $\beta = 1 - \alpha$, α ***varying from 0 to 1 in steps of 0.01 and*** Y ***being GPP or ER.***