

Author's response to the discussion of: "Compound soil and atmospheric drought events and CO₂ fluxes of a mixed deciduous forest: Occurrence, impact, and temporal contribution of main drivers"

Author's response

Scapucci et al.

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We kindly thank the editor and the referees for their valuable comments and insights that will surely improve the manuscript. We list here all the modifications that were implemented in the revised version of the manuscript; in addition, we briefly summarize the detailed answers given to the referees in the earlier step of the revision process. We understood that the more critical points of the manuscript were the concept of acclimation (point 1 below), and the use of conditional variable importance (CVI) vs. SHAP analysis (point 2 below). Furthermore, we understood that the section "2.2 Ecosystem-level measurements" needed to be rewritten and that a better division of the paragraphs was necessary for section "1 Introduction" and "4 Discussion". We also addressed all the Line-by-line comments of the referee 1 and 2. Finally, we introduced some additional changes to improve the clarity and accessibility of the manuscript (i.e., we uploaded the scripts in an online repository).

1. Acclimation

We understood the importance of a better definition of *acclimation* that we now stated as NEP sensitivity to abiotic factors like Tair, VPD, and SWC during each growing season. Therefore, we introduced this definition already in the section "1 Introduction" to provide the reader with the necessary context to understand further analyses (Lines 56-59 of the revised manuscript). Then, we explained how we estimated acclimation (NEP sensitivity) to Tair, VPD, and SWC, namely by calculating the Tair, VPD, and SWC values that indicated maximum marginal contribution to NEP (feature_NEPmax), i.e., maximum SHAP values for the respective driver variable (feature) for different growing seasons in the section "2.5 Data analyses" (Lines 197-210 of the revised manuscript). According to the definition, we then stated in the section "4 Discussion" that there was an acclimation of NEP to soil and air dryness during the 2022 growing season (Lines 402-403 of the revised manuscript). Moreover, this acclimation differed among growing seasons, dependent on the environmental conditions during the respective growing season (Lines 457-467 of the revised manuscript). We changed the first sentence of the section "5 Conclusions" to argue that we saw first signs of NEP acclimation to soil and atmospheric drought during the same growing season (Lines 512-514 of the revised manuscript). Finally, we added Figure A6 in the section appendix A of the manuscript, and we used it to increase the understanding of NEP sensitivity to environmental drivers. Please refer to the "Answer

2. Conditional variable importance (CVI) vs. SHAP analysis

We clarified that the conditional variable importance (CVI) is an approach for estimating feature importance specifically designed when there is a collinearity between different features (e.g., Rg and Tair, VPD and SWC), thus a more reliable metric for feature importance (as stated in lines 170-172 of the revised manuscript) compared to SHAP analysis. We also specified that random forest (used for the CVI) and XGBoost models were run for each year separately (Line 170 and 185 of the revised manuscript). Furthermore, we stated that we did not use absolute SHAP values because we were interested in the direction of the drivers' effects (Line 188 of the revised manuscript). However, for comparison between the CVI and SHAP analysis we calculated absolute SHAP values

for daily mean NEP (Line 193-196 of the revised manuscript), also reported in figure A3 of the revised manuscript. Finally, we clarified that for the SHAP analysis we preferred the use of daytime mean NEP (referred to as NEP_{DT} in the revised version of the manuscript) over daily mean NEP to highlight the effects of the drivers when photosynthesis is dominating (Line 174-175 of the revised manuscript).

3. Section 2.2 Ecosystem-level measurements

We understood the similarities of section 2.2 Ecosystem-level measurements of the manuscript with Shekhar et al. 2024 (<https://doi.org/10.1016/j.scitotenv.2024.169931>) so we rephrased it accordingly.

4. Better division of the paragraphs

We improved the division of the paragraphs in the section “1 Introduction” and “4.2.2 Net ecosystem exchange, NEP”.

5. Line-by-line comments referee 1

We addressed all the comments from the referee 1 and updated the manuscript. The line numbers given here refer to the older version of the manuscript. Referee comments are given in *italics* and author’s comments in normal text.

Line 22: What is the 30% decrease relative to?

Rephrased in the manuscript as “The CSAD events reduced daily mean net ecosystem productivity (NEP) in all three CSAD years by about 38% compared to the long-term mean, with the highest reduction during 2022 (41%). This reduction in daily mean NEP was largely due to decreased gross primary productivity (GPP; >16% compared to the long-term mean) rather than increased ecosystem respiration (Reco) during CSAD events.” lines 21-24 of the revised manuscript.

‘largely’ → ‘large’.

We replaced “largely” with “mostly”.

Line 28: remove the second ‘always’; add ‘has’ after ‘net radiation’.

The sentence was changed to “Air temperature had negative effects, while net radiation showed positive effects on NEP_{DT} during all CSAD events.” Line 29 of the revised manuscript.

Line 31-32: remove the sentence of acclimation if more convincing evidence is not found.

The sentence was left in the manuscript as we better clarify acclimation of NEP to CSAD events in the manuscript. We also added the word NEP to specify NEP acclimation.

Line 61: ‘be it?’ ‘particular’ → ‘particularly’

The sentence was changed to “Clearly, most drought impact studies use data measured above the canopy, i.e., net carbon dioxide (CO₂) exchange or remote sensing of vegetation. Particularly the latter is largely neglecting the below-canopy component of the forest (also known as forest floor), although it might show contrasting responses to drought conditions compared to the top canopy sensed from above (Chi et al., 2021).” lines 64-67 of the revised manuscript.

Line 107: please add the description of measuring CO2 storage change.

The sentence was changed to “The net 109 ecosystem CO₂ exchange (NEE) was calculated as the sum of FC and the CO₂ storage term estimated from concentrations based on 1-point measurements (Greco and Baldocchi, 1996).” lines 109-110 of the revised manuscript.

Line 132: please report the depths.

We specified the depths of the sensors both in the text and in the table A1.

Line 134: How to centerly normalzied the SWC data

We improved the sentence as follow “To account for spatial heterogeneity, we normalized the SWC data using a z-score transformation, we then used z-scores of SWC for further analyses.” lines 134-136 of the revised manuscript.

Line 171: daytime mean NEP and daily mean NEP are easy to get confused in the many parts of the manuscript. Using ‘NEPdaytime’ and ‘NEPdaily’ could help.

We now use NEP for daily mean and NEP_{DT} for daytime mean NEP.

Line 177: ‘Shapley, 1953’ is missing in the reference.

The reference was added to the reference list.

Line 182: Please clarify why the mean SHAP value instead of the mean absolute SHAP value is used to indicate the overall feature importance.

The concepts were clarified in the section 2.5 Data analyses and in particular in the sentence “The models were run for each year separately, and we obtained the marginal contributions of each feature for each day of each growing season, which allowed to observe their temporal course. Then we calculated the mean SHAP value during the CSAD events for each predictor of NEPDT and Rff for the CSAD years to determine the dominant direction of the effect of each feature” and “However, since we were interested in the short-term changes in driver importance, including the direction of their effect, we did not follow up using absolute SHAP values in this study” lines 185-188 and 195-196 of the revised manuscript respectively.

Line 189-195: please refer to Figure 7.

We only referred to Figure 7 in the 3. Results section.

Line 212-217: All the events' length seem to be 1 day shorter. Same in table 1. Please check.

Lengths were adjusted accordingly (See text lines 225-237 of the revised manuscript and Table 1).

Line 237-204: What are those shade areas around dashed lines?

We updated the sentence as follow “Comparison of 5 day moving averages of daily mean (a-c) Tair, (d-f) VPD, and (g-i) SWC in the years when a CSAD event happened against the long-term means (2005-2022). The band around the dashed line indicates the standard error of the long-term mean 2005-2022. The coloured areas mark the CSAD events, i.e., periods with co-occurring lowest SWC and highest VPD.” lines 252-254 of the revised manuscript.

Line 241-243: Why Max. or Min. has a standard deviation?

We explained the reasoning in the answers to the referee comments.

Line 266-272: 1) What are those shaded areas around dashed lines in the left panels?

We updated the caption to “Figure 3. Comparison of daily mean (a) net ecosystem production (NEP), (c) gross primary productivity (GPP), (e) ecosystem respiration (Reco), and (g) forest floor respiration (Rff) of the years when a CSAD event occurred (2015, 2018 and 2022) against the respective long-term means (a, c, e, g). The grey areas around the long-term means represent the standard error of the respective long-term-mean CO₂ fluxes. Soil respiration (SR) measurements are given as daily means (\pm SD) measured manually in 2022 only. Thicker lines represent CSAD events. The right panels (b, d, f, h) show the cumulative difference between the actual fluxes recorded during a CSAD event and the respective long-term mean fluxes (2005-2022 for NEP, GPP and Reco; 2019-2021 for Rff); The error bars show the cumulative standard errors of the long-term mean CO₂ fluxes for the respective CSAD event”. lines 282-288 of the revised manuscript.

2) What are those error bars in the right panels?

See previous comment.

Line 358-359: How to calculate this standard deviation?

We added the following sentence to the section 2.5 Data analyses “For this, we fitted a local polynomial regression between the SHAP values of the driver variable and the driver variable

itself, i.e., a loess curve, and calculated the residual standard error from the loess function of the stats R-package.” lines 200-201 of the revised manuscript.

Line 371-373: Since SR vs. TS and SWC during CSAD are not significant, please rephrase ‘tend to decrease or increase’ as ‘non-significant’.

We updated the text as follow “When no CSAD event was recorded, daily mean SR significantly increased with TS ($R^2 = 0.76$, P of 0.002; linear regression). However, during the CSAD event, SR did not respond to TS ($R^2 = 0.19$; Figure 9a). On the other hand, independent if a CSAD event was recorded or not, SR did not respond to variation in SWC ($R^2 < 0.01$ and $R^2 = 0.3$ respectively; Figure 9b).” lines 387-390 of the revised manuscript.

Line 385: If still keep ‘acclimation’, please briefly describe what acclimation is here.

We updated the text as follow “. In addition, we saw first signs of acclimation of NEP to such CSAD events, i.e., changed sensitivities of NEP to its drivers, both within the same and among different growing seasons. This also suggested that predictions of site-specific CSADs and their impacts might become more challenging in the future.” lines 402-404 of the revised manuscript.

“Line 419-421: You found air temperature is not important for daily mean NEP during CASD based on conditional variable importance in Figure 4, while air temperature is still important for daytime mean NEP during CSAD based on SHAP in Figure 5. Although daily mean NEP and daytime mean NEP are different, the results using the two methods seem to be inconsistent. Therefore, please also report the overall feature importance of predicting daily mean NEP based on SHAP.

We better clarified this point in the section 2.5 Data analyses of the manuscript as stated in the section “2. Conditional variable importance (CVI) vs. SHAP analysis” of the Author’s response.

Line 438-447: again, suggest removing if more convincing evidence is not found.

We updated the text as follow In addition to the standard response of NEP (and its components GPP and Reco) to abiotic drivers (VPD, SWC and Tair), NEP sensitivity to those drivers could change from one growing season to another (Grossman, 2023), especially during drought conditions, indicating acclimation of NEP (Crous et al., 2022; Aspinwall et al., 2017; Sendall et al., 2015; Sperlich et al., 2019). This difference in NEP sensitivity to VPD, SWC and Tair during the 2015, 2018, and 2022 growing seasons was clearly observed in our study (see response curves in Figure 7). The thresholds derived from the response curves of SHAP values vs. the abiotic drivers (Figure 7) indicated acclimation of NEP to higher VPD (in 2018 and 2022), and lower SWC (in 2022), as we observed a shift towards drier conditions of the VPD, and SWC values corresponding to the maximum marginal contribution of the features to NEPDT in CSAD years (Figure 7, A5).” lines 456-463 of the revised manuscript.

Line 492-493: same as above.

The text was changed to “For our mixed deciduous forest, we found first signs of NEP acclimation to more extreme soil (low SWC) and atmospheric drought (high VPD) conditions when comparing sensitivities of NEP to these drivers during the same growing season, which will be fundamental for drought resistance in the future.” lines 512-514 of the revised manuscript.

6. Line-by-line comments RC2

Line 80: What does percentual cover mean for the species, by leaf area/volume?

The largest limitation of the presented study is bare minimal information regarding the forest structure. I believe that authors should include the development (annual) of standard parameters such as stand LAI and species specific DBH, height and density. This is especially important for the interpretation of the values between years and comparison with reference period. You should show that these differences were not due to differences in forest structure.

As this is managed site, the time between 2015-2022 is pretty long period that could include some significant change in species composition. This could influence your Figure 7,8 comparison of variable sensitivity between years.

As we saw no significant change in LAI and no difference among the CSAD years we stated it in the section 2.1 Forest site as follow “The CH-Lae forest has a complex canopy structure with a rather high species diversity, the dominant species are European beech (*Fagus sylvatica* L., 40% cover), ash (*Fraxinus excelsior* L., 19% cover), Sycamore maple (*Acer pseudoplatanus* L., 13% cover), European silver fir (*Abies alba* Mill., 8% cover), large-leaved linden (*Tilia platyphyllos* Scop., 8%) and Norway spruce (*Picea abies* (L.) H. Karst., 4% cover) (Paul-Limoges et al., 2020), 89 showing no significant trend of leaf area index (LAI) over the years.” lines 86-89 of the revised manuscript.

Line 82: First time mentioning Fraxinus excelsior, Acer pseudoplatanus etc. please use full latin nomenclature as you did for European beech and Norway spruce.

The Latin names were updated in the text, see previous comment.

Line 151: R version missing.

We added the R version to the manuscript.

I would suggest to include the variable of interest (NEP, Rff) in Figures 5-8 to include in the figures directly, not only in the description.

We added the terms NEP and Rff in the figures as title for the y axes “SHAP values for NEP_{DT}” and “SHAP values for Rff” for all the referred figures.

Could the figure 7c, f, I be interpreted in a way that the temperature optimum for NEP shifted between the years? If yes, I think you should explore possible reasons in the discussion.

We better addressed acclimation in the revised manuscript, see previous responses and we added the figure A5 in the section Appendix A to better discuss the topic.

7. Additional changes

- We adjusted the literature to the new changes in the text (see section References)
- We improved the readability of figure 5 and 6 adjusting the axes size.
- We improved figure A6, changing the axes names to be consistent with the text.
- We uploaded all the scripts in an online repository as recommended. The scripts can be found here <https://github.com/lscapucci/Compound-soil-and-atmospheric-drought-events-and-CO2-fluxes-of-a-mixed-deciduous-forest>. The link was added to the manuscript. Once accepted, we will upload the data at the openly available ETH Zürich repository. Thus, no supplements will be uploaded.