Contrasting drought legacy effects on gross primary productivity in a mixed versus pure beech forest

Xin Yu, René Orth, Markus Reichstein, Michael Bahn, Anne Klosterhalfen, Alexander Knohl, Franziska Koebsch, Mirco Migliavacca, Martina Mund, Jacob A. Nelson, Benjamin D. Stocker, Sophia Walther, and Ana Bastos. *Biogeosciences Discussion*

Response to Reviewer #2

R2C1: The authors present a sophisticated collaborative work and the development of a new method to separate GPP legacy effects. The analysis clearly demonstrates the value and importance of long term flux measurements with eddy covariance in combination with biometric data for the evaluation of concurrent and legacy effects of ecosystem GPP on different temporal scales. The potential applicability to other ecosystems is attractive as well. Only very few remarks needed for clarification.

We thank the reviewer for the encouraging evaluation of our manuscript and for constructive comments and suggestions. Below, we provide a point-by-point response to the comments.

R2C2: Regarding the importance of changes in the energy balance caused by drought and legacy effects, a bit more evaluation of evapotranspiration would improve the paper even more. Even though transpiration seems not to be influenced by drought / drought legacy here, it is unclear whether the term 'transpiration' in the manuscript is standing for 'evapotranspiration' from eddy covariance data.

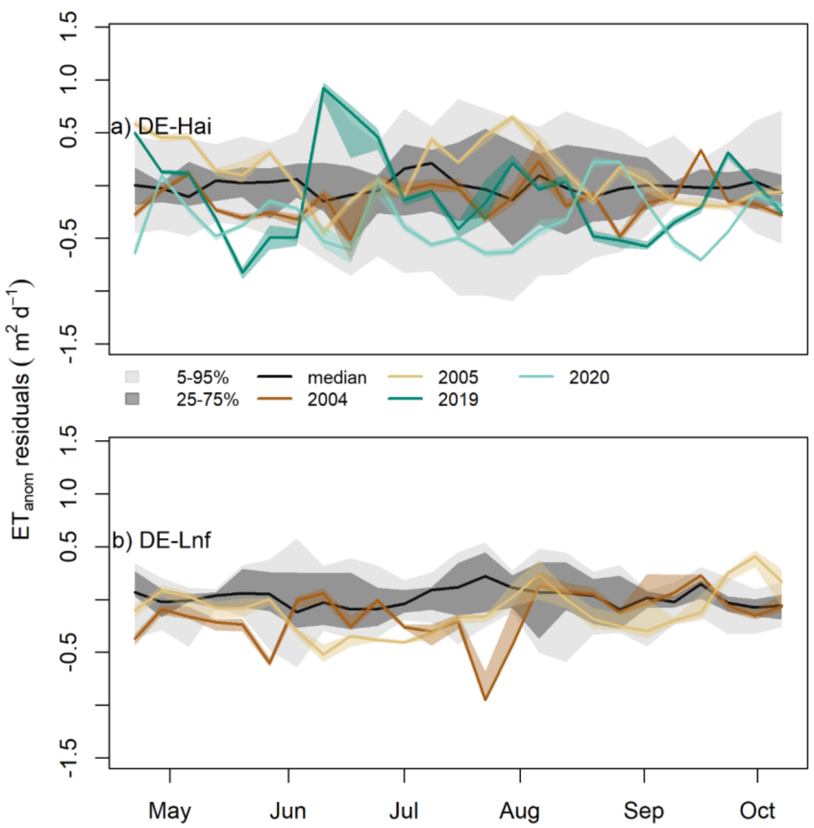

Figure R2.1. Residuals of evapotranspiration anomalies at the seasonal scale in legacy years at a) DE-Hai and b) DE-Lnf.

In Figure R2.1, we show the legacy effects on evapotranspiration (ET) calculated using the same methodology we applied for GPP and which is described in Section 3.4. We found the legacy effects on ET are small compared to the legacies on GPP at both sites. Nevertheless, evapotranspiration includes not only transpiration but also soil evaporation and interception evaporation as well. Given a certain amount of energy, even though transpiration decreases due to legacy effects caused by plant hydraulic damage, it could be compensated by increased soil evaporation. In the end, the amount of evapotranspiration might remain unchanged. Therefore, in the manuscript, we quantified legacy effects on transpiration estimated by the TEA (Transpiration estimation algorithm) approach (Nelson et al., 2018) to infer possible legacy effects due to plant hydraulic damage, which was briefly described in line 194 of section 3.4.

'The same method was used to quantify legacy effects on transpiration (Tr)'

After the reviewer's comment, we have clarified the respective paragraph in line 194 of the revised manuscript.

'In order to infer possible legacy effects due to plant hydraulic damage, the same method was used to quantify legacy effects on transpiration (Tr) estimated by the TEA (Transpiration estimation algorithm) approach (Nelson et al., 2018). The TEA approach first isolates the periods when evapotranspiration is most likely dominated by transpiration. Then, a quantile random forest model (Breiman, 2001; Meinshausen and Ridgeway 2006) is trained during the separated periods and transpiration can be estimated at every time step. More detail can be found in Nelson et al., 2018. Not using evapotranspiration (ET) is because given a certain amount of energy even though Tr decreases due to plant hydraulic damage but it could be compensated by increased soil evaporation, and the amount of ET might remain unchanged.'

R2C3: Mortality of trees is mentioned to be already caused by droughts. Can the effect of mortality / less trees over time be separated already? Have these trees been in the flux footprint? It should also be mentioned whether the biomass data from dendrometers and the litter harvest were from within the footprint.

Unfortunately, the methodology and available data do not allow separating the mortality effects, but we can confirm that there is significant tree mortality in the period 2018-2020 in the flux tower footprint. This is based on observations by the site PIs, who co-authors this study. We also confirm that dendrometers, leaves, and fruits data were collected within the main footprint area. We have added this information in line 106 of section 2.3:

'Annual mean tree ring width (TRW) was measured via permanent band dendrometers. The dendrometer trees represented the main species and their respective size classes <u>of the main footprint</u> at DE-Hai for the years 2003 to 2020. Because of technical constraints, damages and a natural dieback of single trees, the number of measurement trees per year varied between 54 and 95. Net primary productivity (NPP) of fruits for the years 2003 to 2020, and NPP of leaves for the years 2003 to 2016 resulted from litter samplings (25-29 traps) <u>within the main footprint area of the flux tower</u>'

And in line 403 of section 5.2:

‘This might be associated with significant tree mortality <u>in the forest covering the main footprint of the flux tower</u> in the period 2018-2020 (about 6% year^{-1} between 2017 and 2020 compared to less than 1% year^{-1} between 2005 and 2017) mainly caused by the storm Friedrike in January 2018 and the heat and/or drought in summer 2018 and 2019 (unpublished data)’

Specific remarks:

L 212ff: could you clarify a bit more the description of the model setting with EVI anomalies? It seems not to be totally clear how structural effects are removed

We have added more details and rephrased the description in line 213 of section 3.6:

‘Combining GPP and satellite-based EVI allows separating these structural and physiological effects. To do this separation, we used two model settings: 1) RF, which was the original setting described in section 3.4, included both structural and physiological effects; 2) RF_{EVI}, which added EVI anomalies as an additional predictor to the original model, only included physiological effects, <u>because structural effects have been reflected by the predictor EVI anomalies and GPP_{anom} residuals from this model are expected to be caused by physiological effects</u>. Therefore, physiological legacy effects on GPP were quantified as GPP_{anom} residuals from RF_{EVI} while structural legacies were quantified as the difference between GPP_{anom} residuals from RF and RF_{EVI} (i.e. RF-RF_{EVI}).’

L 223: “…other factors in addition to…”

corrected.

L 331/332: “…using eddy-covariance data at two forests in central Germany in the same climate but with different management and species composition.“ I suggest to repeat here briefly what these forests have in common and where they differ.

We have added the information.

L 338: “…if they appear only in critical periods of the growing season,…” –check formulation

corrected.

L 349: “Finally, our approach allows determining the uncertainties in estimated legacy effects…” replace one ‘estimate’

corrected.

L 365: “…negative legacies on GPP (reduced uptake) in the…” -just for the reader’s convenience

We have added it.

L 399: “…of stand age the heat and drought impact on carbon….”

We have rephrased it.

L 431 + 432: this should probably be evaporation instead of evapotranspiration

Thanks, this should be evapotranspiration, because this refers to the total evapotranspiration including soil evaporation and transpiration from the shallow layers (0~30 cm).

Fig. 2:

As a) represents DE-Hai for 2003 and following years and b) represents DE-Hai for 2018, I suggest to write such:

Figure 2: "Daily GPP in the selected drought and legacy years at a), DE-Hai 2003, b) DE-Hai 2018 and c) DE-Lnf showing the 2003 droughts and following legacy years, respectively."

We have rephrased it.

Similar for Fig. S2

We have rephrased it.

Fig 5: seasonal GPP anomalies: lines ResEVI (structural effect) in figures hard to distinguish from Res. Could you e.g. zoom in to the periods discussed?

We have zoomed in on the periods discussed in Figure R2.2 but have found it is too informative. Therefore we have added Figure R2.2 to the supplementary materials and have added the description in line 285 of Figure 5.

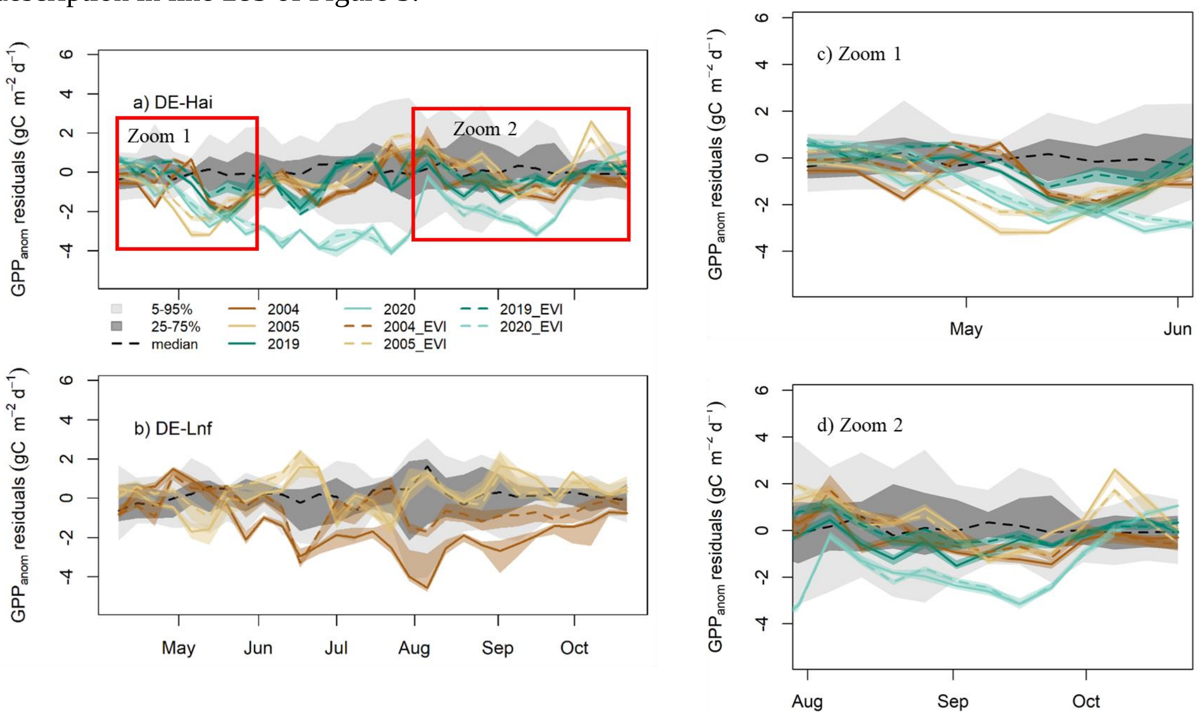

Figure R2.2. Residuals of GPP anomalies from RF and RF_{EVI} (see Section 3.6) in legacy years at a) DE-Hai and b) DE-Lnf.

‘Figure 5. Residuals of GPP anomalies from RF and RF$_{EVI}$ (see Section 3.6) in legacy years at a) DE-Hai and b) DE-Lnf. *Residuals of GPP anomalies are characterized by observed minus predicted GPP anomalies (GPP$_{anom}$ residuals). The color lines and bands show the median and 5th-95th percentile GPP$_{anom}$ residuals of ensemble model runs (see Section 3.4), respectively. The solid and dashed lines show the residuals based on RF and RF$_{EVI}$, respectively. The model uncertainties from RF$_{EVI}$ (dark and light grey shaded area, respectively) are characterized by the 25th-75th and 5th-95th quantile ranges of GPP$_{anom}$ residuals in non-legacy years. The black dashed line was the median of GPP$_{anom}$ residuals from RF$_{EVI}$ in non-legacy years. The ticks denoted the start of each month. Figure S4 shows the results for April-June and August-October at DE-Hai in more detail.’*