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Interactive comment on "Carbon–Water Flux Coupling Under Progressive Drought" *by* S. Boese et al.

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We thank Referee #3 for his valuable feedback on the submitted manuscript. Below, we address general remarks and important specific remarks that required a response and describe how we incorporate these in the revised manuscript. In addition we carefully considered all specific comments related to spelling, clarity and references and integrated them into the revised manuscript where appropriate.

GENERAL REMARKS

1. MECHANISMS OF LIMITATION

This is a critical point of our approach and we agree that the previous version of the manuscript communicated this insufficiently. In a previous study, Boese et al. (2017)

first observed the existence of a GPP-independent association of transpiration to radiation. As in the present work, its semi-empirical approach targeted at a high model performance of predicted evapotranspiration, while associating the detected effects to plausible physical variables. In our manuscript, we aimed to expand this research to water-limited periods, in which the water supply is an additional factor controlling transpiration rates.

As we demonstrate, declining GPP due to stomatal contraction proves insufficient to explain ET decline during dry-down events (Fig. 2, 3, 4). Yet even integrating the effect of soil-water limitation (Zhou+SWL) on uWUE did not provide substantial benefits to model performance (Fig. 4). Instead the complete reduction of stomatal and non-stomatal (r * Rg) transpiration components (+Rg+SWL) provided the highest performance of predicted ET. As the attenuating factor s is not exclusively reducing stomatal conductance in this model, it could be interpreted as sign of a process affecting both source of transpiration. A reduced stem hydraulic conductivity during water-limitation (Ladjal et al. 2005), could be responsible for this generalized decrease of transpiration. Nevertheless, our empirical approach at ecosystem-scale makes it difficult to pinpoint the mechanism responsible for the observed effects. In the discussion, we now make this clear and further highlight the importance of following up on the results with mechanistic studies in controlled settings.

2. STRATIFICATION OF SITES ALONG VEGETATION STRUCTURES

In the updated version of the manuscript, we added a third category, "mixed", for savannah type ecosystems. This admittedly only partially resolves the problem that vegetation types are only crude proxies for the actual height of plants in ecosystems (which in turn can vary substantially for any given site). However, we also clarify that the stratification can reflect – through predominating growth forms – both differences in water-use strategies and rooting depths. Yet it has to be stated in the manuscript that these categories are at best imperfect proxies for variables (e.g. average rooting depth or plant water-use strategies of woody vs. non-woody plants) that as of now are not at all or not consistently measured. Overall, the semi-empirical models we employed provide an effective description of how different ecosystem fluxes interact empirically. While the calibration to local properties impedes ad-hoc generalizations, the variability of parameters between sites can be interpreted as reflecting the variability of ecosystem functional properties (such as uWUE). For ecosystems containing various plant types with differing structural or physiological properties, the observed patterns are then aggregated signals for the whole system.

3. SREM AND ANTECEDENT CONDITIONS

The utilized Srem variable does indeed have important shortcomings. As we described, our motivation for its introduction was to serve as a proxy variable for extractable soil-water that does not rely on incomplete and inconsistently measured observations of soil-water content. However, due to its nature as calculated proxy metric, it suffers some notable limitations. As you mention, its reliance on an approximately exponentially decreasing ET omits preceding water-stress. However, antecedent conditions can be reflected in this metric. Consider an ecosystem that experienced intermittent periods of water-limitation that did not qualify as dry-down events according to our definition. After a given last, weak precipitation event, we might see a longer period without any rain-fall in which ET starts following an exponential dry-down decay. Even though we identify only the latter part as dry-down event, plants in the ecosystem are already in drought stress at the beginning of the event. Yet this lower water availability would then also manifest in the reduced ET at the beginning of that event and subsequently a smaller integral of ET used to obtain Srem. Any normalization of the variable for the sites (p4 l10–11) will of course prevent a possible interpretation of q values between sites (as Srem_max can no longer be compared across sites).

We further verified the robustness of our results by using two additional calculations of Srem. In these, we used the lower and upper 95% confidence intervals of the parameters (ET_0 and k) used in the exponential model to obtain a higher and lower variant of Srem. The discrepancy of the two Srem calculations therefore incorporates uncertainties about how the exponential fit could capture the ET decline despite unknown initial conditions and missing values in the time series. We attached this comparison as figure below. Nevertheless, antecedent conditions might well be responsible for deviations of the highly idealized behavior of the models we employed. As such, we haven given this limitation more prominence in the discussion.

3.1 RELIANCE ON LOCALLY-CALIBRATED STATISTICAL MODELS

The local optimization of parameter values is certainly a limitation if the insights are to be generalized or included in mechanistic models. The lack of firm process understanding on the scale of ecosystems does however make a semi-empirical approach a valuable approach to capitalize on the availability of eddy-covariance observations for whole ecosystems. In this approach, local parameter estimates are understood as ecosystem functional properties which regulate ecosystem responses to environmental conditions. Therefore, the empirical justification of model terms (such as the linear Rg-term and the +SWL term) and systematic patterns in their parameter estimates provide information about the interaction of variables on ecosystem scale. Nevertheless, we agree that this decidedly non-mechanistic approach has shortcomings that more process-motivated investigations can address. For the purpose of the study, we see the detection of the soil-water limitation effect and its variability across sites as a good starting point for further work. To clarify which mechanisms might be responsible for the effect and how they drive differences between ecosystems, different observations such as leaf and xylem water potentials as well as volumetric soil-water content might be necessary. In the revised introduction and discussion, we provide a better explanation for the scope of our study and highlight how our findings could stimulate experiments under controlled conditions and factorial model experiments. We also omitted the separation into two different calibration schemes which unnecessarily distracts from the main outcomes of the analyses.

3.2 WATER-USE EFFICIENCY VS ET IN EQUATIONS

We agree that our choice of ET as metric to evaluate water-use efficiency models needs a better explanation. In brief, using ET = f(GPP, x) instead of WUE = f(x) is merely a reformulation that focusses on how different WUE models affect the flux magnitudes of ET rather than the ratio WUE = GPP / ET. In the latter approach, small GPP and even smaller ET values can lead to very high WUE values and can in a least-squares regression bias the analysis towards time periods that should not receive as much weight. We have thus added an appropriate paragraph to the introduction.

SPECIFIC REMARKS

- "P3 L12: How did you define a precipitation event (> 0mm?)?"

We used a cut-off value of 0.2 mm/d to define precipitation events. We have added this criterion to the methods section.

- P3 L15: How did you handle observed vs. gap-filled data? If some of the dry-down periods were heavily gap-filled or missing, were these still analysed? If so, I would question what can be learnt from these sites as it seems unlikely the gap-filled data can accurately reflect fluxes during extreme conditions. Also how were the sites selected? On line L22 you mention 31 sites were used, but there are many more in the La Thuile release alone (of course not all with dry-downs). I'm surprised if there are only 47 dry-down events in the 200+ site records, but this is of course possible.

Thank you for highlighting this important point. In the selection and preprocessing of the data, we applied strict filtering that only uses high-quality data that is either observed directly or gap-filled with high confidence. If this filtering resulted in gaps during dry-down events, they were only filled by interpolated values from an exponential fit to allow the calculation of a continuous time series of Srem. In all model fitting and evaluation, days with low quality observations in one variable were omitted completely from the analyses. Nevertheless, the fact that dry-down events, when not occurring seasonally, represent extreme conditions where data quality becomes particularly important is now stated explicitly in the revised manuscript.

- "P4 L10: How many missing values did you allow for?"

We did not set a specific threshold value for missing values during dry-down events. Instead, we check whether an exponential model could explain at least 40% of the variability of ET during these events. Please also see our comment regarding the antecedent conditions above for how we ascertained that the uncertainties in parameter estimations originating from longer gaps did not affect our results qualitatively.

Additional References

Boese, S., Jung, M., Carvalhais, N., & Reichstein, M. (2017). The importance of radiation for semiempirical water-use efficiency models. Biogeosciences (Online), 14(12).

Ladjal, M., Huc, R., & Ducrey, M. (2005). Drought effects on hydraulic conductivity and xylem vulnerability to embolism in diverse species and provenances of Mediterranean cedars. Tree physiology, 25(9), 1109-1117.

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Discussion paper

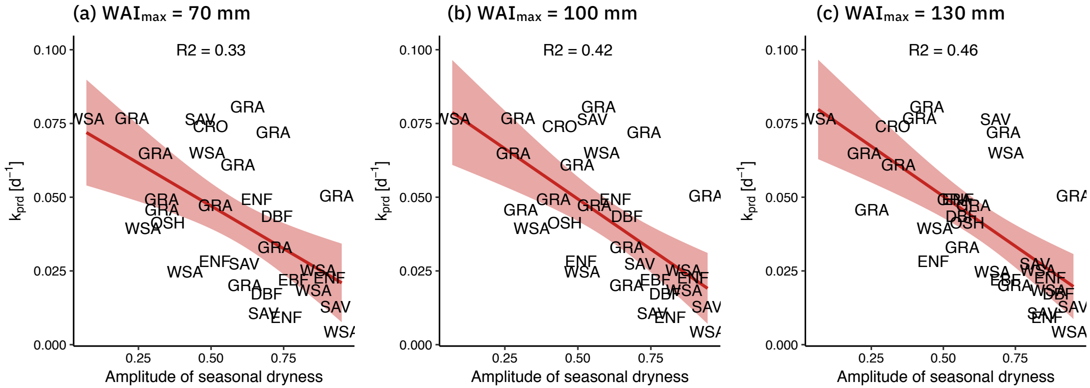

Fig.: Response of the relationship of k to the amplitude of seasonal dryness for three different values of WAI$_{max}$.

Fig. 1.

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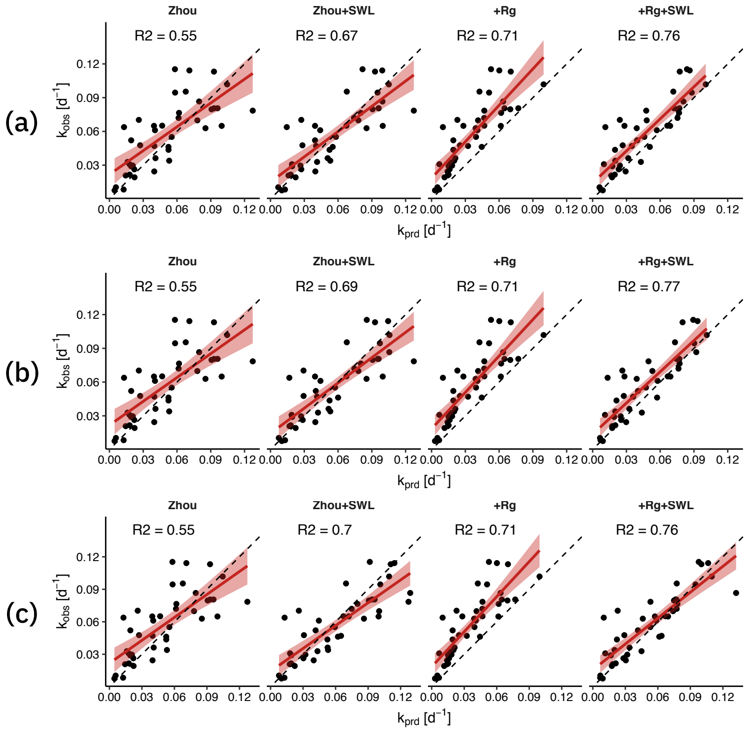

Fig.: Sensitivity of the comparison of predicted vs. observed k for three different calculations of S_{rem}. (a) Using the upper bound of the 95% confidence interval of the calculation of the initial S_{rem}, (b) the most likely value of the initial S_{rem}, as used in the manuscript, (c) using the lower bound of the 95% confidence interval.

Fig. 2.

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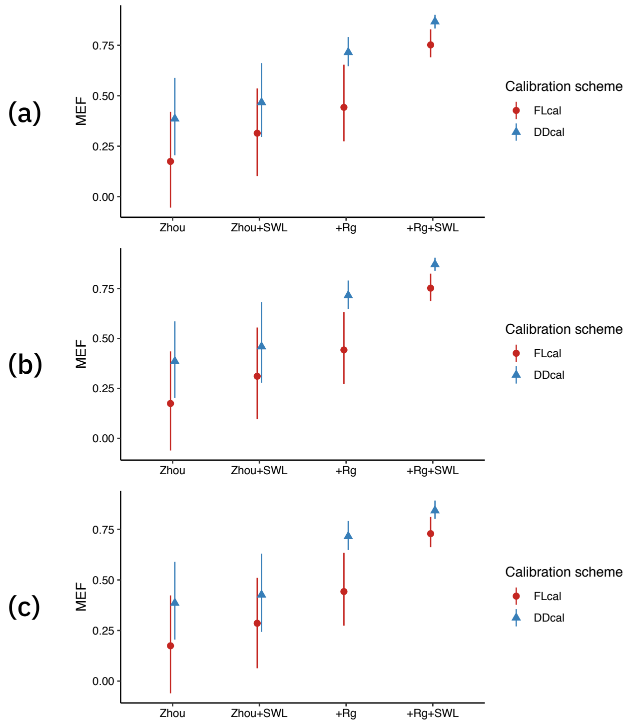

Fig.: Sensitivity of the comparison of model performances for three different calculations of S_{rem}. (a) Using the upper bound of the 95% confidence interval of the calculation of the initial S_{rem}, (b) the most likely value of the initial S_{rem}, as used in the manuscript, (c) using the lower bound of the 95% confidence interval.

Fig. 3.