Biogeosciences Discuss.,
doi:10.5194/bg-2016-198-AC3, 2017

Biogeosciences Discussions

Interactive comment on "Response of water use efficiency to summer drought in boreal Scots pine forests in Finland" *by* Yao Gao et al.

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Received and published: 18 April 2017

Currently, global carbon and water cycles as well as the associated carbon-water coupling relationships are receiving more and more attentions in this research field. Particularly under the changing climate, how extreme climate events affect the carbon sequestration of terrestrial forests directly related to the future climate projections. This study aimed to reveal the responses of ecosystem water-use efficiency to summer drought in northern Europe, which will also enrich this hot topic. The work is well organized with clear structure. However, plenty of questions still need to be solved.

Major comments:

1. In the part of "Introduction", the authors used a lot of sentences associated with ecosystem water-use efficiency, such as WUE, EWUE, and IWUE. Moreover, they want

to express the potential effects of drought on different WUE expressions. I strongly suggest the authors to explain the differences of various WUE definitions, and the reasons adopted in the present study. Then, the authors used many phrases to describe soil water status. However, it is crucial that how do they define the droughts, especially severe or moderate.

AR: The definitions and background of those WUE metrics have been given in the revised introduction. In the revised manuscript, we use the soil moisture index (SMI) to describe the soil moisture status rather than the different droughts at the study site. Thus, in the revised manuscript, the soil moisture conditions were classified into five SMI groups with an interval of 0.2: very dry: $0 \leq$ SMI < 0.2, moderate dry: $0.2 \leq$ SMI < 0.4, mid-range: $0.4 \leq$ SMI < 0.6, moderate wet: $0.6 \leq$ SMI < 0.8, very wet: $0.8 \leq$ SMI <1.

2. In the part of "2.5 Soil Moisture Index (SMI)", the authors used SMI derived from simulated soil moisture and soil parameters in JSBACH to define soil moisture conditions. It may lead to the uncertainty owing to the model performance and the results in this study. Then, why not validate the accuracy of the modeled data. The SMI results are also classified as severe drought, moderate drought, mid-range, moderate wet and very wet. However, only 11-year dataset for Hyytiala and 8-year dataset for Sodankyla, which may be not enough for drought analyses.

AR: In section 3.1 of the revised manuscript, the simulated SMI that is calculated with simulated soil moisture and soil parameters in JSBACH has been compared with the observed SMI based on observed soil moisture and measured soil parameters. The simulated SMI agreed well with in situ observed SMI over the 11-year study period, with a correlation coefficient (0.625) and a root-mean-square error (RMSE) of 0.225. Moreover, a very good time correlation (0.965) between simulated and observed SMIs were found for year 2006, despite the simulated SMI is systematically lower than the observed SMI (RMSE = 0.12). As we have answered to the above major comment from reviewer #3, the five SMI groups were renamed to represent different soil mois-

ture conditions rather than drought conditions. Unfortunately, we have used the entire data period of the measured soil moisture at the sites. However, Muukkonen et al. (2015) showed that the summer drought in 2006 has caused severe forest damages in southern Finland. Using SMI calculated from regional soil moisture simulations over the past 30 years (1981-2010), such extreme drought affecting forest health has been illustrated to be rare in Finland, and the summer drought in 2006 was the most severe one in the 30-year study period (Gao et al., 2016). In the revised manuscript, we had more detailed analysis of the severe summer drought in 2006 at Hyytiälä, and the Sodankylä site was not included in the paper anymore due to no such severe soil moisture drought in the study period.

3. In the part of "Results and Conclusion", the authors concluded that based on observed data, the ecosystem level water use efficiency (EWUE) showed a decrease only during a severe soil moisture drought at Hyytiälä, whereas the inherent water use efficiency (IWUE) increased when there was a severe soil moisture drought at Hyytiälä and a moderate soil moisture drought at Sodankylä. However, on one hand, this study is based on "no severe soil moisture deficit at Sodankylä during the study period", on the other hand, it seems to be a lack of persuasion. Maybe more data need to be supplemented to enrich the objectives of this study.

AR: Yes, we agree with the reviewer that sentence was a bit misleading because there was no such severe drought at Sodankylä during the study period. Please also see the answer to the previous comment.

4. In the part of "Discussion", I suggest the authors to supplement the uncertainties of SMI, which is used as drought indicator of soil water. In addition, a lot of biotic and abiotic factors controls the differences of GPP, ET, WUE of the two forest sites. So, how do they directly compare the effects of drought on Scots pine forest under different local environmental conditions. Apart from this, I think in northern Europe such as Finland, temperature anomaly may be more sensitive than drought.

AR: As answered to the comment 1, we realized that it is inappropriate to use fixed SMI groups to describe different drought conditions. However, SMI that ranges from 0 to 1 describes the status of soil moisture available to plants. How to divide the groups of SMI is a matter of choice. In the revised manuscript, we grouped SMI with an interval of 0.2 to reflect different soil moisture status: very dry: $0 \leq$ SMI < 0.2, moderate dry: $0.2 \leq$ SMI < 0.4, mid-range: $0.4 \leq$ SMI < 0.6, moderate wet: $0.6 \leq$ SMI < 0.8, very wet: $0.8 \leq$ SMI <1.

We also agree with the reviewer's opinion that it is a bit uncertain to draw the conclusion about the comparison between the southern site and northern site (scots pine has weaker response to drought in the southern site than in the northern site) by analysing current available data, especially there is no severe soil moisture drought in the studied period in the northern site. Therefore, in the revised manuscript, we focused on the drought event and its impact on plant functioning in the southern site.

Minor comments:

1. P1 L13 & L23 "at daily time scales" should be changed to "at the daily time scale".

AR: We did the change as reviewer suggested.

2. L15-L18 This long sentence is too tedious. Please reconstruct it.

AR: The sentence has been reformulated according to the revised results.

3. P2 L37 Terrestrial plants assimilate carbon dioxide (CO2)...

AR: We did the change according to this comment in revised manuscript.

4. L59 EWUE is broadly adopted as a surrogate for WUE due to data availability. Why? This expression is abrupt without explanation.

AR: The sentence has been reformulated as: "EWUE is broadly adopted as a surrogate for the leaf level WUE because more data are available at the ecosystem level than at the leaf level.".

5. L65 It is inappropriate to cite the paper of Reichstein et al. 2002. Ecosystem water-use efficiency of gross carbon uptake decreased during the drought, regardless whether evapotranspiration from eddy covariance or transpiration from sapflow had been used for the calculation.

AR: Indeed, the reference was misused. we deleted this reference in the revised manuscript.

6. P3L90 Lack of the information on forest ages between the two flux sites.

AR: We have given the forest age information in the revised manuscript.

7. P4L112 "For our analysis, daily values of GPP and ET fluxes were calculated as daily sums of half-hourly values and only good quality gap-filled data were used." It is confusing. How do they guarantee the comparability of different days?

AR: The original sentence was confusing and not total correct. It has been deleted in the revised manuscript. Actually, the bad quality data was also gap-filled, and the gap-filled data were used. The gap filling method for GPP and ET was introduced in the manuscript. Thus there is no problem with the comparability of different days.

8. P4L131 Grammar mistakes. "The models of Farquhar et al. (1980) is used for photosynthesis of C3 plants."

AR: We have corrected the sentence to be " The models of Farquhar et al. (1980) and Collatz et al. (1992) is used for photosynthesis of C3 and C4 plants, respectively."

9. P6L188 "However, process-based ecosystem models can be used to reveal plant physiological processes by separating evaporation and transpiration." Please cite the associated references.

AR: This sentence should be reworded as: "However, process-based ecosystem models do resolve evaporation and transpiration, which together composing evapotranspiration". We do not think a reference is needed after reformulation.

10. P9L311 "The consequence of decreased ET due to soil moisture drought would be increased atmospheric VPD, which in turn accelerates stomatal closure..." Please reconstruct it.

AR: We have reworded the sentence as "The decrease of ET due to soil moisture drought could lead to increased atmospheric VPD, which in turn intensifies stomatal closure ..."

11. Please specify the time scale of data used in the figures. In addition, the data points are too dense. It is hard to extract useful information from the merged figures.

AR: The time scale of data (the averaging period and the study period) has been added in the figures. As the data has been reprocessed in the revised manuscript to exclude rainy days and certain amount of dry days after the rainy days, the amount of data shown on the figures has been reduced. The figures have been reselected and composed in the revised manuscript. We think it should be OK to extract useful information from figures in the revised manuscript.

12. In Figure 4, many values of WUE at the daily time scale exceed 10 g C kg-1 H2O, especially for simulated results of EWUE and IWUE. Do you think it is rational or just statistical?

AR: It was quite statistical due to the small ET values, which are mainly impacted by rainy days and days after rainy days with high atmospheric humidity, as well as night time condensation effect. In the revised manuscript, the data has been reprocessed to exclude precipitation and night time impacts on GPP and ET. Thus, there are only three days with EWUE values larger than 10 g C kg-1 H2O for the simulated results in the updated figure, and no EWUE values are larger than 10 g C kg-1 H2O for the observed results.

Interactive comment on Biogeosciences Discuss., doi:10.5194/bg-2016-198, 2016.