Dear Maik Renner,

Thank you for the review of our manuscript and the interest in our study. Your comments made us realise that some elements are not yet explained well and that our argumentation misses some intermediate steps. Therefore they are very valuable for improving our manuscript. Below we have replied in more detail to all your comments.

The results show that S increases towards the south, increases with biomass, but decreases with area of peatlands due to high water tables. Since root biomass is used as a metric for verification, more details are required on how this was derived.

We will add a description for the calculation of root biomass. Data is based on multi-source national forest inventory data provided by Finnish Natural Resources Institute (LUKE). Data is based on field data, satellite images, digital map data and other georeferenced data sets. More information can be found from Mäkisara et al. 2016. http://jukuri.luke.fi/handle/10024/532147

The statistical analysis is presented in a way to suggest that root zone storage is independent of the climate variables (P, Ep, T, SWE), while indeed it is derived from these data. Actually the analysis of climate controls is performed like an uncontrolled sensitivity analysis of a bucket model with different inputs. The outcomes of this sensitivity analysis (Fig 6, Sect. 3.2, 4.2) are difficult to interpret since the influence of the other input parameters changes from one catchment to the next. I also wonder why there is no precipitation frequency / drought index be used to correlate with S?

We agree with you that the root zone storage capacities are dependent on climate variables. Actually, for the calculation of S_r four climate parameters are used, namely: daily precipitation, daily snow water equivalent, long term averaged discharge and long term monthly averaged potential evaporation. Although climate parameters were used in Figure 6, these are not variables that are directly used in the calculations (mean annual temperature, maximum snow water equivalent, snow off date and the ratio of precipitation and potential evaporation).

As the estimation of S_r is not one calculation, but derived from the simulated soil moisture deficit (we will explain this clearer in the description of the method) the influence of different climate variables is not always straight forward. Therefore, we used these plots to see if there is any correspondence between S_r and climate variables that were not directly used in the estimation of S_r. We realise however, that we made this aim not fully clear in the discussion of the results and we will change the text accordingly in the revised version of the manuscript.

With regard to the precipitation frequency/drought index: we included P/E_p in the analysis, which is a definition of the aridity index. Further, we compared S_r with runoff coefficients during the analysis, which showed a strong relation. This is logical, as it is one of the main inputs in the estimation of S_r and probably even has a stronger effect on the calculation than S_{SWE}; therefore we considered the other plots more interesting to incorporate.

With respect to precipitation frequency a comparison with inter-storm duration (I_{isd}) could be made; we did not do this during the first analysis. The relation between S_r and I_{isd}, based on total precipitation and an interception capacity of 1.5 mm, can be seen in the figure below. It can be seen that the variability in I_{isd} between the catchments is very limited. Therefore, we don't think that adding this plot in the revised manuscript is valuable for the analysis.

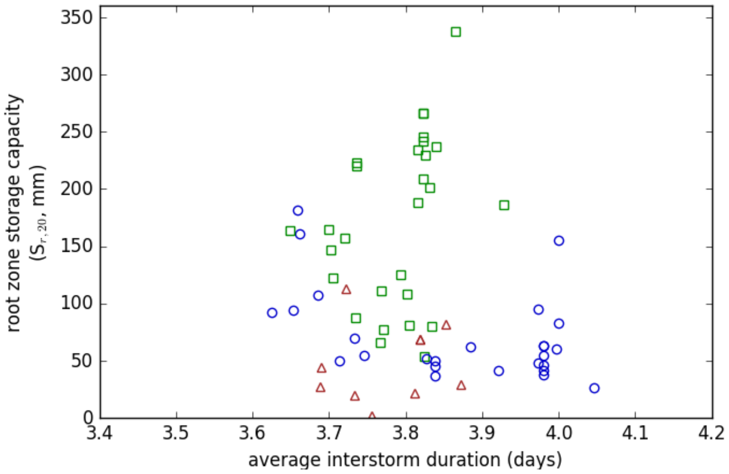

Figure 1| Average interstorm duration in relation to derived root zone storage capacities, different symbols indicate different boreal regions (green squares = south boreal; blue circles = mid boreal; red triangles = north boreal)

An interesting point is the influence of drainage of peatlands on S. Although the authors claim to identify an effect, I could not identify the mentioned influence of drainage in Fig 7. Unfortunately, the analysis lacks a reference to compare drainage with pristine peatlands. Here a stratification of the data could be useful means to assess this point.

From Figure 7 it can be seen that more catchments exist with larger S_r values and larger percentages covered with drained peatland than with larger S_r values and larger percentages covered with pristine peatlands. In Figure 8 a negative correlation between S_r and both drained as pristine peatlands can be observed, although this correlation is stronger for pristine peatlands. However, two reasons for this difference can be given. First, the drainage of peatlands for forestry probably creates larger transpiration demands and thus larger root zone storage capacities. Or, second, as most of these drained catchments are located in the south boreal region, it can also be that S_r values were already higher in these catchments before the peatlands were being drained. Unfortunately the available data series are not long enough to compare S_r values before and after drainage of some of the drained catchments. In the revised version of the manuscript we will change the text accordingly to make this clearer.

I do not understand how the method can be applied in climate or land-use change analysis. To my understanding an estimate of transpiration is required to estimate S and both are unknown for a given change scenario. Please explain.

For climate and land-use change analysis often data are available for a long period containing a change, this change is probably reflected in the corresponding S_r values as well. In case change scenarios are used, these scenarios can include a change in precipitation and/or discharge and (additionally) a (relative) change in transpiration. With respect to the land-use change analysis, this can include a hypothesised change in transpiration as well. In addition to this, it is likely that different vegetation types adjust to different return periods (Wang-Erlandsson et al, 2016), so a change in land-use can in that way have an effect on the estimated S_r values.

In our opinion it may be worthwhile to include the estimation of (changed) S_r values in these types of analyses, as they could give more information about how the hydrology of a catchment changes under the studied climate or land-use scenarios.

We will elaborate this in more detail in the revised manuscript.

Detailed comments:

P1L17: Check the causal order of the mentioned processes "Retreating..."

We will modify the sentence accordingly.

P2L2: add references

We will add support references, for example

Laudon et al. 2011. Consequences of More Intensive Forestry for the Sustainable Management of Forest Soils and Waters. Forests 2, 243-260.

Nieminen et al. 2017. Impacts of forest harvesting on nutrient, sediment and dissolved organic carbon exports from drained peatlands: A literature review, synthesis and suggestions for the future. Forest ecology and management 392, 13-20.

P2L7: "but so far none have studied changes in transpiration (patterns) at the catchment scale in boreal regions." Please check (Jaramillo et al., 2018; van der Velde et al., 2013).

We will change the sentence and consult/incorporate the mentioned references.

P2L17: "Thus, climate (or the balance between precipitation and transpiration) has a large influence on the developed S r ." Doesn't transpiration depend on the root zone storage (and not the other way around)?

Yes, we agree with you that transpiration is sustained by the root zone storage capacity and in that sense influenced by it. This is reflected in the used method by assuming that the vegetation has developed a root zone storage capacity to sustain the transpiration demands. However, to calculate this required root zone storage capacity, the long term water balance is used to estimate the transpiration demands of the vegetation. This entire approach assumes equilibrium in the catchment and therefore can be seen as working in two directions: if either the root zone storage capacity or the transpiration demand changes, the other will (probably) change as well. We will make this clearer in the extended description of the method (see also our reply to the comments of the first reviewer).

P4L3ff: To my knowledge there is a significant undercatch of precipitation, especially in winter. It is not clear if the undercatch was corrected for, but if not, then I disagree with the choice of the authors to correct SWE with P.

We used a spatially interpolated dataset with a resolution of 10 x 10 km^2 for the meteorological parameters (precipitation, air temperature) constructed by Finnish meteorological institute (FMI). In this data set the measurement error caused by gauges has been checked and corrected in operative quality control. For snow data (S_{SWE}), we used snow line data provided by Finnish Environment Institute and measured by standard methods. Since S_{SWE} was closest available and not always situated within the study catchment, we corrected S_{SWE} with local precipitation.

Sect 2.3 climate derived root zone storage capacity. Since the results show how climate variables correlate with S, I recommend to repeat the key equations to show how climate input is used in the method. Then also the choice of a return period of 20yr may become more clear.

We will include more details about the used method in the revised manuscript (see also our reply to the first reviewer). The choice of a 20 year return period follows from the analysis of Gao et al. (2014), who found that on average it is most likely that vegetation adapts it root system to a drought with a return period of 20 years.

P5L12: wording "transpiration demands" is unclear to me

Transpiration demand is used for the long term deficit between precipitation and discharge. The vegetation in the catchment should be transpired this about of water to close the long term water balance with the given precipitation and discharge. We will make this clearer in the extended description of the method to estimate S_r.

Results / Discussion: report correlation and significance in text. For example in Sect. 3.1

Where relations between variables are discussed in the text, we will add correlation coefficients and significance as well.

P8L21: check argument: "The presented results show that climate derived root zone capacities are related to vegetation characteristics, climate variables and vegetation cover, which strongly indicates that the S r - method can be used for boreal regions containing seasonal snow cover." Since S is computed from climate data, the relationship is not a verification of the method!

We agree with you that this statement is not well formulated; the relationship between climate data and variation of S_r values is indeed not a verification of the method. However, as discussed earlier, we think it valuable to incorporate the comparison with some climate variables. In the revised manuscript we will change the argument into: "The presented results show that climate derived root zone capacities are, besides climate variables, also related to vegetation characteristics and vegetation cover."

P9L2: unclear from results "This seems to indicate that in case of low transpiration demands the plant's resources between below and above soil elements are more equally divided than for areas with higher transpiration demands."

In Figure 3a stronger relation between leaf cover/tree length (above ground biomass) and derived S_r values (below ground biomass) can be visually observed for smaller S_r values (< 115 mm). For larger S_r values, the leaf cover/tree length is more constant. This indicates that the vegetation uses more resources for below ground biomass in cases of larger S_r values. As the derived S_r values are strongly determined by the transpiration demands, the catchments with large S_r values also have high transpiration demand.

We will change the text in the revised manuscript accordingly.

P9L6f: unclear argument "However, for pine in mid- and south-boreal regions a negative correlation was observed, which means that the vegetation is able to create a larger storage capacity with fewer or thinner *roots." Please calculate the significance of the correlation and possibly use a bootstrap to check the influence of outliers. Please check/report how root biomass was calculated. Also check for other influencing variables.*

We will report in more details the calculation method for root biomass. We will look into correlations and incorporate the outcome in the revised manuscript.

P9L12: please provide references for shifting management activities

We will add some references in the revised manuscript for example: Hasper et al. 2016. Water use by Swedish boreal forests in a changing climate, Functional Ecology 30, 690-699.

There is no specific reference for shifting management activities. However, when forest resources are growing faster due to changing climate also forest management activities shift.

P10L5: please provide references

We will add some references in the revised manuscript to support statement for peatlands and high water tables. For example: Menberu M, Tahvanainen T, Marttila H, Irannezhad M, Ronkanen A-K, Pentttinen J, Kløve B. 2016. Water table-dependent hydrological changes following peatland forestry drainage and restoration: Analysis of restoration success. Water Resources Research, 52(5), 3742-3760.

P10L8: "Peatland drainage for forestry changed this pattern: higher S r values were observed in areas with larger cover of drained peatlands (Figure 7)." I could not see this effect!?

As discussed earlier, there can be two reasons for the difference between drained and pristine peatlands. We will change the text of the revised manuscript accordingly to make this clearer.

Sect. 4.4: Explain how the method is applied to a change scenario when data on transpiration is required a priori?

Data on transpiration is indeed used in the analysis; however, this data is derived from the long term water balance (precipitation, discharge and S_{SWE}). When the change scenarios are constructed, the transpiration can again be estimated from the water balance or be assumed to change in a certain way. By subsequently calculating S_r values, the effect on the hydrology of the changing conditions can be further explored. We agree that this is not yet a complete analysis, but we definitely see a potential for further research.

We will change the text to make this clearer.

Figure 1: Missing y-axis labels; Add points to the boxplots. Panels of Fig1 are insightful, but hardly touched in text. Add relevant topographic info to the map.

We will change the figure accordingly; however, adding topographical info will make the figure less clear to read, so we prefer not to include it.

Fig 2: use white text in dark boxes

We will change this in the revised version of the manuscript

Fig 6c, Fig 8: Julian date for snow off in Fig.6 and Julian Date for max SWE in Fig 8. Please be consistent.

We will change all these to 'day of the year', as suggested by the first reviewer.

Fig 7c,d: Peatland area per catchment? Why does the number of points change?

Figure 7c illustrates the percentage of the catchment covered with drained peatlands and Figure 7d shows the same for pristine peatlands. The Number of points change since some catchments does not have pristine peatland areas and vice versa.

Fig 8: show correlation as text in one of the diagonals

We preferred to only mention the correlation values in the text to prevent the figure from overflowing with information. For the revised manuscript we will see if there is a way to include the values in the figure as well.

Fig. 9: What is the ordering in y-axis? Coloring: black lines are hardly seen on dark blue background. Why is PET always the same?

The ordering on the y-axis is by increasing estimated S_r value and the figure does not show the amount of potential evaporation, but the period in which E_p is occurring/measured. We will clarify this in the figure caption and change the colour of the lines to white.

References:

Jaramillo, F., Cory, N., Arheimer, B., Laudon, H., van der Velde, Y., Hasper, T.B., Teutschbein, C., Uddling, J., 2018. Dominant effect of increasing forest biomass on evapotranspiration: interpretations of movement in Budyko space. Hydrol Earth SystSci 22, 567–580. https://doi.org/10.5194/hess-22-567-2018

van der Velde, Y., Vercauteren, N., Jaramillo, F., Dekker, S.C., Destouni, G., Lyon, S.W., 2013. Exploring hydroclimatic change disparity via the Budyko framework. Hydrol. Process. https://doi.org/10.1002/hyp.9949

Gao, H., M. Hrachowitz, S. J. Schymanski, F. Fenicia, N. Sriwongsitanon, and H. H. G. Savenije (2014), Climate controls how ecosystems size the root zone storage capacity at catchment scale: Root zone storage capacity in catchments, Geophys. Res. Lett., 41, 7916–7923, doi:10.1002/2014GL061668.

Wang-Erlandsson, L., Bastiaanssen, W. G. M., Gao, H., Jägermeyr, J., Senay, G. B., van Dijk, A. I. J. M., Guerschman, J. P., Keys, P. W., Gordon, L. J., and Savenije, H. H. G.: Global root zone storage capacity from satellite-based evaporation, Hydrol. Earth Syst. Sci., 20, 1459-1481, https://doi.org/10.5194/hess-20-1459-2016, 2016