Hydrology and
Earth System
Sciences
Discussions

Interactive comment on "Controls on root zone storage capacity in boreal regions" by Tanja de Boer-Euser et al.

Tanja de Boer-Euser et al.

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Note that this is almost the same reply as the one posted by Hannu Marttila on 28 May, with some small changes following the review of anonymous referee #2.

Dear referee,
Thank you for reviewing our manuscript and your positive evaluation of the general findings. The more detailed comments you have given made us realise that especially some elements of the used method need more attention in a revised version of the manuscript. Below we have replied in more detail to all your comments.

A weakness in the analysis is that S_r is derived at the basin scale, and then assessed

against vegetation type and attributes, but different vegetation types prefer different soil texture and moisture conditions. A diverse catchment likely has a diverse soil and an S_r value that may not apply very well to any of the vegetation types in the particular catchment. Conversely, I would expect stronger correlations and more valid S_r values in catchments containing a dominant vegetation type. From looking at Figure 3, I suspect that peatlands never make up enough of the catchments for the S_r value obtained to be applicable to them, and this would also be the case for many of the agricultural areas. Forest is usually the dominant vegetation type and this is shown by its close agreement with the broad boreal zone plot.

We agree with the reviewer that stronger correlation between S_r and vegetation characteristics could have been found if the catchments contain only one dominant vegetation type. We used existing small catchment data which allowed us to compare catchment attributes to S_r values, but boreal catchments are rather heterogenic and thus suitable data from catchments with single vegetation type does not exist. However, the calculation method assumes equilibrium in the catchments: all vegetation in the catchment managed to survive there together. This means that the catchment representative root zone storage capacity is appropriate to sustain the transpiration demands of the vegetation. Although S_r is a catchment average conceptual parameter we expected that is related to different vegetation characteristics, which we have shown in the results.

Regarding the land cover types in Figure 3, we agree with the reviewer that the derived S_r values cannot fully be attributed to one of the land cover types; however, by presenting the results in this way, we think that possible influences of certain land cover types on the derived S_r values can be explored.

We will discuss the effect of the heterogeneity of the catchments in the revised version of the manuscript.

There appear to be inconsistencies in the data that are presented in subsequent plots. These need to be corrected or explained. In Figure 3a there are two points with rela-

tively low leaf cover and S_r values of about 230 and 110 mm. These points show up in the boreal regions plot (3d) as northern points, so they are northern forests. Based on Figures 3e and 3h, the 230 mm S_r value is also associated with a large tree length of about 210 m while the 110 mm S_r value is associated with a medium tree length of about 100 m. I'm wondering if there is something about these two basins that makes them different. Why is the leaf cover low and yet one of them has the largest observed tree length? Was there a defoliation event? When I look in Figure 4, I see no northern forests with an S_r value anywhere near 230 mm. At first I thought that perhaps it wasn't pine, spruce or deciduous, but it doesn't even appear in figure 4d. What happened to this forest that stands out in Figure 3? Figure 3 shows two northern catchments with S_r values not far from 110 mm, one is mostly forest with some peatland and the other has a bit less forest but still more forest than peatland. Figure 4 only shows one northern catchment with S_r values close to 110 mm. What happened to the other catchment? Figure 3 shows two northern catchments with S_r of 70-80 mm and one at about 50 mm, and these appear to be forests or mostly forests, but in Figure 4 the S_r values do not fit the same distribution of two in the 70-80 mm range and one at 50 mm but instead it appears that two are at about 70 mm and one at about 85 mm. These plots appear to be derived from somewhat different datasets with respect to S_r values. The data used in the figures needs to be made internally consistent, or explanations provided for data appearing in some figures and not in others

Thank you very much for pointing this out. In Figure 3 the data for leaf cover was slightly shifted, creating an inconsistency in the presented data. We have corrected this error, resulting in Figure 1 below. We will update this figure and the corresponding text in the revised manuscript. Further, the x-axis caption is changed from tree length (m) to tree height (dm) for more clarity.

From my experience, some pine species like to grow in sandy well-drained soil, and here contribution to discharge is likely high and transpiration low. In such a catchment the estimated T should be low and there will not likely be large deficits, even though

the soil can get quite dry. Spruce trees like to grow in moist soil, often in poorly drained areas. Such areas don't often dry out and contributions to discharge also likely follow precipitation quite well, except following a drought when there is recharge; again such areas may not see very large deficits. So we have pine in dry areas with small deficits and spruce in wet areas with usually small deficits.

We agree with the reviewer. Pine trees favour dry sandy soils whereas spruce favour more moisture locations. However, in our data set there were also many pine trees in drained peatlands and thus we cannot fully follow this simplification in our analysis. The small expected deficits for both pine and spruce trees, is also reflected in the derived S_r values: many catchments have S_r values below 100mm and spruce and pine are the dominant tree species. With the used method S_r values larger than 500 mm are found worldwide (Gao et al., 2014; Wang-Erlandsson et al., 2016).

Deciduous trees tend to have larger transpiration demands and can grow in poorly or well drained soils. If deciduous trees exist more often in areas with larger deficits and adjust their root mass accordingly, this may explain why the best correlation is for deciduous trees in Figure 4.

Thank you for pointing this out, we will include it in the discussion of the results.

However, much of this detail would be smeared out because each basin contains multiple tree and other vegetation types and probably a combination of wet and dry areas. With this in mind, I understand why the correlations and patterns are not as strong as one might hope for.

As mentioned before, the study catchments were indeed rather heterogenic as typical boreal landscape is. However, some correlations were found between S_r and detailed catchment data. We will include in the discussion something about the influence of the heterogeneity of the catchments on the found correlations.

Some of the relationships appear to be curvilinear rather than linear, so it might be more informative to try fitting some nonlinear relationships (exp, log, polynomial) to see which correlations increase and whether the relative importance of parameters changes. Perhaps a flexible generic nonlinear model could be used.

Thank you for the good suggestion; however we do not see need for the non-linear methods since results can be shown in linear methods. Using one methods allow us to compare directly between the parameters.

More specific comments:
P4 line 4-7: Are the authors aware of the type of precipitation gauges used to measure snowfall, whether they were shielded and whether they were corrected for undercatch based on coincident wind speed measurements? Precipitation gauges always measure less than the true snowfall amount, but if properly located, shielded and adjusted using established correction factors based on wind speed, one can arrive at an accuracy that is comparable with a snow survey.

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.

P4 line 22-23: I am somewhat perplexed that canopy interception is included for rain but not for snow, when it is well known that boreal forests can store close to an order of magnitude more mass of snow versus water on the canopy, and interception losses on the order of 30% or more are common over a winter.

We used snow line data to provide snow water equivalent values for the S_r calcula-

tions. This data represent rather well the snow water contributing to the runoff, soil moisture and recharge, and is therefore suitable for our analysis. In addition to that, the interception included in the calculations to estimate S_r is, besides the availability of water, driven by the potential evaporation. As the latter is not measured, as it is close to zero, during winter time (so during occurrence of snow), including interception for snow would not really influence the estimated S_r values.

P5 Section 2.4: I think an explanation of the specific method used to obtain S_r is required. I looked at de Boer-Euser et al. (2016) and based on that, I think I understand what was done, but a brief overview would be helpful.

We will provide some more details about the method in the revised manuscript, especially focussing on the principle, input data and assumptions of the method.

In Figure 3 are the values of leaf cover and tree length basin values or are they specific to each vegetation type? I see for example the two northern basins with S_r near 70-80 mm and leaf cover near 24-28% in Figure 3d, and these appear to have corresponding large forest fractions, small peatland and smaller agricultural fractions with the same leaf cover values. This suggests that these values are basin-scale and are not specific to each vegetation type. Since most of the basins are forest-dominated, when we look at the peatlands or agricultural plots, in most cases when the fractions of these vegetation types are small, we are not looking at leaf cover or tree length values that have anything to do with the peatland vegetation or crops other than they happen to be in the same basin. This should be made more clear.

Values in Figure 3 are basin scale and thus not specific for the vegetation types. Figure 3 illustrates the general patterns of S_r value in boreal catchments and variation with main landscape types. It cannot be used to detect vegetation type changes. We will clarify this in the revised manuscript.

P6 line 19: The statement "...and this correlation decreases for higher percentages of peatland..." is a bit misleading. There hasn't really been an analysis of correlation for basins with high and low peatland cover. When I look at Figure 3f, it does appear that there may be some correlation between S_r and tree length in pristine peatlands for the basins with small fractions of pristine peatlands (because the correlation is coming from the larger forest fractions) and the pattern looks more scattered (implying a lower correlation) for the larger circles or basins with a larger peatland fraction. It should be made clear that these are just visual interpretations, not a comparison of calculated correlation coefficients.

This statement is also based on Figure 7 and 8. We will make this clearer in the revised manuscript, together with indicating whether observations in the results are based on calculated correlation coefficients or based on visual inspections.

P6 line 20: The variability in leaf cover and tree length is small within the boreal regions but appears greater when the three regions are examined together. It appears that factors affecting tree length and leaf cover act largely but not exclusively along the latitudinal gradient such that the correlation is weak within each region. I think the strong relationship between Day of Year (date of snow-off) and S_r has more to do with the fact that the snow-off date is correlated with both maximum SWE and air temperature than a special relationship with the phase of snowmelt. For example, the timing of maximum SWE is probably determined almost exclusively by temperature, whereas the amount of maximum SWE is a combination of snowfall amount and temperature (and other factors).

We agree with you: latitudinal and climate gradient in data set affects strongly to the results, which we shortly discussed in section 4. We will make this point clearer in the revised version of the manuscript. For this point please also refer to our reply to the comment about the principal component analysis of anonymous referee #2.

Regarding the influence of snow-off date on S_r, we agree there is a strong link between

max S_{SWE}, mean air temperature and snow-off date. However, from our analysis it turned out that especially the timing of the snow melt is important. Although this is strongly determined by temperature, it is not directly reflected in the mean annual air temperature. Various studies using the climate derived S_r showed that mainly two variables are important for S_r: the absolute difference between water supply (liquid precipitation or snow melt) and water demand (transpiration) and the phase difference between these two (ie. difference in timing of the majority of the supply and demand). In areas with moisture constrained evaporation the absolute difference is likely to be dominant, while in energy constraint (like boreal areas) the phase difference is likely to be dominant. So, the study areas have similar absolute differences between supply and demand on a yearly basis, while the phase difference strongly differs depending on the snow-off date and onset of potential evaporation. We will make this argumentation clearer in the revised version of the manuscript.

P7 line 22: While it is true that the clearing of land for agriculture increases soil exposure (more evaporation) and crops tend to have high transpiration demands (more transpiration), there is also the likelihood that croplands are more prevalent in the south because of the longer growing season and increased likelihood of a successful crop. So did the crops in the south cause larger S_r values because of their higher water demands or were they planted in a warmer area because it is beneficial for the crops and that just happens to coincide with larger S_r values (warmer, more evaporative demand)? I would say it works in both directions.

Thank you for pointing this out; we agree that this works in both directions. To investigate whether one of the two mechanisms is dominant, a more detailed comparison should be made between catchments in the southern region with more and less agricultural cover or between different periods of the same catchment (before and after clearing). We will elaborate this further in the discussion section of the revised manuscript.

P8 lines 1-3: Peatlands generally develop in areas where the soil does not dry out very often, either because of cold temperatures and low evaporative demand, or a combination of positive P-E and poor drainage. Since the soil does not tend to dry out, the S_r value calculated will be small because large deficits of P-T are rare.

We agree with you that S_r values will be small due to small deficits of $P - T$. We have discussed some other reasons for low S_r values in peatland areas in section 4.3 as well.

P8 line 11-12: Maximum SWE and mean annual temperature and the snow off date are likely highly correlated within a small region. A regression model that attempted to include all three would almost certainly show that all three are not necessary. I would be inclined to predict that mean annual temperature and maximum SWE are the most important, but maximum SWE is partially dependent on mean annual temperature based on the length of the snow period and when melt starts. Perhaps mean annual temperature and winter precipitation would do better.

In Finland and in our data set there is latitudinal and longitudinal variation in maximum S_{SWE}, mean annual temperature and snow off date since different areas are affected either Atlantic (Western areas), Continental (Eastern areas) or Arctic (Nordic areas) weather patterns. Thus all of these parameters are relevant to include to the analysis, although correlation between them exists (see also our reply to the comment of anonymous referee #2 about a principal component analysis of the tested variables). And as discussed before, the timing of the water supply is very important for S_r, thus so is the snow-off date.

P9 line 6: I have read that jack pine have a tap root to access deeper water. If this is true of the pines in the Finland catchments, it may be that deeper water is accessed without a large increase in root density and this may lessen correlations between S_r and root biomass. The authors would want to find an appropriate citation before using

this point as an explanation.

Scots pines have shallow rooting depth and typically have no access to deeper water. Also in our data set many mid- and south boreal catchments contained drained peatlands which might influence on this negative correlation.

P9 lines 1-3: Yes, peatlands develop in places where the decomposition rates are slower than the annual increment, due to a combination of cold temperatures and/or poor drainage and anoxic conditions. Peatlands are created by the same conditions that cause the estimated S_r to be low, but I doubt that peatlands cause the small S_r values.

The climate method uses the assumption that equilibrium exists in the catchments between the existing vegetation and the develop root zone storage capacity. As the root zone storage capacity is a catchment representative value, it is 'caused' or created by the combination of all the vegetation (and thus land cover) in a catchment. So, we agree that the peatlands alone do not cause a low S_r value, but they probably contribute to it. We will clarify this in the revised version of the manuscript by extending the description of the method to derive S_r and by adding a part in the discussion about the effect of the heterogeneity of the catchments on the derived S_r values. Further we will focus more on relations between S_r and other variables and less on a causal relation between the two, as discussed in the replies to the review of anonymous referee #2 as well.

Minor comments and corrections:
S_r,20 is never defined in the text. It is stated in Section 2.3 that a drought return period of 20 years is used, but the symbol S_r,20 is not introduced here; it simply appears in figures but not in the text.

We will change "S_r" to "S_r,20" in the text.

P4 line 21 and elsewhere: Why is S_{SWE} used for Snow Water Equivalent instead of

SWE?

Although SWE is more common in literature, we used S_{SWE} (Storage as snow water equivalent) to prevent abbreviations with multiple capital characters, as is requested in the author guidelines of the journal.

P5 line 14: "Tree length" is never defined. It is certainly not tree height, but I don't see the term in the literature.

The variable presented in figure 3 is actually tree height, but in dm and not in m. We will change the term in to tree height and clarify the meaning, further we will correct the unit in the revised manuscript.

P7 line 24-25: In Fig. 7c I might view the southern boreal region as showing a negative correlation between Drained peatland % and S_r with two outliers.

Thank you for pointing this out, we will change the text accordingly.

P9 line 24: I would change ".... for example indicates that...." to "...for example may indicate that...."

We will change this in the revised manuscript.

Figure 1: Add a North Arrow. Perhaps outline Finland so as to make the study area boundaries more clear.

We will change this in the revised manuscript.

Figure 3: The letters need to be on the plots (e.g. a, b, c.... h).

We will change this in the revised manuscript.

C11

Figure 6: Change Julian date to Day of Year. Julian date or Julian day is not the same as Day of Year.

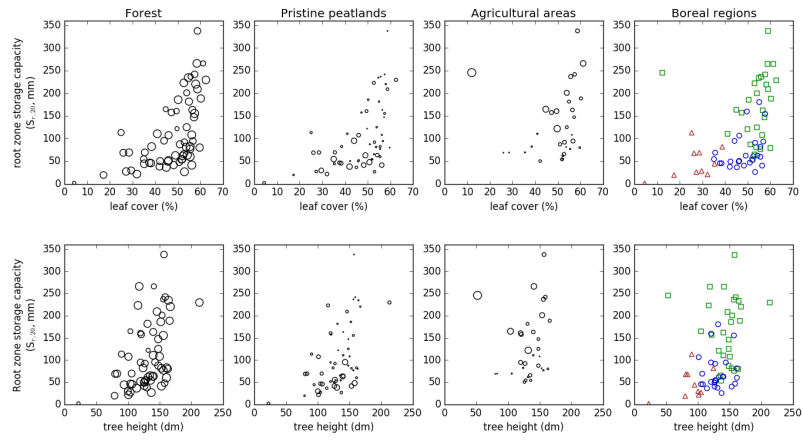We will change this in the revised manuscript.

Figure 8: What do the size of the boxes represent? There is no scale provided to interpret this.

The sizes of the boxes indicate the p values of the correlations; we will extend the figure caption on this point.

Fig. 1. Calculated root zone storage capacity versus average leaf cover (top) and tree height (bottom) - updated version of figure 3 in original manuscript

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