

Interactive comment on “Technical Note: Hyperspectral lidar time series of pine canopy physiological parameters” by T. Hakala et al.

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This is an interesting paper with significant novelty in testing a range of spectral indices derived from multispectral laser scanning. The study is very small in scale and includes only very limited sampling, but does provide an initial demonstration of the potential of this technology for plant physiological measurements. In this context it does represent a significant and original contribution to the literature. It is likely to be of significant interest to both the plant physiology and remote sensing scientific communities. However, it could be improved by English language editing, clarification of the methodology and a more thorough discussion of results as outlined below.

RESPONSE: Thank you for the comments.

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Specific comments: 1) The title of the paper refers to ‘physiological parameters’ but the study only really considers the single parameter of chlorophyll content. I think the title could be more specific and therefore more fitting to the study. The lidar system would also be better described as multispectral as it measures at only 8 discrete wavelengths.

RESPONSE: Changed the title from ‘physiological parameters’ to ‘chlorophyll content’. The definition of hyperspectral is generally vague. It is true that this particular prototype is more multispectral than hyperspectral since it uses selected bands. However, we have 16 spectrally continuous channels available and the reason we only use 8 is more financial and practical than technical. Therefore I would define the instrument as prototype of hyperspectral.

2) Page 15022, lines 5–8: A single panel of 99% reflectance is used to normalise the lidar intensities. This will account for range influences, but is a single reflectance panel sufficient? Is the detector response linear? Is the laser output intensity constant? Given the focus of the paper is on the intensity data the normalization method is of considerable relevance.

RESPONSE: The intensity of each transmitted pulse is not constant. This is taken into account by measuring the intensity of each transmitted pulse using the same detector as for the echo measurement. This is done by using a beam sampler and bypassing the other optics. This part of the signal also triggers the measurement. We also have a 4 color Spectralon that we have used to check the linearity, but these results are not published.

3) Page 15022, lines 18 – 24: Only a very small number of needles are sampled at each time period. The majority of the results discussed rely on the Chlorophyll content of just 2 needles from 2 branches (i.e. 4 needles in total) at each time period. This limitation is acknowledged by the authors, but does reduce conclusiveness of the study somewhat. Whilst little can be done retrospectively to remedy this, the sample size should be made clear upfront in the methods not just later on in the discussion (i.e. the number

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of needles per sample needs to be included here in all cases).

RESPONSE: Added information about sampling to methods. It was unfortunate that we were unable to use most of the laboratory data. We measured 6 different branches with 3 cohorts each, but were able to only use data of 2 cohorts. In future work the visibility of the sampled cohorts in lidar data must be ensured.

4)Page 15023-15024: A range of indices are tested, benefitting from the multiple wavelengths of the lidar. This is a novel and interesting aspect, representing an advance on previous attempts to retrieve physiological parameters from single / dual-wavelength systems. However, a little more discussion of these indices would be useful in terms of the extent to which using different wavelengths (those of the lidar) to those for which they were designed might influence results and their sensitivity to structural changes and multiple scattering. With this system, needles will be significantly smaller than the footprint so these factors as well as physiological parameters could have significant influence (and structural changes might influence results based on a time series).

RESPONSE: We used slightly different wavelengths for the indices than what was stated in the original articles describing the index. This will cause uncertainty and difficulties in comparing our results to results published elsewhere. I added some discussion about this to results, and mentioned this in methods before the indices are introduced. Also added to discussion that the use of spectral indices reduce the effect of geometric effects (needles smaller than footprint). Also, since lidar echoes from needles have high variance, multiple echoes are needed to get meaningful results.

5)Page 15024, line 14 (and fig. 2 caption): There is reference here to the branch parts 'drying out'. It is unclear where the physiological measurements to demonstrate the shoots are drying are and which spectral index would show water loss (rather than other physiological / structural changes). Only NDVI is plotted. Can it be demonstrated the NDVI changes are due to loss of moisture content?

RESPONSE: What was meant here was that the oldest needles defoliated and dropped

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off, which can be observed as loss of chlorophyll and changes in NDVI. The drying out was a visual observation of the situation. This was normal for the growth of the tree, as these needles would be most shaded by other parts and therefore less valuable than the new needles in outermost cohorts. I changed the 'drying out' to 'defoliate'.

6)Conclusions: I find the conclusions reached rather broad. The paper demonstrates, based on a quite limited sample, that Chlorophyll content (not all 'physiological parameters') can be estimated from a multispectral lidar system and that changes over time can be detected. It less clearly shows the extent to which spatial variation can be mapped as only a limited needle sample from a small number of branches was taken. It would be useful to see a more thorough discussion of the findings and the potential challenges of applying such systems (e.g the role of multiple scattering, how to determine if a point is a needle rather than woody material, influence of structural change on physiological parameter estimates). At least an acknowledgement of such issues should be included. Re. the 'further work', what specifically would be needed that hasn't already been examined in the hyperspectral remote sensing / leaf optical properties modelling literature? Are there reasons the indices likely to work with lidar might be different to those for passive optical systems?

RESPONSE: Added several paragraphs to the discussion (paragraphs 3,4,6 in revised article) to address these questions.

7)Figure 3: While there is some relationship shown for mean values in Fig. 3 bottom row, it would be useful to know if there was any statistically significant differences in laboratory and lidar measurements for each branch (and the tree) between dates. The spectral changes look rather limited and the indices quite variable (top row graphs) compared to the laboratory measurements.

RESPONSE: The variance of the lidar measurements is very high because of the nature of the measurement. A single laser point may hit a needle/group of needles at any incidence angle relative to the needle and also may hit any point at the length of the

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needle. Therefore only average of the data is meaningful at this scale (cohort). The plots 3-5 top row show the 25 to 75 % percentiles (box) that show significant differences between measurement dates and the trend of these follow relatively well the laboratory measurements (as shown in the scatter plot).

Technical corrections: There are a number of grammar errors in the paper. It would benefit from detailed language editing. Page 15025, lines 16-19: This is unclear. Rephrase this. What is meant by 'the weight of the year 0 and 2 laboratory measurements'?

RESPONSE: Rephrased. What is meant here is that we took constant number of samples from the branches, but the point density varies when the needles are growing or defoliating. Therefore if we average over whole tree and use all the laboratory measurements, the few needles that were left in year 2 cohort after defoliation have higher weight in laboratory average than in the lidar point cloud, since very few lidar points are acquired from cohort 2 compared to eg. cohort 0.

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