Answers to referee 1

Arnqvist et al.

Correspondence: Johan Arnqvist (johan.arnqvist@geo.uu.se)

We appreciate the time the referee has taken into reading the manuscript. We agree with most of the reviewer comments and beleive that the text have been improved in many places. In the following we address the comments made and point out changes in the revised manuscript. Please also read the comments to Referee # 2 for other revisions of the manuscript.

Comments

1. *No accuracy assessments/ statistical analysis to validate the improvement of the new proposed results. The new proposed approach applied scaled intensity information to Beer-Lambert law to improve the PAD estimation, and compared it to three other methods (IR: un-scaled intensity return method, FR: first return method, and AR: all return method). And it also has LAI2000 data as field measurements. However, there is no statistical analysis / accuracy assessment, such as r-squared and paired t-test to show the new results preforms better than the other three. The only discussion on this was based on the visualizations on Fig 2 on Page 8.*

We acknowledge the lack of statistical measures in the original manuscript and have updated the revised manuscript with more quantification. As we argued in the initial response, our goal is not a validation with with ground-based observations (which would also need to quantify weaknesses in current ground-based techniques). The aim with our study is instead to present the new method and illustrate how it combines benefits of previously published ALS to PAD methods. The improvements are in short; limiting the influence of the albedo of first order ground returns (relative to the IR method), limiting attenuation problems in dense areas (relative to the FR method) and making estimates more in line with published values of leafless canopies (relative to FR and AR methods). In the revised manuscript we have worked to further emphasize and quantify that. Our changes include:

- Addition of 95% confidence bounds to the regression lines.
- Added a discussion based on winter PAI values for Beech forests from the litterature to assess the PAI magnitudes of the different methods for the winter scan.
- Replaced the map plots for the reference methods to difference plots between the new method and the reference methods (see Fig. 1, 2 and 3 below)
- Clarified the purpose of Fig 5 and accompanying discussion.

– Added a sensitivity study to the intensity values of ground returns to quantify that IR is more sensitive than SR (2.5-13 times as sensitive). Please see answer #2 for more information.

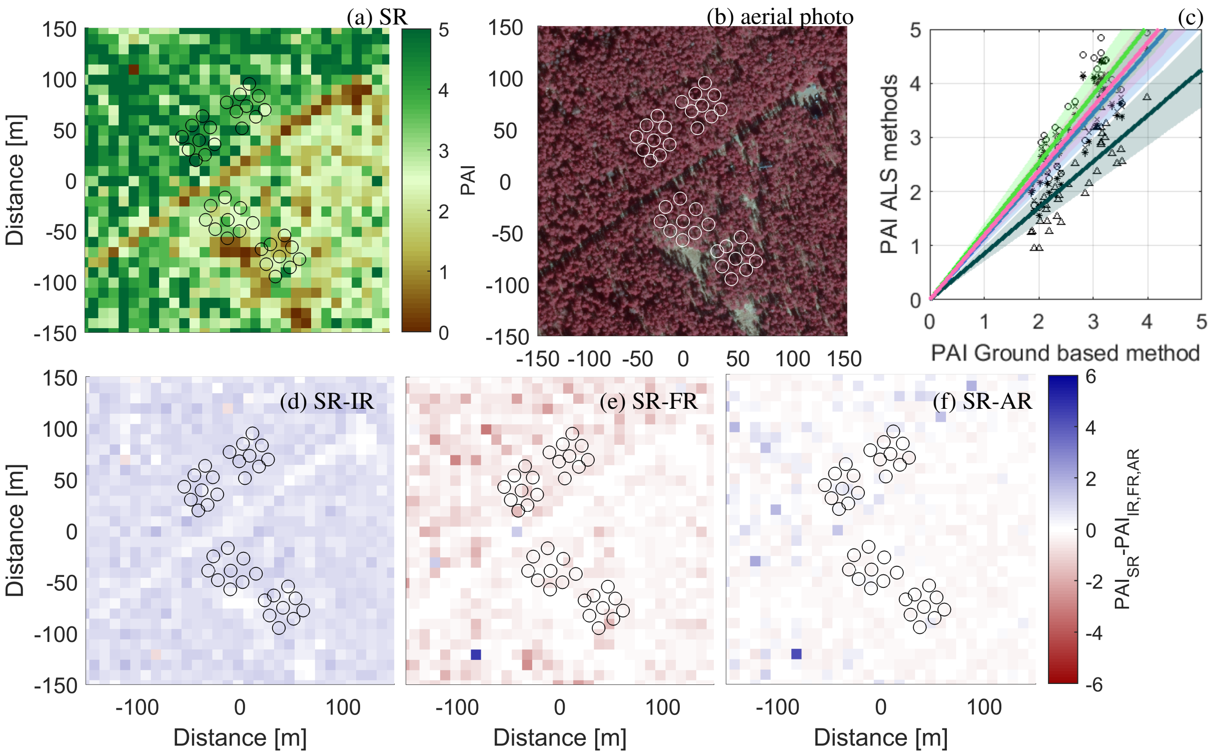

Figure 1. PAI estimates from Norunda by various methods. *a*) show PAI in a 10 m × 10 m square grid based on the SR method. *b*) shows an aerial photo over the site. *c*) is a scatterplot of the hemispheric photo estimates and the ALS methods. The lines show linear regression forced through zero with shading indicating 95 % confidence level (1.96 times the standard error). SR is represented by blue and stars, IR is represented by dark green and triangles, FR is represented by bright green and circles and AR is represented by pink and crosses. The circles in the maps displays the positions of the ground based measurements. *d*)-*f*) shows the difference between IR and the reference methods IR, FR and AR respectively.

2 *The results of the proposed method is very similar to the results of AR on Fig 2. So the conclusion of this study is arguable without statistical tests for comparison and statistical validation with field measurements.*

As noted in the initial response, we would like to direct interest to the single grid cell illustration, for clarification of the differences. In order to further highlight the contrasts between the different methods we have replaced Fig 2-4, b-d with difference plots. The main difference is in the winter scan of the deciduous forest. As can be seen in Fig. 6 and Table 2, both the median and the mean value of the PAI in the winter scan is high for FR and AR relative to SR and IR. In comparison to published values of winter PAI for beech forests, both FR and AR are above the maximum finding in Bréda (2003). In addition

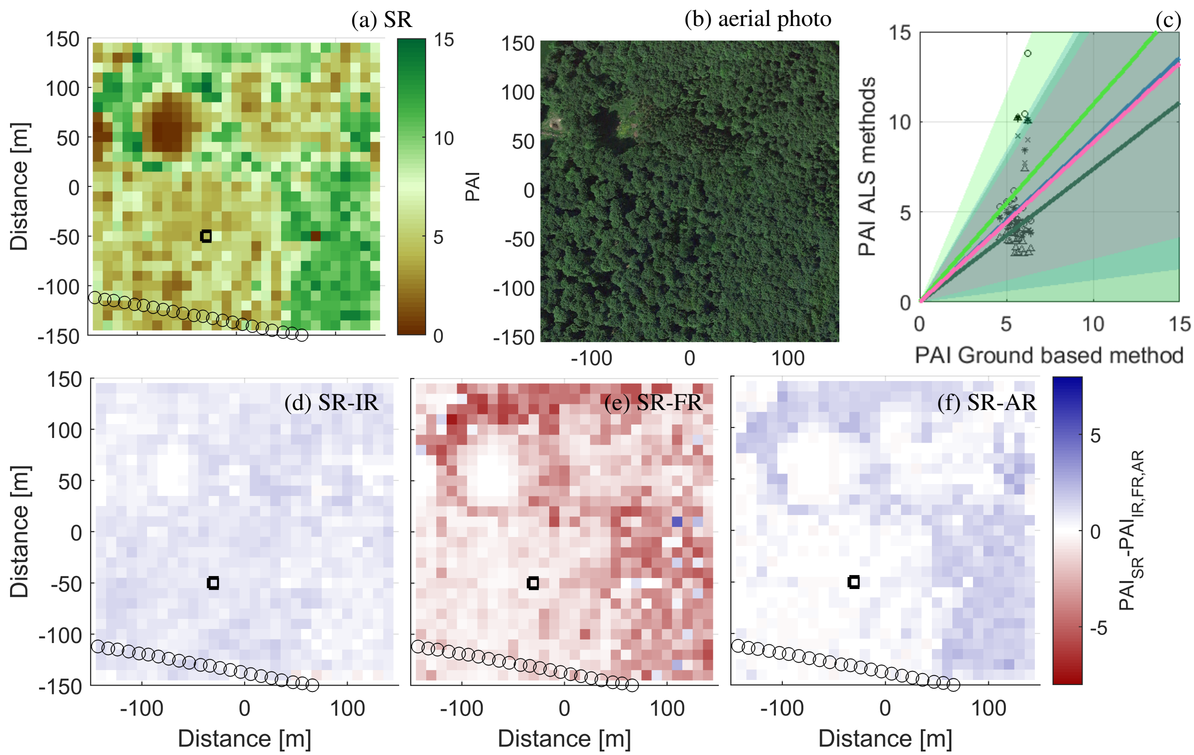

Figure 2. PAI estimates from Falster summer by various methods. *a*) show PAI in a 10 m × 10 m square grid based on the SR method. *b*) shows an aerial photo over the site. *c*) is a scatterplot of the hemispheric photo estimates and the ALS methods. The lines show linear regression forced through zero with shading indicating 95 % confidence level (1.96 times the standard error). SR is represented by blue and stars, IR is represented by dark green and triangles, FR is represented by bright green and circles and AR is represented by pink and crosses. The circles in the maps displays the positions of the ground based measurements. *d*)-*f*) shows the difference between IR and the reference methods IR, FR and AR respectively. The black square marks the edges for the data used in Section 4.2.

to that, the ratio of winter to summer PAI is in excess of 0.4 for both FR and AR, also that above the maximum presented in Bréda (2003). We have clarified the relative differences in the results section and added into the discussion:

"The winter estimates of average PAI in FR and AR exceed the maximum value for Beech trees reported in Bréda (2003). In addition to that, the ratio of winter to summer PAI is in excess of 0.4 for both FR and AR, also that above the maximum presented in Bréda (2003)."

3 *The writing needs improve. Equations should go to the method section. And some equations are redundant e.g. Eq. 4, 5, and 6 are basically the same equation with different inputs.*

We have created a new subsection, *3.3 Evaluation parameters*, where the comparison methods of *Spatial differences, Comparison with ground based methods, Sensitivity to ground albedo* and *Sensitivity to grid size* are explained. This facilitated a

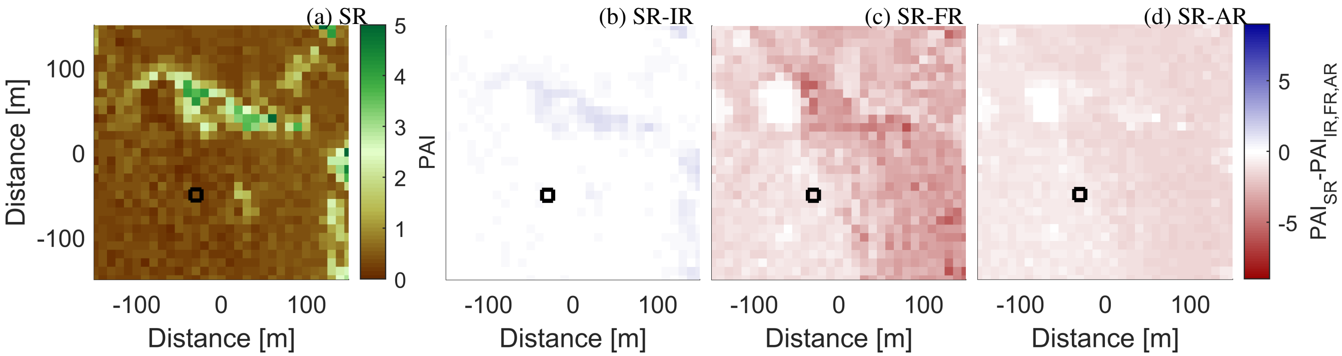

Figure 3. PAI estimates from Falster winter scan by various methods. *a*) show PAI in a 10 m × 10 m square grid based on the SR method. *b*), *c*) and *d*) shows the difference between IR and the reference methods IR, FR and AR respectively. The black square marks the edges for the data used in Section 4.2.

move of method oriented paragraphs from the results section to the method section and, we hope, clarified the structure of the manuscript.

Eq. 4-6 serves to explain the foundation of each method, and is therefore important for the remainder of the text. Even though the differences may seem small, in fact they are important, as can bee seen in the new figures (also included here as Fig. 1, 2 and 3). Furthermore, the style is in line with previous literature (Hopkinson and Chasmer, 2009), and we have therefore kept them as they are.

> 4 *The description of new approach is vague and confusing. And there is no explanation why the scaled intensity is able to fix the issue of ground PAD reflections in IR.*

We have made revisions to the text clarifying the SR method further. To quantify the sensitivity to difference in ground albedo to canopy albedo we have included results from artificially varying the ground return intensities. This enables us to say that the sensitivity of SR is significantly less than for IR. We include the updated text below.

In the methods section:

"In order to investigate the sensitivity to ground albedo, a test was constructed where the intensity values of returns classified as ground were manipulated. Intensity from ground returns were increased or decreased by a factor of 1.1 or 0.9 after which PAI was calculated and compared to PAI derived from the original data set. The manipulation only affects SR and IR, as FR and AR excludes intensity information. Both SR and IR showed only minor differences in sensitivity between a 10 % decrease and a 10 % increase in ground intensities, so results are presented as sensitivity to a 10 % ground intensity alteration.

And in the results section:

"The way first order ground returns are treated leads to a difference in ground albedo sensitivity between SR and IR. The difference in scaling technique between the SR and IR methods is visible in Fig. 5, particularly in the winter scan, through the dominance of the ground reflections in IR. Since SR uses scaling of each pulse, the intensity of a higher order ground reflection is always smaller than that of a single first reflection, no matter the actual back scattered intensity. This can be an advantage, as some surfaces may very effectively block the pulse despite sending relatively low back scattered intensity. Furthermore, the first order ground returns in SR all have the same weight, whereas in IR the weight is directly proportional to their share of the total backscattered intensity.

The sensitivity to ground albedo was investigated through artificially changing the intensity values of the ground returns according to Sec. 3.3. For the open pine forest in Norunda, the difference in sensitivity was large, with SR showing only 0.4 % change of PAI for a 10 % change in ground return intensity. The corresponding number for IR was 5.3 %. For the summer Beech forest in Falster, the sensitivity to a 10 % change in ground return intensity was 0.8 and 2.7 % respectively for SR and IR. For the bare trees in winter the corresponding values were 2.4 and 6.0 %. The larger difference in Norunda comes from the larger share of first order ground returns, owing to the less dense forest."

5 *And also, lots of the statements have grammar issues and debatable context, which made the manuscript hard to read.*

We have revised the manuscript to clarify our statements and remove incorrect grammar.

The comments from the reviewer have certainly helped us to improve our manuscript and we hope that the comments have been taken into consideration satisfactorily.

References

Bréda, N. J. J.: Ground based measurements of leaf area index: a review of methods, instruments and current controversies, Journal of Experimental Botany, 54, 2403–2417, https://doi.org/10.1093/jxb/erg263, https://dx.doi.org/10.1093/jxb/erg263, 2003.

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