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Biogeosciences Discussions

Interactive comment on "Detection of large above ground biomass variability in lowland forest ecosystems by airborne LiDAR" *by* J. Jubanski et al.

Anonymous Referee #1

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General Comments: This paper uses airborne lidar to estimate above ground biomass (AGB) across a broad area of forested peatlands and swamps in Indonesia. This supports current REDD monitoring initiatives within areas that are rapidly changing and expensive to monitor using traditional forest mensuration methodologies. While I find it an interesting and timely use of lidar data, especially with the integration and testing of a Landsat classification, the processing of lidar data is not clear, discussion of methods are limited, except for rather complex derivations of weighting of AGB due to 'density'. I am concerned that some errors have been propagated throughout the analysis. I am also guessing that areas surveyed contain some standing water (e.g. peatland swamp), which can be particularly problematic for lidar height estimates. I am request-

ing major revions to give the authors the opportunity to elaborate on the methods used and possible errors in the analysis (with reference to the relevant literature).

Specific comments:

General proofreading throughout is required. Punctuation isn't always correct, words are missing, etc.

Abstract - well written, clear, good context.

Introduction – Some sentences require proofreading (e.g. 11817, L9-11; 11818, L1-2. . .inevitably isn't correct word – perhaps unequal? And others).

Throughout the paper, there are many grammatical and topographical errors. I am not able to complete a thorough assessment at this time, but will try to get to it within the next couple of weeks.

Materials and Methods 2.1 lidar acquisition

11820, L7 – is that +/- 30 deg? (likely)

11820, L10-13 – Just wondering where these numbers came from. Check 2 cm accuracy in lab (these sound like terrestrial lidar accuracies) – this will not apply to forest or vegetation heights. Vertical and horizontal accuracies you state are typical for accuracies stated by service providers and are based on calibration over flat, unambiguous surfaces. Have you validated the vertical and horizontal accuracies at your plots (beneath tree canopies)? It is unlikely that you would get such high accuracies in forested environments. Also, what are the relative accuracies between scanlines? Have they been strip matched? How many scan lines typically make up a transect? These can also vary accuracies a lot. Vertical accuracies will also be made worse by soil saturation. What is the ground surface soil moisture like? Is there much standing water (I am thinking perhaps there might be if these are forested peat swamps). Standing water will absorb laser pulses and may increase vertical error both at the ground level and within trees. Further, wide scan angles (if +/- 30 degrees) will cause more reflections from the side of trees than from the ground surface, and may increase errors in tree height estimates (because of reduced resolution of the DTM, etc.). These should be validated at the ground and for tree heights within plots.

11820, L15-19 –What algorithm was used to filter the data (or do you have a reference for it)? Was there any validation of the accuracy of the ground classified data? It looks like the classification didn't work very well (looking at Figure 2, if you are using above ground points only). This could influence both the DTM accuracy and the normalisation of the returns above the ground (e.g. height).

11821, L1 – why were trees <7 cm DBH excluded? Were there many of them? Understory vegetation can influence C balance and biomass. These trees are also detectable within lidar data.

11821 - There seems to be quite a lot of detail on translation of tree names (which is important, but perhaps too much detail), and too little detail on initial lidar data processing (which is critical to the accuracy of this study). Were AGB estimates species-specific? (Authors state that they use the equation for moist, tropical forests, but don't indicate if species types were separated. . .which perhaps negates the need to go into species translation details provided above).

In general, how confident are you in the accuracy of your plot AGB data? How did you locate plots and related these to lidar data? How representative are the plots within the larger 1,000,000 ha area?

2.2 Generation of regression models 11821, L23 – what bin range did you use? 1m?

11821, L26 – How was the Centroid Height calculated? Using a quick search, I have only found it with reference to full waveform lidar. Is this the median height (it looks like approx median height)? What is the quadratic mean height? I can't find reference to it in Asner et al. 2010 and can only find it with regards to diameter. I'm sorry, I am not familiar with this terminology. Were 'all' data used to estimate the profile? You

mention excluding the first bin because this contains ground returns. . .(illustrating that the ground classification didn't work very well).

11822, L4-11 – The problems that you are having with point density is more likely to be because of the scan angle geometry, not necessarily the point density. Using a frequency distribution approach, so long as you aren't looking at the tails of the distribution (e.g. canopy height at the 95th to 99th percentile), and you are looking at the shape of the distribution (which I think is what you are getting when you look at the centroid height and quadratic mean height), you shouldn't need to weight the height histogram based on density. I know that you can't really do much about this, but here is some info for future reference: There is a problem here where you have +/-30 degree scan angle and you don't have 50% overlap of scan lines. The scan geometry is varying significantly as the system is scanning out from nadir, and returns are reflecting from different parts of the trees. This can be compensated for by using a 50% overlap of scan lines (allowing pulses to reflect from both sides of the trees instead of one side, which effectively corrects/cancels out scan geometry problems for overlapping scan lines, reduces problems of occlusion, etc.). Without this, you should be correcting for scan angle as opposed to weighting based on density, if it is required. I believe some lidar manufacturers include these corrections in their software already (e.g. Optech). You might also want to clip the overlapping areas at the edges of scan lines in TerraScan - I think that this will help to remedy the problem and won't require weighting of some of the data. Please see papers by Naesset, Hopkinson, and I think Holmgren has published something on this as well.

11822, L15 –What do you mean by the "classic approach"?

11822, 23 – I am a bit confused here, do you use CH only for the rest of the paper? Or both CH and QMCH, because your figures show both, but here you say that the chosen regression model was CH. . .

2.3 Rigorous covariance propagation analysis I am following all of this somewhat, but am not fully comfortable with my knowledge of it, so please bear with me and correct me if I am wrong in my understanding of what you are doing. To my mind, before you get into weighting, propagation of error, etc., you should first demonstrate that changes in scan angle geometry (density) biases frequency distributions within plots. Perhaps in some cases it will and in some cases it won't. By looking at Figure 3 (to see if I can see it in the weighted vs. 'classic' AGB estimates), I can't tell which regression points were calculated using the 'classic' approach and which were calculated using the 'weighted' approach, so I can't tell if there was a difference. Were they significantly different?

Eq 1, 2 – Sounds like your model is very highly optimized, but this will likely break down if you apply it beyond the plots used to parameterize it (unless they cover a very broad range of environmental conditions and types).

I can understand the propagation of error due to variance, and the need to weight AGB to reduce the error, but I am not sure that I understand covariance propagation (my limited understanding). This seems to be propagation of similarity. . . ? This could be improved greatly by adding simple explanations of expected results/objectives for each set of equations. (e.g. 'these demonstrate the range of error, and where it exists (which plots)'; 'these equations force outliers towards the power function'; 'these equations correct for scanline geometry (density) issues', etc.) for those of us who aren't able to follow all of the details of what is going on.

Pg 11824, L15 – How were these equations applied to CH and QMCH models? What strikes me about this paper is that so much is put into these equations, with very little detail on the important things like DTM generation, ground point classification (see Hutton and Brazier, 2012 for a good analysis), and vertical error (between scan lines – sometimes a major source of uncertainty). If there are errors in the processing of the lidar data, these errors will be propagated. I am not saying that errors in data processing exist, but I just don't know because there are few details. Correcting for density is something that will obviously stand out as you look at the data, but you may

be correcting for the wrong reasons.

2.4 Comparison between optical remote sensing and lidar for AGB estimation 11825, L14 –Did you gather endmembers from non-disturbed plots? Was there a range of plot types for endmember data collection? Do you show an image of the SMA for the 1 million ha image in this paper?

11825, L16-17 – Please specify that you are comparing with AGB estimated from the Landsat classification.

Were these forested peatlands? Why did you compare with only those covering peatlands (or is the entire area made up of peatlands?)

Results 11826, L20 – The highly optimized nature of the model for these plots will yield a good r2. Applying the model without the weighting and if needed, corrections for scan geometry, would be more universal (and perhaps more useful).

11827, L3-7 – please state "for this forest type" This will vary depending on the type of forest studied, the forest structure, and the scanner used.

Figure 4. I am a little confused by this figure, but it may be that I am just not understanding it very well. You state that in B) the 'logging activities are not visible anymore'. But if they aren't, how is it that you are getting a Landsat classification that looks like C) in 2007, with classified areas that have been logged (are they historical e.g. dating back to 1997 using Landsat data)? In D) are the field plots averaged in this figure? It doesn't seem correct that you have two plot numbers for AGB extended over a 10 km long strip. Surely they don't represent the entire 10 km strip? Did you have plots along this strip? If you did, it would be good to see where they were located, and to plot the AGB to plot scale according to the LiDAR data (e.g. as a point). Also, when referring to the Landsat data, what do you mean by 'gap filled'?

11828, L5-7 – are there any more classes than these two? It looks pretty homogeneous to me.

11828, L 9 – site specific inventory data should be displayed as point measurements at the location of measurement, compared with the lidar data. Perhaps the point that you should be making is that plot measurements are not contiguous (like lidar is).

11828, L10-12, and Figure 4 – I don't think that it is a fair test of Landsat to display bands 5, 4, 3 and then saying that the variability does not represent the heterogeneity in AGB found in Lidar data. At least a spectral vegetation index would be a more suitable test, I think (although I know that there are problems with SVAs in high biomass environments). This could at least be explored – or a contrast stretch applied. I can actually see quite a lot of heterogeneity in the Landsat data (darkened vs. lightened areas and patches) that do correspond with red to blue patches in the lidar data. Lightened areas correspond with red lidar areas (near 0 AGB) and darkened patches correspond with blue and green areas (near 80 AGB). Does this improve using a SMA (which you discuss in the methods, but provide only a very limited classification in the results section)?

11828, L13 – what is the 'indirect method'?

Figure 5 – Which line(s) refer to the Landsat estimates? You include Field Plots, Regional Database, and IPCC default – the last two? Why, in b, c, and d, are there small decreases in all three (Field plots, regional database, and IPCC default) lines (other than lidar) that are equal in size and occur at the same place? Are these based on individual Landsat pixel classes (e.g. all are the same class, so they are flat-lined)? It would be good to include the plot point estimates of AGB, as mentioned earlier. 11828, 23-24 – "forest regrowth was much slower than expected. . ."Do you know this from your plot measurements, etc.?

11828, L26-28 – "The lidar AGB indicates significantly lower AGB values for the peat swamp forest. . ." What is the soil moisture like in these areas? Is there standing water? I suspect that there could be if this is a peat swamp? The trouble with lidar is that, a) if there is standing water, laser returns will be absorbed in the NIR and many may

not be recorded; b) if vegetation is short, multiple returns from canopy and ground will not be recorded (although this depends on how waveform data is discretized into individual returns); and c) if your classification algorithm isn't working correctly, you may be classifying short vegetation as ground, which could result in artificially reduced AGB estimates from lidar, not necessarily a result of unfavourable growing conditions (although I am not excluding that possibility by any means). I wouldn't necessarily think that lidar provides the best possible estimate of height and fractional cover in all environments. There are limitations cited in the literature.

11829, L2-3 – 'whole study area' – Are you confident that your plots, used to parameterize the lidar data, represent all vegetation species types, structures, and topographic classes found in the entire study area? Are you able to prove, to what extent, these plots cover these ranges (e.g. by percent area coverage?)

Table 2 – Did you apply the AGB estimates for the entire 1 million ha study area? Or did you only apply this to the classified land cover types within the large study area (and not everything else)?

Discussion 11830, 17-18 – lower AGB in water logged areas is very likely due to inability of lidar sensor to detect ground, resulting in mis-classification of returns from veg returns to ground returns. This will artificially reduce veg height and fractional cover, etc. A limitation that should be discussed.

11830, L21 – Did you apply to only 59% of the area represented by plot measurements? Or did you apply it to the entire area? If to the entire area, then I don't think that this is appropriate.

Interactive comment on Biogeosciences Discuss., 9, 11815, 2012.