

# **Response to Referee#1**

## **General Comments:**

### **Referee#1**

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

### **Authors' response**

We would like to thank the referee#1 for the constructive comments. We will consider the remarks and rewrite the Manuscript according to the comments. Especially we will provide more information on LiDAR data processing, DTM generation, and accuracies. Below we address the comments of referee#1 point by point.

## **Specific comments:**

### **Referee#1**

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

### **Authors' response**

We will proofread the manuscript with assistance of a native English speaker.

### **Referee#1**

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

### **Authors' response**

11818, L1-2 we will change inevitable to necessary.

### **Referee#1**

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.

### **Authors' response**

For the final manuscript we will proofread the manuscript.

## **Materials and Methods 2.1 lidar acquisition:**

### **Referee#1**

11820, L7 – is that? (likely)

### **Authors' response**

We will change the text to +/- 30 deg.

### **Referee#1**

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.

### **Authors' response**

The figure of 0.02 m comes from the instrument manufacturer and is used to illustrate the potential accuracy. The sentence can be deleted. In the next sentence we provide figures for the accuracy of the acquired data set.

The acquired data set has an relative vertical accuracy of  $\pm 0.15\text{m}$  and horizontal accuracy of  $\pm 0.50\text{m}$  Root Mean Square Error (RMSE).

To determine the accuracy of the DTM we measured terrain elevation in 88 locations covered by dense forest and regrowing forest by dGPS and land surveying equipment. The mean point density in these locations was 0.43 pt/m<sup>2</sup> with a RMSE for the height measurements of 0.40 meters.

### **Referee#1**

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.

### **Authors' response**

Each transect was created from single scan line (swath approx 500 meters). Figure 1 shows the position of the flight tracks. We did not determine relative accuracies because AGB was estimated based on the relative height of each LiDAR point in the point cloud above the DTM.

**Referee#1**

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.

**Authors' response**

We will add the following information in the manuscript.

The survey was planned and conducted in the middle of the dry season (5<sup>th</sup> to 10<sup>th</sup> August) to avoid problems related to standing water. Own field observations and data from an extensive network of water table measurement locations in the area installed for several years showed that the peat surface is dry during this period and no standing water occurs in forests.

**Referee#1**

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.

**Authors' response**

The RMSE for the height measurements was 0.40 meters., This is compared to average tree height determined by QMCH of 14-25 meters small and will not lead to wrong AGB estimates.

Refer also our response and graph further down in this document.

**Referee#1**

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 normalization of the returns above the ground (e.g. height).

**Authors' response**

We will provide more detail concerning the LiDAR point cloud filtering and the DTM generation in the manuscript. Both filtering and interpolation were implemented through the Inpho software package (DTMaster and SCOP++). In our study the LiDAR point cloud filtering was the separation between ground and off-ground points. Since within the study area all off-ground points consisted of vegetation no further classification was necessary. The filtering methodology used was the Hierarchic Robust Filtering (Pfeifer *et al.* 2001), followed by a strict quality control.

For the precise description of the terrain surface, SCOP++ uses linear prediction. The theoretical basis of linear prediction is presented in detail in various publications (e.g. Kraus 1998, Assmus 1975). Linear adaptable prediction corresponds to the statistical estimation method Kriging, often applied in Geo-sciences (Kraus 1998).

Figure 2 shows the normalized heights of all points of the plot location, ground points inclusive. We preferred to use the whole dataset and cut the first bin in order to eliminate possible filtering outliers and echoes from aerial roots and undergrowth herbage. This approach was presented in (Lefsky, 1999), and used in many other studies e.g. (Asner, 2010).

#### **Referee#1**

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.

#### **Authors' response**

It is common in forest inventories to measure only trees below a certain DHB (usually 5cm). We used 7cm because in the highly inaccessible peat swamp forests we found this a good tradeoff between the time required for the in in-situ measurements, the number of sample plots which could be measured with the available resources and measuring a sufficient number of trees (Pearson et al. 2005). As the proportion of trees with small diameter on the overall AGB was very small we decided to accept a slightly lesser accuracy in overall AGB estimation order to minimize the invested time per sample plot. In reducing measuring time per sample plot more sample plots could be recorded, which represented more different environmental and ecological peatland conditions.

#### **Referee#1**

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).

#### **Authors' response**

AGB was calculated using an allometric model for tropical forest stands from Chave et al. (2005). Two models are proposed by them for moist forest, one which includes tree height, DBH and wood density, the other includes DBH and wood density, but not tree height. It was decided to use the second model excluding tree height as accurate tree height measurements in the field were highly inaccurate and often impossible to take because of the dense and tall forest canopy. Tree species are required to determine wood density from a database. The AGB within the plots was calculated for each tree individually. We will describe this in more detail.

#### **Referee#1**

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?

### **Authors' response**

As mentioned above we used an allometric AGB model developed by Chave et al. (2005) for moist tropical forest stands excluding height. They provide a critical assessment of the quality of these models across tropical forest types, using a large dataset of 2 410 trees harvested in 27 study sites across the tropics. Also the models were tested for secondary and old growth forests and for dry, moist and wet forests, for lowland and montane forests, and for mangrove forests. They showed that the most important predictors were, in decreasing order of importance, trunk diameter, wood specific gravity, total height, and forest type (dry, moist, or wet). Overestimates prevailed, giving a bias of 0.5-6.5% when errors were averaged across all stands.

We located our plots with a GPS device (GPSmap60CSx, Garmin) which had an average a horizontal accuracy of 5-10 meters if measurements were averaged over 10 minutes. The location of the plots were chosen on the basis of our experience in the area (one author, Florian Siegert, does research in this area since more than 15 years) and using an extensive data base of aerial photos, multispectral and SAR satellite imagery such as RapidEye, Landsat, ALOS ENVISAT and TerraSARX) and land cover maps derived from these imagery. In addition the plot locations were selected based on accessibility and representativeness for different environmental and ecological conditions. We will describe this in more detail in the manuscript.

### **Referee#1**

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

### **Authors' response**

We used 1m bin range. We will add this information.

### **Referee#1**

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).

### **Authors' response**

We used full waveform lidar in this study. The centroid height is a concept that we adapted from the processing of full waveform large footprint LiDAR, like GLAS (see Ballhorn, 2011). It represents approx. the median height. We consider the histogram formed by each plot as a large footprint return. The Quadratic Canopy Mean Height (QMCH) represents the mean height of the canopy in the plot. This parameter has been used in Asner (2010), but a better reference to these parameters is Lefsky (1999). We will add this reference.

The complete point cloud except the first bin was used to generate the histograms. The point cloud has been normalized to the DTM, so the heights in Fig. 2 are relative heights. We preferred to use the whole dataset and cut the first bin in order to

eliminate possible filtering outliers and echoes from aerial roots and undergrowth herbage. This approach was presented in (Lefsky, 1999), and used in many other studies e.g. (Asner, 2010). Very low growing vegetation has practical no influence on the AGB.

### **Referee#1**

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.

### **Authors' response**

First, we have no problems with point density. We try to improve current approaches and investigate cost versus benefits when planning surveys. Compare e.g. were the most suitable point density is guessed (Evans et. al., 2009) and not based on a quantitative analysis. Acquiring data sets with high point densities is expensive. That's why we investigate the role of point density on the quality of the AGB estimate.

Second, we are fully aware of the scan angle problem: we excluded 10 % of the swath width (25 meters of each side of the strip, see red bars in Fig A1A) from the analysis. Fig. A1A shows the point density distribution of a typical across track transect on our study area. 80% of our field plots were collected within the swath of 15 degrees.

In addition we found that point density on ground for scan angles > than 15° is high enough to separate ground points from vegetation. We observed a reduction in point density of 25% to 40% from nadir to the edge of the swath (see fig. A1A). We collected 88 dGPS measurements (using Trimble 4700 and 5700 dual frequency geodetic GPS receivers) in various locations along and across track. We found a DTM accuracy of 0.4m RMSE which is in our opinion sufficient to perform AGB estimations (see fig. A1B).

The mean point density on the locations where these points were collected was of 0.43pt/m<sup>2</sup>. We also classified the locations per point density (< 0.5pt/m<sup>2</sup> and >0.5pt/m<sup>2</sup>). The locations with lower densities (red) tend to show worse results. We will add this scatter plot with our accuracy assessment as well the profile of point densities across track in the manuscript.

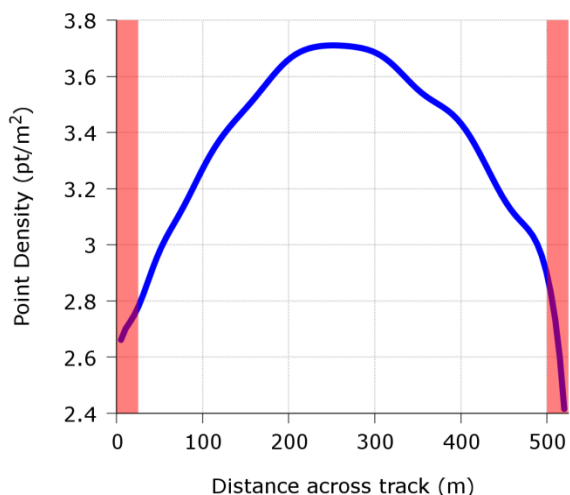


Fig A1A: Point density variation across track.

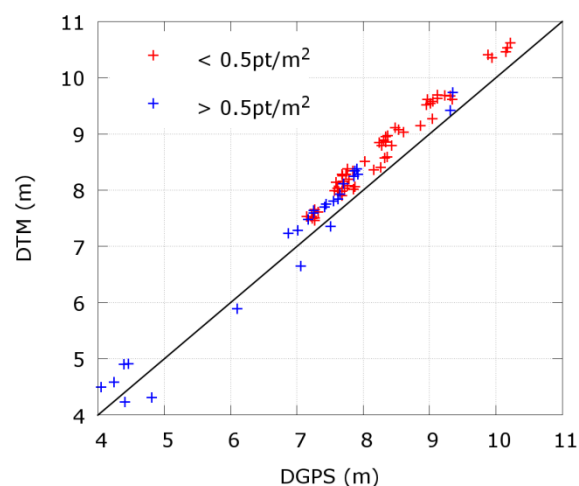


Fig A1B: DTM Accuracy assessment for 88 dGPS points.

#### Referee#1

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

#### Authors' response

With “classic approach” we meant to derive the regression model without point density weighted adjustment. We will change the sentence the following way: “For both studied metrics (CH and QMCH) the regression models were derived with and without point density weighted adjustment.”

#### Referee#1

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...

#### Authors' response

We use CH for the rest of the paper because it is the parameter we are proposing to correlate with AGB, which correlates better than the QMCH in PSF.

#### Referee#1

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?

### **Authors' response**

See above. The accuracy differences caused by scan angle effects are taken in account when weighting the plots accordingly to point densities. We will clarify this issue in the manuscript.

### **Referee#1**

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).

### **Authors' response**

When collecting plot data we covered all major environmental and ecological conditions. The model is optimized for peatlands in Central Kalimantan.

### **Referee#1**

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.

### **Authors' response**

This will be better explained on the final manuscript. It is not similarity propagation but statistic error propagation. Error propagation is a popular terminology for covariance propagation. Rigorously speaking, random errors cannot be determined, but variances and covariances can be modeled. For this reason, error propagation is not an exact term to use.

### **Referee#1**

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.

#### **Authors' response**

We don't apply the covariance propagation equations when calculating AGB. We model the influence of point density on our regression models. Hutton and Brazier, 2012 performed an analysis with focus on the use of LiDAR for hydrological projects. Hydrological applications require very accurate terrain morphology. We agree with the authors when they say that "... filtering parameter uncertainty affects the performance of the interpolation procedure; resultant errors may propagate into the Digital Elevation Model (DEM) and subsequently derived products, such as Canopy Height Models (CHMs)...". However, we think that for our application (AGB estimation), the point density (which is not taken in account in the cited paper) plays a major role in comparison to small topographic structures. For this reason we consider a global RMSE enough for assessing the accuracy of our DTM's.

#### **Referee#1**

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?

#### **Authors' response**

End members were identified through exploring multiple 2-dimensional scatter plots and minimum noise fraction transformed images. Endmembers were derived from a range of undisturbed plots (green forest vegetation (GV)), from bare soil areas (soil), from areas with non-photosynthetic active vegetation (NPV) and shade (refer to our paper Frank et al., 2012 for more details). We do not think that an SMA image would improve the paper.

#### **Referee#1**

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

#### **Authors' response**

We changed the sentence the following way: "Next the LiDAR AGB estimates for 28284 ha of LiDAR tracks, covering pristine and degraded peat swamp forests, were quantitatively compared to AGB estimates based on a Landsat classification."

#### **Referee#1**

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

#### **Authors' response**

See question above. The entire study area is made up of peatlands.

**Referee#1**

Results 11826, L20 – The highly optimized nature of the model for these plots will yield a good  $r^2$ . Applying the model without the weighting and if needed, corrections for scan geometry, would be more universal (and perhaps more useful).

**Authors' response**

We think that our methodology with weighting point density is universal and useful because it models an important uncertainty source for AGB estimations. This leads to better results and therefore higher  $r^2$ .

**Referee#1**

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.

**Authors' response**

Ok.

**Referee#1**

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)?

**Authors' response**

(A) shows the impact of logging which occurred in the year 2000 and before. Most of these impacts are not detectable in (B). (C) shows the classification of the 2007 image (B). Logging before 2000 was in most cases not correctly classified while logging which occurred between 2001 and 2007 was classified correctly..

**Referee#1**

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).

**Authors' response**

(D) compares different methods to determine AGB. We feel that this is clearly explained in lines 11828 3ff with references. What might be missing is a more detailed explanation on how the AGB was determined along the LiDAR transect.

We will add this sentence to the paragraph:

In order to evaluate the AGB variability along the LiDAR transects, we estimated AGB in a grid with 5m resolution within the LiDAR tracks outlines. For each cell we used LiDAR points within a radius of 20m (the same radius of the field plots). In this way it was possible to compare the direct and indirect methods.

**Referee#1**

Also, when referring to the Landsat data, what do you mean by 'gap filled'?

**Authors' response**

May 31, 2003, the Scan Line Corrector (SLC), which compensates for the forward motion of Landsat 7, failed. Without an operating SLC the line of sight now traces a zig-zag pattern along the satellite ground track resulting in data gaps. Gap filling is the procedure where these gaps are filled with additional fill scenes.

**Referee#1**

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

**Authors' response**

In this specific subset shown in Fig 4 there are only two classes which can be identified in Landsat. In total we discriminate six classes relevant for AGB in the study area.

**Referee#1**

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).

**Authors' response**

In-situ field plots of AGB were collected for the different strata (land cover types) and the AGB values of these field plots were then averaged for each strata. In Figure 4D these values are shown as a line because the indirect method assigns to each contiguous Landsat pixel of the same class a single site and class specific AGB value. That is why there are only two values, one for pristine and one for logged forest.

Contrary to, the LiDAR transect gives a AGB value for each 0,13 ha unit and thus reveals that there is a significant variability of the AGB even with e.g. the class pristine peat swamp forest.

This is exactly the advantage of the LiDAR approach. Figure 1 shows the location of the in-situ field plots used to determine the site specific AGB.

**Referee#1**

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)?

**Authors' response**

We have extensive experience in classifying Landsat and other multispectral satellite data in this region. There are patterns visible in this small Landsat subset shown in Fig 4, but most of these cannot be assigned to specific classes using vegetation indexes or SMA classification approaches (see e.g. our recent paper Franke et al., 2012). The classification result shown in 4C is what can be done with state of the art SMA classification methods to identify logging impacts which occurred several years back in time.

**Referee#1**

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

**Authors' response**

It is explained in 11828 L3-4

**Referee#1**

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.?

**Authors' response**

Figure 5 is made using exactly the same logic as Figure 4D. It illustrates how AGB is over and underestimated in other land cover classes (B: another section with logging impact; C: regenerating forest after fire impact and D: fire scars). All lines, i.e. site specific inventory data, regional database, and IPCC are based on the Landsat classification.

**Referee#1**

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 unfavorable 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.

**Authors' response**

As it was stated before we made sure that there was no standing water during the time of LiDAR data acquisition. We also make clear that we only investigated transects on peat with forest cover (undisturbed, disturbed, regenerating). The location of the profile in D is shown in figure 5A, it transects a peat swamp forest and two fire scars.

The important point here is peat swamp forests show a very large variability in AGB which this is linked to growth conditions (availability of nutrients, water logging etc.). This variability is by no means detectable in Landsat or other multispectral satellite imagery.

Your concerns (b) are not applicable because the trees in these peat swamp forests are 15-30 meters tall.

The LiDAR AGB values we obtained in fire scars (which are covered either by regrowing forest or ferns and vines) show that your concerns (c) do not apply.

**Referee#1**

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?)

**Authors' response**

Yes, we are able to provide figures such as percent area coverage for the different vegetation types in the study area. We have full area coverage land cover classifications based on Landsat and Rapideye imagery available which were validated by us by extensive field and aerial surveys.

As stated before we work in this area since more than 15 years, please refer to our papers we published e.g. in Nature, PNAS, RSE etc. Using this background in field experience and remote sensing information we carefully selected the field plots considering ecosystem variability, representativeness and practical aspects such as accessibility.

**Referee#1**

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)?

**Authors' response**

Table 2 shows that we applied AGB estimates to the study area (911 450 ha).

**Referee#1**

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.

### **Authors' response**

We propose to change this sentence as follows: "We conclude that AGB is lower in forests which grow in areas where the water-table is permanently high. In such an environment grows a forest type which was termed low pole peat swamp forest (Page et al., 1999)

Remark: "permanently high" does not mean that there is standing water in the dry season.

### **Referee#1**

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.

### **Authors' response**

We have field plot measurements for all land cover types represented in the classification (peat swamp forest undisturbed, peat swamp forest logged Bushland/Regrowth, Grassland/Fern, and Burned. Therefore we were able to apply it to the entire classified area.

### **References**

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