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## ***Interactive comment on “Tree height integrated into pan-tropical forest biomass estimates” by T. R. Feldpausch et al.***

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Review comments of Feldpausch et al., 2012. The paper addresses one of the key questions about the use of tree height in improving the biomass allometry. This paper is definitely an excellent contribution to improving the biomass estimation in tropical forests. The presentation of the methodology and the results are sound and accurate. However, the paper suffers from some general and to a large extent unrelated and sometimes erroneous statements in the discussion section. The discussion section is long and includes many subsections covering a variety of topics, and in most cases longer than the methodology and results sections. The authors try to comment on everything from remote sensing methods, carbon, REDD, climate, global emissions, sources, sinks, etc. I recommend the paper for publication after major revisions and re-

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duction of the discussion section. Revisions are mainly editorial and do not suggest any revisions of the analysis or the results.

General Comment: The authors present a negative view of the remote sensing results in the discussion section. They have several claims that are not correct: 1. “Transforming variation in tropics-wide biomass estimate due to H into reliable. . . “ is not a correct statement. The authors should not forget that the recent enthusiasm in biomass estimation at spatially refined scales and inclusion of height predominantly originated in the remote sensing community when forest height measurements from space became available. Height could not and cannot be measured accurately in the field and if it was not because of Lidar and to some extent radar technology, height would’ve been ignored completely in field inventory data. Most of the field data, including Rainfor data never included height estimation in earlier years. In recent years, several algorithms have been developed to relate forest height metrics (various estimates of height such as maximum, mean canopy height, etc.) to biomass. There will never be one algorithm to fit all. However, with few models in place, we have the general form that can work for tropical forests. I think the remote sensing approaches related to height and biomass is definitely more developed than field approaches and allometry. 2. The authors claim that in Saatchi et al., 2011, “this study estimates biomass based on equations that were developed using height data collected from temperate forests from North America and tropical forests rather than exclusively from tropical forests.” This statement is not correct. Saatchi et al. 2011. They used individual lidar waveform data from ICE-SAT GLAS sensor (not Lefsky 2010 height map), then computed Lorey’s height using the form of the equation given by Lefsky 2010 for broadleaf forests, but calibrated the relation with only the data in tropical data (coefficients of the equations are different). The supplementary material of the PNAS paper states this: “The model was calibrated with three study areas with ground estimates of height in the Amazon basin, located in the municipalities of Santarem, Para State; Manaus, Amazonas State; and Canarana, Mato Grosso State, all in Brazil.” Even though the form of the model is the same for the broadleaf forests shown in Lefsky 2010, the coefficients are different. In addition,

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Saatchi et al. 2011-used Lorey's height to biomass relationship developed strictly from tropical data (Figure 1; shows equations from 493 plot data). In fact, the slightly lower estimate of biomass in tropical America from Saatchi et al 2011 can be partially attributed to the use of height for biomass estimation.

### Specific comments

1. Introduction: Biomass cannot be estimated by passive remote sensing (landsat). Drake, Stienenger, and Mitchard did not use Landsat to estimate biomass. It is better to change the statement and mention radar and lidar, both active sensors and use references such as Saatchi et al., 2011; Mitchard et al., 2011; Drake et al., 2002; Asner et al., 2009. 2. Introduction: line 25: The statement: "Nevertheless, these all require plot-based..." needs to be changed. I am not sure why the authors say this. Almost any technique needs to be calibrated and validated. Even the ground measurement of biomass (harvesting) or estimation (allometry) should go through calibration and validation. Furthermore, the statement says at the end "and have large uncertainty." This is again a wrong statement what has large uncertainty? High-resolution Lidar data calibrated with the ground measurements can have less uncertainty over landscapes than limited samples of ground plots estimating landscape scale biomass. I suggest, the authors be careful about use of these terms. Unfortunately, field researchers have assumed what they estimate from ground over highly selective areas are not uncertain or biased. In fact, most of the recent results show that field data from research plots (using preferred locations) is extremely inadequate to understand distribution of biomass in tropics. Most of the field plots are located in selectively large biomass forests. A reasonable field estimation approach requires systematic sampling of the forest and a true error propagation effort. S such field techniques are very common in Forestry practices in Northern Hemisphere. 3. Please do not use Houghton et al 2001 as an example of biomass being uncertain. Since that publication, there have been several papers including new papers by Houghton in 2010, Saatchi et al., 2007; and others. Houghton et al. 2010 used very old data (44 plots), do not have a remote

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sensing estimate of biomass. 4. “Accounting for H:D allometry may reduce uncertainty may reduce. . . from plots to pan-tropical scales.” I agree that it is important to include H in allometry. However, it is still not clear how the authors extend this to pan-tropics. First, H cannot be measured accurately in the field. Second, uncertainty in pan-tropic estimate of biomass may be related to sampling error than allometry. This has not been proven yet. It is in fact easy to argue that the largest uncertainty may be in sampling and measurement errors. Other errors such as wood density can contribute to the same degree as height to biomass estimation over large regions. 5. In the four-step process, the assumption of height estimation from diameter may also introduce large errors. In fact, in most studies, including papers by authors, it is obvious that estimation of the height of large trees from H:D allometry can contribute to the error. Height needs to be measured as accurately as possible for large trees. I suggest the authors discuss this point. H:D allometry has large errors for large diameter trees (either over estimating or under estimating depending on the relationship). This error can impact the biomass estimation because of the contribution of large trees.

6. Referring to Figure 1 and the location of plots, I am afraid the plots cannot be used to extrapolate over the entire continents. The number of plots is relatively small, and they do not represent the landscape variations within each continent. The authors have better data over Amazonia but not in Africa and Asia. I suggest the paper focuses on showing the results on existing plots rather the continental scale extrapolations.

7. Section 3.3. I suggest removing this section. There is no real significance of these results because it is basically an algebraic extrapolation of results from few samples to global. These numbers do not mean anything and can be readily verified. As mentioned above, the sampling is extremely biased and limited and cannot be used to discuss global carbon stock. Everyone reads the paper can easily guess that the implication of the results of the paper can potentially be large on the global scale. However, there is no reason to include these numbers. The community is getting more confused from groups from limited ground data trying to artificially create large scale science re-

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sults. We should try to be careful about throwing these numbers out there without any justification. What if, having enough samples over the tropical forests suggest that the biomass may increase or decrease depending on the landscape (topography, geology, soil) variations, climate, and disturbance history and the ensemble effect is negligible.

8. Section 4.1.2. The authors do not mention the use of Lorey's height as a good height index that can correct for both small and large tree biomass estimation and work that can work on plot scales rather than tree level. One of the main problems with current allometric equations is their application on the tree level data. By developing new allometry that can be applied on the plot level, using parameters such as Lorey's height, basal area, regional wood density values. If the goal is to be able to estimate biomass relatively accurately over landscapes, plot level allometry may be the way forward. Even after bringing together many destructively sampled tree data sets, we may still have large errors in estimating biomass. Plot level allometry can be readily integrated with future remote sensing data when height, basal area, and average wood density values may become available spatially and globally.

9. Section 4.13. This section is long and it is all speculations. I suggest the author reduce or delete the section. Most of the material in the second paragraph about "Harmattan Winds," "herbivore fauna," arrival of humans in south America 12000 yr ago (there is evidence of 40,000 years of human presence in Brazil.), are all anecdotal examples, and sometimes wrong, and are not relevant to the paper. There is no reason to spend some words (more than the description of the method and results) on these remotely related issues.

10. Section 4.1.4. Keep this section. It is short and relevant to the paper.

11. Section 4.1.5. You can add this to section 4.1.4 based on the relevance of forest structure on the regional allometry and variations of the biomass. The results on crown size distribution from Barbier et al. 2010 may not be as relevant. Central Amazonia with wetter climate appears to have smaller crown size and tree stature based on some

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more recent results from remote sensing and ground data.

12. Section 4.2. The remote sensing section can be reduced or deleted based on the earlier general comment. The only relevant implications of the paper for remote sensing are: 1. Remote sensing provides height and this height can be integrated in the allometry (perhaps more on the plot level than tree level). 2. Height included allometry may be more relevant to remote sensing estimation of biomass. In fact, most remote sensing data using height and tropical field data for calibration to estimate biomass show similar results as the paper. Lower biomass in South America and higher in Africa and Asia. In general, the comments about remote sensing techniques and papers including Baccini et al. is not valid and fair. These comments are only relevant when the authors are writing a remote sensing paper. Otherwise, it clearly sounds like passing a judgement without any in depth analysis or understanding the work presented in the papers.

13. One key issue about estimating biomass is also scale of analysis. Eventually allometry should be applied on the tree level data collected within a plot. The size of the plot is extremely important in estimating biomass and the errors associated with it. In general, the difference between allometry equations reduces (not disappear) when applied on larger plots ( $> =1$ ha) relative to small plots. Studies that use small plots ( $< 0.2$  or  $0.25$  ha) often have large errors in estimating biomass regardless of including or excluding tree height. The effect of tree height may also be less or more important when the plot size increases. The authors use large plots in their analysis. However, not all field measurements globally are in sufficiently large plots.

14. Section 4.3. This section on sink and source is also a typical algebraic extrapolation that provides numbers without any verification. In fact, we find changes in sink and source values depending on the use of allometry with or without height regardless of any drought impact. A careful analysis is required to separate the effect of height, allometry, and sampling in understanding the source and sink effects on the pan-tropical scale carbon. Who knows which one has the largest effect and in what direction unless

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such an experiment is developed and implemented. In general, all of these points and potential implications can be lumped together in a small paragraph in the discussion section.

15. Section 4.4. Another discussion section that can be easily deleted without any damage to the paper. Comparison with global emissions from IPCC is really a stretch of the findings of the paper.

16. Section 4.5. Another section that can be deleted without impacting the paper. No need to have a large section on this.

17. Reduce the conclusion by focusing on the findings of the paper. There is no need to bring in 21 century estimate of tropical forest area and its errors in the conclusion.

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