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Discussions
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Interactive comment on "Imaging tropical peatlands in Indonesia using ground penetrating radar (GPR) and electrical resistivity imaging (ERI): implications for carbon stock estimates and peat soil characterization" *by* X. Comas et al.

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We truly appreciate all comments and constructive revisions from all authors. Below is an explanation, point by point and organized by reviewer, detailing how each comment has been addressed. The manuscript has been substantially modified to address all comments from the reviewers. We particularly stressed: 1) restructuring and shortening of all sections to make it less technical; and 2) better defined objectives which are stressed in the discussion. Also, we are including two versions of the new manuscript, one annotated and showing the changes to the previous version, and a clean one with

all changes accepted. Additionally a total of 4 figures have been modified following some of the comments from the reviewers and are also attached here.

Reviewer #1:

- 1. In Figure 4 (a), could you explain why you use 200 MHz instead of 100 MHz for GPR analysis? Most of the profiles shown in this paper were collected using the entire array of antennas available (i.e. 50, 100 and 200 MHz). The 50 MHz antennas however malfunctioned during the end of the campaign and therefore were unfortunately not available when investigating "deep peat" sites. For brevity purposes, only one frequency per profile is shown. Since Figure 4 corresponds to a very shallow site, we chose to display the frequency that provides best vertical resolution for shallow depths. The 200 MHz antenna has the lowest depth of penetration while providing the best vertical resolution (plus the smallest ground coupling effect) and for that reason is chosen here since we are targeting a minimum thickness of the peat column of only a few cm.

- 2. In Figure 5 (a), "TG2.1-TG.3" is misspelled and "3.4 m" is too large. Misspelling in the legend is now corrected. We do not however understand the reference to 3.4 m being too large. This reading corresponds to the depth of the peat-clay interface as detected from coring.

- 3. In Figure 7, what does black diamond mean? Black diamonds have now been removed from the figure.

Reviewer #2:

- 1. Organization This paper has much content about technical method and its results on "Discussion". I think it is not a proper article. Please consider reconstructing this section into two sections, Methods and Discussion. Moreover, the paper lacks information about how to estimate peat thickness by using the GPR and ERI data. I suggest the authors should add more information in the Introduction and clearly explain it in Methods. We agree that the original version of the paper was perhaps too heavy on

methodology. For that reason the introduction has been rewritten to focus on the importance of peatlands and current estimation of peat volume and thickness in peatlands. A lot of specific details on methodology have been removed to stress those points above. Also, see next comment for more specifics on how the introduction has now been focused on peat thickness characterization as suggested by the reviewer. The methods section has also been considerably shorten particularly some of the more technical details on inversion of ERI datasets. The discussion section has been also substantially rewritten and new subsections have been added to stress results and implications and many of the more technical aspects have been removed, such as some particularities on how picks for both GPR and ERI datasets were conducted. See more details about these changes in point number 4 for Reviewer 3. Some remarks have been also added to the abstract and conclusions to clarify objectives and acomplishments.

- 2. Introduction The paper is currently too “heavy” in “Introduction”. The authors should just briefly describe the importance of peatland and put the focus more on the methodology part, for example, about the conventional methods used for peatland and its technical problems, and also the estimation of peat thickness using the GPR and the ERI. See response to previous comment above. The introduction has been shorten and mostly rewritten to exactly stress peatland importance (paragraph 1); traditional approaches to peat thickness (and problems related to those approaches) (paragraph 2); previous studies using geophysical methods used in this study and justification for applicability in tropical systems and focusing on peat thickness characterization (paragraph 3), and objectives of the paper (paragraph 4). Following the reviewer suggestion, paragraph 3 is now rewritten and focused on previous studies using GPR and ERI to characterize peat thickness.

- 3. Objective The objective is not clear, because the estimation is not alluded on Introduction. I think that this paper will be more suitable for this journal if authors develop more accurate estimation by using the GPR and the ERI data in a woody peatland. As described above the paragraphs preceding the last paragraph in the introduction

are now focused on peat thickness characterization, including several recent studies using GPR to compare estimates from traditional coring methods. While we stress the results from those studies as related to accuracy when comparing methods at larger (basin) scales, we intend to focus on smaller scales and exemplify how our datasets could be extrapolated to larger scale investigations. The objectives have been also slightly modified to stress that the intention of the paper is to investigate the potential of the methods for peat thickness characterization.

- 4. Discussion In the results of peat thickness estimation (Fig. 9), the author describes the appropriateness of the estimation, but the values have a quite large variation. Readers will interpret the estimation as not accurate and cannot be used. In order to avoid this kind of misunderstanding, the author should explain about the error. Additionally, the results should be described in “Results” section. As previously explained and following previous comments from the reviewer, the discussion has been substantially modified. In general we have added subsections to make things clearer. We have included in several instances how GPR is able to detect thickness at cm vertical resolution, while ERI is not as suitable for accurately detecting this boundary(i.e. paragraph 2 of the Discussion). The main advantage of ERI however is the fact that is less limited when investigating deep peat columns (i.e. where the GPR signal is not able to reach). In that regard our error analysis in the discussion section also reflects this showing average errors of +/- 0.05 m for GPR while exceeding 0.5 m for ERI. For that reason only our GPR estimates are used to quantify changes in C stock estimates as described in paragraph 5 of the Discussion.

- 5. Specific comments 1. Please add the explanation the calculation of carbon of Table 2. If we understand this comment correctly, further details on Carbon analysis are included in the methods section (section 3.3).

- 6. L292 & L299: Generally, the citation does not list it in “Results”. If we understand this comment correctly, citations should not be included in the results section. For that reason in both cases they have been removed and/or moved to the discussion section.

- 7. Figure 2: What is “woody layers?”? In order to avoid confusion, the term "woody layer" in Figure 2 has now been replaced with "woody area" as explained in the text (section 4.1).

-8. Figure 2 and 5, 6: Water table elevation is water table depth "Water table elevation" has been replaced with "water table depth" in all figures.

Reviewer #3: - 1. The paper presents interesting data on a critical issue: estimation of carbon stocks of tropical peatlands. However, the paper, as currently written, is not well structured for Biogeoscience discussion. It is too technical and focused on the geophysical methods. The paper should be restructured and extended for a publication in Biogeoscience discussions or sent to another journal more focused on geophysical methods. The authors should, in the discussion section, present direct answers to the objectives stated at the end of the introduction. The demonstration of how geophysical methods help to increase the accuracy of peat C storage should be more clearly presented. As further detailed in the responses to the comments from Reviewer 2 the introduction has been restructured and many of the more technical details related to the methodology part have been removed. The methods section has been substantially shorten, particularly the ERI section, where some of the more technical details on inversion of datasets have now been removed. Furthermore, we have now included subsections in the discussion with a clear mention to the objectives as related to the text in the end of the introduction. We hope this helps clarifying how the discussion is answering those objectives. The specific subsections are: peat thickness, peat C stocks, peat formation, and peat matrix.

- 2. A great interest of this study and geophysical method is, as stated in the conclusion, the ability to detect wood buttress in the peat matrix. These features are critical in tropical peat system and strongly influences peat density and carbon stocks estimates. The author should emphasize this aspect and how it could actually improve the carbon stock estimates. Although the feature described in the end of the discussion seems to be rather isolated in our dataset we have now expanded our interpretation of buttressed

tress by including some recent study on tip-up pools by Dommain et al, 2005 (see reference list in manuscript). We have also included the importance of such features from a perspective of carbon accumulation rates and paleo-environmental reconstructions.

- 3. The results description is too detailed. Certain details of the results section have been shorten, particularly as related to some technical aspects of GPR data processing (i.e. migration), or ERI results as compared to values obtained in northern systems. Description of figures has not been modified since we believe that they are fairly concise and they mainly stress results as related to peat thickness and thus are critical for the points risen in the discussion.

- 4. The discussion section should be shorten and structured and emphasize a few clear points. As already explained in our response to comment 1 from reviewer 2, the discussion section has been substantially rewritten and reorganized to make it shorter, less technical, and to emphasize objectives as stated in the end of the introduction. These objective are highlighted as the headers of subsections as follows: 1) peat thickness; 2) peat C stocks; 3) peat formation; and 4) peat matrix. We have also deleted substantial parts of the discussion for brevity pursposes (i.e. some of the discussion towards the end as related to the properties of the peat matrix, see annotated version).

- 5. Detailed comments: Table 1: Please provide the peat bulk density values that were measured to calculate ‘peat profile C stock’ (p202, l3). Peat bulk density values are now included in Table 2

-6. P203, l19-21, How do the authors relate resistivity values to ionic concentration? First we would like to clarify that we do not intend to generate a formal relationship between resistivity and ionic concentration. As mentioned in the paper however, and as explained in previous research in other peatlands ionic concentrations may dictate bulk resistivity values. For instance, resistivity values for the upper layer of the peat column are comparable with values obtained in northern peatlands and partly attributed to the low ionic concentration of the peat pore water in these northern systems.

Reviewer 4: - This paper has explained the prospects of the use of ground penetrating radar (GPR) and electrical resistivity imaging (ERI) as an alternative approach of peat depth and peat carbon estimates as well as for characterization of other features of tropical peat- land. I gathered have a clear picture of what this technology can do for peat depth estimate and it's a good enough information. This paper will be more powerful if the estimate of C stock is more clearly explained – what these two techniques can and can not do in terms of C stock estimate. As explained earlier the paper has been substantially reworded and reorganized to stress the potential of the methods as related to C stock estimation. Asides from all the changes explained above (particularly in the discussion section), the text in the discussion related to our first objective (refine peat thickness and C stocks) has been substantially reduced in size by removing some technicalities in the approach, and reworded to stress more clearly how each method can be used to refine peat thickness estimates and consequently C stock estimates. The discussion now also includes a direct mention to the objectives as sub-headers to stress how those are addressed in the paper. We particularly stress both the potential and limitations of the methods. Furthermore, changes to the abstract and conclusions have been also included to stress the potential and limitations of the methods and the relation between our peat thickness estimate and C stock determination.

- Specific Comments: 1. Title: I raised expectation that this technique can speed up the estimate of peat C stock, but I did not get satisfactory explanation on this aspect. Be more specific in the title. We have now replaced "carbon stocks" with "peat thickness" in the title to be more specific about the objectives outlines in the manuscript.

2. Abstract, last sentence: Make a clearer statement whether with the absence of wood layers etc. this technology can provide a reliable estimate of peat C content and how close the estimate is compared to the analytical technique (peat sample analyses of bulk density and C content). Following some of the previous comments we have now included a few sentences that specifically provide a quantification of our estimates in the abstract (see annotated manuscript version).

3. Introduction Line 23: Indonesian peat area estimate is no longer 21 Mha (Wahyunto et al. 2003, 2004). Ritung et al. 2011 (in which Wahyunto is a coauthor) has made a new estimate of 14.9 Mha. This new estimate is used for national development agenda such as the moratorium map. Please check at: http://bbsdlp.litbang.pertanian.go.id/index.php?option=com_phocadownload&view=category lahan-gambut-indonesia&Itemid=185 We have now included that estimate and reference in the text.

Page 194, line 12: Include the more recent papers such as Ballhorn et al. (2012). Following some of the previous comments, this sentence has now been removed and therefore the reference suggested is no longer applicable here.

Page 194, line 24-27, explain which source of uncertainty among area, depth and volume that can be tackled by the proposed techniques. Can these technique potentially be adapted to airborne observation for speeding and improving the quality of conventional peat distribution and depth mapping? We have now included the following sentence to address the reviewer's comment: "Refinement of estimates on depth and volume of peat soils in Indonesia is the focus of this paper."

Page 195, line 7, "These peats accumulated at rapid rates". Usually people refer to slow rate of formation under natural condition and rapid rate of decomposition under drained peat. Following some of the previous comments, this sentence has now been removed from the text.

Page 196, line 25, be clear whether carbon content is the main objective. Otherwise remove the phrase between brackets. It raised lots of expectation. We agree with the comment and sentence in brackets has now been removed.

Page 197, line 2: (related to the second objective, above) I would expect that this technology will improve the assessment of peat subsidence and below ground C stock change. We also agree with the comment and the sentence in has been added to the text.

Page 197, line 26: “4-5 m of peat”, do you mean “4-5 m deep peat”? Remark has now been added.

4. Methods Page 199, line 4: “being 50-70 depending on peat type”. Do you mean “being 50-70 times”? 50-70 refers to the value of relative dielectric permittivity, which is unit less. We have included a remark in the text that the number refers to the value of relative dielectric permittivity.

Page 200, line 2: “particle size distribution”? Grain has been replaced by particle as suggested here. Please note that the paragraph has now been placed in the end of the first parafraph under the description of ERI method (section 3.2).

Page 201, line 11-13: Either unclear or it involves grammatical problem. Following some of the previous comments, this sentence has now been removed from the text and no longer applies.

Page 202: No explanation about C content determination technique. We have no incorporated more information about the methodology used for C content estimation.

5. Table 2: Add a column of bulk density Mean peat bulk density has now been added in Table 2.

6. Conclusions Make a clearer statement of what these technique can do about C content estimation, or clarify in the Introduction that it’s not part of the objective. We have added a few sentences in the conclusions to clarify accomplishments as related to peat thickness determination. Furthermore, a few sentences have been added in the third paragraph of the discussion to clarify that GPR/ERI are unable to directly estimate C content in peat samples and therefore extraction through coring and subsequent laboratory analysis are required.

Please also note the supplement to this comment:
http://www.biogeosciences-discuss.net/12/C1337/2015/bgd-12-C1337-2015-

supplement.zip

Interactive comment on Biogeosciences Discuss., 12, 191, 2015.

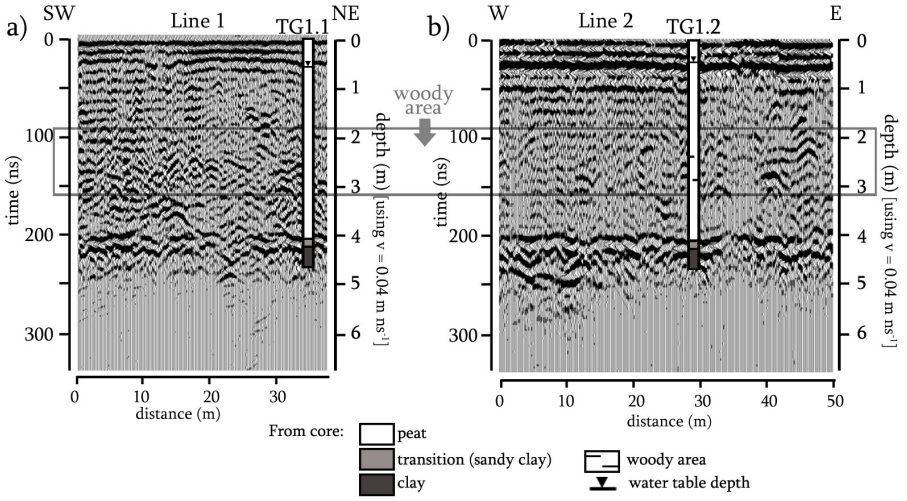
a)
SW
Line 1
TG1.1
NE
b)
W
Line 2
TG1.2
E
woody area
time (ns)
depth (m) [using v = 0.04 m ns⁻¹]
distance (m)
From core:
peat
transition (sandy clay)
clay
woody area
water table depth

Fig. 1.

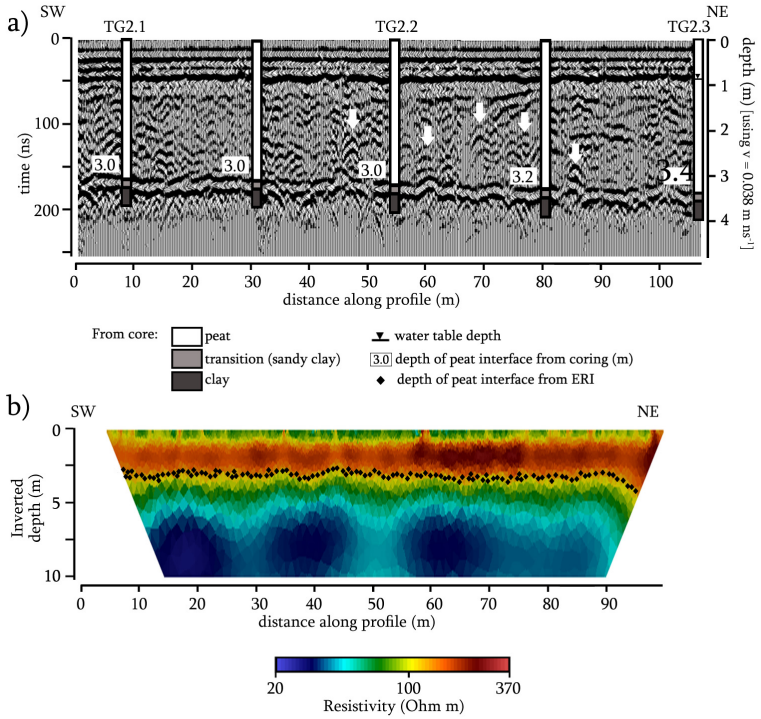
a)
SW
TG2.1
TG2.2
TG2.3
NE
time (ns)
depth (m) [using v = 0.038 m ns⁻¹]
distance along profile (m)
From core:
peat
transition (sandy clay)
clay
water table depth
depth of peat interface from coring (m)
depth of peat interface from ERI
b)
SW
NE
Inverted depth (m)
distance along profile (m)
Resistivity (Ohm m)

Fig. 2.

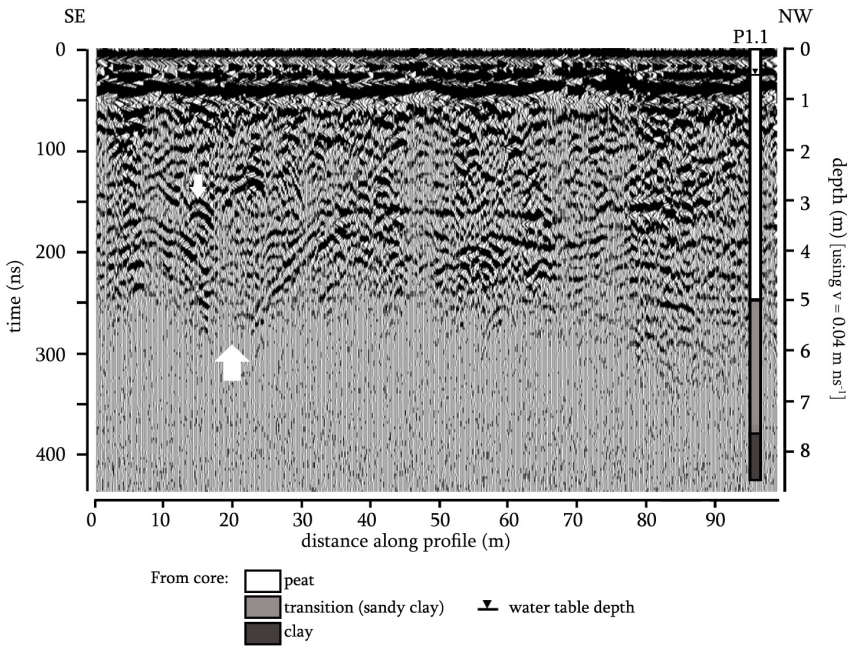
SE
NW
P1.1
time (ns)
depth (m) [using v = 0.04 m ns⁻¹]
distance along profile (m)
From core:
peat
transition (sandy clay)
clay
water table depth

Fig. 3.

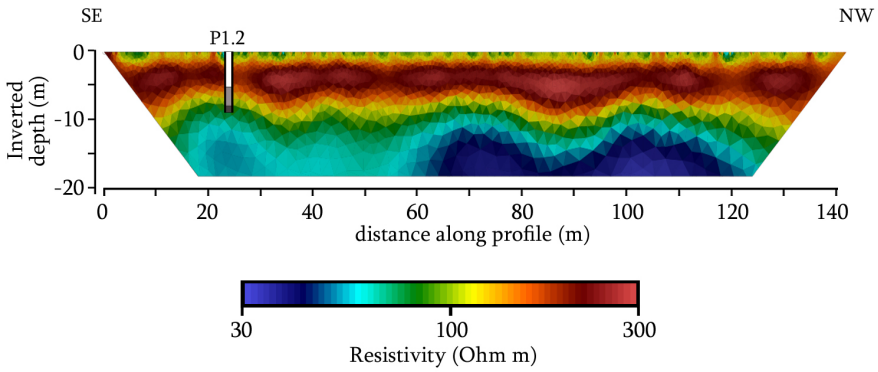
SE
NW
P1.2
Inverted depth (m)
distance along profile (m)
Resistivity (Ohm m)

Fig. 4.