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Biogeosciences
Discussions

Interactive comment on "Structural analysis of three global land models on carbon cycle simulations using a traceability framework" *by* R. Rafique et al.

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Anonymous Referee #2 Received and published: 28 July 2014 1 General comments Comment: In this paper, the innovative traceability framework established and applied to CABLE in Xia et al. (2013) is applied here to CABLE, CLM3.5-CASA and CLM4. Although the traceability framework is intriguing, it is unclear which conclusions, if any, could not have been gained through simple examination of the flowcharts presented in Figures 2-4, which summarize model structure, pool size and residence times, or from Figures 1 and 6, which display model output. The results and their discussion do not clearly outline the relevance of findings, or how these might be used to inform

model development, benchmarking or analysis, although this is presented as a central contribution of the paper. The traceability framework is also mentioned as a strategy to characterize the C cycle in models, but conclusions regarding model complexity are made on the basis of the number of pools, not on traceability results.

Response: Based on the reviewer's comments, the results, discussion and conclusion sections have been revised substantially. We hope that the RM presents the findings of this study a more clear way.

Comment: The main differences found relate to differing spatial distributions of NPP and ecosystem C storage between CABLE and CLM*. CABLE has much larger ecosystem C storage in arctic regions than CLM*, and CABLE indicates boreal regions as having the largest NPP, whereas CLM* have the largest NPP in tropical regions. Which of these models agrees more closely with MODIS NPP, or modeled residence time from HWSD and MODIS NPP? What drives these differing patterns? If the greatest differences observed are spatial, why is the traceability framework then applied at the mean global scale?

Response: The main purpose of this study is to examine the models structures and understand their behavior. The full detailed spatial pattern was not in the scope of this present study. The spatial maps of modeled NPP, carbon storage and residence time were used as an example to see how the modeled results can be interpreted. For this specific study, we used global mean values form all three models to see how much they deviate from the observed data. These modeled global values were also examined against the available measured data. These mean values were further used in detailed model analysis to estimate the NPP partitioning, transfer coefficients at individual pool levels. We have clarified the goal and scope of this study more clearly in RM.

Comment: The traceability framework seems to have primarily been applied to determine the mean global NPP and mean global residence time of three model. How does this "help fully characterize the behavior of complex land models"? What insights does the traceability framework provide which other appraoches cannot? There are mentions throughout the paper of the benefits and importance of the traceability framework, such as: “This study provides useful information for data assimilation, benchmark analysis and future model development by evaluating the relative importance of model components and source of variations.” However, these statements are empty unless the advantages of the traceability framework are well explained in the introduction, and unless the results, discussion and conclusions make use of the unique contributions of the traceability framework, and provide tools or insights which could assist with model development, benchmarking or data assimilation.

Response: We have replaced the word “fully” with “largely” to stay within the scope of the present study which is to understand the models structural differences. In this study, the traceability framework helped to dissect the models into different components (such as NPP partitioning and transfer coefficients into different pools) which play an important role in determining carbon residence time and thus the carbon storage capacity. To explain further, we have revised the introduction section to explain the traceability framework based on and in response to reviewer’s comments.

2 Specific comments

Comment: Was ecosystem C storage similar or dissimilar among models? Why did certain models have more or less C storage than others?

Response: The total carbon storage among models is not largely different. However, the total carbon storage in plants biomass and soil pools does differ among different models. For example, CLM4 showed more storage in plant biomass while CABLE showed higher storage in soil pools. The higher storage in CABLE is mostly due to slower turnover rate of soil carbon. This point has been clarified in RM to make the finding more precise.

Comment: Abstract lines 11-12: “the spatial distribution of total ecosystem C storage and residence time differ greatly among the three models”

Response: The word “greatly” has been replaced with “considerable” in RM to be consistent with other information in results and discussion sections.

Comment: Discussion p.9994 l.16-17: “The land models used in this study displayed considerable spatial variations in the global distribution of NPP, total C storage and C residence time.”

Response: The information in this sentence is now consistent throughout the RM.

Comment: Discussion p.9996 l.4-8:“the NPP is not highly variable among the models due to similar environmental conditions. As expected the resultant C storage was also very similar among the models. The variations amongst these models can also be largely explained by examining the C transfer rates from one pool to the others”

Response: The confusion has been clarified in the RM. We believe the information throughout the manuscript is more consistent now.

Comment: Abstract lines 12:15 describe comparisons of models against “measured” C storage and residence time. It would be helpful to mention which measurements are used, and to refer to these as estimates, as MODIS NPP is not a true measurement. If there is a lack of space, the sentence beginning with “However,” could be deleted entirely as it repeats details already mentioned in the previous sentence.

Response: This has been clarified and the reference sentence has been deleted from the abstract of RM.

Comment: The introduction aptly mentions that the strong dependence of C storage on NPP and residence time has been well-established in previous research. Residence time is then described as less studied, and challenging (p. 9981 l. 19:21). Some further explanation and justification of these statements on residence time is required. Why is residence time challenging? What aspect of the association between residence time and NPP has not previously been well established, but can now be described using the traceability framework.

Response: The introduction section has been revised based on and in response to reviewer's comments.

Comment: The third paragraph on p.9981 and first paragraph on p.9982 provide justification for using the traceability framwork on the basis that models are complex, and their uncertainties need to be attributed to their sources. It concludes with: "For example, Mishra et al. (2013) have identified the modeling uncertainties of soil C in permafrost regions but insufficiently attributed these variations to their sources. This shortcoming can only be addressed after gaining a thorough understanding of the model's fundamental structural differences and understanding its traceable components controlling the C dynamics." In this paper, is the traceability framework applied to attribute model uncertainties to their sources? If so, how is this achieved, and where are the results from this analysis? The traceability framework appears to describe differences in C dynamics according to differences in soil, vegetation and litter pools, not uncertainties. The comparison of modeled residence time to estimated residence time using modeled residence time from MODIS NPP and HWSD represents a further model output intercomparison, not an attribution of errors to their sources.

Response: No uncertainty analysis was performed in this study. The main objective was to compare the models stricture based on the guideline provided by traceability framework. However, the framework has the potential to attribute the uncertainties to the sources of variance among models as described in Xia et al., 2013.

Comment: A stated goal of the traceability analysis is to "characterize the complexity of C cycle in the models" (p. 9983 l. 2-3) but in the results sections, the number of pools alone is used to inform comparisons of model complexity. How did the traceability framework assist in this stage? Isn't it standard for model intercomparisons to assess differences in model structure to explain differences in model outputs?

Response: Traceability analysis helped to examine models structure, in terms of number of pools, NPP portioning coefficients, transfer coefficients and thus the residence

time. In section 3.3 of results we describe all of these components in detail and explain how the models used in this study differ from each other in terms of allocating NPP and transferring carbon from one pool to other. I In order to clarify further our finding. We have revised the results section based on and in response to reviewer's suggestion.

Comment: The description of models could safely be moved from out of the methodology section, since they were not built or modified for this paper. Furthermore, the information presented on these models differs widely, and makes it difficult for readers to examine differences between models. I would suggest rewriting and lengthening these descriptions so that they provide the central equations, environmental scalars, and processes through which C is transferred in order to inform later discussion. It is also crucial that obvious statements (e.g. that CLM3.5 is used for climate change simulations, or that CO2 is released through respiration), or any information provided directly in the flowcharts or introduction, be removed to reduce redundance. The descriptions at present are not informative for interpreting results.

Response: The description of the models in method section has been improved as much as possible. We hope that the current information is more specific and consistent for all three models.

Comment: Why was the SASU method used for only two models? Could this have affected the output?

Response: The main purpose was to spin up the models to get to steady state without preferring any particular methods. We observed no significant difference in the results obtained from two different methods of "spin up".

Comment: Why do the models use different meteorological forcing? If different forcings are used then there must also be some comparison provided of the forcings. There are otherwise too many confounding factors which complicate any true model intercomparison.

Response: This comment has been clarified in response to comments of reviewer 1 (see above).

Comment: "These simulations were customized to not account the effect of any disturbance effect" is unclear, and needs to be rephrased.

Response: The sentence has been changed in RM.

Comment: Why were three different resolutions used for model runs? What does this assist with? How does the traceability framework make use of multi-scale data? Providing justification for the method used, and explanation of its implementation, should be established in the methodology section.

Response: The point has been explained in RM in response to comments of reviewer 1 (see above).

Comment: The first section of the diagnosis provides motivation or context, which belong in the introduction. Instead, this subsection should fully describe the implementation of the diagnosis.

Response: The correction has been made in RM.

Comment: The fraction of C entering each pool is described as a hidden variable; however, can this not be easily determined from model output? Why is a traceability framework required?

Response: The fraction of carbon can be obtained from models' output. However, the traceability framework was used as a guiding principle in performing the model structural analysis throughout this study.

Comment: Similarly, why is a traceability framework required in order to determine accumulation in pools?

Response: The traceability is used to determine the contribution of different processes to accumulation pools, or highlighting the sensitivity of the pools to different processes.

We are suggesting this as a useful tool for this purpose. We have presented the traceability in more clear way in RM and hope that helps to further explain this specific point.

Comment: Does Figure 6 represent mean values from 2000, the year for which MODIS NPP was used? Please also provide diagrams of the "measured" data (modeled from MODIS NPP and HWSD), as well as figures indicating the difference between spatial outputs from these models and the "measured" data.

Response: Yes, the MODIS NPP was also from year 2000. We have provided the global numbers of measured data in figure 2. One of the aims of this study is to examine the models against the global mean observed values, independently. The extra information about the spatial patterns of measured data is beyond the scope and the main objective behind the structural analysis of models presented in this study. We thank you for this idea that could potentially be the basis of a future study.

Comment: How did you combine HWSD with MODIS to get C residence time? Do you consider the resulting estimates to represent measurements of C residence time, or would these better be considered as 'estimates'? Has this appraoch previously been applied? How accurate are the HWSD and MODIS NPP considered?

Response: The residence time was estimated as the ratio of carbon storage (HWSD) to NPP (MODIS). We have clarified this in the method section of RM. Although the HWSD and MODIS data has received some critics in the literature but we believe it is still being used and considered reasonable method hence we used it in our study consistent with other previous studies (Todd-Brown , et al., 2013, 2014).

Comment: All context and justification belong in the introduction, and all methods belong in the methodology. Portions of the second paragraph of the results belong in the methodology section. Restructure the methodology and results sections so that they correspond to one another.

Response: The methods, results and discussions sections have been restructured based on and in response to reviewer's comments.

Comment: Why did you do a comparison of spatial, global-scale model estimates from process-based models (CABLE, CLM*) with MODIS NPP (?) using barplots of mean global values? Over which period of time were these values averaged? Were these results generated using the traceability framework, or are they simple mean values from model output?

Response: The global mean values were averaged over year 2000. The bar plots (using mean values from models outputs) were used to obtain the total carbon storage capacity in plant and soil (fig 2), and compared to measured data. This analysis further helped to identify models differences at finer scale (fig 7).

Comment: Why are spatial patterns of NPP and ecosystem C storage more similar in CLM* than CABLE?

Response: The spatial variations in three models have been described more clearly in the RM.

Comment: The description of model allocation schemes should be one of the central components of the model description subsections, presently in the methodology. This only belongs in the discussion if it is used in the interpretation of results.

Response: The description of model allocation schemes have been moved to models' description section in method section in response to this comment.

Comment: Are the allocation schemes in CABLE and CLM 3.5 constant? If so, what purpose did the traceability framework fulfill? It seems a major part of this project involves summarizing what is already known about these three models.

Response: Based on our current information, the allocation schemes in CABLE and CLM3.5 are constant. Although there are many model inter-comparison studies but the basic structural analysis differences are not clearly highlighted by the studies published in open literature. Traceability framework helped us to quantify the structural

differences in these three models for better understanding of models' behavior yielding different results.

Comment: Subsection 3.3 should be summarized in a table, and the results should be described in relation to existing findings rather than merely repeated.

Response: In order to present the models' allocations, transfer, residence times, and storage capacity, we assumed the flow diagrams are more suitable than tables. There are too many numbers with different level of complexities and table(s) may not be a suitable option to present them to convey the whole picture. All the numbers for three models have been given in the flow diagrams (Fig 3-5). However, there is also a table which gives the very basic fundamental differences among models used in this study.

Comment: CABLE seems to represent fine roots as having the same residence time as wood, which is contrary to many other models, and contrary to what is known. CABLE is described as having the most realistic spatial distributions of NPP, and as having the best performance in terms of C storage capacity (concusion: p.9999 l.8-12). On what basis do you decide that CABLE performs best in terms of C storage capacity, when its roots and wood have the same residence time? This would be one of many central points that should be brought up in the discussion.

Response: The CABLE model's best performance was examined in comparison with the observed data as presented in Fig 2. The total carbon storage in plant biomass from CABLE is ∼600 Pg which is very close to the observed data. Similarly, the total carbon storage in soil from CABLE is ∼1200 Pg which is also very close to observed data. On the other hand, CLM4 and CLM3.5-CASA showed over estimation in plant biomass and underestimation in soil storage part. Overall, the models' results show that the CABLE model is performing better. We have revised our discussion section and offered the necessary caveat that the results of this study could benefit from future verification by future studies.

Comment: It seems the final result of this paper is summarized in Figure 8, which shows a scatter plot of NPP and residence time for the three models. However, only one value per model is shown in each scatter plot. Is this the global mean NPP vs global mean residence time? What insights into model performance does this provide? The scatter of the points does not appear to have a strong shape or direction, and these plots are not well interpreted in the discussion.

Response: The global carbon storage capacity in models is determined by the global NPP and global residence time. The hyperbolic curves in the figure represent the constant carbon storage capacity at given NPP and residence time values. The 2nd and 3rd panels of the figure 8 show more clearly how the NPP and residence time play an important role in determining the carbon storage capacity. For example in panel 3rd, the highest carbon storage capacity was observed at higher residence time and moderate NPP value. Based on reviewer's suggestion, Figure 8 has been more clearly described in discussion section of RM.

Comment: Why are mean global values used, when the largest differences in models exist at the spatial scale? Can the traceability framework be applied over selected regions to gain insights into why

Response: There are considerable differences in spatial distribution of carbon storage, residence time and NPP values based on different assumptions in models. The traceability framework can be applied at regional scales to examine these models differences. However, in this particular study, the main focus was on global scale and to assess the models' behavior at global level. Since this traceability approach has not been used for model intercomparison, we started with a focus on global simulation as a more suitable choice. Consistent with the reviewer's comment, we are suggesting a focus on understanding the complexity of models at regional level to be a focus of future studies. . This suggestion has been made in the discussion section of RM.

Comment: There are many unfounded statements in the last section of the discussion, conclusions, and abstract that describes what the traceability framework will do, or

has done, but these appear unaccomplished in the text. Can the residence time, and associations with NPP, be acquired from model output without a traceability framework? Which advantages does a traceability framework provide?

Response: We have substantially revised the abstract, introduction, methods, results, and discussion and conclusion sections of the manuscript based on and in response to the reviewers' comments. We hope the major revision is responsive to the reviewers' comments and suggestions.

Comment: A central result from the traceability analysis of CABLE by Xia et al. (2013) is that environmental scalars control C dynamics. It is strange that the analysis presented in this paper was then not informed by this finding, but instead repeats this recommendation. "One way to elaborate the analysis is to further examine the effects of environmental scalars and environmental forcing data which strongly influence the C residence time and transfer from one pool to another." Why were these environmental scalars not presented? If meteorological differences drive differences in model behaviour, then why were different environmental met forcings used to drive models?

Response: The main purpose of this study was to perform the model intercomparison based on their structural analysis. Traceability framework helped us to accomplish this objective. However, this study doesn't fully implement the traceability framework as it was described in Xia et 2013. Therefore, we have suggested including environmental scalars in further studies if warranted. We have substantially revised the manuscript and hope that the core messages of this study is more clear now.

Comment: The main conclusion from this type of analysis cannot be simply that there are differences in models because of differences in C transfer and pools. After completing this analysis, the results should be fully describe why certain models have greater/smaller NPP, residence times, storage etc., and describe these differences according to specific aspects of model structure.

Response: The conclusion section in RM has been carefully revised according to reviewers' suggestions.

Comment: Provide justification for this statement: “The results of this research will provide valuable information for the future study of model development, data assimilation and benchmark analysis.” How can model development, data assimilation or benchmark analysis be improved using the results and discussion you have presented?

Response: This section has been significantly revised in RM to explain the justification of the implementation of present study in model development, data assimilation and benchmark analysis. We hope this satisfies structure the reviewer's concern.

Technical corrections

Comment: The clarity of the ideas presented in this manuscript is undermined by incorrect use of the English language. Grammatical and spelling errors need to be fixed, and sentences need to be better structured. The paper as a whole needs to be restructured to allow readers to quickly grasp what is being presented (e.g. methods in methodology section, results in the results section).

Response: The English language has been checked and improved including sentences and grammatical errors. We have also restructured the manuscript according to all comments provided by the reviewers. We hope the present draft of manuscript represent more clearly the findings of our study. .

4 References Xia, J., Luo, Y., Wang, Y.-P., and Hararuk, O.: Traceable components of terrestrial carbon storage capacity in biogeochemical models, Global Change Biology, 19, 2104– 2116, 2013.

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