Responses to referees' comments (bg-2013-56)

We have fully considered the referees' comments in the revision and improved the manuscript accordingly. Answers to referees' questions are italicized and in blue color.

We thank anonymous referees for their thoughtful and constructive comments and helpful suggestions. We also thank Dr. Liu for his careful handling of this manuscript.

Anonymous Referee #3

General comments: The authors of this manuscript made a good attempt to reduce the uncertainties of atmospheric inversion of the CO2 flux by integrating forest age information with atmospheric CO2 observations. Using the NPP-based age factor to constrain the spatial patterns of CO2 fluxes at the continental scale is rational and reasonable because of the connections between the productivity of forest ecosystems, carbon sequestration, and the CO2 flux. By integrating spatially-explicit information on forest stand age with atmospheric CO2 observations from the global observation network, the authors have convincingly proved that the forest age factor method was effective for reducing the uncertainties of atmospheric inversion of the CO2 flux, resulting in improved the inversion estimates of the flux to some degree. This method should benefit the inversion research community and may promote similar research in this field for improving atmospheric inversion of the CO2 flux.
Datasets used in this manuscript consist of the forest age map for North America derived from forest inventory data, large fire polygons, remotely-sensed data, gridded NEE dataset for temperate North America over the period 2000–2006 extrapolated from the NEE measurements to large areas with MODIS, and observations of global atmospheric CO2 concentration (The GLOBALVIEW-CO2 data). They are robust, well developed, appropriately used and cited in the manuscript.
In sum, this work is considered timely and relevant to a current problem: the uncertainty in atmospheric inversion of the CO2 flux, and fits the Journal BGD properly in content.
The manuscript is well-written and organized, logical, easy to comprehend, containing all necessary background information. Previous work relevant to this research has been well cited. The results are clearly presented and well discussed.

We thank Anonymous Referee #3 for the positive and constructive comments, which we used to improve our manuscript. More detailed description of the changes we made per comment is given below.

Specific comments:

1. Page 4793, Eqn (5) and (6): It may help readers better understand the relationship between fs and f(age) if an explicit equation for f(age) and fs can be provided;

Answer: *We rewrote equation (6) and redefined some relevant items according to the detailed suggestion of referee #4, which could help our readers to better understand the relationship between fs and f(age).*

2. Page 4794, line 6_7: "because NEE variations with age are mostly determined by NPP variations with age", reference is needed here;

Answer: *We have added an appropriate reference (Amiro et al. 2010) here:*

Amiro, B. D., Barr, A. G., Barr, J. G., Black, T. A., Bracho, R., Brown, M., Chen, J., Clark, K. L., Davis, K. J., Desai, A. R., Dore, S., Engel, V., Fuentes, J. D., Goldstein, A. H., Goulden, M. L., Kolb, T. E., Lavigne, M. B., Law, B. E., Margolis, H. A., Martin, T., McCaughey, J. H., Misson, L., Montes-Helu, M., Noormets, A., Randerson, J. T., Starr, G., and Xiao, J.: Ecosystem carbon dioxide fluxes after disturbance in forests of North America, J. Geophys. Res., 115, G00K02, 10.1029/2010jg001390, 2010.

3. Page 4800, line 11_14: A comparison between the most densely observed regions and sparsely observed regions for the forest age factor method could be more persuasive for the authors' conclusion here;

Answer: *Your suggestion is really good, but we don't have the forest age map for another continent to conduct a similar inversion modeling, and thus we cannot make such a comparison at present, and this should be one of our future research directions.*

4. Further discussion on what are spatial and temporal limitations of the forest age factor method may help readers understand how to improve and apply it to practice;

Answer: *We added a paragraph at the end of Sect. 4.3 Further Remarks to discuss the limitations in order to help readers understand how to improve and apply it to practice.*

"However, it is necessary to point out the limitations of the forest age factor method. The demographic variations associated with forest disturbance and regrowth could be considered as a low-frequency force superimposed on the physiological effects mostly determined by both short-term and long-term variations in climate. Considering the forest age factor itself could help us to resolve the spatial distribution of carbon sources and sinks on average, but hardly improve our knowledge of the seasonal variation and interannual variation of regional carbon fluxes, which are critical for us to understand the relationship between climate and the terrestrial carbon cycle. Therefore, developing and improving a terrestrial ecosystem model containing the physiological mechanisms mostly driven by both short-term and long-term variations in climate, and the demographic mechanisms as reflected by changes in the age structure of forests could improve our bottom-up estimates of the spatial and temporal variations in the terrestrial carbon flux. This is because the seasonal and interannual dynamics we are interested in change as a function of forest age. Not describing the age structure correctly can thus lead to biases in the carbon cycle response to climate, and provide biased a priori information for the inverse modeling of the carbon source and sink distribution. The method discussed above could contribute to limiting such biases."

Technical corrections:
1. There are a few wording issues as follows: Page 4783, line 11_12 “despite : : :.”, not quite sure what the authors mean;

Answer: *We rephrased the sentence ‘except for a few inversions conducted on systems with many regions.’ to replace ‘despite some exceptions of inversion systems with many more regions’.*

Page 4783, words “apparent” and “balanced manner” are kind of vague, better replaced with more objective and explicit words;

Answer: *We rewrote the sentence as “As a result, the inverted fluxes of a local region containing observation site(s) and a region without observation sites under similar climate are constrained with imposed spatial links, the deduced fluxes and their spatial variations will be closer to our intuitive expectation.’*

2. Page 4785, line 13 “: : :and the atmosphere”;

Answer: *Done.*

3. Page 4785, line 13_17 “These types : : :observations”, rewriting may be needed to make the sentence simple and clear;

Answer: *We rewrote the sentence as, “These physiological mechanisms controlling the carbon cycle have been considered in a global atmospheric inversion by using a prior carbon flux with diurnal and seasonal variations simulated by an ecosystem model that includes these mechanisms (Deng and Chen, 2011).”*

4. Page 4788, line 26:”: : :the driving forces”;

Answer: *Changed.*

5. Additional words should be added for Figure 1 to indicate what numbers and green dot circles stand for, respectively;

Answer: *Added.*

6. Explain briefly how to produce Figure 2 in the caption of Figure 2;

Answer: *We changed the caption of Figure 2 to “The distribution of* f_s *for North America where forest stand age information is available.* f_s *is defined in equation (5), as the age varied NPP calculated from equation (4), normalized by the maximum NPP determined by climate condition of a grid cell.* f_s *was calculated at a spatial resolution of 1000 meters, and mapped using an Albers Conic Equal Area projection.”*

7.To match the legend of Figure 3: using “empty square” and “red solid square” instead of (1) for age as a constraint and (2) for age not as a constraint could be better from the point of consistence (similar needs for Figure 4);

Answer: *Done.*

8.A diagonal line in Figure 5 (b) is missing.

Answer: *We redrew the figure.*

Anonymous Referee #4

Overall Evaluation
This manuscript represents a very useful exploration of the use of forest stand age information into an atmospheric CO2 inversion methodology applied to North America.
Although there are minor differences between the inversion with and without the use of stand age information, the comparison does suggest some qualitative improvements in the spatial distribution of flux estimates. Also, in comparison with the inversion estimates without forest stand information, there is also better agreement between the inversion estimates with forest stand information and an independent estimate of carbon exchange from an empirical model that uses satellite-based information. The manuscript is well organized and well written. Most of my specific comments below are minor. In summary, I think this is a good first exploration of how one might use stand age distribution in an atmospheric CO2 inversion, and this study should provide a good basis for others to explore different ways of using stand age information in inversions.

Answer: *Thanks for your positive remarks to our effort in using tree stand age to constrain atmospheric CO_2 inversion. We really appreciate your constructive suggestions. The comments are a great help to improve the manuscript. Below you can find our detailed responses to the comments.*

Specific Comments
1. Title: I’m not sure this is the best title, as it is not clear that the “carbon flux estimate” was improved. Also, it is not clear to me if anything was necessarily improved. The value of this study is a demonstration of how forest age information might be used. I would suggest a title like “The use of forest stand age information in an atmospheric CO2 inversion applied to North America”.

Answer: *We changed the title to “The use of forest stand age information in an atmospheric CO_2 inversion applied to North America” as you suggested.*

2. Introduction: Although the Introduction is written in a scholarly fashion, it is a bit long. If other reviewers suggest that it be shortened, I would concur with that recommendation.

Answer: *We shortened the introduction by deleting a paragraph from L14 P4784 to L6 P4785, and from L6 to L8 P4786, without affecting the main research problem in this paper.*

3. Lines 16 and 20 of page 4787: Should "reanalyzed" be changed to "reanalysis"?

Answer: *Corrected.*

4. Line 17 of page 4787: Change "taken" to "implemented"?

Answer: *Changed.*

5. Line 18 of page 4787: Change "at each grid" to "at each grid point"?

Answer: *Changed to "at each grid cell"*

6. Line 3 of page 4788: "shows greater seasonal and diurnal variation" than what? Do you mean "is characterized by substantial seasonal and diurnal variation"? or do you mean "greater than over the ocean"?

Answer: *Here we mean that "The atmospheric CO_2 concentration over land often shows greater seasonal and diurnal variations as a result of the temporal covariations between the atmospheric transport and the surface flux, producing a rectifier effect" than that if no temporal covariations between the atmospheric transport and the surface flux are existing, and thus could lead to different interpretation. We changed the sentence to "The atmospheric CO_2 concentration over land is characterized by substantial seasonal and diurnal variations as a result of the temporal covariations between the atmospheric transport and the surface flux, producing a rectifier effect" according to your suggestion.*

7. Line 16 of page 4789: Note that you haven't defined the "50 regions" yet, and the reader doesn't find out about these until they read the caption for Figure 1, which isn't cited until section 3.1.

Answer: *Corrected.*

8. Line 28 of page 4789: Change "as a weight in modifying" to "in a weighted fashion to modify"?

Answer: *We changed the sentence according to your suggestion.*

9. Line 1 of page 4790: Change "same weight was also used" to "same weighting approach was also used".

Answer: *Done.*

10. Lines 2 and 3 of page 4790: Change to "respectively, as used in Eq. (2) below"?

Answer: *Done.*

11. Lines 24 and 25 of page 4793: I was really confused by the use of “regional” in this sentence. At first I thought it was equivalent to “North America region”, but then I realized that it was referring to regions within North America. Here is my suggestion for improving the sentence: “The ratio was then scaled to a quantity (fri) for each region i within North America as an area-weighted average of fs, and for each region we defined an age factor as f(age)i = fri – fc (6) where fc is the mean of the fr for all North America regions”. I think adding in the subscript i helps the reader.

Answer: *Done.*

12. Line 20 on page 4795: Change “were solved with” to “resulted in”?

Answer: *Done.*

13. Line 22 on page 4795: Change “aged” to “old growth”?

Answer: *Done.*

14. Line 23 on page 4795: Change “by the a priori that could” to “by the a prior fluxes that could”?

Answer: *Done.*

15. Line 14 on page 4796: Change “aged forests” to “old growth forests” or “old forests”?

Answer: *Done.*

16. Line 16 on page 4797: Change “conducted in a higher” to “conducted at a higher”?

Answer: *Done.*

17. Line 19 of page 4797: Change “from CO2 alone” to “from CO2 concentrations alone”?

Answer: *Done.*

18. Line 22 of page 4798: Change “9 to 30” to “9 to 28”.

Answer: *Corrected.*

19. Sentence spanning lines 7-9 of page 4799: I would suggest rewriting the sentence as follows: “In other words, the EC-MOD product likely has included some age effects with respect to above-ground productivity, and this makes it worthwhile for comparison with an atmospheric inversion that implements an age constraint.”

Answer: *We changed the sentence as suggested.*

20. Line 11 of page 4799: It is not clear what you mean by “better” in this sentence. I think you should add the following text to the end of the sentence: “than the inversion without age constraints”.

Answer: *Yes, we added the text as you suggested.*

21. Lines 13 and 14 of page 4799: Change “the unity and decrease” to “unity and the decrease”. Note that I’m not convinced that this is necessarily a “sign” of improvement, as we don’t fully understand the biases in the EC-MOD product. It is a model-model comparison, and this is why I suggest removing “improves” from the title. I would suggest changing “are signs of : : :” to “may indicate improvements achieved through using age information in the atmospheric inversion”.

Answer: *You are right and we made changes according to your suggestion.*

22. Line 15 of page 4799: Change “of the complicated” to “of a complicated”?

Answer: *Done.*

23. Line 16 of page 4799: Change “at age around” to “at an age around”?

Answer: *Done.*

24. Line 12 of page 4800: Change “the implication of the positive effect is that” to “our study suggest that”.

Answer: *Done.*

25. Line 13 of page 4800: Change “adding the forest stand age” to “adding forest stand age”?

Answer: *Done.*

26. Line 21 of page 4800: Change “have influence” to “have an influence”.

Answer: *Done.*

27. Lines 23 and 24 of page 4800: Change “a major : : :” to “the dominant association among regions, and a general NEP function : : :”.

Answer: *We changed the sentence according to your suggestion.*

28. Line 25 of page 4800: Change “along novel ways” to “along with novel ways”.

Answer: *Done.*

29. Line 2 of page 4801: Change “Before that” to “In the meantime”?

Answer: *Done.*

30. Line 17 of page 4801: Change “atmospheric constraint” to “atmospheric constraints”.

Answer: *Done.*

31. Line 19 of page 4801: Change “old” to “old growth”?

Answer: *Done.*