Biogeosciences Discuss., 7, C1983–C1995, 2010
www.biogeosciences-discuss.net/7/C1983/2010/

Biogeosciences Discussions

Interactive comment on "Age structure and disturbance legacy of North American forests" *by* Y. Pan et al.

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Received and published: 25 July 2010

Dear Editor:

First of all, I would like to thank you very much for granting us more time to finish this revision. I am very sorry for not being able to meet the earlier deadlines for a few justifiable reasons.

In this revised version, we carefully went through all questions and comments brought up by two reviewers, and made responses to all by revising, editing, adding new materials or interpretations. In general, two reviewers are quite positive to this manuscript and their comments really helped improve the quality of the manuscript. In particular, we have enhanced the uncertainty and error analysis of the product and added a new

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table to include the key information for potential users of the product from this research. The following pages include our responses (black color) to the review comments (blue color). I've also attached two versions of manuscript, a version with track changes and a clean version. I hope you find the revised manuscript is acceptable for a further review leading to finally publishing the article in Biogeosciences.

With best regards, Yude Pan

Response to GB Discussion: Review #1:

Review comments: Although I'm convinced of the need and usefulness of the underlying map, I have some problems with the presentation of the manuscript. The making of the map is hidden in the appendix whereas the manuscript emphasizes its potential use. I may be mistaken but I believe most of this community is convinced that such a map is useful. However, part of the community, including myself, needs to be convinced that crown reflectance can be converted in a meaningful 'age structure/disturbance legacy' map. This paper convinced me that the current product is of good enough quality to be applied at regional and continental scale and therefore, I recommend publication of this manuscript. Nevertheless, I see some opportunities to strengthen the presentation and content of the paper. I would like to see the methodological appendix moved forward in the manuscript as this part represents the progress made by the team.

Our answer: First of all, to make the methods more visible, we moved that section to the text as suggested (We hope this is the format acceptable for the journal).

This age map was developed based on the combination of remote sensing (crown reflectance) data, ground-based inventory data and other data (such as historical fire data). The ratios of shortwave infrared to near infrared reflectance can be used to identify differences in vegetation growing status after the disturbance, but these ratios have to link to ground data to develop the algorithm for dating disturbances. However, this remote-sensing based approach is only used for identifying forest age structure for

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some areas, particularly for regions without good inventory data (Canada's case). The US map is more dominated by forest inventory data and less determined by remote sensing. In a new table, we have more detailed descriptions of the methods and data assimilation processes for generating the age map.

Review comments: I'd like to encourage the authors to prepare a figure or table that shows the data assimilation process at a glance (including the similarities and differences between Canada and the US). This section should end with a reference or where the map can be obtained and the conditions for its use by others. Because the authors advertise the potential of their map (section 3) it should be made available to the community (or clearly stated that it is a commercial product). I would like to see that the discussion mentions that, for the moment, there is no way to directly measure age through remote sensing. Unless, I'm mistaken, age is derived from a series of relationships that link canopy reflectance to age. Hence, it would be informative to cite some results for the measures of classification success (i.e. remote sensing age vs inventory age).

Our answer: We added a table (Table 1) for a method glance and have made the map available on a website for the scientific community to use the age map data.

In my previous response, I explain a bit about how remote sensing data were used to detect disturbance and date the years after the disturbance. It is not directly to identify forest age, which is not possible anyways. Also, the age map is based primarily on statistically-sampled field data, so there is no reason to compare with remote sensing estimates, nor is it possible to assess errors by comparing with field observations – the field data is from a very large statistical sample and our results match the probability distribution of observed ages.

Review comments: Section 2 contains a qualitative validation of the age map. Currently, part of the discussion seems speculative (i.e. frequent use of the words 'may' and 'likely'). Therefore, I would like to see a clear separation between the features of

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the histograms that are really confirmed by historical facts i.e. the colonization, abandoning of farm land, fire suppressions, rise and fall of wood industry, establishing large protected areas, etc. and the features that are not well understood 'episodes of large fires'. Along the same lines, the authors could make a concluding statement for each region quantifying how well the age structure of this can be explained. This could help to identify regions where land-use history is poorly understood or regions where the data assimilation is poor.

Our answer: The analysis in section 2 (now section 3) was based on the age structures (histograms) to reflect the dominant land-use histories or natural disturbances in large regions, which in turn represent much more complex and diverse land-use histories and disturbances that took place at much smaller scales. We can produce more local based histograms which can show more detailed forest dynamics, but it is impossible to include such detail in the paper. If detailed land-use history data were available, both chronically and spatially, we could inter-compare land-use histories and forest age structures, and possibly quantify the effects of various facts/ episodes. However, such data is scattered among various data bases and literature references, and not compiled in an organized and spatially explicit way. To meet the expectation from the reviewer for clear separation of effects on age structure may require a separate study to compile existing land-use/disturbance history data into a comprehensive data base, and more regional studies of land-use histories. Still, we are able to identify some regions where the age structure is likely in error because of poor data or lack of knowledge of land-use history (as the Canadian northern region). In this revision we added new analysis and statements for documenting such effects.

We are quite convinced that by analyzing forest age-structures to reflect land-use history/disturbances based on general knowledge and available references, we prove that the age map is validated as reflecting forests dynamics in the region and the general causes of current age-class distributions. In response to this reviewer's comment, we revised the section to provide more clarified statements that represent our best attempt

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to synthesize the available literature regarding historical land-use and disturbance histories for each region.

Review comments: Section 3 demonstrates the potential use of the map. Although I agree with the authors that specifying potential use is an essential part of this paper, I find this section too wordy and find the examples not extremely informative. In my opinion a single example where you compare a regional sink estimate without to an estimate with age structure and disturbance legacy would more convincingly show the importance of this type of information. Our answer: We revised this section and referred to a recently submitted paper in which we addressed exactly the question raised by the reviewer, to compare a regional C estimates with and without using age data. The result shows the improvement and importance of using this age data layer in an inverse model.

Specific comments -Page 983 line 19. There seems something wrong with the age classes

Our answer: These are not the age classes, they are dominant age ranges in different regions, I revised the sentence to make it clear.

-Page 988 line 18: Figure 1 does not contain any information on dryness or fires as suggested by the reference.

Our answer: Yes, the Figure doesn't contain such information, and we should use a more proper reference. We now use a reference that addresses fire and climate conditions in the area.

-Page 991 line 20: NEP and carbon accumulation are not the same. Following the data, you mean NEP.

Our answer: Yes, you are right, we change the term to NEP.

-Page 992 line 21-23: In my opinion, this could only be concluded from an NBP map, not from an age map. However, if this can be concluded from an age map, please,

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explain.

Our answer: We indicated that by using the NEP values of reforestation sites there is lower regional NEP (Table 3). Table 3 is the result calculated based on age data and site NEP values. We did not make the conclusion from the age map. However, we revised the sentences to clarify the issue.

-Page 996 line 20-23. This claim is too strong. I did not find any evidence in your analysis that age is an indicator of successional status after disturbance (in my opinion it was even one of the assumptions of this study). The link to NEP was established in Smith et al 2006. However, I fully agree with the claim the map could improve analyses and models.

Our answer: First, I would like to indicate again that Smith et al (2006) only provides the information of carbon stocks that linked to forest age. We used that information to derive NEP values for this analysis.

I think "successional status" perhaps is not very accurate, given the definition of "succession" standing for complex forest dynamics. However, in our other study, the forest age histograms based on tree species in a more local scale landscape (the north Wisconsin) show very clear successional dynamics of forests. Nevertheless, we change "successional status. . ." to "forest development status", which shall be more accurate because forest stand age shows the development status of forests such as young, middle-aged or old.

-Do you need to show Tables 2a & b? This information seems to be presented in Smith et al 2006.

Our answer: These tables are different from the table of Smith et al. because Smith's tables are for carbon stocks. However, we removed these two tables because the most information can be represented by Figure 6a and 6b, however there were some numbers in the table we referred in the text, now we just describe them without reference.

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-The lay-out of Figures 4 and 5 is poor. Table 3 clearly shows the different regions. Make a matrix of plots and refer to the regions in the plot title. Plotting the histograms on top of a geographical map does not add any information especially because the geographical map is almost entirely covered by the histograms.

Our answer: We have revised Figures 4 and 5 and only have the histograms without overlaying on maps.

- What is the difference between Fig 6 a,b and Table 2 a,b? - Fig 7, use a uniform lay-out for your maps. I prefer the style of Figure 1.

Our answer: We removed Table 2a,b. and revised Figure 7 to use the same style of Figure 1.

Review #2 Review comments: Although I feel the authors over-state the potential utility of their product from a forest management perspective, they rightly point out the value of this map product in terrestrial C modeling and improving land constraints in atmospheric inversion modelling. The paper would be improved if the authors were more clear about the nature of their product, including its spatial resolution, quantification of its accuracy, uncertainties, errors, and key complicating issues that users of the product ought to be aware of before attempting to use the product as input to their models (such as advice on the handling of uneven-aged stands – which are not recognized as such in the product, but do form an important presence on the landscape in some regions).

Our answer: To answer the first question about the over-state: (1) we did make a statement in the end of this section about the limits using the age product for forest management perspective; and (2) we have recently developed a new product using age data and NEP table values to show how the data can be used for assessing future forest carbon management opportunity. We revised the section to address the utility of forest management more reasonably with mentioning of our new study.

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We added a new subtopic in the Section 2 (method and data) to address the reviewer's question in terms of features and problems of this product, and added a new table (Table 1) to provide the details about this product including such as the data assimilation processes, spatial resolution of the product, uncertainties, error sources, key issues for users to know, etc.

Review comments: Error structures in this map, I suspect, are not consistent across the continent given differences in methodology and data between US and Canada, and between regions in Canada (CanFI is certainly non-uniform in the quality of information it provides). I would like to request that in their revisions the authors please include some discussion on this basket of issues so that users of the product that are familiar with one region are not misled into thinking that the issues they will encounter in other regions of the continent will be similar.

It would also be fantastic if the authors could indicate how to obtain a copy of the product (unless the preferred means is to have interested parties simply contact the lead author directly).

Our answer: We have added a new section in the method to discuss the differences between Canada and the US in terms of data and approaches. We have also added information about unique regional aspects of the product, and a paragraph in discussion for highlighting different features of the map in the Canadian and US components. The new Table 1 provides the detailed information of comparison and also provides the website of the product for users.

Specific comments and concerns: p.991 line 17 ! decomposition of slash left on site following harvest is important, but not acknowledged. Post harvest NEP dynamics will depend on the predominant harvesting methods employed and on the standard or typical handling of slash or logging debris. In some jurisdictions, operators are required to pile and burn logging slash, which causes greater immediate C losses but lower subsequent Rh C losses.

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Our answer: In this analysis (the northeastern US), the data we used to develop NEP values of deforestation sites are based on averaged information of FIA plots including carbon components of deadwood, woody debris, litter and soil. Therefore, the carbon losses shown in the NEP curves are only averaged values for the region. There is no further information about various slash treatments within different regions, to reflect patterns of logging slash after different harvesting methods. This issue could mostly affect the estimate of those heavily harvested timber industrial areas such as the southern US, northwestern US, and British Columbia of Canada. We added text to reiterate the reviewer's points.

p.992 ! Section 3.1 – Although I agree in principle that this sort of decision support function could be provided using a detailed forest age map, I do not see reported in the manuscript that your map product provides spatial presentation of the data at appropriate scale for this type of management decision-making support. That said, the Age-NEP relationship approach you describe could be an excellent approach to take in forest estate planning, such as in models that take as input high resolution forest inventory (e.g., 1:10 000 scale vector mapping) and optimize for various combinations of goals using LP solvers, of which NEP or C stock maximization could be one goal. In sections 3.2 and 3.3 you describe a much more likely direct application of your map and a more immediate contribution of this product to terrestrial C cycle research.

Our answer: For the US, we recently use the Age-NEP relationship to develop a NEP map at 250 m, and also made some projections referring to forest carbon management opportunity. As the reviewer suggested the product can also be used for various combinations of goals facilitating management issues, though at significantly larger scales than individual stands of trees. We added information to mention use of our new product (also to answer the question by the first reviewer), although the relevant manuscript has not been submitted yet.

p.996 line 10 ! not only is the assignement of age an imprecise exercise under the most straight forward of circumstances, there are also large areas of tolerant hardwood and

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other forest ecosystem types that are managed under selection harvesting silvicultural systems or whose disturbance regimes are otherwise characterized by nonstand-replacing mortality-causing events. For these ecosystem types, there can be no meaningful assignment of a simple ordinal age. This is perhaps a more serious problem than you acknowledge here. What may be required is some discussion on the issue that stand age as estimated using time since disturbance as a proxy may not relate to tree age, particularely in some ecosystem types (and in very old stands generally). I agree that sensitivity of regional NEP estimates calculated using the map and age-NEP relationships may not be excessively high as a result of this issue, but I think it should be a good idea to warn users of the perils they may encounter if they ignore these complications, especially if they are wanting to use the map for purposes other than those described in this paper (as I suspect will be the case - creative users may find novel uses for your product once it is made available). Can you quantify the proportion of forest by region that is likely not adequately described using ordinal age (e.g., include a class for "uneven-aged") and suggest possible ways that users may choose to make use of this information if it is only provided as metadata (i.e. each pixel has an ordinal age assigned, but metadata describe regionally what might be going on with respect to unevenaged forests that one does not see in the map product itself)?

Our answer: The methods and data of developing this age product really decide the nature of ages assigned to different pixels: (1) for uneven-aged forest stands, which may have a few age classes, we averaged them before developing age polygons. However, in the FIA plot data base, there are very few plots classified as uneven aged because FIA assigns an average age in most situations; and (2) ages can only represent, statistically, aggregated neighboring forest age structures based on available plot data. Relatively, it's simple to provide proportions of uneven-aged plots in each region, however, the current product can quantify the proportion of forest in different age-classes, but cannot quantify the class of uneven-aged forests (because already averaged). However, it is not impossible to redo the product by developing age polygons with identified uneven-aged forest plot data, but this product is only a metadata

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product. We include this discussion to the new paragraph in the end of Section 3 (now section 4) and provide more background and guidelines for users.

p.997 Section A1.1 – You should point out to your readers that data in CanFI are referenced to a wide range of data collection dates. One might find in CanFI two forest inventory records that both indicate stand age 100, for example, but one stand was inventoried as age 100 in 1950 and the other in 1986. The fact that CanFI was compiled from many different source inventories was the cause of this problem – but it makes CanFI a very difficult product to work with when one is interested in time-dependent stand attributes, such as age.

Our answer: Although CanFI data were collected from different dates, the data we used were derived from Penner et al. (1997) that were updated to 1991 as polygons at 10 km resolution. The remote sensing data and LFDB data were used to develop algorithm for dating disturbances and update inventory-based forest ages. The results are not perfect, but to some extent resolved the problem the reviewer indicated. We also added sentence in the new paragraph and information in Table 1 to bring to light of this issue.

p.1018 Fig 5 – you show bi-modal age class distributions for all of Canada, and this is most strongly exhibited in Canada's northern region. I find myself deeply suspicious of your findings for Canada's north in particular. This is an area where monitoring has been inconsistent (even in the LFDB; Stocks et al. 2002) and productivity is so low that estimation of age from spectral characteristics is very poor, especially for mature stands. Is there any independent justification you can provide to support these findings? The age class structure you report suggests that there was near zero disturbance in forests N of 60 during the period 1930-1970 and almost no forest older than 120 years in the entire region. The former is unlikely and the latter is simply not the case. More likely we have a bias here driven by the fact that stands (predominantly low productivity black spruce) show virtually no change in optical properties beyond a certain age. To be fair, Canada has very poor data on these forests, so even with these

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issues, your product still has value – there is no better alternative at present. Utility of your product, however, will be enhanced by providing thorough documentation of known issues and uncertainties.

Our answer: For the Canadian data, unlike the data of the US that we can get access of mostly updated data, we are limited by available and high quality data. For Canadian north, the data are poor. There is no inventory data. The forest ages are determined using remote sensing dating algorithm for years 1973-2003. The earliest LFDB data that only include large fires are back to 1959. So, the forest ages older than 1940s are very inaccurate. Ages of these older forests (because there are no recent disturbances) are generated based on the average disturbance rate of each ecoregion. The use of remote sensing data in 1998 was very helpful in detecting the disturbance rates in each ecoregion and fill in the data gap for the far north in a reasonable way. Because the renewal process of boreal forests occurred on average every 75 to 100 years and created even aged stands interspaced with natural fire breaks (Disturbances and Renewal in the Forest, State of Canada's Forests, 2003-2004, p. 74), the pattern shown in the age distribution is not totally surprising. A general bi-modal age distributions in Canada, particularly in drier and colder regions, are likely reflecting periodic fire disturbances (site-replaced types) and fire-induced regeneration dynamics.

Even as described above, I agree with the reviewer's point that the long period without evidence of fire (or other disturbance) over 1930-1970 is very unlikely. There are examinable biases in the data source and the estimate of forest ages in the North region. We have added our analysis and discussed likely errors to in the age structure of this region. Nevertheless, we have tried our best to get all available data for producing an age map. As the reviewer is familiar with Canadian data, this is all we can do. We are planning to continue update this product, along availability of relevant data.

Please also note the supplement to this comment:

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http://www.biogeosciences-discuss.net/7/C1983/2010/bgd-7-C1983-2010-supplement.pdf

Interactive comment on Biogeosciences Discuss., 7, 979, 2010.