Biogeosciences Discuss.,
doi:10.5194/bg-2015-657-AC3, 2016

Biogeosciences Discussions

Interactive comment on "Underestimation of boreal soil carbon stocks by mathematical soil carbon models linked to soil nutrient status" *by* B. Ťupek et al.

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Received and published: 9 April 2016

Referee's comments are highlighted by the bold font.
Author's replies are indicated by the italic font. The normal font indicates text of the manuscript.

Review of Tupek et al.
Summary:
Three soil models (Q, Yasso07 and CENTURY) are ran against Swedish forest soil inventory data to gauge how well they can estimate soil C stocks. The

soils were additionally broken down into 10 distinct groupings based on soil characteristics or 5 on site characteristics. Generally the models perform well enough but have problems with certain sites characterized by high fertility and are generally well-sorted for parent material.
Thank you for your comments! We appreciate and considered them all, and below we reply to each in detail. Based on your comments we have resimulated CENTURY SOC stocks with tuned parameters accounting for the variation of topsoil mineral N, C/N ratio of litterfall in relation to site N deposition and productivity class. We redrawn Fig. 3 and 4, supplement Fig. S5, S7, and S8, and added Fig. S10, S11, and S12. We reformulated text by following your remarks and according to improved performance of CENTURY model (as in the marked up version of the manuscript attached into the supplement of this comment).

I have some troubles with understanding the point of the paper.
The point of the paper was evaluating Yasso07, Q, and CENTURY model estimates of SOC stocks wheather they can follow the variation of measured SOC stocks when those were grouped according to site nutrient status (Fig. 3 of the BGD manuscript), and helping to understand why models performed well for 2/3 of sites and failed for more fertile sites. We reformulated Conclusions.
The authors took three separate soil C models and ran them then compared them. That is fine but why not have examined how the special characteristics of CENTURY could have helped its performance?
We presented our model intercomparison keeping some special CENTURY characterisitcs constant, because we included the main driver of these models, litter input, and did not acount for all drivers in CENTURY as we expected them to have small effect on estimated SOC stocks. We have now confirmed by CENTURY sensitivity simulations that in comparison to litterfall including parameters of topsoil mineral N, and C/N ratio of the litterfall had small effect on SOC stocks (Fig.1).
The authors noted that CENTURY simulates its soil C to only 20 cm and they

noted that it should likely be increased by 40-50 % like Yasso07, but then why not show on plots how that would look?

We did not scale CENTURY estimates because we were interested more in reproducing the pattern of the grouped measurements. Scaling the topsoil horizon SOC stock by adding 40% of estimated site specific SOC stock to account for the deep carbon in the current version of the manuscripts (described in section 2.2) helped CENTURY estimates to agree with measurements, thus in the current version of the manuscript we presented scaled CENTURY SOC stocks.

Similarly, CENTURY is capable of N dynamics and the authors explicitly note that N deposition at some sites seems to be important, so why not do a run with the N-cycle turned on? Then at least we could see how well the model does when its full capabilities are used. This strikes me as taking a Ferrari, deflating all of its tires, filling it with poor petrol and then racing against a Honda. Sure it's performance can be evaluated but it is hardly ideal conditions to see how fast it can really go.

We noticed that part of our BGD manuscripts discussion on line 464, in particular that "...the feedback of nitrogen input to plant productivity was not included in this study" *was misleading and has to be reformulated into* "...the feedback of nitrogen input to plant productivity was primarily included in this study indirectly, through estimated steady state litter input based on site productivity class which strongly correlated with Nitrogen deposition (Fig. A1 and S11)."

As litter input indirectly reflected N deposition, we focused on C part of CENTURY (that is common by modelling studies) by accounting for the main drivers of SOC stocks sequestration site specific litter input, climate, and soil texture and structure. Although in our BGD manuscript we did not presented the results of CENTURY soil sub-model in its full capabilities, in the current version of the manuscipt (Section 2.2) we further accounted for N part through the contribution of site specific parameters of topsoil mineral N (relative to N deposition, Throop et al. 2004), C/N ratio of the litterfall (relative to production, Merilä et al. 2015), and we also included effect of drainage

(relative to long-term soil moisture, Raich et al. 2000) (Fig. 2). We also found and corrected a mismatch between the site specific soil silt-, clay-, sand- contents and other input data (correctly used litterfall and climate) that caused under-performance of CENTURY in our BGD manuscript. After soil input data were matched correctly with the other input data, then the CENTURY SOC stock estimates improved into more pronounced spatial (between group) differences. The CENTURY estimates were markedly larger for the groups with higher clay contents and generally lower for the other groups (Fig. 2).

Throop, H. L., Holland, E. A., Parton, W. J., Ojima, D. S. and Keough, C. A.: Effects of nitrogen deposition and insect herbivory on patterns of ecosystem level carbon and nitrogen dynamics: results from the CENTURY model, Global Change Biol., 10, 1092-1105, 2004.

Merilä, P., Mustajärvi, K., Helmisaari, H., Hilli, S., Lindroos, A., Nieminen, T. M., Nöjd, P., Rautio, P., Salemaa, M. and Ukonmaanaho, L.: Above-and below-ground N stocks in coniferous boreal forests in Finland: Implications for sustainability of more intensive biomass utilization, For. Ecol. Manage., 311, 17-28, 2014.

I also worry about the litter inputs. I would have liked to see some way of independently evaluating the litter input contributions.

The main driver of the SOC stock accumulation, the forest plant's litterfall, was precisely estimated based on the ground measurements of Swedish forest inventory data and Scandinvian biomass and litterfall functions, and for the main Swedish regions agreed with Ortiz et al. (2013). The developed functions based on f_{APAR} were through removing the effect of the management (the present stand development) the main contributors for accurate estimation of the long-term mean litter input (newly added Fig. S11 in the supplement of the edited manuscript). The allometric biomass models used to derive our f_{APAR} biomass models were based on studies using extensive data from boreal forest of Scandinavia (lines 133-134). The biomass estimates of the published allometric functions and our f_{APAR} functions strongly correlated (R^2

values close to 0.9, Table B1 and Fig. B1). Litterfall estimation as a proportion of forest biomass was also based on studies from Scandinavia (lines 153-165) and our estimates of litterfall components of steady state forests (newly added Fig. S10 in the supplement of the edited manuscript) were within the range of reported values (Ågren et al. 2007, Mukkonen and Lehtonen 2004, Lehtonen et al. 2004, Viro 1955, Mälkönen 1974, 1977, Kleja et al. 2008, Leppälampi-Kujansuu et al. 2014, Liski et al. 2006, Ortiz et al. 2013). For an improved understanding of the f_{APAR} biomass models we reformulated Section 2.1.1, Appendices A and B, redrawn Fig. A1 and B1, and added supplement Fig. S10 and S11. The appendix Fig. A1 was redrawn in order to increase clarity of biomass/litterfall modelling based on the productivity class, and supplement Fig. S10 shows the range of litter input, Fig. S11 increases clarity of biomass/litterfall modelling on the Nitrogen deposition.

I recommend the authors do some further simulations to make this paper more interesting and to offer up a better analysis of how the model processes can contribute to estimated SOC stocks (thinking here the N cycle in CENTURY). I usually don't like to ask for more simulations but in this case I think it is necessary to make the paper have wider appeal. If not a more specialized journal could be appropriate.
In the current version of the manuscipt (in supplement of this comment) we present results from the tuned CENTURY model that includes site specific parameters of topsoil mineral N, C/N ratio of the litterfall, and drainage. However, tuning of CENTURY parameters to site specific topsoil mineral Nitrogen, C/N ratio of the litterfall, and drainage (Fig. 1 and Fig. 2) showed that this impact on SOC stocks estimates was small in comparison to sensitivity of SOC stock estimates to litterfall. The Fig. 1a showed that 30% increase in litterfall increased SOC stocks by 15 $\mathrm{tC\,ha^{-1}}$*, whereas tuning the parameters of C/N ratio of litterfall by 30% resulted only in SOC stock change up to 1* $\mathrm{tC\,ha^{-1}}$ *(Fig. 1b) and increasing mineral N by 30% increased estimates up to 2* $\mathrm{tC\,ha^{-1}}$ *(Fig. 1c). Further increase of topsoil mineral N resulted to maximum*

SOC stock increase around 5 $\mathrm{tC\,ha^{-1}}$ *compared to setting used in our BGD manuscript (Fig. 1c and 1d). The Fig. 1 and Fig. 2 showed that litterfall was the main driver of the estimated SOC stocks and therefore accurate SOC stocks depended on accurate biomass and litterfall estimation.*
We added description of the CENTURY simulation with N, C/N and drainage parameters into the manuscript (section 2.2.), added Fig.1 to supplement as Fig. S12, and redrawn the figures containing CENTURY estimates. Although the main message of the edited manuscript remained similar to the previous version, we reformulated our findings regarding the improved performance of the CENTURY model and conclusions.

Specific comments:

1. The paper is generally not well written and would greatly benefit from English copyediting. I mention this as I often had to re-read sections to understand what was written. There are a few areas where I still don't understand what was being communicated.
English language of our BGD manuscript was revised by a native speaker. For the additional clarity we reformulated mainly sections 2.1.1 and conclusions. Manuscript in final form would undergo English copyediting services.

2. The section on fAPAR was hard to follow ('actual state'? I don't understand if this was an English problem or if this term was meant. It is a strange term to be used). In the end I was not sure how good this fAPAR method worked out. I can't see anywhere that this was explicitly tested against some sort of observations. Since the litter inputs are pretty important to drive the models with, shouldn't this be very well evaluated?
We reformulated section 2.1.1 for increased clarity between the actual and steady state forest, and the use of f_{APAR} models. We meant to use the term 'actual state'

referring to current state, existing at the present time, as used to describe phenomena in physics. However, our focus was not on the actual state, but on the long-term mean conditions what we referred as 'steady state'.
Our use of f_{APAR} models for steady state was motivated by the need to remove the effect of management from the Swedish Forest Inventory measurements and to produce biomass/litterfall estimates accurately representing the mean long-term conditions (defined by estimated steady state) for small regions (defined by degree of latitude and productivity class for dominant species) (see redrawn Fig. B1). The higher precision of the estimates applied for the period of the last few thousands of years would be uncertain due to high variation of factors affecting plot history. As shown by Fig. S11 the litterfall based on f_{APAR} models of steady state forests were sensitive to regional differences in N deposition that correlated to site productivity, and estimated litterfall components (Fig. S10) were in agreement of studies from Scandinavia.

3. How was the stump defined for the biomass? Usually I think of stem, coarse roots, and fine roots with the stump being what is left after a site is logged. How was it meant here?
#The stump was defined and calculated as a difference between the felled part of the tree and roots that were attached to it (Pettersson and Ståhl 2006, lines 131-134).
Petersson, H. and Ståhl, G.: Functions for below-ground biomass of Pinus sylvestris, Picea abies, Betula pendula and Betula pubescens in Sweden, Scand. J. For. Res., 21, 84-93, 2006.

4. Line 264 - But the CENTURY simulation was run to equilibrium, right? Also how was equilibrium defined for the models?
The equilibrium state of a model was a state where the litter input equals decomposition and it is referred as the steady state soil carbon stock (described on lines 224-225 for Q, 235 for Yasso07 , and 262-264 for CENTURY models).

5. Table 2, how is the productivity class derived?
We added following sentences into section 2.1.3 of edited manuscript:
The productivity class (H100, m) in our manuscript refers to a site index which can be converted to site productivity. Soil site index is based on dominant height at a certain age (100 years) and is determined according to a dominant height curve (Swedish Statistical Yearbook of Forestry 2014).
Swedish Statistical Yearbook of Forestry. Official Statistics of Sweden, 370 p., Skogsstyrelsen. 2014.

6. Table 2 - The depth of soil is assumedly cut off at 1 meter?
Yes, the SOC stock represented the soil assumedly cut off at 100 cm (Stendahl et al. 2010). We added this information into the header of Table 2.:
The soil was cut off at 1 meter.

7.Table 3 - Parameters (leftmost column)? What is meant here? How the model was parameterized? I found this confusing.
#Parameters (leftmost column of Table 3) used in models represented different scales. Yasso07 parameters were global, Q parameters were regional (Scandinavian), and CENTURY parameters were combination of global and site specific for soil and C/N ratio of litterfall. We reformulated this line of Table 3 as:
Parametrization: Global, Scandinavian, Global and site specific.

8. Table 3 - CENTURY, is the soil depth adjustable from 0.2?Could it be increased to 1.0 to more simply make it comparable to the other models?
We added following sentence into the section 2.2. of edited manuscript:
In order to account for the deep soil carbon (Jobbágy and Jackson 2000), we scaled CENTURY estimates representing the topsoil horizon by adding 40% of estimated site specific SOC stock.
Jobbágy, E. G. and Jackson, R. B.: The vertical distribution of soil organic carbon and its

relation to climate and vegetation, Ecol. Appl., 10, 423-436, 2000.

9. Figure 2 and text in main - Soil group 8 has only 8 samples within it. Is this reasonable to keep as a group?Given how many uncertainties develop as this regression tree is created (calculation of SOC, assignment to weather stations, measurement uncertainty, etc.) is it reasonable to let a group be only 0.24% of the total?

The soil group 8 that has only 8 samples was in our opinion distinct from the others as found by the rpart (Fig. 3). We added following sentences into the section 2.1.3:

We acknowledge the fact that this is a small distinct group based only on 8 observation. However, we don't have any reasons to exclude these datapoints as outliers.

FIGURE CAPTIONS:

Fig. 1. (Fig. S12) Sensitivity of simulated SOC stocks ($tC\,ha^{-1}$) of CENTURY model to variation in litterfall (a), C/N ratio of litterfall (b), topsoil mineral N ($gN\,m^{-2}$) (c), and to variation of factors together (d). SOC stocks of CENTURY are output of spin up simulation up to 1000 years.

Fig. 2. Bean plot of density functions for 10 physicochemical groups of the soil carbon ($tC\,ha^{-1}$) measurements (grey fill) and estimates simulated by the soil carbon models Yasso07, CENTURY, and CENTURY tuned (including site specific mineral N in topsoil, C/N ratio of litterfall, and drainage), Q with the litter input derived from the steady state forest. The thin lines are the density distributions. The thick lines are the group means and dashed lines are their confidence intervals. The n is number of samples. For description of group levels of SOC stocks, moisture, and fertility see Fig.2 and Table S1. *Note that in the edited manuscript (Fig. 3) we show CENTURY estimates including all used parameters (tuned), in order to keep balance with the results of Yasso07 and Q models.*

Please also note the supplement to this comment:
http://www.biogeosciences-discuss.net/bg-2015-657/bg-2015-657-AC3-supplement.pdf

Interactive comment on Biogeosciences Discuss., doi:10.5194/bg-2015-657, 2016.

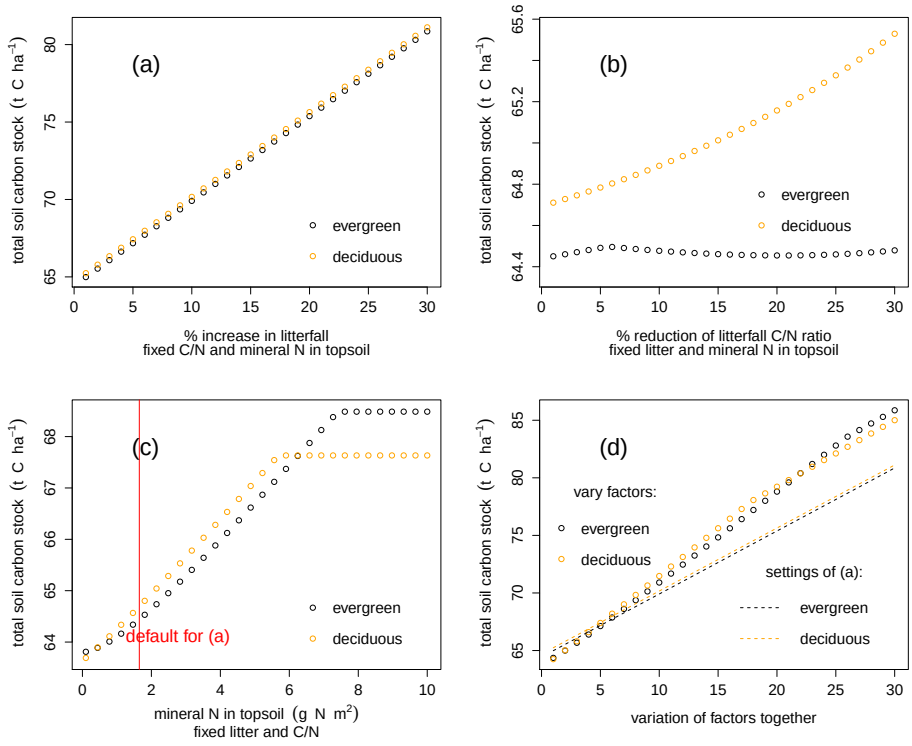
(a)
total soil carbon stock (t C ha^{-1})
% increase in litterfall
fixed C/N and mineral N in topsoil
evergreen
deciduous
(b)
% reduction of litterfall C/N ratio
fixed litter and mineral N in topsoil
(c)
default for (a)
mineral N in topsoil (g N m^2)
fixed litter and C/N
(d)
vary factors:
settings of (a):
variation of factors together

Fig. 1.

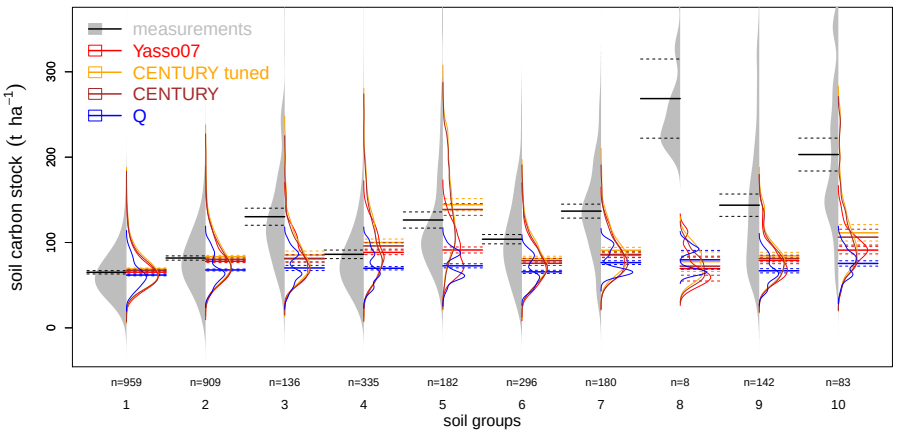
measurements
Yasso07
CENTURY tuned
CENTURY
Q
soil carbon stock (t ha^{-1})
n=959
n=909
n=136
n=335
n=182
n=296
n=180
n=8
n=142
n=83
soil groups

Fig. 2.