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Soil carbon models for carbon stock estimation – where do we fail?

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Abstract
Soil organic carbon (SOC) stock change estimates are needed in order to understand CO_2 exchange between atmosphere and biosphere. Repeated nationwide SOC inventories are rare and expensive. In the absence of soil inventories, models are used to estimate SOC changes. These models are applied widely with GHG inventories under UNFCCC and with earth system models (ESM), e.g. for IPCC assessment reports.
Soil carbon models simplify complex processes and often lack history of soils in a given region. Therefore, it is not surprising that these models fail as sub-modules of ESMs (Guenet et al. 2013, Todd-Brown et al. 2013). The major reason for poor performance of SOC models results from the uncertainty with steady state SOC stock for model initialization.
Here we compare different soil carbon models (Yasso07, ROMULv, Century and Q) against Finnish and Swedish SOC inventories and we identified conditions under which these models fail. We also analyzed SOC outputs of ESMs and compared those to global SOC databases.
We found that models were failing on nitrogen rich sites, we also found underestimation of SOC stocks on water limited sites and on those with excess water.
Our findings provide directions for modelling community in order to further improve models and their ability to quantify SOC stocks.

Keywords: Yasso07, Century, ROMUL, modeling,

Introduction, scope and main objectives

Several countries apply SOC models for estimating soil carbon stock changes for their forests. Models are often used due to fact that it is the only option due to high price of soil inventories. The use of models has been expanded after Kyoto protocol adoption 1997. Countries have to be able to provide SOC estimates at national level and report those annually for the UNFCCC. In addition to the reporting actual estimates countries report uncertainty estimates for those emissions and therefore there has been lot of research focusing on the uncertainty of SOC models.
At the same earth system modelling (ESM) community develops models and predicts future CO2 feedbacks between biosphere and atmosphere. According to the results by Guenet et al. (2013) ORCHIDEE model is not able to predict SOC observations, they found that model estimates and measurements did not have any correlation. Similarly, Todd-Brown et al. (2013) reports that most ESMs are not able to produce measured soil carbon stocks at a grid level. ‘
(i) Here we used Yasso07, Century and Q models to estimate SOC levels for Sweden. We compared models estimates and measured data and evaluated conditions where these models fail (Tupek et al. 2016). (ii) We also tested Yasso07 and ROMULv models against Finnish SOC data (Lehtonen et al. 2016). (iii) In addition to that we compared ESM SOC estimates against with global SOC databases and we identified those conditions where these global vegetation models fail with soil carbon (Hashimoto et al. 2016).
The overall objective of our works has been identify conditions under which typical soil carbon models fail.

Methodology

This paper is based on three separate studies, where (i) Tupek et al. (2016) and (ii) Lehtonen et al. (2016) test different SOC models against nationwide SOC inventories in Sweden and in Finland. Study (iii) Hashimoto et al. (2016) uses boosted regression tree (BRT) methodology in order to evaluate drivers that affect SOC estimates on both, different ESMs and with global soil carbon databases.

Studies (i) and (ii)

Both studies (i) and (ii) use forest inventory data, biomass models and litter turnoverrates to estimate annual carbon flow from vegetation to the soil system. This annual flow is then used as a litter input and with that models have been driven to steady state. Thereafter steady state SOC stocks have been compared against measured soil carbon data. In study (i) this comparison was done in eight classes that were formed by using regression tree technique, while in study (ii) this comparison was done according to the south-north gradient of Finland.

Study (iii)

In study (iii) data mining method BRT was applied. With this method we analyzed ESM inputs and their impact to estimated SOC stocks. Similarly we analyzed with BRT method various candidate drivers for SOC stocks. Comparison of drivers for ESMs SOC stocks and those for observational SOC stocks revealed factors that did not agree between these two independent data sets.

Results

In study (i) we found that Yasso07, Century and Q models were able to estimate SOC stocks on 2/3 of cases. Models were successful on typical nutrient poor and medium fertility sites on Sweden. On the other hand these models failed on nitrogen rich forest soils and also on those that had high nitrogen deposition. Century model outcompeted Yasso07 and Q models on sites with high clay content.
In study (ii) we found that generally models failed on Southern Finland to estimate right SOC levels. This was due to fact that these models did not have decay limitation due lack of moisture. ROMULv model was able to map increased SOC stocks in south when applied with measured soil water holding capacity. We also found out here understorey vegetation has a major role providing litter input especially in Northern Finland. The role of understorey vegetation has been often neglected.
Study (iii) identified that ESM drives were different than those with global soil data. Our analyse indicated that providing use of carbon:nitrogen ratios of soils and soil texture information with SOC models would improve their performance.

Discussion and Conclusions

As national SOC inventories are expensive and those should be repeated in order to have soil carbon stock change estimates, the use of SOC models will likely increase.
Our studies reveal that these models are able to estimate SOC stocks under mean conditions, but at the same time we see that these models fail on conditions that have water limitation or excess water or exceptionally high nutrient levels.
In order to have more reliable GHG inventory results and more reliable future CO2 feedback estimates these SOC models should be improved in a way that those take into account variable soil fertility conditions and also soil texture that affects directly to soil water availability.

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