Modelling soil carbon balance at large scales

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Outline: Modelling soil carbon balance at large scales

1. Need for soil carbon modelling
2. Requirements for soil carbon modelling
3. Specific questions
4. Summary
Need for soil carbon modelling

- To understand functioning of soil carbon
- To upscale experimental results
  - Interpolation
  - Extrapolation
- To estimate scenarios (what if)
  - Environmental
  - Management
- Users
  - Scientists
  - Policy-makers
  - Consultants

Requirements for soil carbon modelling

- Reliability
  - Reliable answers to questions asked
- Relevance
  - Answers to the questions asked
- Feasibility
  - Possibility to conduct the calculations
Reliability: Determinants

■ Structure of a model
  • Correct and comprehensive description of processes and affecting factors

■ Parameter values of a model
  • Accurate (free of systematic error)
  • Precise (small uncertainty)
Reliability: Evaluation methods

- Model structure
  - General knowledge, purpose of use of a model
  - Comparison of results to measurements
  - Comparison of different models

- Parameter values
  - Comparison to measurements
  - Sensitivity analysis
  - Uncertainty analysis
Relevance

- Model structure
  - Relevant processes included

- Driving factors
  - Relevant included
Feasibility

- Technical possibilities to conduct calculations
  - Computing resources, user resources
- Calibration data availability*
- Input data availability*
- *availability
  - Variables needed
  - Spatial and temporal resolution
Specific questions

1. Identifiability of soil carbon models
2. Uncertainty analysis of the Yasso model
3. Soil texture effects on soil carbon
4. Mapping soil carbon using statistical models in Finland
Identifiability of soil carbon models

- High requirements for the results of soil carbon models
  - Reliability, objectivity, transparency
- Possibility of estimating parameter values of a model unequivocally from measurements available
- Objective and transparent determination of parameter values, statistical uncertainty estimates
Identifiability of the Yasso model

- The present model not identifiable
- Additional measurements needed
  - $X_{\text{lig}}$ and $X_{\text{hum1}}$, or $X_{\text{hum2}}$
  - $p_{\text{lig}}$ and $p_{\text{hum1}}$, $k_{\text{hum1}}$ or $k_{\text{hum2}}$
- Changes in the model needed
  - $(X_{\text{hum1}} + X_{\text{hum2}})$ and $X_{\text{lig}}$ or $X_{\text{hum}}$ measured or $p_{\text{lig}}$, $k_{\text{lig}}$, $k_{\text{hum}}$ known
Identifiability of soil carbon models: Discussion

- Identify mismatch between the structure of a model and calibration measurements
  - To develop the model
  - To develop the measurements
- Identifiability requires simple models
  - Adequate description soil processes?
  - Relevance?
- Strengthen the link between modelling and measuring
Uncertainty analysis of the Yasso model

1. Uncertainty estimates for the parameter values
2. Sensitivity of steady-state soil carbon estimate to changes in the parameter values
3. Uncertainty in the results of the model
## Uncertainty estimates for the parameter values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Absolute</td>
</tr>
<tr>
<td><strong>Exposure rates of woody litter to microbial decomposition (year⁻¹)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine woody litter ($a_{wl}$)</td>
<td>0.54</td>
<td>0.077–1.0</td>
</tr>
<tr>
<td>Coarse woody litter ($a_{cel}$)</td>
<td>0.030 or 0.077</td>
<td>0.028–0.032 or 0.072–0.083</td>
</tr>
<tr>
<td><strong>Decomposition rates (year⁻¹)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extractives ($k_{excl}$)</td>
<td>0.48 or 0.82</td>
<td>0.45–0.51 or 0.71–0.93</td>
</tr>
<tr>
<td>Celluloses ($k_{cel}$)</td>
<td>0.30</td>
<td>0.28–0.31</td>
</tr>
<tr>
<td>Lignin-like compounds ($k_{lbg}$)</td>
<td>0.22</td>
<td>0.17–0.29</td>
</tr>
<tr>
<td>Faster humus ($k_{hml}$)</td>
<td>0.012</td>
<td>0.002–0.02</td>
</tr>
<tr>
<td>Slower humus ($k_{hml2}$)</td>
<td>0.0012</td>
<td>0.0017–0.0008</td>
</tr>
<tr>
<td><strong>Formation of more complex compounds in decomposition (proportion of decomposed mass)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extractives to lignin-like compounds ($p_{exl}$)</td>
<td>0.2</td>
<td>0.1–0.3</td>
</tr>
<tr>
<td>Celluloses to lignin-like compounds ($p_{cel}$)</td>
<td>0.2</td>
<td>0.1–0.3</td>
</tr>
<tr>
<td>Lignin-like compounds to faster humus ($p_{lbg}$)</td>
<td>0.2</td>
<td>0.1–0.3</td>
</tr>
<tr>
<td>Faster humus to slower humus ($p_{hml1}$)</td>
<td>0.2</td>
<td>0.1–0.3</td>
</tr>
</tbody>
</table>

Sensitivity of a steady-state soil carbon estimate

<table>
<thead>
<tr>
<th>Parameter value</th>
<th>Change in soil carbon (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure rates of woody litter to microbial decomposition (year(^{-1}))</td>
<td></td>
</tr>
<tr>
<td>(a_{fw1})</td>
<td>-0.04</td>
</tr>
<tr>
<td>(a_{cw1})</td>
<td>-0.04</td>
</tr>
<tr>
<td>Decomposition rates (year(^{-1}))</td>
<td></td>
</tr>
<tr>
<td>(k_{ext})</td>
<td>-0.01</td>
</tr>
<tr>
<td>(k_{cel})</td>
<td>-0.07</td>
</tr>
<tr>
<td>(k_{lig})</td>
<td>-0.07</td>
</tr>
<tr>
<td>(k_{hum1})</td>
<td>-0.26</td>
</tr>
<tr>
<td>(k_{hum2})</td>
<td>-0.51</td>
</tr>
<tr>
<td>Formation of more complex compounds in decomposition (proportion of decomposed mass)</td>
<td></td>
</tr>
<tr>
<td>(p_{ext})</td>
<td>0.05</td>
</tr>
<tr>
<td>(p_{cel})</td>
<td>0.24</td>
</tr>
<tr>
<td>(p_{lig})</td>
<td>0.77</td>
</tr>
<tr>
<td>(p_{hum1})</td>
<td>0.51</td>
</tr>
</tbody>
</table>

Uncertainty in the results of the model

Uncertainty analysis of the Yasso model: Conclusions

- Soil carbon stock estimates uncertain by nature
  - Dependent on the uncertain humus parameter values
- Soil carbon change estimates more reliable
  - Depend on the other, less uncertain parameter values
Soil texture effects

- Fine particles stabilize soil organic matter by slowing down decomposition
Soil carbon stocks in different forests: model estimates vs. measurements

Soil texture effects: Discussion

- Effects of soil texture on productivity far more important than those on decomposition in these forest soils.
- Variability in texture between soil horizons makes modelling of the texture effects on decomposition difficult.
Mapping soil carbon stocks in Finland

- **Background**
  - No estimates for soil carbon stock in Finland's forests in the mid-1990s
  - Limited resources in a research project to come up with the estimates
  - Most important affecting factors: site productivity and temperature

- **Material and method**
  - Soil carbon measurements at 60 sites (30 site productivity effects, 30 temperature effects)
  - Statistical models for soil carbon density: organic layer = f(site productivity), 0-1 m mineral soil = f(site productivity, temperature)
  - Estimates for NFI sites (n=46,000)
  - Interpolation over the entire country

Soil carbon in Finland’s upland forests

Organic layer

0-1 m mineral soil layer

Soil carbon in Finland’s upland forests

<table>
<thead>
<tr>
<th>Soil layer</th>
<th>Areal weighting estimate</th>
<th>Interpolated blocks estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tg</td>
<td>%</td>
</tr>
<tr>
<td>Organic</td>
<td>315</td>
<td>28</td>
</tr>
<tr>
<td>Mineral soil 0–1 m</td>
<td>754</td>
<td>68</td>
</tr>
<tr>
<td>Mineral soil below 1 m</td>
<td>40</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>1109</td>
<td>100</td>
</tr>
</tbody>
</table>
Potential error in the estimates of soil carbon stock

<table>
<thead>
<tr>
<th>Error source</th>
<th>Organic layer</th>
<th>Mineral soil layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stoniness of soil</td>
<td>0</td>
<td>-21</td>
</tr>
<tr>
<td>Shallowness of soil</td>
<td>0</td>
<td>-7</td>
</tr>
<tr>
<td>Dominance of broadleaved trees</td>
<td>-3</td>
<td>-3</td>
</tr>
<tr>
<td>Forest harvesting</td>
<td>-16</td>
<td>0</td>
</tr>
<tr>
<td>Slash and burn cultivation</td>
<td>0</td>
<td>-4</td>
</tr>
<tr>
<td>Drainage properties of soil</td>
<td>+6</td>
<td>+6</td>
</tr>
</tbody>
</table>

Summary: Modelling soil carbon balance at large scales

- **Questions asked**
  - Soil carbon stock
  - Soil carbon changes
  - Effects of different factors on soil carbon (changes)

- **Choice of model**
  - Statistical vs. dynamic
  - Simple vs. complicated

- **Requirements for soil carbon modelling**
  - Reliability
  - Relevance
  - Feasibility
### Evaluation of different modelling approaches

<table>
<thead>
<tr>
<th></th>
<th>Reliability</th>
<th>Relevance</th>
<th>Feasibility</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Structure</td>
<td>Param.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stock</td>
<td>Stats.</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Dyn.</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>δstock</td>
<td>Stats.</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Dyn.</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Simple</td>
<td>?</td>
<td>+</td>
<td>?</td>
<td>+</td>
</tr>
<tr>
<td>Complex</td>
<td>+</td>
<td>?</td>
<td>+</td>
<td>?</td>
</tr>
</tbody>
</table>