Climate control on soil carbon turnover: observations, simple models, and CLM

C. Koven, G. Hugelius, D. Lawrence, W. Wieder, R. Fisher, B Sanderson, and LMWG

Supported by BGC-Feedbacks SFA
Problem

• Lots of parametric uncertainty in CLM; we want to calibrate the model to reduce uncertainty via observational constraints to the extent possible
• Soil carbon slow to equilibrate so less amenable to short-duration parametric ensembles we’ve been using for productivity calibration.
• Soil stocks contingent on everything upstream—i.e. everything
• So we would want to separate fast (productivity) from slow (turnover) variables.
Turnover times useful for removing influence of productivity on carbon stocks. Here define “inferred $\tau$” as ratio of stock to input flux.

Inferred Turnover Time (years)

HWSD & NCSCD Soil C to 1m (kg m$^{-2}$)

MODIS NPP (g C m$^{-2}$ y$^{-1}$)
Next plot as variable-variable relationship to identify control of $\tau$ by major climate variables: $T$ and precip
1: Focus on temperature:
Separate out moisture control by ignoring gridcells that are either too wet (peatlands) or too dry (P minus PET < -1000 mm/yr)
Differentiate best-fit curve to estimate a “climatological $Q_{10}$”

Note that this is just for carbon to 1m depth, so different from the larger permafrost carbon issue, which is dominated by deep carbon.
A simple theory for high cold-climate sensitivity: scaling in volume and time of soil freeze/thaw state

- Turnover time of respiration function (yr) vs. Mean Air Temperature (°C)
  - $Q_{10}=1.5$ at 10 cm
  - Thawed-only $Q_{10}=1.5$ at 10 cm
  - Thawed-only $Q_{10}=1.5$ over 0-1m interval
CLM4.5: results support weak climate-independent depth control of decomposition
2: Compare tails above distribution to assess strength of moisture controls: CLM too weak.
Soil moisture control in CLM

CLM equation:

\[ r_w = \frac{\log \left( \frac{\psi_{\text{min}}}{\psi} \right)}{\log \left( \frac{\psi_{\text{min}}}{\psi_{\text{max}}} \right)} \]

Which is from this paper, but...

<table>
<thead>
<tr>
<th>CLM value</th>
<th>Original reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \psi_{\text{max}} )</td>
<td>-10 MPa</td>
</tr>
<tr>
<td>( \psi_{\text{min}} )</td>
<td>saturation</td>
</tr>
</tbody>
</table>


BARLEY STRAW DECOMPOSITION IN THE FIELD:
A COMPARISON OF MODELS

OLOF ANDRÉN AND KEITH PAUSTIAN
Department of Ecology and Environmental Research, Swedish University of Agricultural Sciences, S-750 07 Uppsala, Sweden

Moisture influence was assumed to be a log-linear function of soil water potential (\( \Psi \)):

\[ E_{\Psi} = \begin{cases} 1 & ; \Psi > \Psi_{\text{max} E} \\ \frac{\log(\Psi_{\text{min} E}/\Psi)}{\log(\Psi_{\text{min} E}/\Psi_{\text{max} E})} & (6c) \\ 0 & ; \Psi < \Psi_{\text{min} E} \end{cases} \]

where \( \Psi \) is the soil water potential and \( \Psi_{\text{max} E} \) and \( \Psi_{\text{min} E} \) are boundary values for maximum (i.e., wet soil) and minimum (i.e., dry soil) water potentials, expressed in megapascals (as negative values). Since the soil was light in texture and well drained, negative effects on decomposition due to waterlogging were not considered. The response function is similar to others used for soil respiration (Wilson and Griffin 1975, Orchard...
Varying minimum soil matric potential for decomposition ($\psi_{\text{min}}$)

Default case

$\Psi_{\text{min}} = -10\text{MPa}$

Inferred Turnover Time (yr)

Mean Air Temperature ($^\circ\text{C}$)

Precipitation (mm/yr)
Varying minimum soil matric potential for decomposition ($\psi_{\min}$)
Varying minimum soil matric potential for decomposition ($\psi_{\text{min}}$)
Varying minimum soil matric potential for decomposition ($\psi_{\text{min}}$)
Varying minimum soil matric potential for decomposition ($\psi_{\text{min}}$)
Still need to reduce $\psi_{\text{max}}$ too, as indicated by maps of $w_{\text{scalar}}$...

$\psi_{\text{min}}=-10\text{MPa}$  

Top Soil Level

$\psi_{\text{min}}=-2\text{MPa}$

Soil Level 10
Summary

• Turnover-climate benchmark is useful way of identifying long-term climate controls on decomposition, and for isolating the parametric controls on soil turnover.

• High temperature sensitivity in cold climates, which emerges from resolved scaling of freeze-thaw state in both simple and complex (CLM) models.

• Benchmark supports a weak value for climate-independent limitations on deep soil decomposition.

• Interestingly, the $Q_{10}$ parameter itself sort of seems fine as-is

• CLM has too-weak aridity controls on decomposition – can be partially remedied by increasing $\psi_{\text{min}}$ parameter and likely we also need to decrease $\psi_{\text{max}}$ to get good dynamic range.