Permafrost-carbon feedback: Sensitivity to deep soil decomposability and nitrogen cycle

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**Motivation:** Enormous stocks of C in permafrost soils, whose stability is contingent on being frozen. What happens to this SOM under warming?

Data: NCSCD (Tarnocai et al., 2008, Hugelius et al., 2012)

Koven et al., 2013
CLM4.5BGC: Simplest approach to represent 1-D permafrost processes (active layer deepening) by including the vertical dimension in SOM cycling, to represent the physical controls on mixing and decomposition rate in soils.
Controls on Soil Turnover in CLM4.5BGC: base rate, temperature, moisture, oxygen, and depth modifiers

\[ k_i = k_{0,i} r_T r_w r_O r_z \]

\[ r_z = \exp \left( -\frac{z}{z_\tau} \right) \]

- \( Q_{10} \) (of 1.5)
- Stoichiometric oxygen supply vs. demand
- Matric potential of (unfrozen) water

Experimental Design: Use \( Z_\tau \) to assess the sensitivity of response to the decomposability of deep SOM
Full experimental setup in CLM4.5:

1. Forced by offline transient historical+RCP8.5 warming and/or CO₂ scenarios to calculate physical and biogeochemical responses to climate change, CO₂ fertilization, and interactions

2. CLM4.5BGC including N feedbacks vs. C-only version of CM4.5BGC to assess role of N feedbacks

3. Vary $Z_\tau$ to assess role of deep SOM
Reversal of vertical profile in environmental decomposition limitation as permafrost changes to seasonally frozen ground. Note that strongest control is via the (liquid) moisture scalar.
C cycle response with non-responsive deep permafrost: sensitivity to C-N coupling and experimental forcing

In the absence of decomposable deep SOM, CO$_2$ fertilization and soil C losses nearly balance each other out for a small net change.
Full response as a function of deep soil decomposability

With decomposable deep SOM, soil C losses dominate and lead to a large positive feedback from the permafrost region.
Why small response of vegetation to additional N from mineralizing deep N?

Seasonal asynchrony between N demands and extra N supply means that deep SOM not as available for plant uptake; Also, plants already getting extra N from shallow soils.
Projected soil C emissions follow the retreating permafrost boundary and persist long after permafrost has thawed.
Global relevance of permafrost C-climate feedback

Zonal Mean C Flux into land

(g C m^{-2} yr^{-1}; positive = sink)
CH$_4$ emissions from deep C are present but projected to be much smaller contribution to feedback (\(~10\%\) in 100-yr GWP) than CO$_2$ emissions and partially offset by drying associated with warming and thawing soils. However CH$_4$ model highly uncertain and sensitive to subgridscale hydrology that is not represented in model.
Conclusions

• Deeper (0.5-3m) SOM decomposability is crucial determinant of permafrost C feedback
  – Without deep C, weak response; with it large positive feedback
• However, it doesn’t seem to matter as much for stabilizing N feedbacks
• Results support idea that this could be a powerful, though perhaps delayed, C cycle feedback
• CLM4.5 is a useful tool for exploring these effects, however the list of potentially important things not included in this model is still very long
• Need to understand what controls the fate of deep carbon in thawing permafrost systems