Permafrost Carbon and Climate Feedbacks in a Warmer World

Dr. Ted Schuur
Bonanza Creek, LTER Annual Symposium
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Global Carbon Pools

Global Vegetation C  650 Pg
Global Soil C (1m)  1500 Pg
Atmosphere  841+ Pg

Permafrost Zone Soil C
- Peatlands (several m)  277 Pg
- Mineral Soil (3m)  747 Pg
- Siberian Deep C (~25m)  407 Pg
- Alluvial Deep C (~25m)  241 Pg

Permafrost Carbon Feedback to Climate

What is the magnitude, timing, and form of the permafrost carbon release to the atmosphere in a warmer world?

- Fossil Fuel Emissions: 365 Pg
- Land Use Change: 151 Pg

Permafrost Zone C Emissions: Future?
- 5-30% Loss?: 85-501 Pg?
Permafrost Carbon Feedback to Climate

Schuur et al. 2008 BioScience
Eight Mile Lake Study Area

- Permafrost Thaw Gradient
- CiPEHR Project
- EC Tower
- NEON D19 Taiga Relocatable Site
Q1: How does permafrost thaw affect ecosystem carbon balance?

Q2: Does permafrost thaw cause old carbon loss?
Feedbacks to the Carbon Cycle

- Positive feedback
- Negative feedback

- Decomposition
- Production
- Nutrient availability

- $\text{CO}_2, \text{CH}_4$
- $T$

- Nutrient availability
- Decomposition
- Production
- Temperature $T$

- $\text{CO}_2, \text{CH}_4$
Feedbacks to the Carbon Cycle

- **CO₂, CH₄**
- **T**
- **decomposition**
- **production**
- **nutrient availability**

*positive feedback*
*negative feedback*
**Warming Experiment**

**Question:** What is the effect of warming on carbon balance in the permafrost zone?

**Approach:** Experimental tundra warming

**Issues:** Previous tundra warming experiments mostly have warmed air or surface soil, but fail to degrade permafrost. Snowfence experiments have warmed deep soil but typically result in extra water inputs or delayed spring.
CiPEHR Project
(Carbon in Permafrost, Experimental Heating Research)

Two Treatments, Factorial
Winter Warming (Snow Fence + Snow Removal)
Summer Warming (Open Top Chamber)
Annual Warming (Combination)
Control (Ambient)

Replicated: 6 times w/ subreplicate plots
Established: Summer 2008
Winter Warming Causes Surface Permafrost Degradation

**Winter warming plots**
Increased T in winter and summer, at depth

**Summer warming plots**
No soil warming
Midday air temp ~+1°C

Natali et al. 2010, Global Change Biology
**Winter Warming Increases Water Table**

**Winter warming**
- 50% increase in total height of water table
- Increased surface soil moisture

**Dryper:** Water Table Manipulation in 2011
(NSF Fellowship + NSF Grant to S. Natali)
Growing Season Carbon Fluxes

**Respiration**
- **Summer warming**: NEE no difference from control (but C sink)
- **Winter warming**: +NEE (C sink)
- **Annual warming**: NEE no difference (but C sink)

**Photosynthesis**
- **Summer warming**: NEE no difference from control (but C sink)
- **Winter warming**: +NEE (C sink)
- **Annual warming**: NEE no difference (but C sink)

**Carbon Balance**
- **Summer warming**: NEE no difference from control (but C sink)
- **Winter warming**: +NEE (C sink)
- **Annual warming**: NEE no difference (but C sink)

Natali et al. 2010
Natali et al. in prep
Verity Salmon PhD
Winter
Summer warming: +NEE no difference from control, but (C neutral 2 of 3 yrs)

Winter warming: Sustained C source (C neutral 2 of 3 yrs)

Annual warming: Same as WW (C neutral 2 of 3 yrs)
Warming a permafrost ecosystem rapidly alters surface hydrology, important even in uplands!

Experimental Summary

Carbon uptake from Arctic greening is offset by C losses from permafrost degradation.

Initial response of experiment matches gradient; this implies a future C source as experiment continues.
Permafrost Zone Soil C
Gelisol Soil Order (3m)*
818 Pg
x 9-13%
77-106 Pg**

Permafrost C Loss
0.8-1.1 Pg/yr
Land Use Change***
0.9±0.7 Pg/yr

Vulnerability of Permafrost Carbon Research Coordination Network (RCN)

http://www.biology.ufl.edu/permafrostcarbon/

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Workshop: May 2013; Annual Meeting @ AGU
Permafrost Carbon Feedback: Expert Assessment

High Warming Scenario (2100): \(162-288\) Pg C (in CO\(_2\) equivalents)

Low Warming Scenario (2100): \(54-90\) Pg C (in CO\(_2\) equivalents)

2.3\% CH\(_4\) = half of emissions in CO\(_2\) equivalents

Schuur, Abbott et al. 2011, 2013

Special Issue: Environmental Research Letters; March 31, 2013
Conclusions

Permafrost C pools are large and sensitive to climate change on decadal to century time scale (4-13%)

Experimental permafrost degradation was consistent with C emissions observed from natural thaw

Future permafrost C emissions will not overshadow fossil fuel, but will serve to accelerate pace of climate change (weakening biospheric sink)

Permafrost C emissions should be accounted for when planning mitigation strategies for avoiding dangerous climate change