When is the Permafrost Carbon Tipping Point?

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Permafrost Primer

**Permafrost:** Ground at or below 0°C for at least 2 consecutive years

**Active Layer:** A layer over permafrost that freezes and thaws annually

**Talik:** A layer or body of unfrozen ground in a permafrost area

**Permafrost Degradation:** A decrease in thickness and/or areal extent of permafrost.

Skiklomanov [2007]
Permafrost Extent

- 24% of land surface in the Northern Hemisphere
- Climate projections indicate substantial permafrost degradation by 2100 [Zhang et al., 2008; Lawrence and Slater, 2005]

Zhang et al., 2003. *EICOP*
Permafrost Carbon

~950 Gt of frozen carbon [Zimov et al., 2006]

Siberia [Zimov et al., 2006]

Siberia [Davis, 2000]
The Permafrost Carbon Tipping Point

- When net flux changes from a sink to a source
- Signals start of permafrost carbon feedback
Experiment Setup

- SiBCASA biosphysical model
- NCEP Reanalysis
- 1948-2007 “spin up“
- 2008-2100
  - Randomly repeat 1998-2007 NCEP weather
  - Increase temperature 4 °C century⁻¹
- 1 simulation with permafrost carbon; 1 without
Permafrost Carbon in SiBCASA

\[ D_{\text{act}} = \text{active layer depth} \]
\[ D_{\text{max\_act}} = 1948-2007 \text{ maximum active layer depth} \]
\[ \rho_{\text{carb}} = \text{permafrost carbon density (2\% by mass)} \]
Results

Barrow

Siberia
Active Layer Projections

- **Barrow**
  - $D_{act\_max}$

- **Siberia**
  - $D_{act\_max}$
Fluxes with Permafrost Carbon

Barrow

Siberia

NEE with permafrost carbon

NEE no permafrost carbon

Year

1940 1960 1980 2000 2020 2040 2060 2080 2100
Finding the Tipping Point

**Barrow**

**Tipping Point**

**Siberia**

**Tipping Point**

- **NEE with permafrost carbon**
- **NEE no permafrost carbon**

![Graph showing cumulative flux with and without permafrost carbon for Barrow and Siberia over time](image)
Uncertainty

- Assumed weather
- Warming scenario
- Sea ice
- Modeling approach
- Permafrost carbon:
  - Spatial distribution
  - Vertical distribution
  - Carbon density
Conclusions

• Only modest thaw induces tipping point
• Permafrost carbon feedback could be fast
• Tipping point shows strong spatial variability
  • Barrow: 2060
  • Central Siberia: 2105
• Arctic tipping point is possible this century
Questions
Barrow Fluxes Without Permafrost Carbon

The diagram shows the trends in Gross Primary Production (GPP), Net Ecosystem Exchange (NEE), and Respiration over the years from 1940 to 2100. The flux values are given in g C m\(^{-2}\) day\(^{-1}\).
Future Work

- Alternate meteorology
- Pan-Arctic simulations
- IPCC Emission scenarios
- Ensemble simulations
- Model improvements
- Methane and wetlands
Permafrost Carbon Feedback

Amplification of warming due to release of CO$_2$ and CH$_4$ after permafrost carbon thaws

Active Layer

Atmospheric Warming

CO$_2$

Permafrost carbon decays
Siberia Cumulative Flux

The graph shows the cumulative flux over time, with data points from 1960 to 2200. The x-axis represents the year, while the y-axis shows the cumulative flux in g C m$^{-2}$. The red line indicates an upward trend, starting around 2080, suggesting an increase in flux.
Siberia Respiration

[Graph showing respiration (g C m⁻²) over years from 1960 to 2200]
NCEP Precipitation Problems

- >2x observed values
- Wave pattern

Mean maximum Snow Depth