Carbon fluxes in boreal and arctic tundra ecosystems from Alaska to Siberia

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- Tundra ecosystems are a slight sink of CO$_2$ to neutral, and boreal ecosystems are a sink of CO$_2$. Both sources of CH$_4$.

- Detailed descriptions (seasonal, multiyear) of C fluxes at the landscape are still relatively rare in tundra and many boreal ecosystems.

- Should identify the possible relationships between summer and wintertime net daily CO$_2$ efflux and various meteorological parameters, as well as understand how these relations may vary across different types of tundra and boreal ecosystems.

Fig. 2. Seasonal patterns in net ecosystem CO$_2$ exchange. Adapted from Baldocchi and Valentini (2004).
Twenty-three site years of full annual measurements, across 7 sites measured with eddy covariance

(1) Net ecosystem exchange (NEE)
(2) Ecosystem respiration (ER)
(3) Gross primary productivity (GPP = NEE - ER)
(4) CH$_4$ flux (two sites)
(5) Meteorological variables

- What is the sink strength of these ecosystems?
- How does this vary interannually?
- What are the environmental variables influencing interannual variability?
The boreal wetland ecosystem peat accumulation in a dynamic system with elevated permafrost and lowered wetlands represents a mosaic of landscape units that have distinct hydrologic and soil thermal regimes.
Pathways of change

Black spruce forest

Collapse scar bog

Fen

Scrub forest

Forest regrowth / permafrost regrowth?

Internal collapse (hydrologically isolated from the fen complex)

Edge collapse (hydrologically connected to the fen complex)

Drier conditions promote shrub growth in the fen
Ancient soils. (Left) Exposed carbon-rich soils from the mammoth steppe-tundra along the Kolyma River in Siberia. The soils are 53 m thick; massive ice wedges are visible. (Right) Soil close-up showing 30,000-year-old grass roots preserved in the permafrost.
MAJOR VEGETATION TYPES AT PLEISTOCENE PARK, SIBERIA

Dense larch forest
Dense stand of thin *Larix sibirica* on dry soil; sparse understory and thin soil organic horizon due to needle litter

Larch shrubland
Sparsely distributed *Larix sibirica* on dry soil with tall *Salix* sp. and *Betula middendorffii*; understory dominated by *Vaccinium vitis-idaea, V. uliginosum, Ledum decumbens*

Graminoid shrubland
*Salix* sp. and *Betula exilis* on moist soil; understory dominated by *Calamagrostis langsdorffii, Carex appendiculata* and *Eriophorum sp.*

Graminoid meadows
Mix of grasses (*Calamagrostis langsdorffii*) on moist low terraces and sedges (*Carex appendiculata, Eriophorum polystachyon*) along wet lake shores; thick soil organic horizon

Open water
Lakes and streams

Eddy covariance tower
Variation in NEE across sites and years
**Collapse Bog**

- **Slope:** 0.45
- **Intercept:** -14.74
- **R²:** 0.50, *p* < 0.0001

**Black Spruce Forest**

- **Slope:** 0.53
- **Intercept:** -15.99
- **R²:** 0.40, *p* < 0.0001
Winter Ecosystem Respiration as a Proportion of Annual Ecosystem Respiration

- Boreal rich fen
- Boreal collapse bog
- Boreal black spruce
- Steppe/forest
- Heath tundra
- Tussock tundra
- Wet sedge tundra

Proportion of snow season ER to annual ER
Wet Sedge Tundra
Predicting Winter Ecosystem Respiration

Winter ER = β₀ + β₁*T_{AIR} - β₂*Snowpack - β₃* Air pressure - β₄* Snowpack * T_{AIR}

Observed ER (µmol CO₂ m⁻² d⁻¹)

Predicted ER (µmol CO₂ m⁻² d⁻¹)

Nov. – Apr.

R² = 0.45, p < 0.0001
Cumulative NEE January 2008 – December 2013
(Positive Value = C Release)

Updated from Euskirchen et al., Ecosphere, 2012
Wet sedge tundra

Late Fall / Early Winter NEE vs. Air Temp.

\[
\text{NEE} = 4.6 \times \text{Air temp.} + 136.8 \\
R^2 = 0.40
\]

Total NEE September – December (g C m\(^{-2}\) y\(^{-1}\))

Mean Air Temperature September – December (°C)

- 2008
- 2010
- 2011
- 2012
- 2013

2013
Methane Emissions

CH$_4$ flux (mg m$^{-2}$ d$^{-1}$)

- Wet sedge tundra 2012
- Wet sedge tundra 2013
- Boreal collapse bog 2013

Cumulatives for measurement period:

- **CH$_4$**:
  - +4.9 g m$^{-2}$
  - +2.0 g m$^{-2}$
  - +1.5 g m$^{-2}$

- **CO$_2$**:
  - -7.2 g m$^{-2}$
  - -55 g m$^{-2}$
  - -183 g m$^{-2}$

CO$_2$ equivalent, combining CH$_4$ release and offset of CO$_2$ uptake:

- Bog 2013: +118 g CO$_2$ e m$^{-2}$
- Wet sedge 2012: -17 g CO$_2$ e m$^{-2}$
- Wet Sedge 2013: -133 g CO$_2$ e m$^{-2}$
Conclusions:

- Important to take into account landscape heterogeneity and interannual variability

- Black spruce showed greatest interannual variability

- Siberian Yedoma steppe tundra/ forest ecotone still serving as a slight sink of CO$_2$

- Wet sedge tundra a greater source of CO$_2$ in recent years with warmer late fall/ early winter

- Smaller proportion of winter ER to total ER in the boreal sites compared to tundra

- CH$_4$ emissions offset CO$_2$ uptake at the boreal collapse bog, but not at the wet sedge tundra
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