Resilience and Vulnerability of Permafrost to Climate Change

Torre Jorgenson, Vladimir Romanovsky, Jennifer Harden, Yuri Shur, Jonathan O’Donnell, Ted Schuur, Mikhail Kanevskiy
Background

- Permafrost dynamics depend on the complex interaction among many physical and biological factors.
- Permafrost can persist at MAAT of +2 °C (in late-successional ecosystems) and degrade at MAAT of -15 °C (in the presence of surface water).
Background

- **Permafrost resilience** – *the capacity to maintain frozen temperatures and similar ground ice contents/morphologies when confronted with perturbations*

- **Permafrost vulnerability** – *the extent to which permafrost both vertically and laterally; amount of thaw settlement occurring in response to thawing of ground ice*
Study Overview

**Research Objective:** To evaluate the relative importance of various environmental factors on the ground thermal regime.

**Experimental Approach:** To assess the relative importance of each factor, we compared changes in mean annual temperature at ground surface (MAST) and at 2 meters (MADT) as universal metrics.
Field Measurements

- **Soil properties** - texture, bulk density, horizon thickness, moisture content (Jorgenson *et al.* 2003; Harden *et al.* 2006; O’Donnell *et al.* 2009a)
- **Soil temperature** (Jorgenson *et al.* 2003)
- **Thermal conductivity** (O’Donnell *et al.* 2009b)
- **Ground ice content** (Shur & Jorgenson 2007; Osterkamp *et al.* 2009)
Modeling Scenarios (GIPL)

1) **Climate effects** – we tested the effects of air temp (MAAT 0 to 5 °C) and snow (50 vs. 100% of mean annual snow depth)

2) **Ecosystem effects** – we tested the effects of co-varying snow-vegetation-soil properties of 11 terrestrial ecosystem at constant MAAT

3) **Organic horizon/moisture** – we simulated the effects of fire by varying organic horizon thickness and soil moisture
Climate Effects on Ground Thermal Regime

- **Top panel** - Large thermal offset between MAAT - MAST (6.6 to 7.4 °C) and MAAT – MADT (5.7 to 6.1 °C).

- **Bottom panel** – Decreasing snow depth reduced MAST (up to 2 °C) and MADT (up to 3.8 °C).

*Simulations on barren silt*
Ecosystem Effects on Permafrost

Mean Annual Ground and Water Temperatures

- Surface
- 2-m Depth

Mean Annual Air Temperature (1997-2007) = -2.2°C

Ecosystems:
- Barren Hill
- Burned
- Tall Low Willow
- Deciduous Forest
- Mixed Forest
- White Spruce Forest
- Black Spruce Forest
- Low Birch-Ericaceous Shrub
- Turf Bog
- Sphagnum Bog
- Herbaceous Fen
- Shallow Water
- Deep Water

* Field measurements
Organic Horizon/Moisture Effects

- At constant moisture MAST and MADT vary by 1.5 °C at different O horizon thickness.
- At constant O horizon thickness, wet conditions resulted in warm MADT (0.4 °C), while moist and dry conditions resulted in cooler MADT (-1.1 and -0.6 °C).
Summary of Thermal Effects

• Standing water increases MADT by up to $10 \, ^\circ{\text{C}}$ relative to MAAT.
• Vegetation removal (barren silt) increases MADT by up to $7 \, ^\circ{\text{C}}$
• Successional processes can reduce MADT by up to $2 \, ^\circ{\text{C}}$ below MAAT
• Snow depth can affect MADT by up to $2 \, ^\circ{\text{C}}$
• Soil moisture can affect MADT by up to $1.5 \, ^\circ{\text{C}}$
Conclusions

1) Vegetation-soil interactions create strong negative feedbacks that reduce permafrost thaw, thus making permafrost more resilient.

2) Ponding of surface water creates a strong positive feedback that promotes permafrost thaw.

3) The magnitude of positive and negative feedbacks (+10 °C to -7 °C) are greater than predicted increases in air temperature for interior AK (~5 °C). This complicates predictions of permafrost response to future climate change.

4) Fire will likely enhance thawing, particularly in upland black spruce ecosystems.