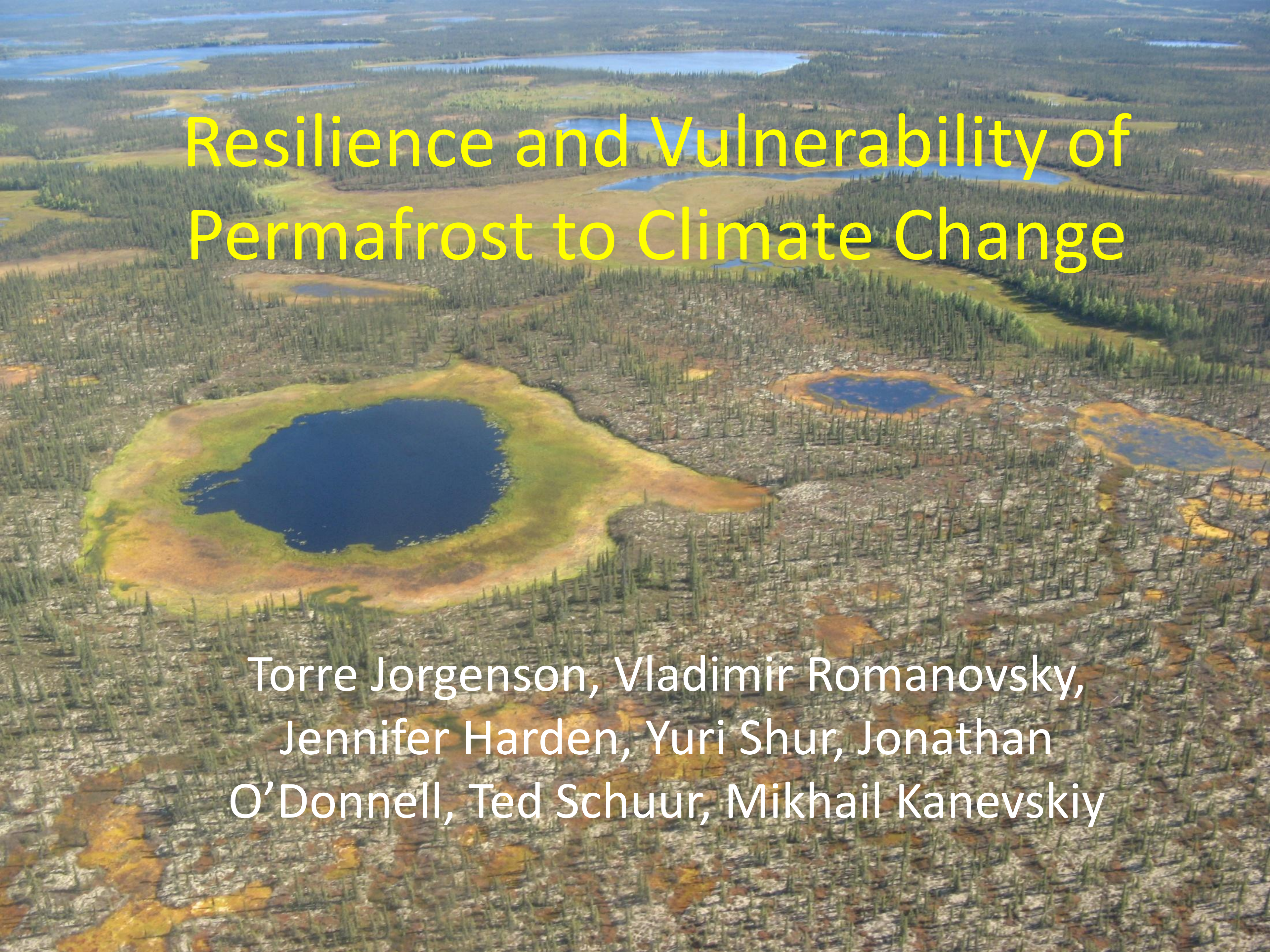
Resilience and Vulnerability of Permafrost to Climate Change



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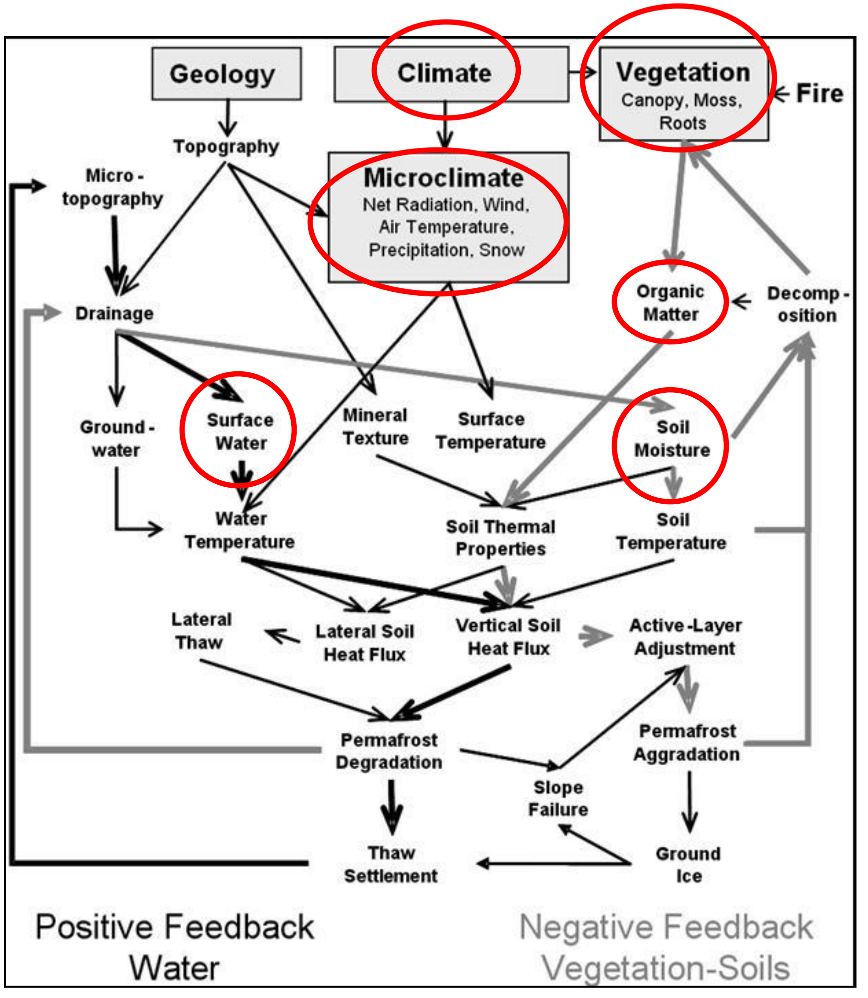
Background

- 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.

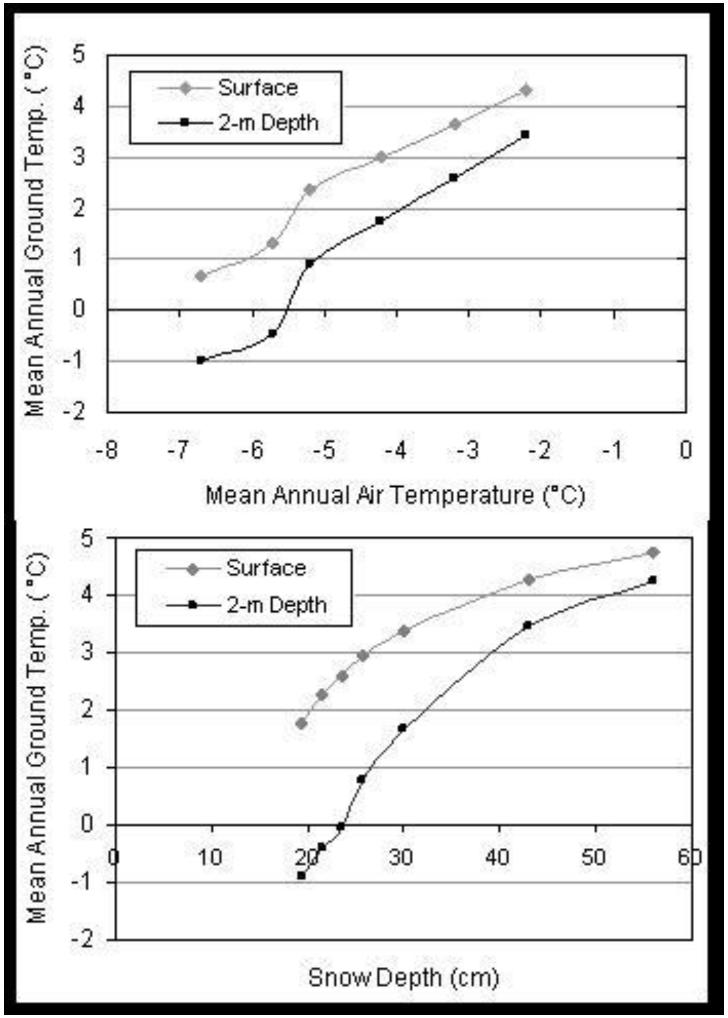
Field Measurements

- **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

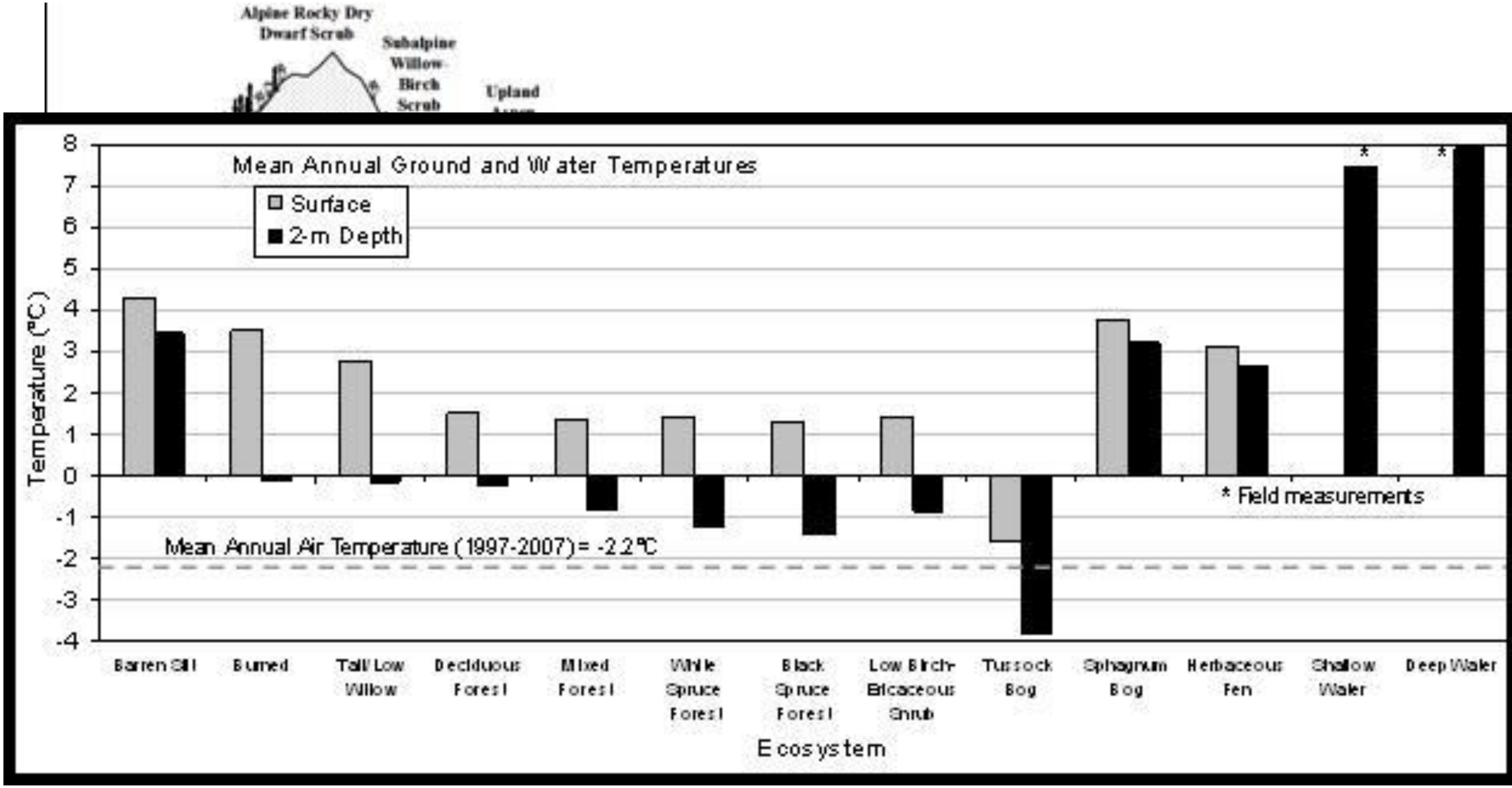
Climate Effects on Ground Thermal Regime



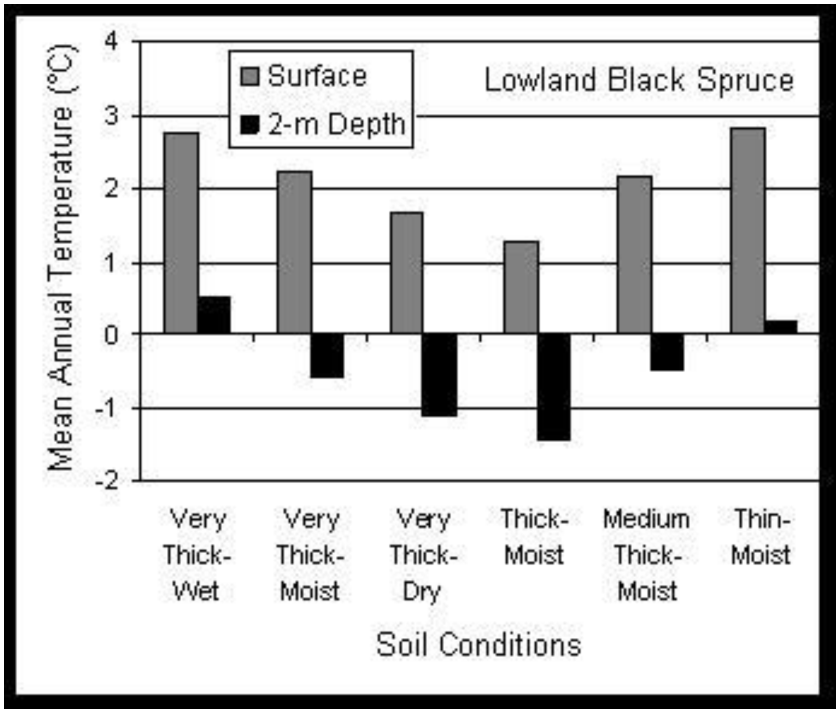
*Simulations on barren silt

- **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)

Ecosystem Effects on Permafrost



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 °C** relative to MAAT.
- Vegetation removal (barren silt) increases MADT by up **7 °C**
- Successional processes can reduce MADT by up to **2 °C** below MAAT
- Snow depth can affect MADT by up to **2 °C**
- Soil moisture can affect MADT by up to **1.5 °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.