Fire's Impact on Energy Balance along Topographic Gradients in Arctic Tundra and Implications for Permafrost Thawing Under Climate Change

Aiyu Zheng[1], Susan M. Natali[1,2], John D. Schade[1,2]

[1]Department of Ecology and Evolutionary Biology, Princeton University, NJ; [2] Woods Hole Research Center, Falmouth, MA

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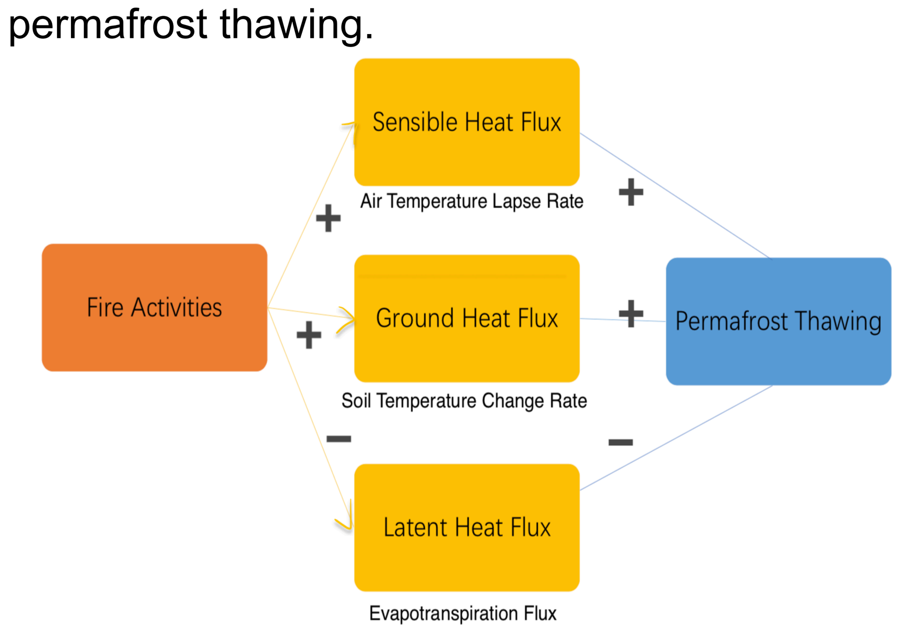
Introduction

Carbon pools in the Arctic have been exposed to greater risk due to permafrost thawing under global warming. Climate change has increased fire activities in Arctic tundra, significantly impacting energy balance by altering heat transferred between air and the ground, within the soil profile, and heat associated with the phase change of water. To understand heat transport along a topographic gradient and its implications on permafrost thawing, this project investigated various mechanisms that alter soil thermodynamic properties in a post-fire regime.

Figure 1. Conceptual Model for fire, energy balance, and permafrost thawing.



Study Site

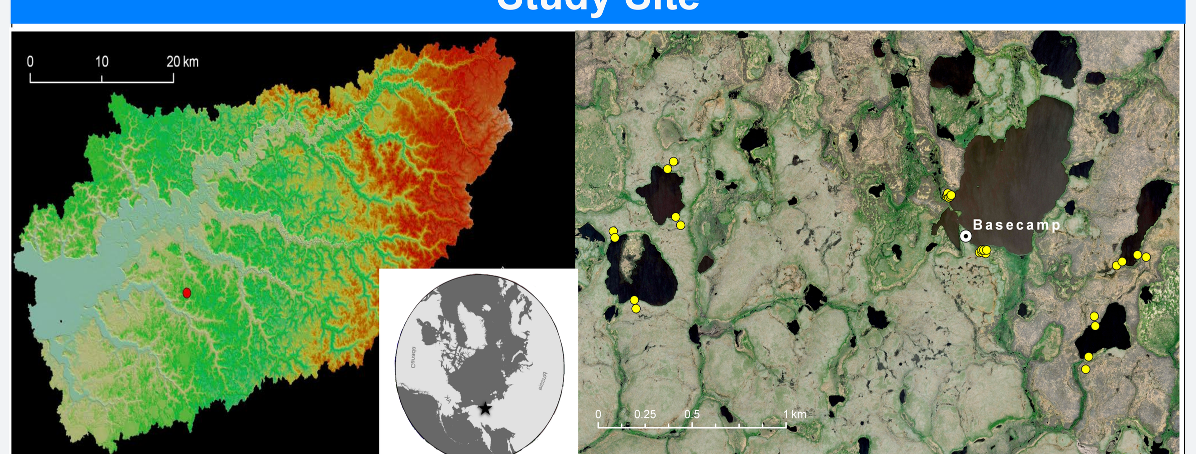
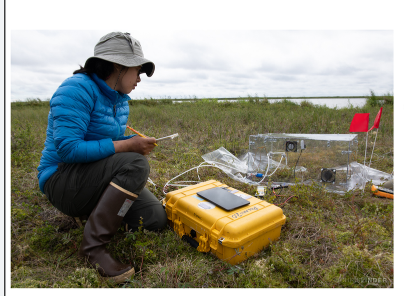


Figure 2. Satellite image of the Yukon-Kuskowkwim River Delta, Alaska. Yellow dots on the right indicate positions of 16 temperature towers placed along burned and unburned topographic gradients (i.e., **Upland Peat Plateau** and **Lowland Water Edge**).

Methods

- Maxim's® ibuttons were installed to measure temperatures at 30 cm below ground, at surface, and at 1m and 2m above ground. Temperature sensors were placed in four burned gradients and four unburned gradients.



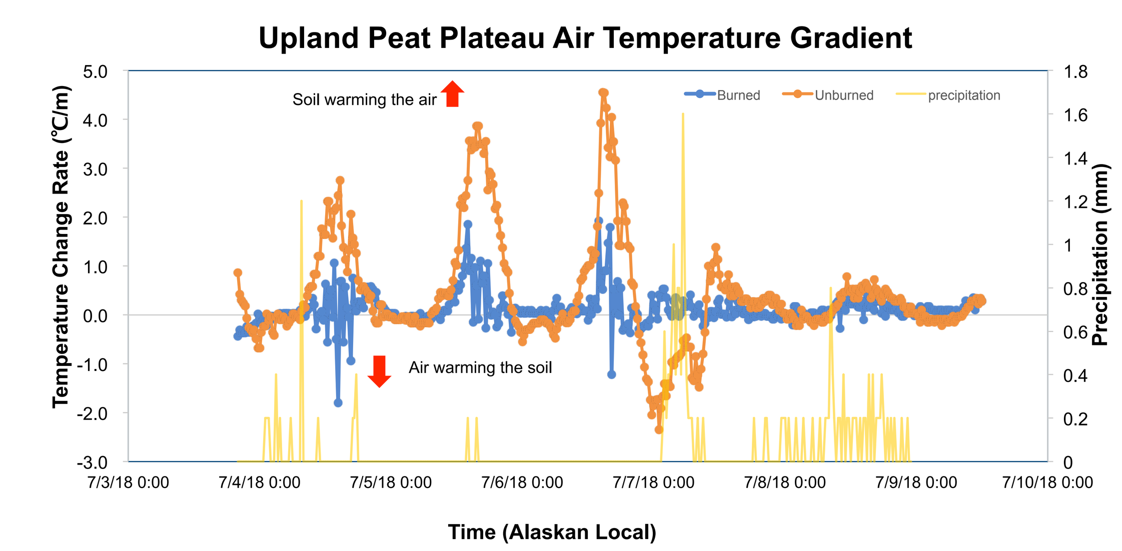
- Licor® LI840 and a transparent chamber were used to measure CO2 and evapotranspiration fluxes from burned and unburned sites.

- Four soil blocks from burned and unburned gradients were used to investigate the relationship between soil moisture and soil thermal inertia to ambient air temperature in lab experiments.

Results

Sensible Heat Flux (Air Temperature Lapse Rate)

Air Temperature Gradient $= \frac{(T_{surface} - T_{air})}{Height}$; arrows indicate directions of sensible heat flux.



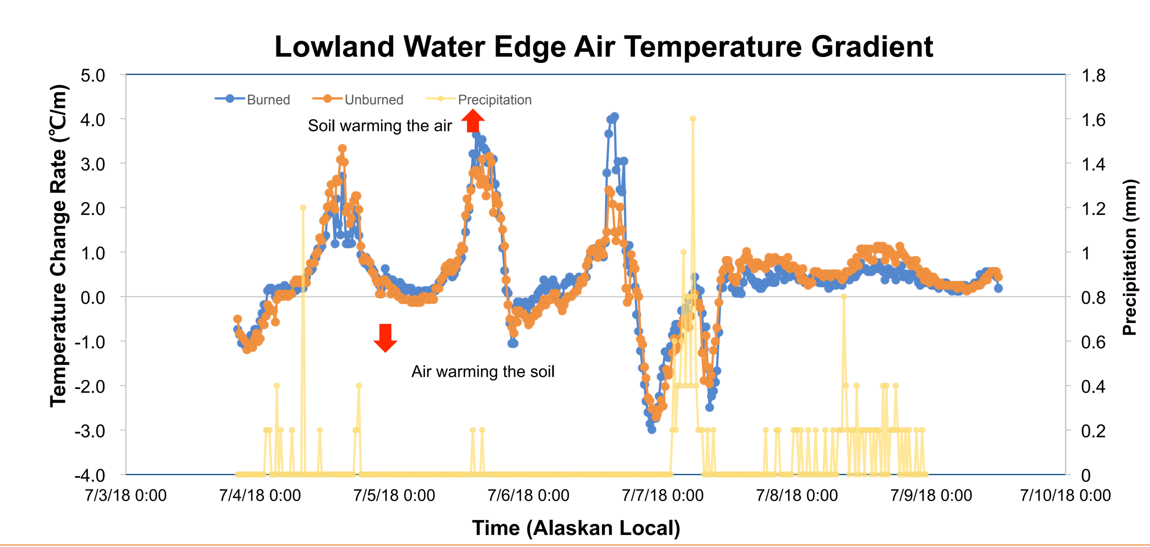
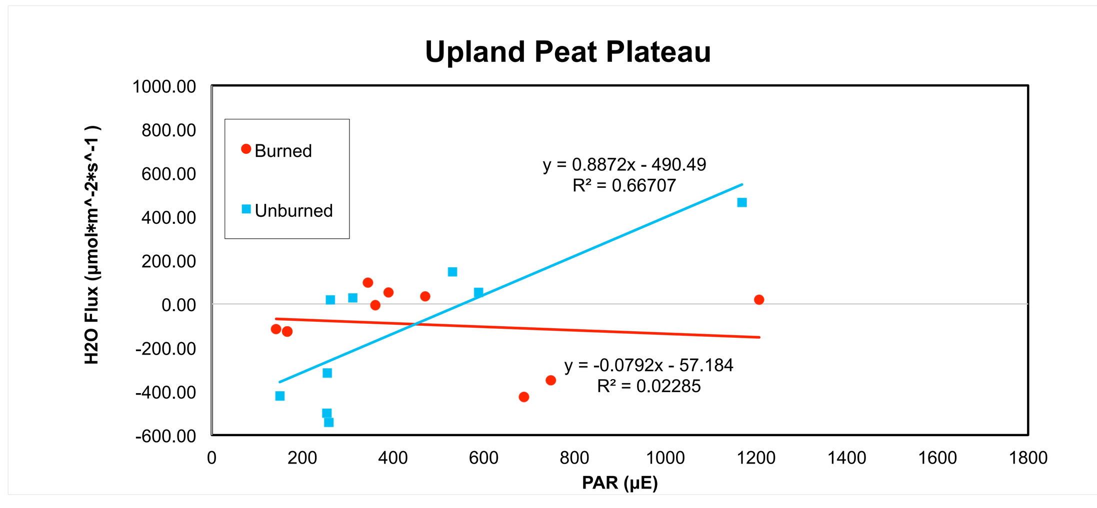


Figure 3. Air temperature gradient as an index for sensible heat flux demonstrates temperature difference between the ground surface and air at 2m. Air temperature gradient is highly correlated with diurnal pattern and precipitation events.

Latent Heat Flux (Evapotranspiration Flux)



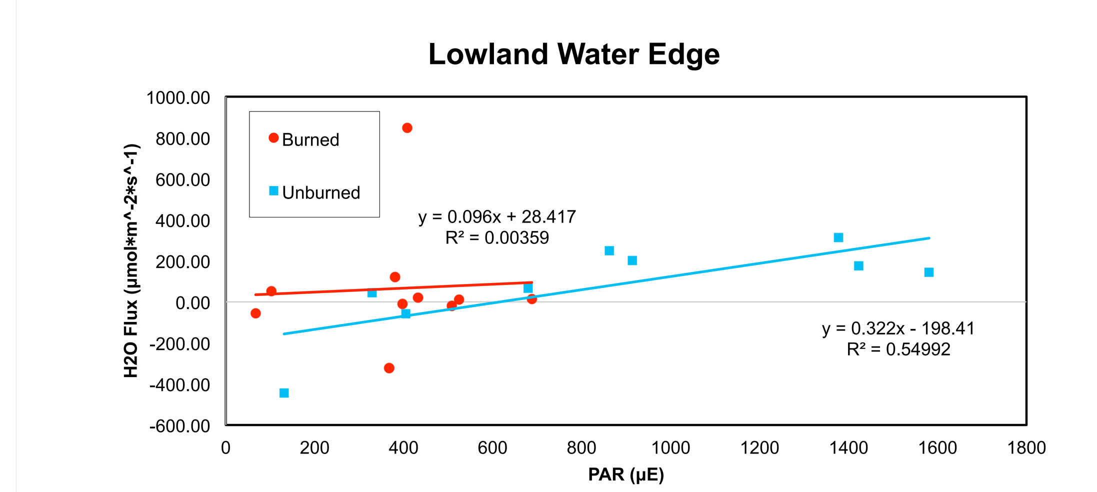


Figure 3. Unburned sites show positive correlation between solar intensity and evapotranspiration, while burned sites do not show any significant relation. Net Ecosystem Exchange (CO2) fluxes display a similar trend on burned and unburned sites (figures not shown here).

Ground Heat Flux (Soil Thermal Inertia)

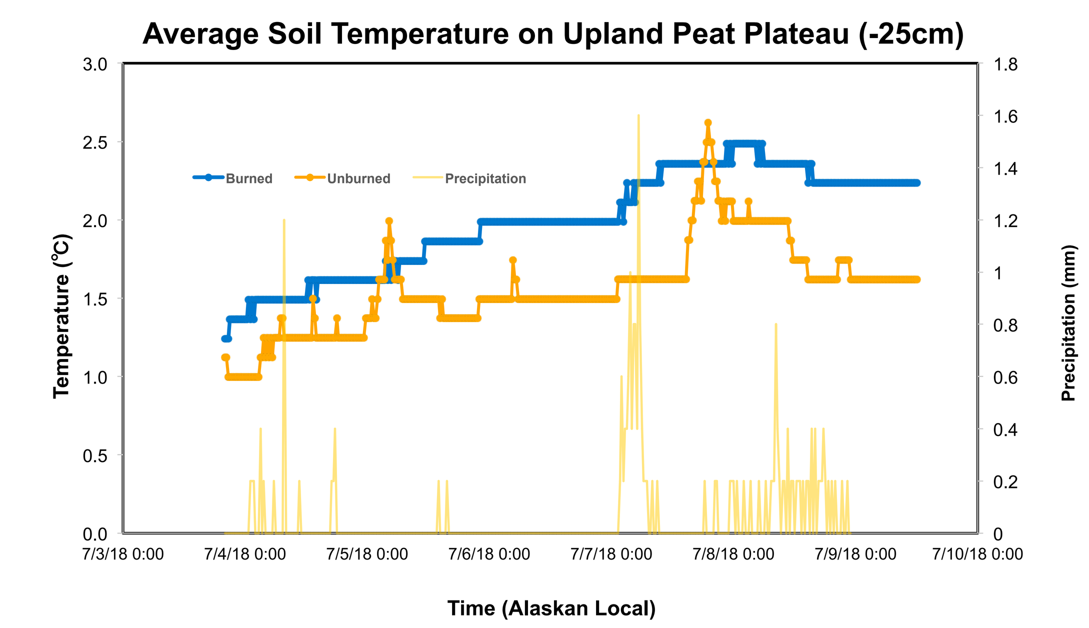
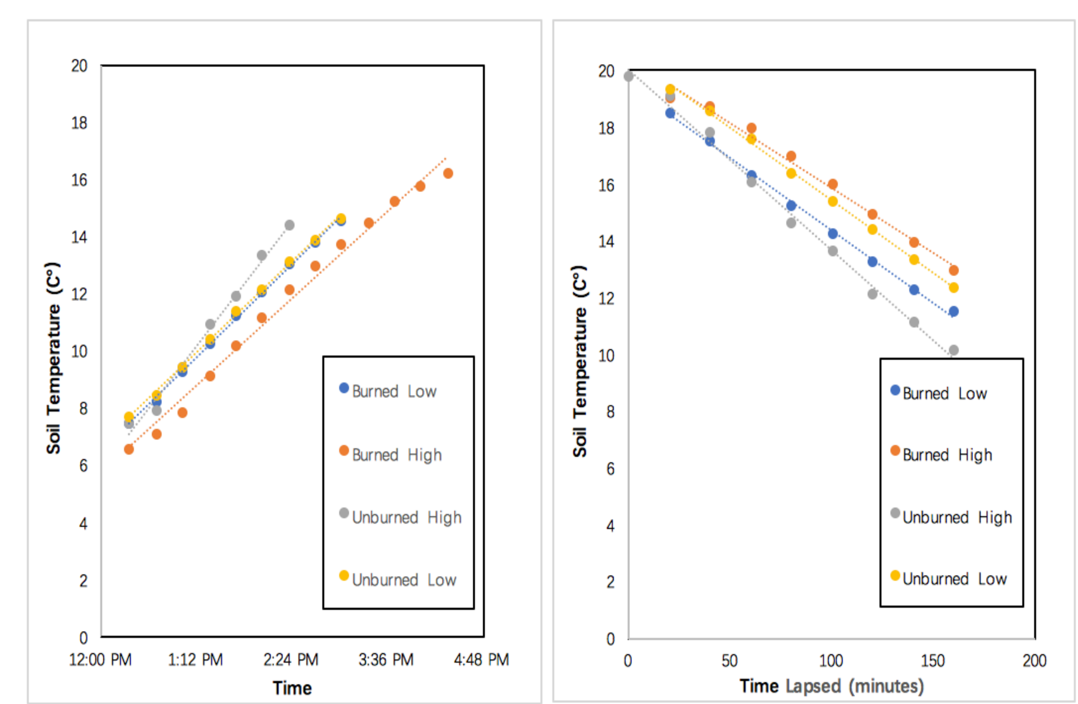


Figure 4. Average soil temperature of burned sites is warmer than the unburned sites. Average soil temperature at lower water edges displays a similar trend in burned and unburned sites (figures not shown).

Field Moisture Level



Field saturation moisture level

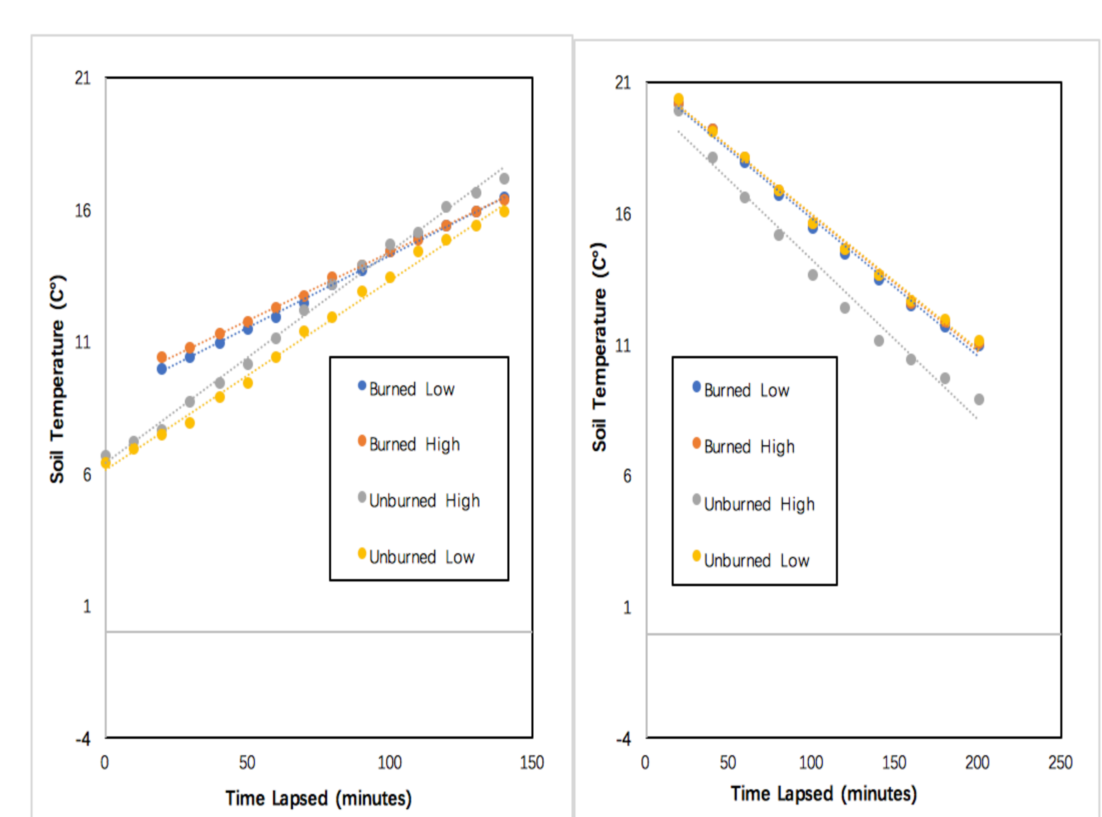


Figure 5. Results of soil block warming (4℃ to 23℃) and cooling (23℃ to 4℃). Soil moisture determines soil thermal conductivity. Unburned highland soil at field moisture and field saturation levels display the greatest temperature change rate as unburned highland soil contains the least moisture; burned highland soil at field moisture and field saturation levels display the least responsive trends.

Conclusion

The 2015 fire in the YK Delta altered energy balance along the topographic gradient.

- Temperature difference between air and soil surface on burned peat plateau decreased due to increasing thermal inertia in burned soils, slowing down soil responses to air temperature change
- Burned soil loses the capacity to shed heat through evapotranspiration, resulting in higher soil temperature
- Fire's alteration of soil structure and moisture level significantly impacted soil thermal conductivity and specific heat capacity resulting in different abilities to conserve heat
- Energy balance changes in response to diurnal radiation and precipitation events, while burned ground induces greater run-off down the gradient from peat plateaus to lakes

Fire exposed burned highland peat plateaus to a greater risk of permafrost thawing by altering soil moisture, soil structure, and vegetation cover. Transport of water from highland to lowland after fire created a positive feedback of lowland water surface expansion and permafrost thawing.

Future research would focus on understanding ecological succession's role in oscillatory behavior and thermodynamic equilibrium of thawed lakes in different size categories.

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References

Oke, T. R. (1987). *Boundary Layer Climates*. London: Routledge.