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Sandia National Laboratories

Peat Fires and Climate Change: Modeling Greenhouse Gas Emissions by 2100

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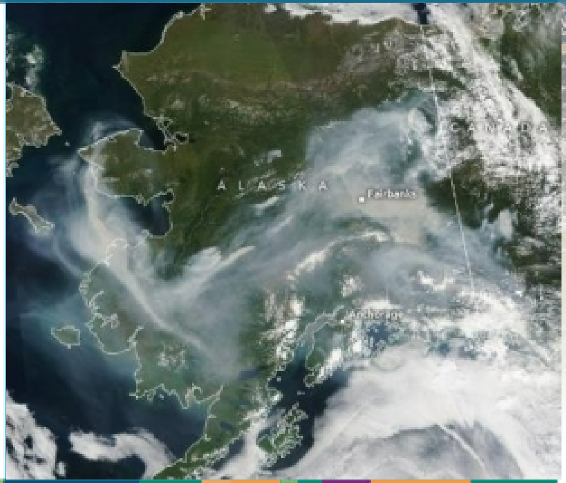

24 May 2022
IAWF Fire & Climate Conference
Pasadena, CA

U.S. DEPARTMENT OF ENERGY
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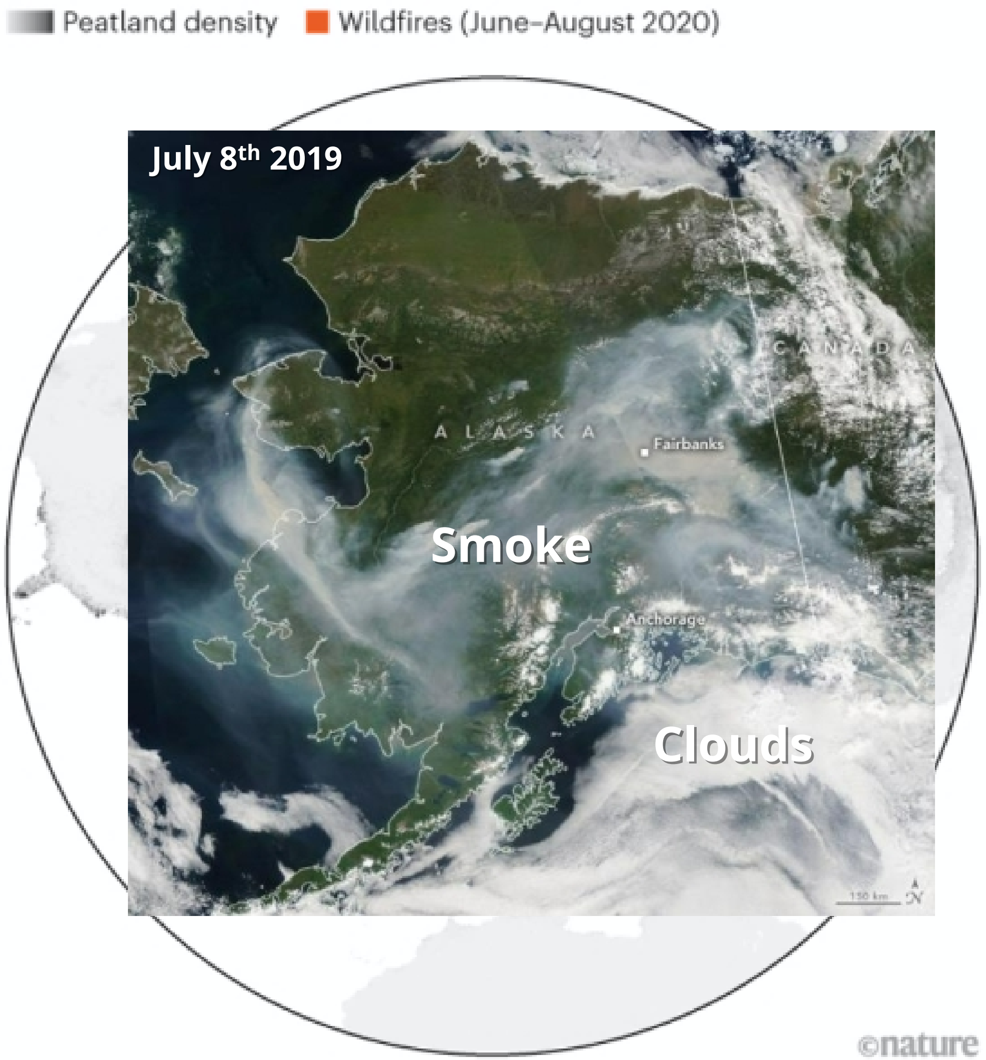
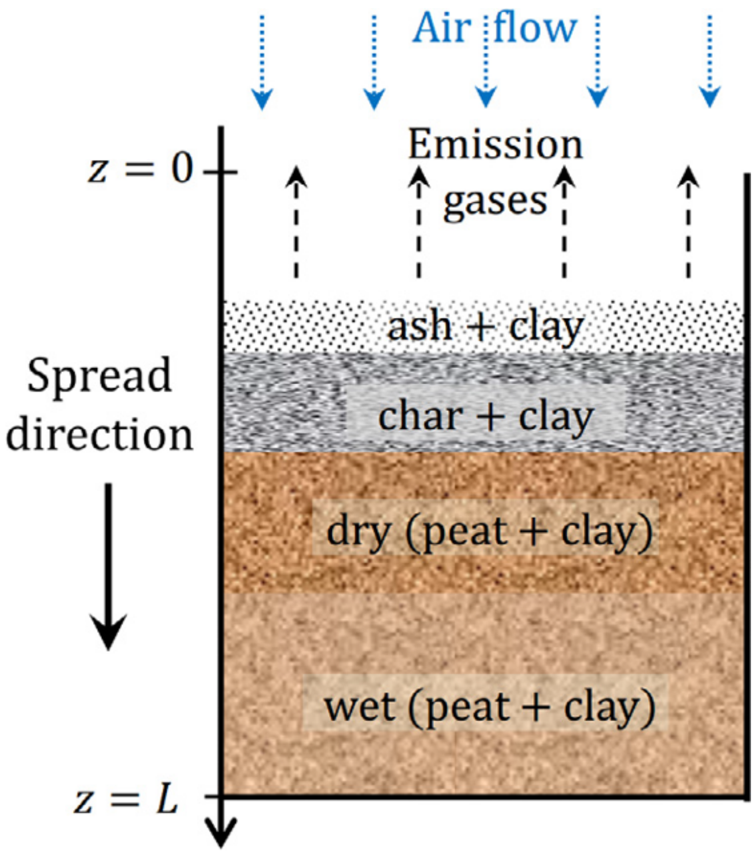
The Peat Fire Problem

- Peat < 3% of land, but contains 25% of terrestrial carbon
- Arctic peat plentiful in boreal forest and tundra
- Fires increase with climate change
- Peat becomes a carbon source
  - Peat fires release substantial CO_2 and other greenhouse gases
  - Estimates of emissions contain large uncertainties
  - Overwhelming uncertainty in mass of peat consumed



Huang and Rein Physically-Based Peat Fire Model

- Development of reaction mechanism
  - **Drying:**
    - Wet peat → Dry peat
  - **Charring:**
    - Dry peat → Alpha-char
    - Dry peat + O_2 → Beta-char
  - **Ash production**
    - Alpha char + O_2 → Ash
    - Beta char + O_2 → Ash
- 1D peat fire modeling
  - Burn depth
  - Critical ignition conditions
- Determination of key soil properties
  - Moisture content (MC)
  - Percentage soil organic matter
  - Bulk density



Huang *et al* (2015) ProCI

Huang and Rein (2014) Combust Flame; Huang *et al* (2015) ProCI; Huang and Rein (2015) IJWF; Huang and Rein (2017) IJWF

Research Approach

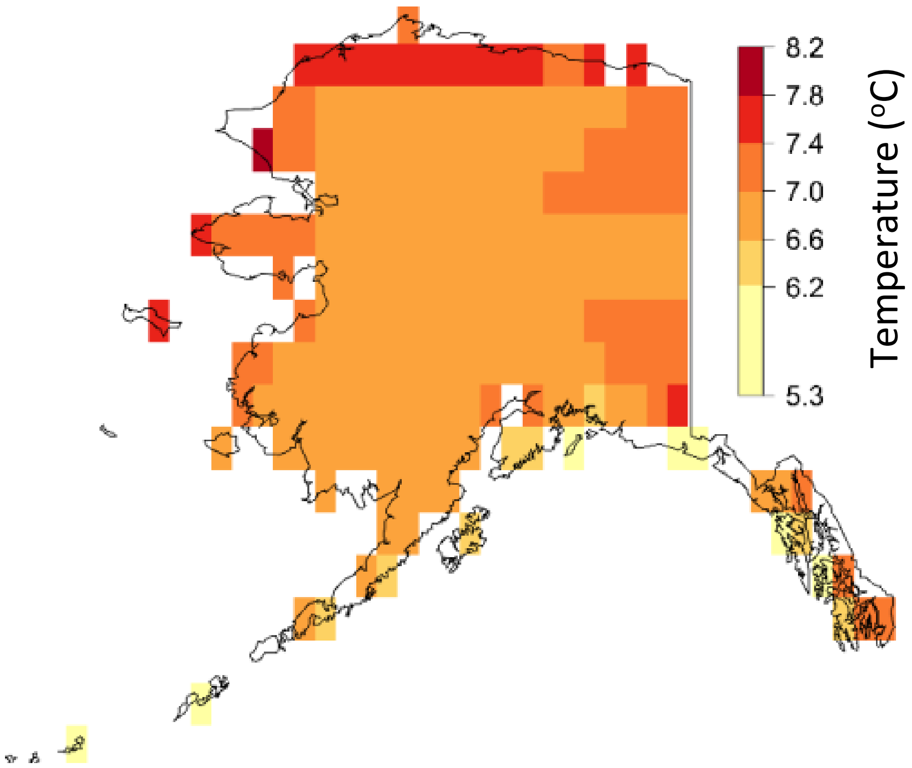
Overarching goal: Determine effects of soil properties that **change** with climate to determine which have the **largest impact** on emissions from Arctic peat

Approach: Explore the parameter space of climate predictions

1. Investigate climate predictions under high emissions scenario (SSP5-8.5 CMIP6)
2. Determine how atmospheric climate predictions influence soil properties
3. Vary soil properties between present and future values in 1D peat model
   - At representative locations in Alaska
   - Compare mass burned/emissions quantities

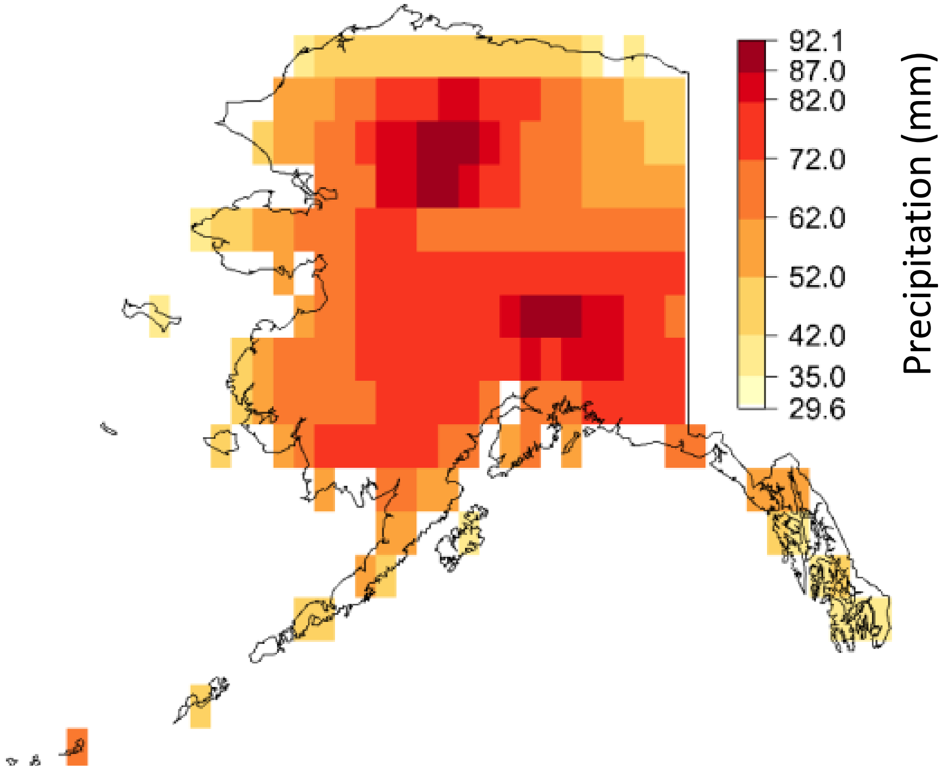
Changes in July Temperature and Precipitation by 2100

Temperature



Temperature increases across the state

Precipitation

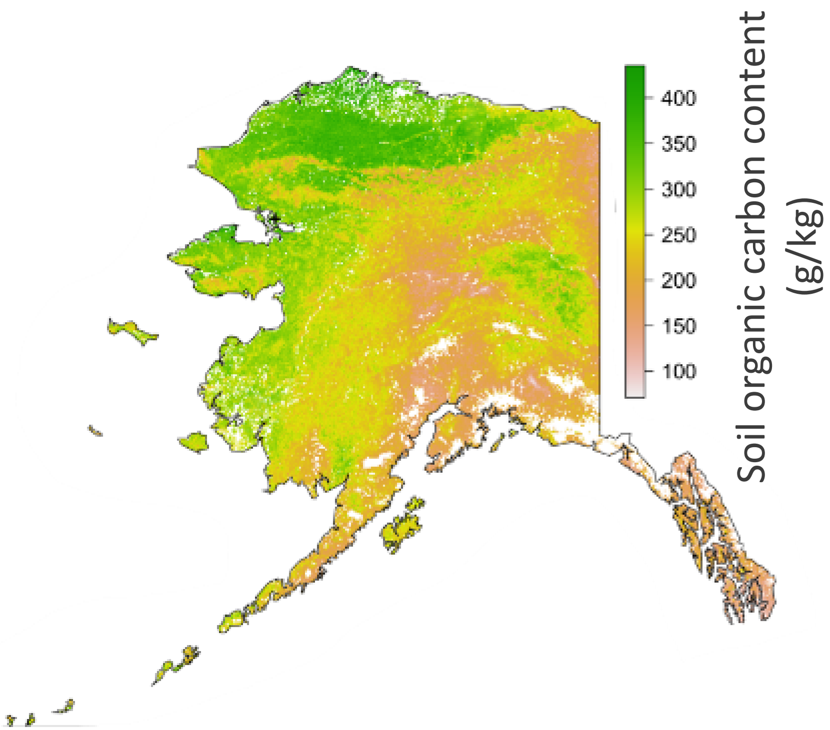


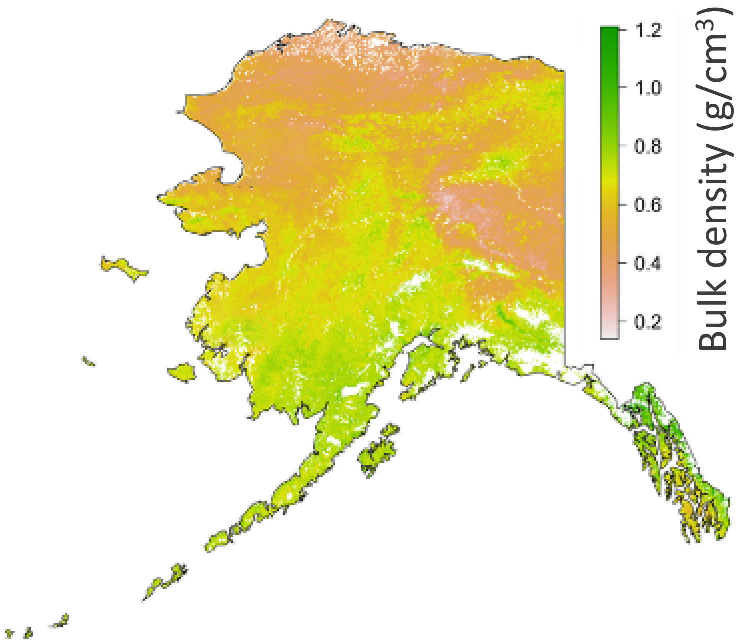
Areas of precipitation increase and areas of decreased precipitation

High emissions scenario (SSP5-8.5) 30-year ensemble-averaged from CanESM, CESM, BCC, and UKESM models

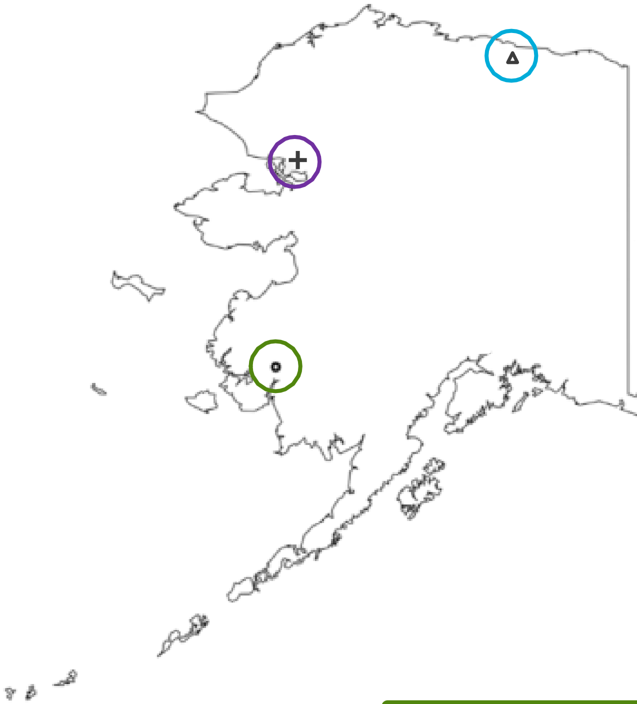
How Atmosphere Affects Soil Properties

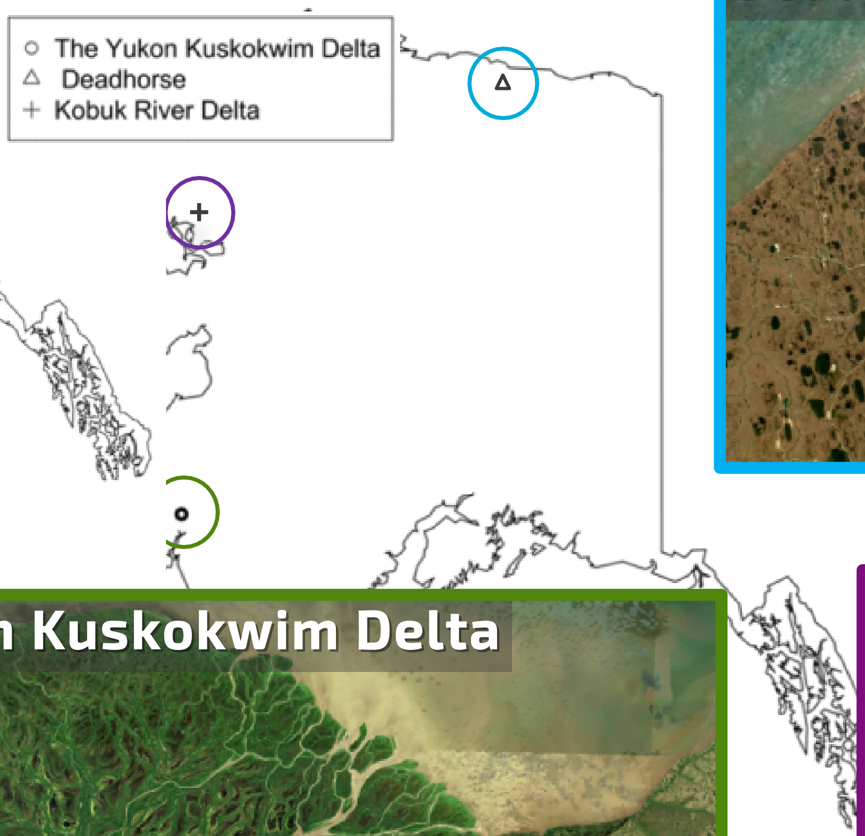
- We don't know **how** climate will explicitly change some properties
  - Combined effects of climate and fire
  - Soil organic carbon
  - Soil bulk density





Representative Tundra Locations in Alaska





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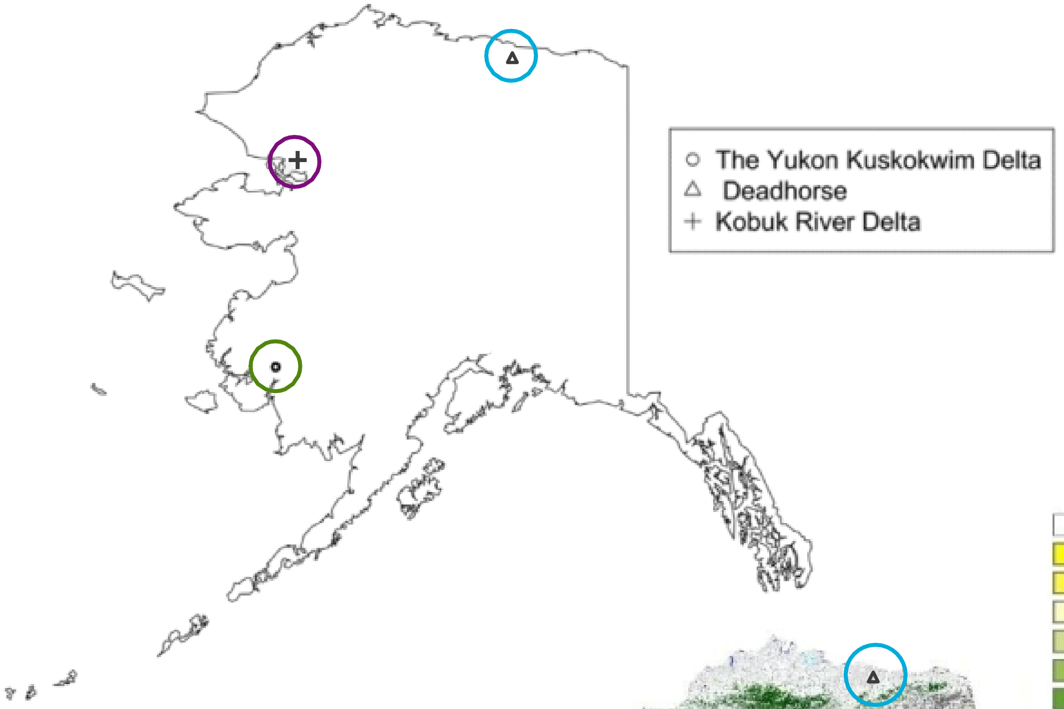
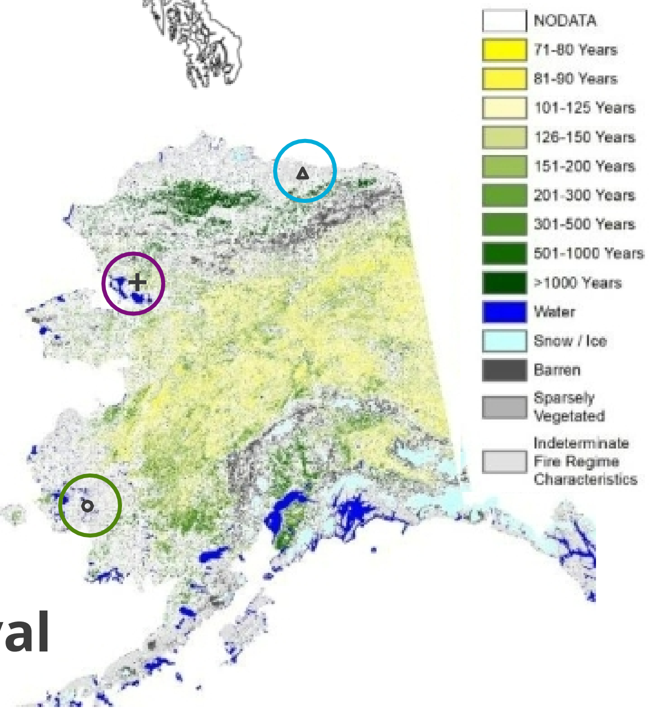
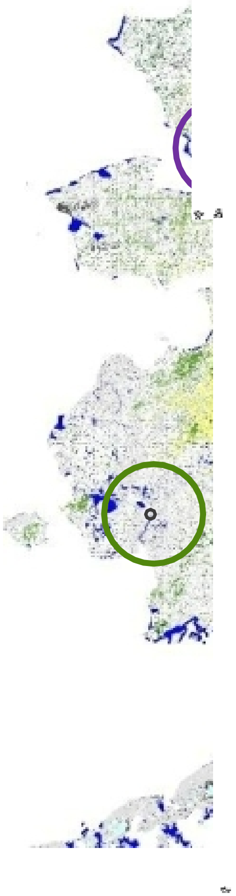
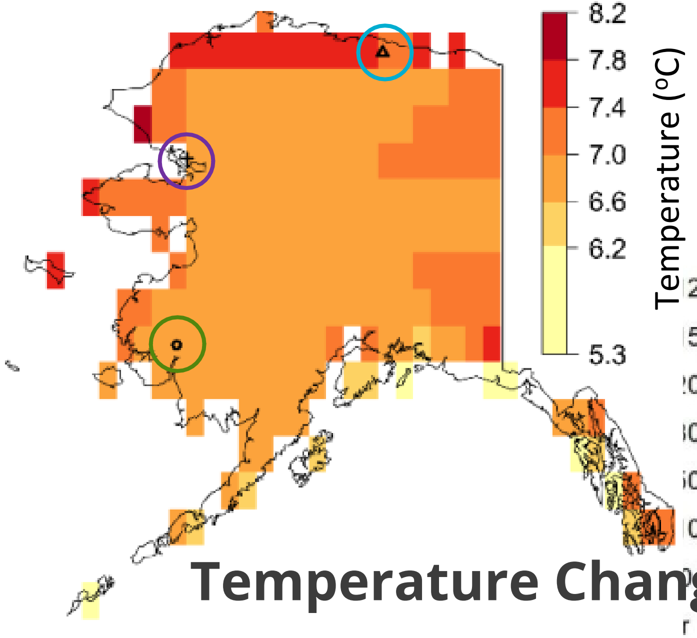


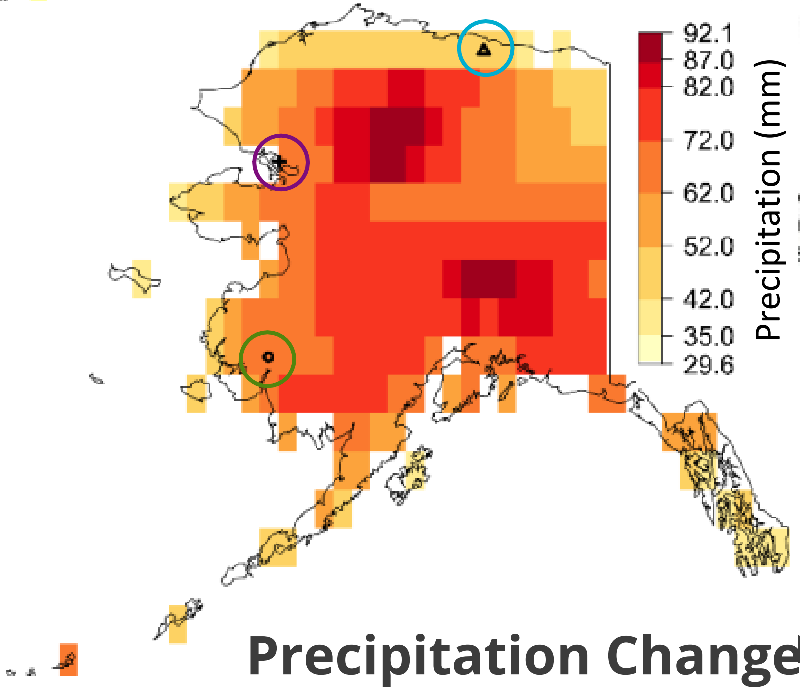


Mean Fire Return Interval





Temperature Change



Precipitation Change

Matrix of Soil Conditions

- Soil properties vary with depth
  - Simulate first 12 cm of peat soil
- Hold current bulk density constant
- Compare current and future July temperatures
  - Use air temperature for soil
- Range of moisture contents

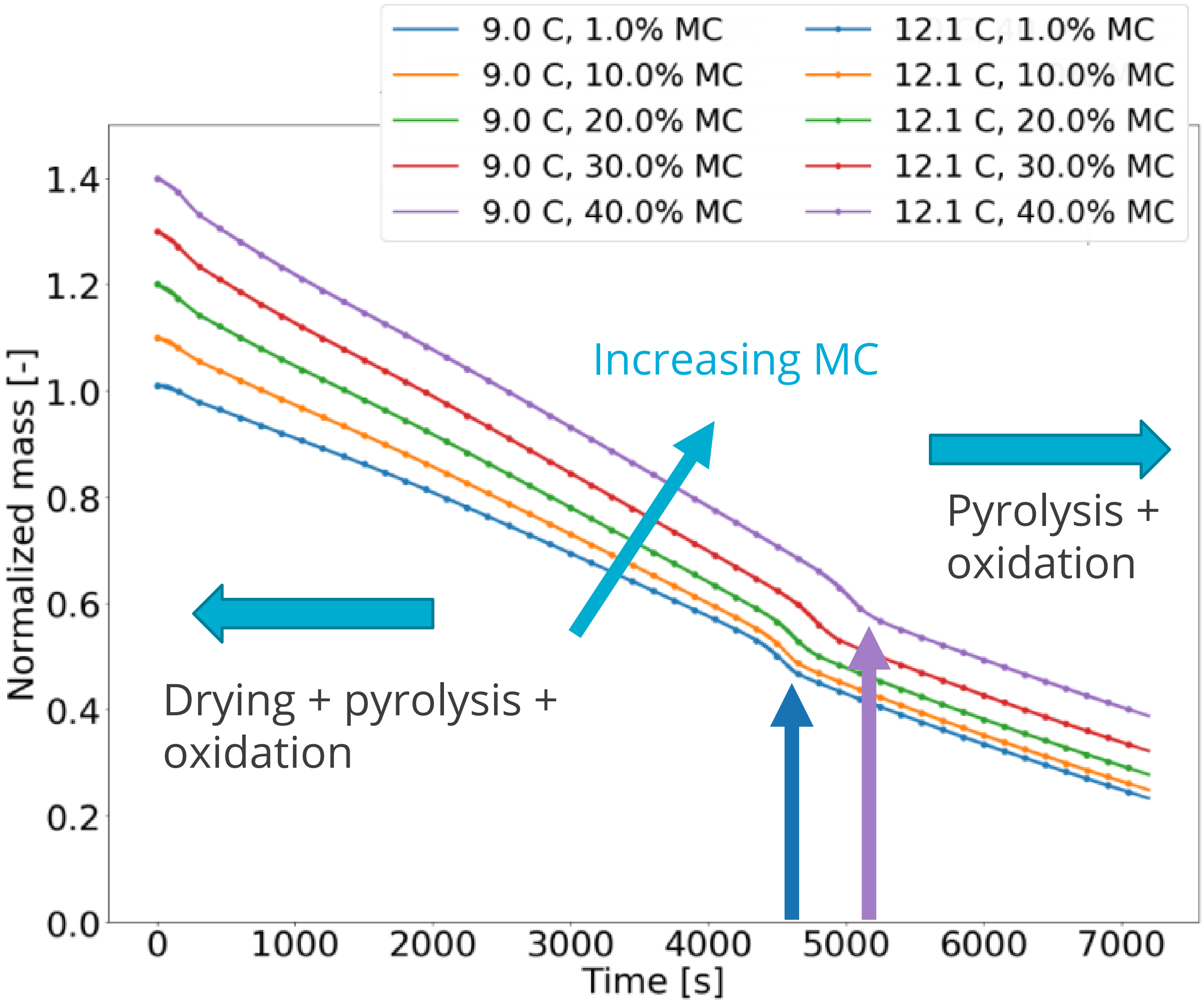
	Yukon Kuskokwim Delta	Deadhorse/ Prudhoe	Kobuk River Delta
Soil bulk density			
Current July temperature			
Future July temperature			
Current MC			
Simulated MC Range			

Modeling Methods

- Implement Huang and Rein's 1D model in Sierra Thermal/Fluids: Aria
- 12 cm column at 0.8 mm resolution
- 7200 s (2 hr) simulation time
- Model inputs
  - Siberian transition-moor kinetics
  - Reaction mechanism and material properties from Huang and Rein
  - Modified densities, porosities, heats of reaction

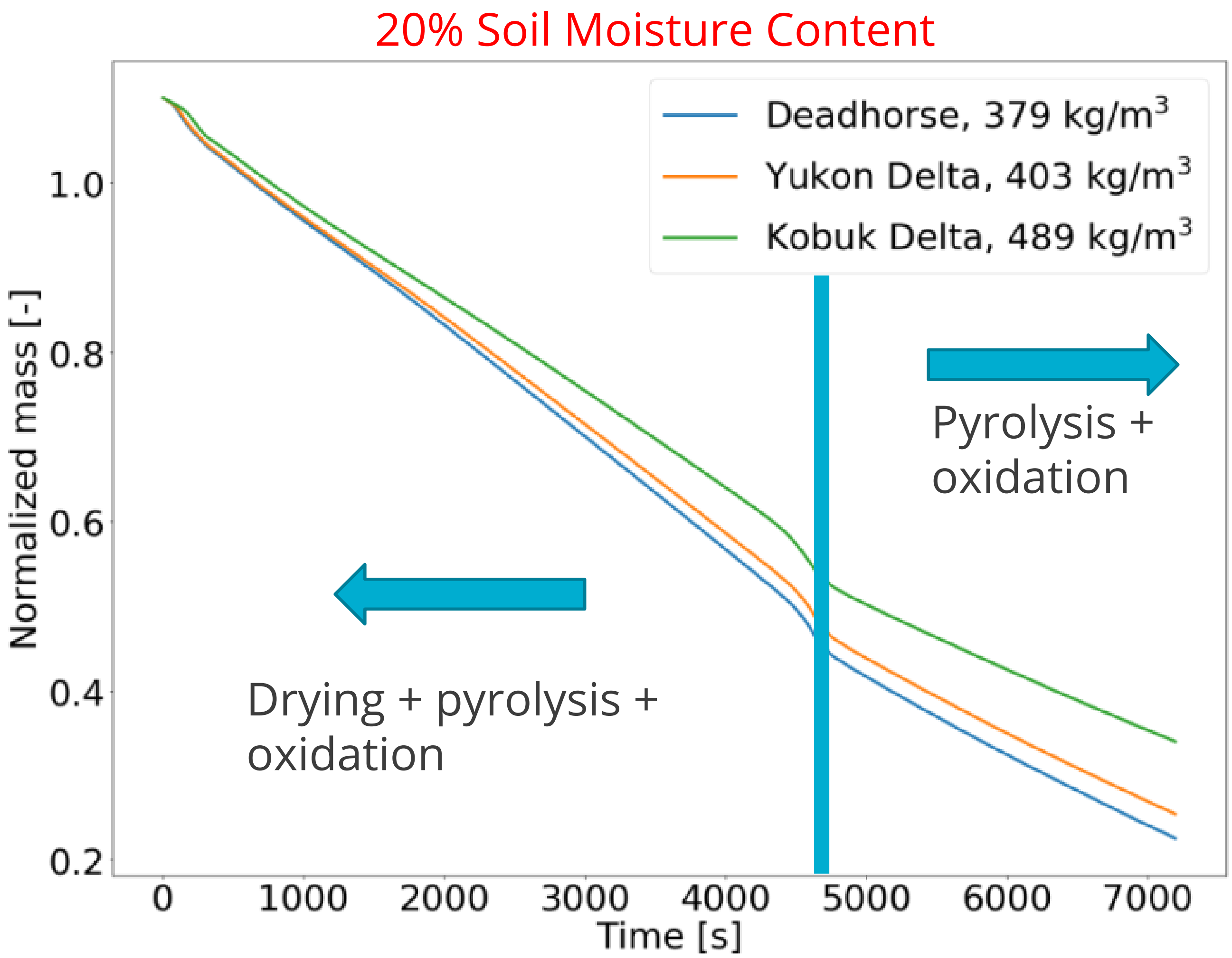
Results for Yukon Kuskokwim Delta

- Yukon Kuskokwim Delta
  - Tundra location
  - Soil bulk density = 403 kg/m^3
- Drop in mass loss rate when full column of wet peat has dried
- No difference between current and future temperatures
- MC has clear effect



Comparing Between Locations

- Different locations represent different soil bulk densities
- Higher density of soil slows reaction down
  - 10 cm of peat burn through for Yukon Delta and Deadhorse
  - Kobuk Delta doesn’t burn through
- 30-40% MC Kobuk Delta burned out



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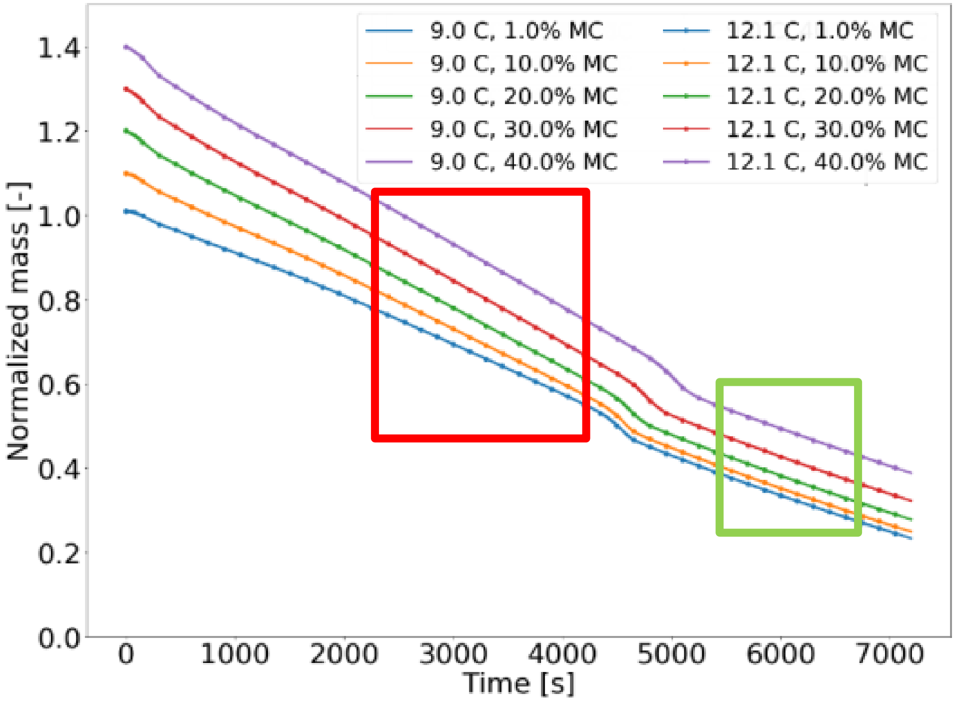
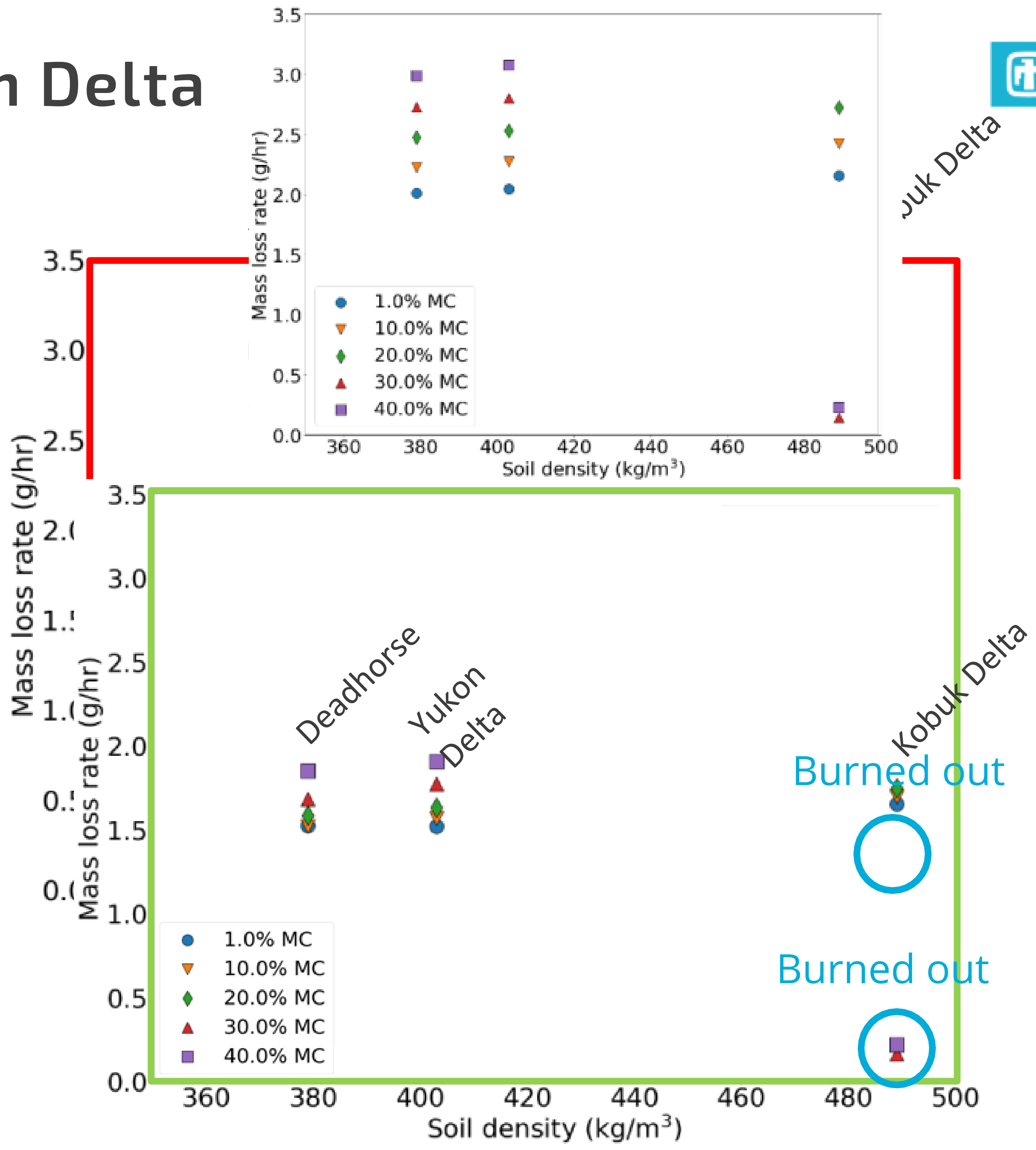
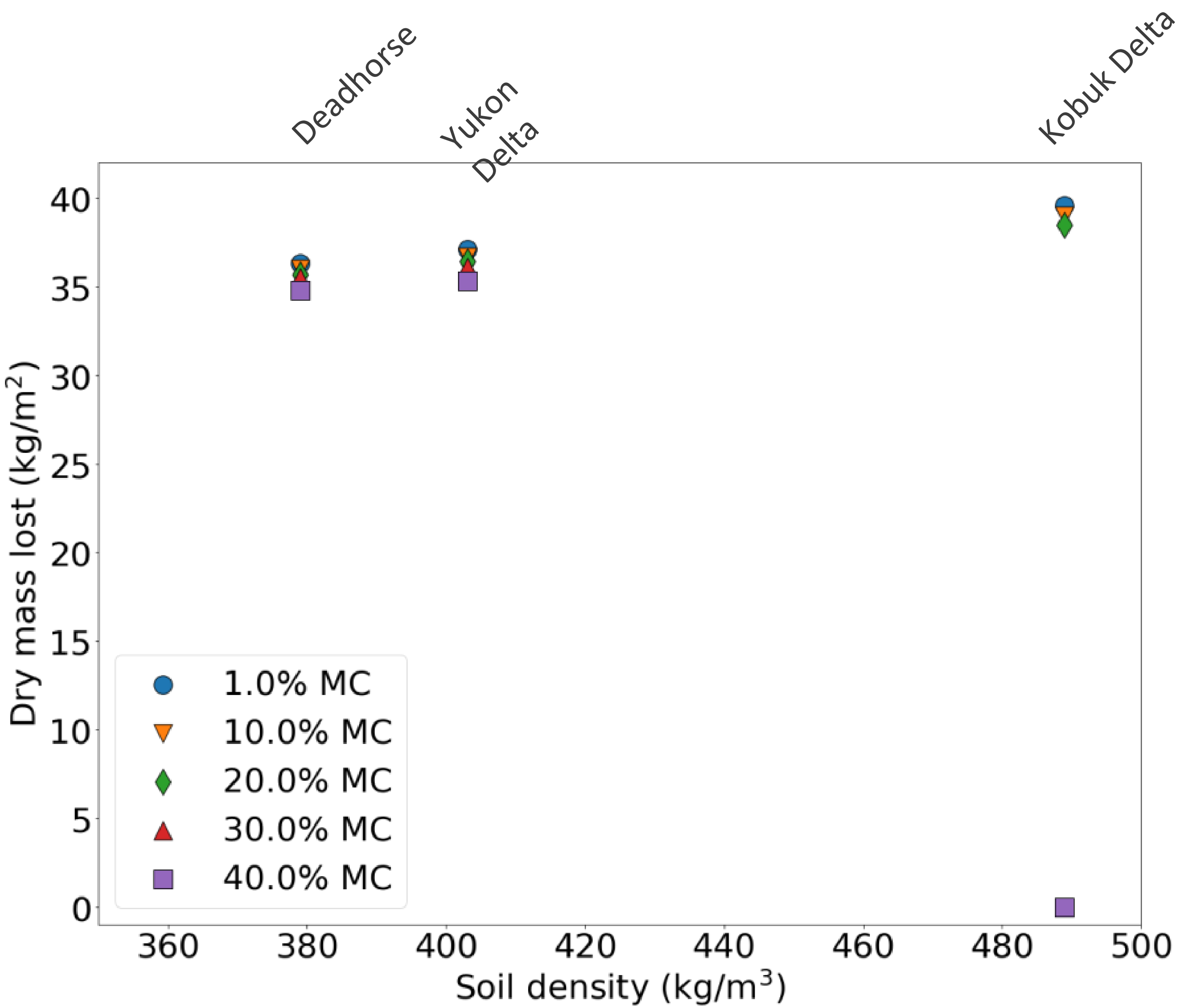




Total Mass Loss From Dried Peat

- Total mass lost increases with increasing soil density
- Small variation of dry mass lost with increasing MC
  - Increasing mass lost for lower MC peat
- Dry mass loss directly related to gas emissions



Conclusions and Future Work

- MC and density have clear impact on mass loss, burn depth, and mass of emissions
- Soil temperature for this range has negligible impact on mass burnt, but air temperature may be important for soil MC
- Locate vulnerable peat sources through combination of location and moisture changes
- More research needed into fires in the arctic, including ignition predictions (e.g. lightning) that will trigger peat fires
- Future work
  - Use samples from Arctic locations to determine kinetic parameters and properties
  - Explore more Arctic locations, including boreal peat, and how active layer affects emissions
  - Investigate how air temperature and precipitation affect soil MC for different topographies

THANK YOU! QUESTIONS?

Extra Slides

Earth System Modeling vs Physically-Based Modeling of Peat Fires

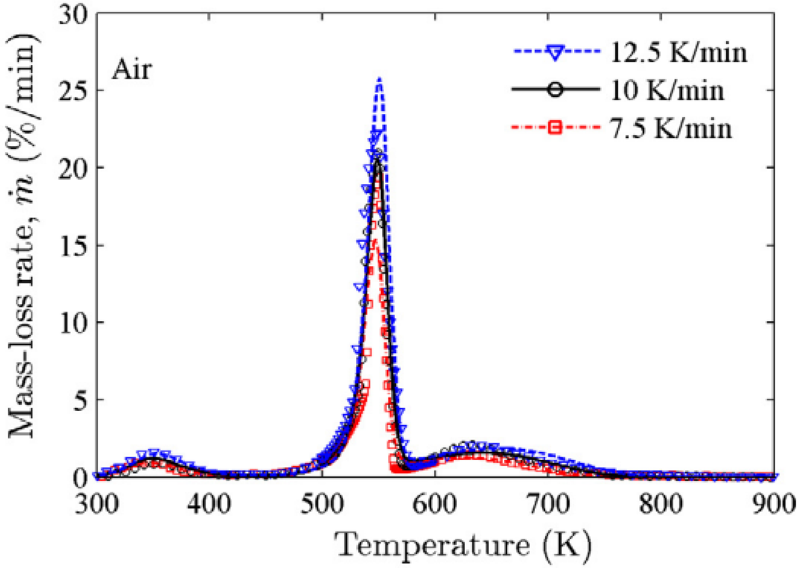
Earth System Models

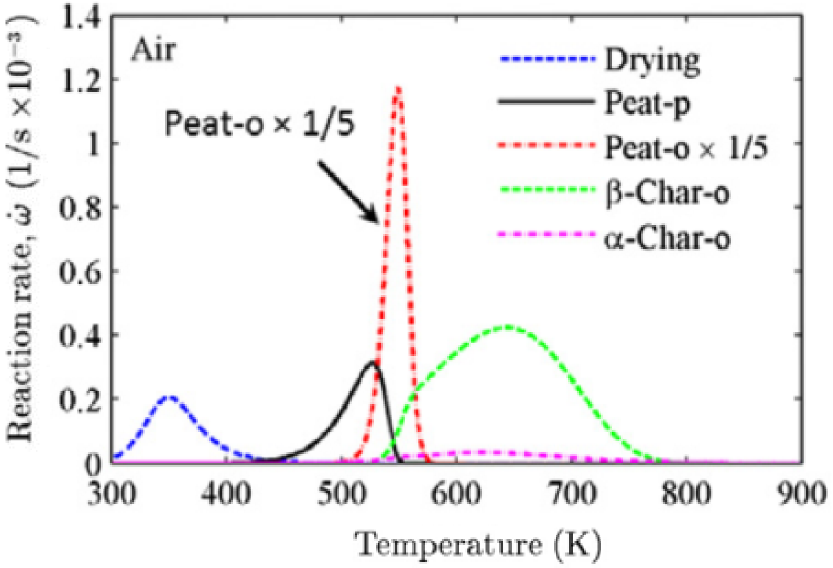
- Earth systems models simulate the present and future climate
- Peat fire representation in E3SM
  - Peat maps
  - Peat represents arbitrary fraction of grid cell that can burn
  - Function of soil moisture and temperature
- Outputs
  - Burn area
  - Emissions (as function of burn area)

Physically-Based Models

- Solve governing equations for mass, species, and energy
  - Gas and solid phase
- Myriad inputs required
  - Reaction mechanisms, material properties
- Outputs
  - Burn depth
  - Mass burnt and mass burning rate
  - Reaction rates
  - Rate of spread
  - Temperature profiles

Reaction mechanisms





$$\text{Peat} \cdot \nu_w \text{H}_2\text{O} \rightarrow \text{Peat} + \nu_w \text{H}_2\text{O(g)}, \quad \text{(Drying)}$$
$$\text{Peat} \rightarrow \nu_{\alpha,pp} \alpha\text{-Char} + \nu_{g,pp} \text{Gas}, \quad \text{(Peat Pyrolysis)}$$
$$\text{Peat} + \nu_{O_2,po} \text{O}_2 \rightarrow \nu_{\beta,po} \beta\text{-Char} + \nu_{g,po} \text{Gas}, \quad \text{(Peat Oxidation)}$$
$$\alpha\text{-Char} + \nu_{O_2,\alpha o} \text{O}_2 \rightarrow \nu_{a,\alpha o} \text{Ash} + \nu_{g,\alpha o} \text{Gas}, \quad (\alpha\text{-Char Oxidation})$$
$$\beta\text{-Char} + \nu_{O_2,\beta o} \text{O}_2 \rightarrow \nu_{a,\beta o} \text{Ash} + \nu_{g,\beta o} \text{Gas}, \quad (\beta\text{-Char Oxidation})$$

$$\dot{\omega} = A \exp\left(\frac{-E}{RT}\right) \rho_i^n$$

Huang, X., Rein, G. (2014). *Combustion and Flame* 161: 1633-1644.

Climate Models Used and Soil Data

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  - Swart, N. C., Cole, J. N., Kharin, V. V., Lazare, M., Scinocca, J. F., Gillett, N. P., ... & Winter, B. (2019). The Canadian earth system model version 5 (CanESM5. 0.3). Geoscientific Model Development, 12(11), 4823-4873.
- CESM
  - Danabasoglu, G., Lamarque, J. F., Bacmeister, J., Bailey, D. A., DuVivier, A. K., Edwards, J., ... & Strand, W. G. (2020). The community earth system model version 2 (CESM2). Journal of Advances in Modeling Earth Systems, 12(2), e2019MS001916.
- BCC
  - Wu, T., Lu, Y., Fang, Y., Xin, X., Li, L., Li, W., ... & Liu, X. (2019). The Beijing Climate Center climate system model (BCC-CSM): the main progress from CMIP5 to CMIP6. Geoscientific Model Development, 12(4), 1573-1600.
- UKESM
  - Senior, C. A., Jones, C. G., Wood, R. A., Sellar, A., Belcher, S., Klein-Tank, A., ... & Mulcahy, J. P. (2020). UK community Earth system modeling for CMIP6. Journal of Advances in Modeling Earth Systems, 12(9), e2019MS002004.
- Soilgrids
  - Hengl, T., Mendes de Jesus, J., Heuvelink, G. B., Ruiperez Gonzalez, M., Kilibarda, M., Blagotić, A., ... & Kempen, B. (2017). SoilGrids250m: Global gridded soil information based on machine learning. *PLoS one*, *12*(2), e0169748.