Identifying Indicators of State Change and Forecasting Future Vulnerability in Alaskan Boreal Forest

SERDP Project Number RC2109

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Alaska Fire Consortium
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Problem Statement

• Permafrost is a major control over the structure and function of boreal ecosystems. Permafrost degradation has the potential to affect ecosystem structure and function, human infrastructure, and land use.

• Understanding the links among vegetation, organic soil, and permafrost is necessary for projecting the impact of climate change on permafrost in ecosystems that are subject to abrupt anthropogenic and natural disturbances (fire) to the organic soil layer.

•Research is needed to couple biogeochemical and landscape fire dynamics models in order to identify those DoD lands that are resistant and those that are vulnerable to permafrost degradation under scenarios of disturbance and climate change.

Objectives

Objective 1 is to determine mechanistic links among fire, soils, permafrost, and vegetation succession in order to develop and test field-based **ecosystem indicators** that can be used to directly predict ecosystem vulnerability to state change.
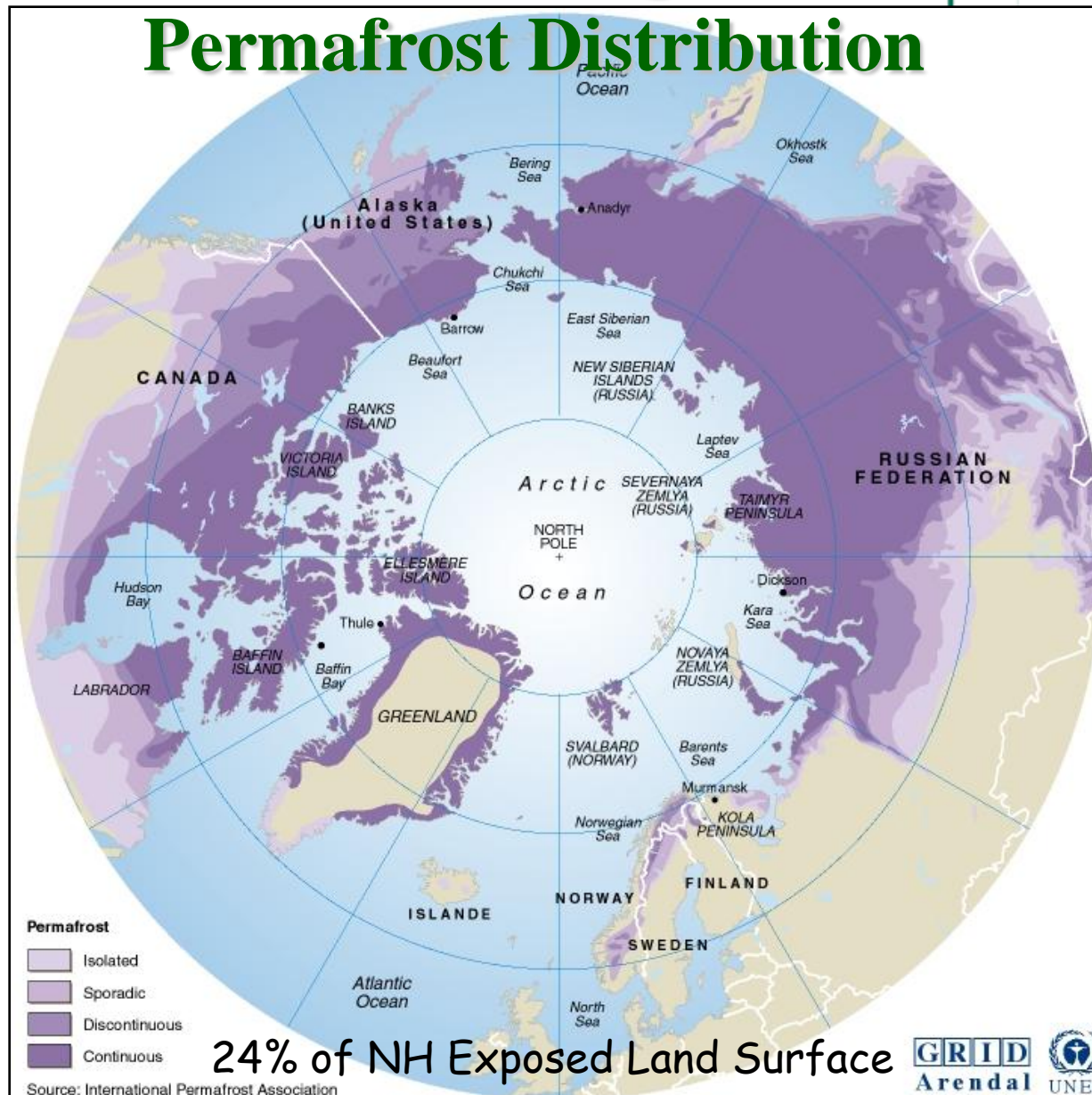
Objective 2 is to develop models that can **forecast landscape change** in response to projected changes in climate, fire regime, and fire management.
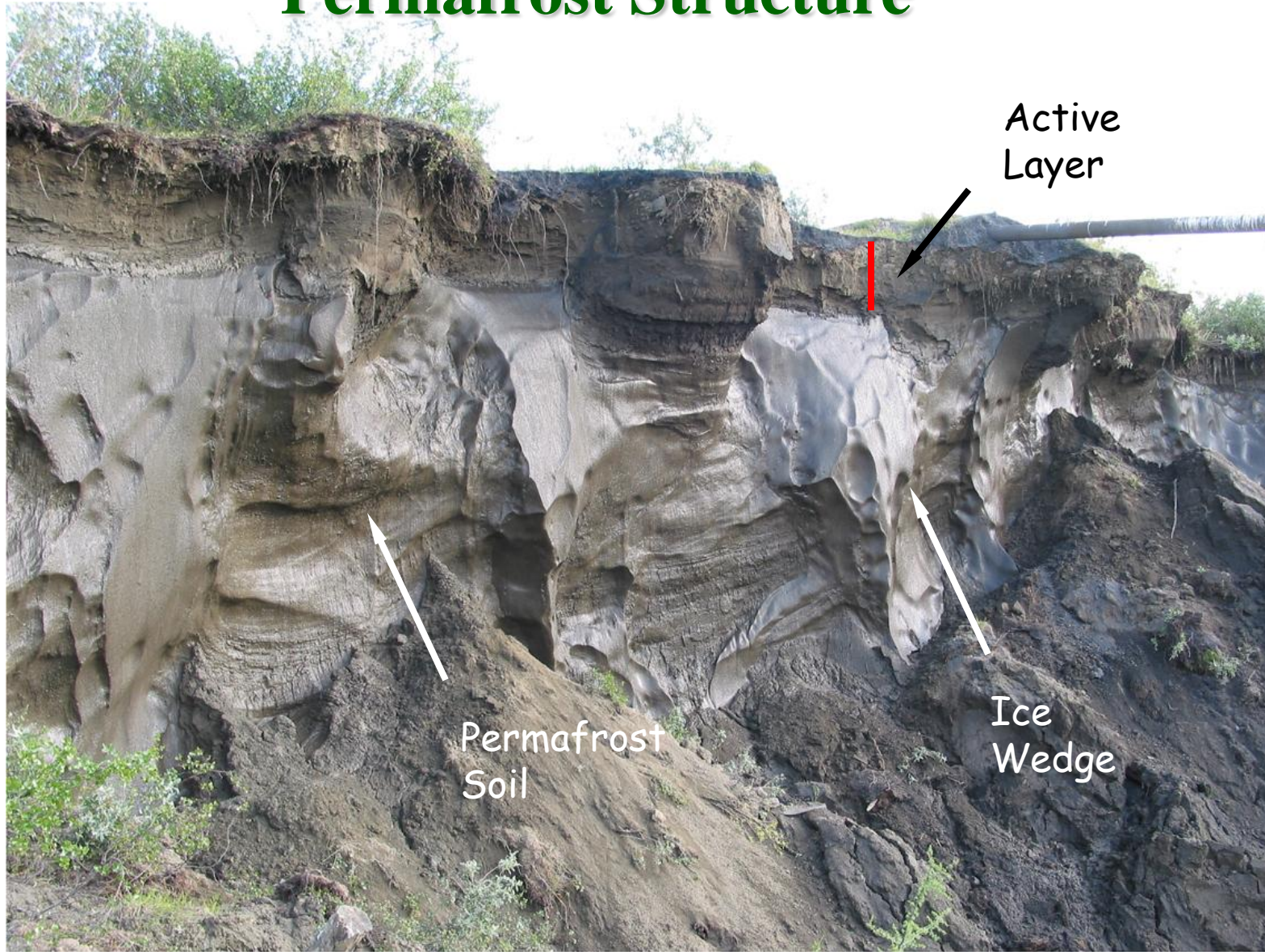
Technical Background: Permafrost Distribution

[from Brown et al. 1998]

24% of NH Exposed Land Surface

Technical Background: Permafrost Structure

Active Layer

Permafrost Soil

Ice Wedge

[L. Yocum]

Technical Background: Threshold Dynamics in Boreal Ecosystems

Conifer cycle:
High moss NPP → Thick organic layer → Cool, moist soils → Slow decomposition → Slow nutrient turnover → High moss NPP

Long fire-free interval (succession)

Low severity fire

High severity fire

Deciduous cycle:
Low moss NPP → Thin organic layer → Warm, dry soils → Fast decomposition → Fast nutrient turnover → High vascular litter production → Low moss NPP
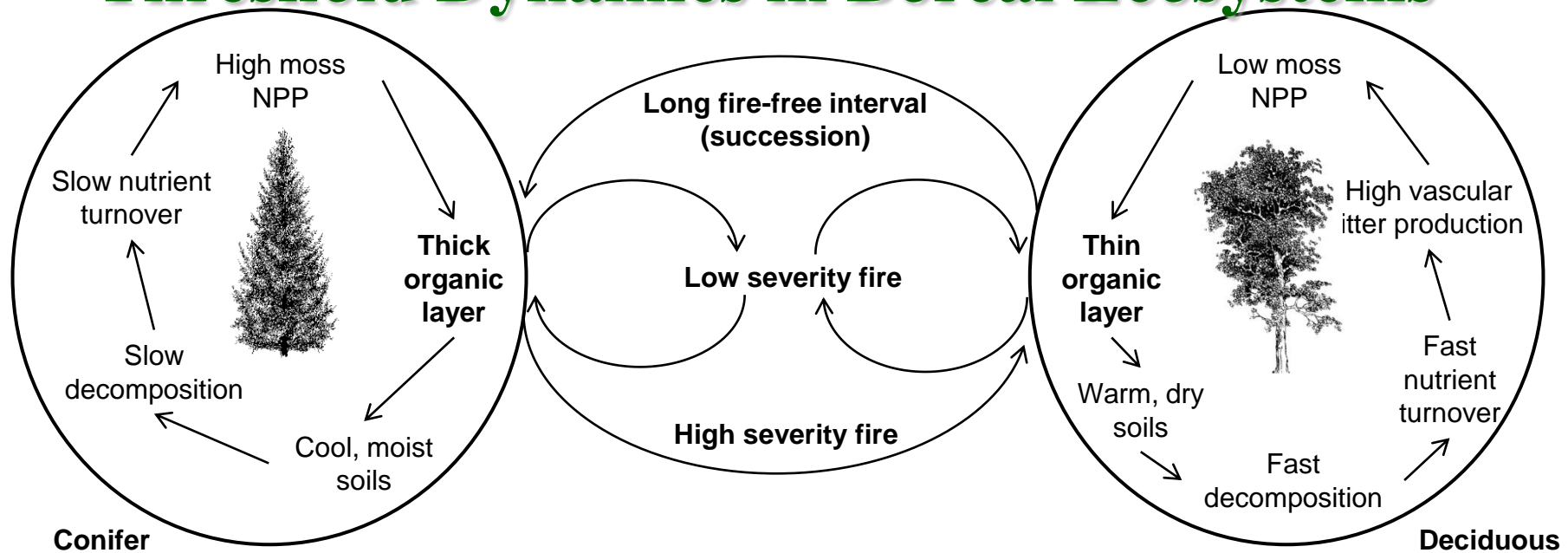
Technical Background:
State Change in the Discontinuous Permafrost Zone
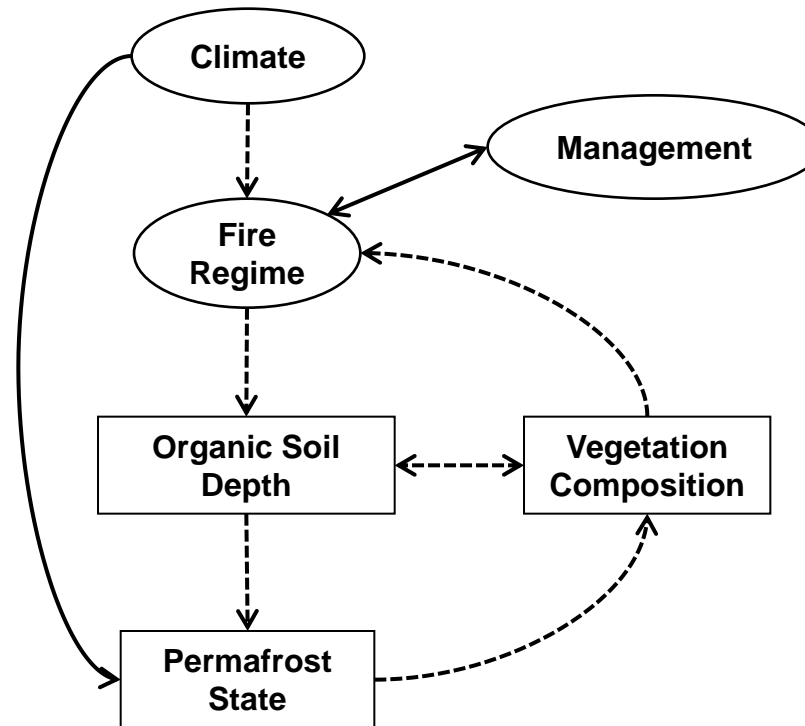
ALFRESCO Landscape Fire Dynamics

Climate
- *Monthly temperature*
- *Monthly precipitation*

Vegetation
- *Stand Age*
- *Vegetation Type*

Fire
Spatially explicit burn algorithm:
- *Lightning Ignitions*
- *Human Ignitions*
- *Fire Suppression*
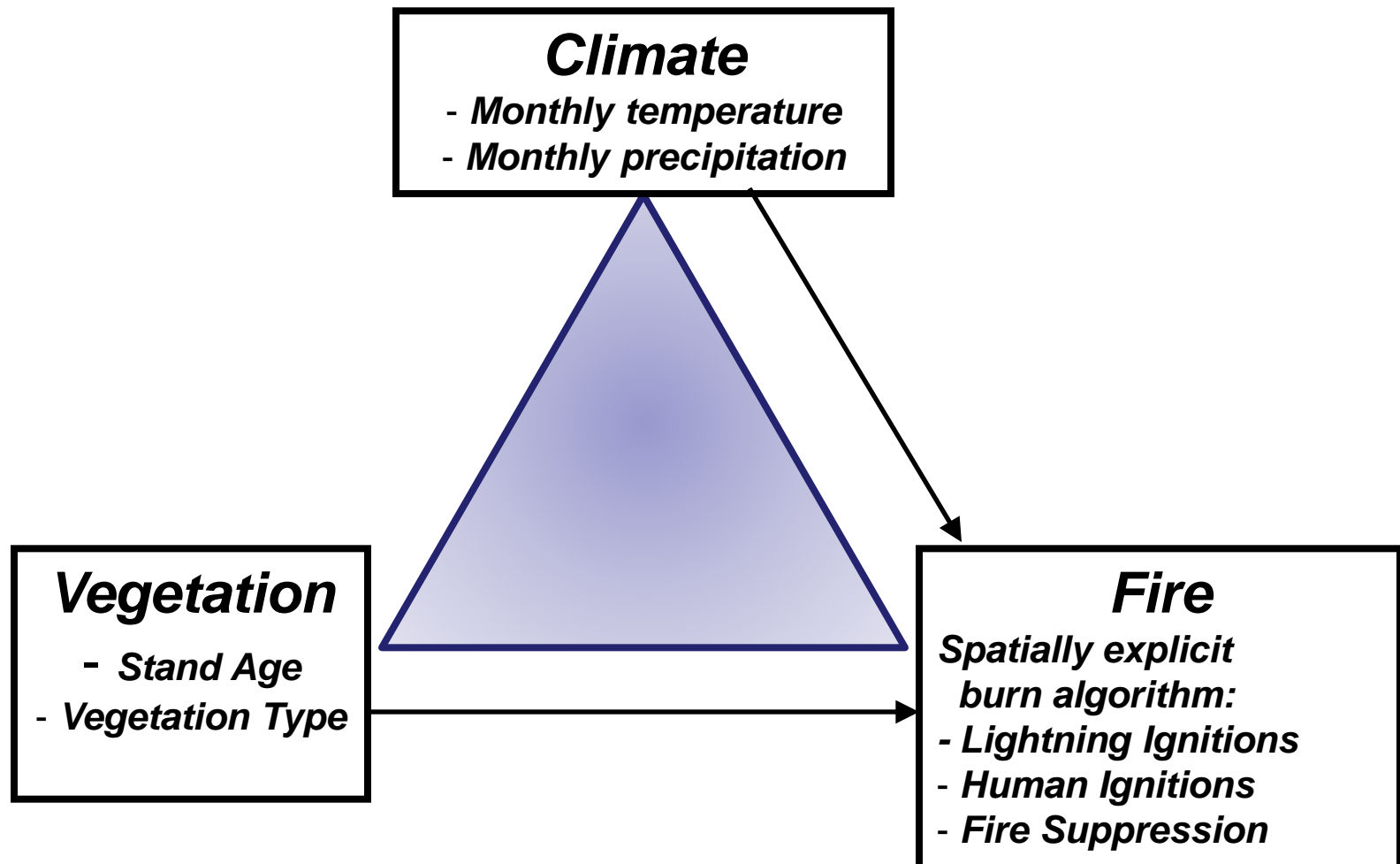
DOS-DVM-TEM Ecosystem Structure and Function
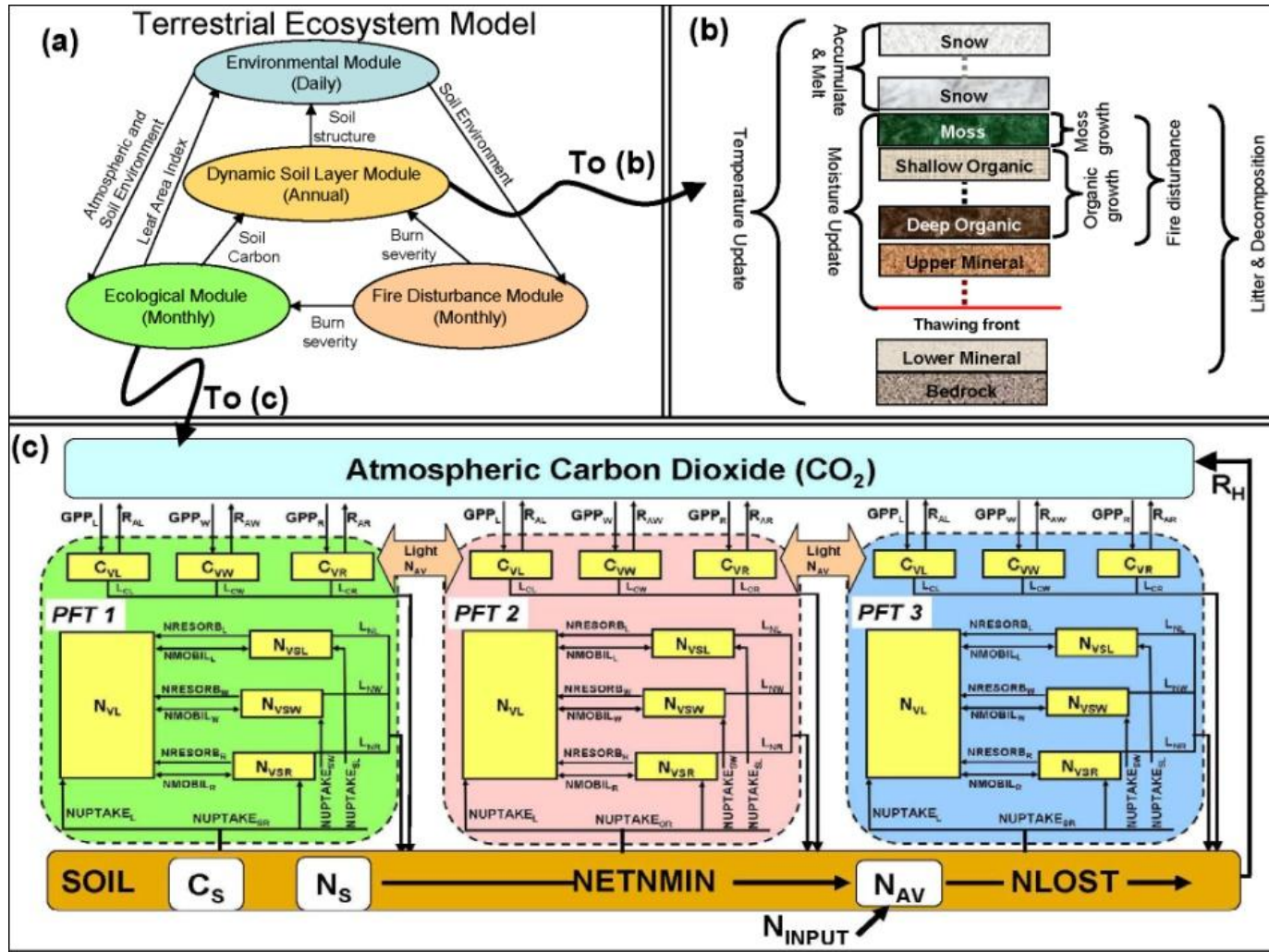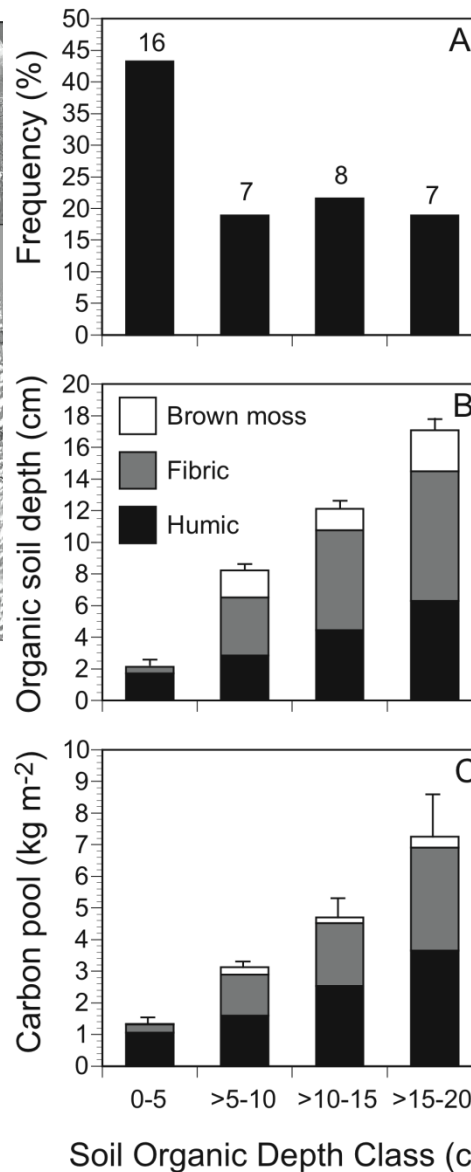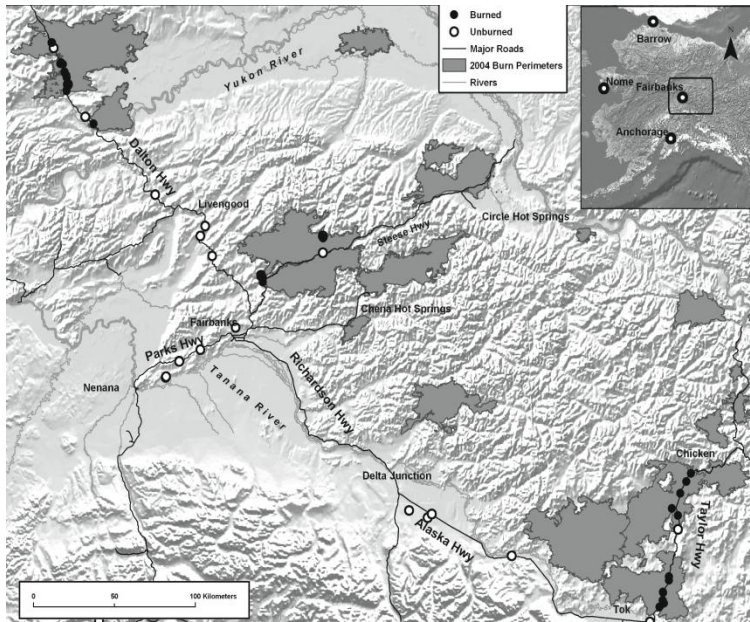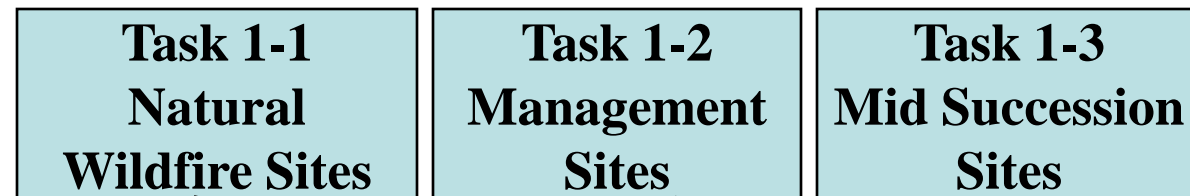
Fire Intensity Sites:

- 38 intensive black spruce sites (30x30m) in 3 large fire complexes that burned in 2004
- Sites chosen to maximize variation in **drainage** and **burn severity**
- 28 unburned reference stands
- Prior Data:
  - Burn severity
  - C and N pool loss and structure
  - Vegetation recovery and tree recruitment
 - N cycling and plant productivity

Technical Approach: Overview

Task 1-1 Natural Wildfire Sites

Task 1-2 Management Sites

Task 1-3 Mid Succession Sites

Task 2-1 Data Assimilation

Task 2-2 Model Coupling

Task 2-3 Model Evaluation

Task 2-4 Model Projections

Communication Plan Workshops Publications Workbook

Objective 1:
Develop and test ecosystem indicators of state change,
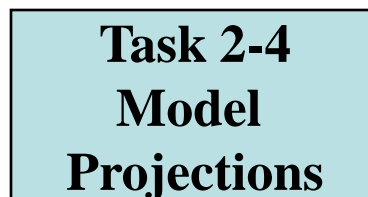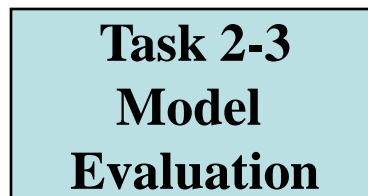
Collect datasets for model parameterization
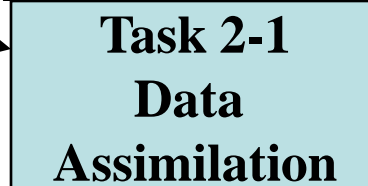
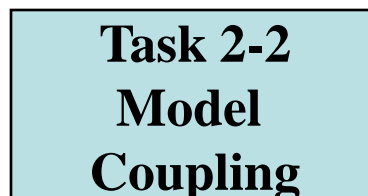**Objective 2:**
Model parameterization,

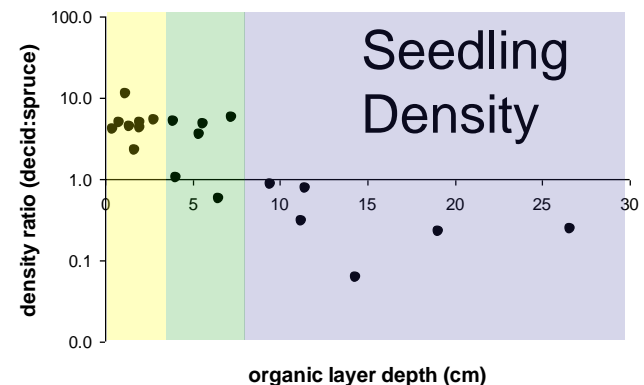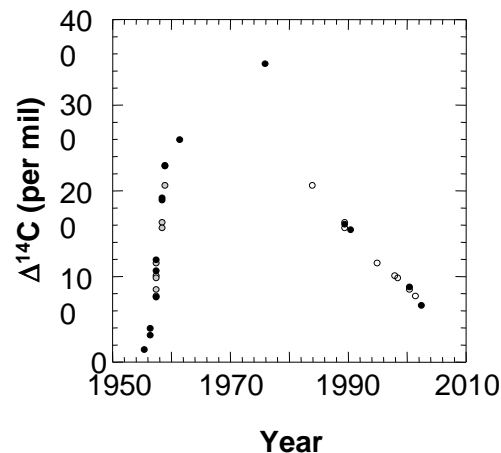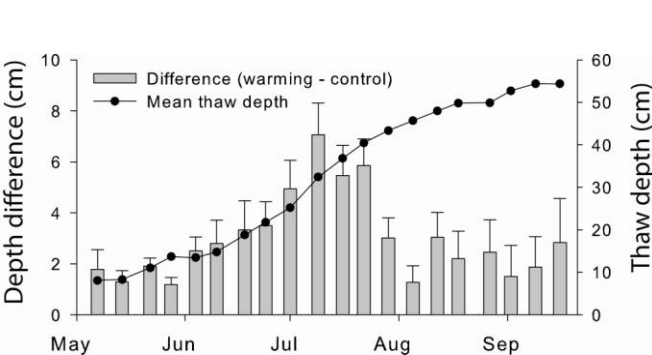Model validation,

Model forecasting

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Task 1-1: Monitor vegetation recolonization, soils, and permafrost in recent, severe wildfires

Proposed Work:

- Extend site network to include burned (and reference) stands of other major ecosystem types: white spruce, deciduous, shrublands, tundra (5 sites per veg type x burned/unburned)

- Measure active layer depth and ground subsidence for permafrost degradation

- Determine "disturbance intensity" using radiocarbon measurements of moss age

- Measure seedling recruitment and plant community composition
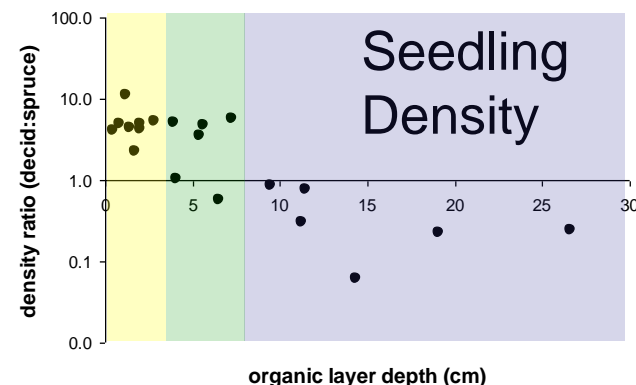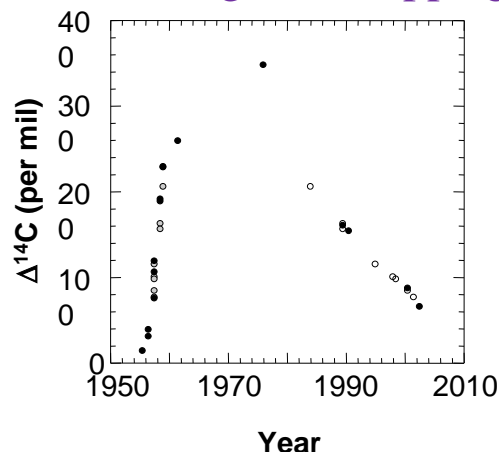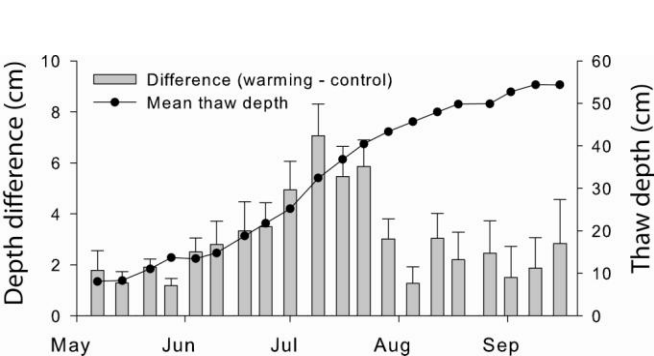

Outcome:

- Identifies sites & conditions with permafrost degradation following fire

- Identifies sites with unprecedented fire severity

- Identifies sites undergoing directional change in plant community composition

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Task 1-1: Monitor vegetation recolonization, soils, and permafrost in recent, severe wildfires

Progress:

- Extended site network to include burned and reference stands of other major ecosystem types: riparian black and white spruce, treeline white spruce, Aspen and Birch, shrublands, and tundra.
- Completed re-survey of seedlings and permafrost degradation in 36 plots black spruce ecosystems burned in the 2004 fires.
- Assessed burn severity (% of pre-fire organic matter combusted) and tested metric of disturbance intensity (radiocarbon measurements of burned soil surface) along toposequnces in new fire scars (Willow Creek, Cascadan Ridge, and Applegate 2010, Moose Mountain 2011).

Outcome:

- Identifies sites & conditions with permafrost degradation following fire
- Identifies sites with unprecedented fire severity
- Identifies sites undergoing directional change in plant community composition

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Patterns of forest recovery after the 2004 fires

- Natural tree regeneration
- Harvest of outplanted seedlings
  - 32 forest sites
- Large variations in composition & growth
- Likely associated with:
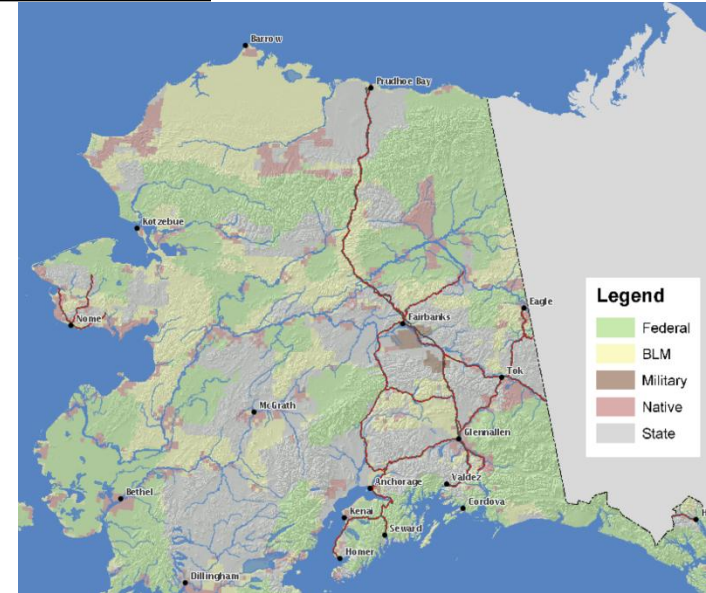 - Fire severity
  - Seed availability
  - Soil nitrogen

Proposed Work:

- Extend site network to include fire management treatments: prescribed fire, stand thinning, fire containment lines (10 sites per treatment)

Outcome:

- Determine those treatments that may minimize future state change from those that may enhance future state change


Legend
- Federal
- BLM
- Military
- Native
- State

Progress:

- Nenana Ridge Experimental Burn: Assessed pre- and post-fire effects of thinning and shearblading treatments on soil organic layer characteristics, permafrost degradation, disturbance intensity and tree seedling recruitment.

- **We are actively seeking new collaborators with prescribed fire and fuel treatments where we can contribute to monitoring.**
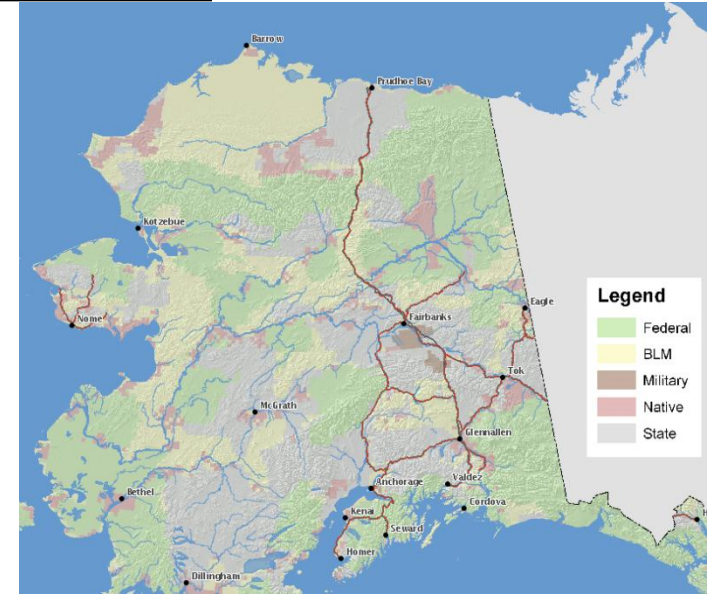
Legend
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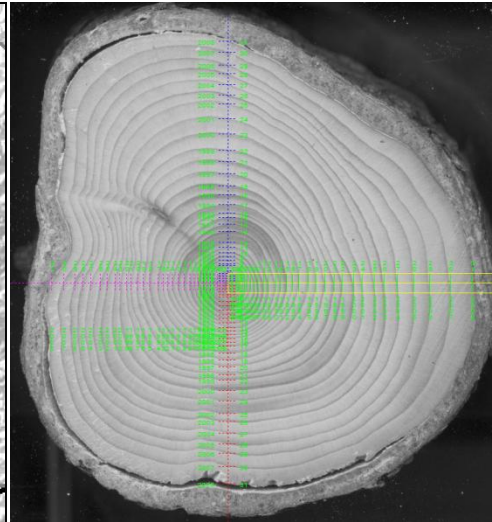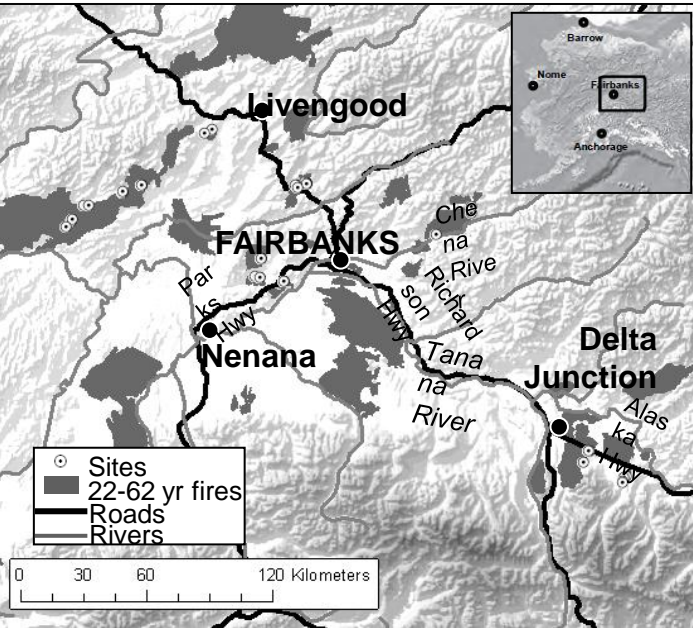
Proposed Work:
- Tree ring analysis of post-fire stands (45 sites)
- Moss and litter landscape correlations (45 sites), and transplantation experiments (1 site, 3 blocks, 5 reps)
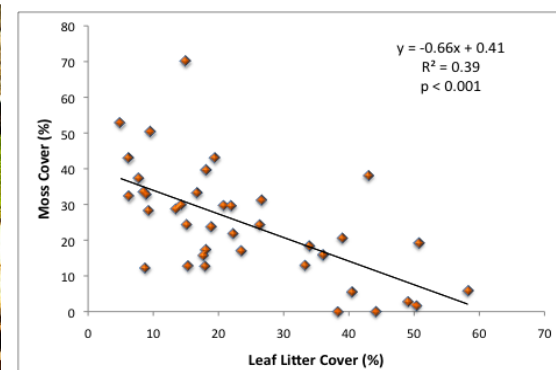
Outcome:
- Determine vulnerable forest types and sites
- Determine important tipping points in plant-soil feedback

Spruce   Mixed   Deciduous

$$y = -0.66x + 0.41$$
$$R^2 = 0.39$$
$$p < 0.001$$

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Can the dendroclimatic response of pre-fire trees predict forest resilience to fire?

→

?
→


Alternate Successional Trajectories

Does fire occurrence or fire management increase the potential for roadside weeds to invade boreal forest?

- M.Sc. Student (Matt Frey)
- 2010 sampling
  - Chronosequence of burns along Dalton & Eliot Hwys
- 2011 sampling
  - Fire management plots
  - Delta chronosequence?

Matt measuring *Melilotus* density on the roadside of the Dalton highway.

Task 2-1: Incorporate field data sets on vegetation, soils, and permafrost (in part developed as part of Objective 1) into a model of landscape fire dynamics and into a model of ecosystem structure and function.
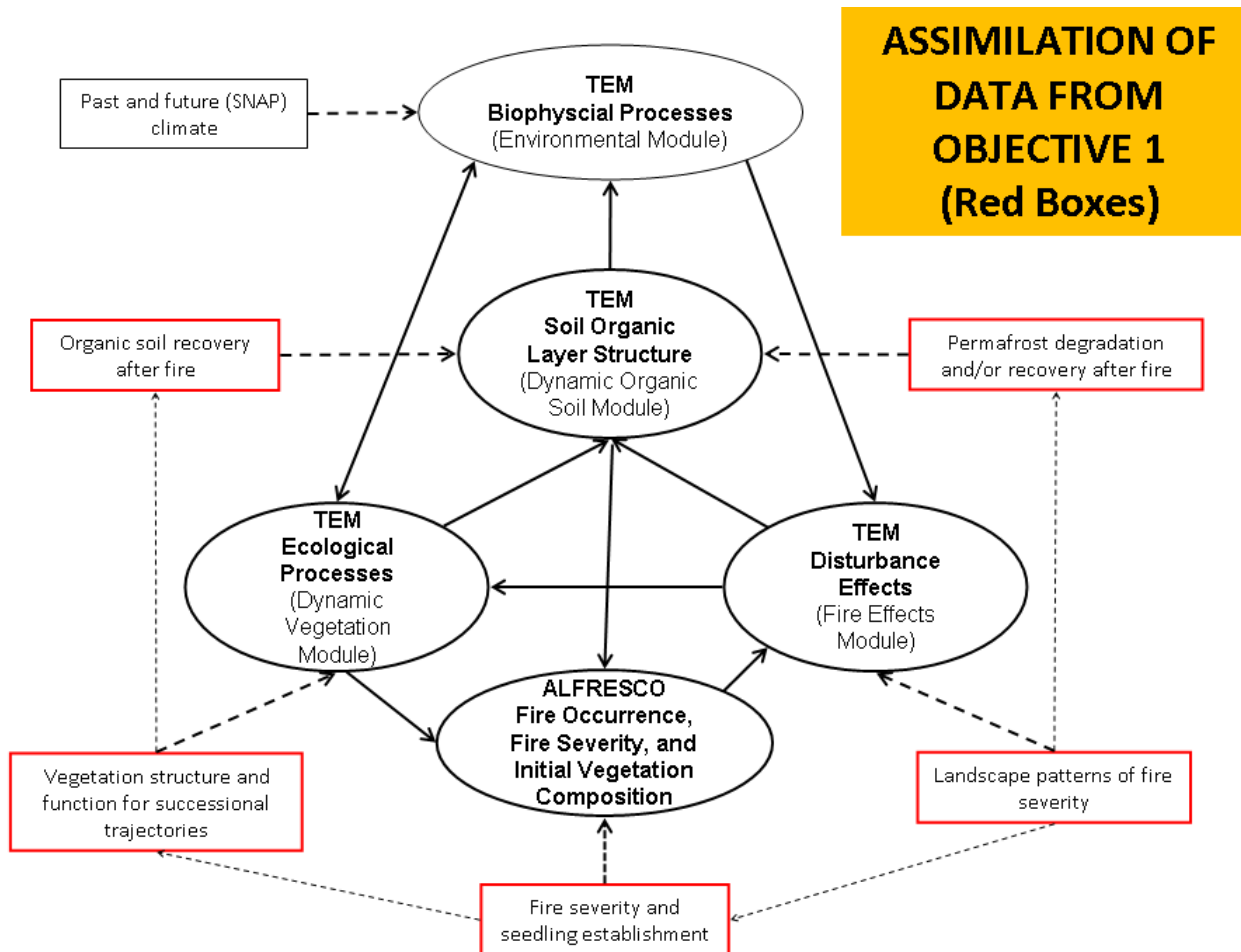
Proposed Work:
- Use data from objective 1 to modify modules in the model framework with respect to conceptual issues, algorithms, and parameters

Outcome:
- ALFRESCO and DOS-DVM-TEM are ready for coupling

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Task 2-2: Couple these two stand-alone models so that the influence of a changing climate on permafrost and vegetation can be assessed together with natural and managed changes in the fire regime.
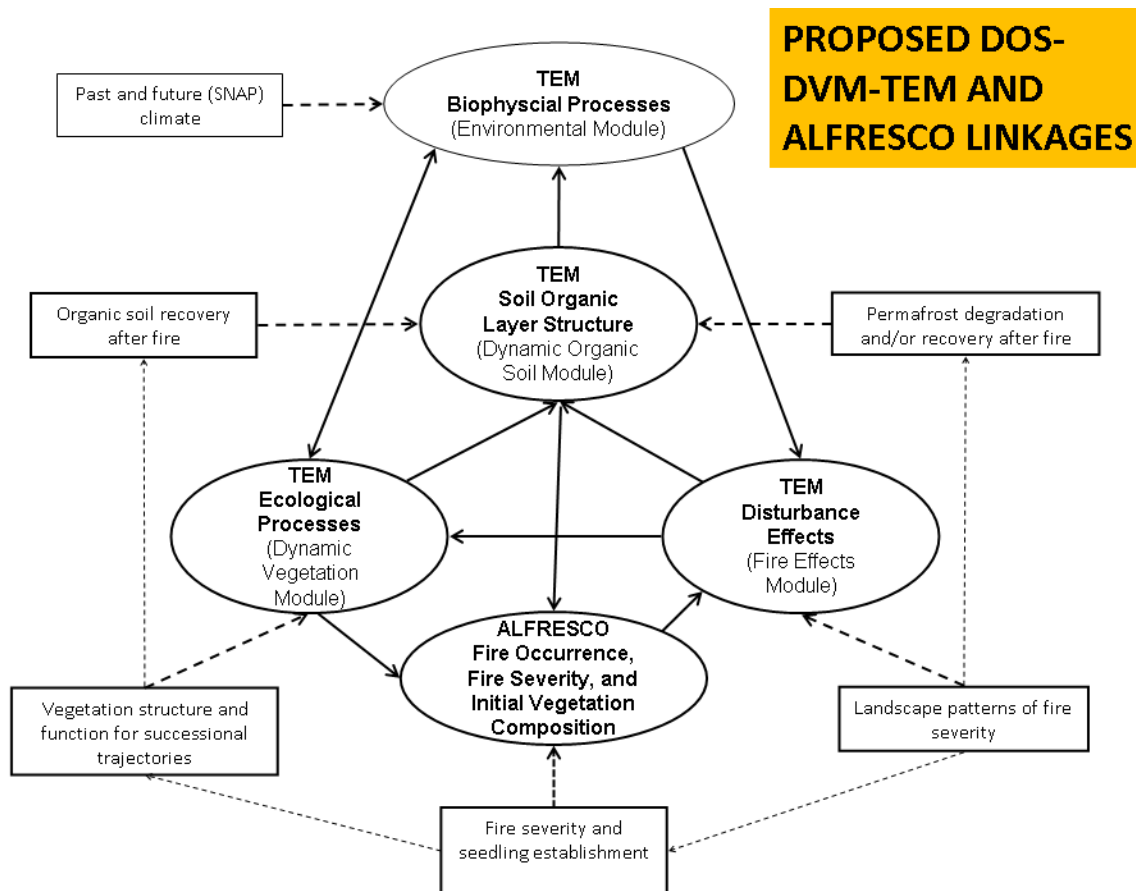
Proposed Work:
- Couple ALFRESCO with DOS-DVM-TEM

Outcome:
- Performance of the model framework is ready for evaluation.

**Task 2-3: Evaluate the performance of the coupled model using retrospective statistical datasets of past fire regime and forest structure in Interior Alaska.**

Proposed Work:

- Evaluate model framework with data sets on historical fire regime (panels a and b), vegetation distribution (panel c) and stand age distribute (panel d).

Outcome:

- Model framework is ready for application.

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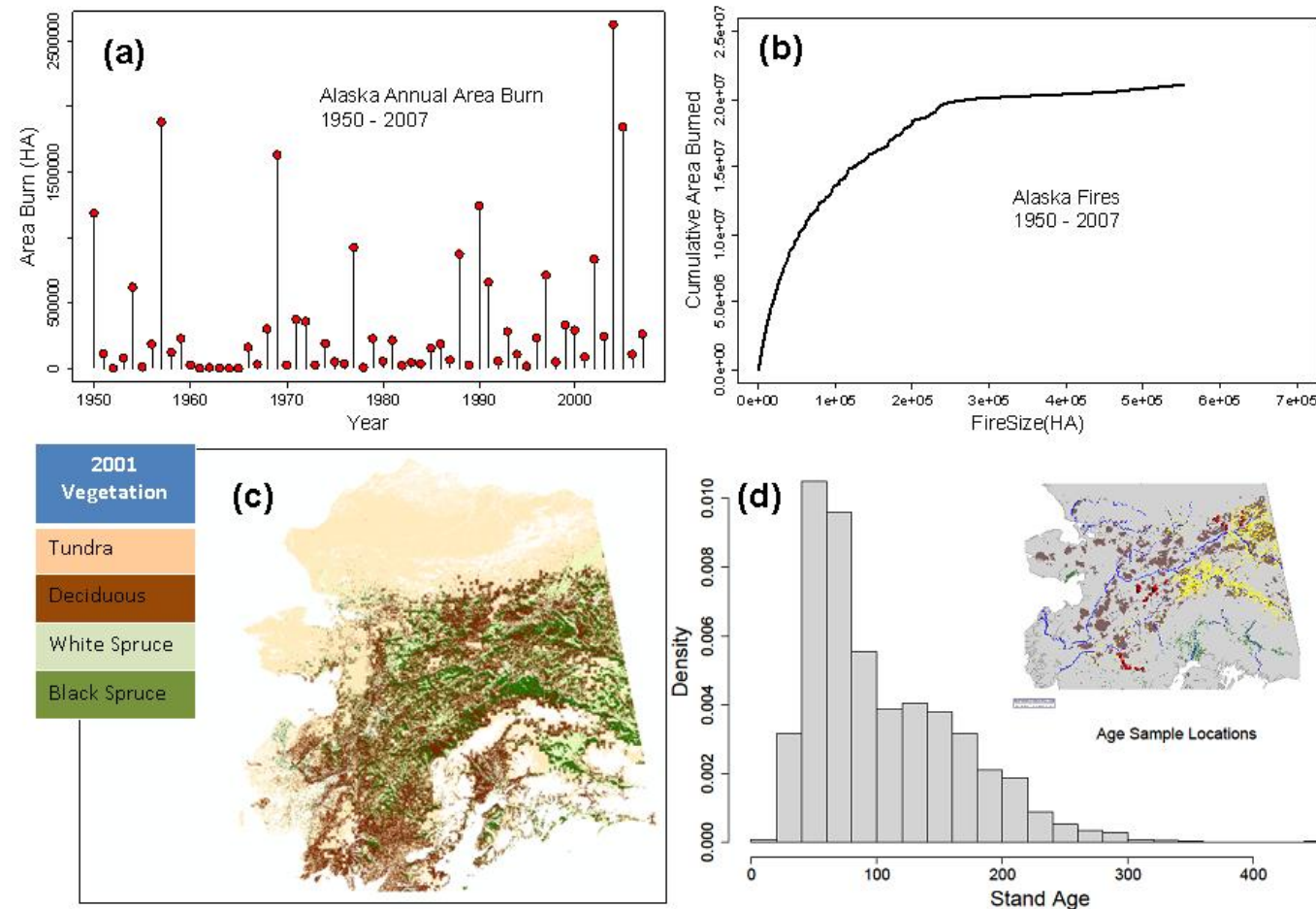
Task 2-4: Project future landscape distribution of vegetation and permafrost using the coupled model in combination with different scenarios of climate change, fire regime, and fire management.

Proposed Work:
- Apply the model driven by future climate scenarios to be developed by the Scenarios Network for Alaska Planning (SNAP) for alternative management scenarios to forecast (1) area burned, (2) changes in permafrost distribution, (3) change in vegetation composition/distribution, and (4) and changes in stand-age distribution.

Outcome:
- These model applications will provide a dynamic mapping tool to help land managers identify those DoD lands that are resistant and those that are vulnerable to permafrost degradation under scenarios of disturbance and climate change.

- These model applications will allow land managers to explore the consequences of interactive changes in climate and management for vegetation composition, fire dynamics, and ecosystem structure and function.

Communication Plan

Organize two technical transfer workshops (end of Years 3 and 5) in order to interact with fire managers in Interior Alaska, particularly those involved with fire management on Department of Defense lands in Interior Alaska.

First workshop: Project results to date and plans for the no-management and management model simulations we envision conducting. The workshop will be primarily focused on helping us to modify the details of the planned management simulations so that the results of the simulations will be most useful to the fire managers.

Second workshop: Present and provide an interactive workbook and mapping tool (user guide) designed make the results of the no-management and management simulations easily accessible and useful to the fire managers in Interior Alaska.

These workshops and the related technological transfer of proposed deliverables will be coordinated through the Alaska Fire Science Consortium. Peer-reviewed literature will also be an important general outlet of findings.