Wildfire emissions and the loss of legacy carbon from arctic and boreal ecosystems

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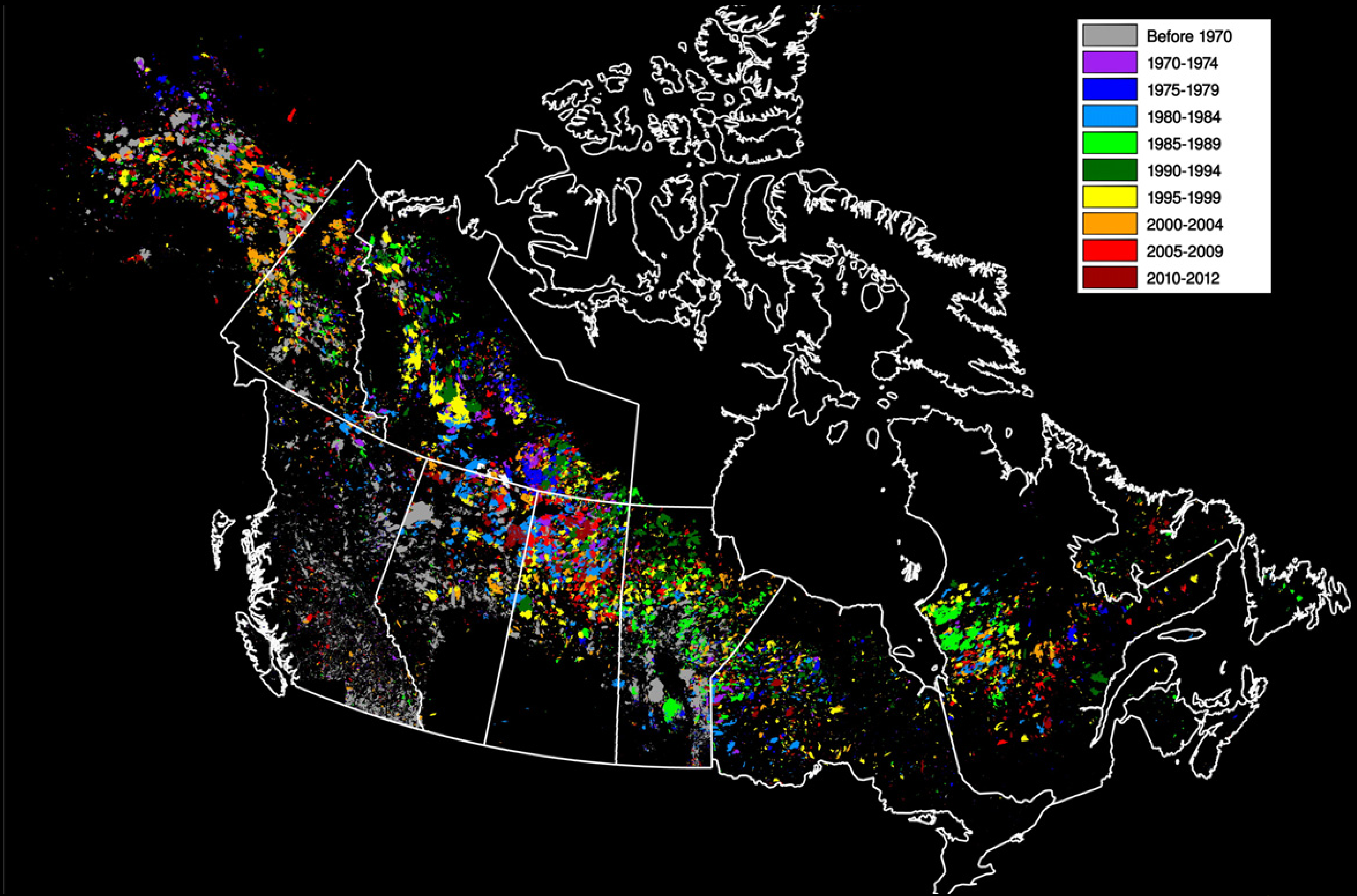
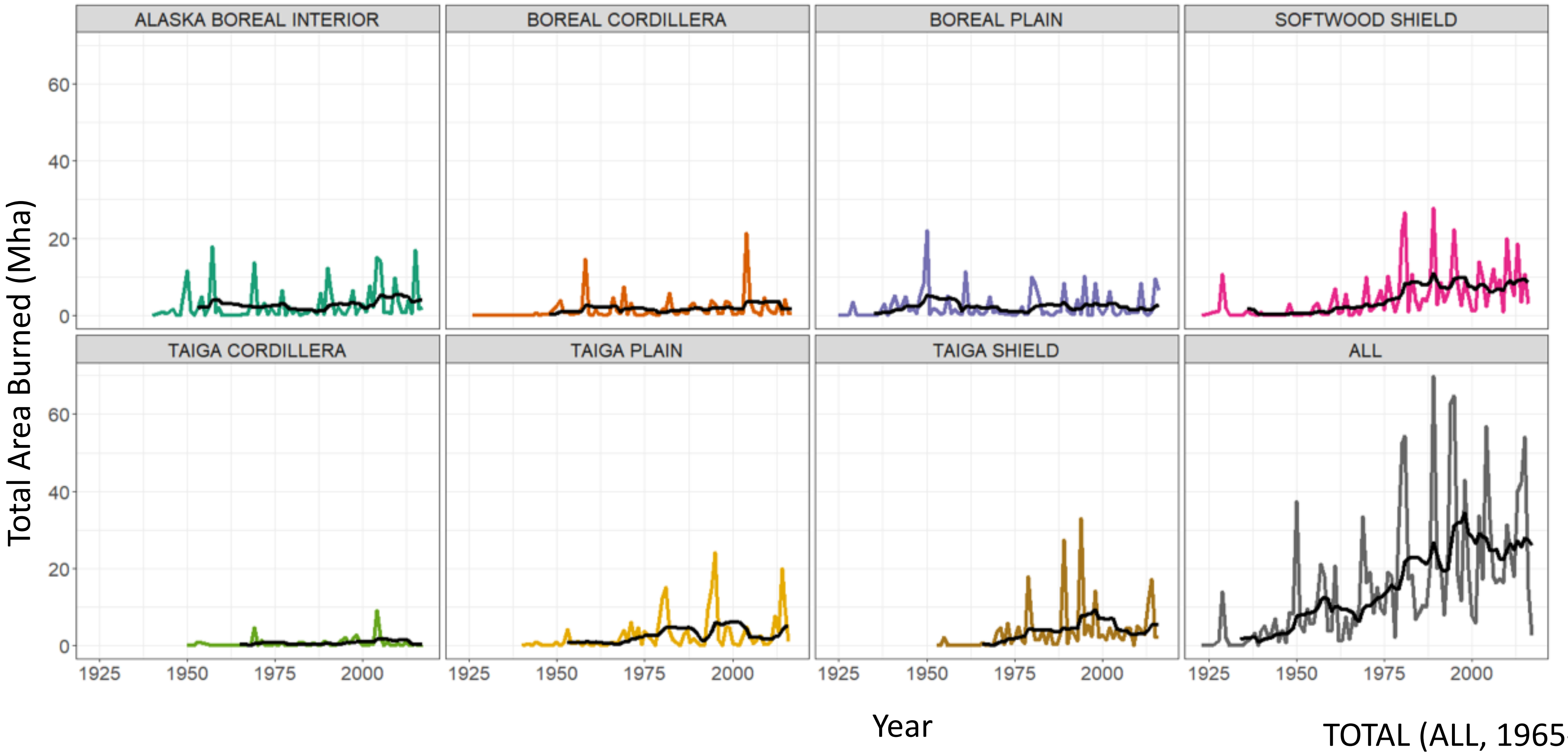
NASA

ABoVE
ARCTIC BOREAL VULNERABILITY EXPERIMENT

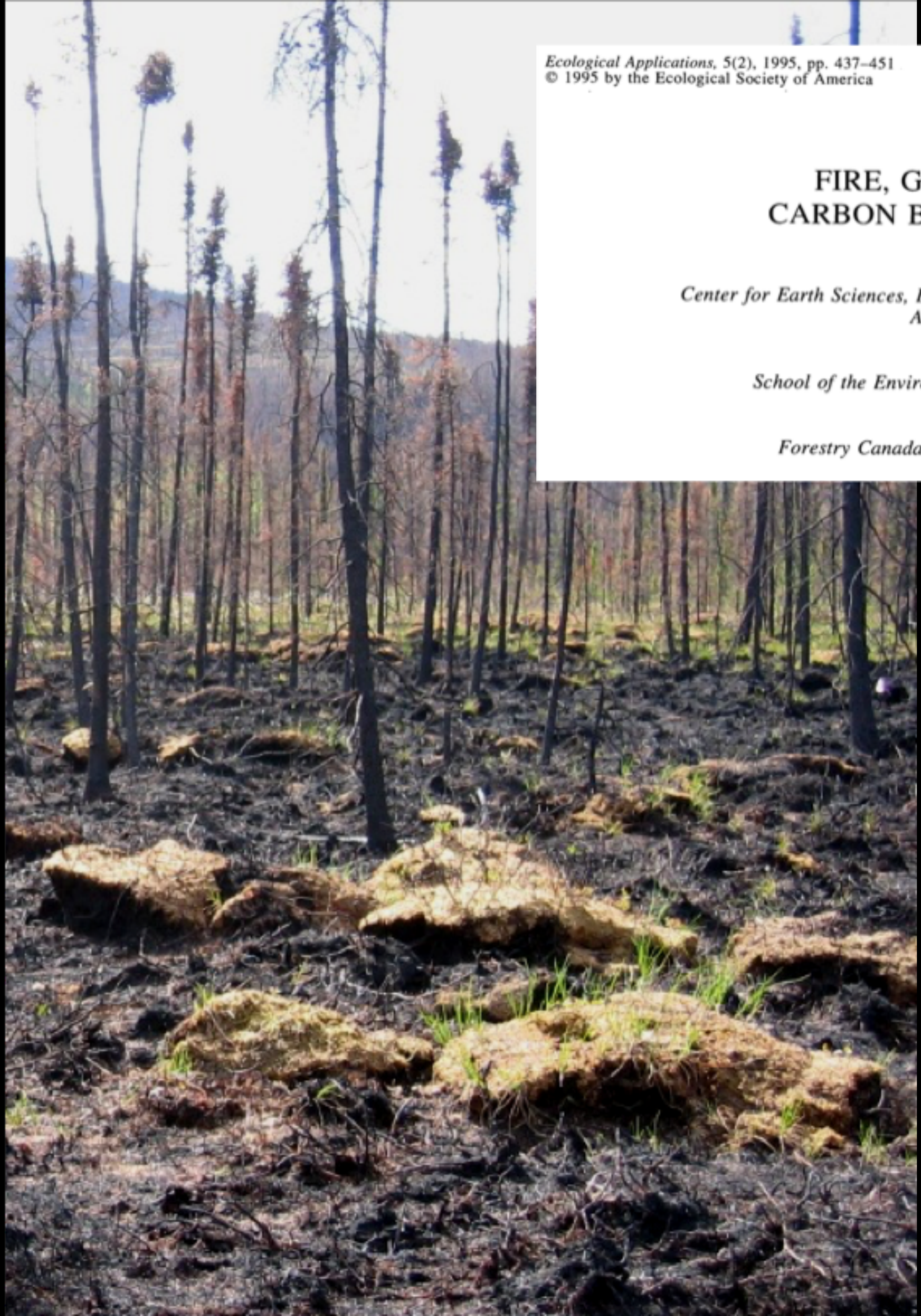


Ju and Masek 2016

Annual area burned is increasing in the ABoVE Domain



TOTAL (ALL, 1965-2017)
Slope =0.36 Mha / year
(R^2=0.64 P<0.001)



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FIRE, GLOBAL WARMING, AND THE CARBON BALANCE OF BOREAL FORESTS[1]

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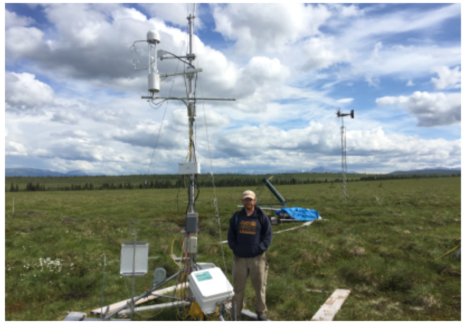
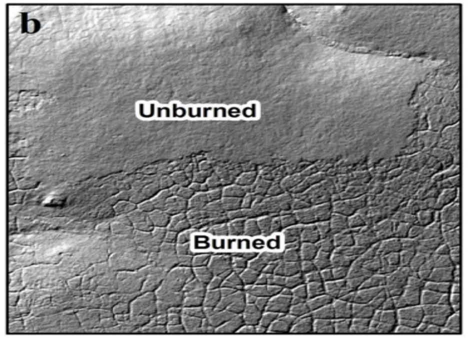
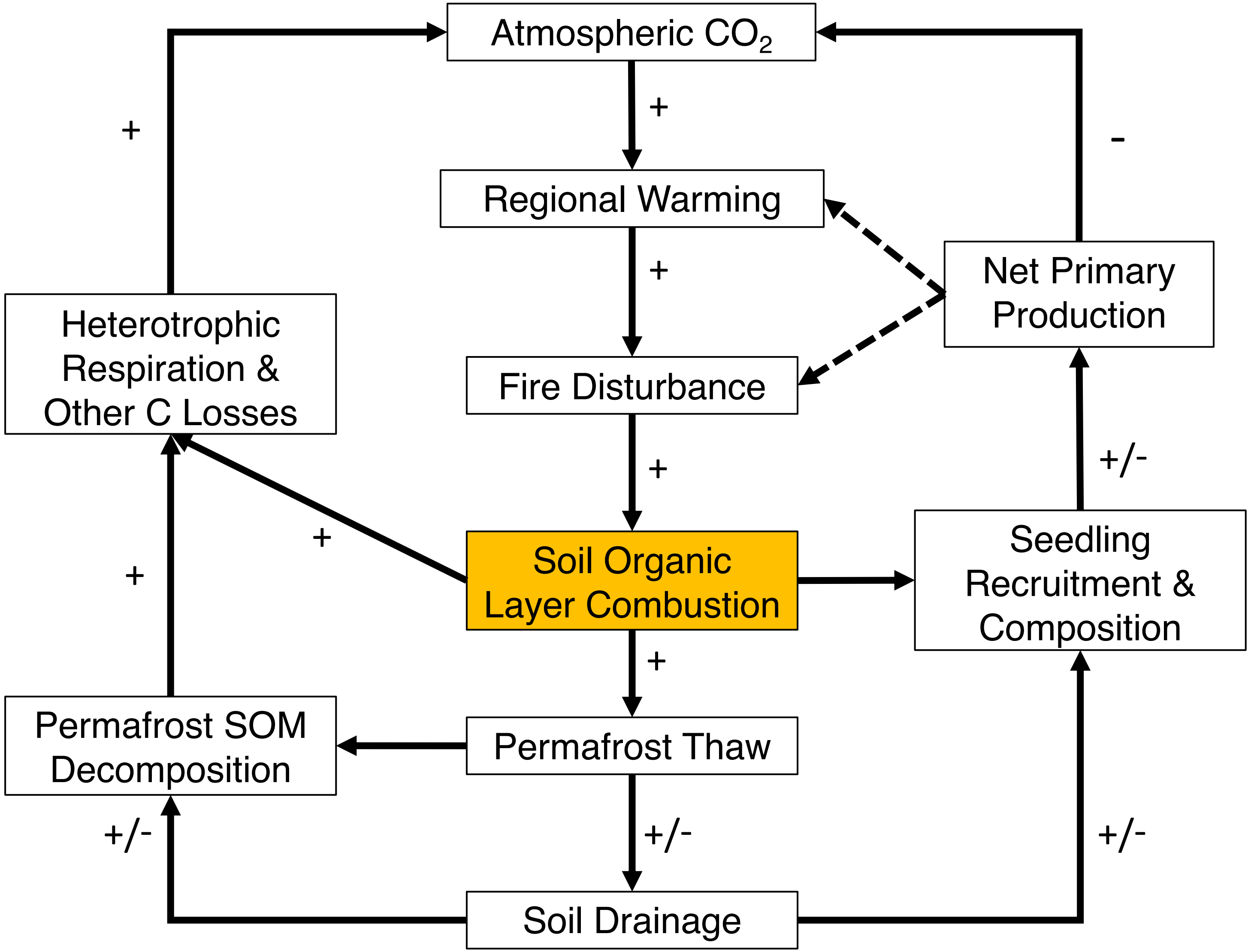
Carbon cycling feedbacks to climate

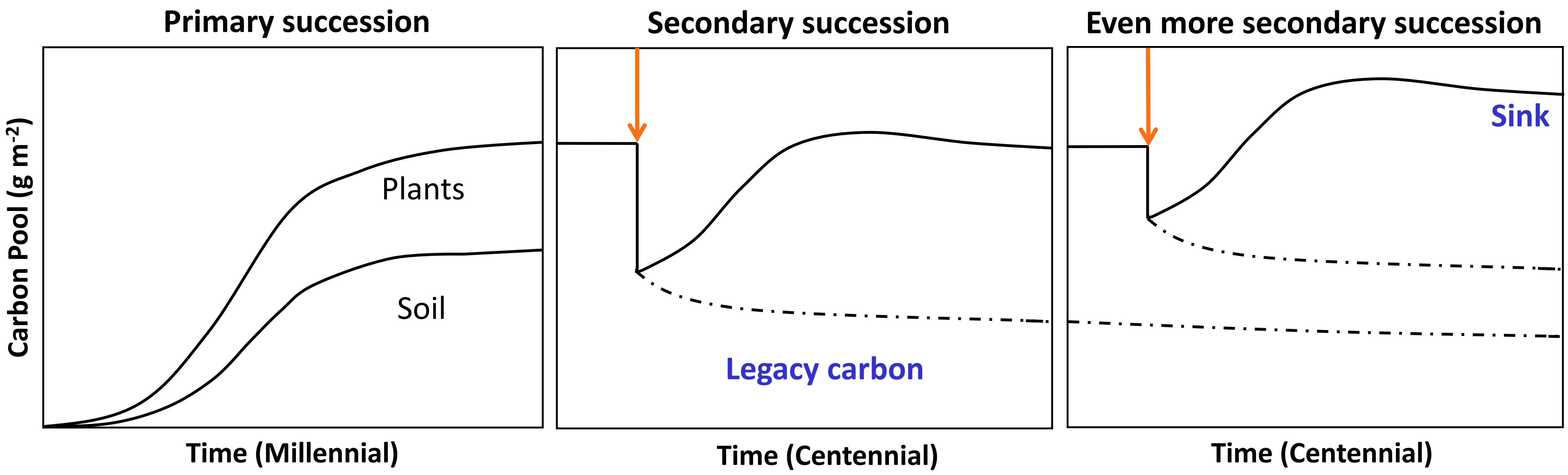






Carbon cycling feedbacks to climate

Net Ecosystem Carbon Balance = dC/dt



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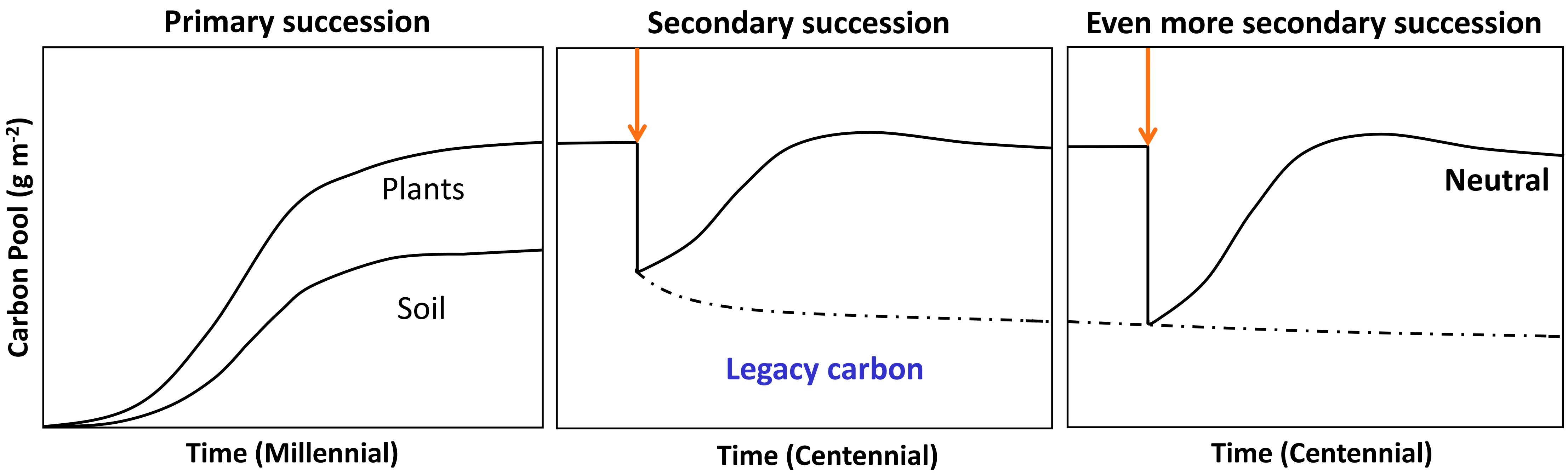



Carbon cycling feedbacks to climate

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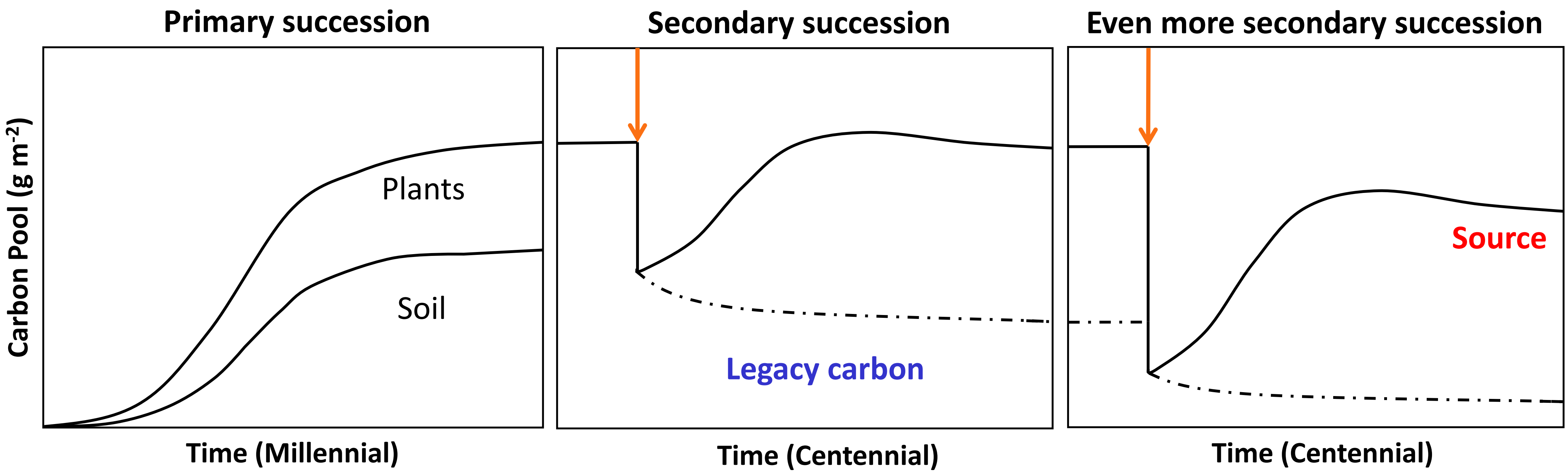
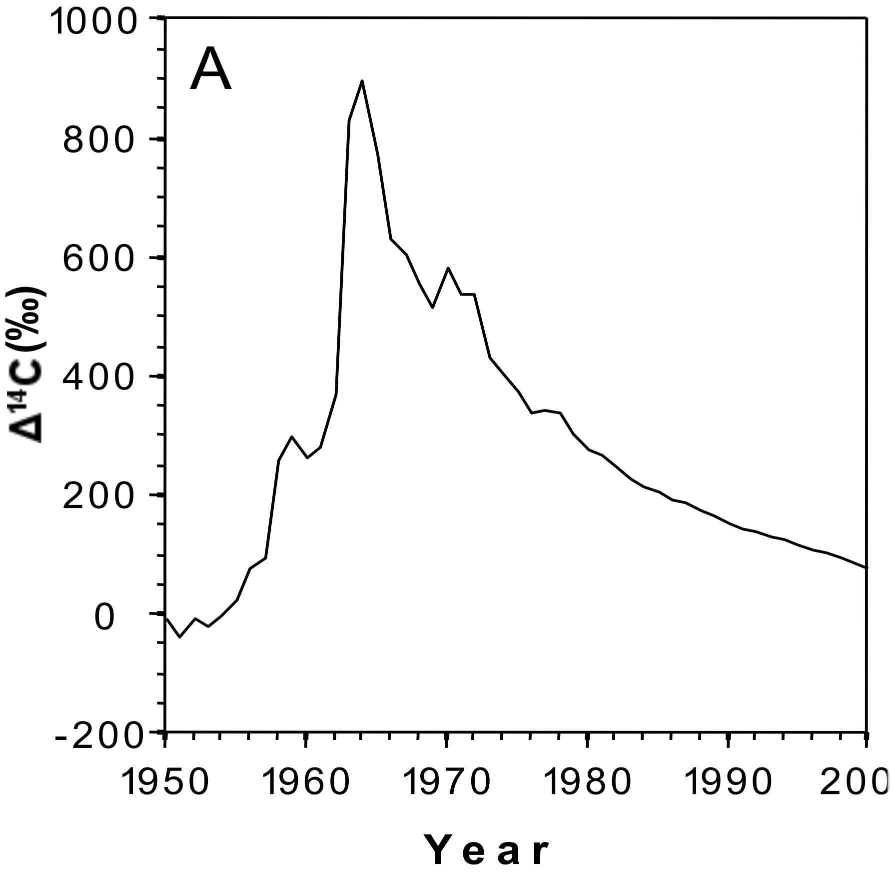
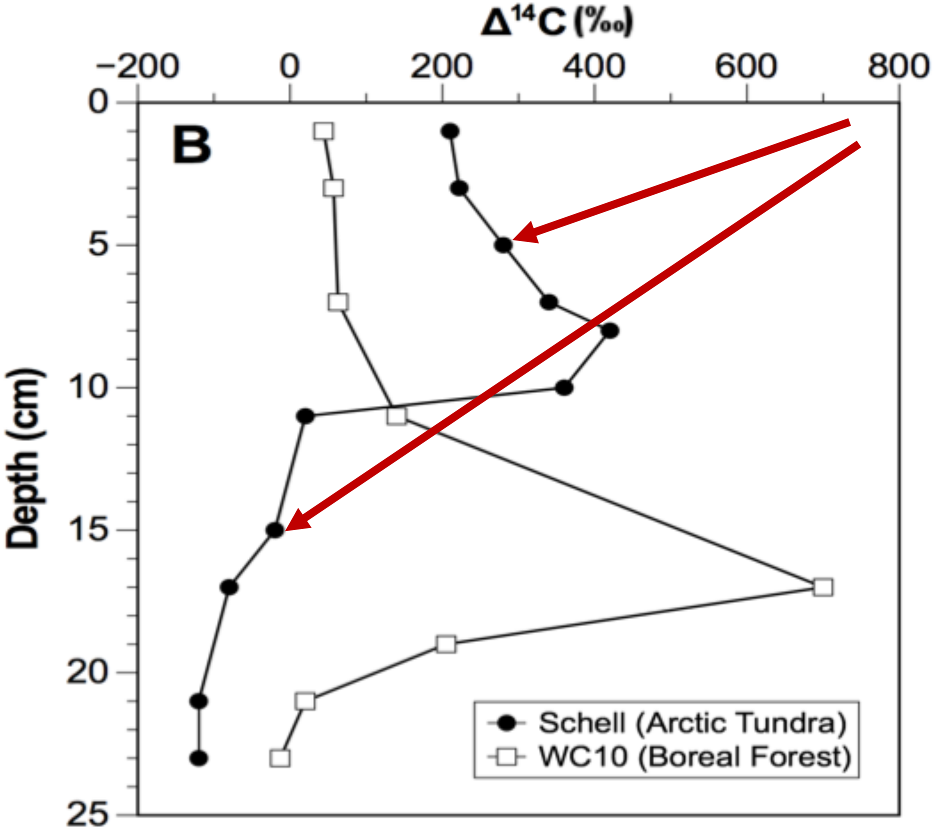


Is increasing depth of burning driving loss of old, legacy carbon from Arctic and boreal ecosystems?

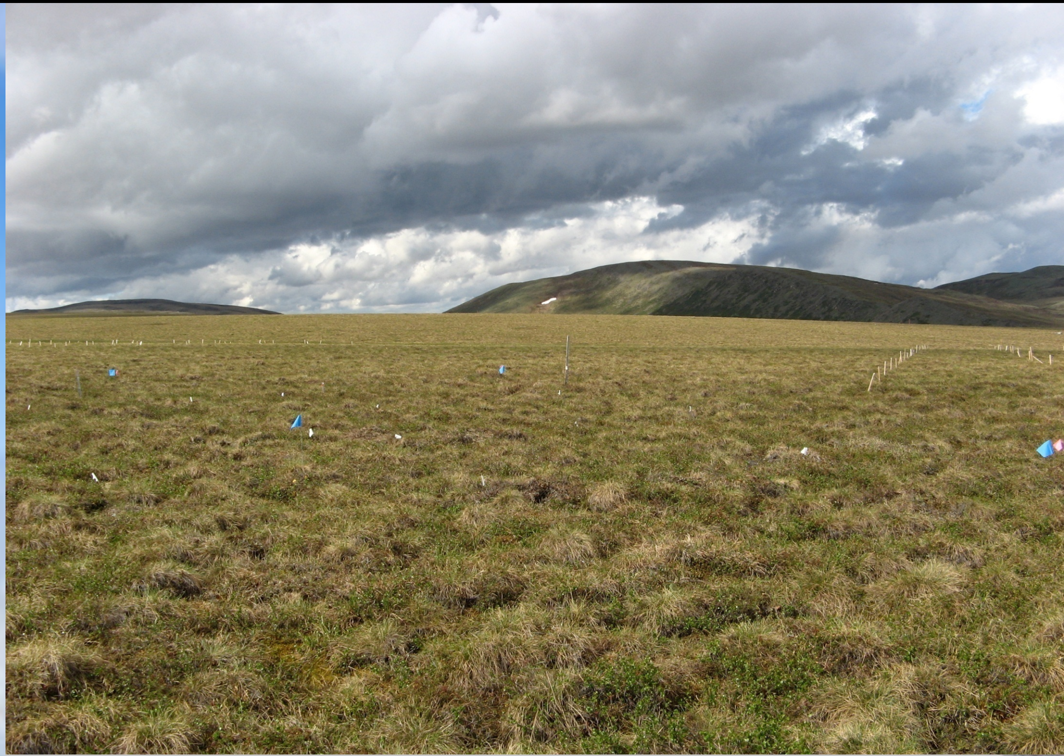
Stratification of soil carbon age in arctic tundra and boreal forest soil organic layers





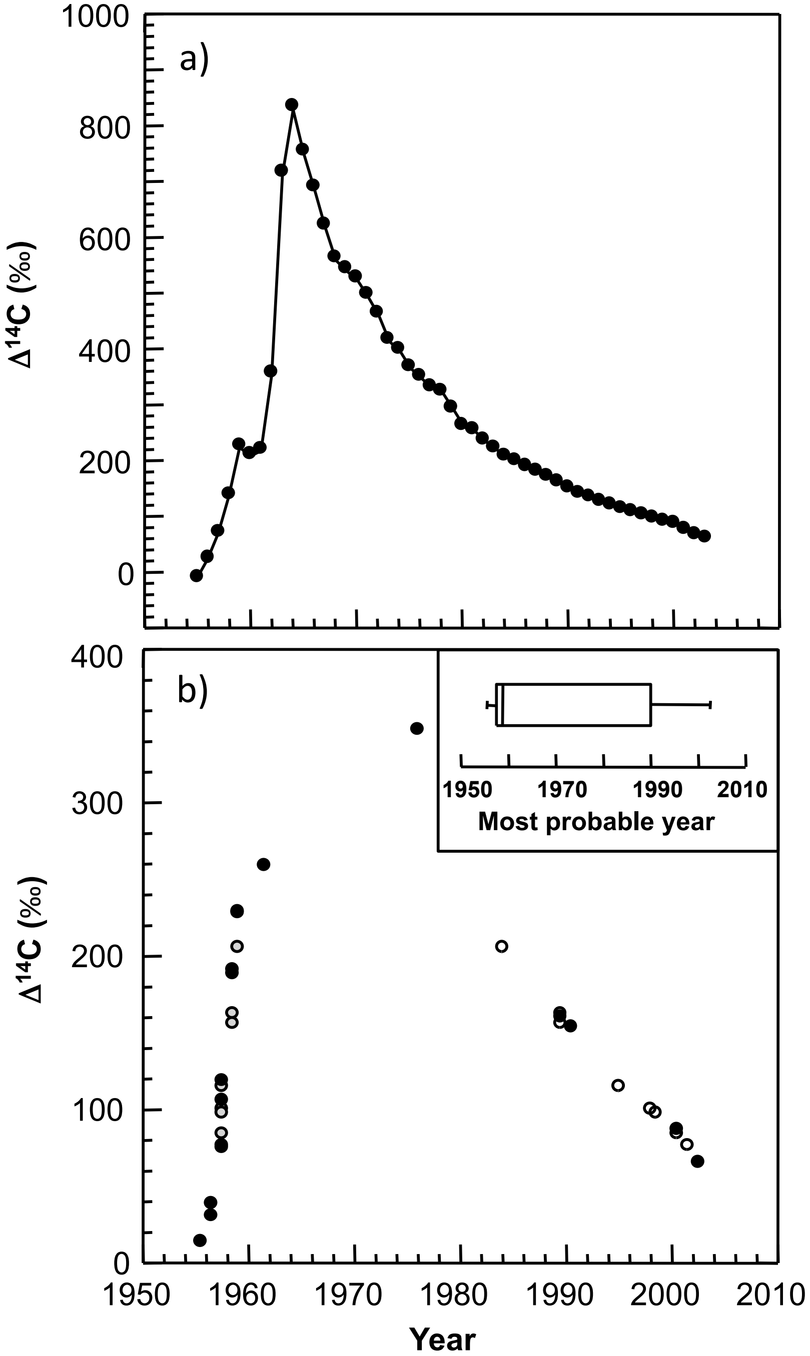
Wildfire in Alaskan arctic tundra

- 25 sites
- Depth of burning
- Regional soil calibrations
- Dated moss macrofossils



Did the Anaktuvuk River Fire burn old carbon?

- 2,000 g C m^{-2} combusted in fire
- 73% of C loss was from the soil organic layer
- Mean age of residual soil surface = 25 years
- Deepest burn (15 cm) had oldest surface (1954)



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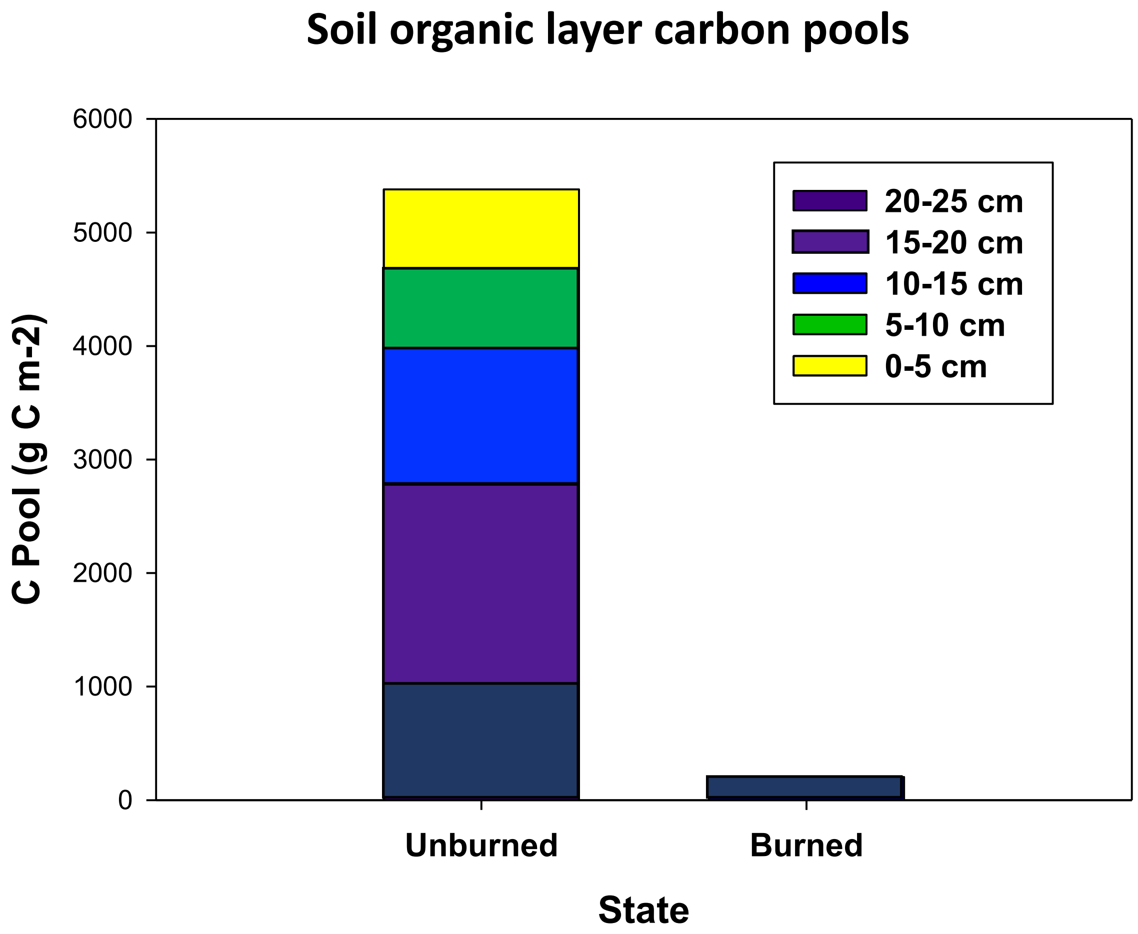
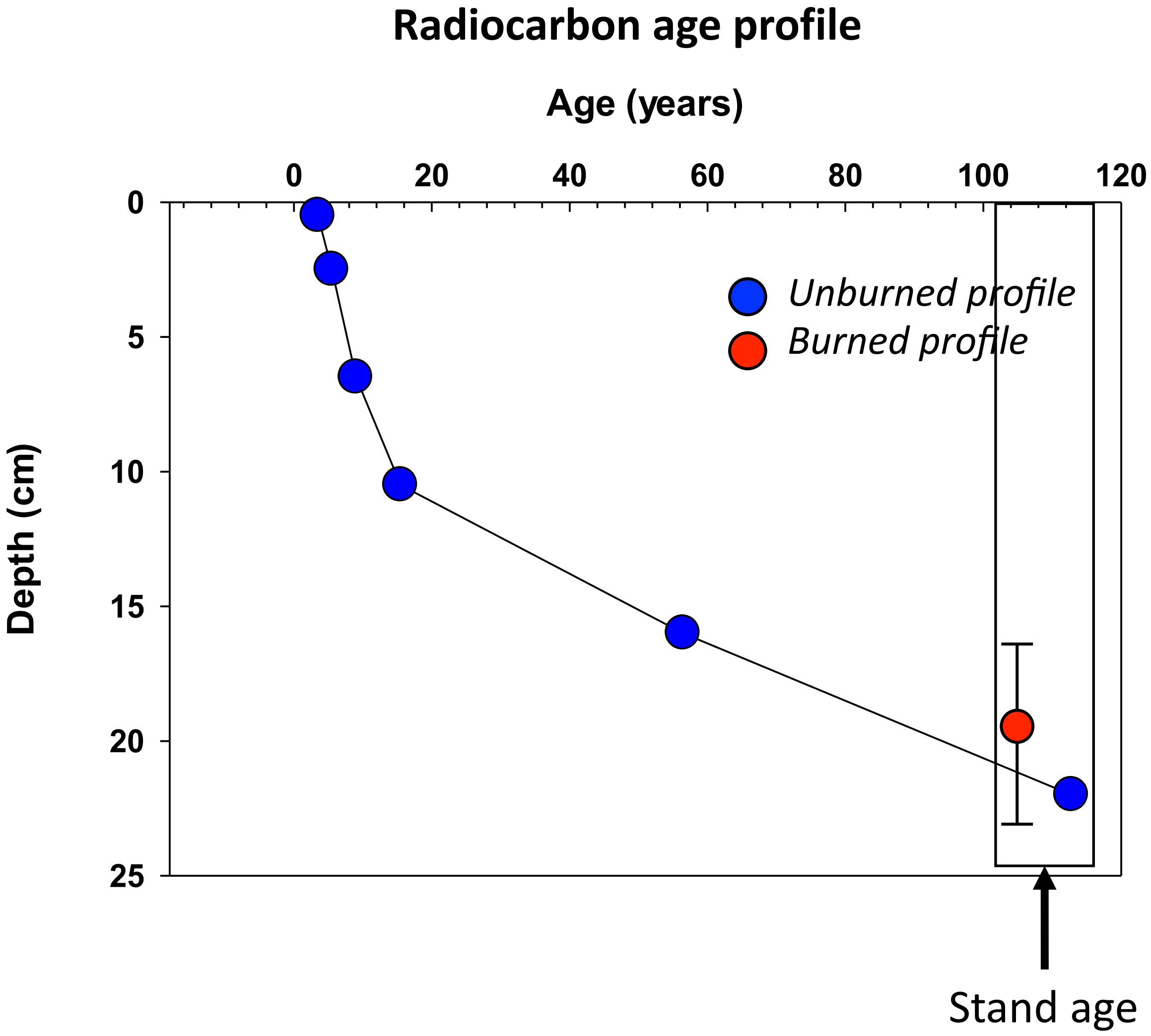
Wildfire in the black spruce forests of Interior Alaska

- Nine sites
- ~100 year old black spruce forests
- Depth of burning
- Dated moss
- Dated base of the soil organic layer
- Aged stand

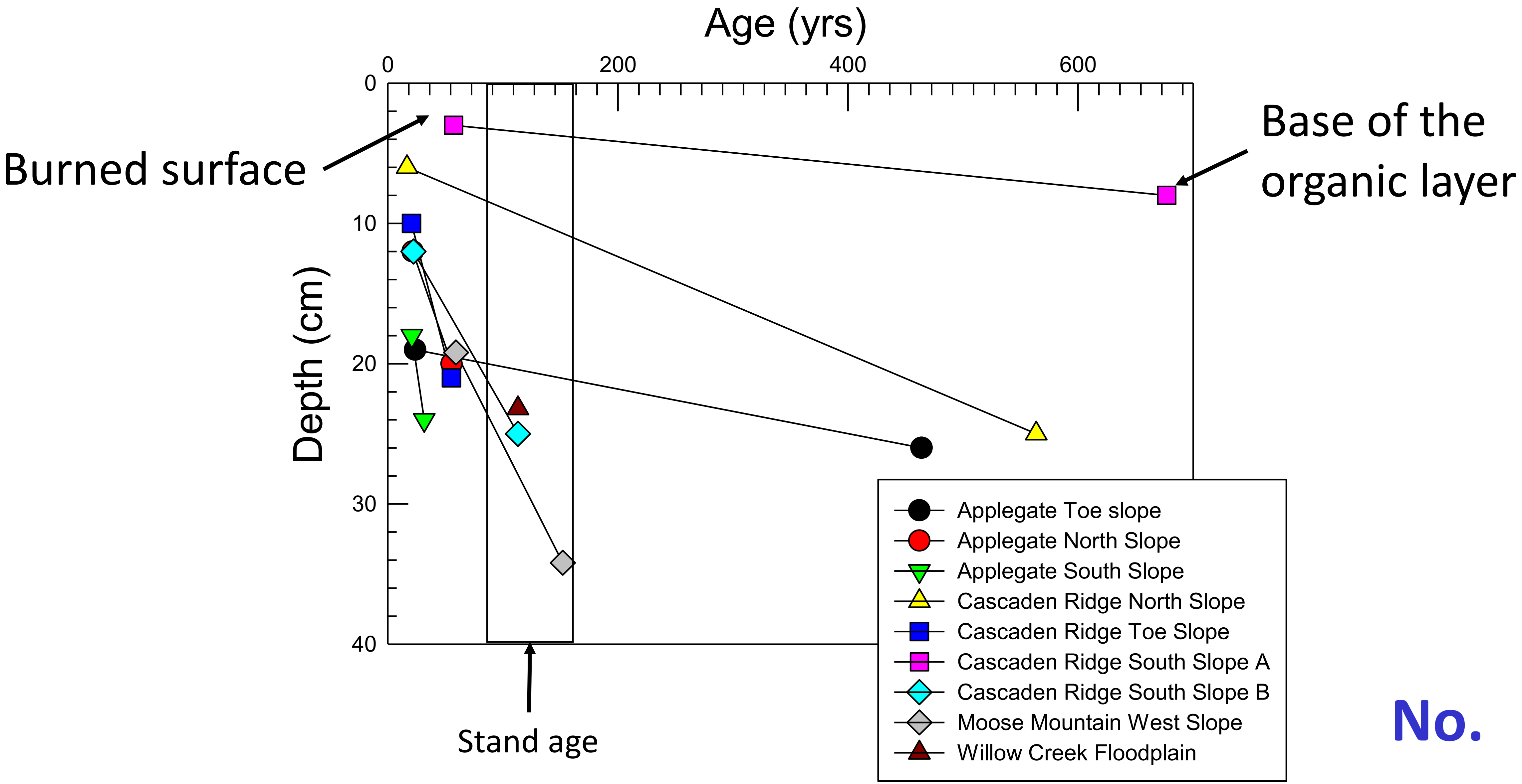
- **Chronosequence: 64% of ecosystem C is a legacy**
- **Supported by charcoal layers and radiocarbon dating**

Willow Creek Fire





Did boreal fires burn legacy carbon?



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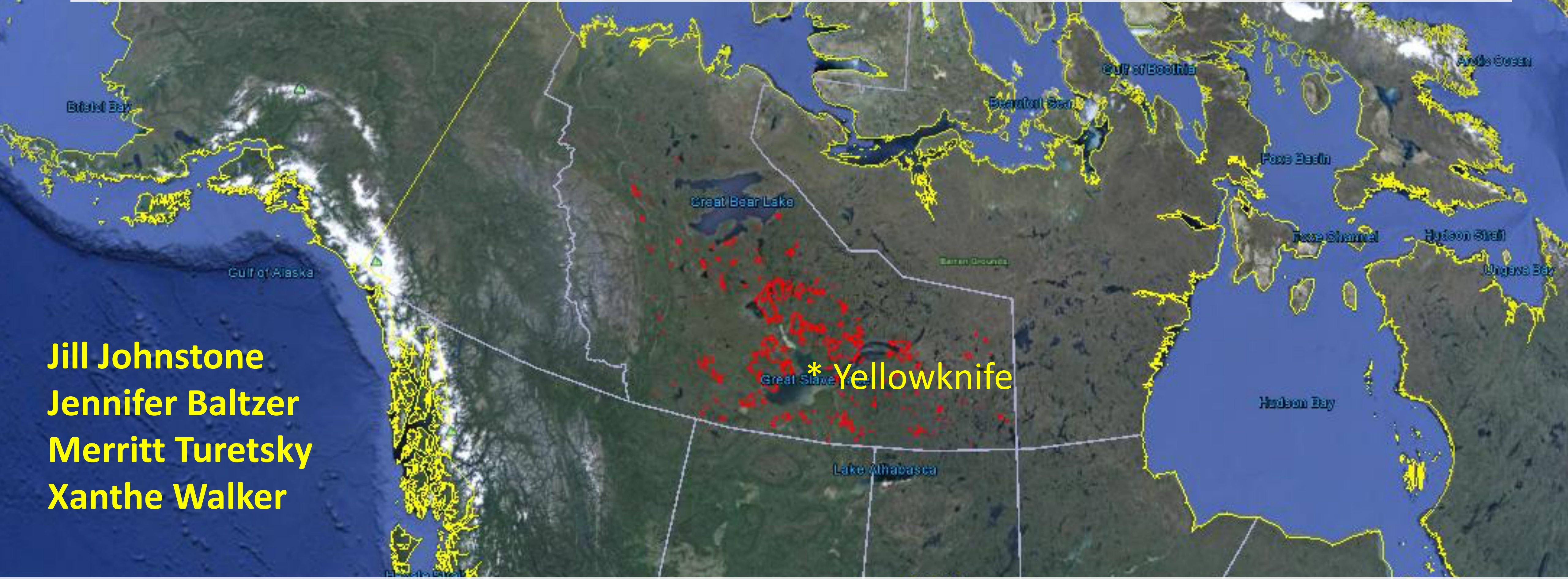
Megafires in the Northwest Territories



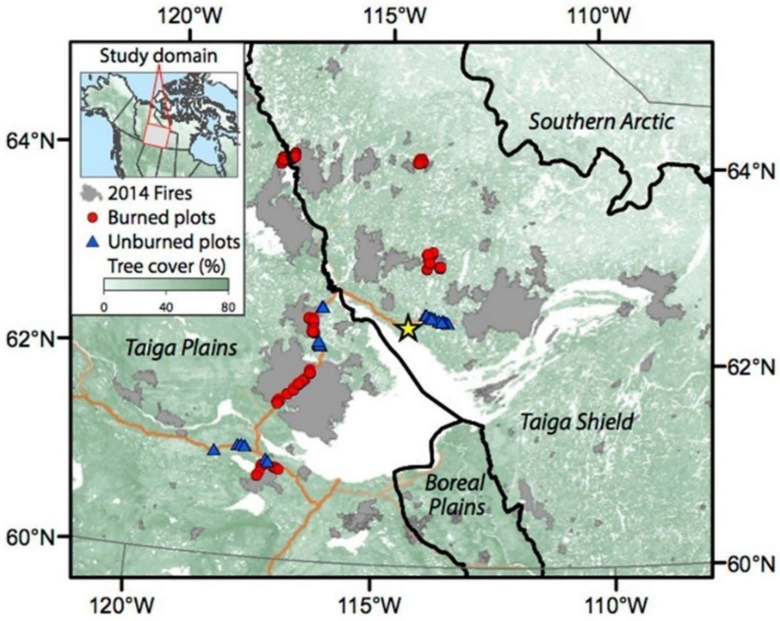
Jill Johnstone
Jennifer Baltzer
Merritt Turetsky
Xanthe Walker

Fires in 2014 burned 3.4 million hectares

"the most intense fire behavior seen by this generation"

Ernie Campbell, the Deputy Minister of the Environment for the NWT

NWT Study Design



- 211 sites in 7 burn scars
- ~100 year old black spruce forests
- Depth of burning
- Local and regional emissions
- Dated fine organic matter
- Dated base of the soil organic layer
- Aged stand

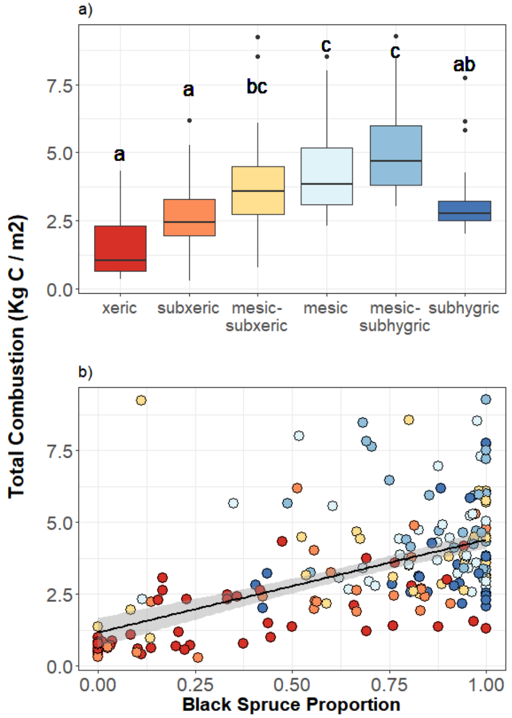
Dry

Mesic

Wet

Estimating carbon emissions

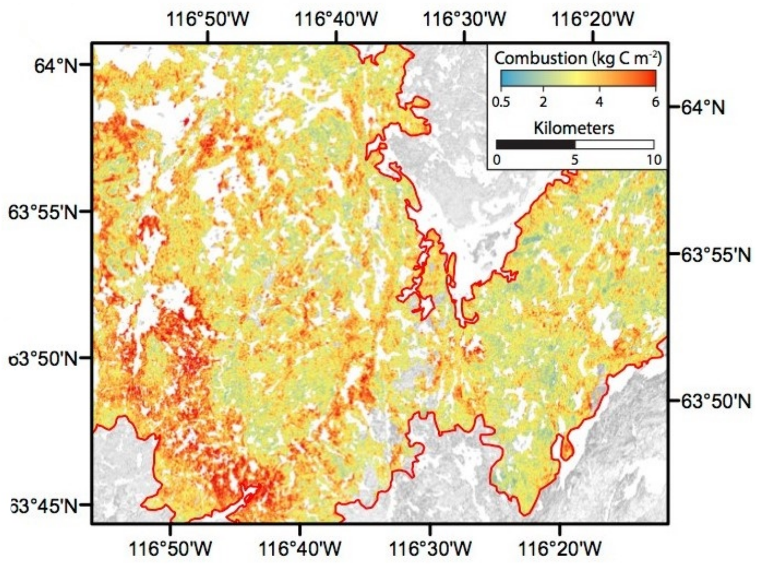
Field data modeling



Combustion emissions increased with topographic wetness and increased with the proportion of black spruce

Full Model: moisture category, elevation, stand age, latitude, proportion of black spruce, and pre-fire tree biomass

Remote Sensing extrapolation



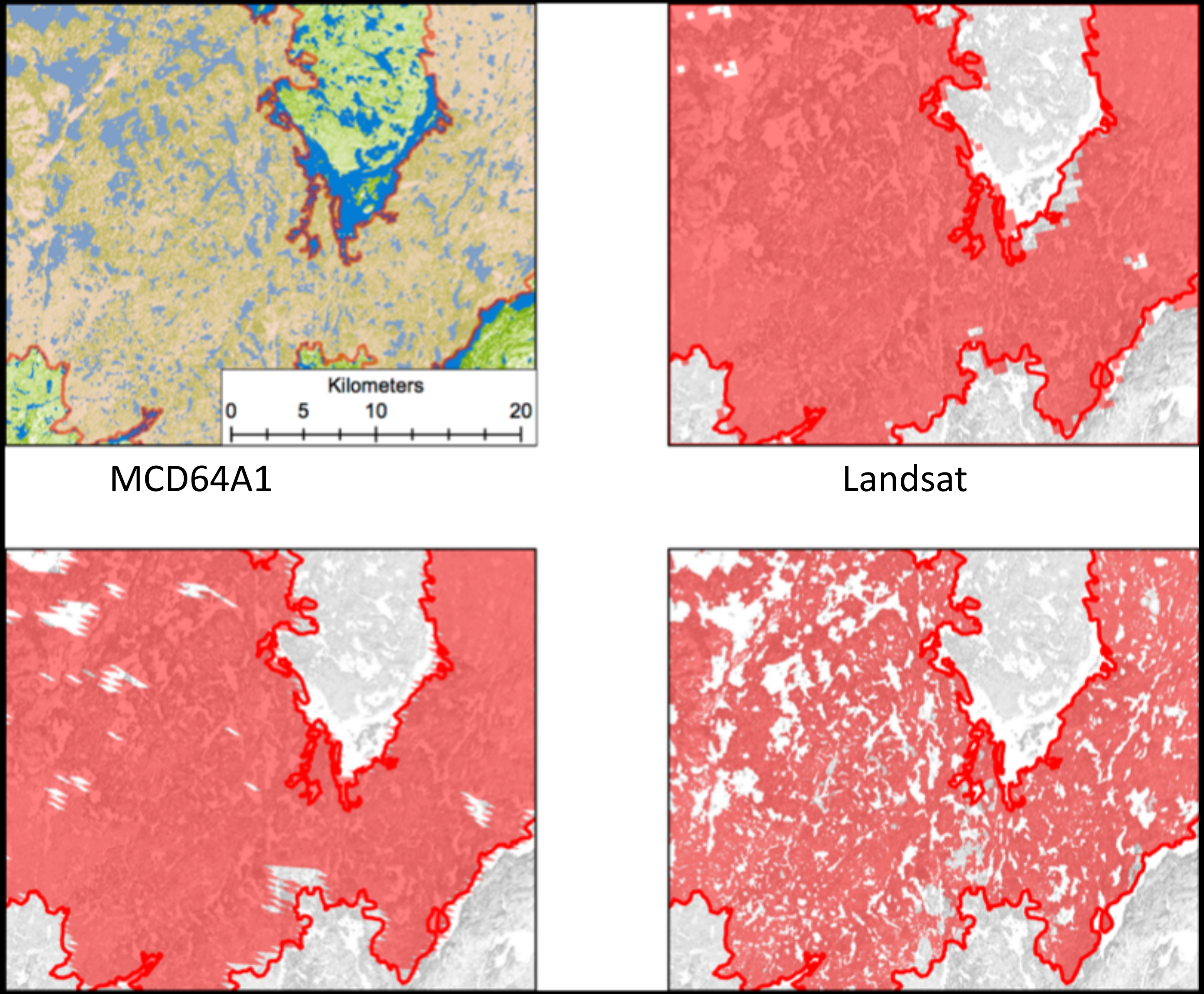
Full Model: topographic wetness index, terrain ruggedness, dNBR, relative change in tree cover, percent black spruce, and percent sand in the top 15 cm of soil.

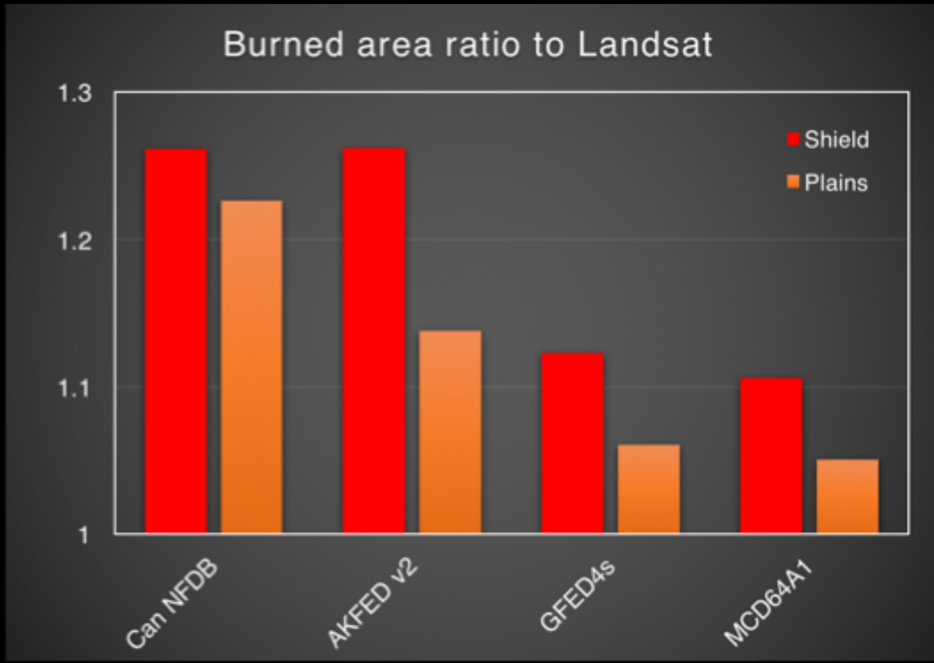
Study	Kg C/m²	Area (Mha)	Total (Tg C)
This study (Walker et al. 2017)	Field: 3.31 (1.3) Remote: 3.35	2.85	94.3
Veraverbeke et al. 2017	4.81	3.41	164

Differences due to:

1) Spatial resolution (30m vs 500m) and ability to capture small water bodies
2) Regionally specific field training data vs. training data from Alaskan black spruce sites

Effects of spatial resolution on burned area

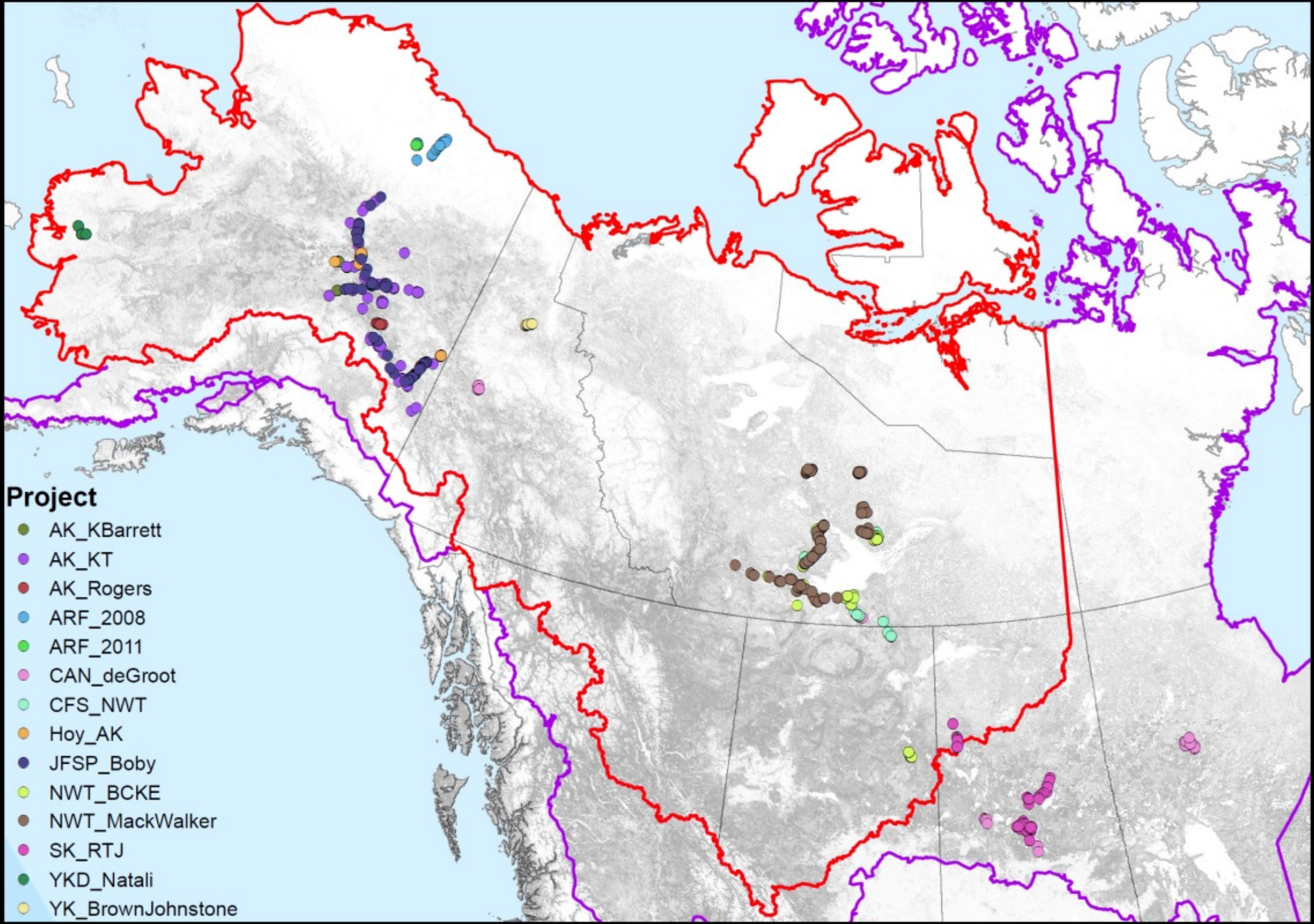




Brendan Rogers

Combustion and regeneration workshop, Spring 2016

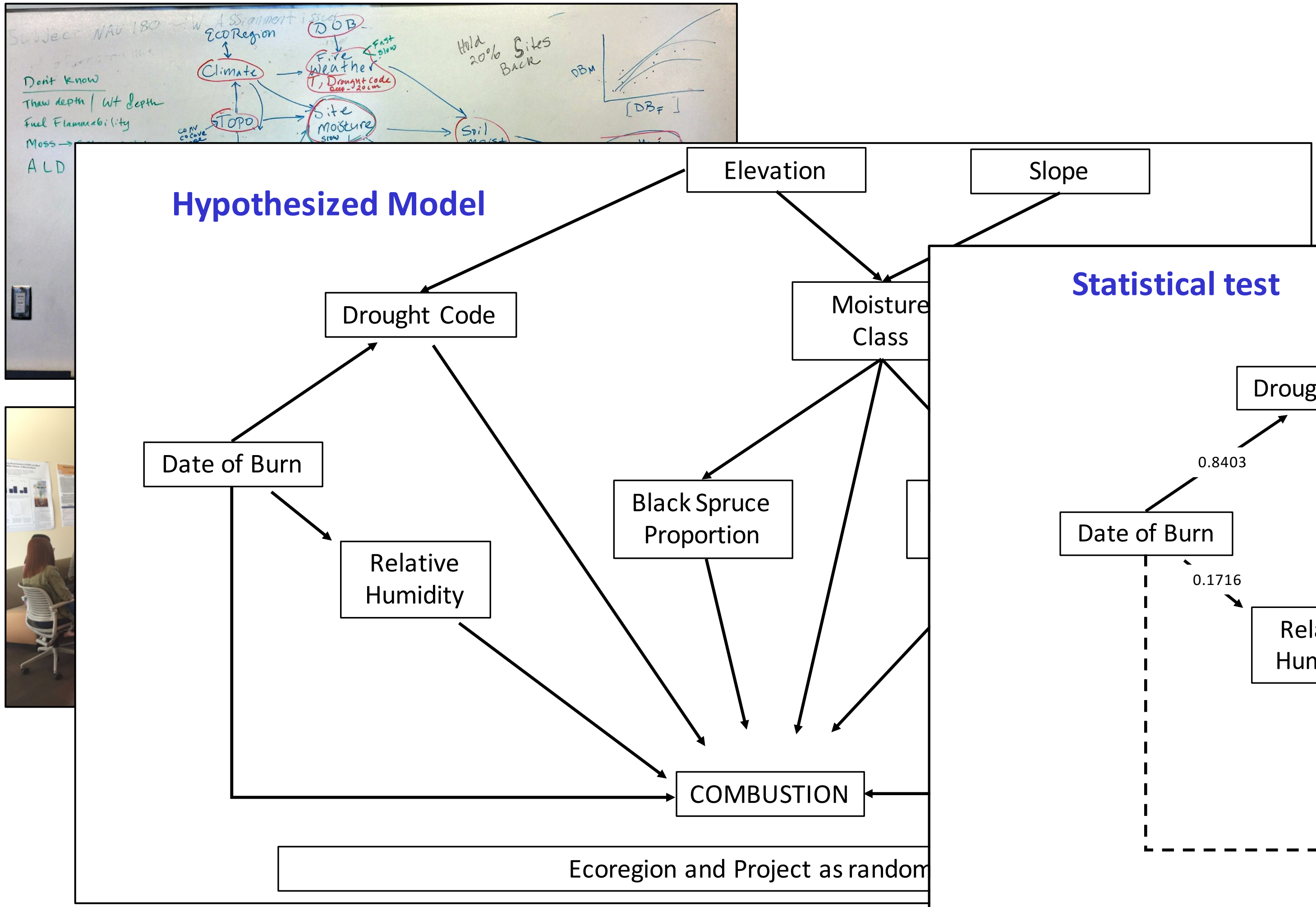
Ecoregion Level 2	# field sites
Alaska Boreal Interior	98
Boreal Cordillera	207
Taiga Shield	202
Taiga Plains	418
Softwood Shield	37
Boreal Plains	69
Taiga Cordillera	16
TOTAL	*1047*

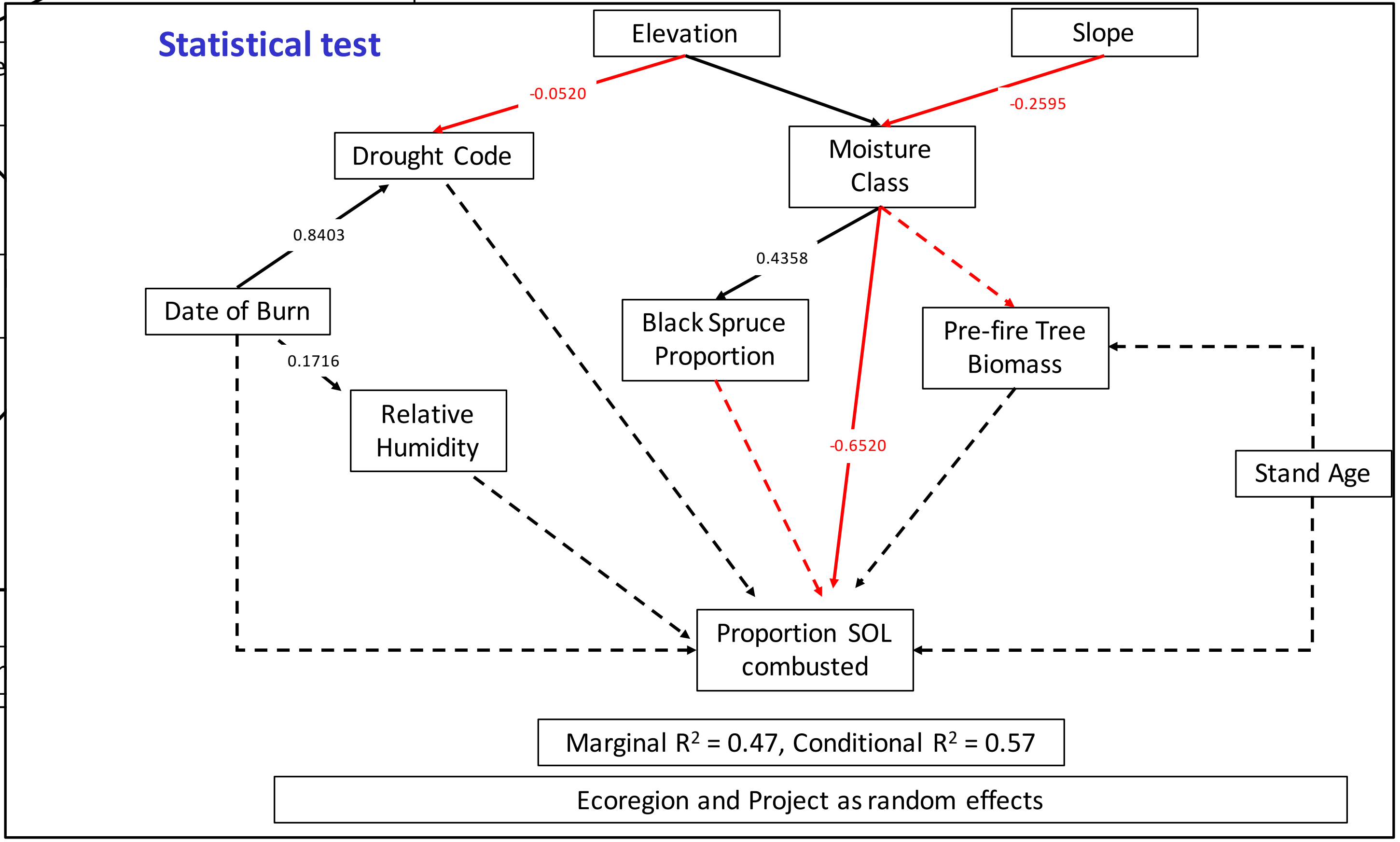


Northern Arizona University · ABoVE Arctic Boreal Vulnerability Experiment · NASA · NSF · Bonanza Creek LTER Boreal Forest Ecology · Wilfrid Laurier University · Northwest Territories Canada · University of Saskatchewan

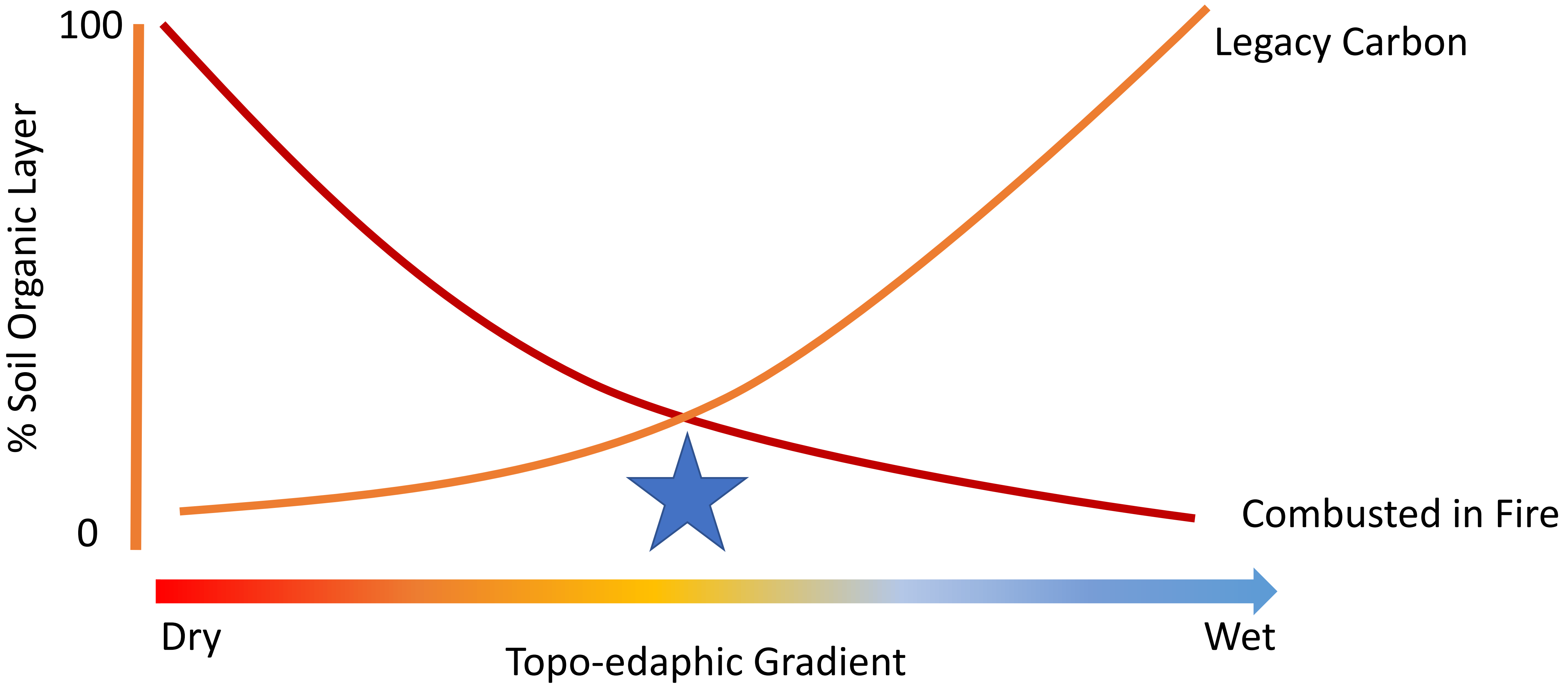
Structural Equation Modeling to test direct and indirect controls over combustion

- **Domain-wide versus regional models**
- **SEM points towards need for high resolution DEM/remote sensing**



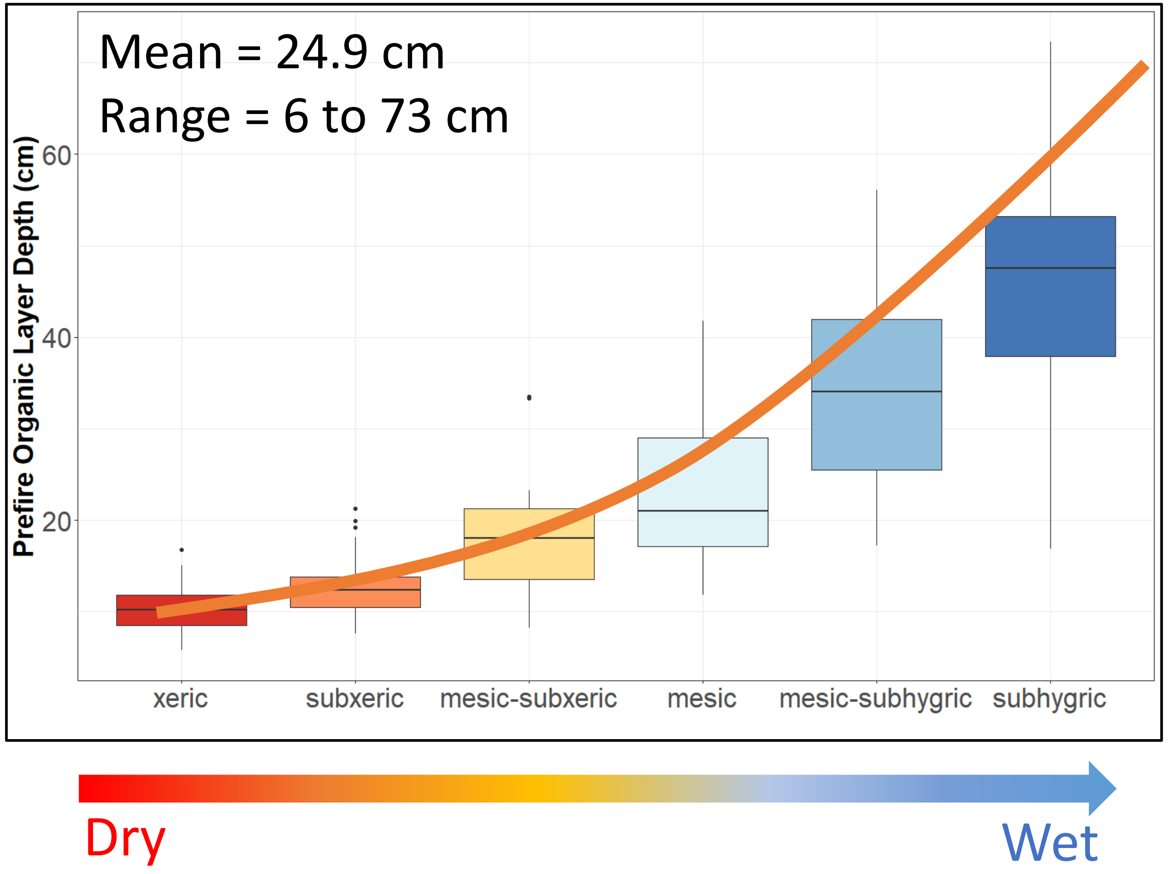


Landscape hypothesis for the loss of legacy carbon

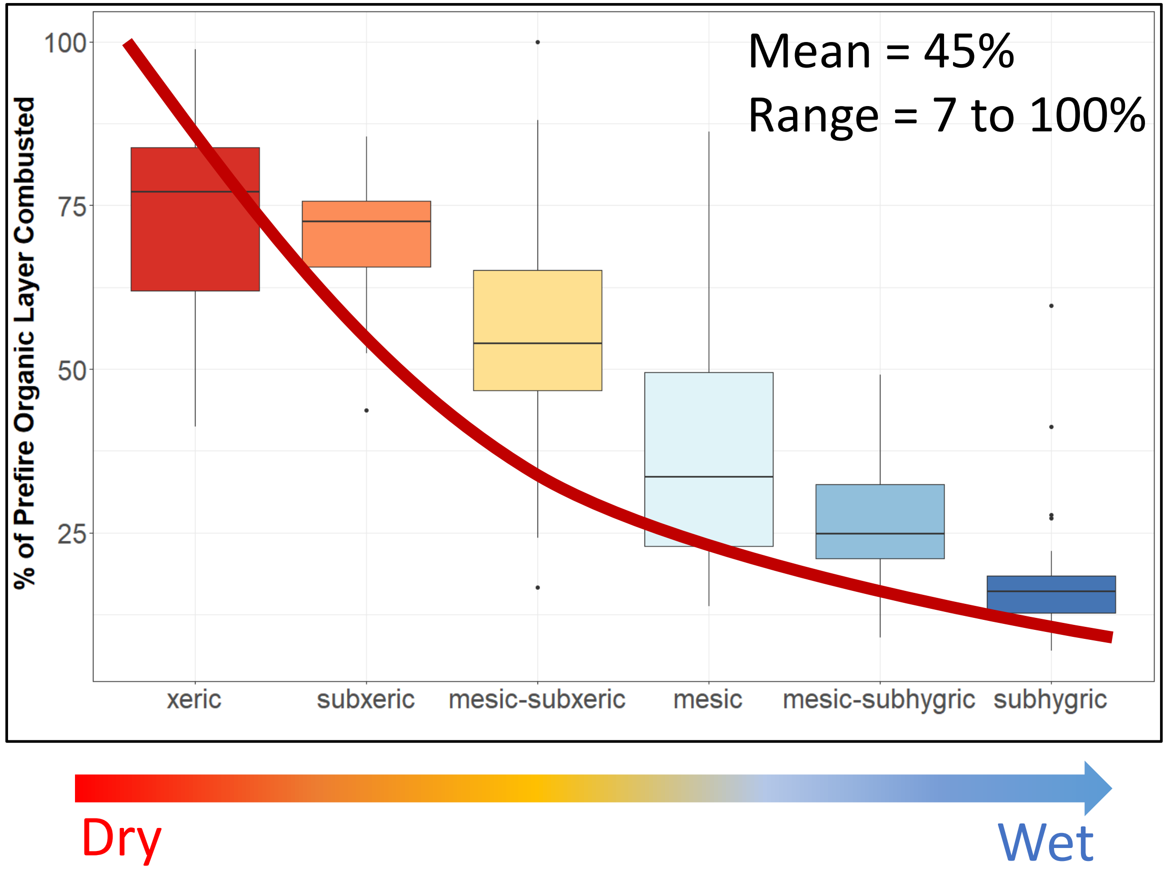


Soil Organic Layer (SOL) Combustion

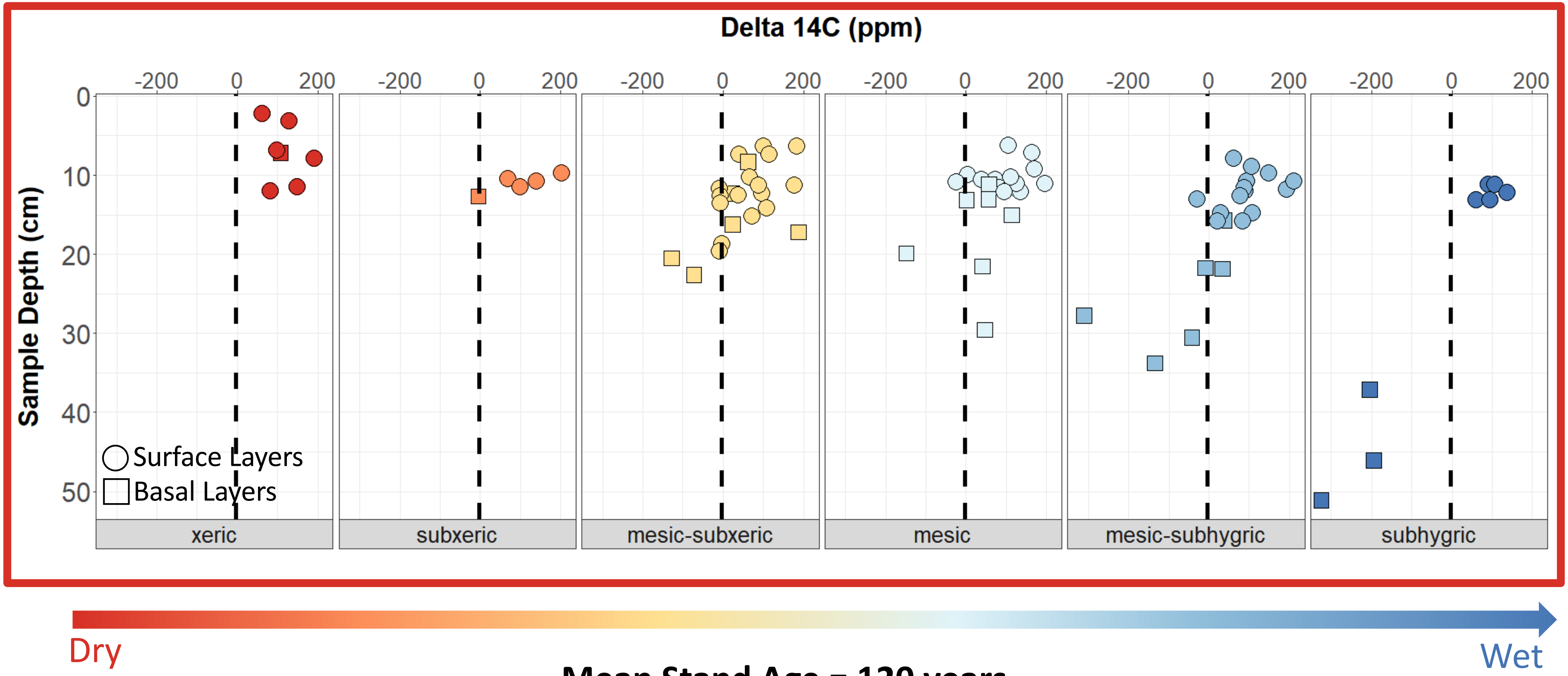
Prefire SOL Depth



% of Prefire Carbon Combusted



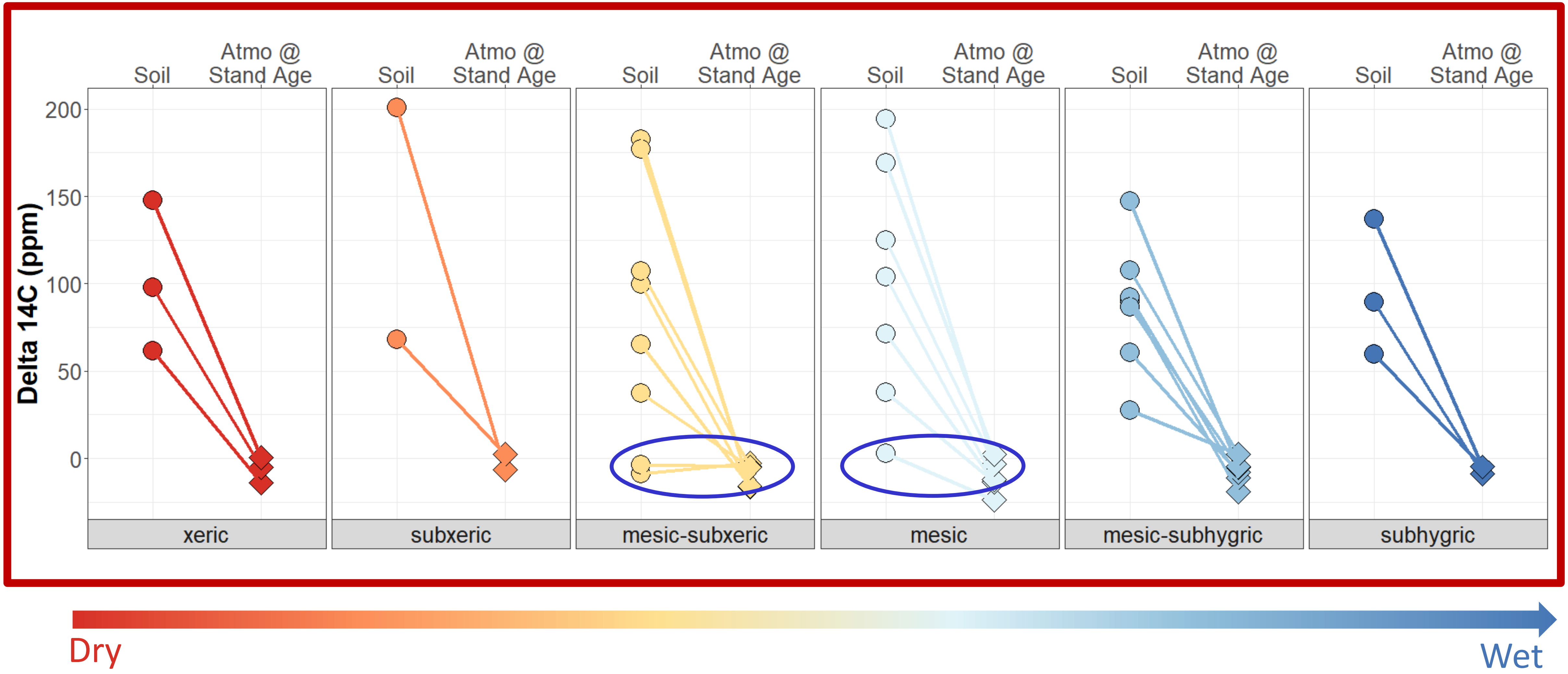
Where is Legacy Carbon on the landscape?



Mean Stand Age = 120 years

Delta 14C in 1895 = -3.1 ppm

Did mega-fires burn legacy carbon?



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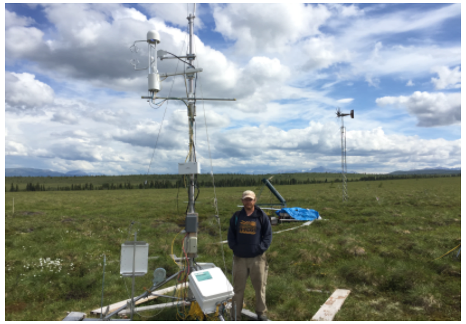
Conclusions

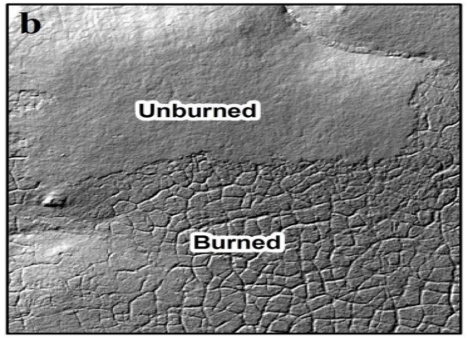
- Legacy C is an important component of NECB in fire-disturbed ecosystems.
- For deeper burning to cause a net loss of C to the atmosphere over the fire cycle, legacy carbon must burn.
- We did not detect legacy C loss in tundra or boreal fires.
- A few NWT mega-fire sites that harbored legacy carbon burned to stand age.

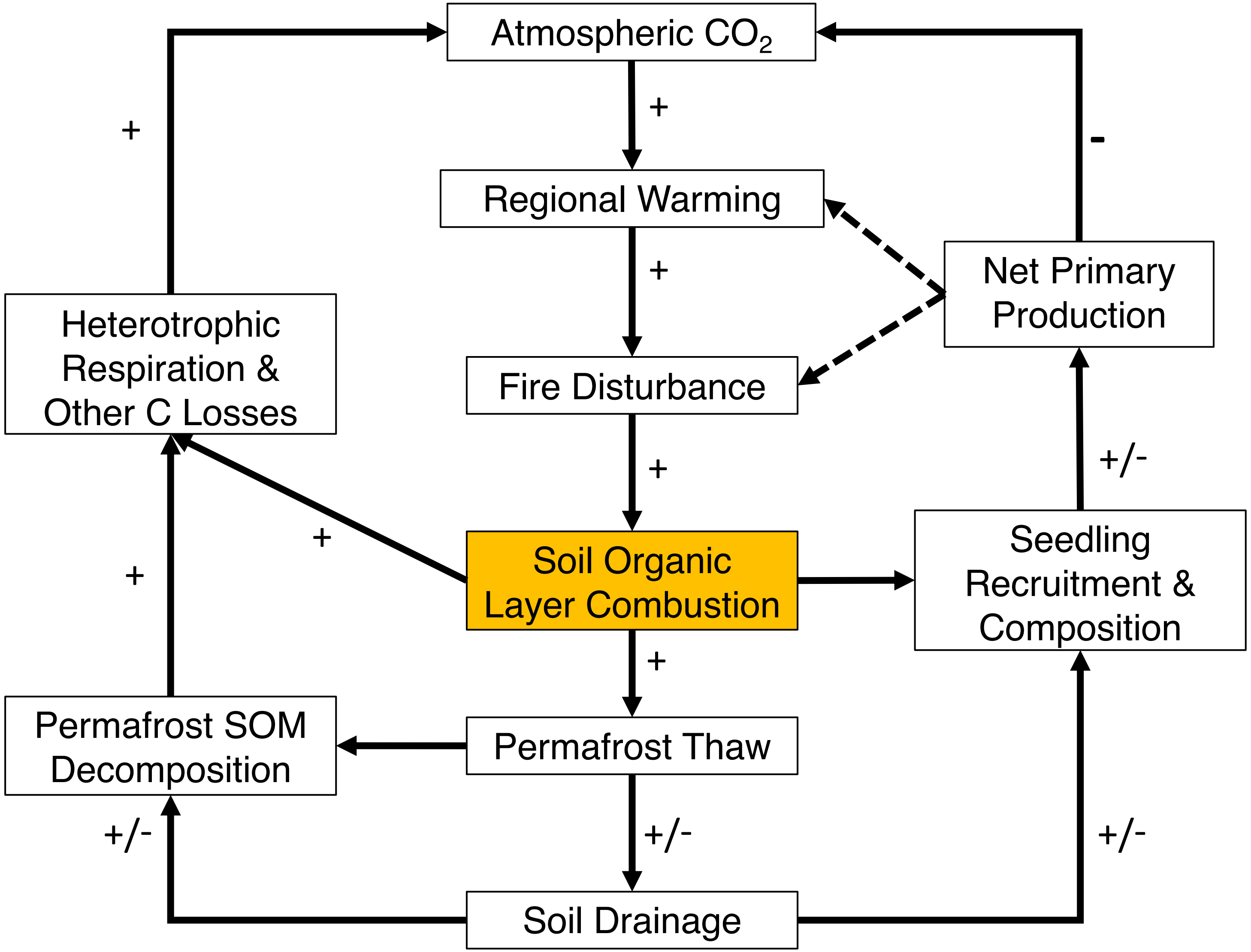
Implications

- Even in extreme fire years and deeply burned sites, soil organic layer C is escaping fire.
- Redouble focus on other dimensions of the fire regime:
  - Fire return interval
  - Inter-fire accumulation; shifts in vegetation.
  - Changing landscape stand age structure.

Carbon cycling feedbacks to climate







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Randi Jandt

Teresa Hollingsworth
Dave Verbyla
April Melvin
Scott Goetz
Brian Howard

Radiative forcing from a boreal forest fire

Forcing agent	Radiative forcing [W (m^2 burned)$^{-1}$]	
	Year 1	Years 0 to 80 (mean)
Long-lived greenhouse gases (CH_4 and CO_2)	8 ± 3	1.6 ± 0.8
Ozone	6 ± 4	0.1 ± 0.1
Black carbon deposition on snow	3 ± 3	0.0 ± 0.0
Black carbon deposition on sea ice	5 ± 4	0.1 ± 0.1
Aerosols (direct radiative forcing)	17 ± 30	0.2 ± 0.4
Changes in post-fire surface albedo	-5 ± 2	-4.2 ± 2.0
Total	34 ± 31	-2.3 ± 2.2

Randerson et al. 2006

Legacy carbon

- The “memory of the system” (Perry 1994)
- Establishes biogeochemical linkages between ecosystems in time
- Indicative of temporal trends in inputs and outputs
  - Historic conditions
  - Escape from disturbance
- Drives transient states in ecosystem response to change