Assessing Carbon Balance in Ecosystems of Alaska: the Role of Remote Sensing

Zhiliang Zhu[1], Bruce Wylie[2], and Tom Kurkowski[3]

[1]U.S. Geological Survey, Reston, VA, USA
[2]U.S. Geological Survey, Sioux Falls, SD, USA
[3]University of Alaska at Fairbanks, Fairbanks, AK, USA

U.S. Department of the Interior
U.S. Geological Survey

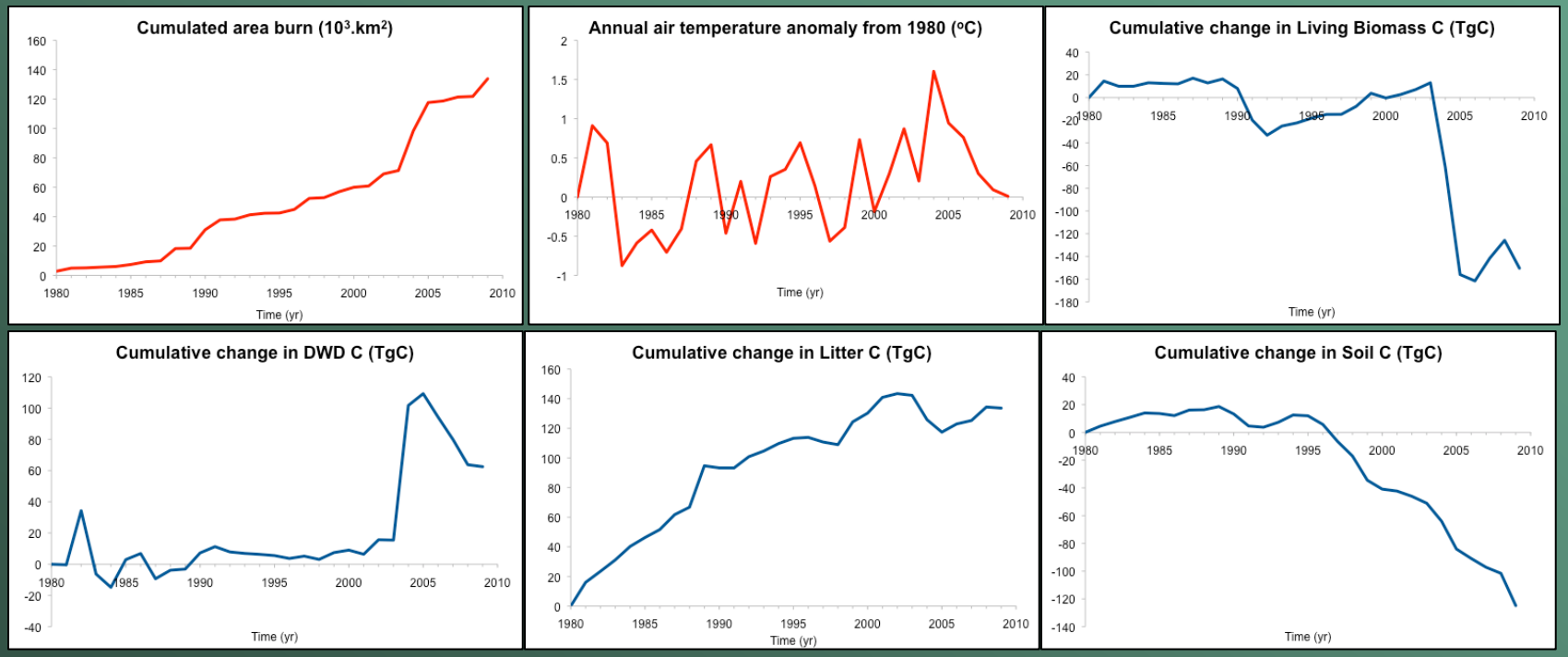
Background on the C assessment

- Much of Alaska boreal and arctic ecosystems have never been included in the U.S. national greenhouse gas inventory report submitted annually to UNFCC
- A lot of research is being conducted in Alaska focusing on the impact of climate change on the fate of carbon in aboveground and belowground pools
- A first-of-its kind comprehensive assessment should provide useful information for policy makers and the science community
- Work of the assessment is still ongoing, preliminary results are reported here

USGS

Cumulative changes in carbon stocks between 1980 and 2009

The increase in fire frequency in the early 2000's induced carbon loss from the living vegetation and soil stocks. This change induced the boreal forest in Alaska to transition from a C sink to a C source in 2005. (Materials from David McGuire)



USGS

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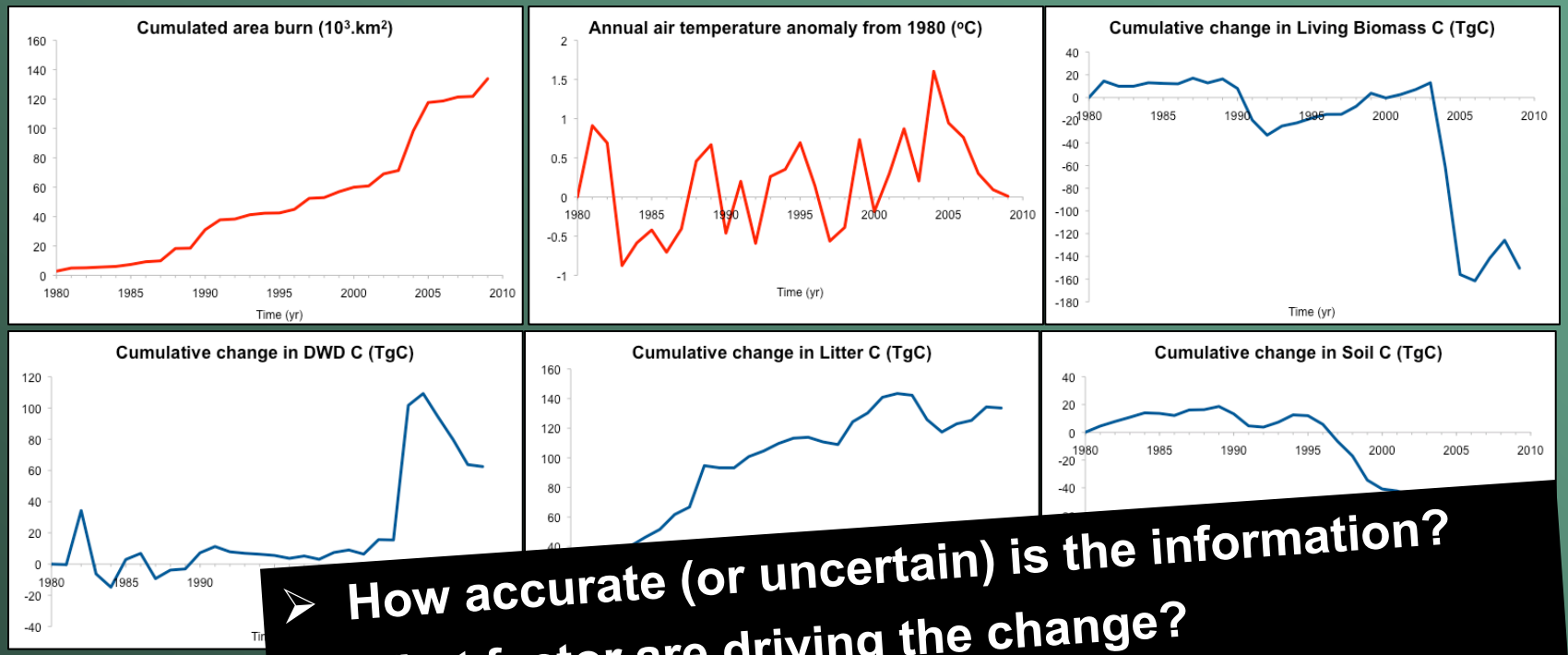
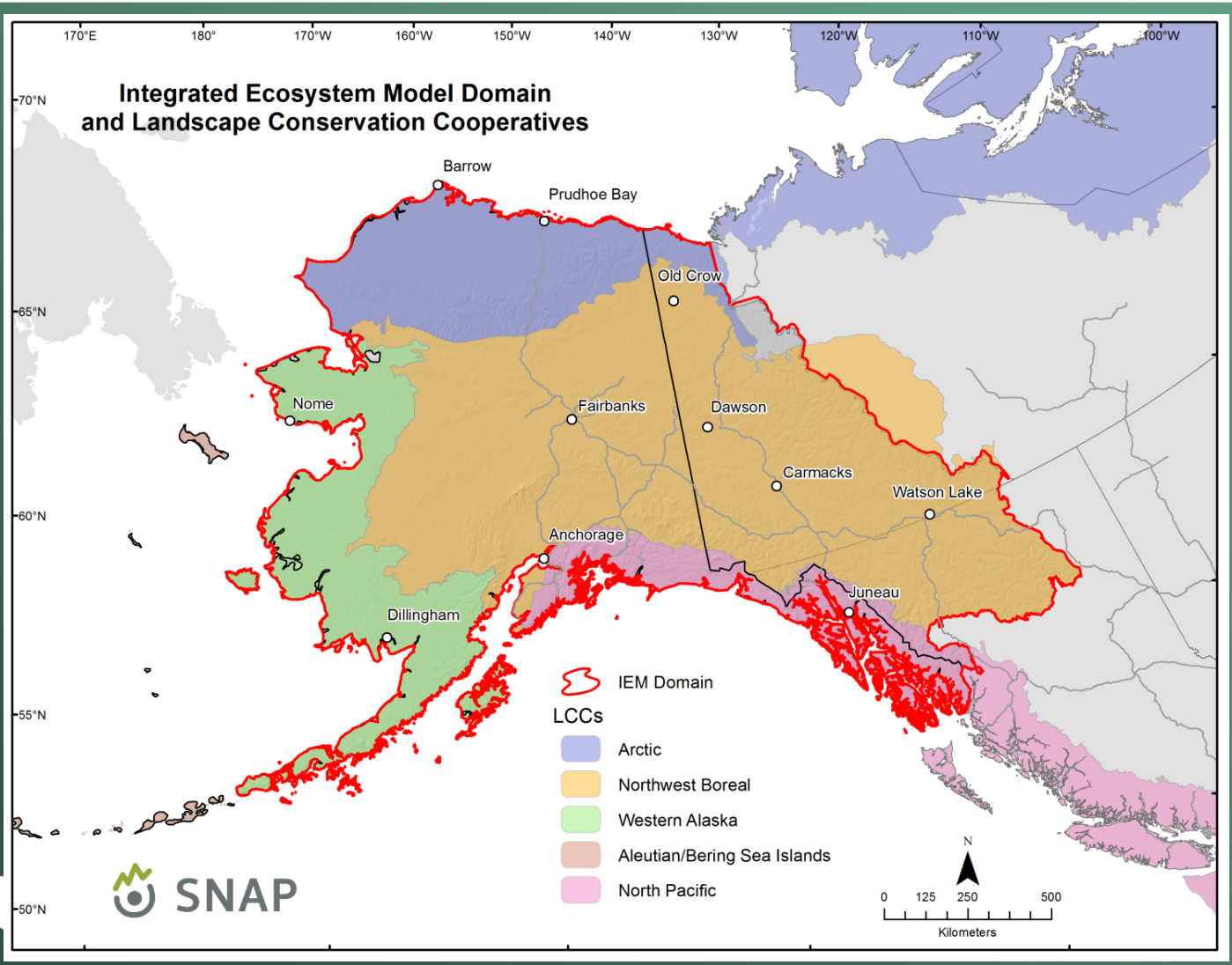


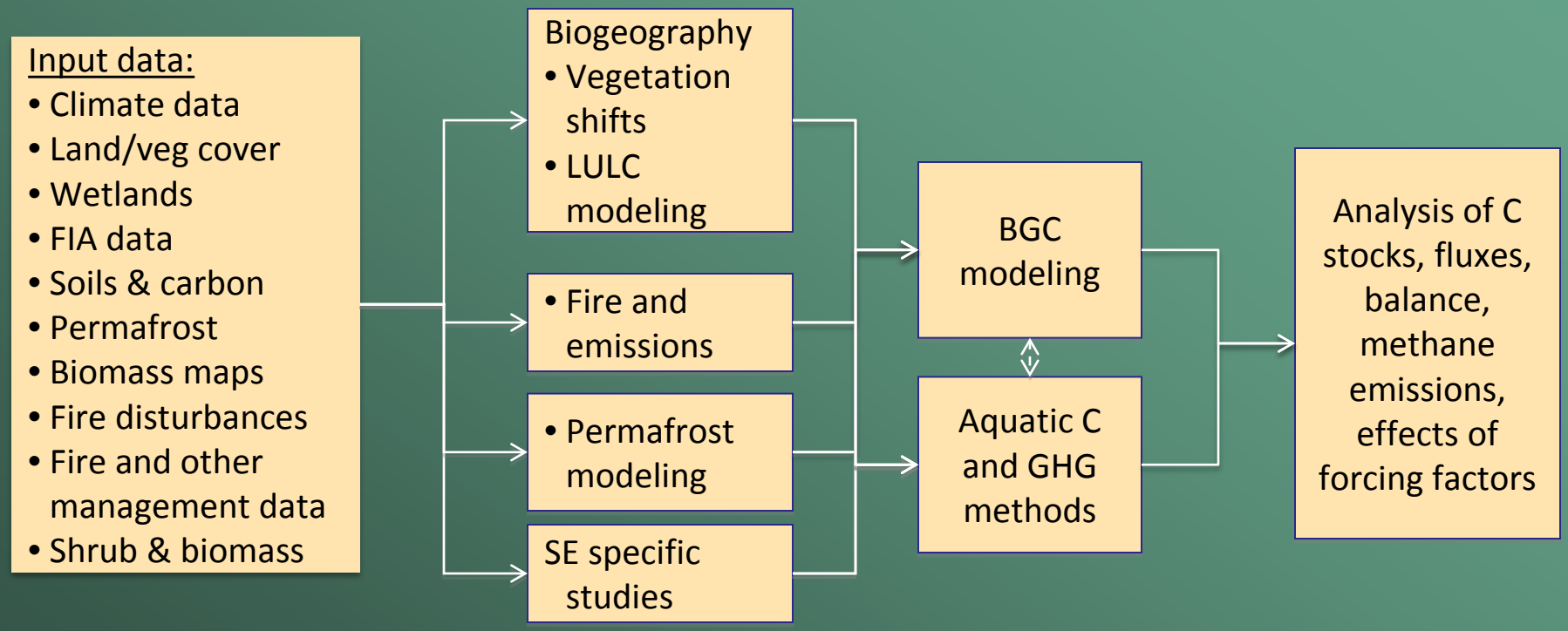
- How accurate (or uncertain) is the information?
- What factor are driving the change?
- Where is the trend going? Will the ecosystems remain a C source in future?

USGS

Spatial domain of the assessment: four geographic regions



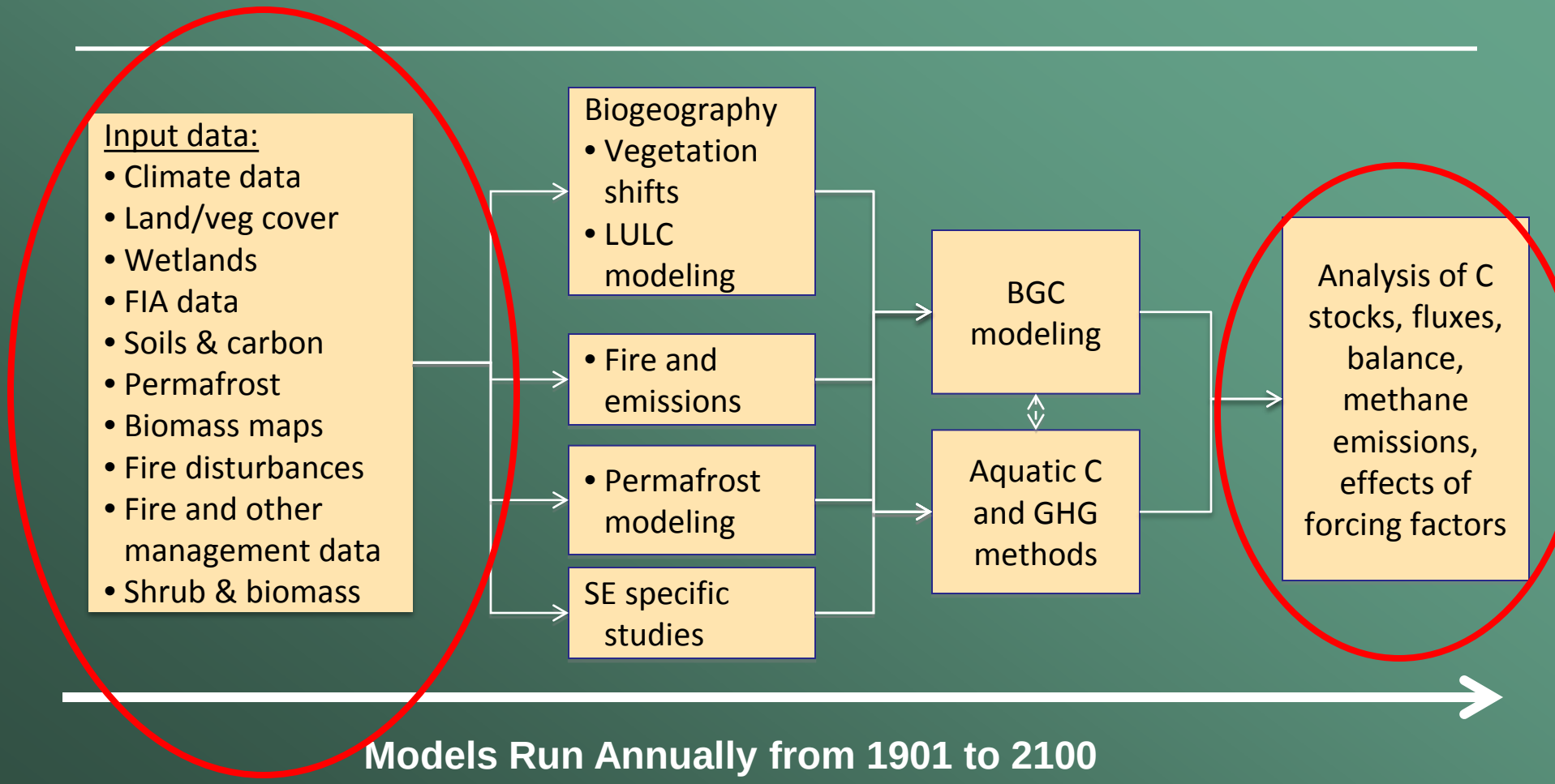
Scope and methods



Models Run Annually from 1901 to 2100

USGS

Scope and methods



Models Run Annually from 1901 to 2100

USGS

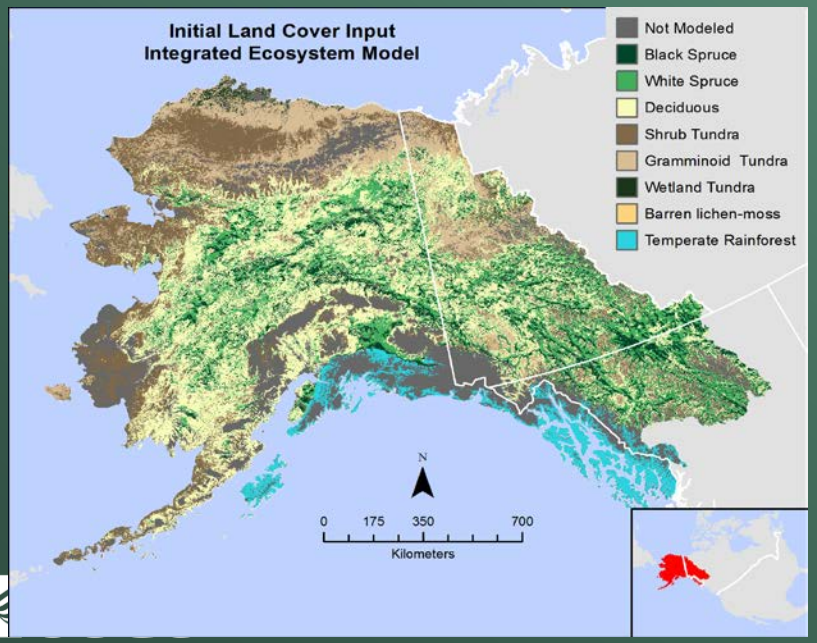
“Issues” for remote sensing

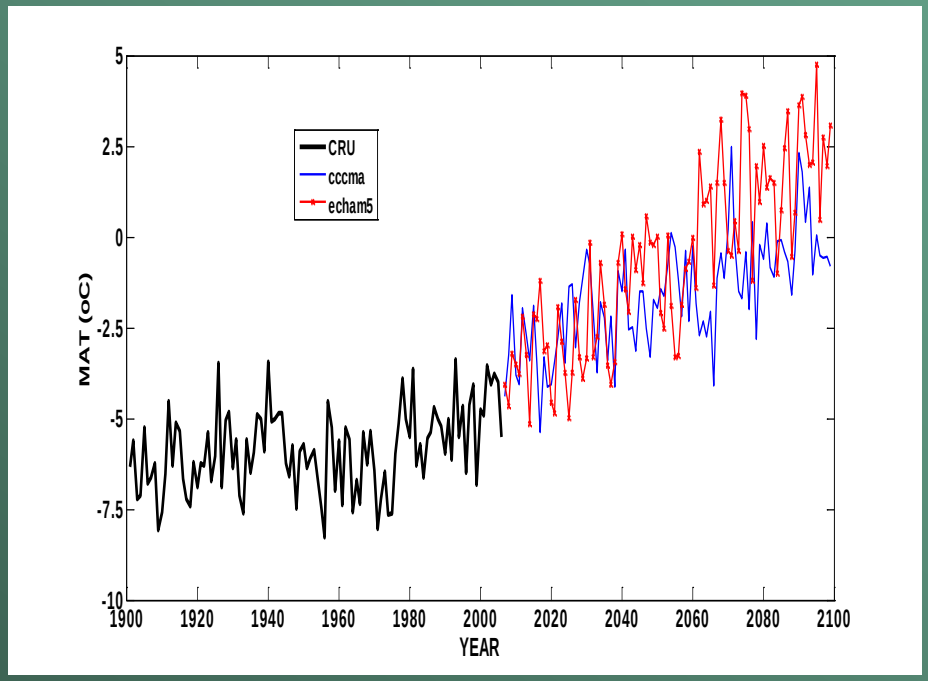
- Difficulty in separating water bodies and wetlands
- Different water and wetland types are not supported in existing data products
- Very high inter-annual and seasonal variability in where the water bodies and wetlands are distributed
- Conventional remote sensing not sensitive to distribution and change of permafrost and active layer depth
- Persistent cloud cover

USGS

Land and water basis of the assessment and climate forcing

- Historic/present land and vegetation cover from improved legacy data products
- Projected future land/vegetation cover modeled using Alaska-specific climate GCM





Impact of wetland mapping on GHG estimation

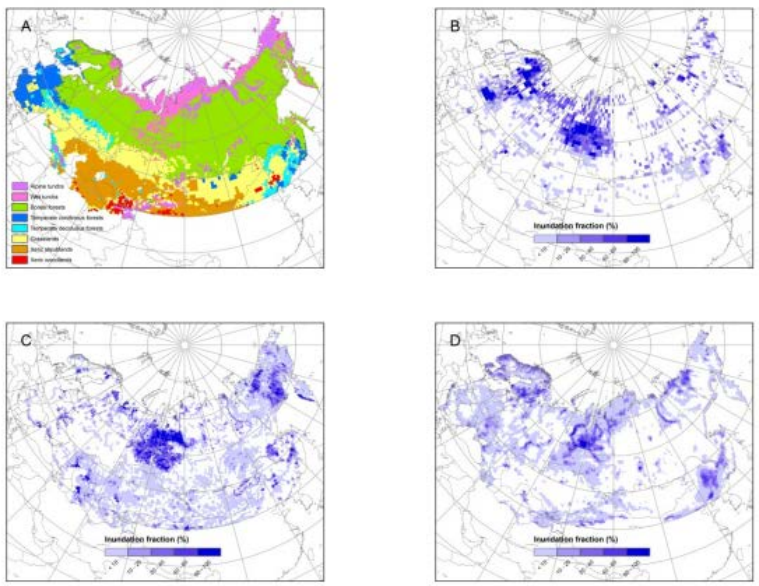
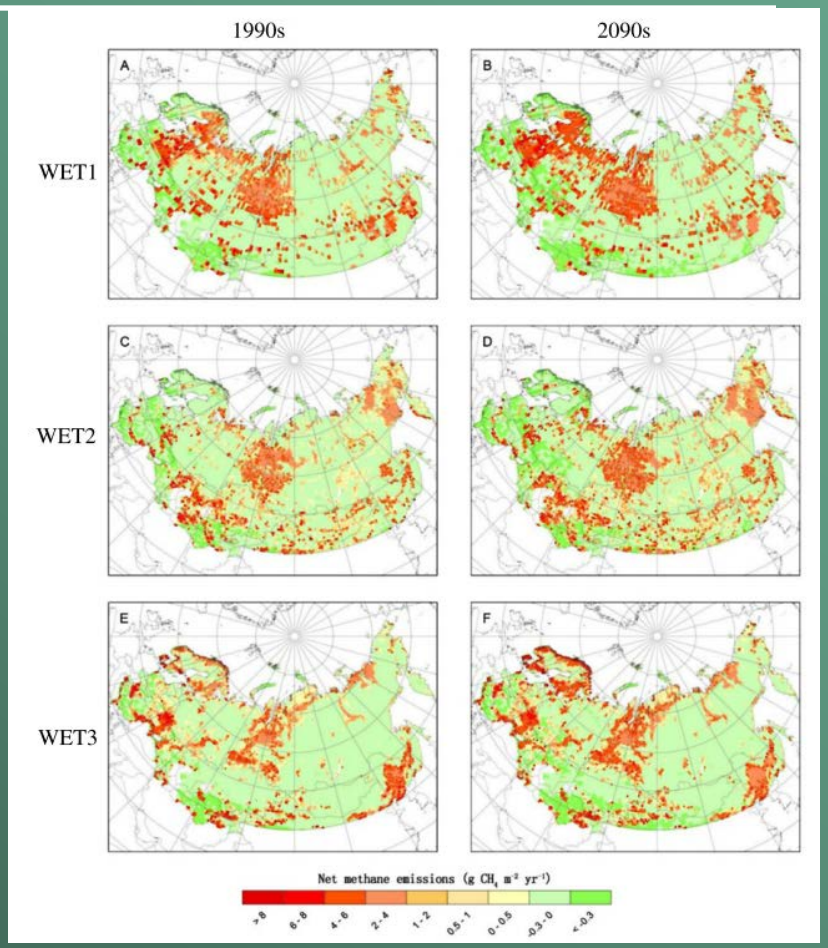


Figure S3. Spatial distribution of vegetation types (A) and wetland extent maps derived from three datasets: (B) WET1 (Matthews and Fung 1987); (C) WET2 (Lehner and Döll 2004); (D) WET3 (Papa *et al.* 2010).



From: Zhu et al 2010 ERL

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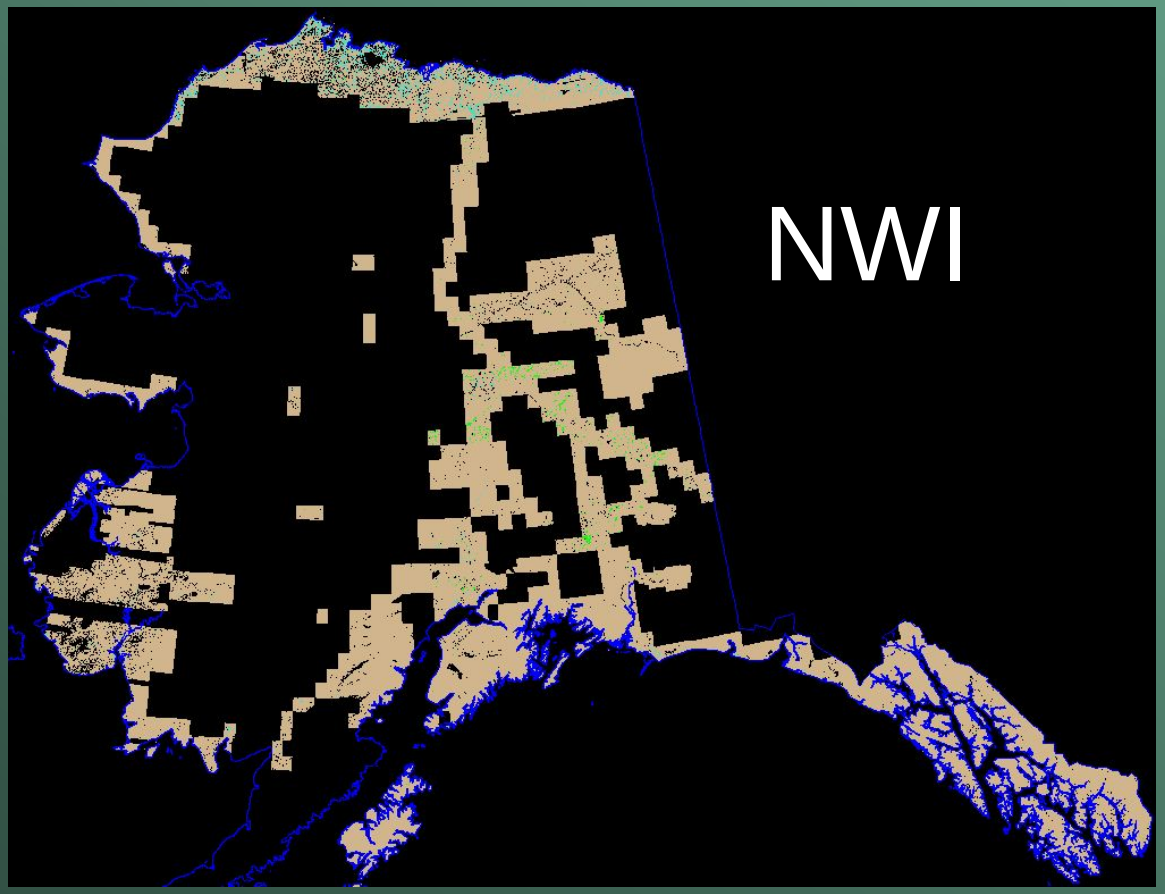
Area determination has the single most impact on the size and uncertainty of estimating GHG emissions

Wetland types not represented in available data products

- Available global data products (NWI, China data, USGS data, etc.) either are incomplete or do not differentiate bog vs fen wetland types, which have very different C and CH4 cycle characteristics
  - Bog: woody wetland where water inputs are only from precipitation and no lateral flows, usually acidic.
  - Fen: herbaceous wetland where water input are primarily from lateral water flow, usually basic.

Bog vs fen at Bonanza Creek LTER

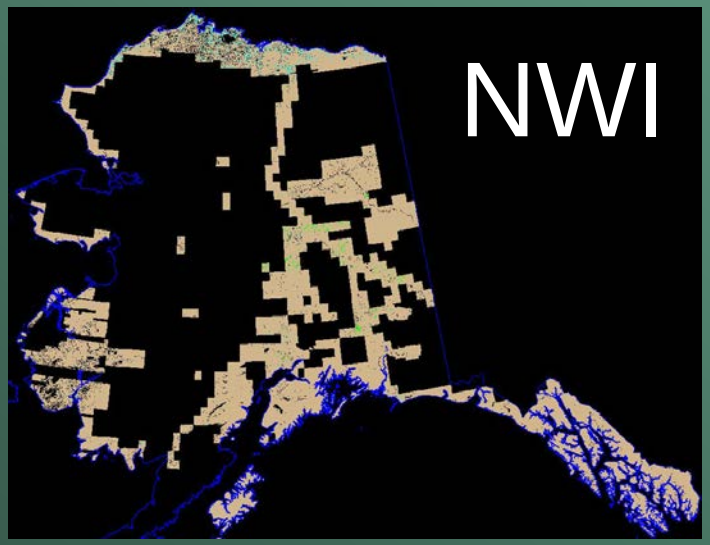
For example: NWI data



- Bog
- Fen
- Other
- Not mapped
- State boundary

USGS

Using a traditional mapping effort



Bog

Fen

Other

Not mapped

State boundary

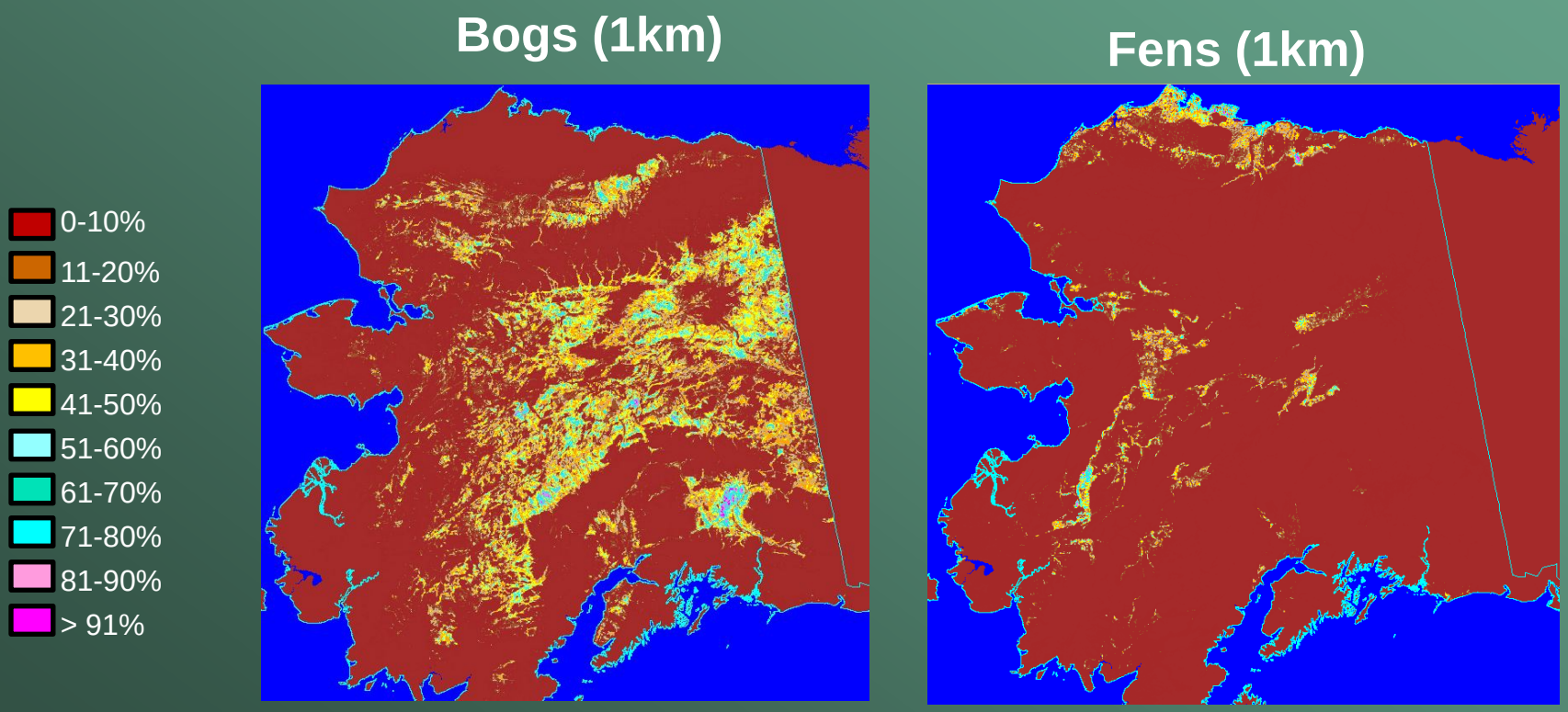
USGS

Regression tree mapping

100%	weld7	68%	VI3
100%	DEM	57%	VI6
97%	Slp_deg	53%	VI8
95%	weld3	49%	weld6
91%	weld4	47%	China2000
87%	NLCD	47%	cti
85%	VI2	47%	VI7
80%	b4b5b6	32%	weld1
71%	weld2	32%	whitcomb
71%	TorreStex		

		Mapped as				
		woody	emerg	non	sum	%
Reference (NWI)	woody	52	3	64	119	43.7%
	emerg	7	188	124	319	58.9%
	non	42	18	532	592	89.9%
	sum	101	209	720	1030	
	%	51.5%	90.0%	73.9%		75.0%

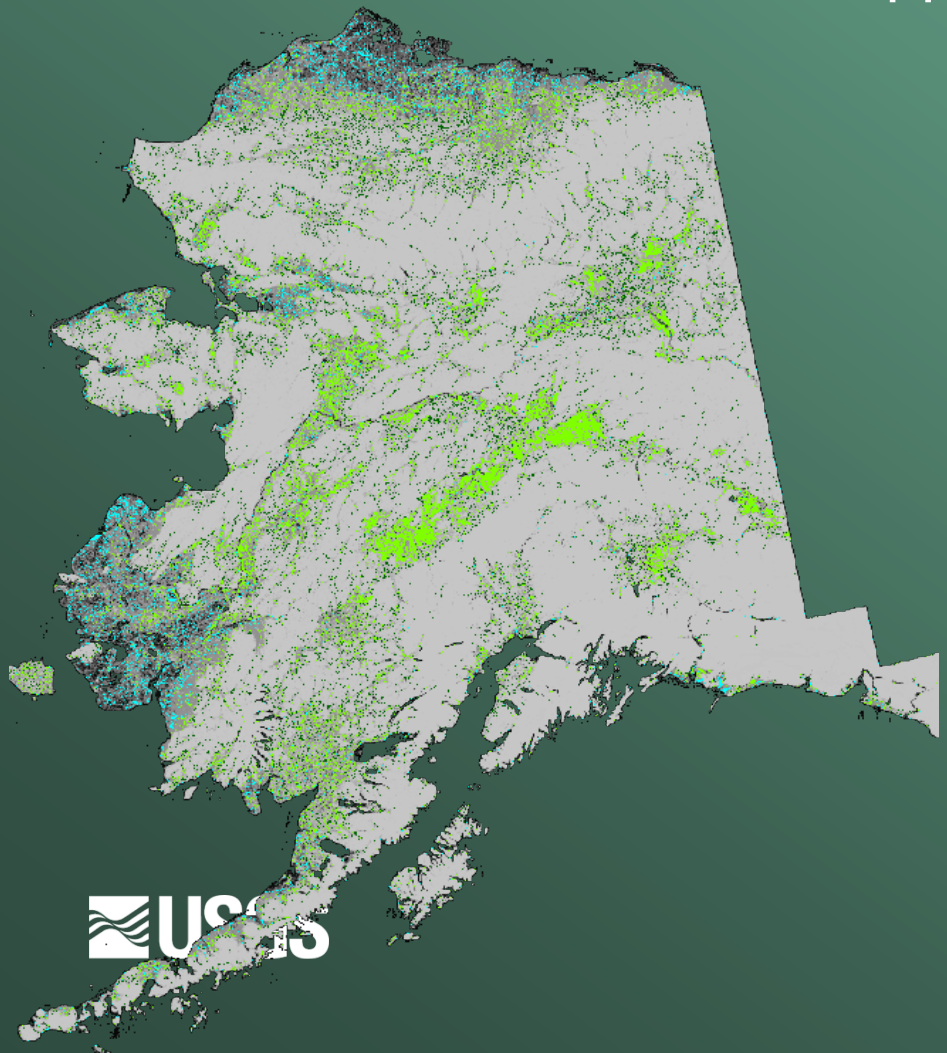
Percent of area within km² that was mapped as either fen or bog



USGS

Bog and fen comparisons

Whitcomb et al 2009 SAR mapping



Wylie et al this study

Alaska water bodies

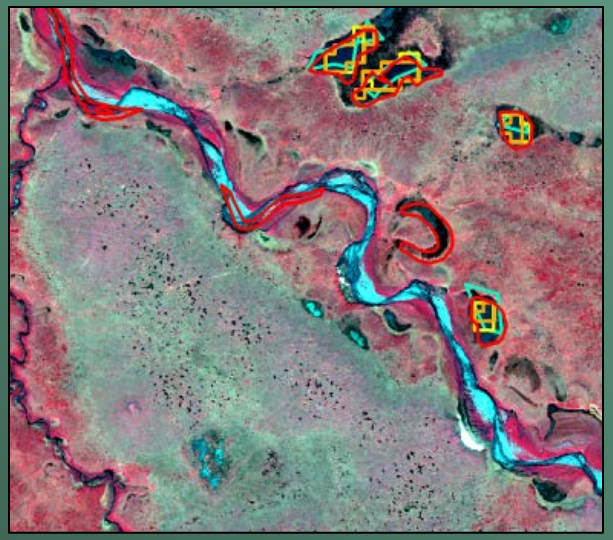
- Evaluated available data products:
  - National Hydrography Dataset
  - NLCD
  - Recent Landsat based product (Chinese State Mapping Bureau)
    - Circa 2000
    - Circa 2010
- Compared the data with high resolution data (~2 m pixel)

Materials from J. Rover and B Wylie

USGS

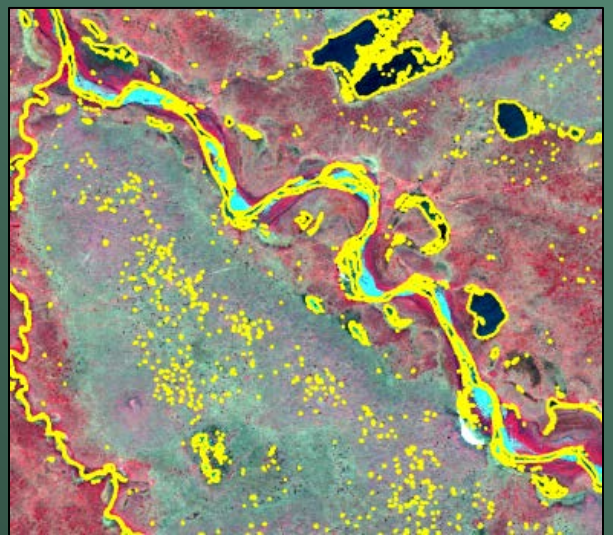
Conducted a comparison study using five study areas

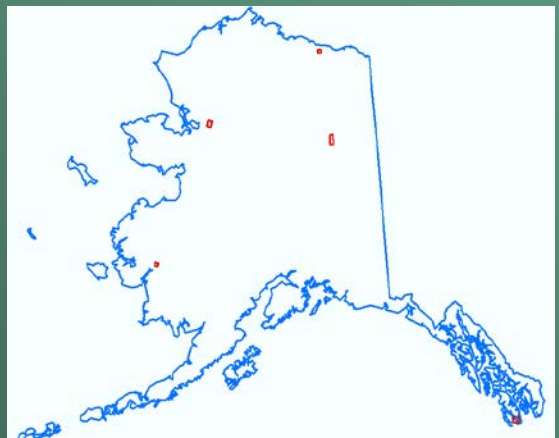
Mapped water bodies



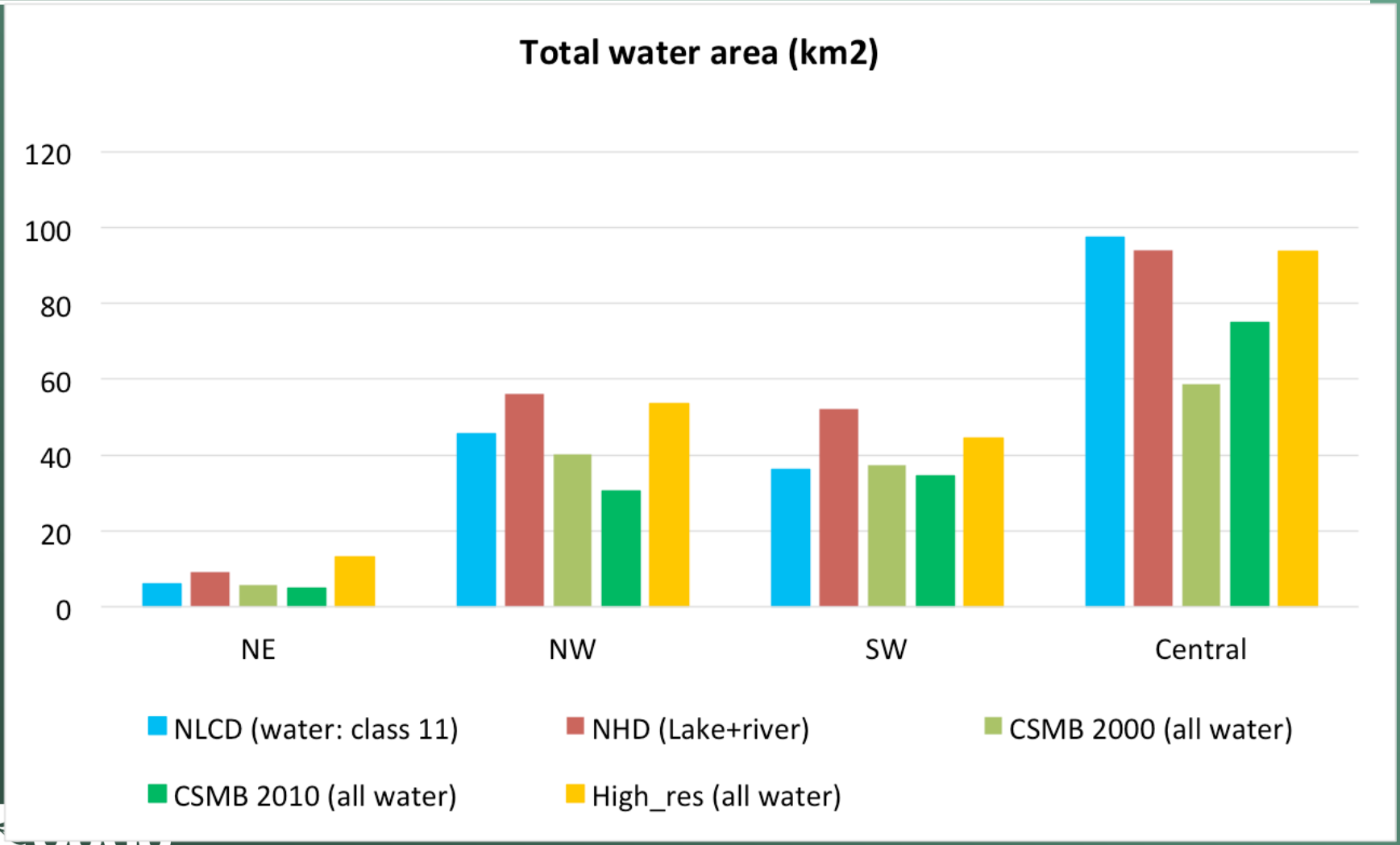
- NHD Lakes and Ponds
- NHD Rivers/Streams
- CSMB 2010
- CSMB 2000
- NLCD

Comparison with high resolution (Geoeye) water extents





Total water area (km^2) by study site



Permafrost, active layer depth, and soil organic layer

Ongoing work by Neal Pastic, Bruce Wylie, and others (e.g. Geodarma 2014)

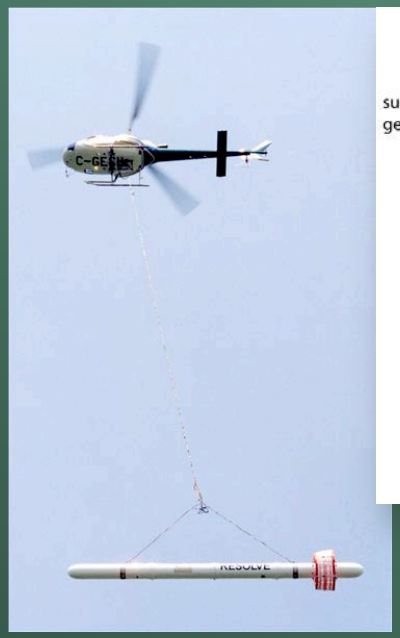
$$S_{c \text{ or } a} = f(s, c, o, r, p, a, n).$$

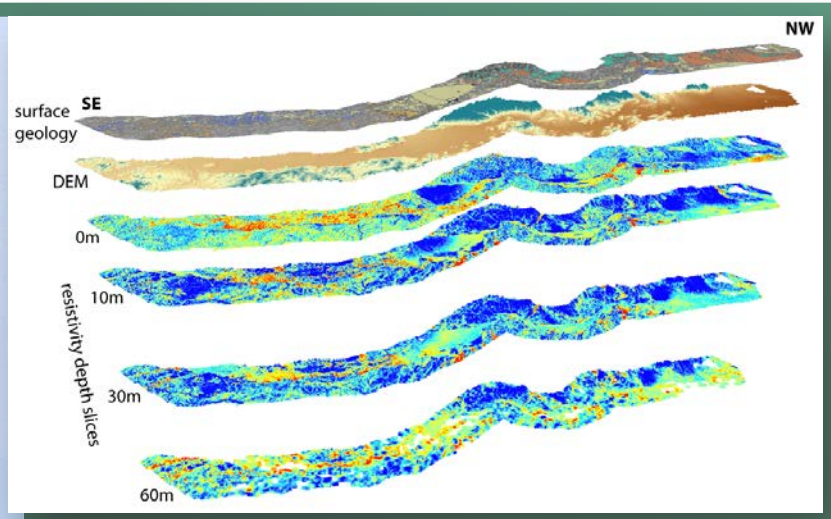
S_c or S_a = soil classes or soil attributes
s: soil, other properties of the soil at a point;
c: climate, climatic properties of the environment at a point;
o: organisms, vegetation or fauna or human activity;
r: topography, landscape attributes;
p: parent material, lithology;
a: age, the time factor;
n: space, spatial position.

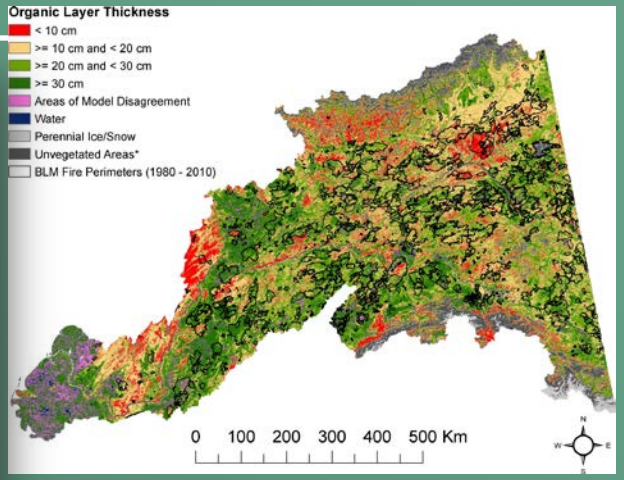
McBratney *et al*., 2003

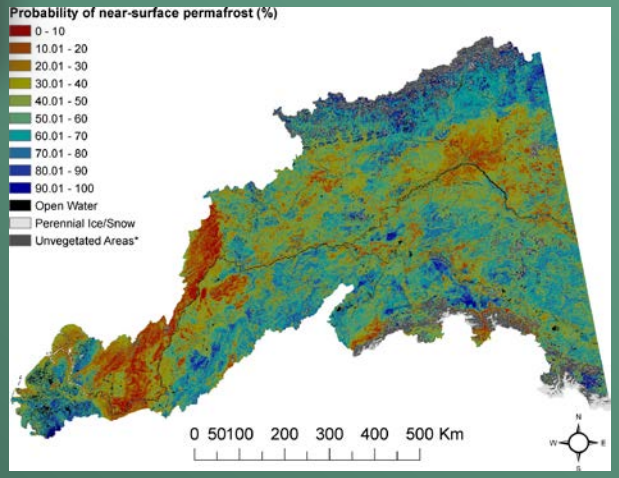
USGS

EM resistivity mapping with optical remote sensing







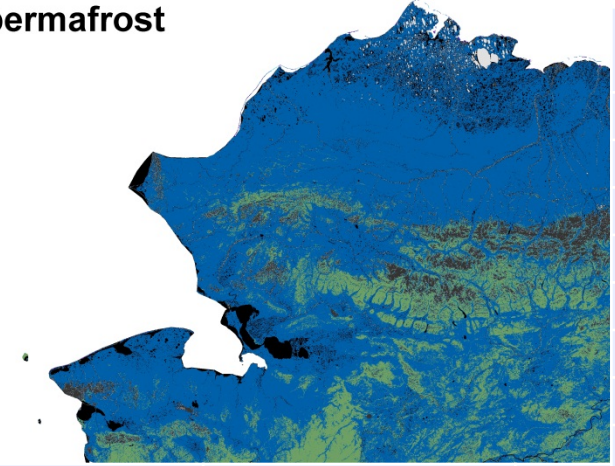


USGS is actively producing up to date and fine resolution permafrost maps by combining EM resistivity probing with conventional optical (Landsat) remote sensing

USGS

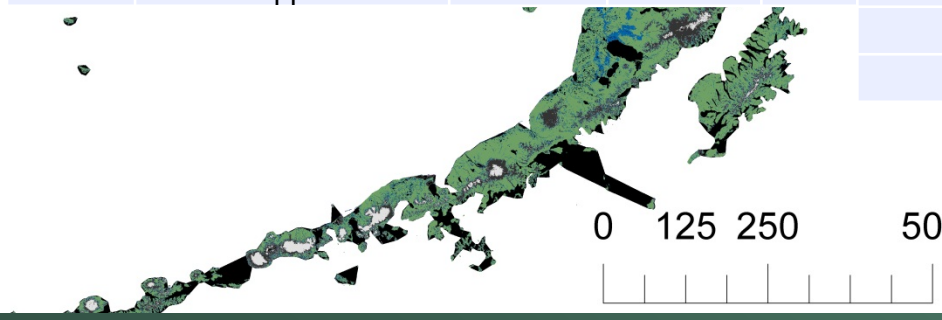
Near-surface (within 1 m) permafrost

- Absent
- Present
- Open Water
- Perennial Ice/Snow
- Unvegetated Areas*



10-fold cross validation accuracy		Field Data		
		Absent	Present	Row T
Mapped	Absent	11234	1248	1248
	Present	1230	3074	430
	Column Total	12464	4322	-
	Producer's Accuracy	90%	71%	-
	Overall Accuracy	-	-	-
	95% Confidence Interval	(89.6 , 90.7)	(69.8 , 72.5)	-
	Overall Kappa	-	-	-

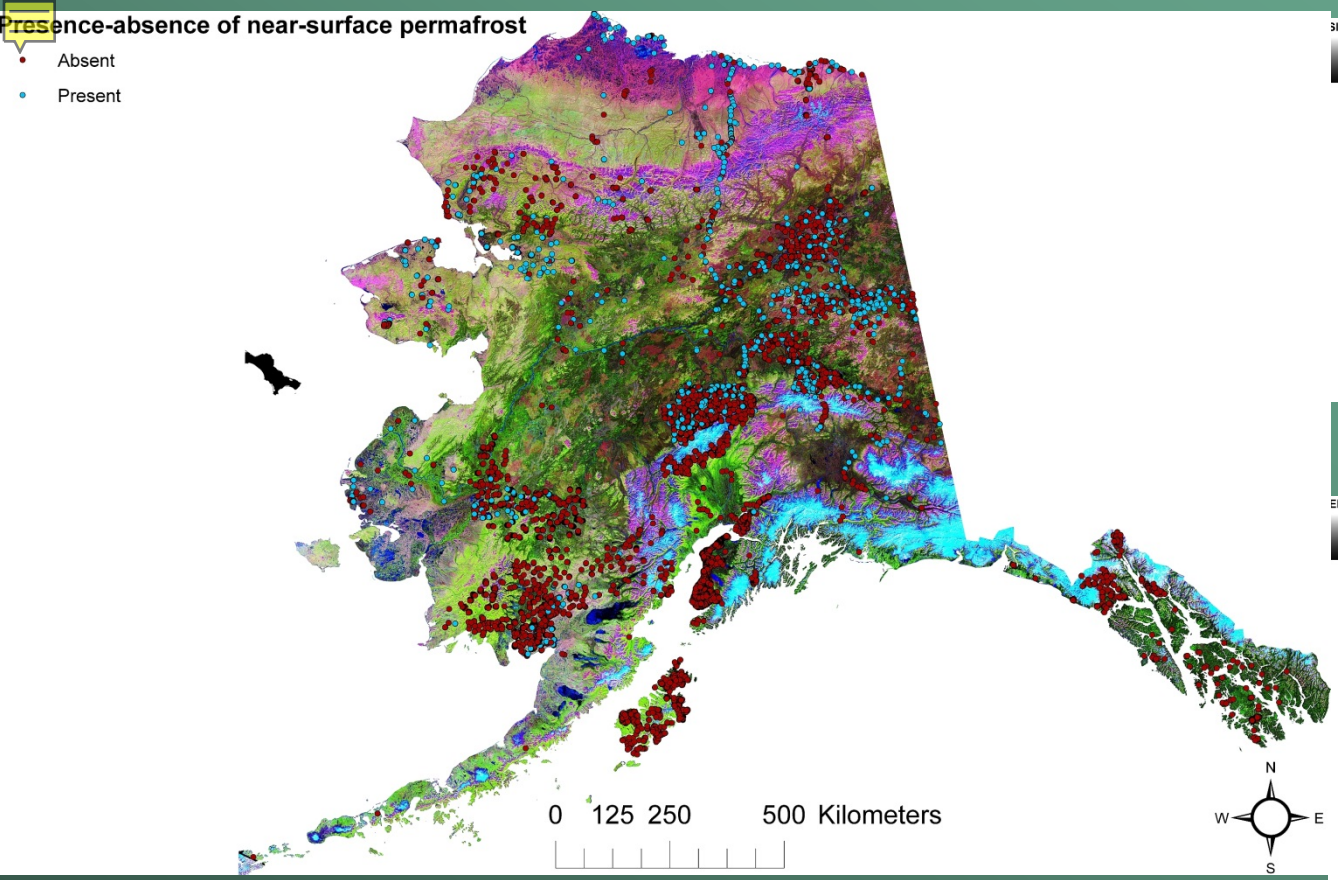
Environmental Predictors	Usage (%)
Mean Air Temperature	100
Date of Thaw	100
Landsat 7 ETM + Band 4	100
Mean Annual Precipitation	98
Mean Winter Precipitation	98
NDII7	80
Date of Freeze	73
NDII	70
Length of Growing Season	69
Coefficient of Variation (Landsat Bands 3,4,5)	68
Land Cover	67
Compound Topographic Index	65
Elevation	54
NDVI	54
Landsat 7 ETM + Band 1	63
NDWI	63
Landsat 7 ETM + Band 7	54
gNDVI	47
Aspect	36

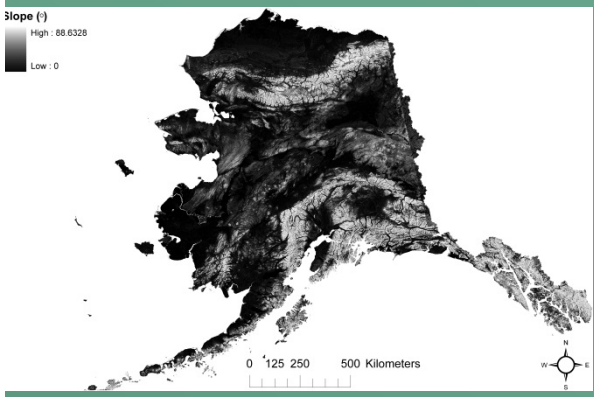


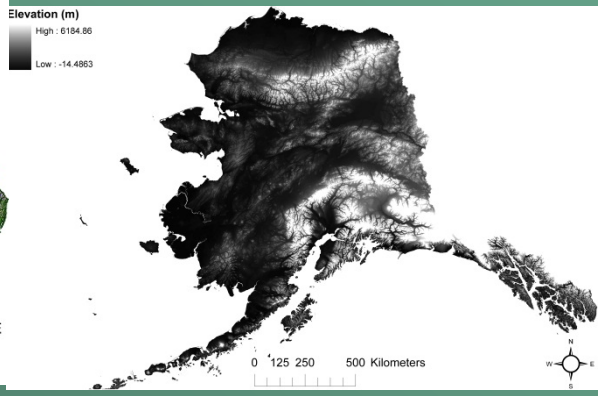
0 125 250 500 Kilometers

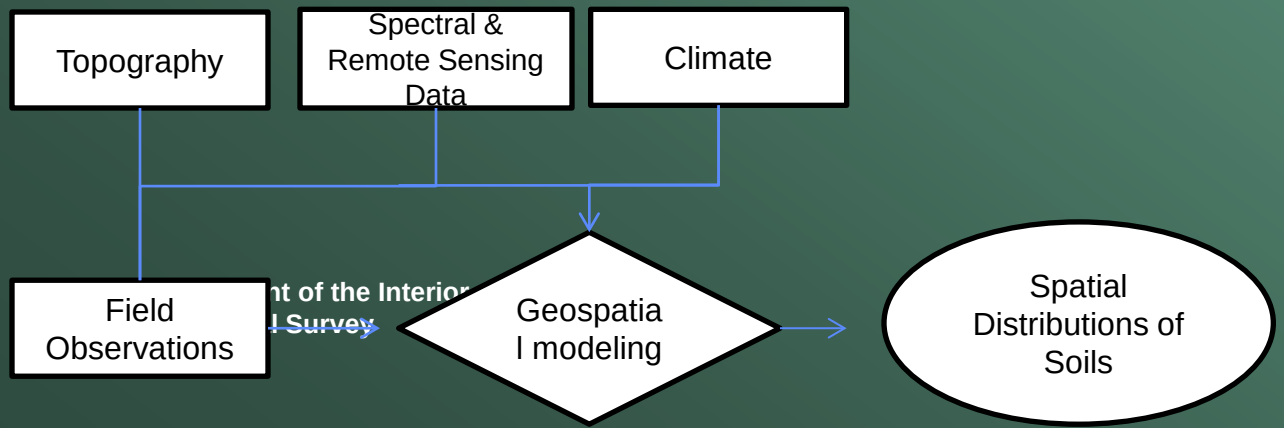
N
W E
S

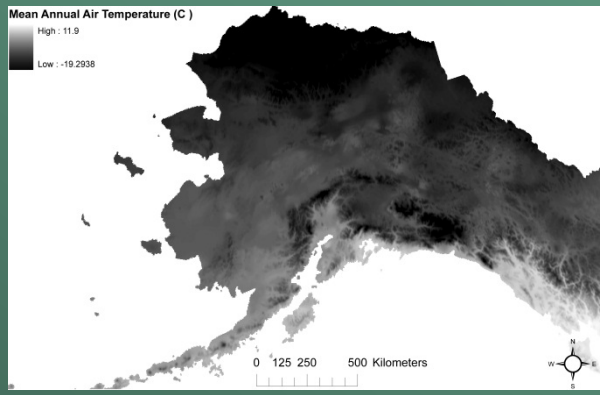
USGS

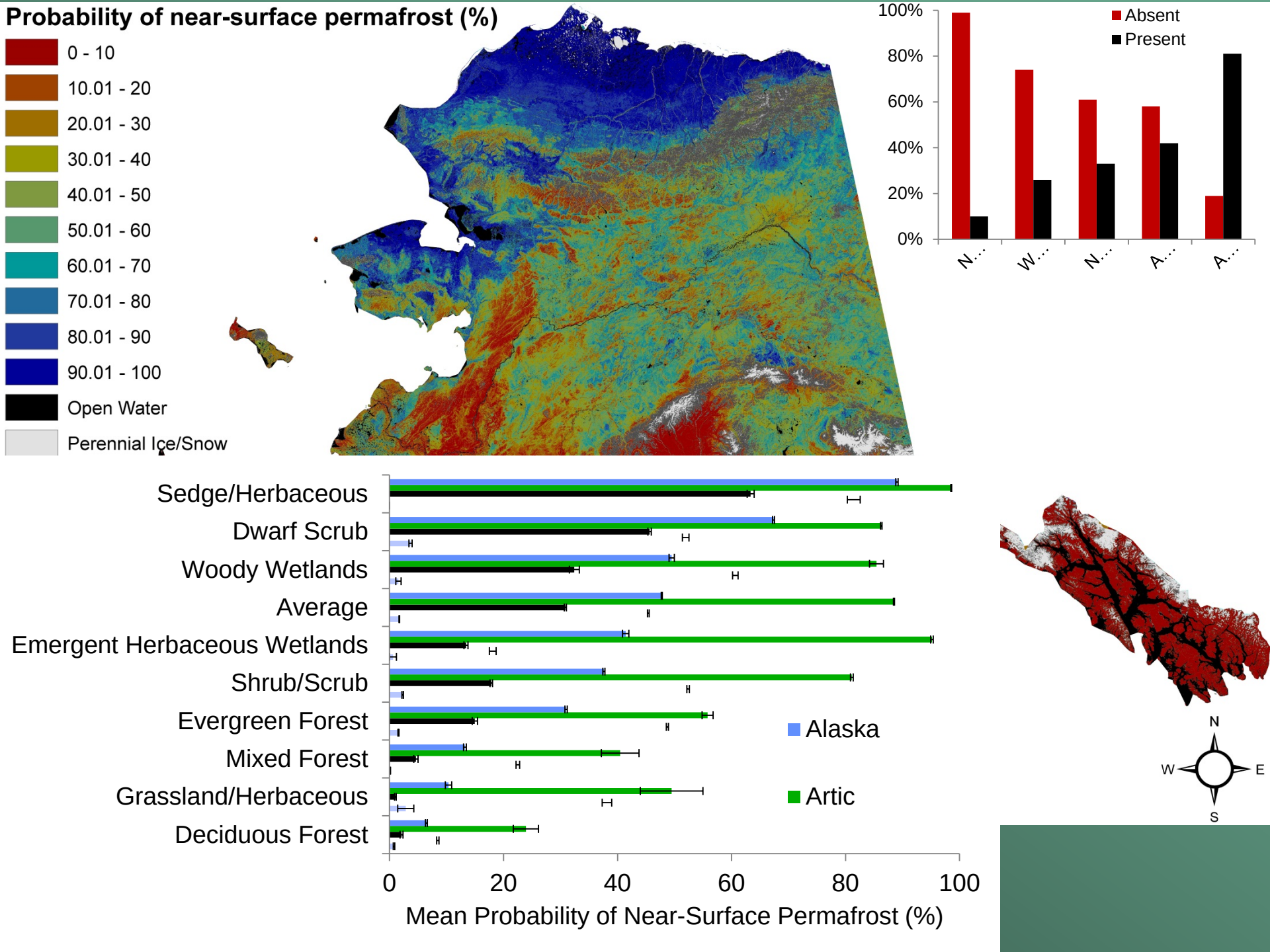

Presence-absence of near-surface permafrost
Absent
Present
0 125 250 500 Kilometers
N
W
E
S

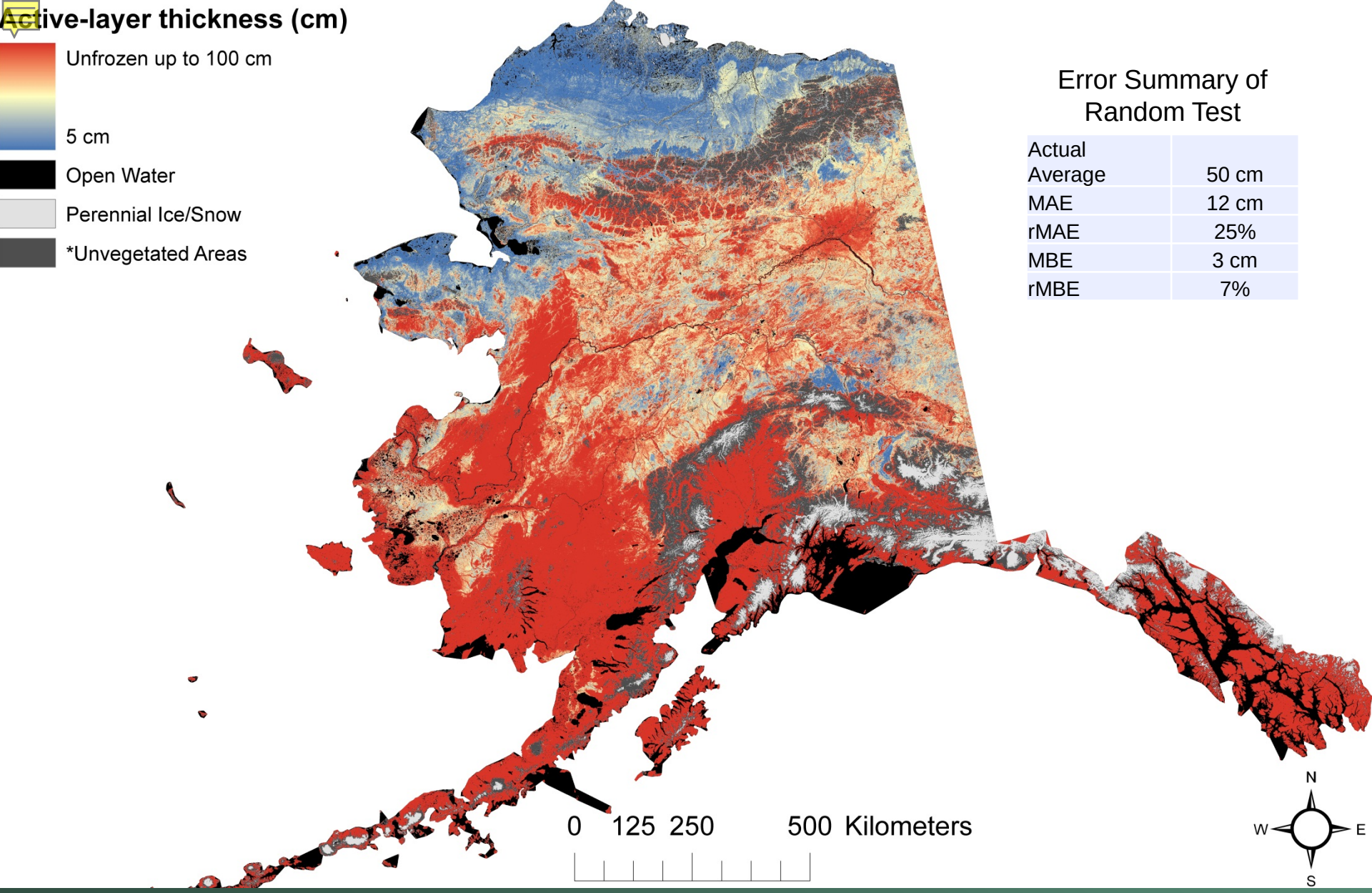

Slope (°)
High : 88.6328
Low : 0
0 125 250 500 Kilometers


Elevation (m)
High : 6184.86
Low : -14.4863
0 125 250 500 Kilometers


Topography
Spectral & Remote Sensing Data
Climate
Field Observations
Geospatial modeling
Spatial Distributions of Soils


Mean Annual Air Temperature (C)
High : 11.9
Low : -19.2938
0 125 250 500 Kilometers


Probability of near-surface permafrost (%)
0 - 10
10.01 - 20
20.01 - 30
30.01 - 40
40.01 - 50
50.01 - 60
60.01 - 70
70.01 - 80
80.01 - 90
90.01 - 100
Open Water
Perennial Ice/Snow
100%
80%
60%
40%
20%
0%
Absent
Present
N...
W...
N...
A...
A...
Sedge/Herbaceous
Dwarf Scrub
Woody Wetlands
Average
Emergent Herbaceous Wetlands
Shrub/Scrub
Evergreen Forest
Mixed Forest
Grassland/Herbaceous
Deciduous Forest
Alaska
Artic
0
20
40
60
80
100
Mean Probability of Near-Surface Permafrost (%)
N
W
E
S

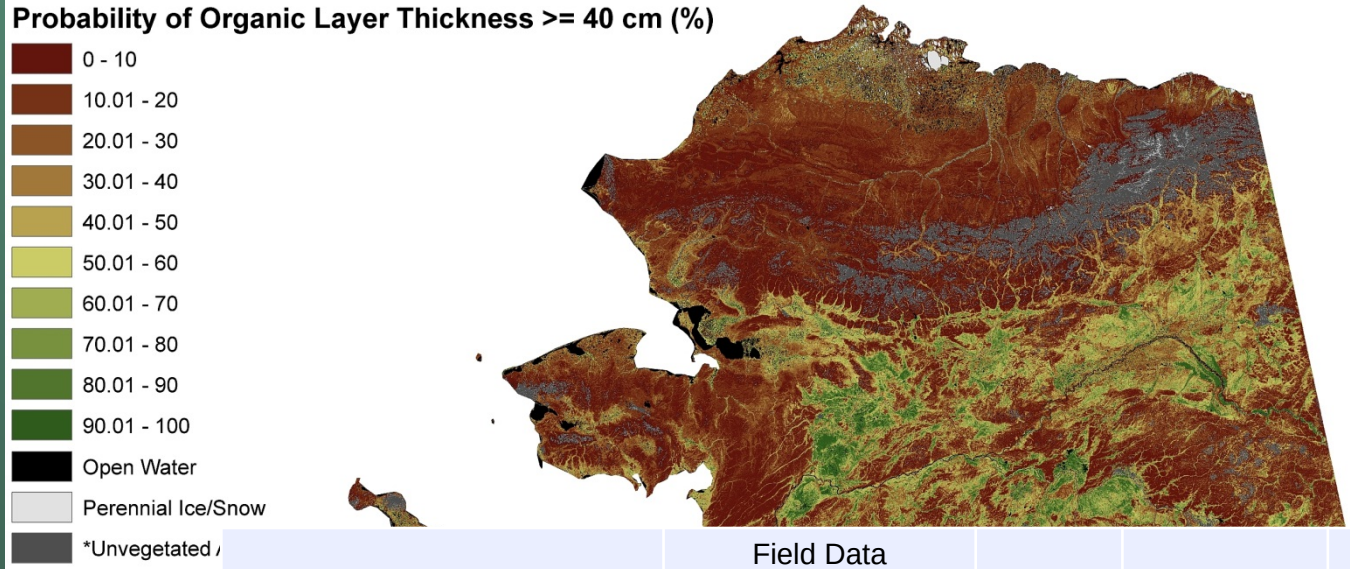


Error Summary of Random Test

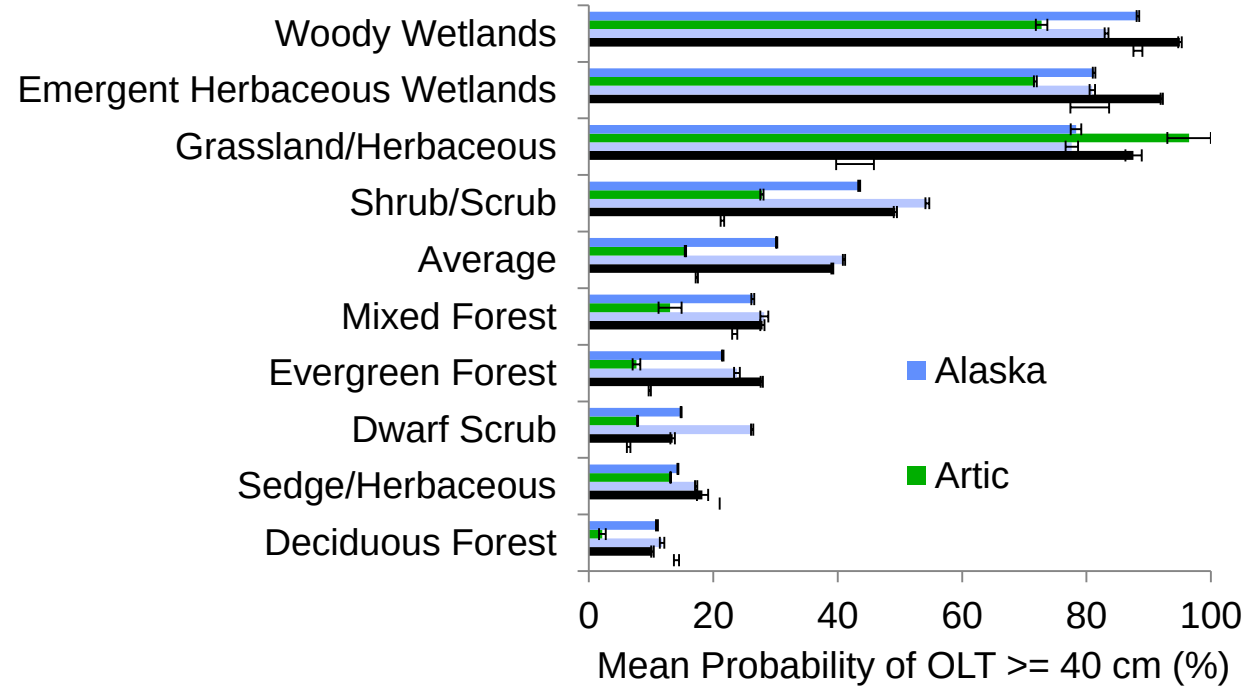
Actual Average	50 cm
MAE	12 cm
rMAE	25%
MBE	3 cm
rMBE	7%

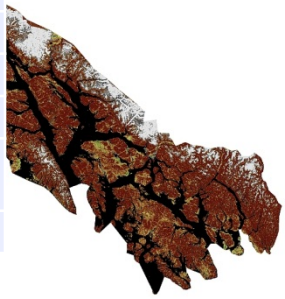
USGS

Pastick et al., in-prep



10-fold cross validation accuracy	Field Data				95% Confidence Interval
	No	Yes	Row Total	User's Accuracy	
ed					(69 , 74.2)
					(70 , 75.4)
					-
					-
					-
					(70.3 , 74)
					0.44





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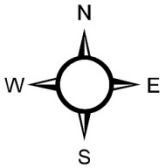
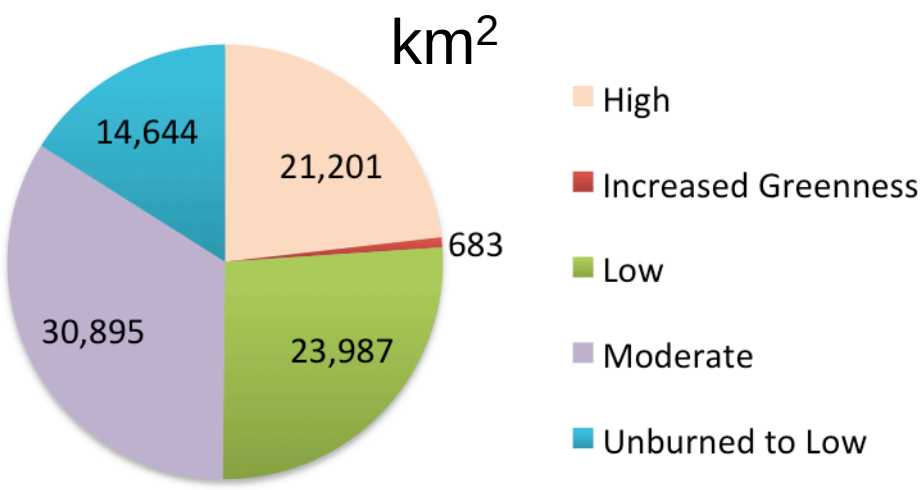
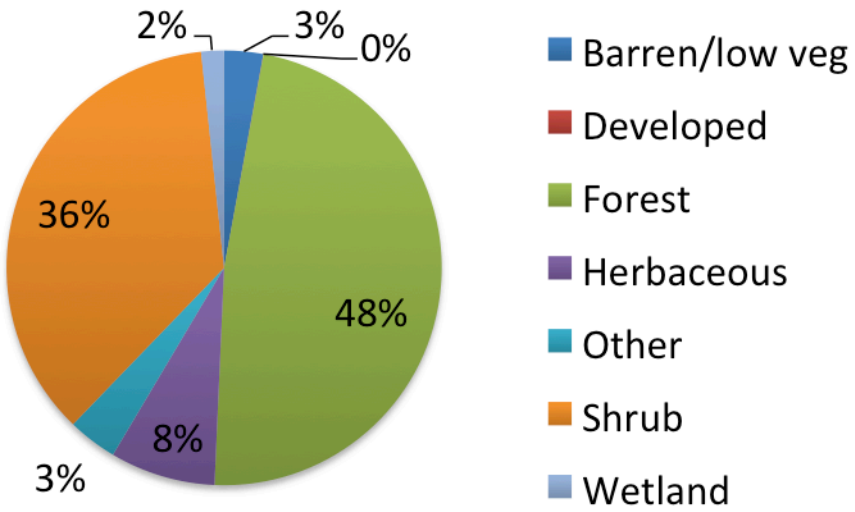


Wildfire mapping in AK

- Produced by the Monitoring Trends in Burn Severity (MTBS) Program
- Used the traditional dNBR method (difference of normalized burn ratio): **NBR = (near IR – mid IR) / (near IR + mid IR)**
- Between 1984 to 2012, approximately 26 M acres (~ 105,000 km^2) were burned and mapped in Alaska

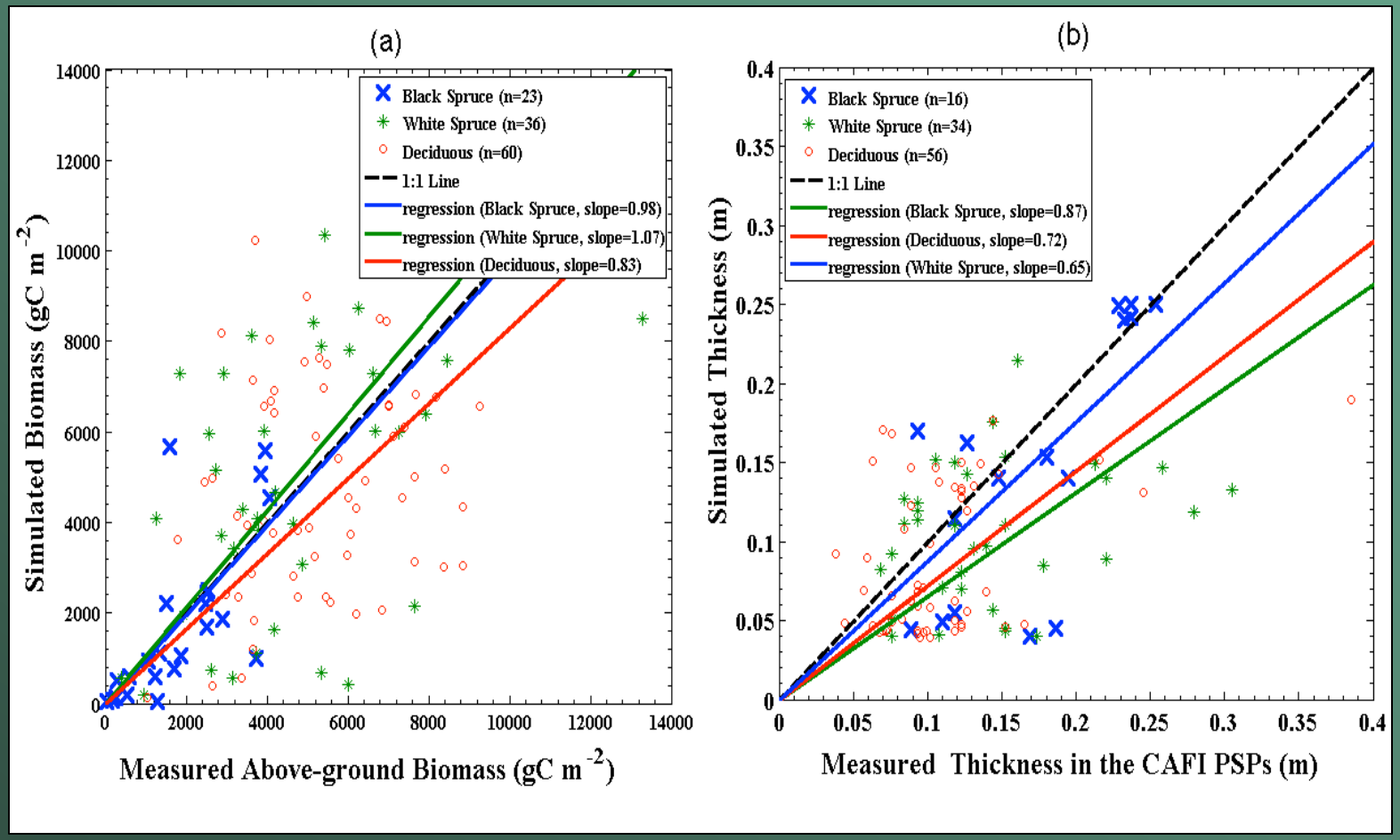




Preliminary assessment results and future directions

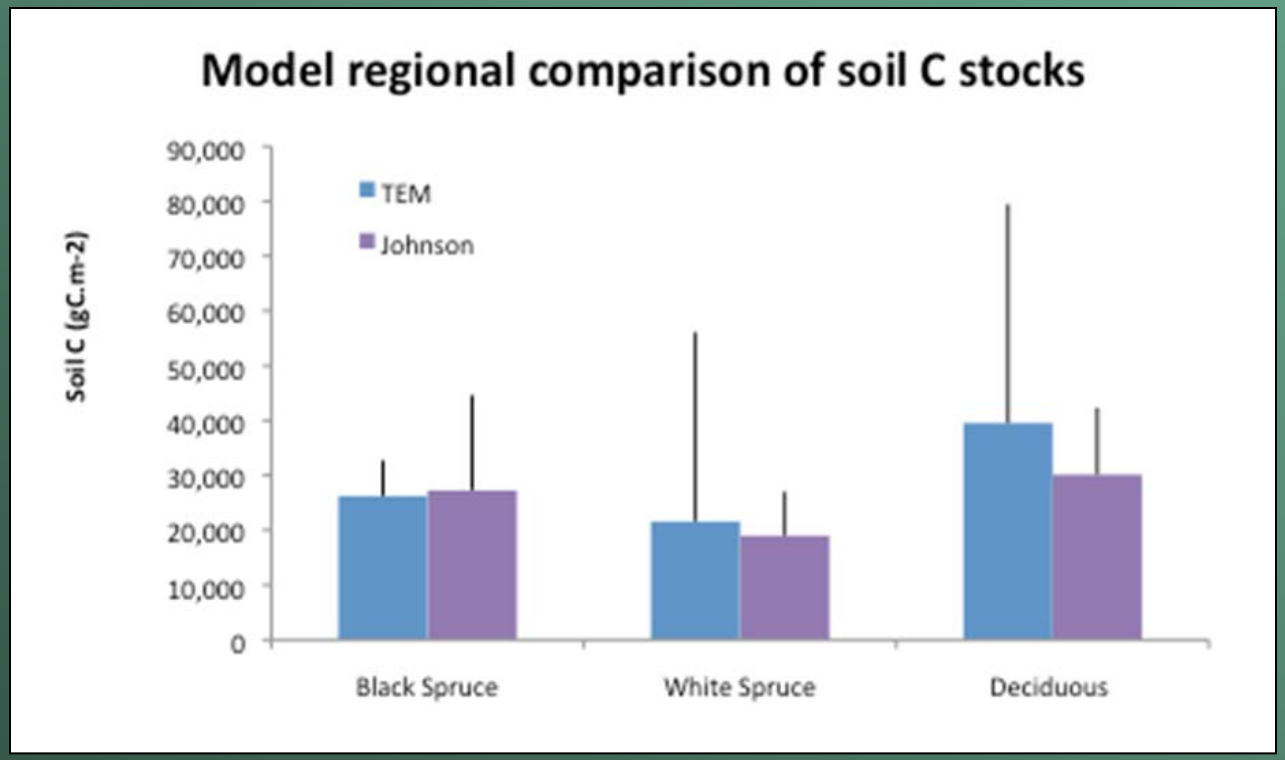
USGS

Biomass and Organic Horizon Thickness

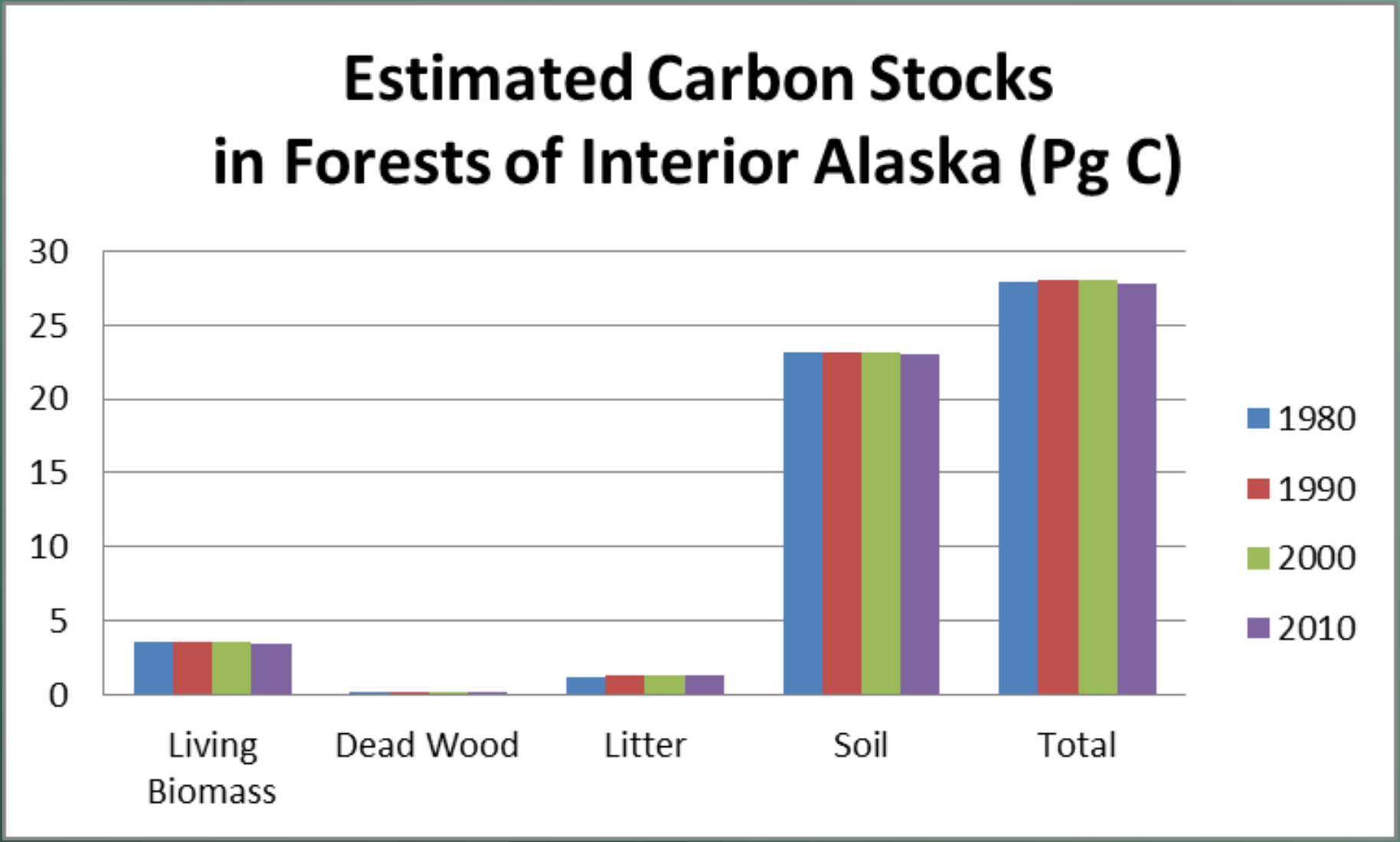


From Yuan et al. (2012, Ecological Applications)

Soil Organic Carbon Estimates

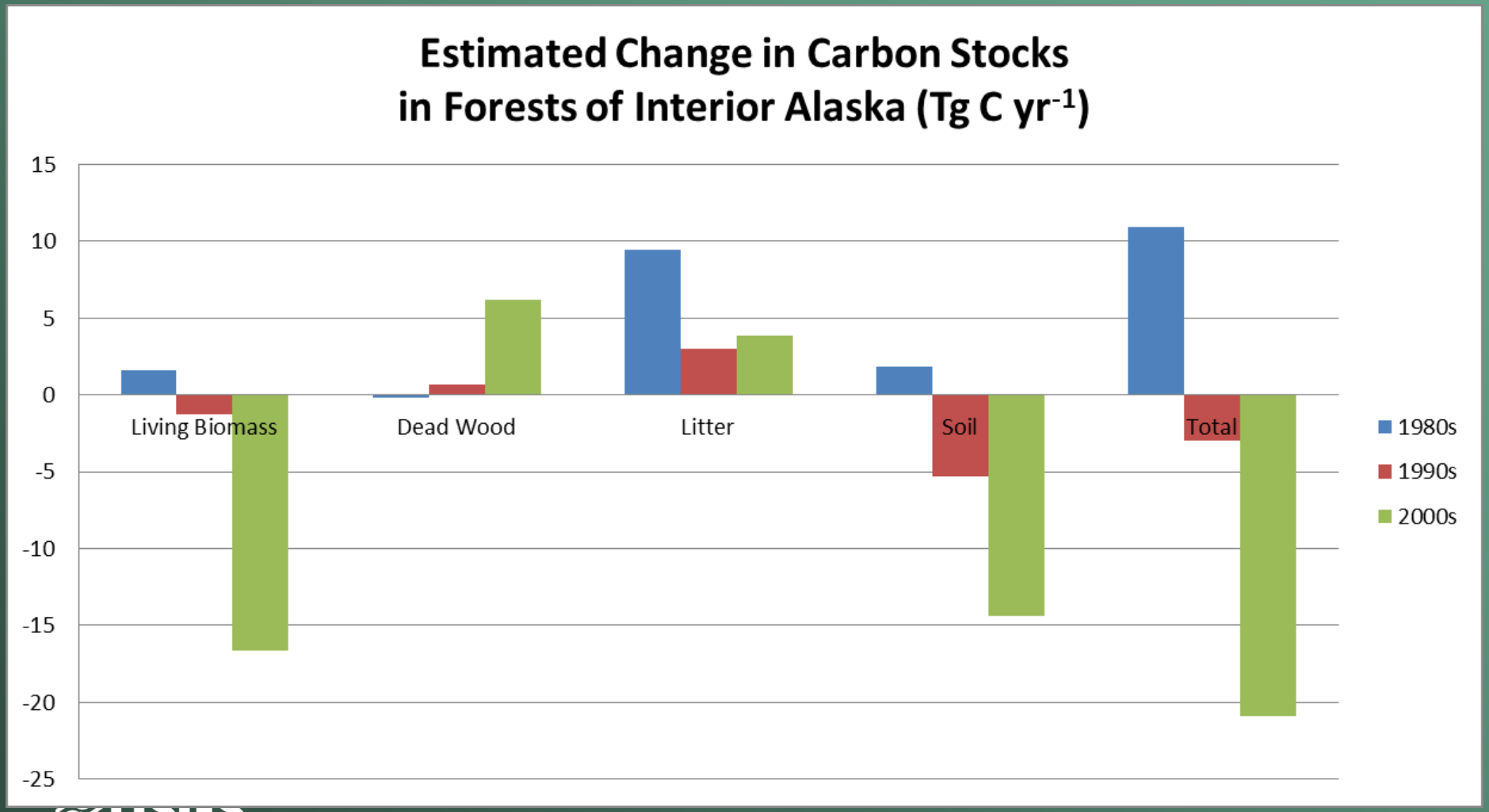


TEM estimated soil C stocks (blue bars) compared with estimates from an empirical model of soil C stocks based on 747 samples collected in Alaska (purple bars; Johnson et al. 2011). Both simulated and "observed" soil C stock estimates are for the organic and 0-1m mineral horizons. The black vertical bars represent standard deviation.


Estimated Carbon Stocks
in Forests of Interior Alaska (Pg C)
30
25
20
15
10
5
0
Living Biomass
Dead Wood
Litter
Soil
Total
1980
1990
2000
2010

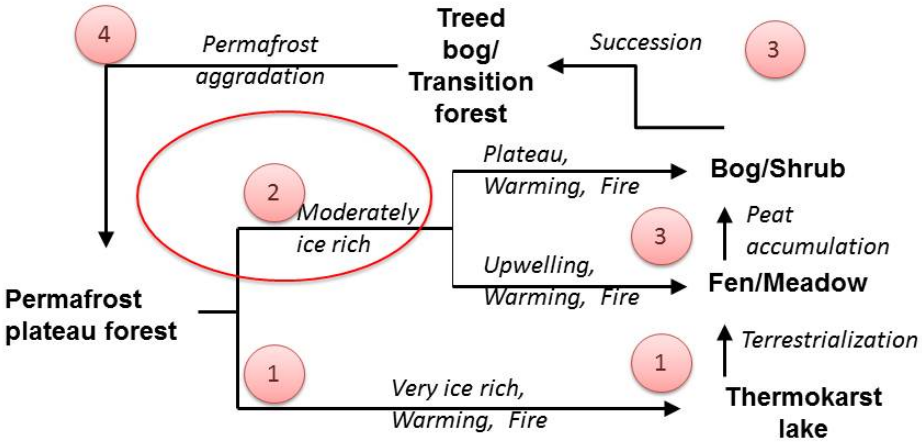
USGS

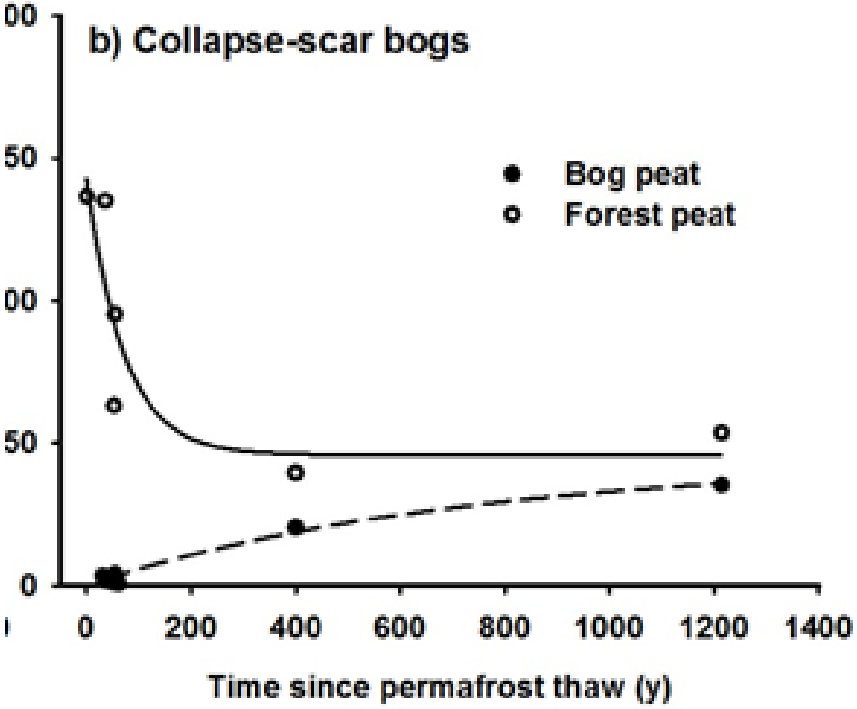
C stock difference (net forest C balance) of the three period



Thermokarst disturbance

Ecosystem Transitions Associated with Thermokarst in the Boreal Forest Region

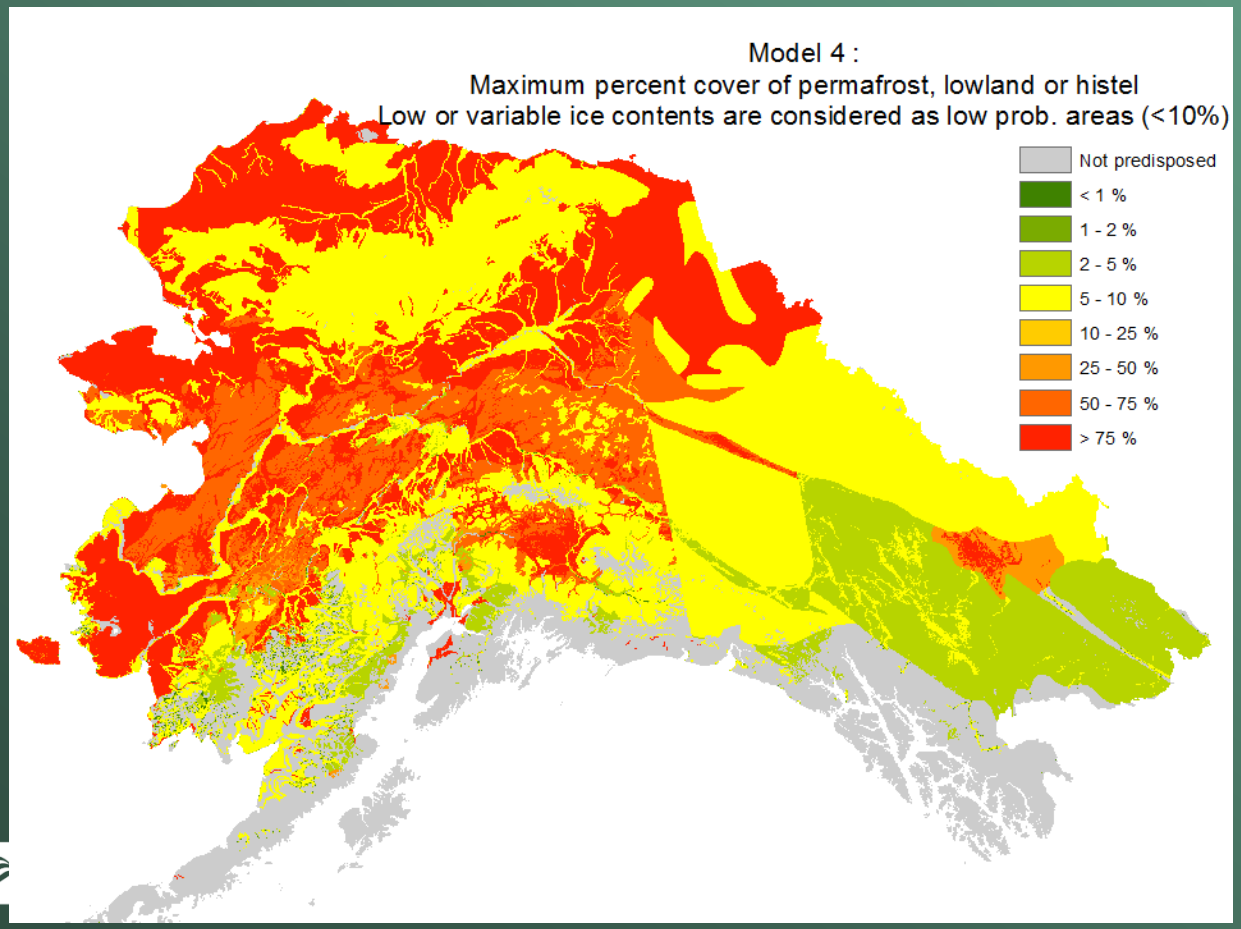




(O'Donnell et al. 2012, Ecosystems)

Areas susceptible to thermokarst disturbance

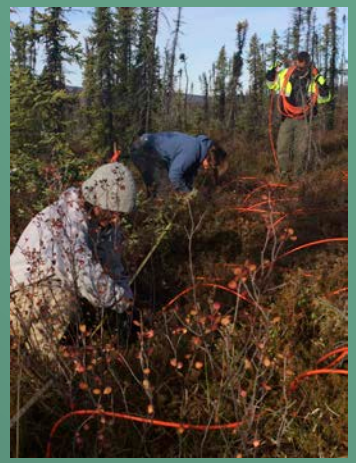
Quantifying the Area Susceptible to Thermokarst: Function of ice content, landscape position (lowlands), presence of peat (histels), and presence of permafrost



(Genet et al.
In prep.)

Improving measurements to investigate wildfire impact on permafrost

- Electrical resistivity tomography (ERT)
  - Transects are approximately 80 – 200 m long, centered on burn perimeters
  - 1 m electrode spacing
  - Detects subsurface electrical properties along profile at depths from <1m to ~10m
    - Frozen/dry = resistive
    - Thawed/wet = conductive
- Nuclear magnetic resonance (NMR)
  - Downhole measurements where possible to auger
  - Quantifies unfrozen water content vs. depth, as well as pore sizes in which water is contained
  - Help to calibrate ERT models



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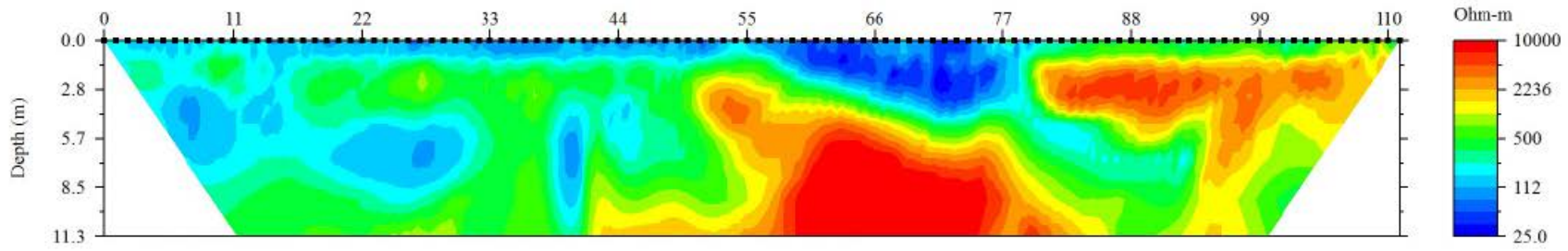
Ongoing work by Wylie, et al.

Bonanza Creek LTER – preliminary ERT result



Blue = low resistivity: unfrozen/wet

Green = intermediate resistivity: frozen, but likely several percent unfrozen water

Red = very resistive: frozen (or dry) with little-to-no unfrozen water

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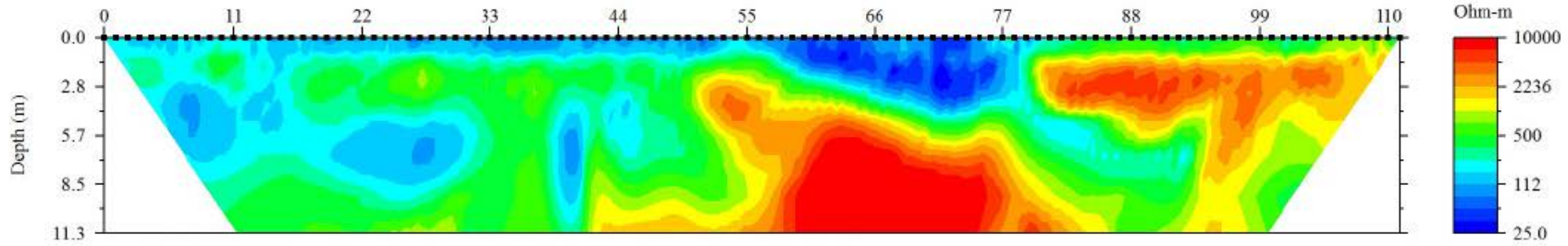
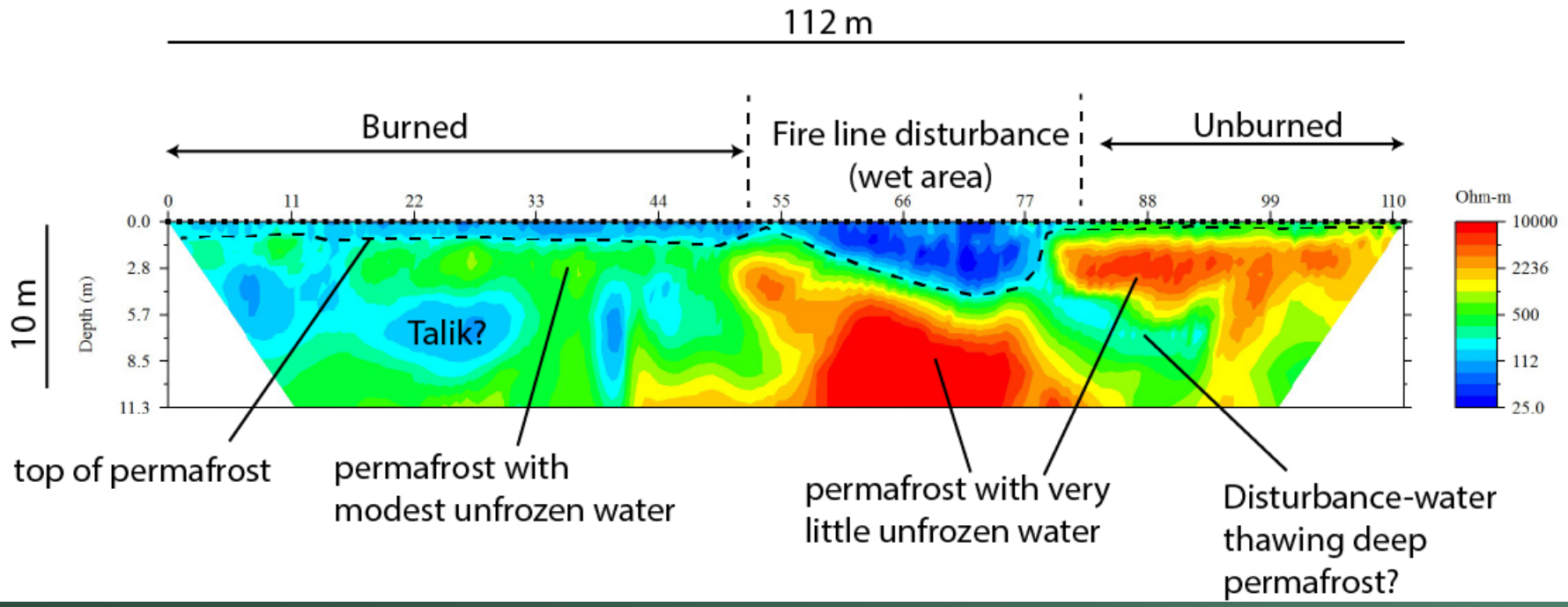
Bonanza Creek LTER – preliminary ERT interpretation





Summary

- The assessment is the first of its kind for Alaska, should produce useful information for national and international policy applications and new insights for science
- Major investment in remote sensing of various properties made for the assessment is expected to help constraint and improve modeling results
- The assessment also highlighted further remote sensing R&D needs:
  - Wetlands, water bodies, at an annual step
  - Permafrost/active layer depth monitoring
  - Thermokarst lake mapping/characterization

USGS

The assessment team