Regional quantitative cover mapping of tundra plant functional types in arctic Alaska

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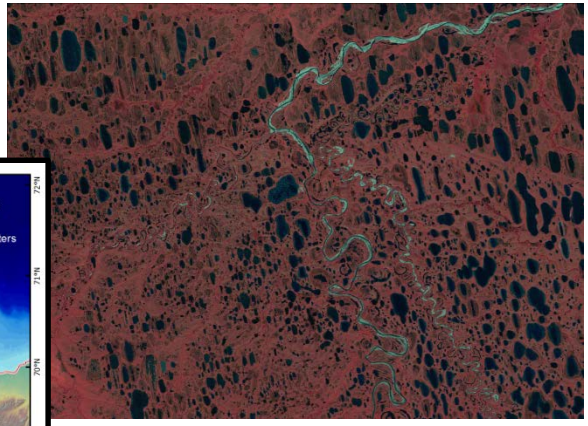

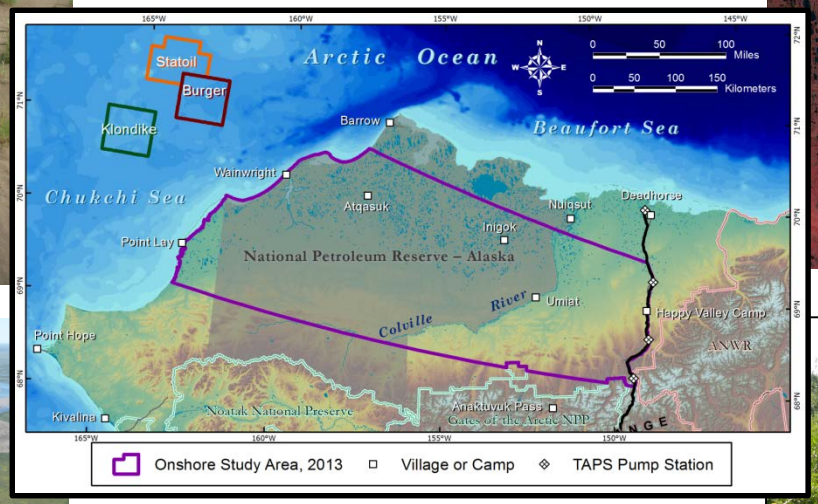

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Background: Ecological Mapping

Ecosystem maps a fundamental tool for:

- Multi-disciplinary support & study design
- Ecosystem monitoring
- Wildlife habitat assessment
- Natural hazards & contingency response
- Permafrost thaw susceptibility

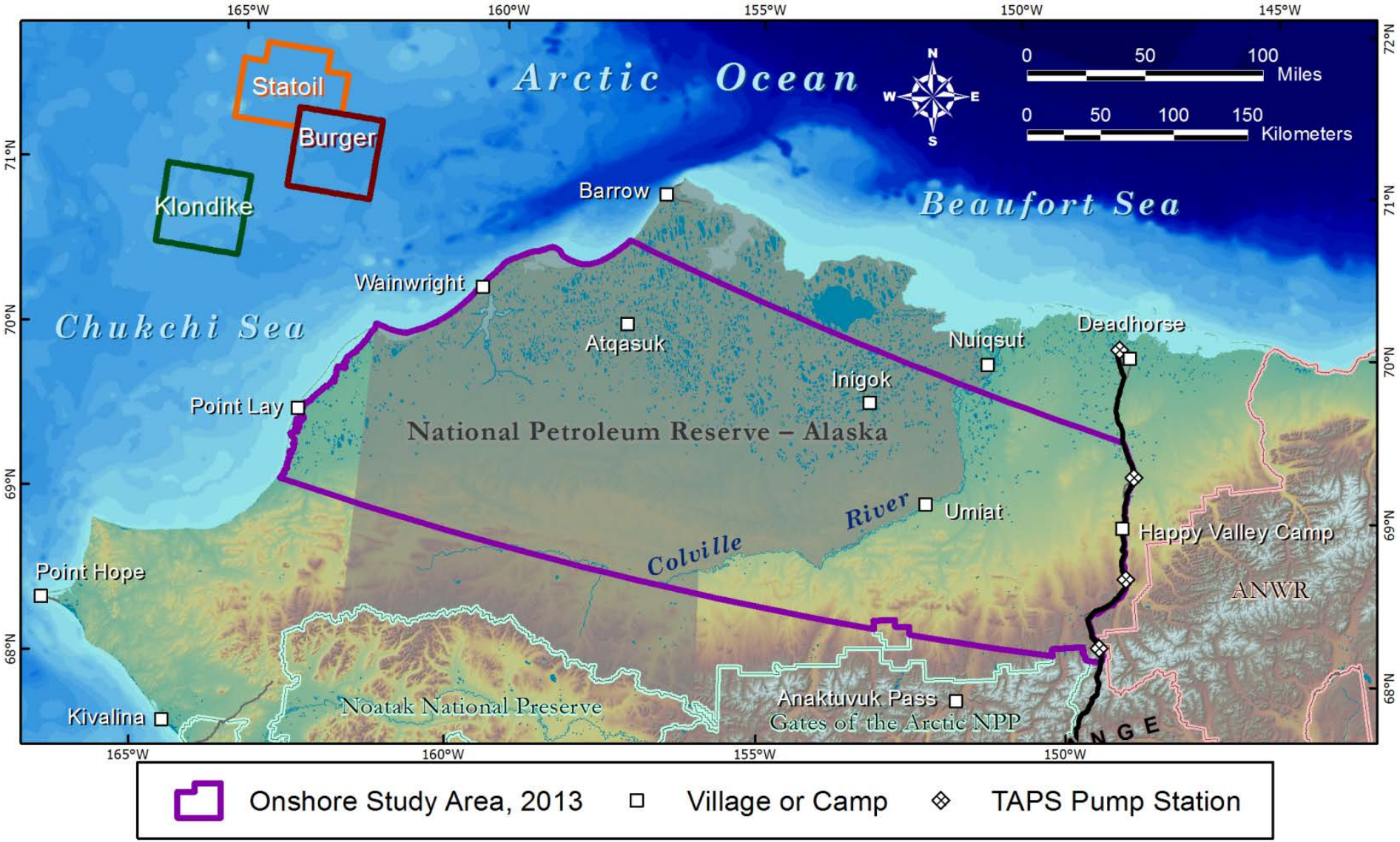
Field studies

- identify vegetation-soil-landform relationships
- classify map units

Remote sensing

- field study design
- distribution of map units
- spatial relationships

Study Motivation



Vector-based Mapping

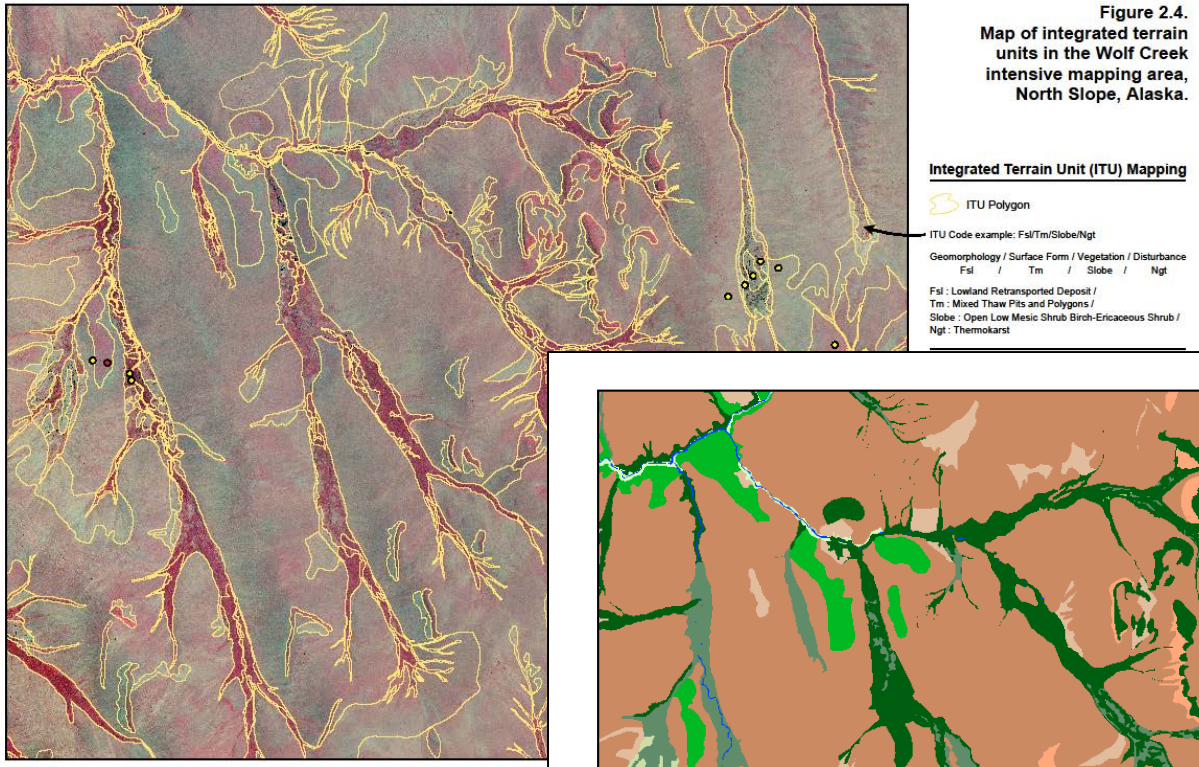


Figure 2.4.
Map of integrated terrain units in the Wolf Creek intensive mapping area, North Slope, Alaska.

Thematic maps emphasize central tendencies of the map units. Not ideal for long-term monitoring, modeling applications.

Figure 2.5.
Map of wildlife habitats in the Wolf Creek intensive mapping area, North Slope, Alaska.

Wildlife Habitat Class

- Upland Tall Shrub
- Upland Birch-Willow Low Shrub
- Upland Willow Low Shrub
- Lowland Birch-Willow Low Shrub
- Riverine Low Willow Shrub
- Moist Shrub-Tussock Tundra
- Ericaceous Dwarf Shrub
- Moist Tussock Tundra
- Moist Sedge-Shrub Meadow
- Nonpatterned Meadow
- Thermokarst Complex
- River or Stream

The habitat classification is based on landscape properties that we consider most important to wildlife: shelter, security (or escape), and food. These factors may be directly related to the quantity and quality of vegetation, vegetation structure and species composition, surface form, soils, hydrology, and microclimate. We emphasize that habitats are not necessarily equivalent to vegetation types. In some cases, dissimilar vegetation types may be combined because selected wildlife species use them similarly. Conversely, wildlife may distinguish between habitats with similar vegetation on the basis of microrelief, soil characteristics, invertebrates, or other factors not reflected in plant species composition. For the Shell Onshore classification, we concentrated on (1) breeding waterbirds that use waterbodies and wet and moist tundra types, and (2) mammals and upland birds that use shrublands and dry tundra types. Habitats are based on recoding of the ITU map using the Shell Onshore habitat classification.

Approximate Scale = 1:24,000

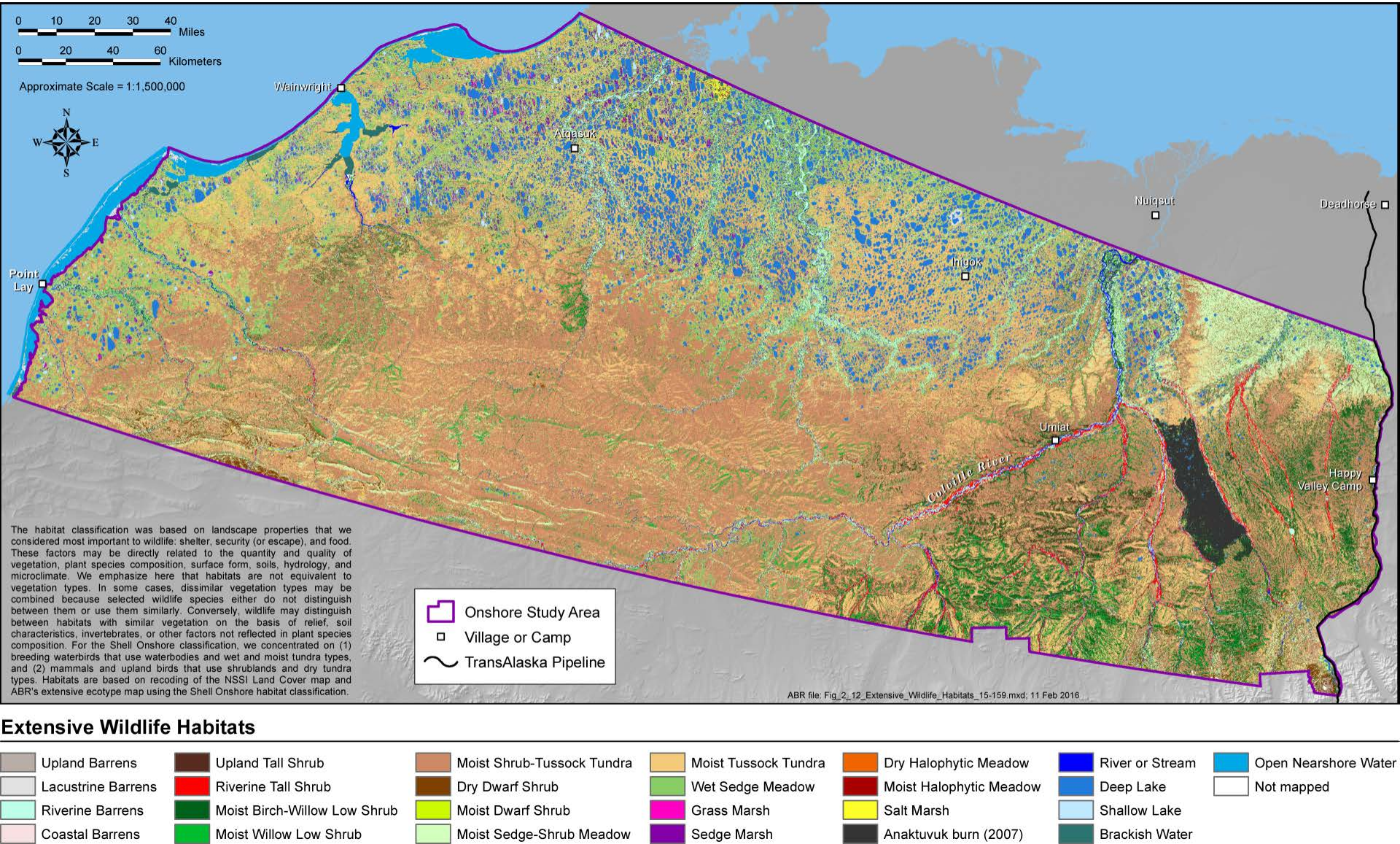
0 0.25 0.5 0.75 mi

0 0.25 0.5 0.75 1 1.25 km

Photo-interpretation based on high-resolution satellite imagery and historical color-infrared orthophotography. GeoEye-1 satellite imagery acquired on 1 July 2010; pan-sharpened pixel resolution is 0.5 m (shown). Historical photography acquired August 1985; pixel resolution approximately 1.6 m. Map projection: Alaska Albers NAD 83. ABR file: Fig_2_05_WolfCr_WildlifeHabitat_15-159.mxd, 24 Nov 2015

Recode “master map” to ecological categories of interest.

Raster-based Map: big picture

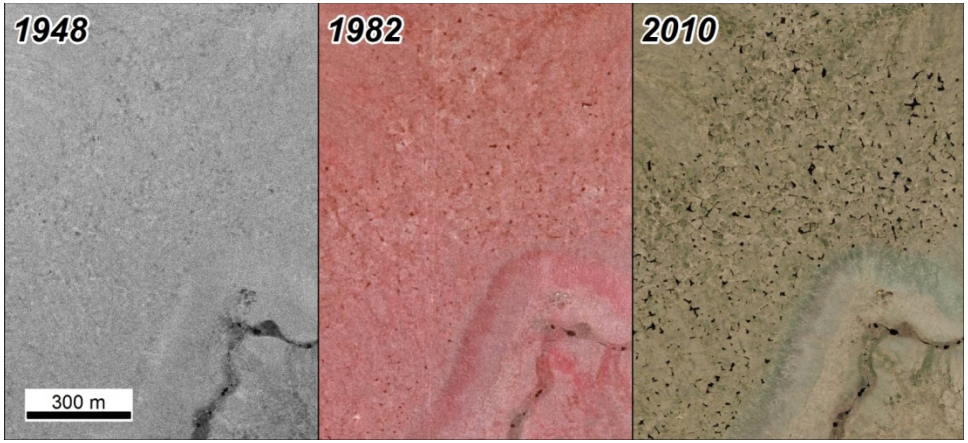


Extensive Wildlife Habitats

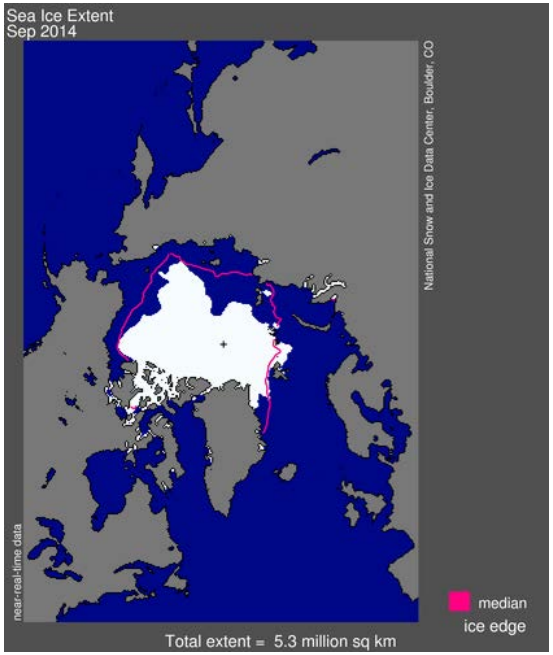
Upland Barrens	Upland Tall Shrub	Moist Shrub-Tussock Tundra	Moist Tussock Tundra	Dry Halophytic Meadow	River or Stream	Open Nearshore Water
Lacustrine Barrens	Riverine Tall Shrub	Dry Dwarf Shrub	Wet Sedge Meadow	Moist Halophytic Meadow	Deep Lake	Not mapped
Riverine Barrens	Moist Birch-Willow Low Shrub	Moist Dwarf Shrub	Grass Marsh	Salt Marsh	Shallow Lake	
Coastal Barrens	Moist Willow Low Shrub	Moist Sedge-Shrub Meadow	Sedge Marsh	Anaktuvuk burn (2007)	Brackish Water	

“The map is changing”

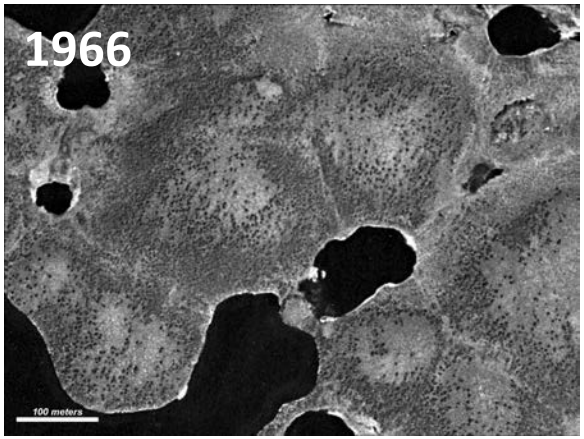
- Vegetation not static
- Disturbance, succession
- Long-term change



Ice-wedge degradation



NSIDC 2014



Shrub expansion

Frost & Epstein 2014

Study Motivation

"Use remote sensing to measure, not just map"
—Anupma Prakash (14th ICRSS)

Continuous field maps improve capabilities:

- Monitor structure and function of tundra vegetation
- Input for earth-system & dynamic simulation models
- Wildlife resource selection functions
- Radiative exchange & surface energy balance
- Permafrost thermal regime

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Plant Functional Types

- plant species grouped according to physiognomy and phylogeny
    - vascular/non-vascular
    - height
    - woodiness
    - leaf habit

Plant Functional Types

Tall Deciduous Shrubs	Deciduous shrubs ≥1.5 m height; mainly *Salix alaxensis*, *S. arbusculoides*, and *Alnus fruticosa*
Low Deciduous Shrubs	Deciduous shrubs 0.2–1.5 m height; e.g., *Betula nana*, *Salix pulchra*, and *S. glauca*
Dwarf Deciduous Shrubs	Deciduous shrubs ≤0.2 m height; e.g. *Salix rotundifolia*, *Arctous* spp., and *Vaccinium uligonosum.*
Dwarf Evergreen Shrubs	Evergreen shrubs ≤0.2 m height; e.g. *Dryas integrifolia*, *Cassiope tetragona*, *Vaccinium vitis-ideas*, and *Ledum decumbens*
Sedges	Herbaceous plants of *Cyperaceae* and *Juncaceae*; e.g., *Carex* and *Eriophorum* spp.
Grasses	Herbaceous plants of *Poaceae*; e.g., *Arctagrostis*, *Arctophila*, *Deschampsia*
Forbs	Non-graminoid herbaceous plants; e.g., legumes and composites
Mosses	Total of all mosses
Lichens	Total of all terricolous lichens

PFTs derived from Les Viereck's Alaska Vegetation Classification

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Lichens	Total of all terricolous lichens
Total Shrubs	Total of all shrub PFTs
Low & Tall Deciduous Shrubs	Deciduous shrubs ≥0.2 m height
Vascular Plants	Total of all vascular PFTs
Nonvascular Plants	Total of all nonvascular PFTs including mosses, terricolous lichens, liverworts, and algae

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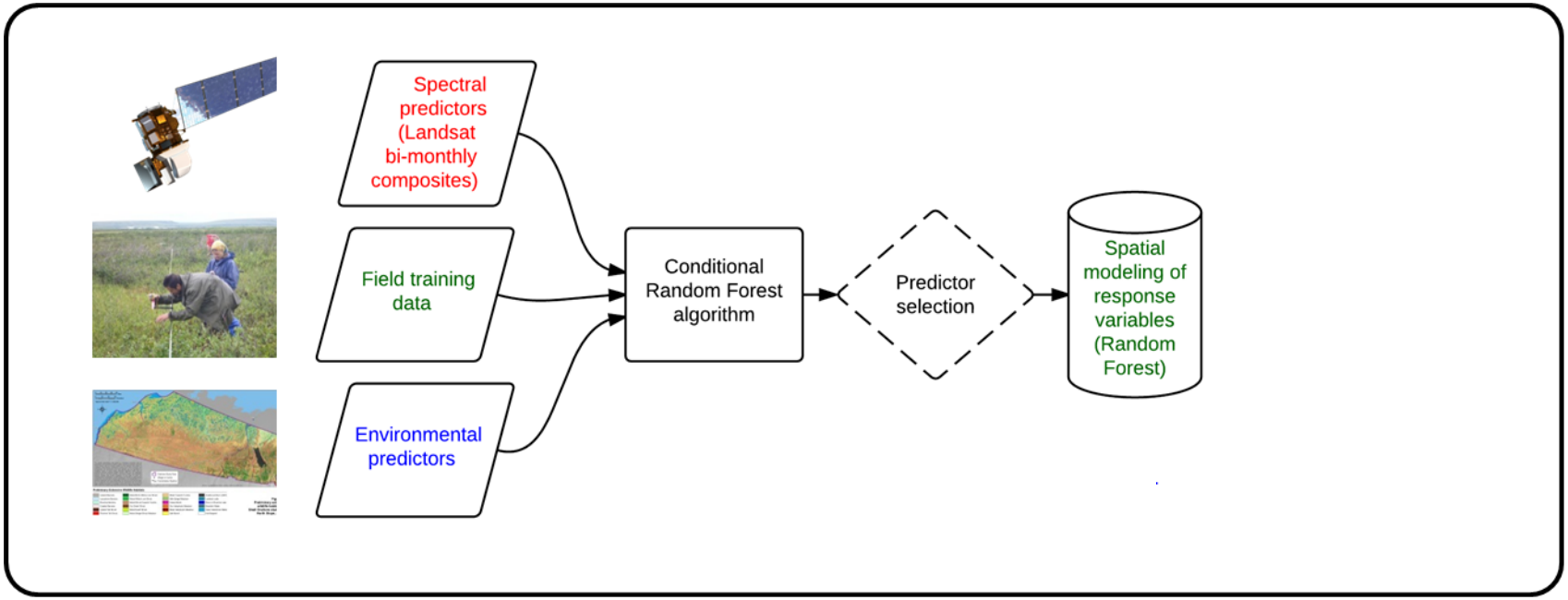
Nonvascular Plants	Total of all nonvascular PFTs including mosses, terricolous lichens, liverworts, and algae
Litter	Dead plant matter
Open Water	Open water
Bare Ground	Bare soil or rock

Study Framework



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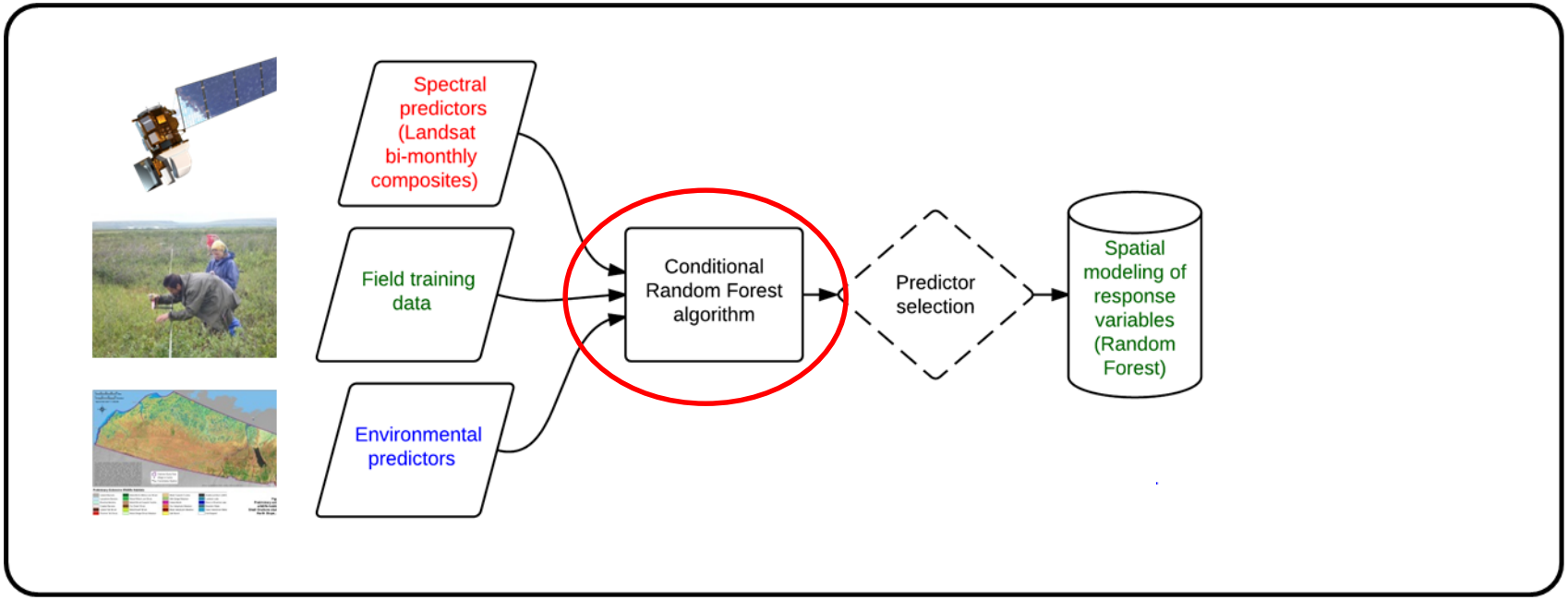

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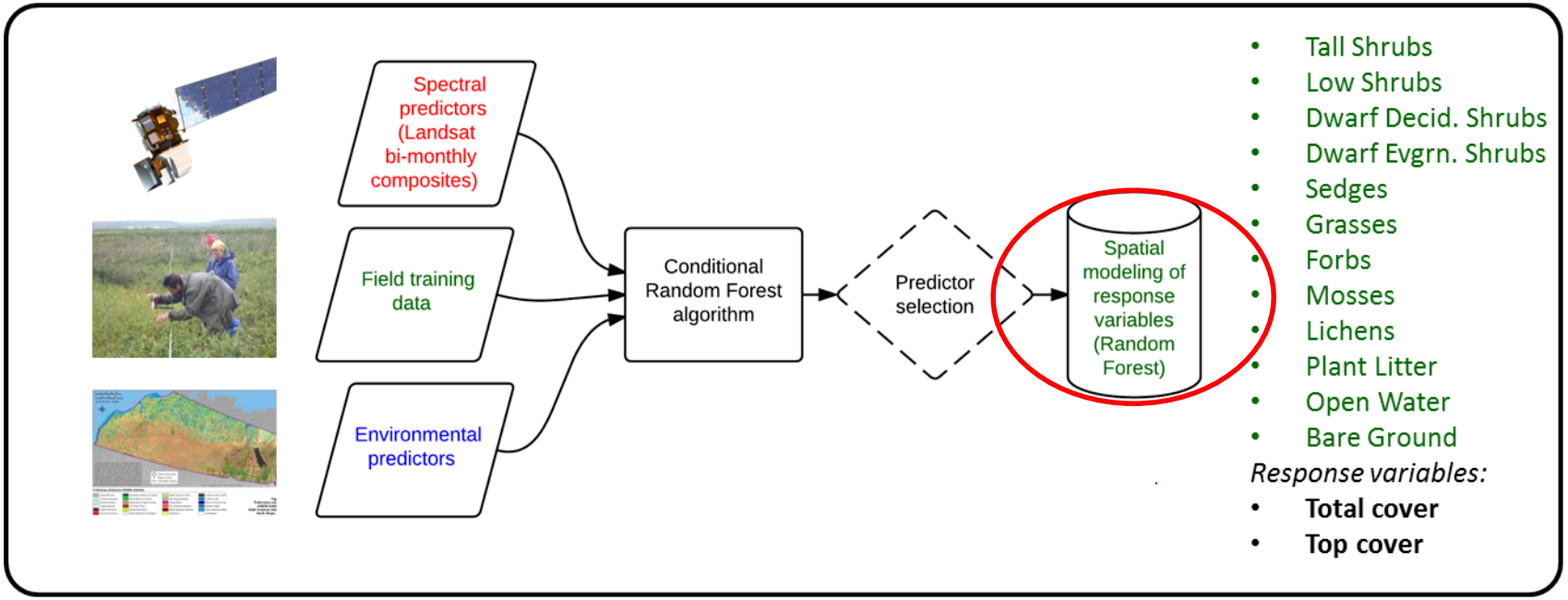
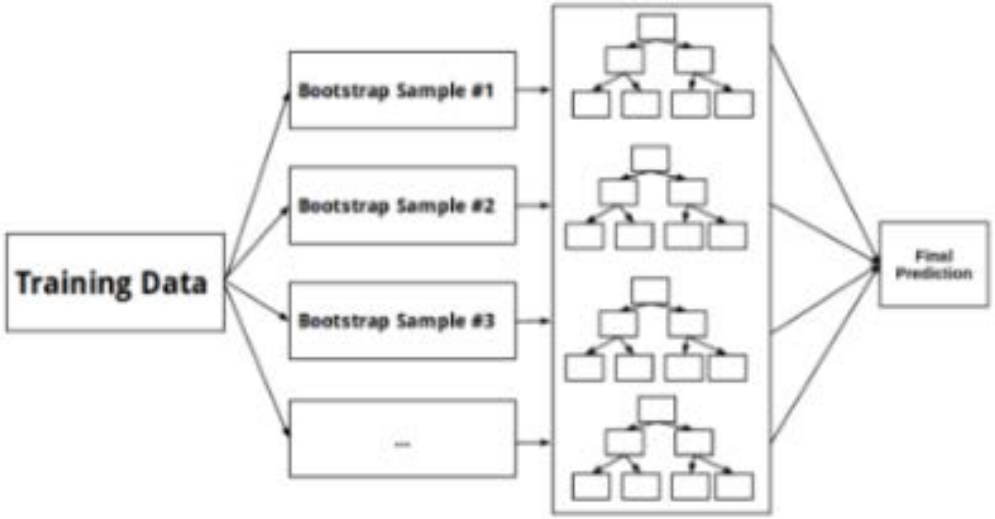


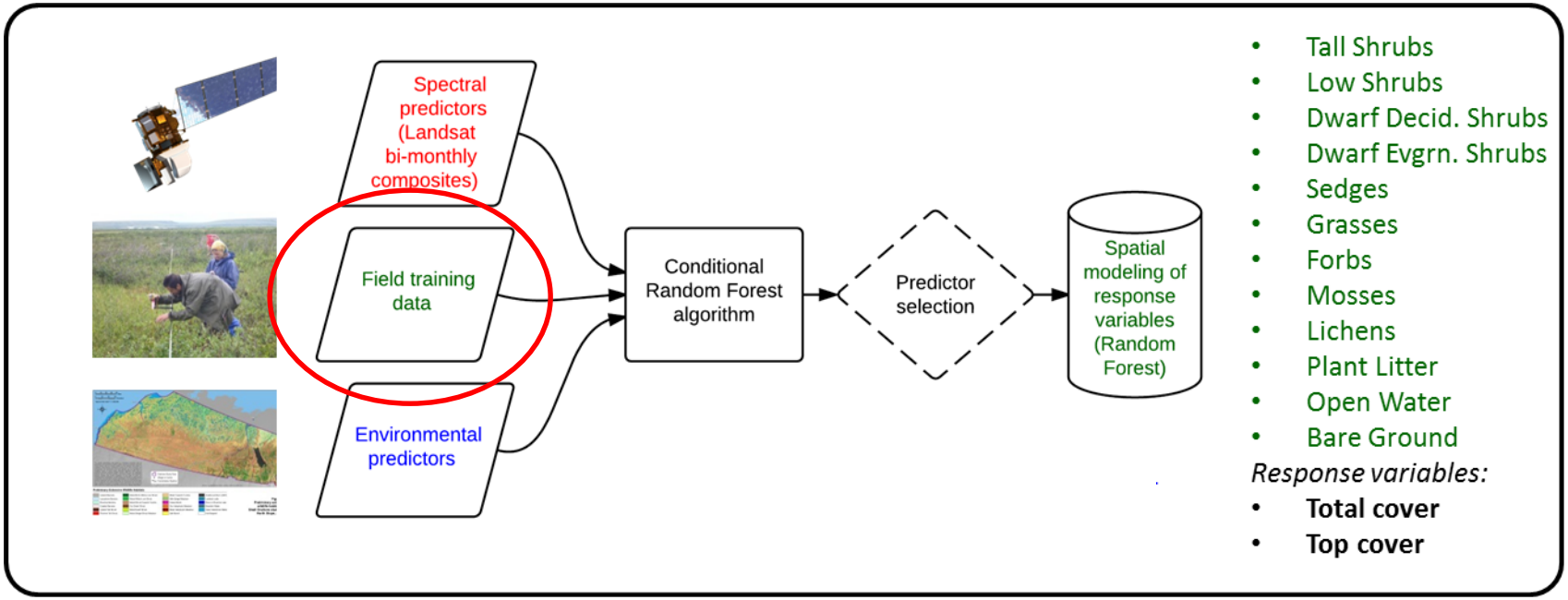
Random Forest

- data mining algorithm (*Breiman 2001*)
- permits use of many correlated predictors (data fusion)
- good at recovering non-linear relationships
- bootstrapping process in which training plots are randomly selected and split according to randomly selected predictors



www.quora.com

Study Framework

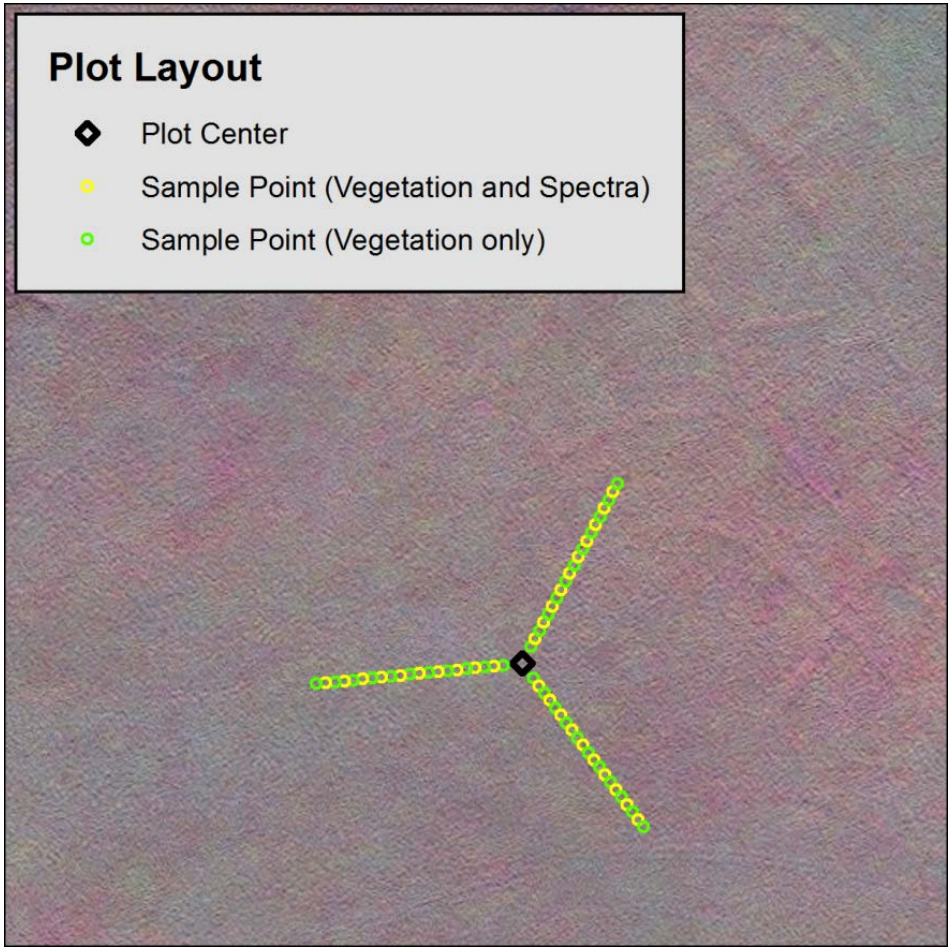


Point Intercept Vegetation Sampling

- Proxy for LAI, above ground biomass, forage quantity
- Fairly rapid and non-destructive
- Commonly used for long-term monitoring
- Well-suited for scaling to remote sensing

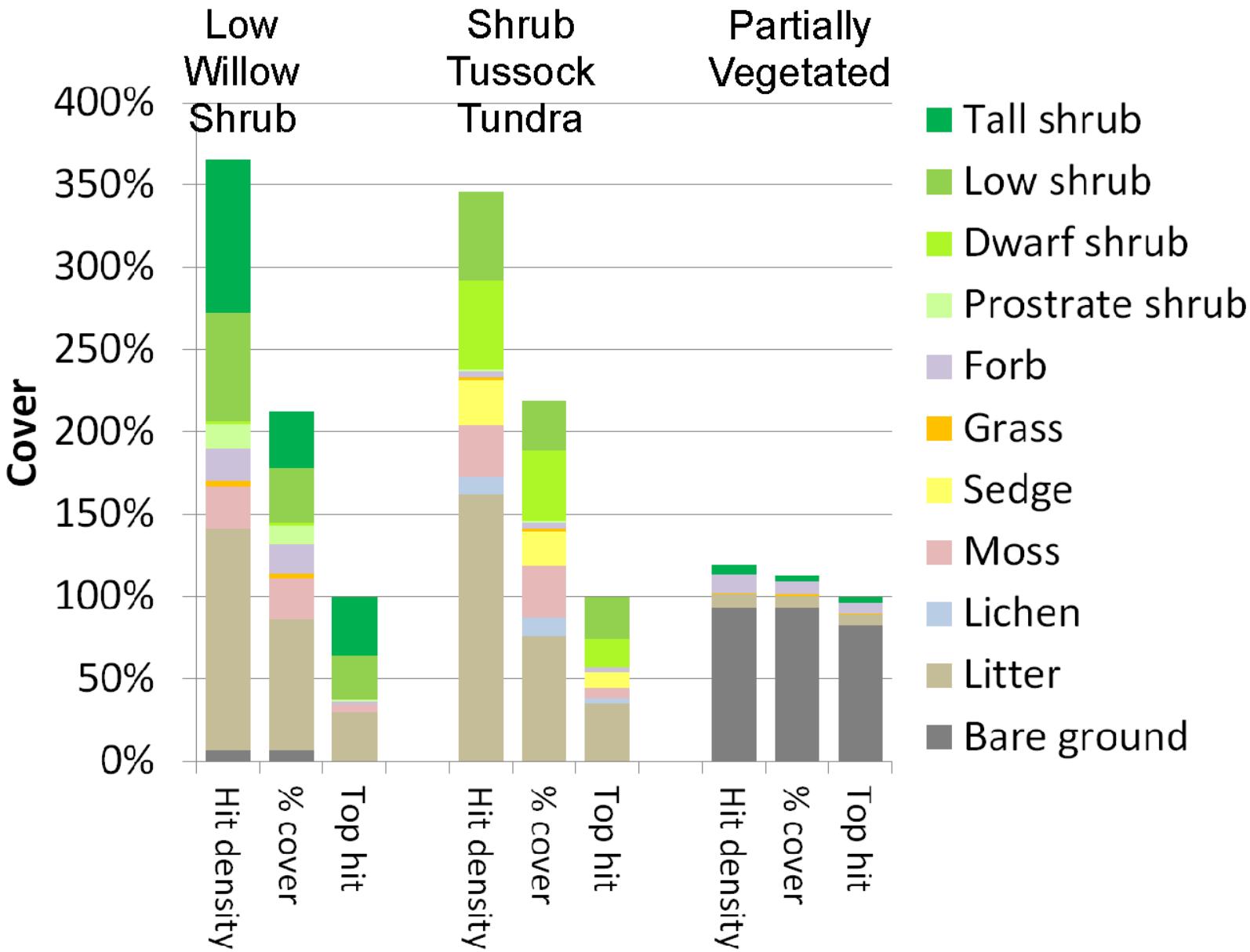
Plot Layout

- Plot dimensions: 3 x 50-m
- Sample points every 2.5 m
- Based on BLM Assessment, Inventory and Monitoring Protocol (AIM) (Toevs 2011)

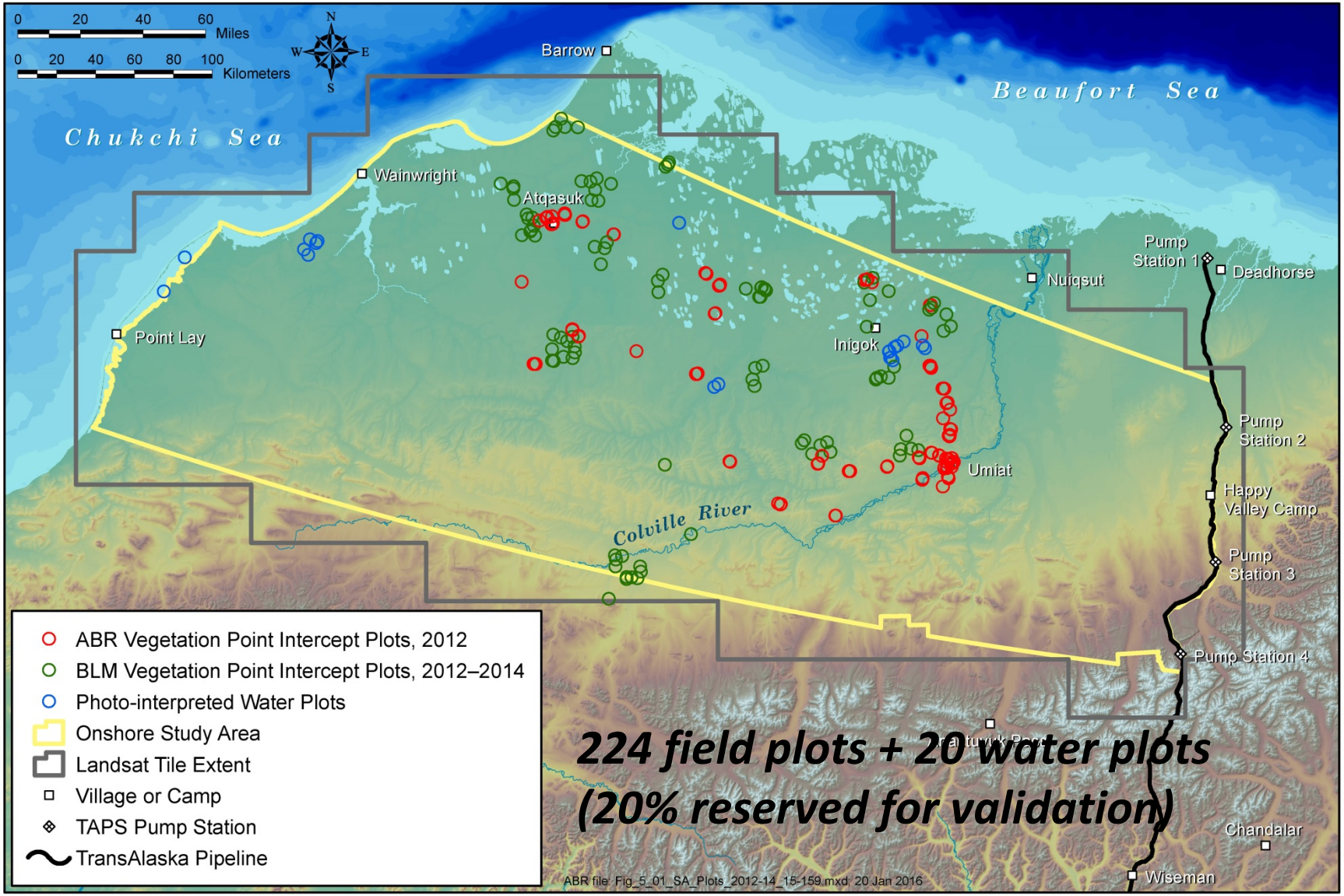


Summarizing Point Intercept Data

- **Percent cover**: % of points where species or functional type occurs
- **Top cover**: % of points where species or functional type occurs as first hit
- **Hit density**: Total number of hits of a species/functional type divided by total number of points

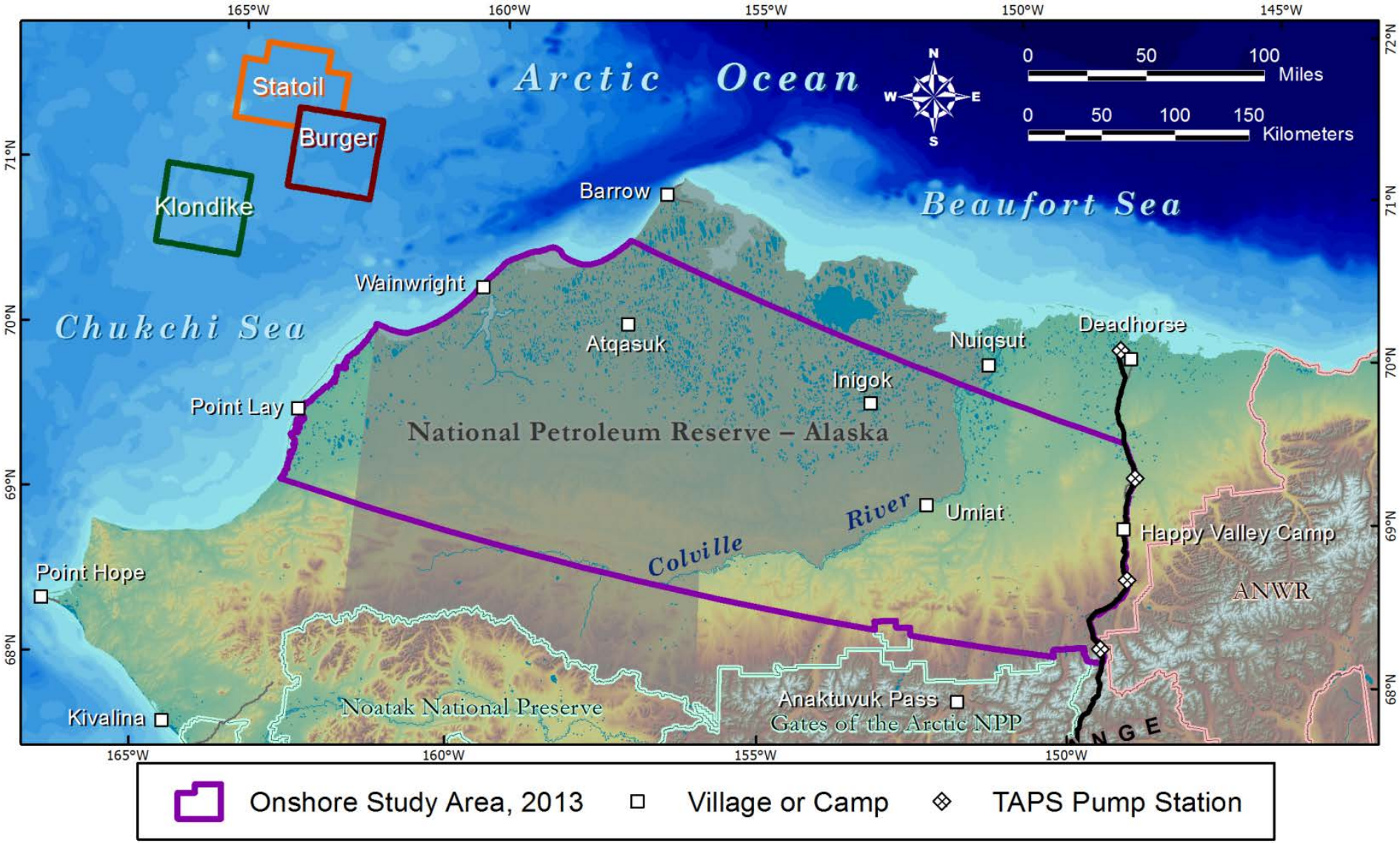

Low Willow Shrub
Shrub Tussock Tundra
Partially Vegetated
Cover
400%
350%
300%
250%
200%
150%
100%
50%
0%
Hit density
% cover
Top hit
Hit density
% cover
Top hit
Hit density
% cover
Top hit
Tall shrub
Low shrub
Dwarf shrub
Prostrate shrub
Forb
Grass
Sedge
Moss
Lichen
Litter
Bare ground

Field training data



224 field plots + 20 water plots (20% reserved for validation)

Mapping Area: Environmental Gradients



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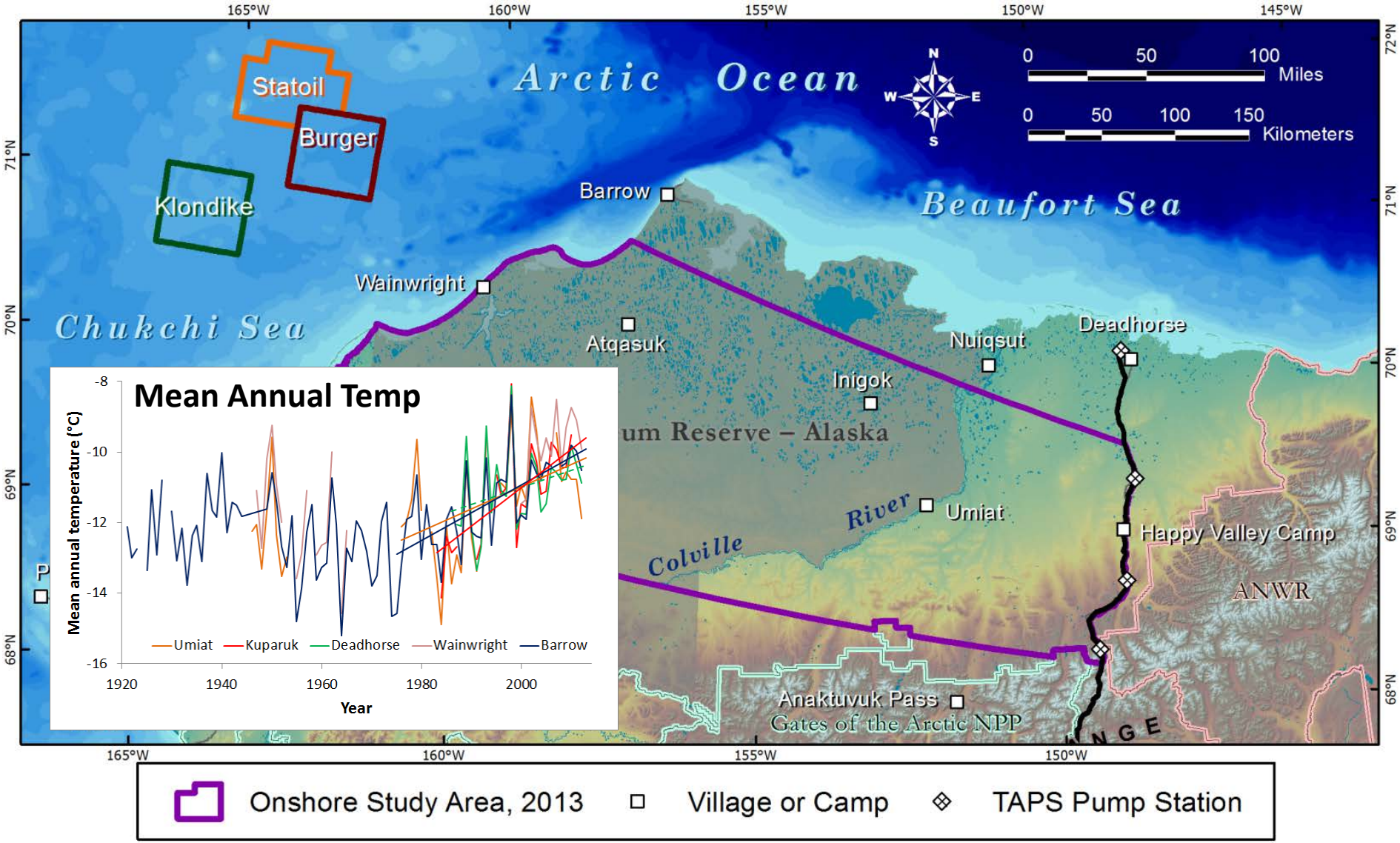

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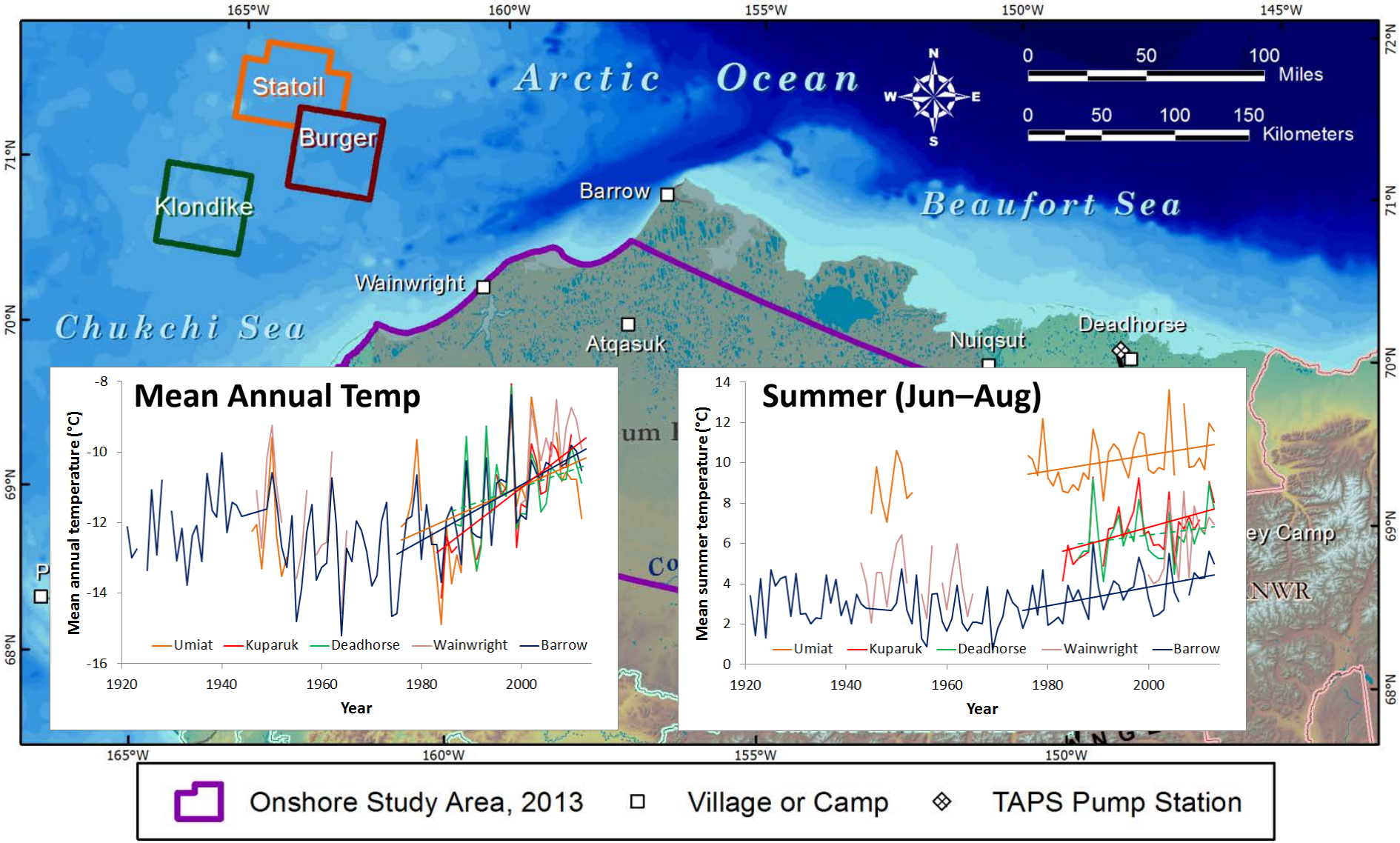
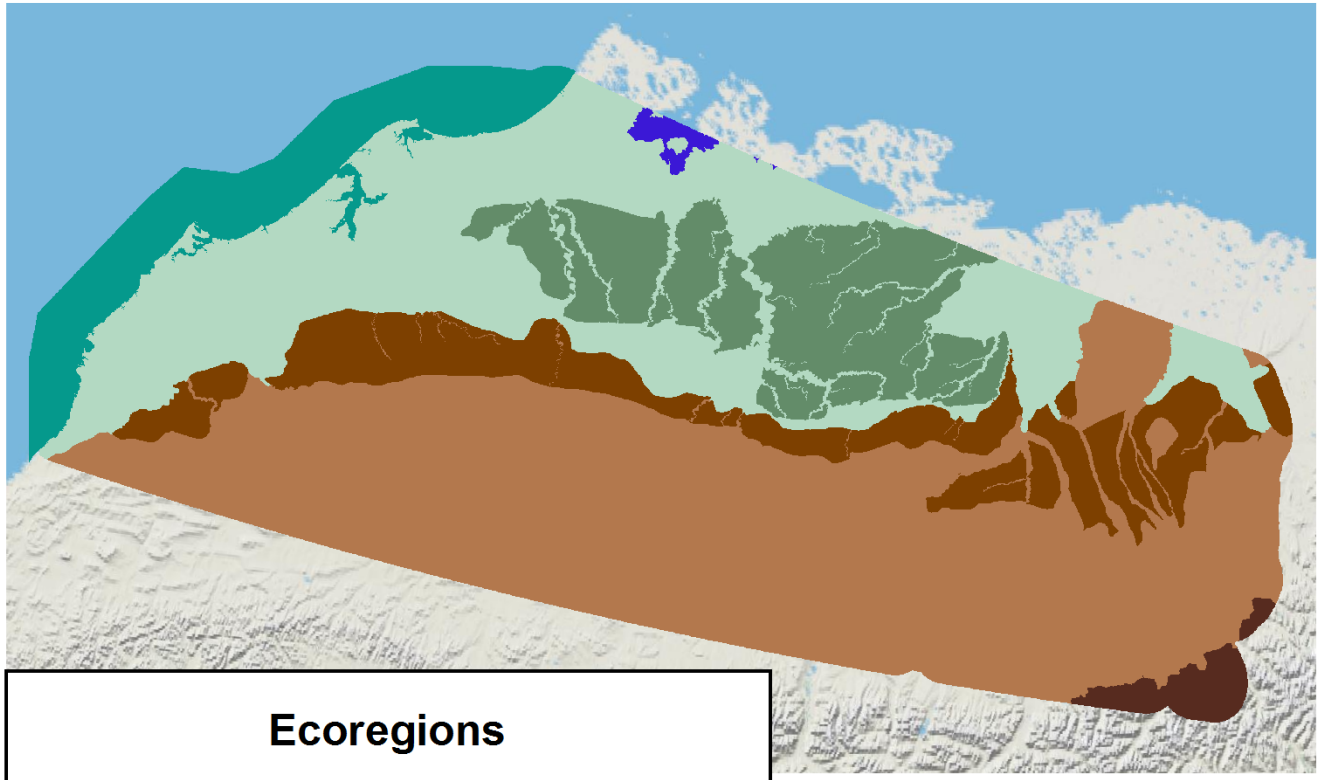


Mapping Area: Topography and Substrate

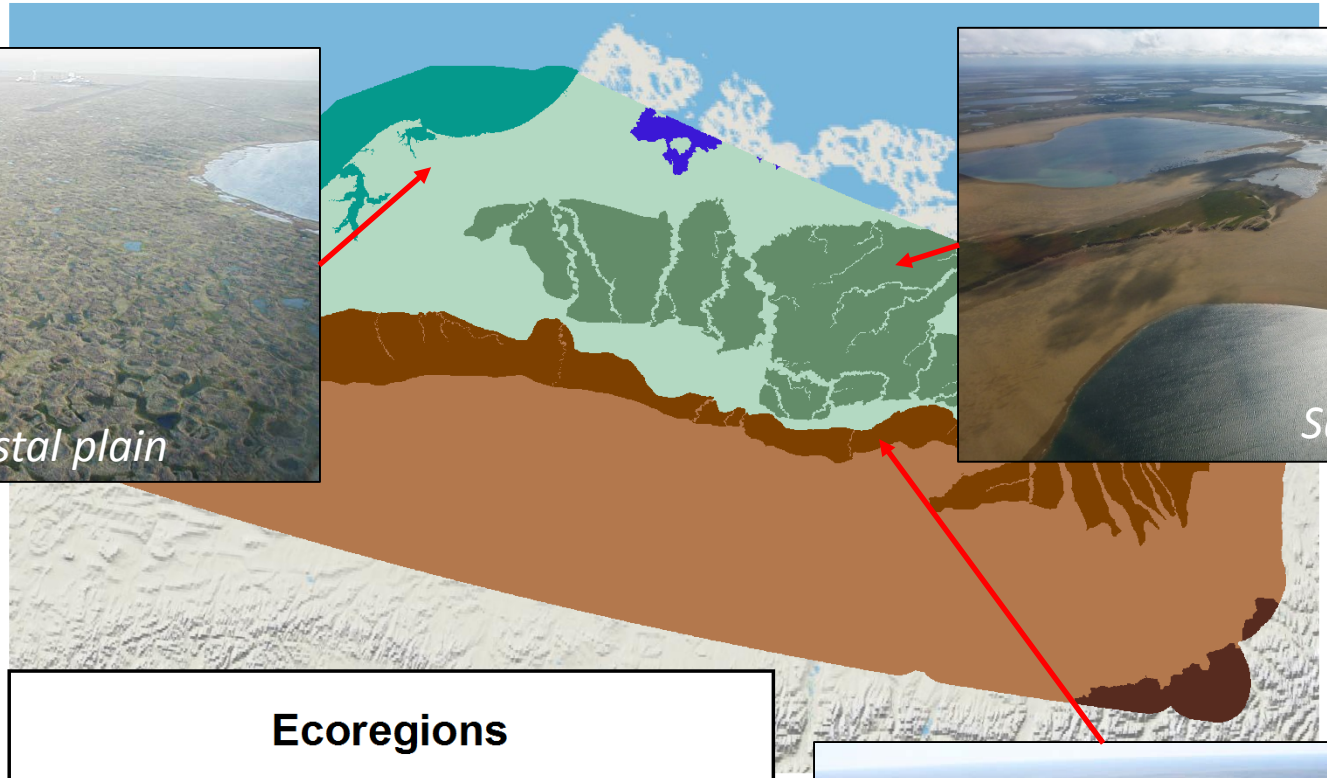


Ecoregions

- Northern Chukchi Coast
- Beaufort Sea Coast
- Beaufort Coastal Plain
- Beaufort Coastal Plain (Sand Sheet)
- Brooks Foothills (Yedoma Belt)
- Brooks Foothills
- Northern Brooks Range

adapted from Jorgenson & Grunblatt (2013)

Mapping Area: Topography and Substrate



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- Northern Chukchi Coast
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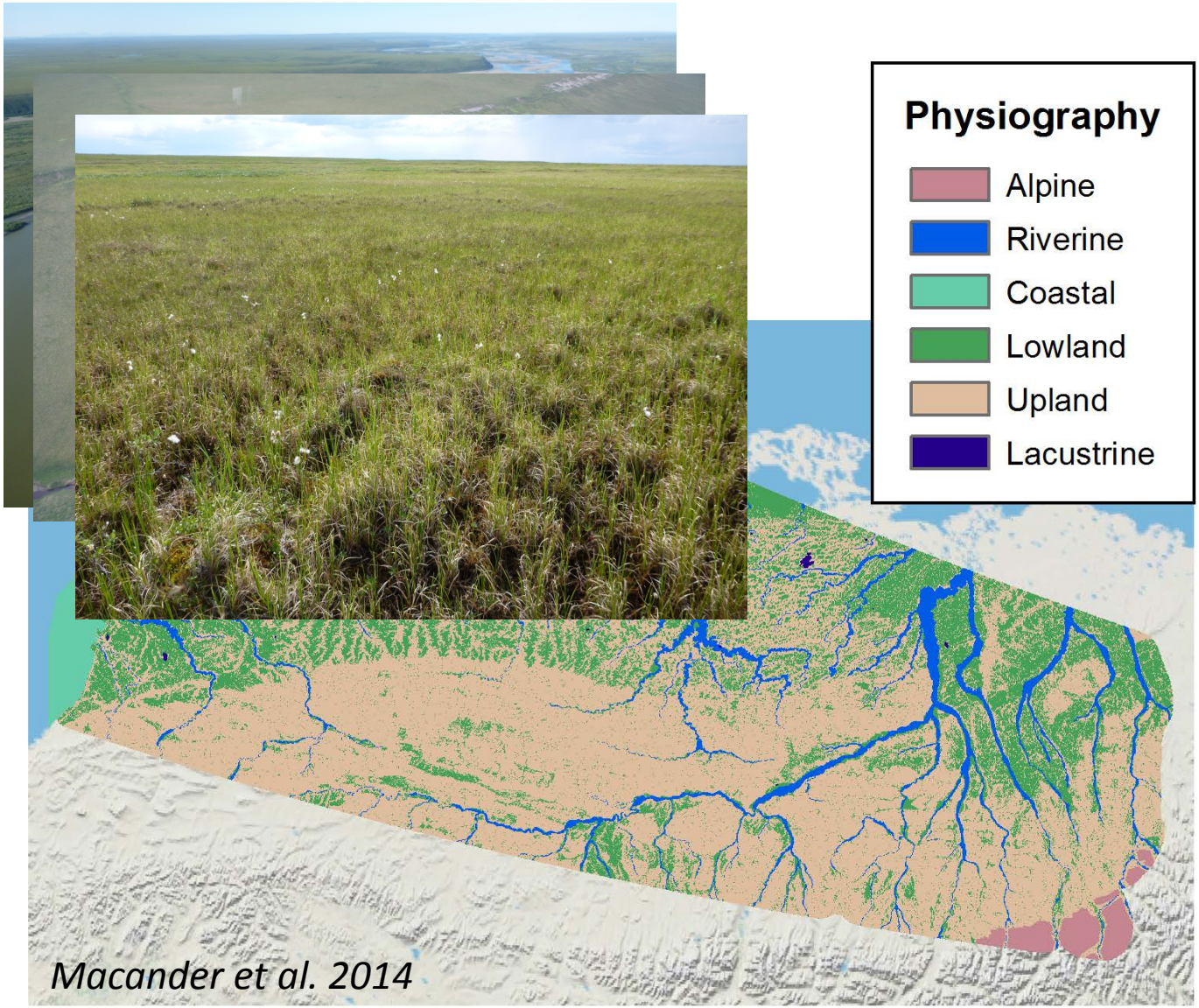
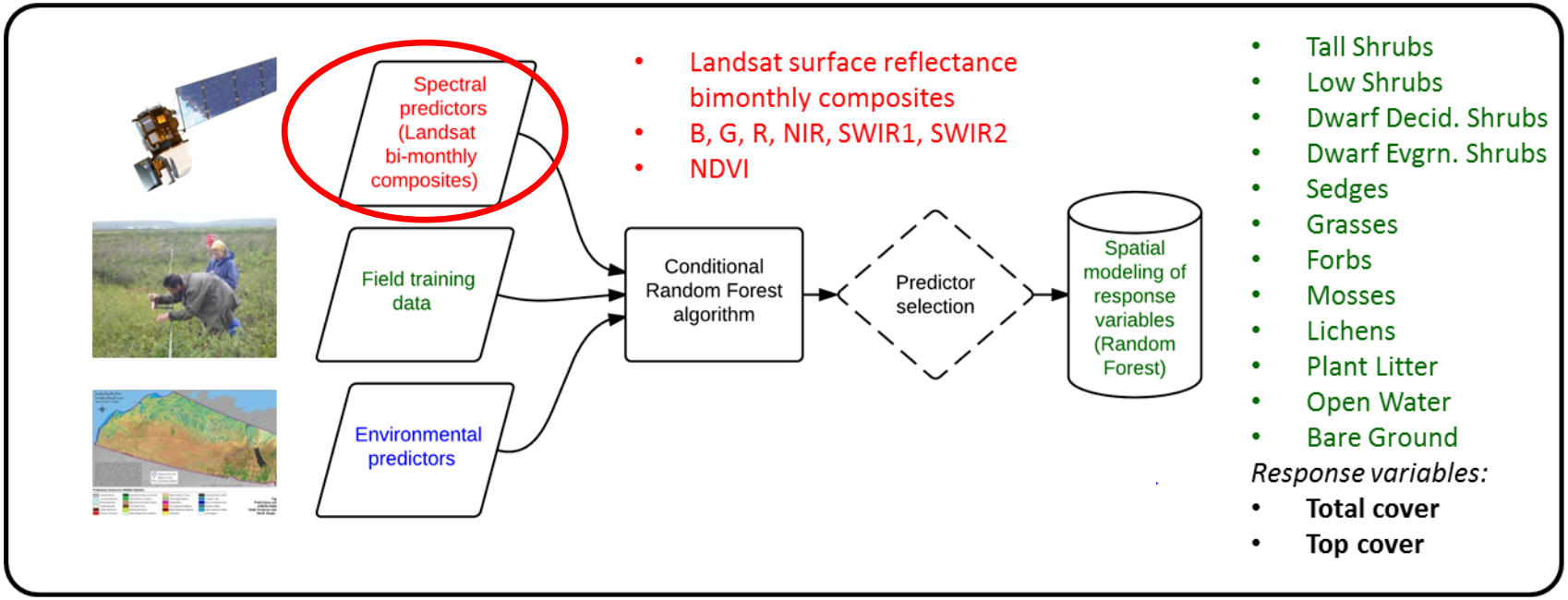
Mapping Area: Physiography

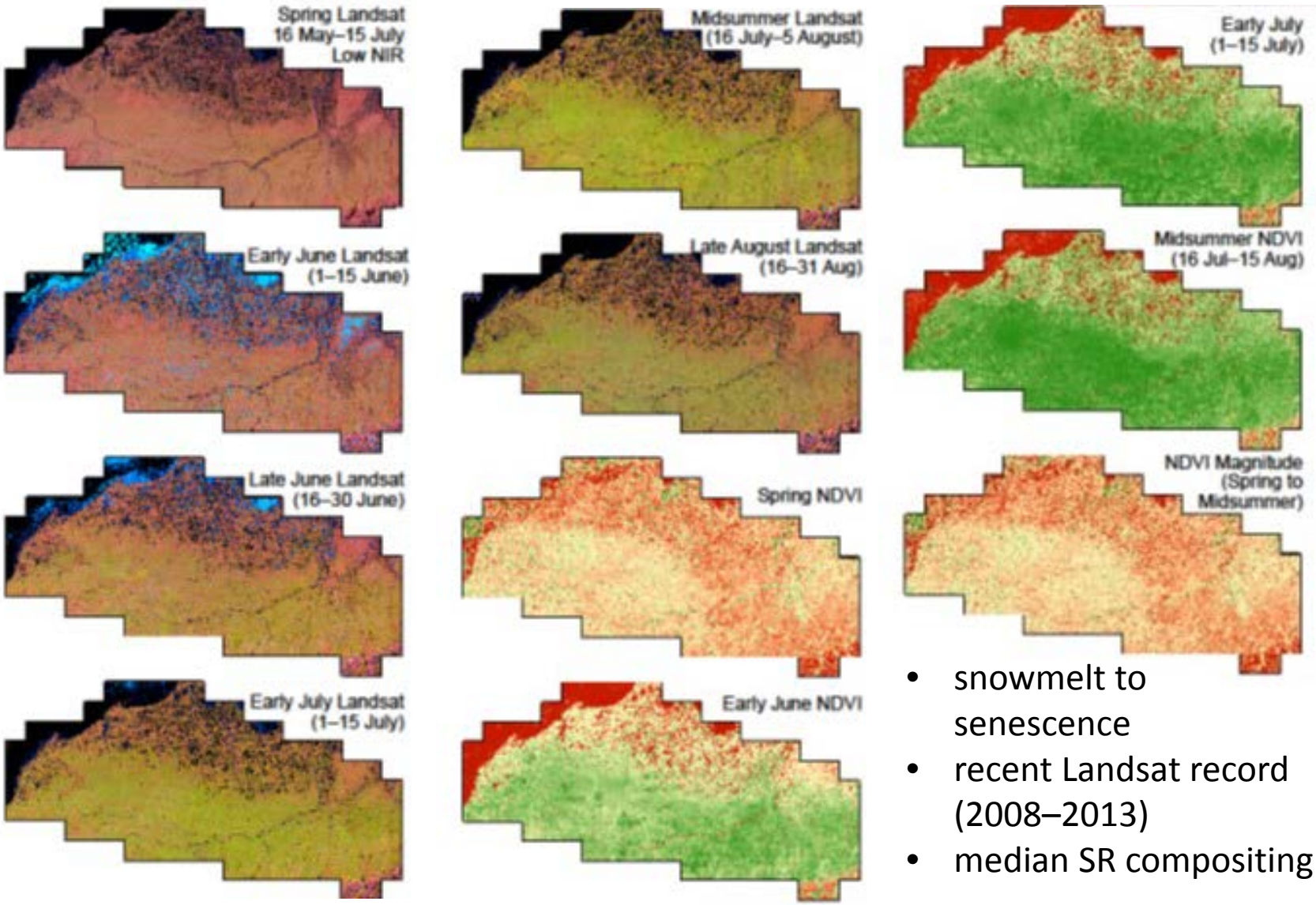


Locally dominant tectonic and geomorphic controls on landform development. Some units digitized, others modeled using DEM.

Inputs and analysis approach

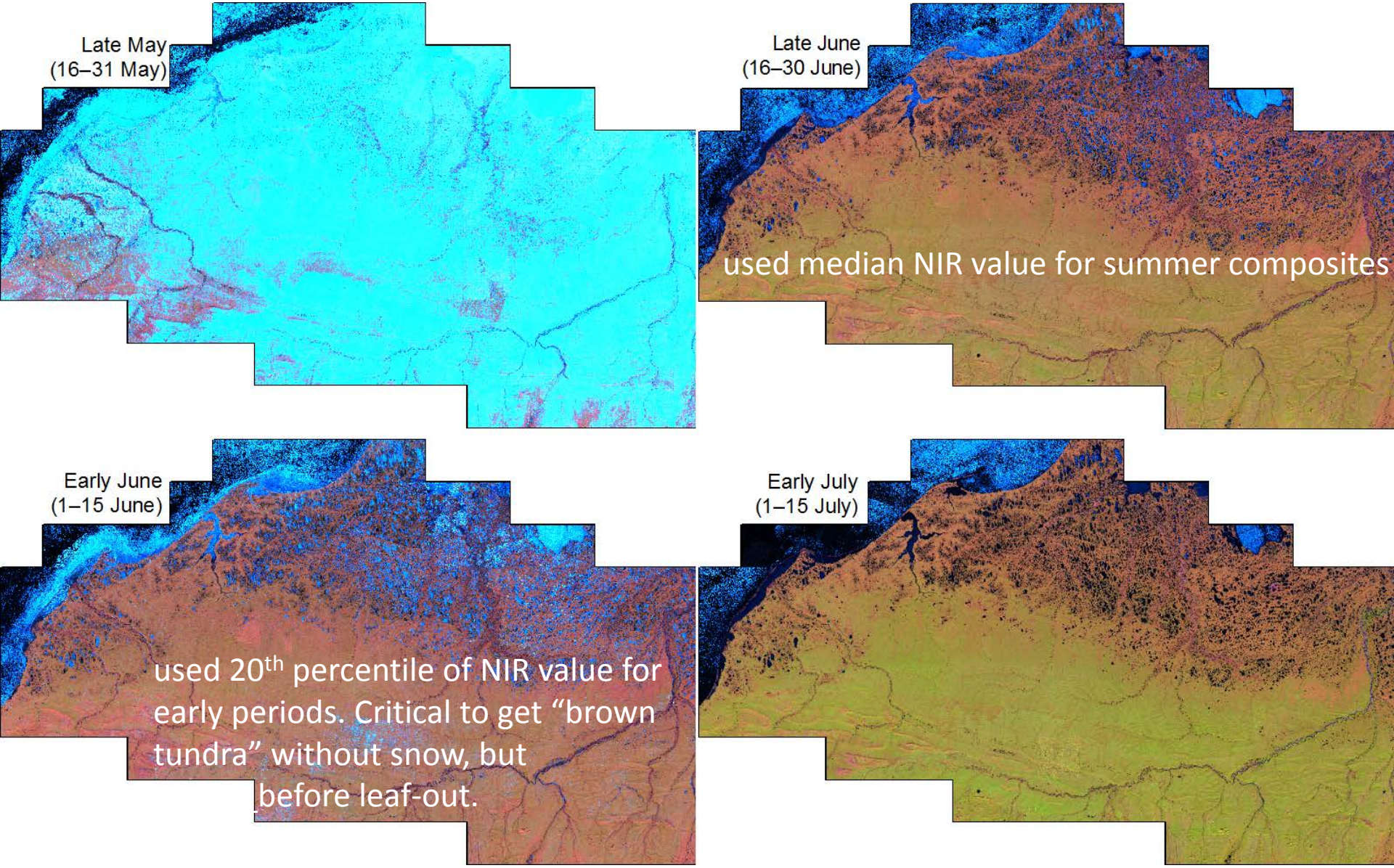


Spectral predictors: Landsat seasonal composites

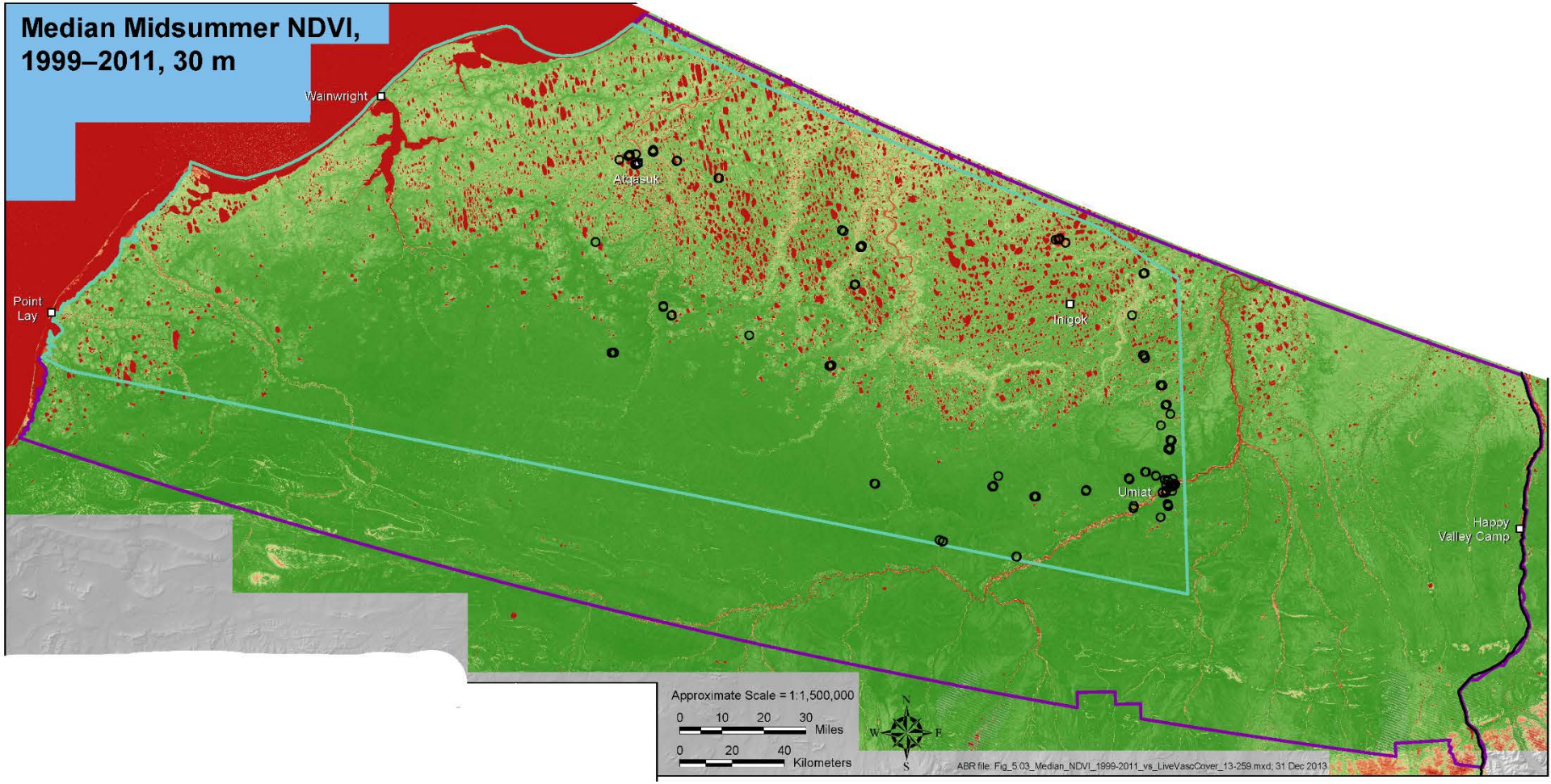


- snowmelt to senescence
- recent Landsat record (2008–2013)
- median SR compositing

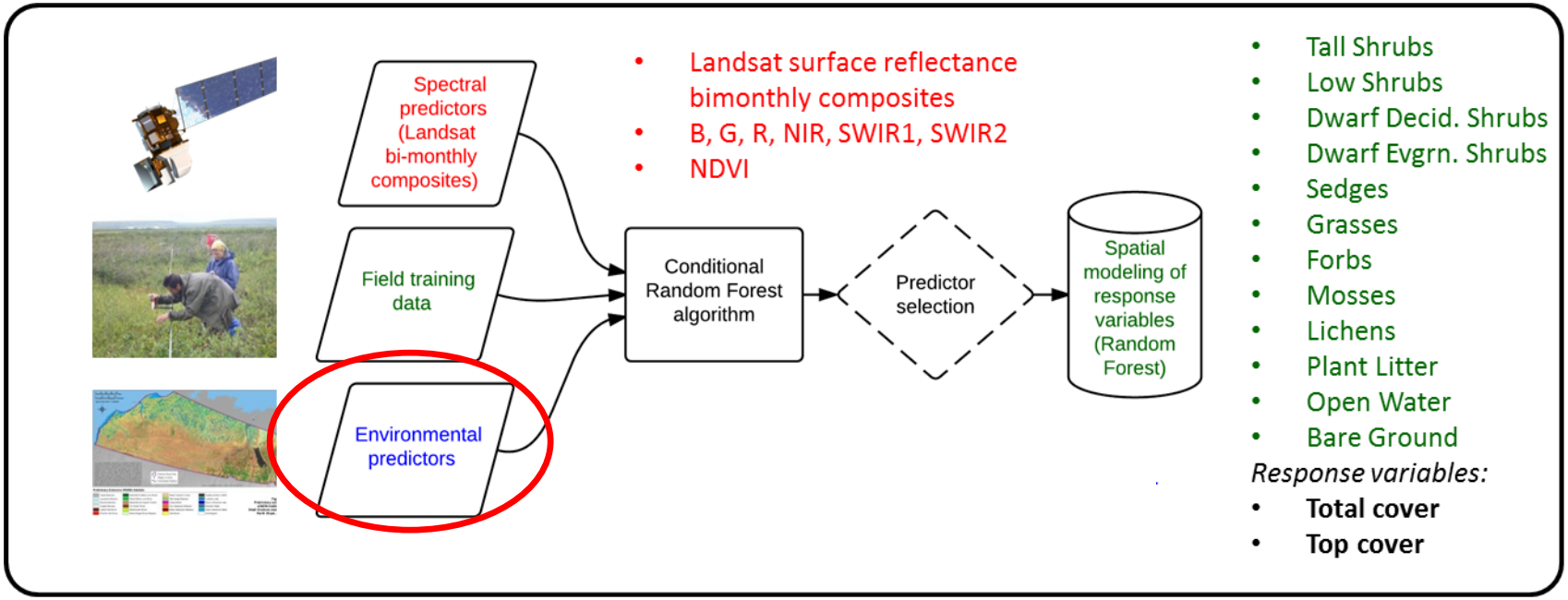
Spectral predictors: Landsat seasonal composites



Spectral predictors: NDVI



Inputs and analysis approach



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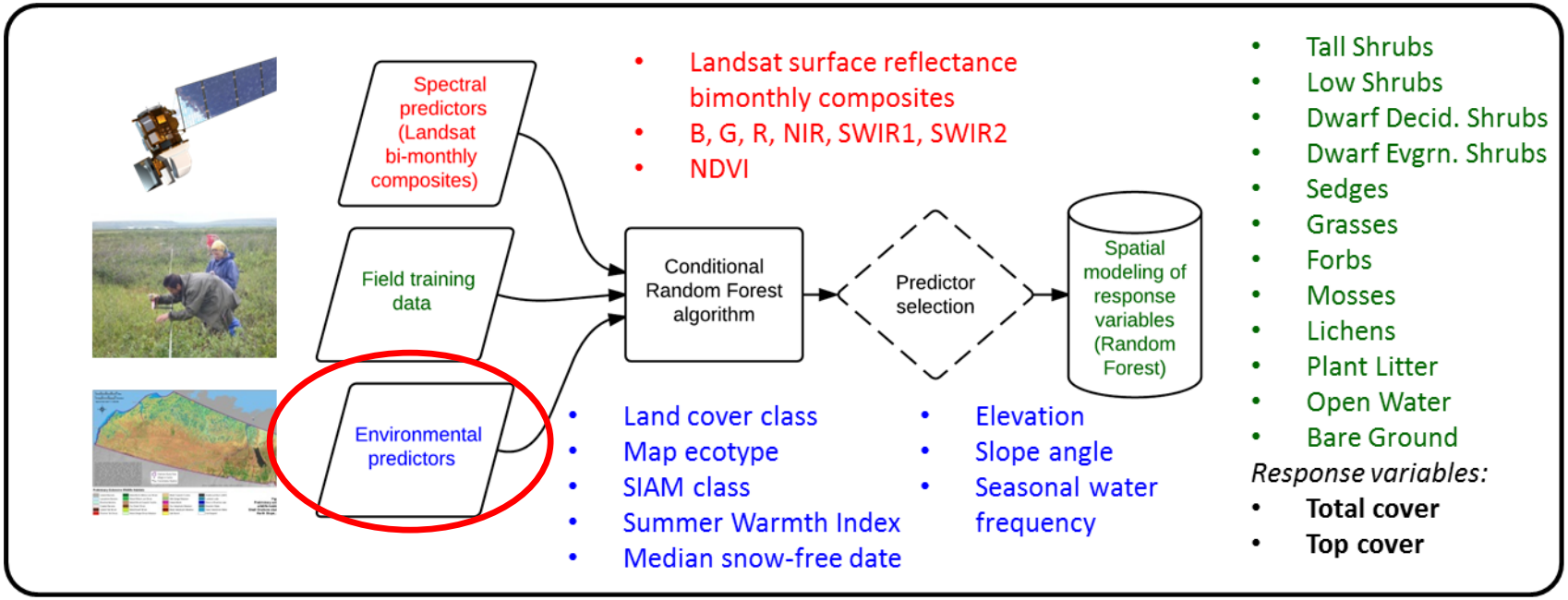
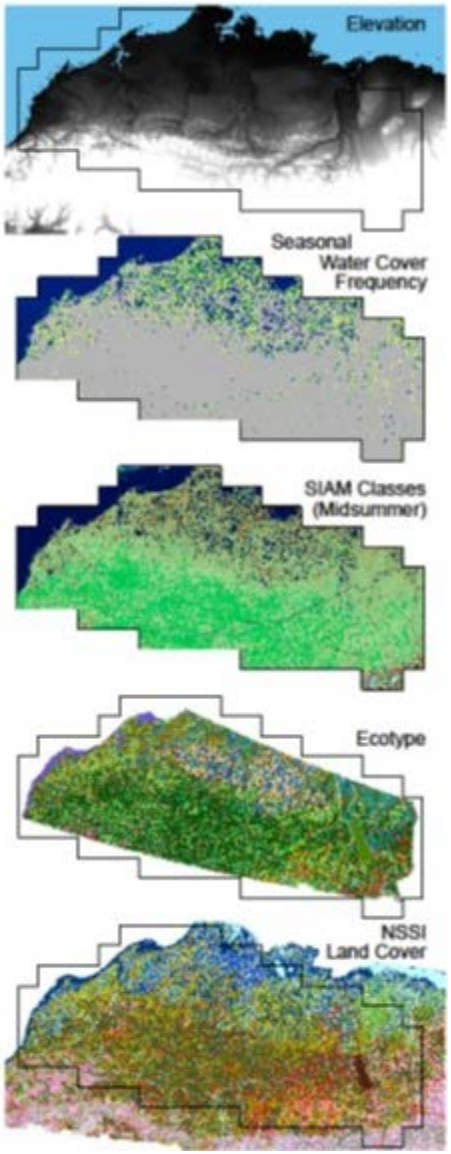


Environmental predictors

Also:

- **snow-free date**
- **Summer Warmth Index (*Raynolds et al. 2008*)**
- **slope**
- **aspect**



SAR + NED
(30 m)

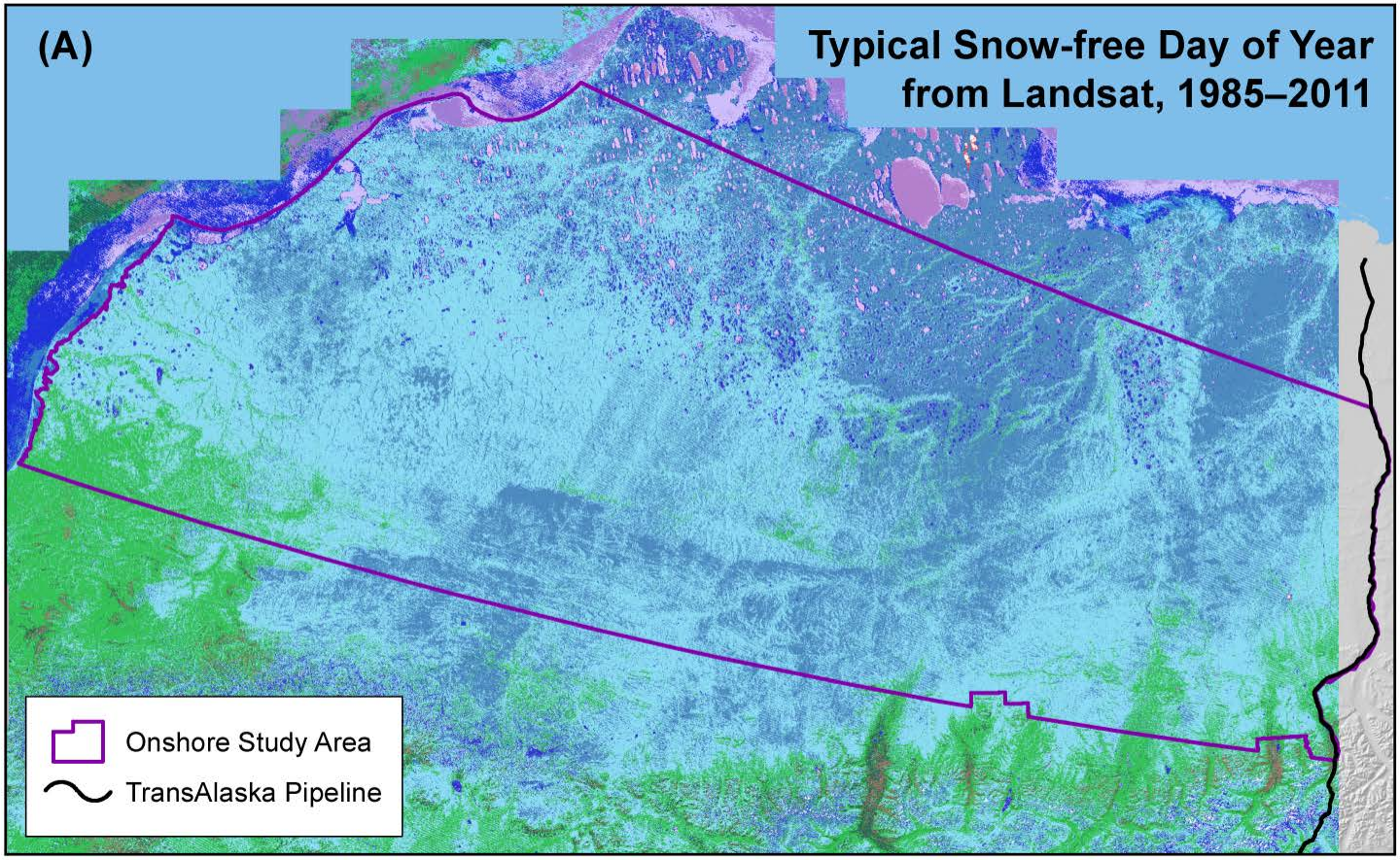
Macander 2014

Baraldi 2006

Macander 2014

NSSI 2013

Example: snow-free date



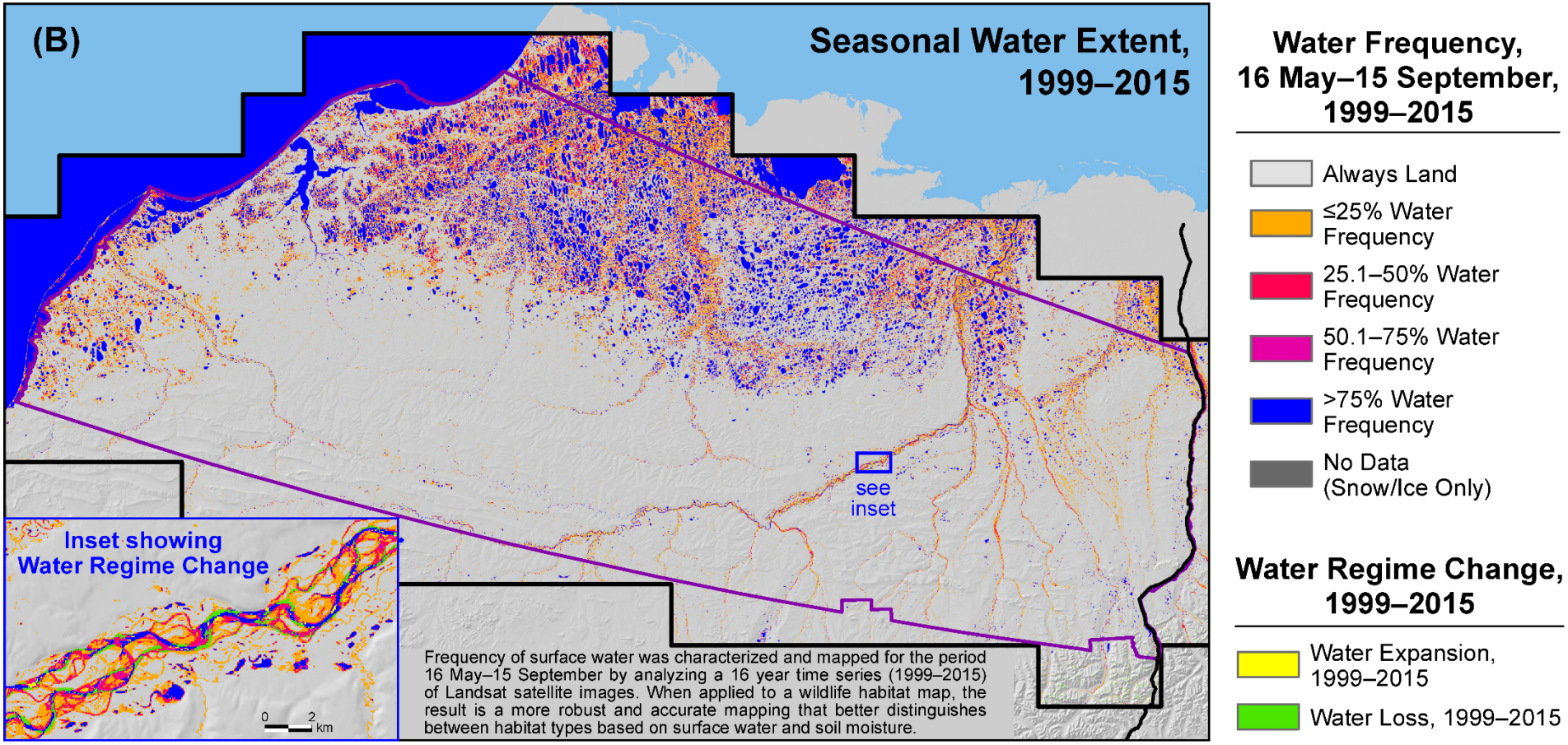
Snow-free Day of Year

- Earlier than May 1
- May 1–10
- May 11–20
- May 21–31
- June 1–10
- June 11–20
- June 21–30
- July 1–15
- July 16–31
- Later than July 31
- No Pattern
- Usually Snow-free
- Usually Snow-covered

A 26 year time-series (1985–2011) encompassing over 10,000 Landsat satellite images was used to characterize winter and spring habitat conditions related to snow depth for the Western Arctic Caribou Herd. Snow depth and persistence affect caribou winter distribution and habitat availability by impacting the energetic costs of locomotion and foraging.

Macander et al. 2015 (RSE)

Example: seasonal water frequency



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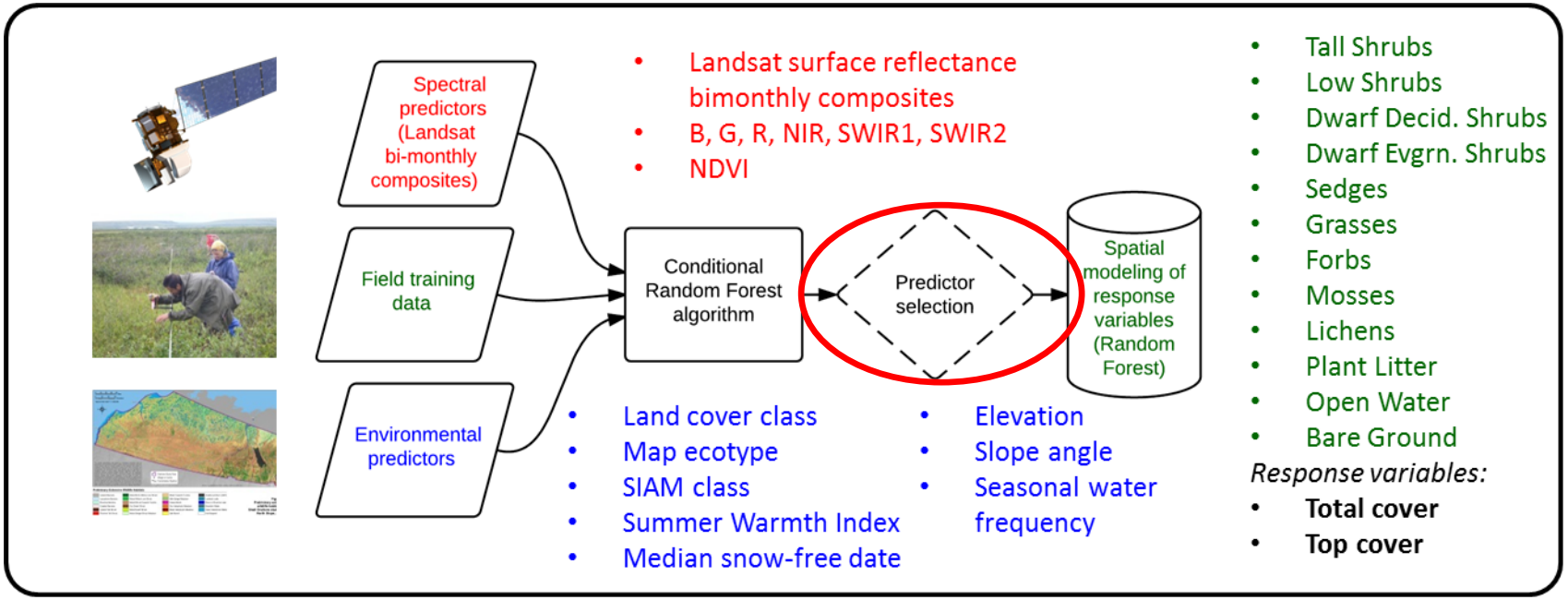
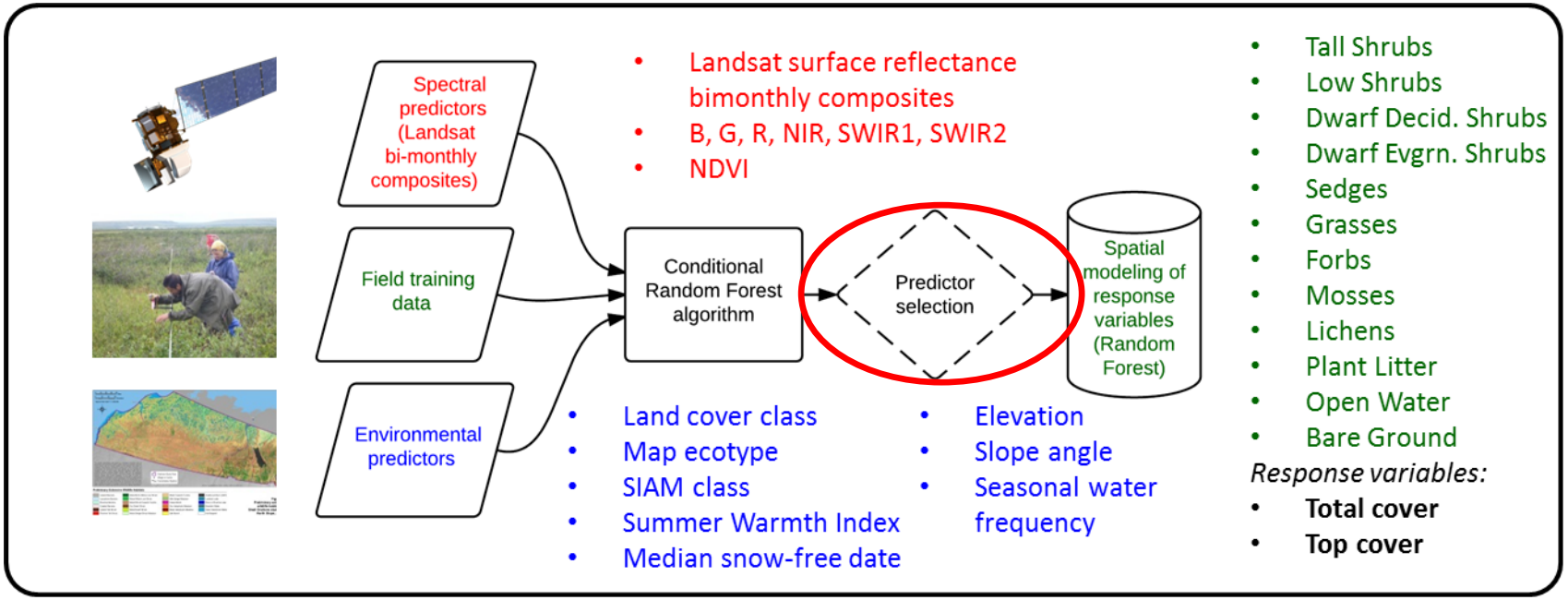


54 total predictors!

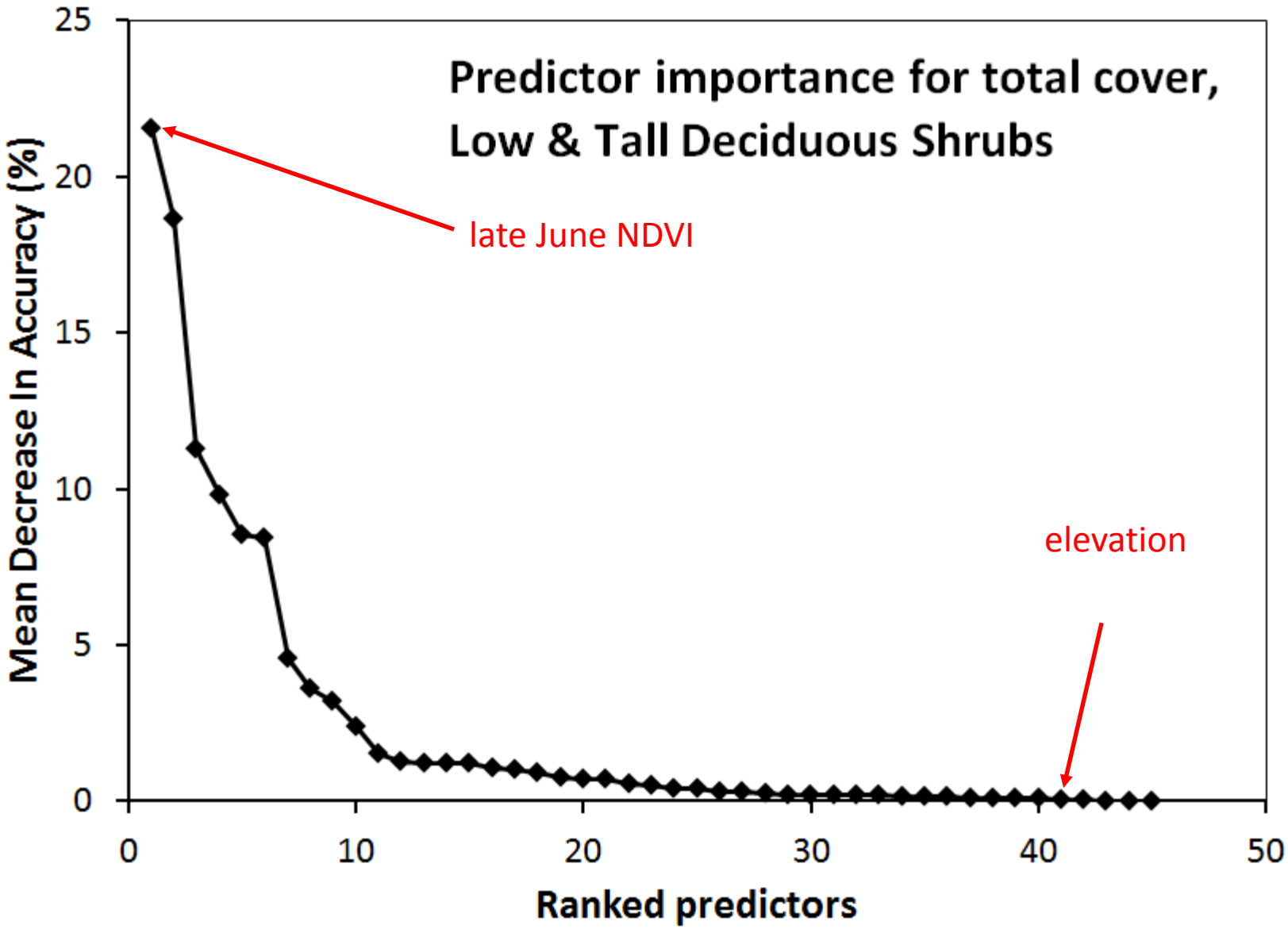
Inputs and analysis approach



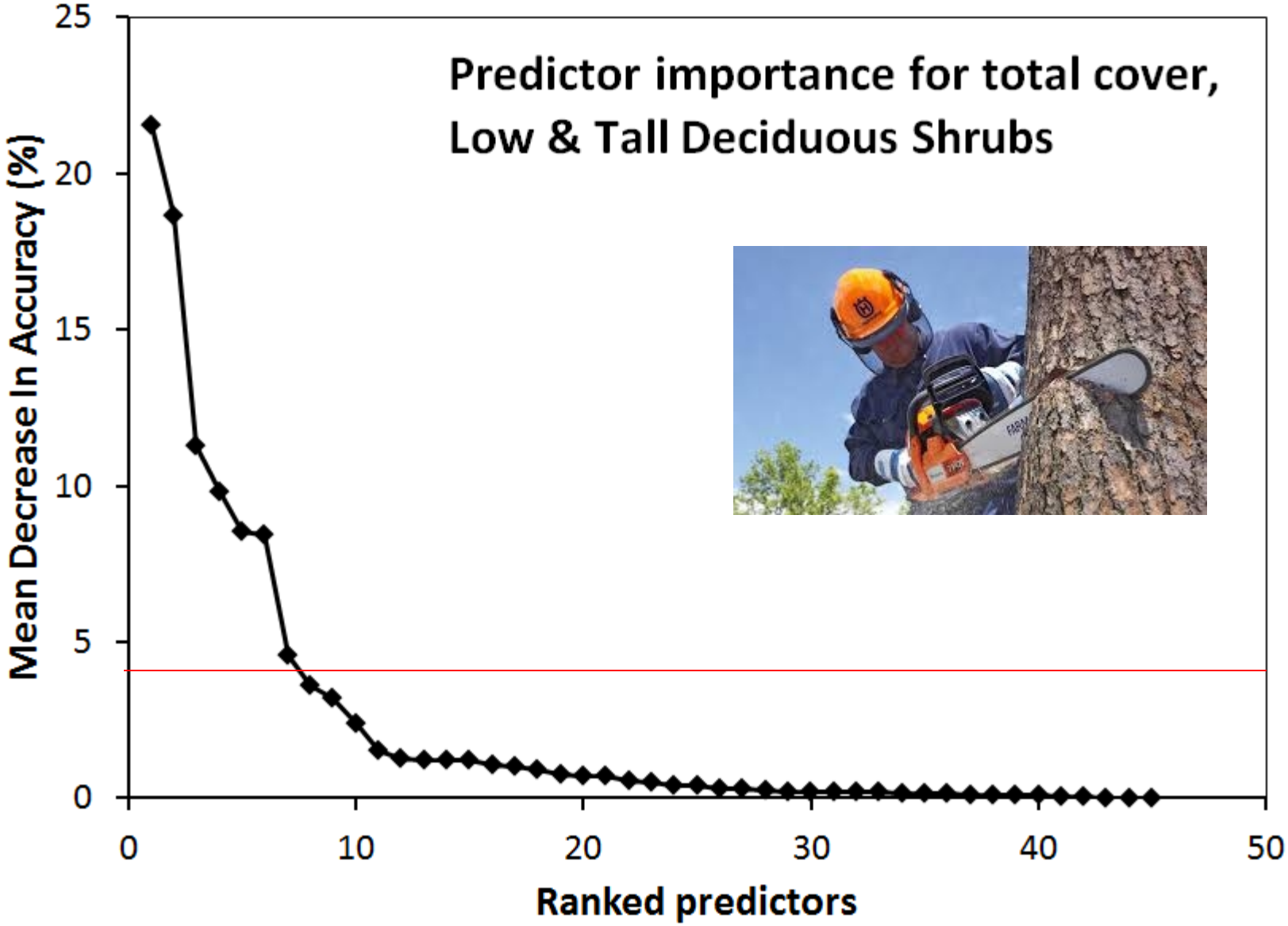
Use reduced set of predictors:

- helpful for map verification
- do the valuable predictors make sense
- informative for future efforts

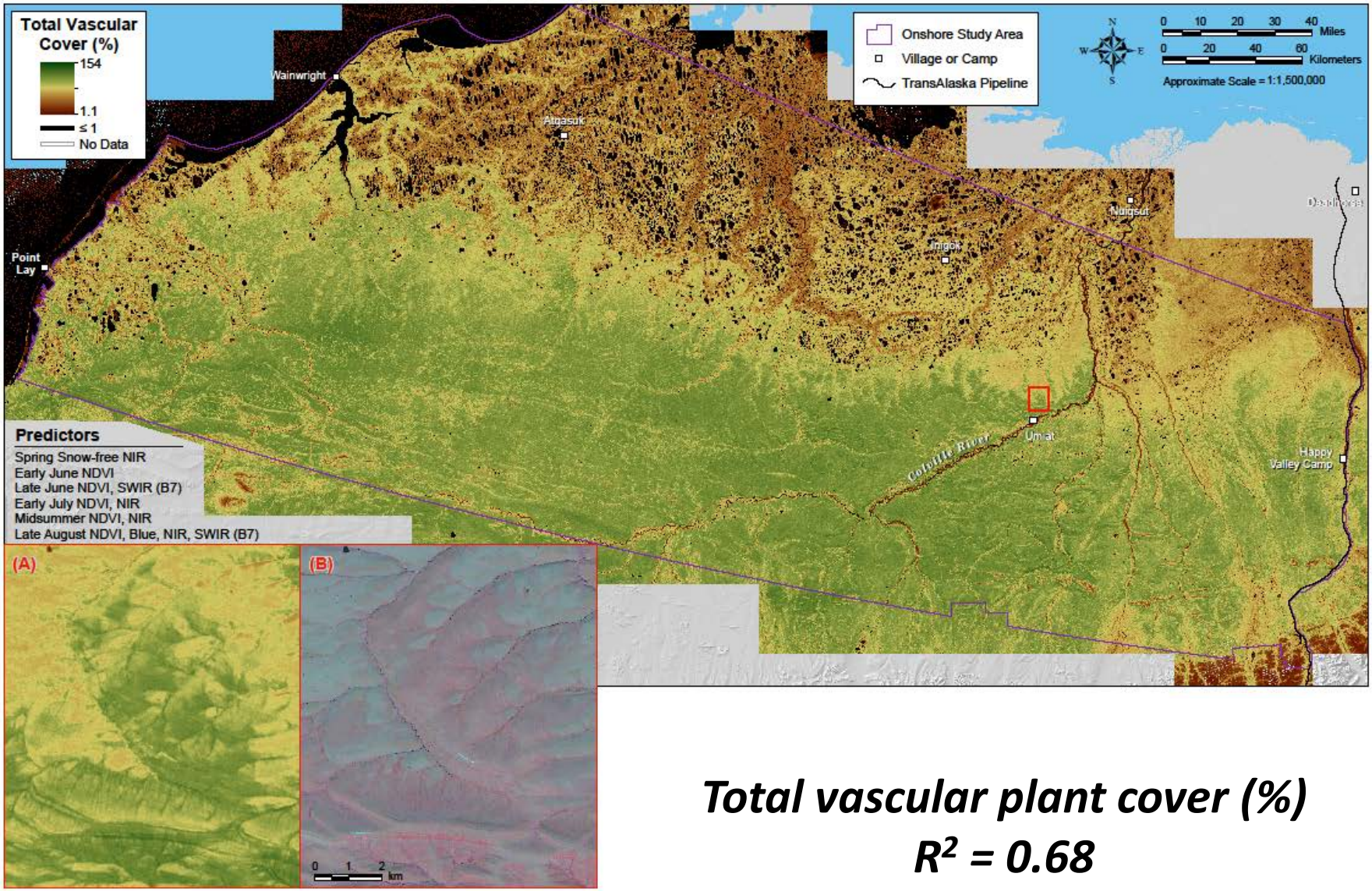
Results


Predictor importance for total cover,
Low & Tall Deciduous Shrubs
late June NDVI
elevation
Mean Decrease In Accuracy (%)
Ranked predictors
0
5
10
15
20
25
0
10
20
30
40
50

Results


Predictor importance for total cover,
Low & Tall Deciduous Shrubs
Mean Decrease In Accuracy (%)
Ranked predictors
0
5
10
15
20
25
0
10
20
30
40
50

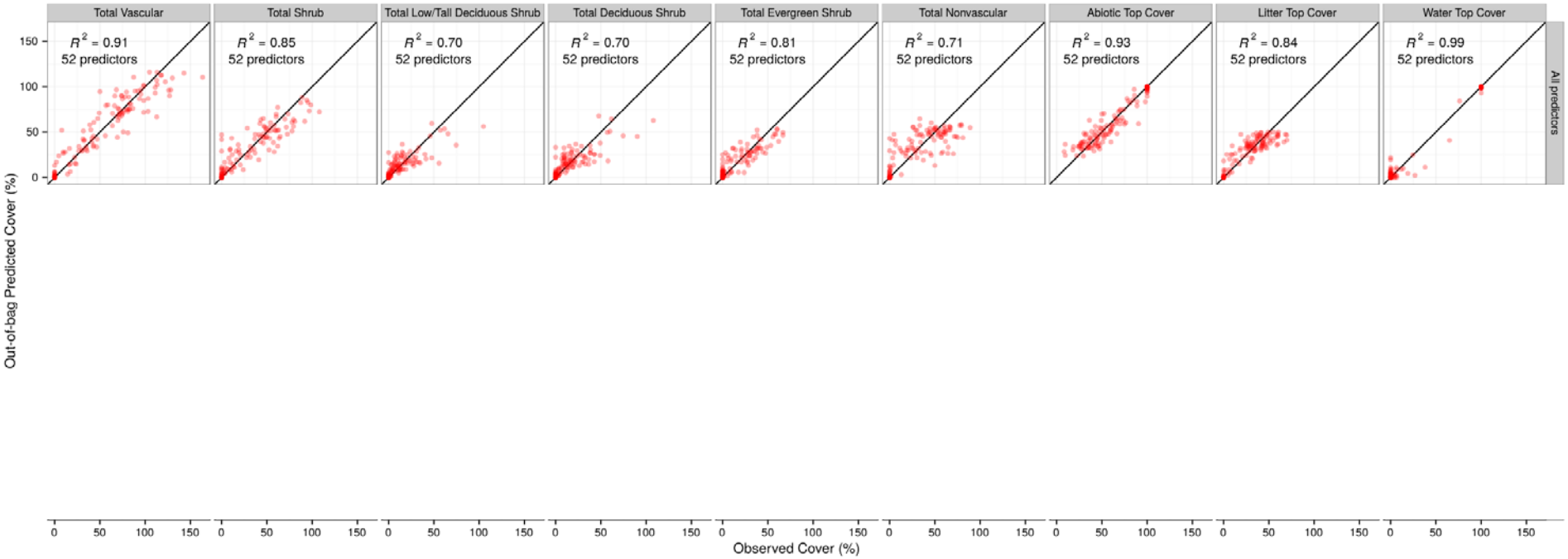
Results



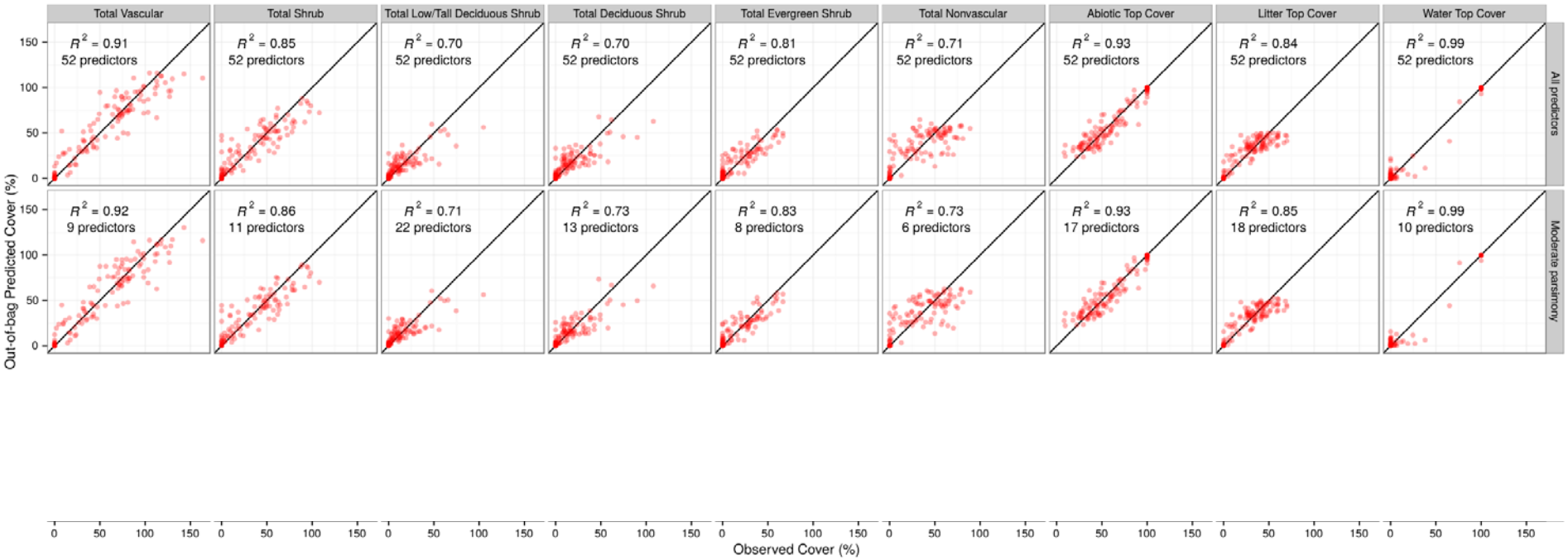
Total vascular plant cover (%)

R^2 = 0.68

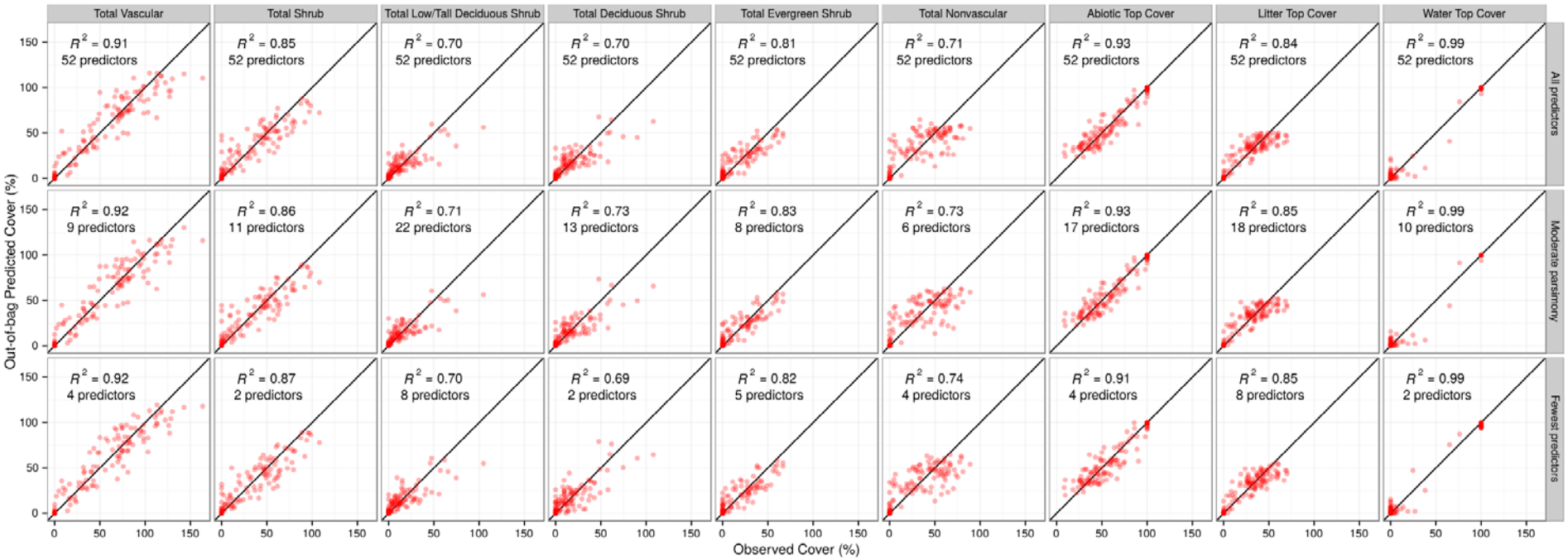
Results


Total Vascular
R^2 = 0.91
52 predictors
Total Shrub
R^2 = 0.85
52 predictors
Total Low/Tall Deciduous Shrub
R^2 = 0.70
52 predictors
Total Deciduous Shrub
R^2 = 0.70
52 predictors
Total Evergreen Shrub
R^2 = 0.81
52 predictors
Total Nonvascular
R^2 = 0.71
52 predictors
Abiotic Top Cover
R^2 = 0.93
52 predictors
Litter Top Cover
R^2 = 0.84
52 predictors
Water Top Cover
R^2 = 0.99
52 predictors
All predictors
Out-of-bag Predicted Cover (%)
Observed Cover (%)
0
50
100
150

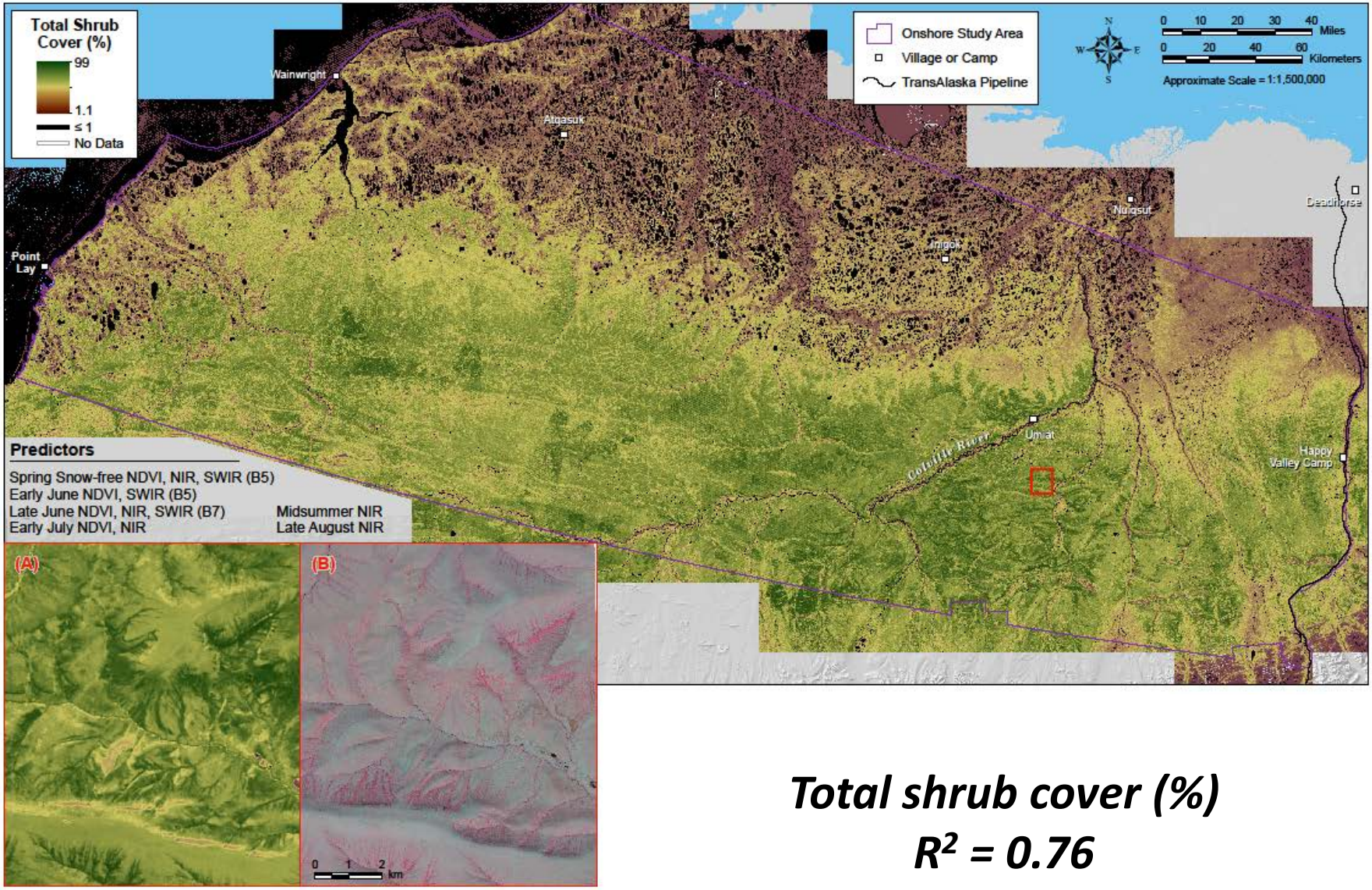
Results


Total Vascular
Total Shrub
Total Low/Tall Deciduous Shrub
Total Deciduous Shrub
Total Evergreen Shrub
Total Nonvascular
Abiotic Top Cover
Litter Top Cover
Water Top Cover
All predictors
Moderate parsimony
R^2 = 0.91
52 predictors
R^2 = 0.85
52 predictors
R^2 = 0.70
52 predictors
R^2 = 0.70
52 predictors
R^2 = 0.81
52 predictors
R^2 = 0.71
52 predictors
R^2 = 0.93
52 predictors
R^2 = 0.84
52 predictors
R^2 = 0.99
52 predictors
R^2 = 0.92
9 predictors
R^2 = 0.86
11 predictors
R^2 = 0.71
22 predictors
R^2 = 0.73
13 predictors
R^2 = 0.83
8 predictors
R^2 = 0.73
6 predictors
R^2 = 0.93
17 predictors
R^2 = 0.85
18 predictors
R^2 = 0.99
10 predictors
Out-of-bag Predicted Cover (%)
Observed Cover (%)
0
50
100
150

Results


Total Vascular
Total Shrub
Total Low/Tall Deciduous Shrub
Total Deciduous Shrub
Total Evergreen Shrub
Total Nonvascular
Abiotic Top Cover
Litter Top Cover
Water Top Cover
All predictors
Moderate parsimony
Fewest predictors
R^2 = 0.91 52 predictors
R^2 = 0.85 52 predictors
R^2 = 0.70 52 predictors
R^2 = 0.70 52 predictors
R^2 = 0.81 52 predictors
R^2 = 0.71 52 predictors
R^2 = 0.93 52 predictors
R^2 = 0.84 52 predictors
R^2 = 0.99 52 predictors
R^2 = 0.92 9 predictors
R^2 = 0.86 11 predictors
R^2 = 0.71 22 predictors
R^2 = 0.73 13 predictors
R^2 = 0.83 8 predictors
R^2 = 0.73 6 predictors
R^2 = 0.93 17 predictors
R^2 = 0.85 18 predictors
R^2 = 0.99 10 predictors
R^2 = 0.92 4 predictors
R^2 = 0.87 2 predictors
R^2 = 0.70 8 predictors
R^2 = 0.69 2 predictors
R^2 = 0.82 5 predictors
R^2 = 0.74 4 predictors
R^2 = 0.91 4 predictors
R^2 = 0.85 8 predictors
R^2 = 0.99 2 predictors
Out-of-bag Predicted Cover (%)
Observed Cover (%)
0
50
100
150

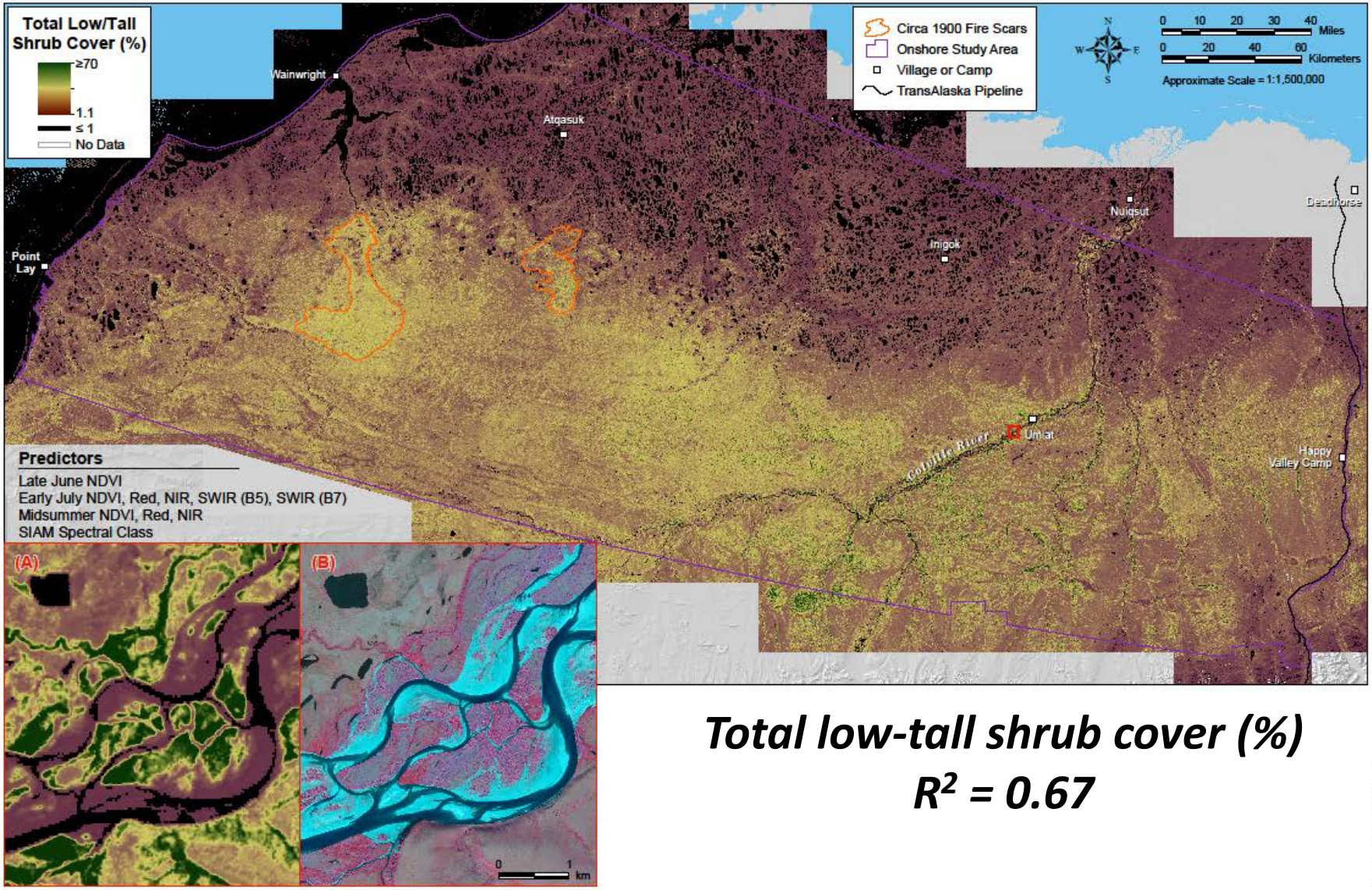
Results



Total shrub cover (%)

R^2 = 0.76

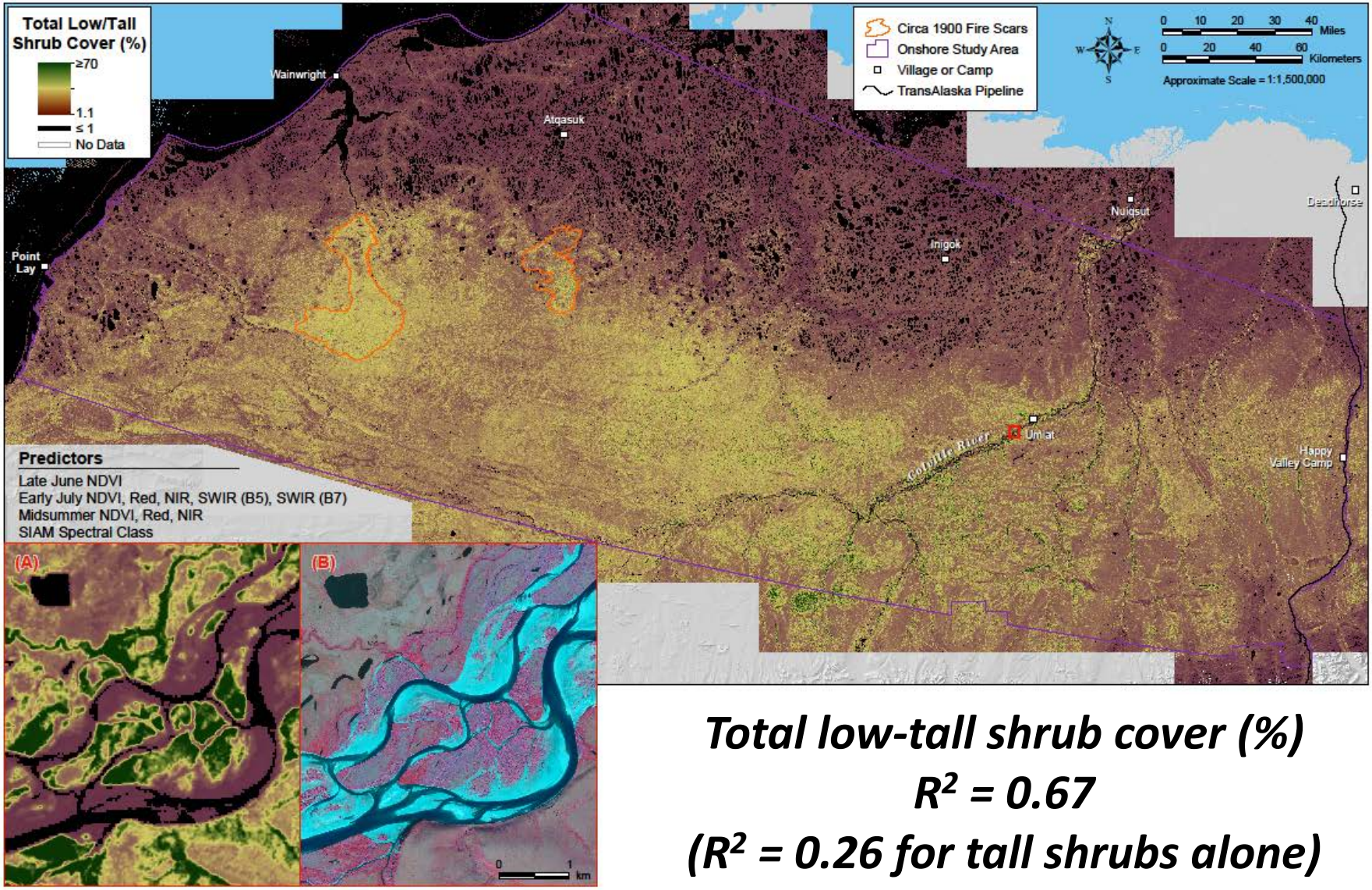
Results



Total low-tall shrub cover (%)

R^2 = 0.67

Results

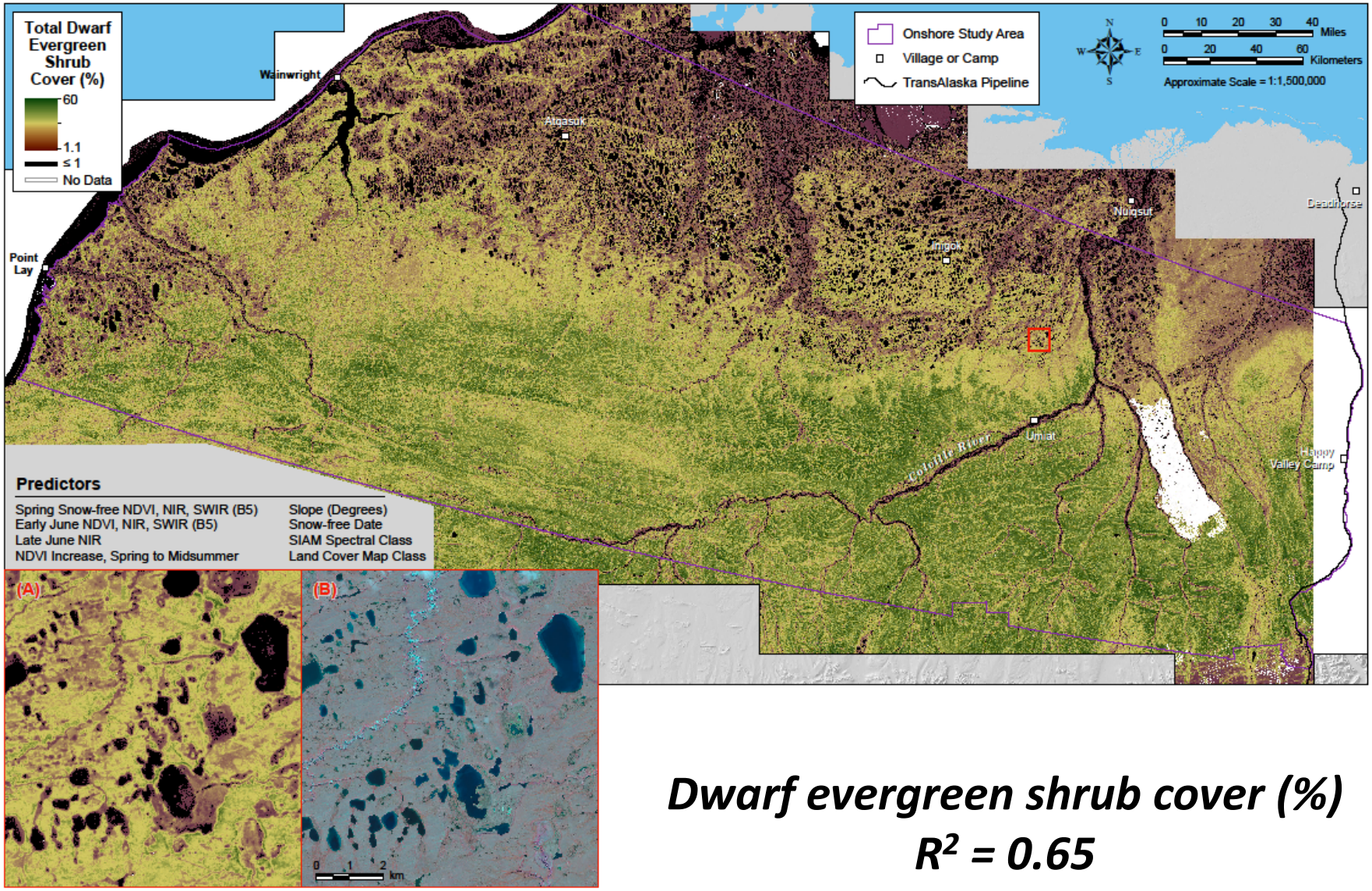


Total low-tall shrub cover (%)

R^2 = 0.67

(R^2 = 0.26 for tall shrubs alone)

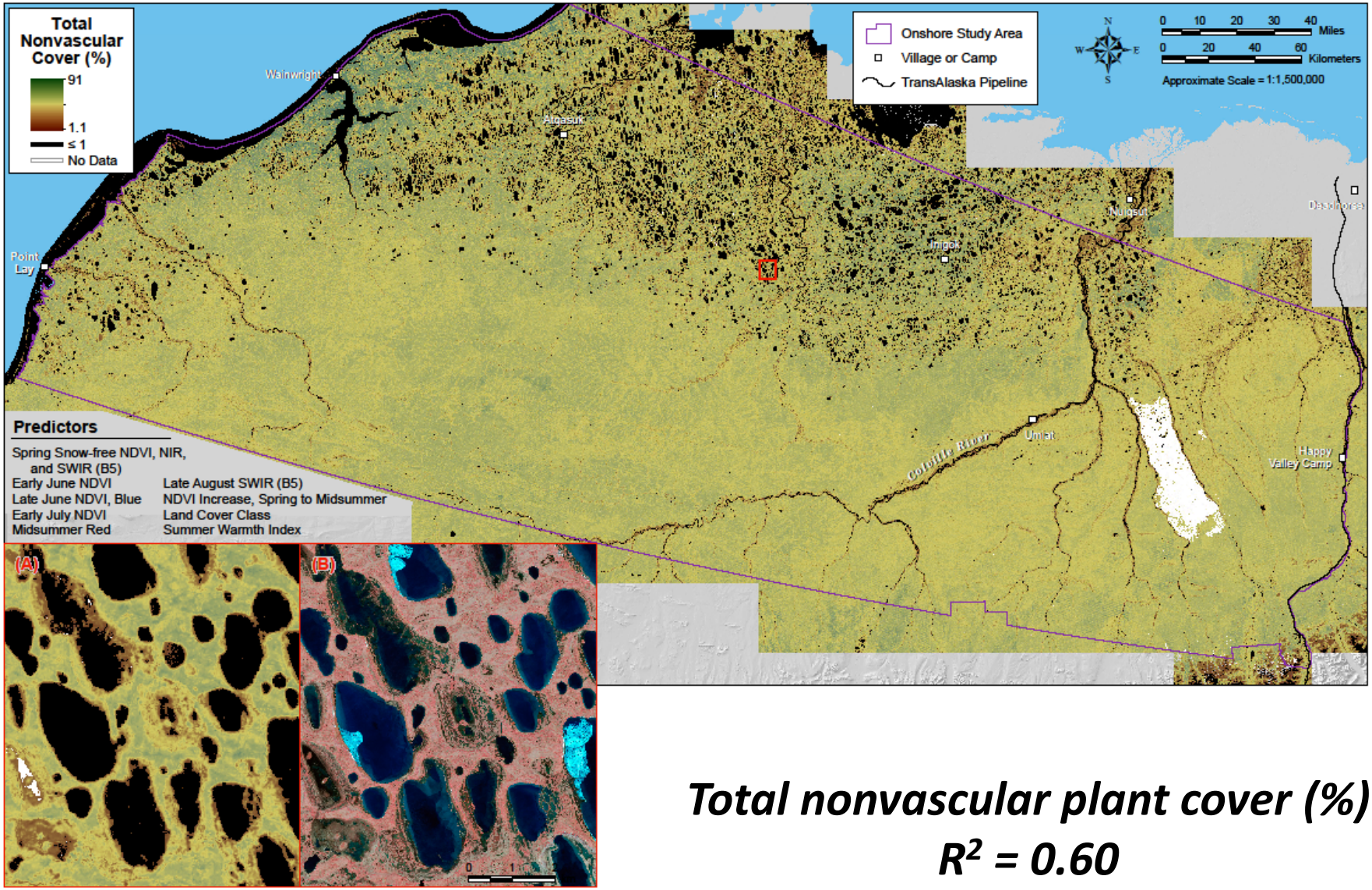
Results



Dwarf evergreen shrub cover (%)

R^2 = 0.65

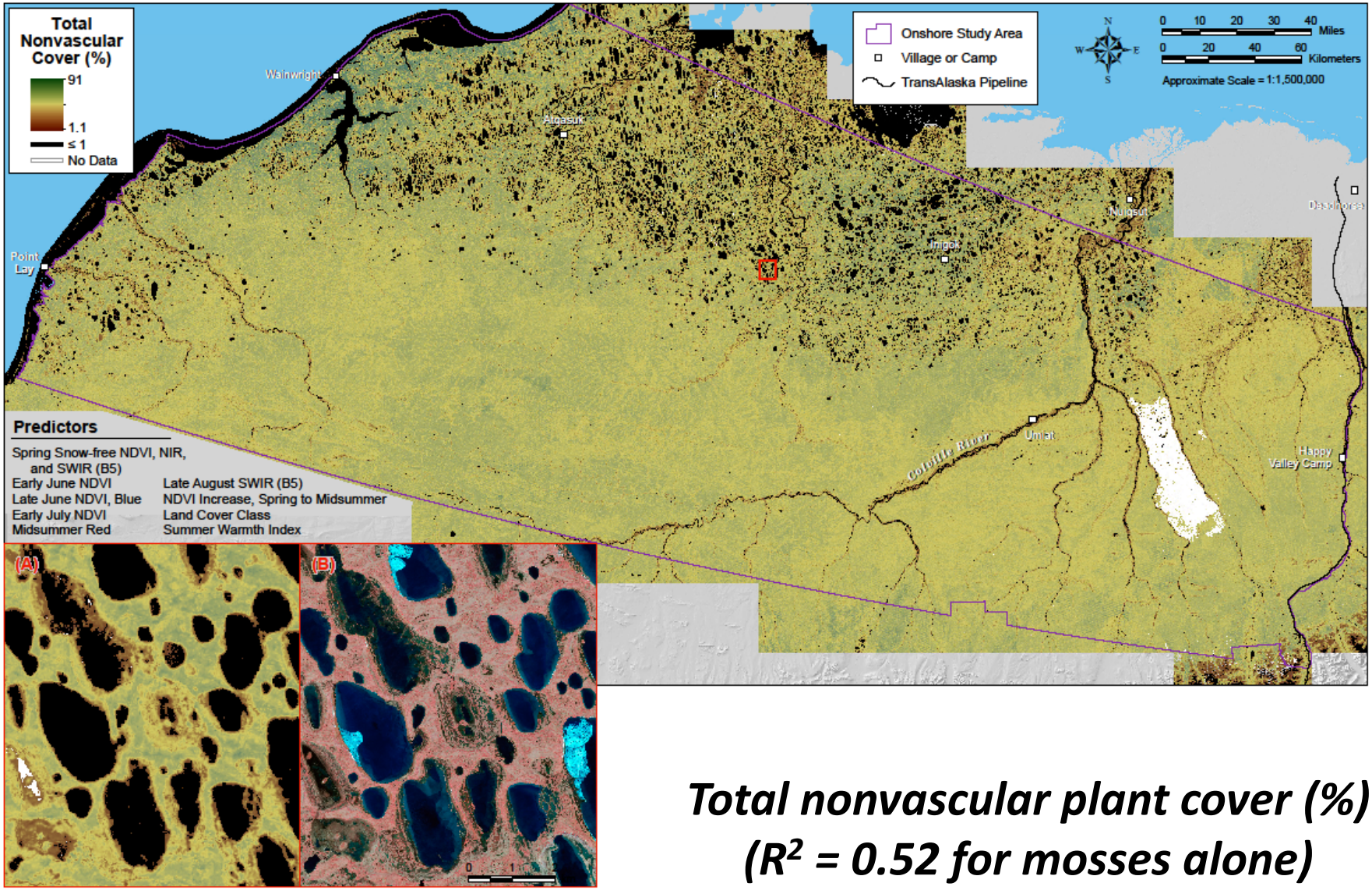
Results



Total nonvascular plant cover (%)

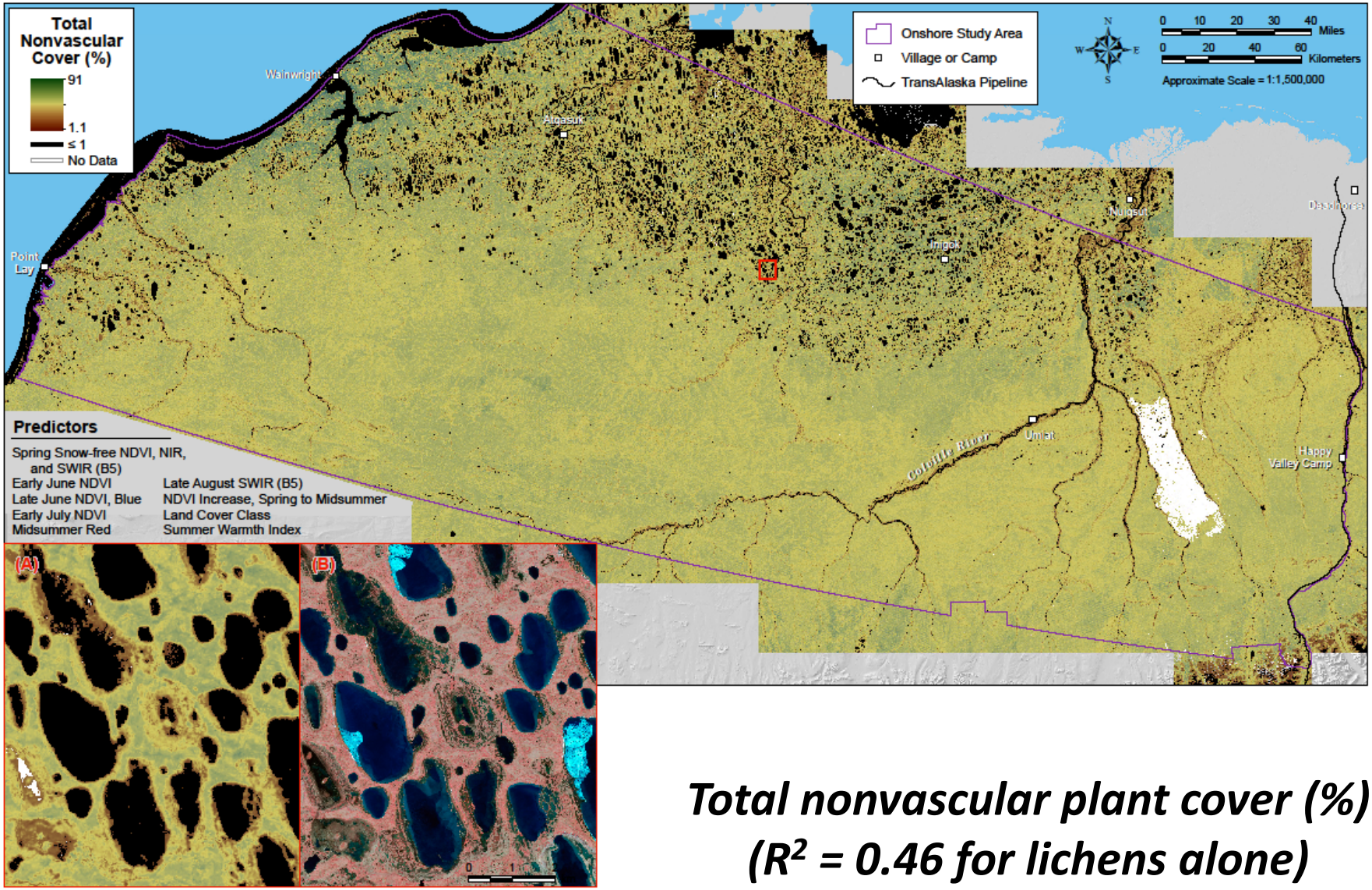
R^2 = 0.60

Results



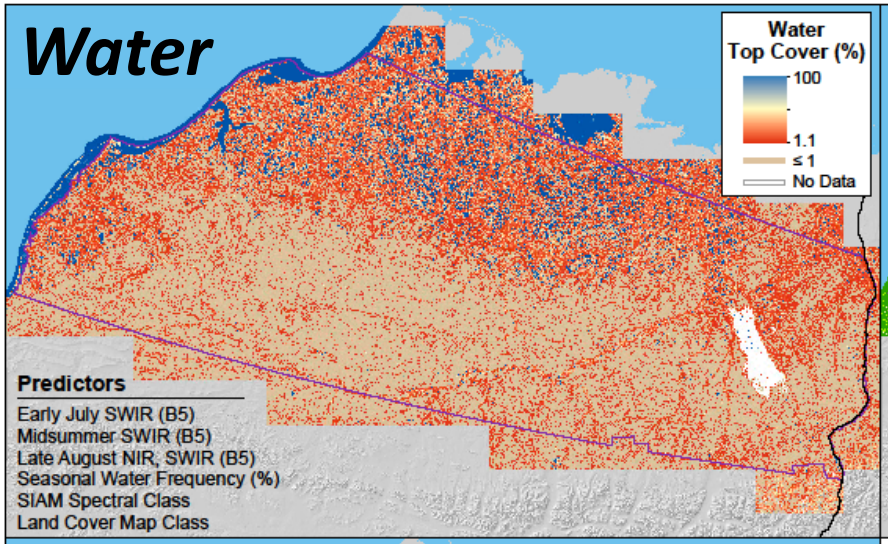
Total nonvascular plant cover (%)
(R^2 = 0.52 for mosses alone)

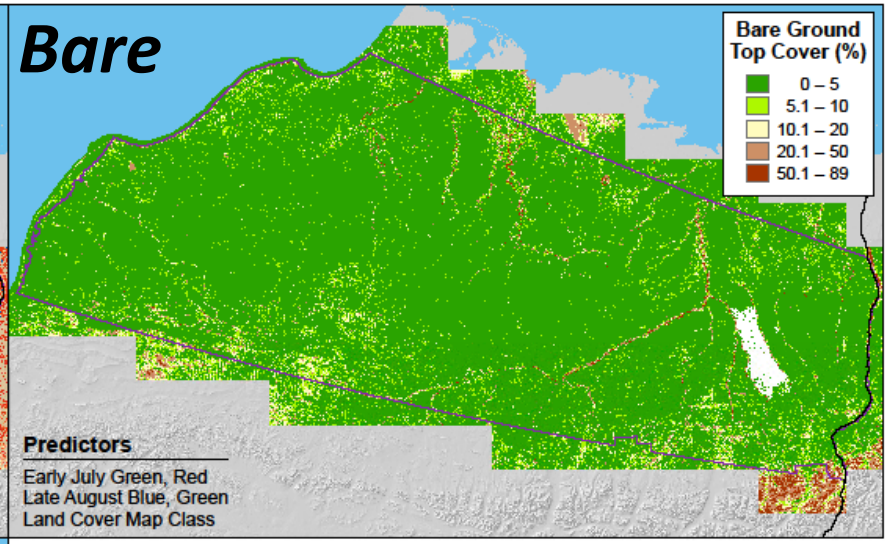
Results

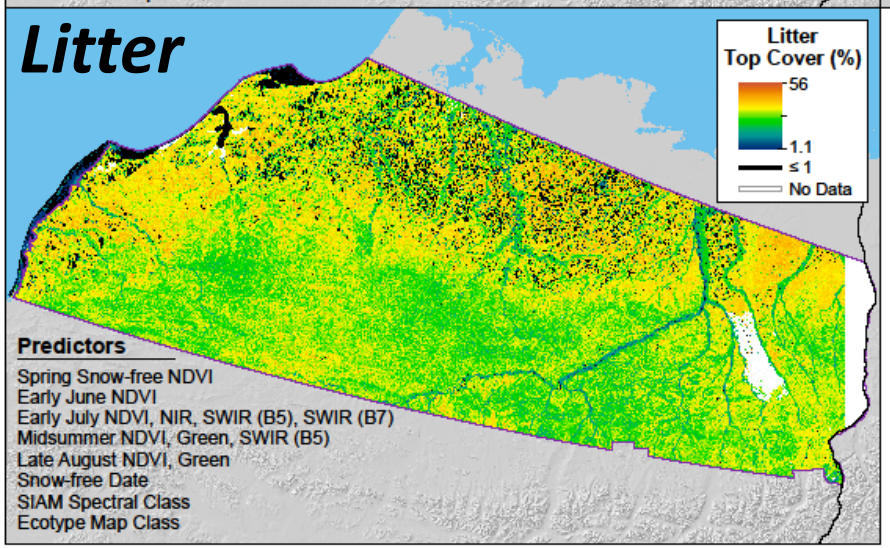


Total nonvascular plant cover (%)
(R^2 = 0.46 for lichens alone)

Results







Onshore Study Area
TransAlaska Pipeline

Approximate Scale = 1:3,000,000
0 20 40 60 80 Miles
0 40 80 120 Kilometers
N W E S

Summary

- At least six spectral predictors were selected for each PFT
- Spectral predictors came from at least three seasonal windows
- Spectral predictors from the Spring Snow-free and Midsummer composites were selected for 4 of 6 PFTs
- NDVI was by far the most common spectral predictor selected from the seasonal composites for reduced models
- Quantitative environmental predictors were infrequently selected

Summary

- Mapped PFTs across ~100,000 km^2
- PFT spatial patterns conform to environmental gradients
- Model performance best for shrubs...
- ...but difficulty in separating low and tall shrubs
- “brown tundra” composites greatly improved detection of evergreen shrubs, nonvasculars
- The maps can be updated after future BLM monitoring campaigns

Acknowledgments

- Michael Macrander, Erling Westlien (Shell)
- Barbara Bohn (Olgoonik-Fairweather)
- Residents of Wainwright and Atqasuk
- ABR and BLM field crews