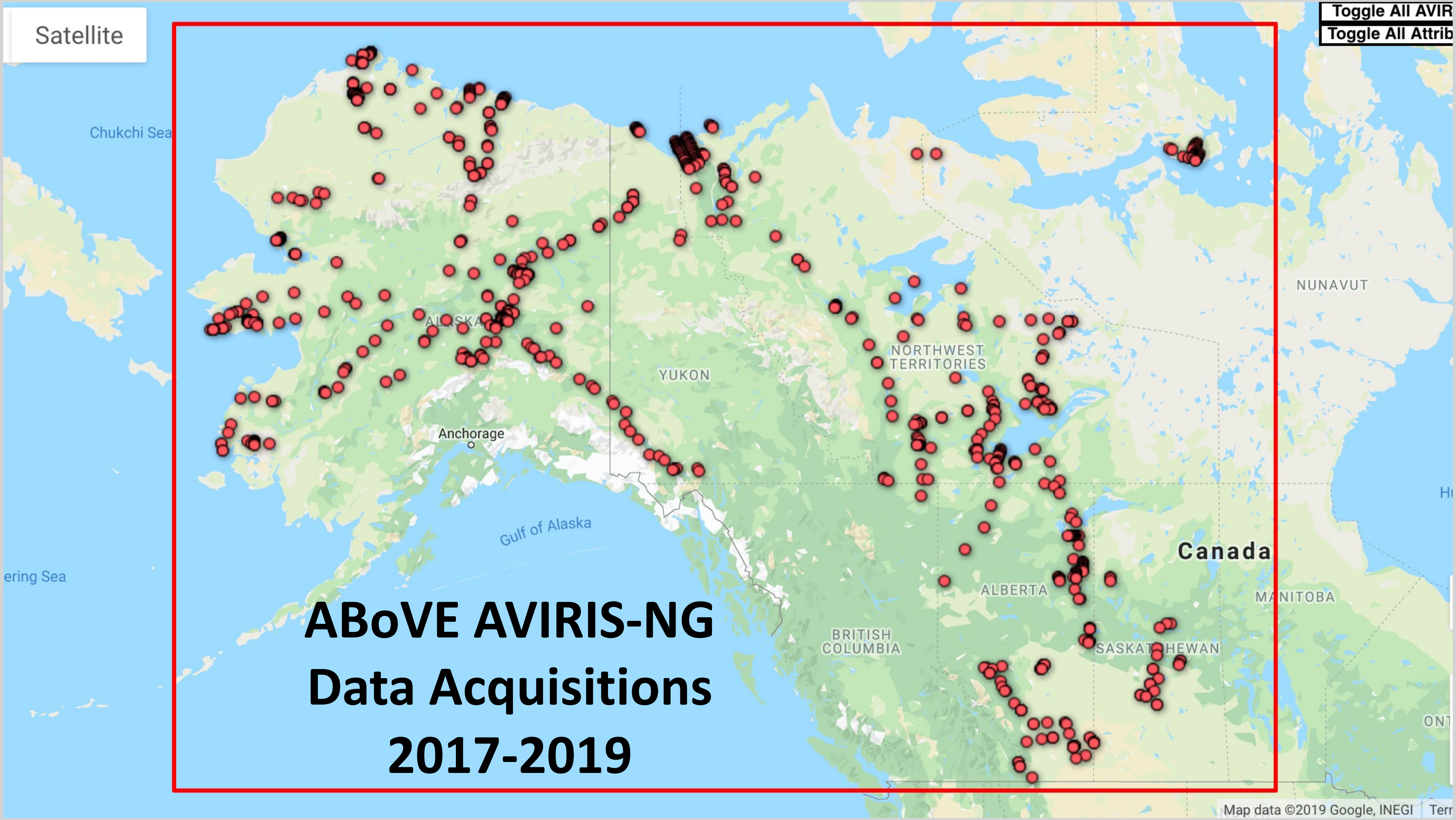
Summary of Emerging Research Results:

AVIRIS-NG Campaigns over Vegetation 2017-2022

Phil Townsend, Chip Miller and Contributors

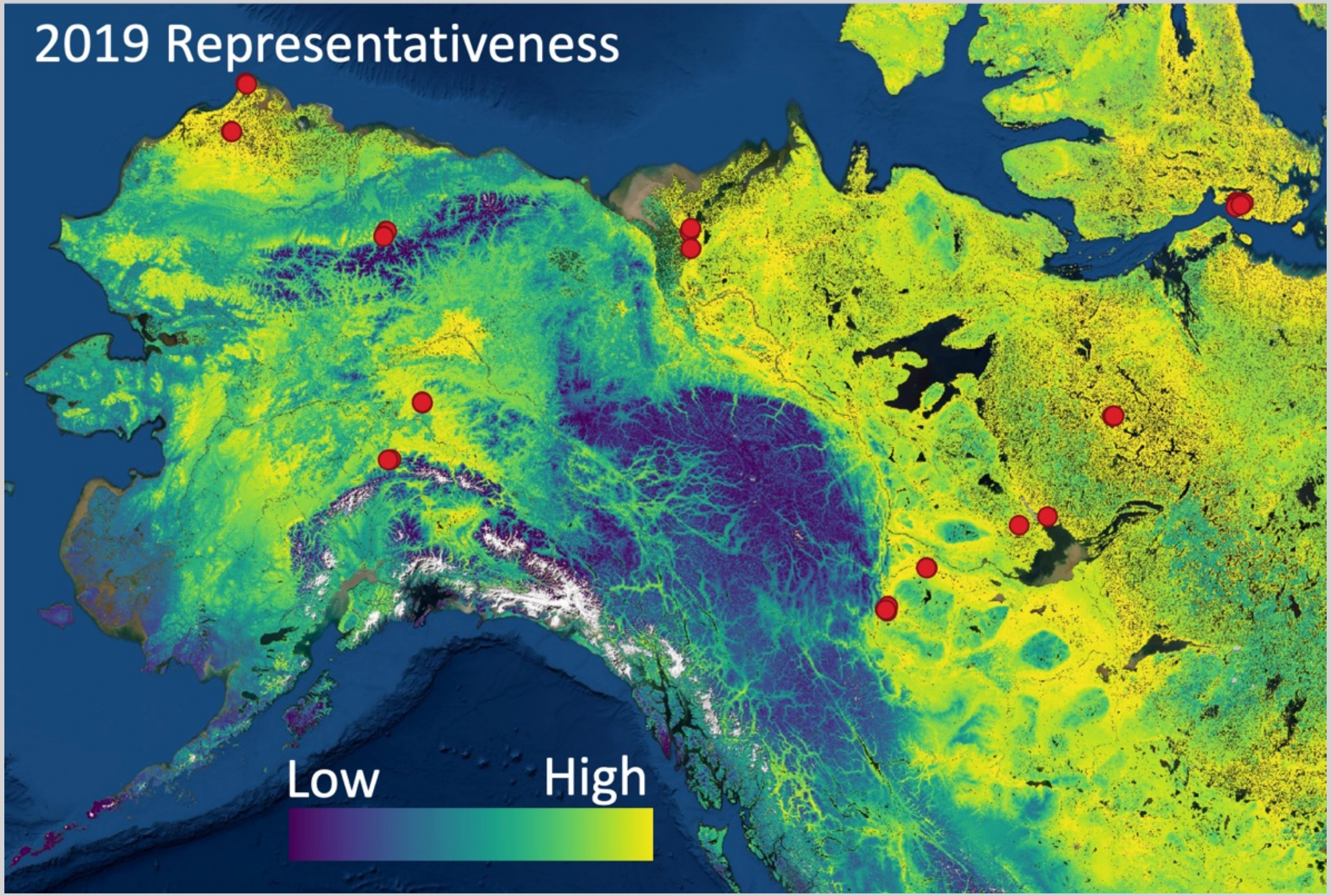


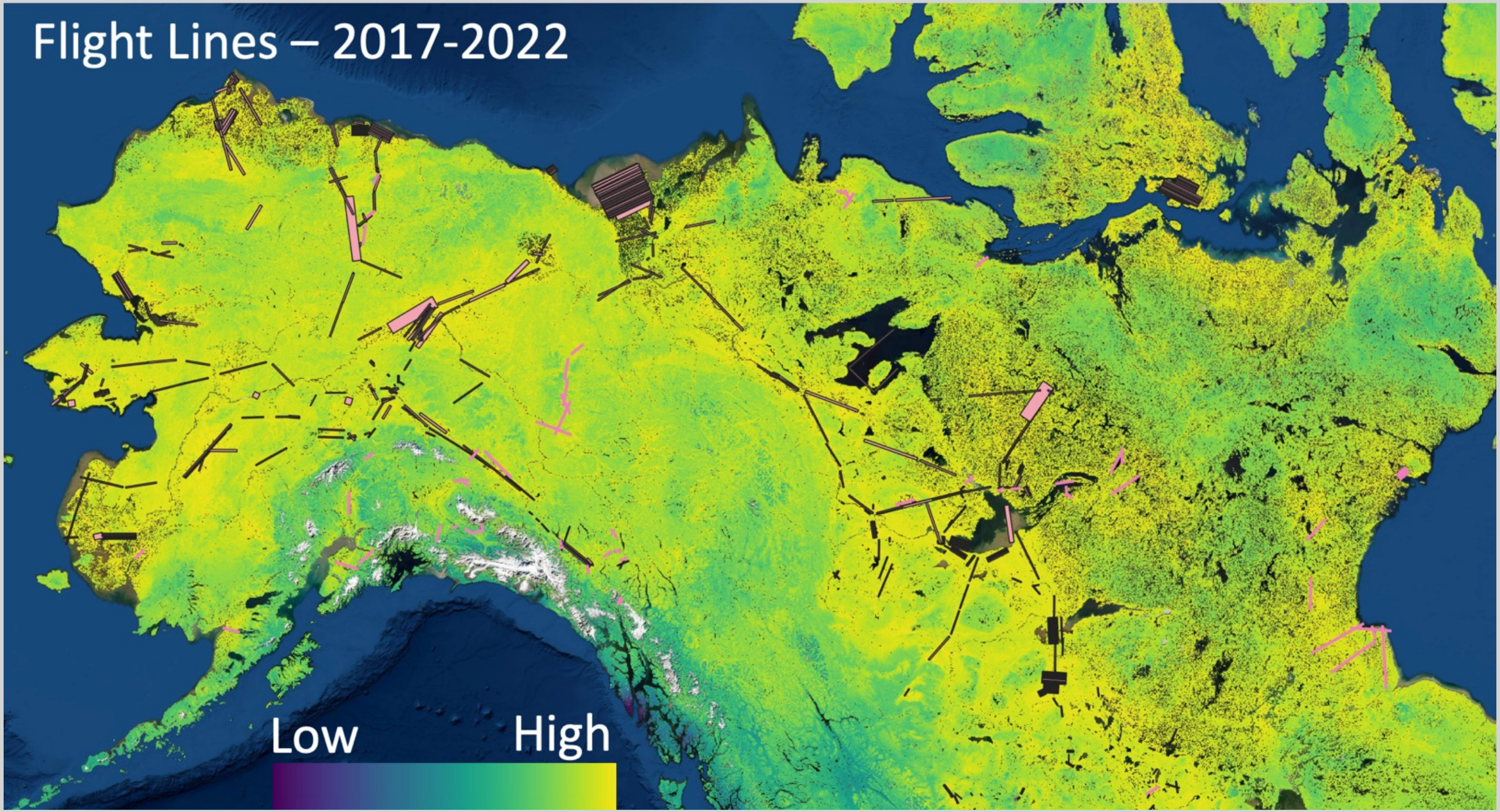
ABoVE AVIRIS-NG Data Acquisitions 2017-2019

New for 2022:
AVIRIS Trait Strategy Fills Representativeness Gaps

Ryan Pavlick (JPL), Kyle Kovach and Phil Townsend (Wisconsin)


A


2019 Representativeness
Low
High


Flight Lines – 2017-2022
Low
High

Four General Areas of Emerging Research

- Image Processing (atmospheric and other corrections)
  - Thompson, Brodrick (JPL), Queally (Wisconsin)
- Species composition and composition change, *and…*
- Upscaling and mapping foliar functional traits
  - Smith, Badola & Panda (UAF); Nelson (Schoodic Institute); Huemmrich, Campbell, Tweedie, Vargas (GSFC/UTEP), Yang & Serbin (BNL); Wenqu Chen and Jennifer Fraterrigo (Illinois); Kyle Kovach, Phil Townsend (Wisconsin) & Ryan Pavlick (JPL)
- Linkage to fluxes (GPP, methane)
  - Miller, Latha Baskaran, Clayton Elder (JPL); Orcutt (Sacramento State), Magney (UC Davis), Frankenburg (CalTech), Maguire (CSP), Pierrat (UCLA)
- Major theme: Scaling: Leaf→Plot→Drone→Airplane→Satellite

Airborne Image Processing

- Challenges of atmospheric corrections in heterogeneous environments (surface and atmosphere)

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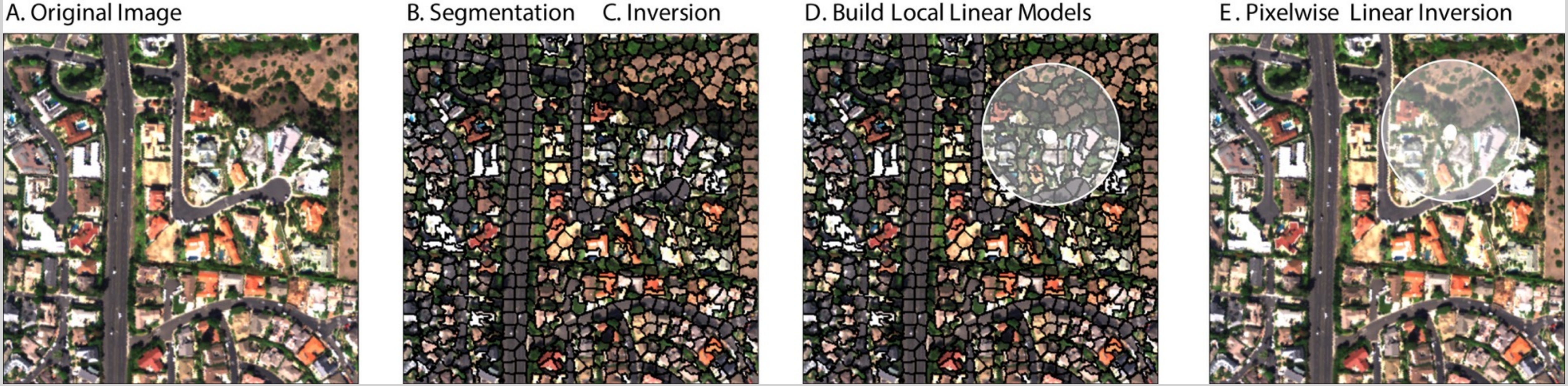
Research Article | Open Access

Atmospheric Lengthscales for Global VSWIR Imaging Spectroscopy

David R. Thompson, Niklas Bohn, Philip G. Brodrick, Nimrod Carmon, Michael L. Eastwood, Regina Eckert, Cédric G. Fichot, Joshua P. Harringmeyer, Hai M. Nguyen, Marc Simard, Andrew K. Thorpe

First published: 09 June 2022 | https://doi.org/10.1029/2021JG006711 | Citations: 1

- Estimation of surface reflectance and atmospheric state is computationally challenging
- ISOFIT uses emulation to capture RTM behavior
- Segmentation is used to preclude inverting every pixel



BRDF, Topographic, Solar Zenith Angle Correction

- ABoVE-wide algorithms require consistent processing across many overlapping flightlines with highly variable surface characteristics

JGR Biogeosciences

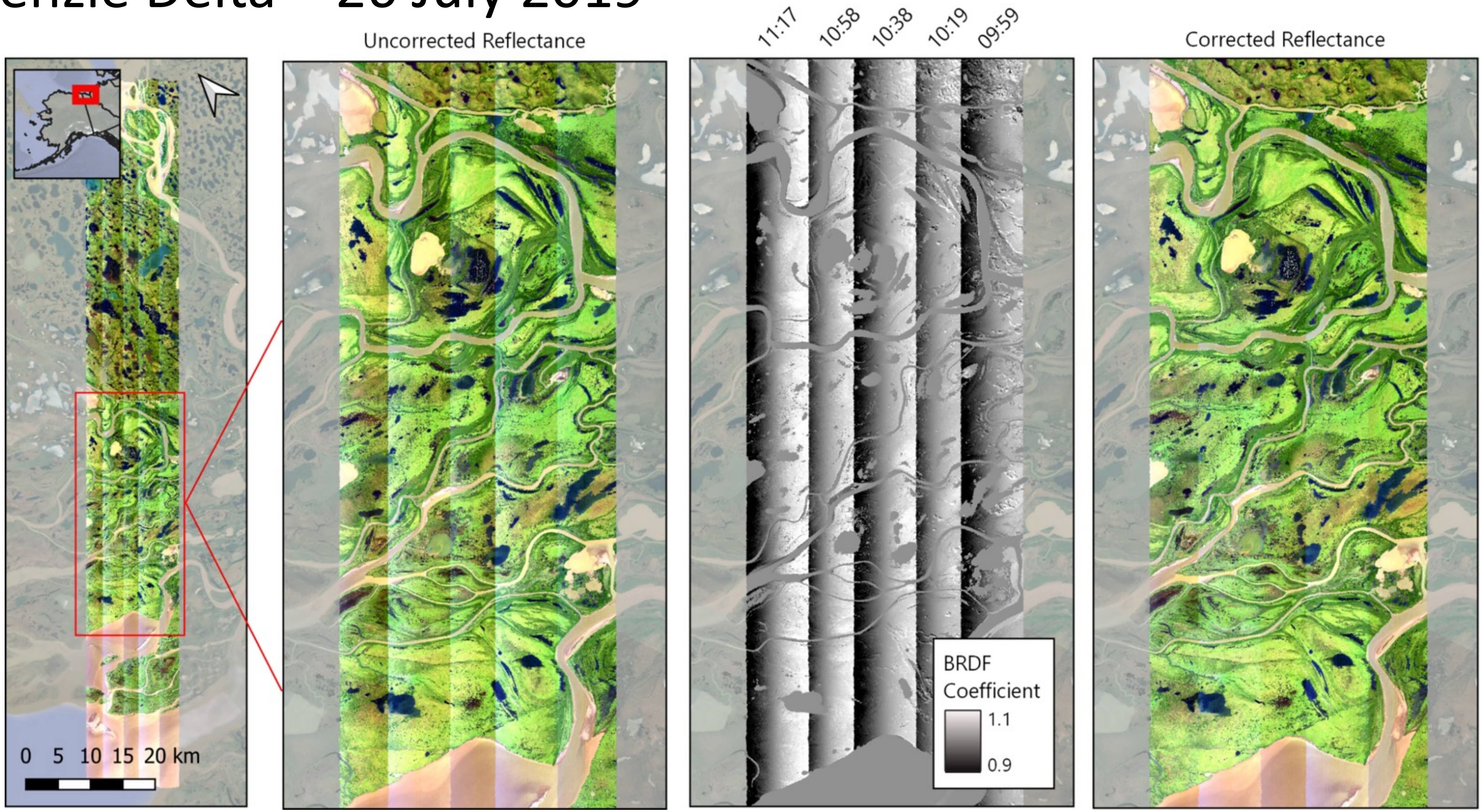
Research Article | Open Access

FlexBRDF: A Flexible BRDF Correction for Grouped Processing of Airborne Imaging Spectroscopy Flightlines

Natalie Queally, Zhiwei Ye, Ting Zheng, Adam Chlus, Fabian Schneider, Ryan P. Pavlick, Philip A. Townsend

First published: 05 January 2022 | https://doi.org/10.1029/2021JG006622 | Citations: 1

Mackenzie Delta – 26 July 2019



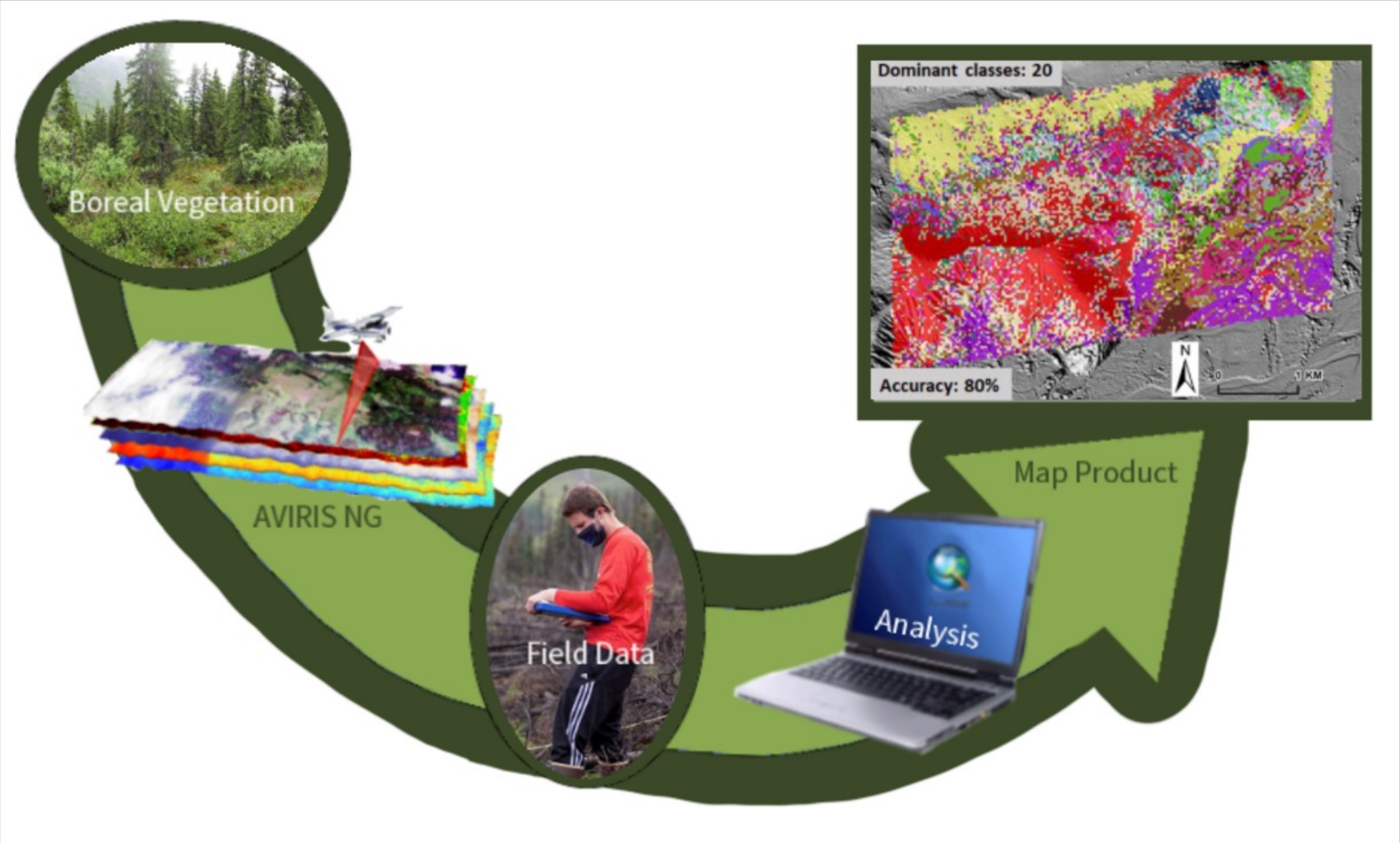
Wildfire Fuel Type

- Santosh Panda, Christopher Smith, Anushree Badola, Uma Bhatt + collaborators (UAF)

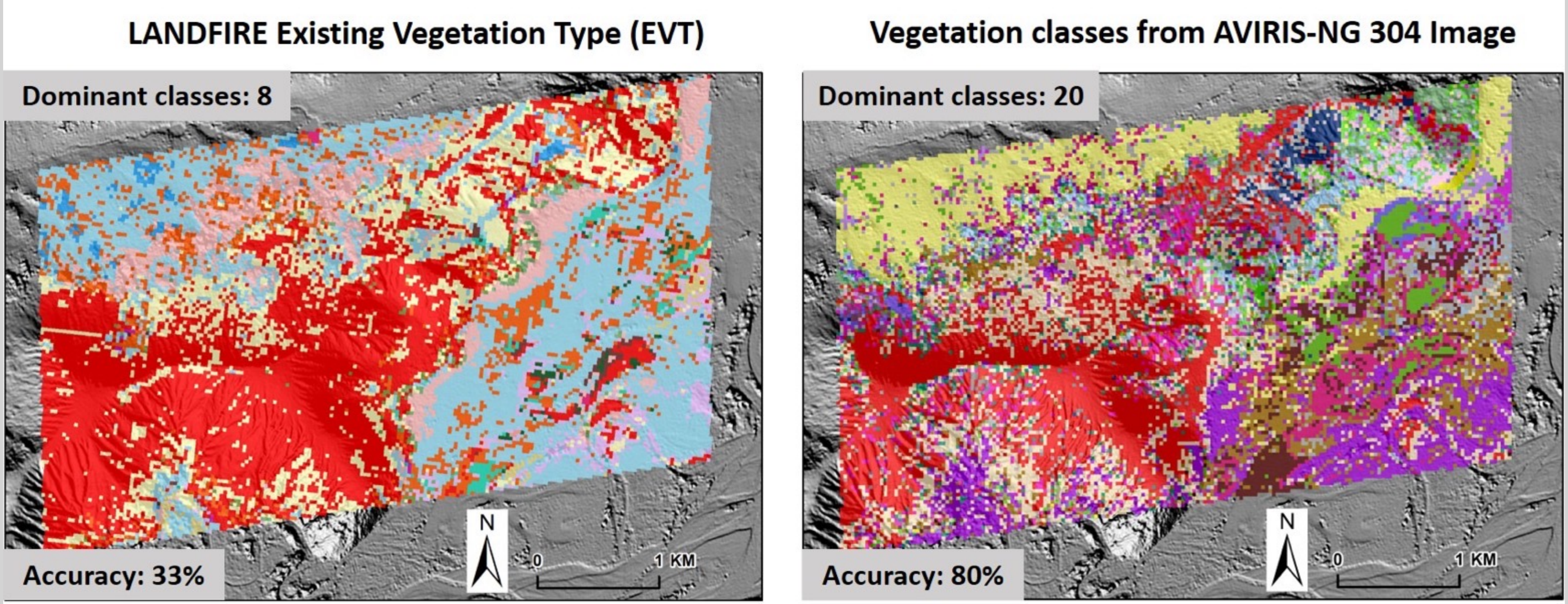
- Badola, A., **Panda, S.K.**, Roberts, D.A., Waigl, C., Jandt, R.R., Bhatt, U.S. 2022. A novel method to simulate AVIRIS-NG hyperspectral image from Sentinel-2 image for improved vegetation/wildfire fuel mapping, boreal Alaska. *International Journal of Applied Earth Observation and Geoinformation,*. V. 112 (102891). *https://doi.org/10.1016/j.jag.2022.102891*
- Badola, A., **Panda, S.K.**, Roberts, D.A., Waigl, C., Bhatt, U.S., Smith, C.W., Jandt, R.R. 2021. Hyperspectral data simulation (Sentinel-2 to AVIRIS-NG) for improved wildfire fuel mapping, boreal Alaska. *Remote Sensing*, *13(9): 1693*. https://doi.org/10.3390/rs13091693
- Smith, C.W., **Panda, S.K.**, Bhatt, U.S., Meyer, F.J. 2021. Improved boreal forest wildfire fuel type mapping using AVIRIS-NG hyperspectral data, interior Alaska. *Remote Sensing, 13(5): 897*. https://doi.org/10.3390/rs13050897

Improved Wildfire Fuel Type Mapping using NASA AVIRIS-NG Hyperspectral data, Interior Alaska (Christopher Smith)

- Urgent need to improve on 30 m Landsat products
- Use RF with AVIRIS-NG to develop vegetation type and fire fuel maps



Comparison of vegetation map products for 2014 LF EVT and AVIRIS-NG 304 band image. Colors represent distinct vegetation classes.



Citation: Smith, C.W. *et al.*, 2021, *Remote Sensing,* https://doi.org/10.3390/rs13050897.
Support: National Science Foundation award OIA-1757348 and by the State of Alaska.
Data: NASA ABoVE for AVIRIS-NG and Polar Geospatial Center Arctic DEM;

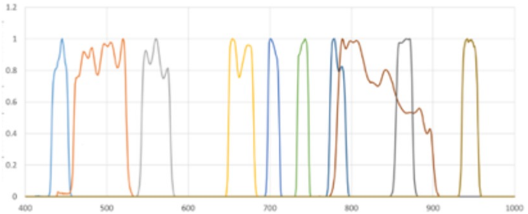
Upscaling improved Vegetation/Fuel Maps for the Boreal Region of Alaska

Research question: How to generate improved vegetation/fuel map for boreal region of Alaska?

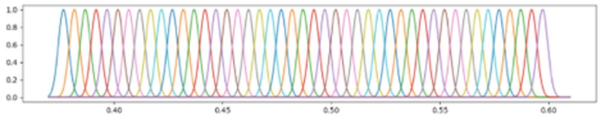
Input

Sentinel-2 Data

Ground Spectra



Spectral Response Function
Multispectral Data



Spectral Response Function
Hyperspectral Data

Process

Universal Pattern Decomposition Method

UPDM Formula:

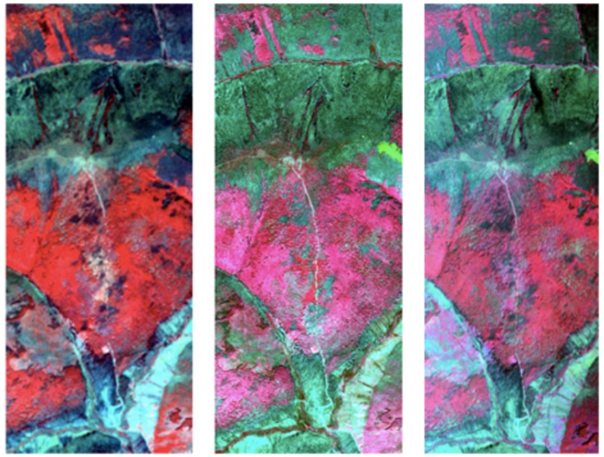
$$R = P_wC_w + P_sC_s + P_vC_v$$

UPDM Matrix Form:

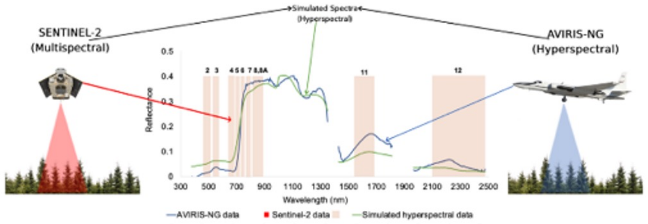
$$\begin{pmatrix} R_1 \\ R_2 \\ \vdots \\ R_n \end{pmatrix} = \begin{pmatrix} P_{1w} & P_{1s} & P_{1v} \\ P_{2w} & P_{2s} & P_{2v} \\ \vdots & \vdots & \vdots \\ P_{nw} & P_{ns} & P_{nv} \end{pmatrix} \cdot \begin{pmatrix} C_w \\ C_s \\ C_v \end{pmatrix}$$

Where,
w= water
s= soil
v= vegetation
n= band number
R= total pixel reflectance
C= proportion of class
P= normalised ground reflectance

Output



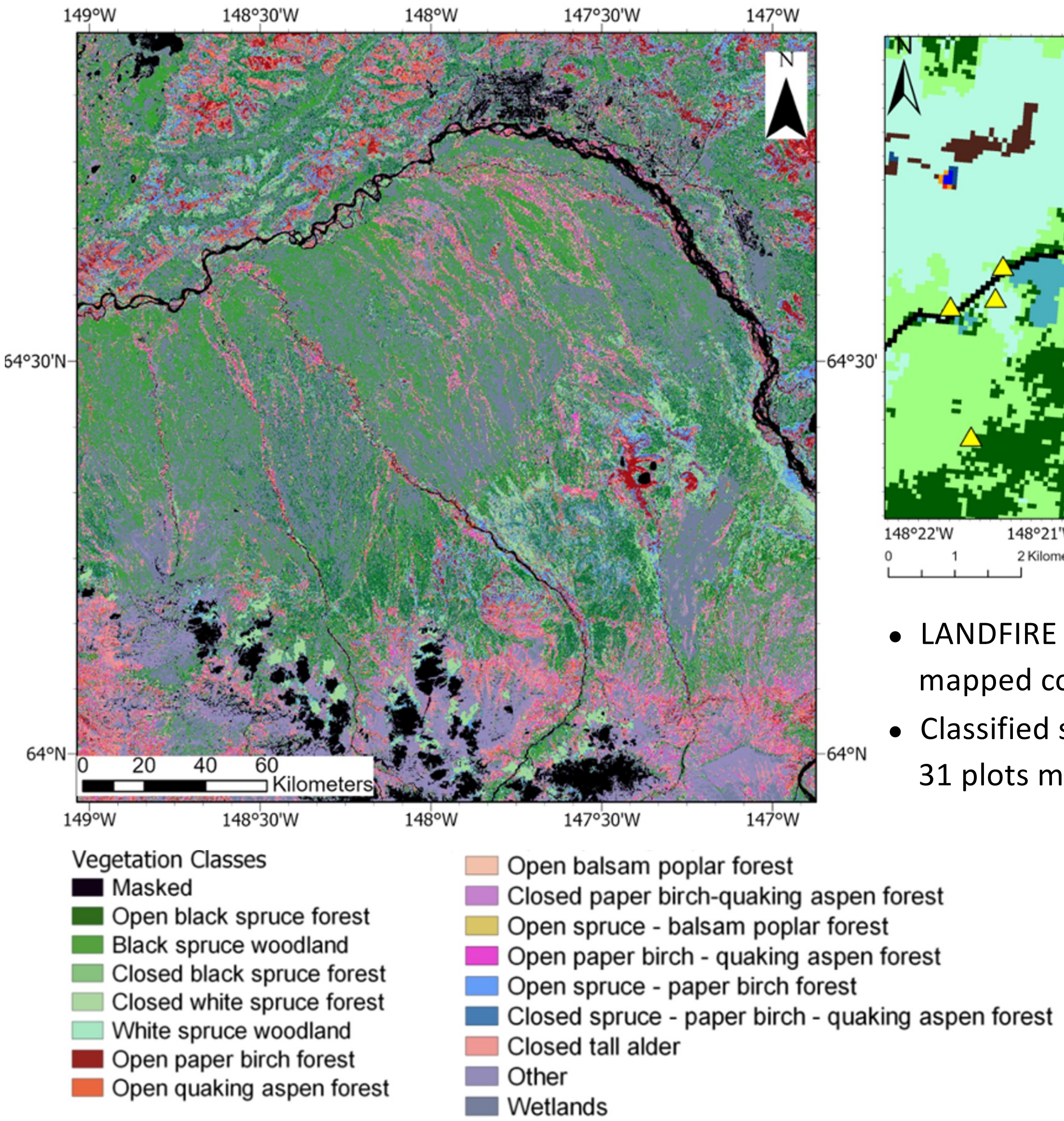
Sentinel 2	**Simulated data**	**AVIRIS-NG**
Pixel Size: 10m	Pixel Size: 10m	Pixel Size: 5m
Bands:11	Bands: 425	Bands: 425



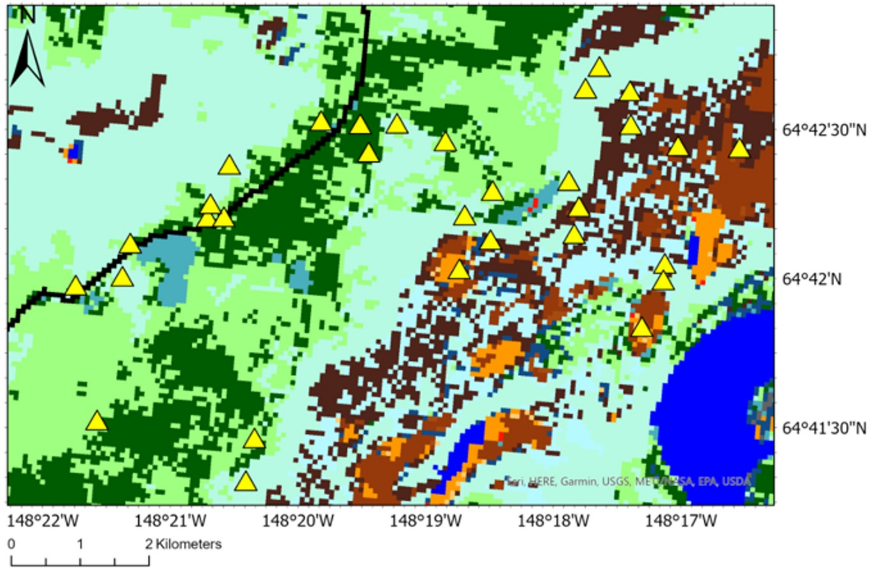
Sentinel-2 to AVIRIS-NG: 2 hours

Badola *et al.*, 2021, Remote Sensing, https://doi.org/10.3390/rs13091693

Vegetation Map, Interior AK

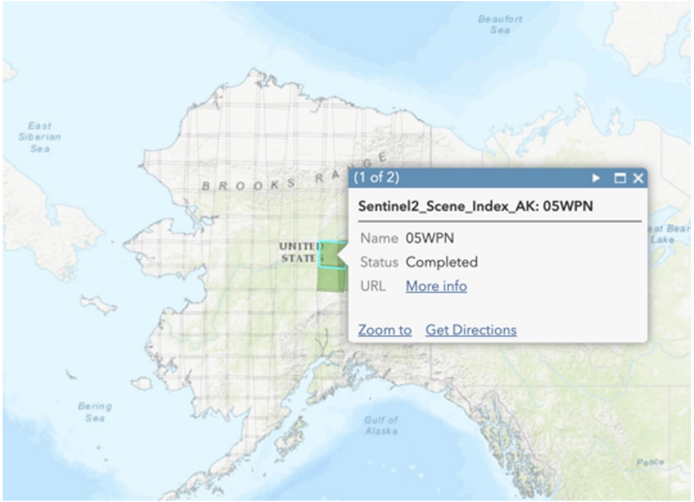


Product Accuracy



- LANDFIRE EVT Product: **32%** (10 out of 31 plots mapped correctly)
- Classified simulated hyperspectral data: **65%** (20 out of 31 plots mapped correctly)

Product Sharing



ArcGIS online

Axiom

A novel pathway to generate low-cost and detailed vegetation/fuel maps for boreal Alaska to aid forest and fire management.

Badola *et al.*, 2022, *Remote Sensing*, https://doi.org/10.3390/rs13050897

Plant Functional Types and Traits

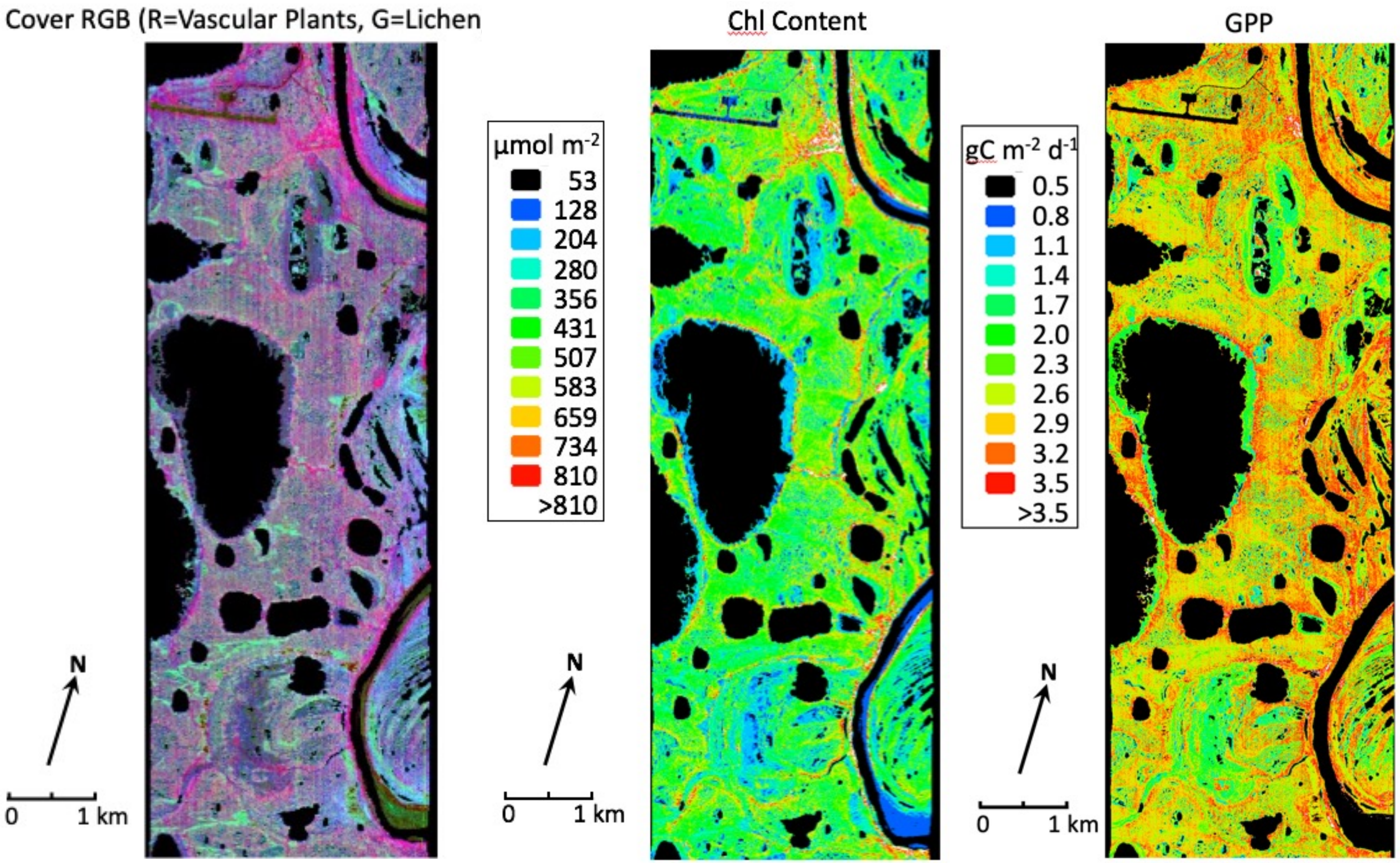
- High-latitudes regions are warming faster than the rest of the planet, increasing plant trait variation across local to regional scales.
- Plant traits (e.g. leaf nitrogen, leaf phosphorus, specific leaf area) are critical to gross primary production and foliar respiration.
- But knowledge of the distribution of plant traits across rapidly changing tundra ecosystems are limited, yet are essential for improving the performance of carbon cycle processes in Earth System Models.

Plant Functional Types and Traits

- Fred Huemmrich, Petya Campbell, Craig Tweedie, Sergio Vargas + collaborators

Utilizing Spectral Imagery to Examine High Latitude Ecosystem Function and Diversity

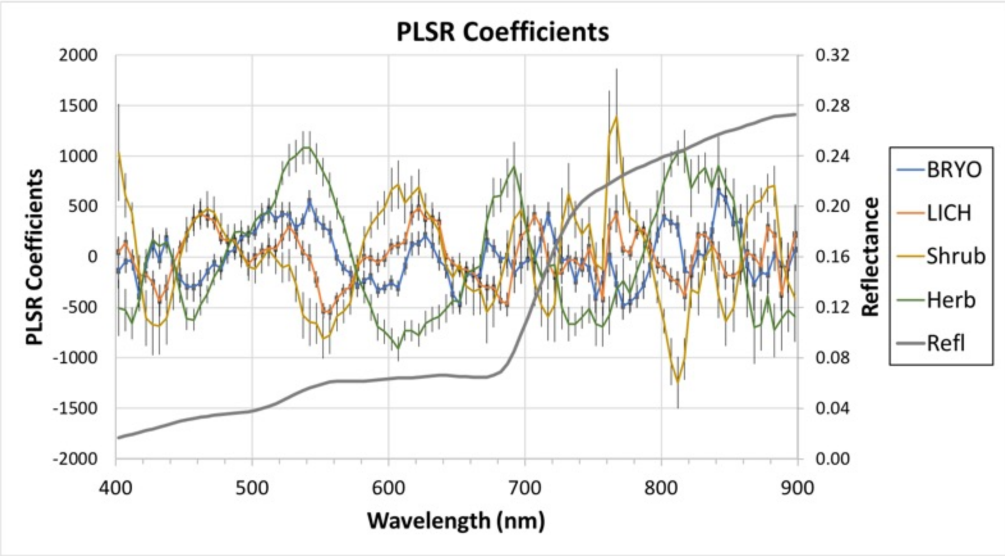
K. F. Huemmrich[1], P. K. E. Campbell[1], S. A. Vargas Z.[2], C. E. Tweedie[2], E.M. Middleton[3]
[1]UMBC/Biospheric Sciences Lab NASA GSFC, [2]UTEP, [3]Biospheric Sciences Lab NASA GSFC



Vegetation percent cover (PLSR): bryophytes, lichens, shrubs, herbs.
RMSE = 22.8%; R^2 = 0.61

Chlorophyll content from leaf level Chl measurements (Unispec).
RMSE = 0.59; R^2 = 137

GPP from ITEX diurnal plot measurements (IRGA). RMSE = 0.45, R^2 = 0.70

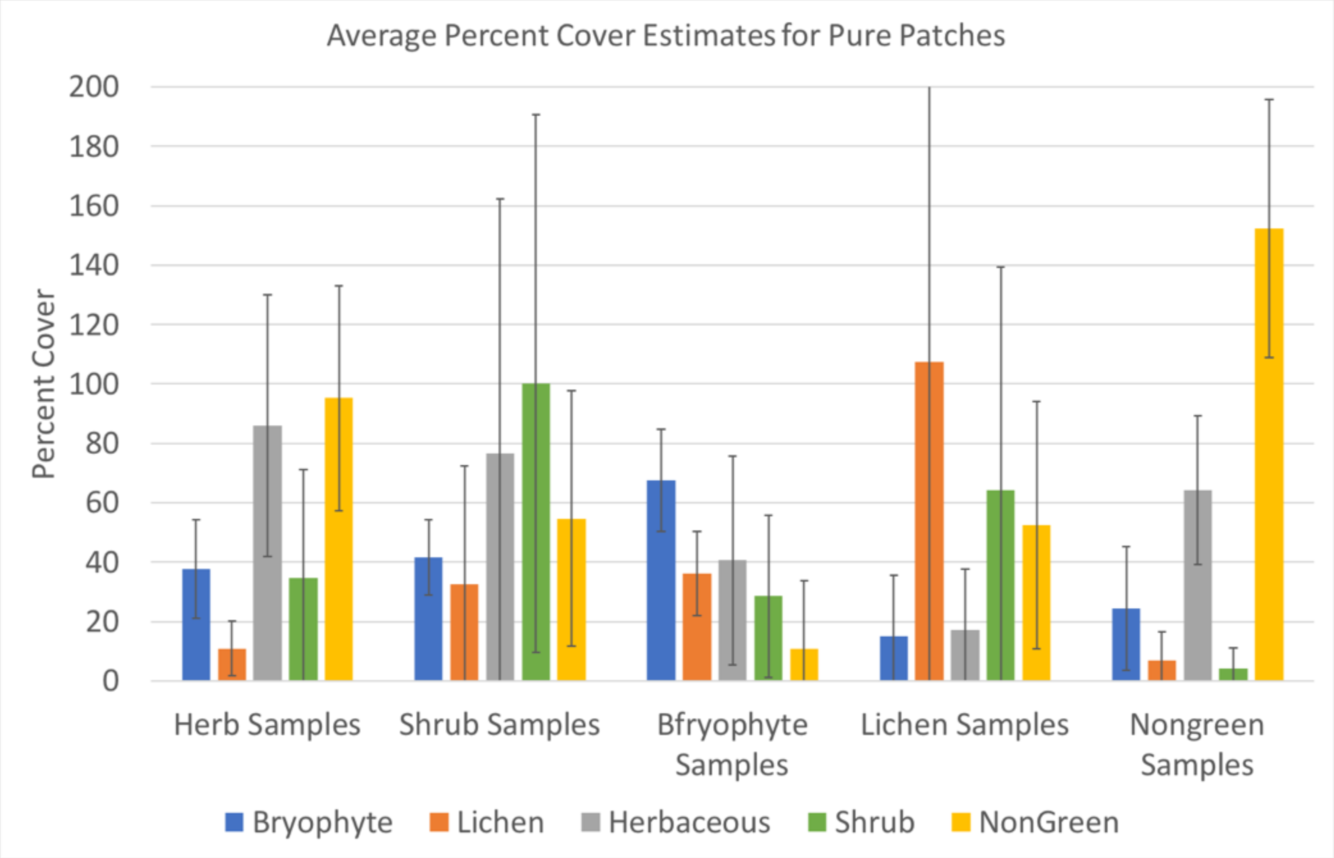


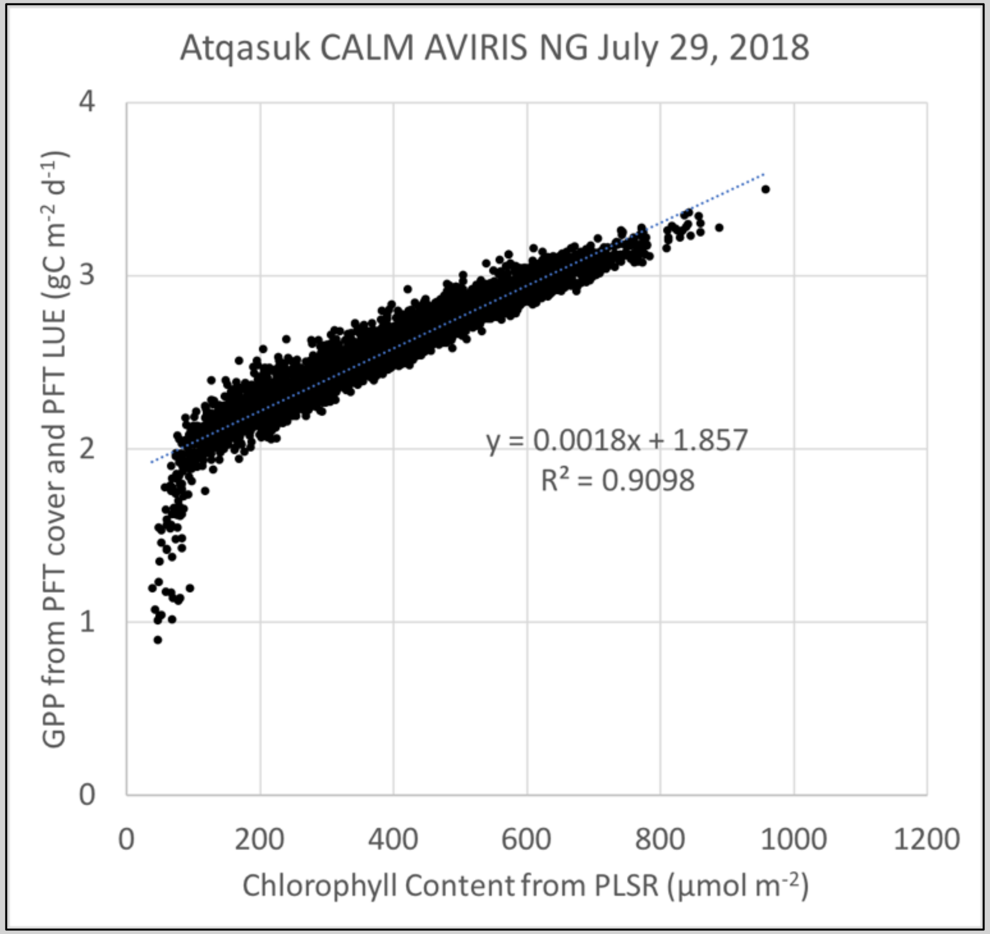
Atqasuk AVIRIS-NG July 29, 2018

Huemmrich, K.F., Campbell, P., Tweedie, C., Vargas, S., Hollister, R., Carroll, M., Gamon, J., and Oberbauer, S. Hyperspectral Mapping of Tundra Vegetation, Env. Res. Comm. *In review.*

K.F. Huemmrich, S.A. Vargas Z., C. Tweedie, P.K. Campbell, E. Middleton, NNX17AC58A Causes and Consequences of Arctic Greening: The Importance of Plant Functional Types

- Functional types rarely occur as pure pixels; challenges for endmembers
- Chlorophyll content strongly predicts PFT-based GPP (from LUE model)





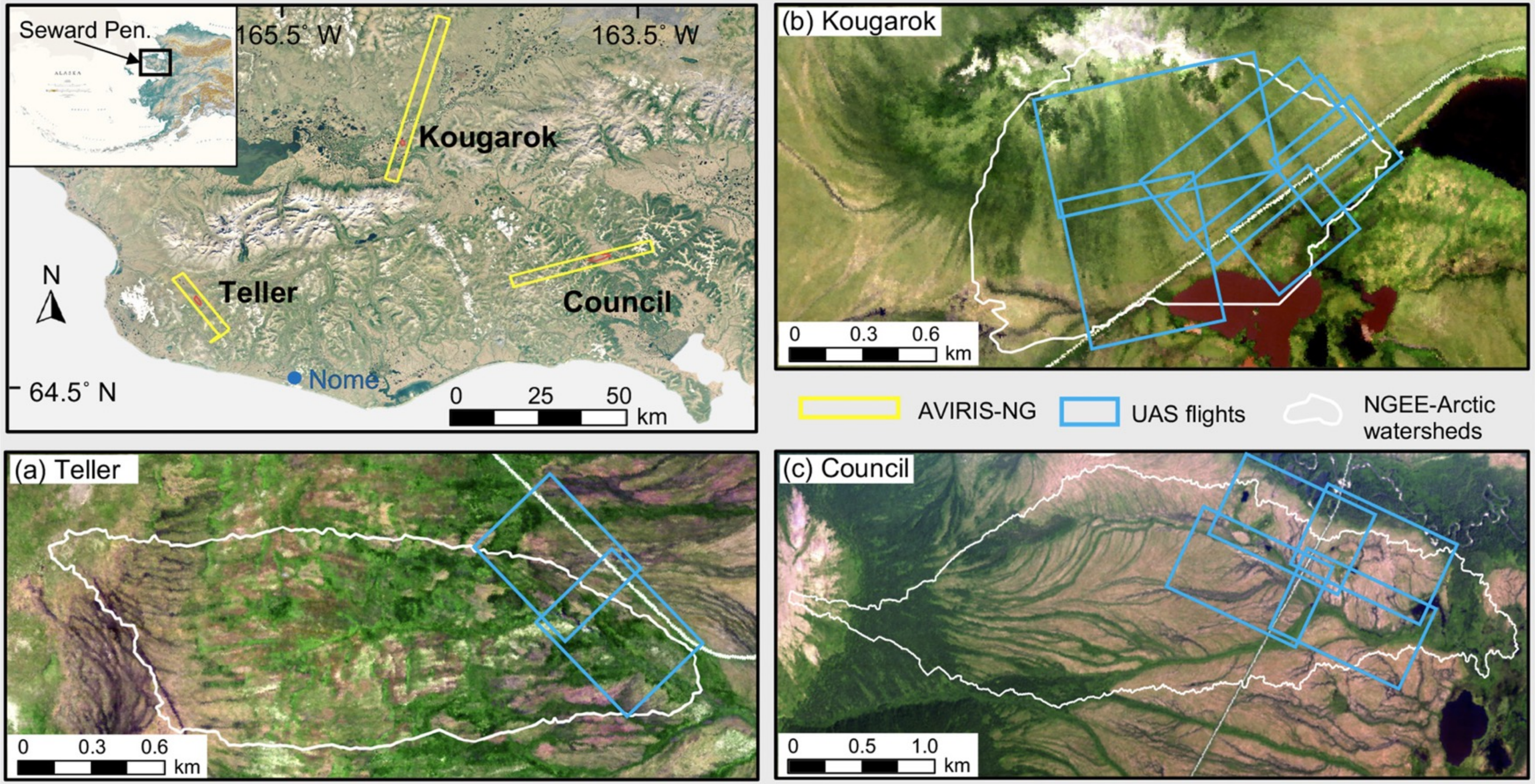
Scaling Fractional Cover (shrubification)

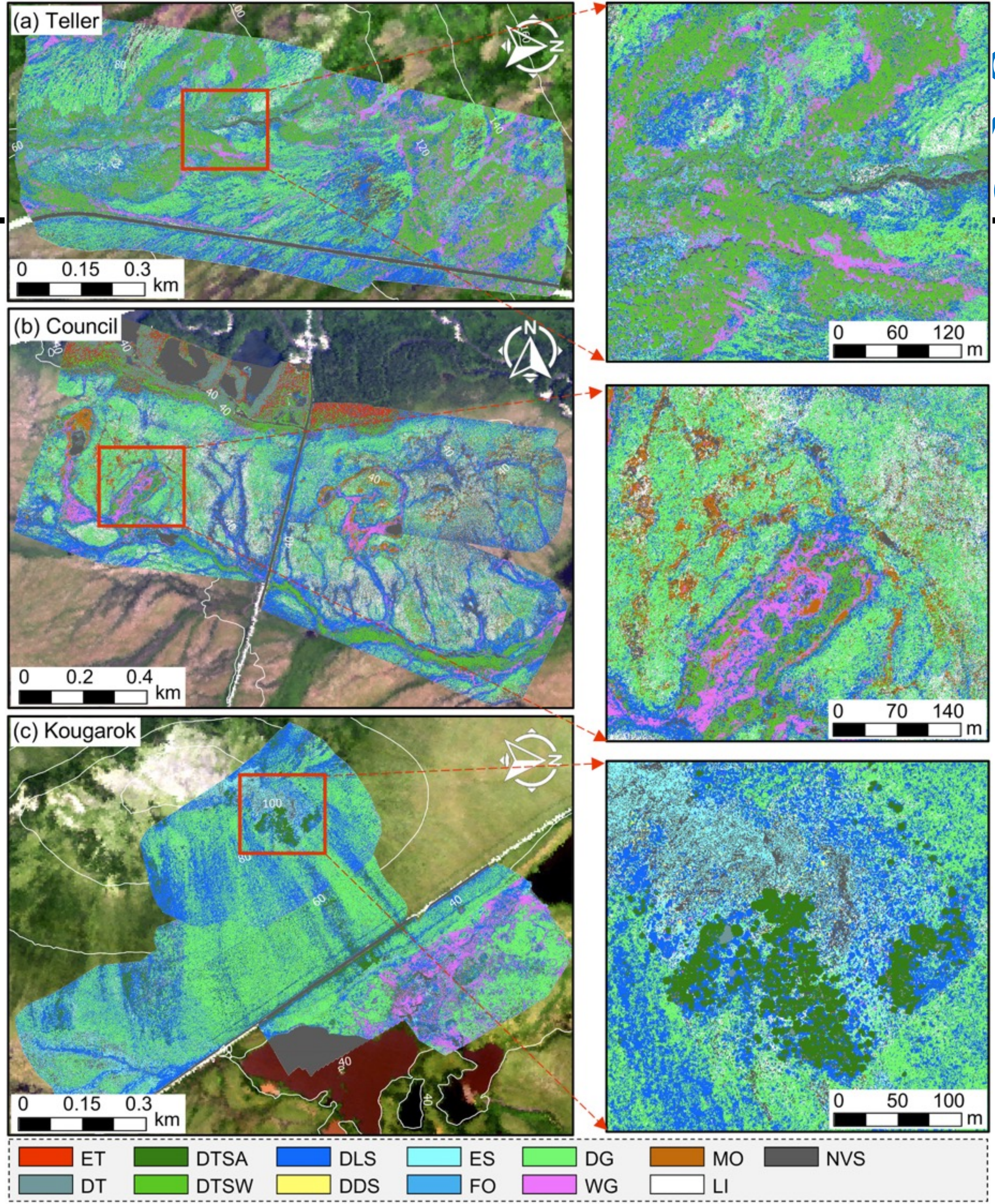
- ABoVE and NGEE-Arctic collaborate to study the drivers of tall shrub species distribution & expansion in low-Arctic using AVIRIS-NG
- Daryl Yang, Shawn Serbin (Brookhaven National Lab) + collaborators

- https://doi.org/10.1016/j.rse.2022.113430

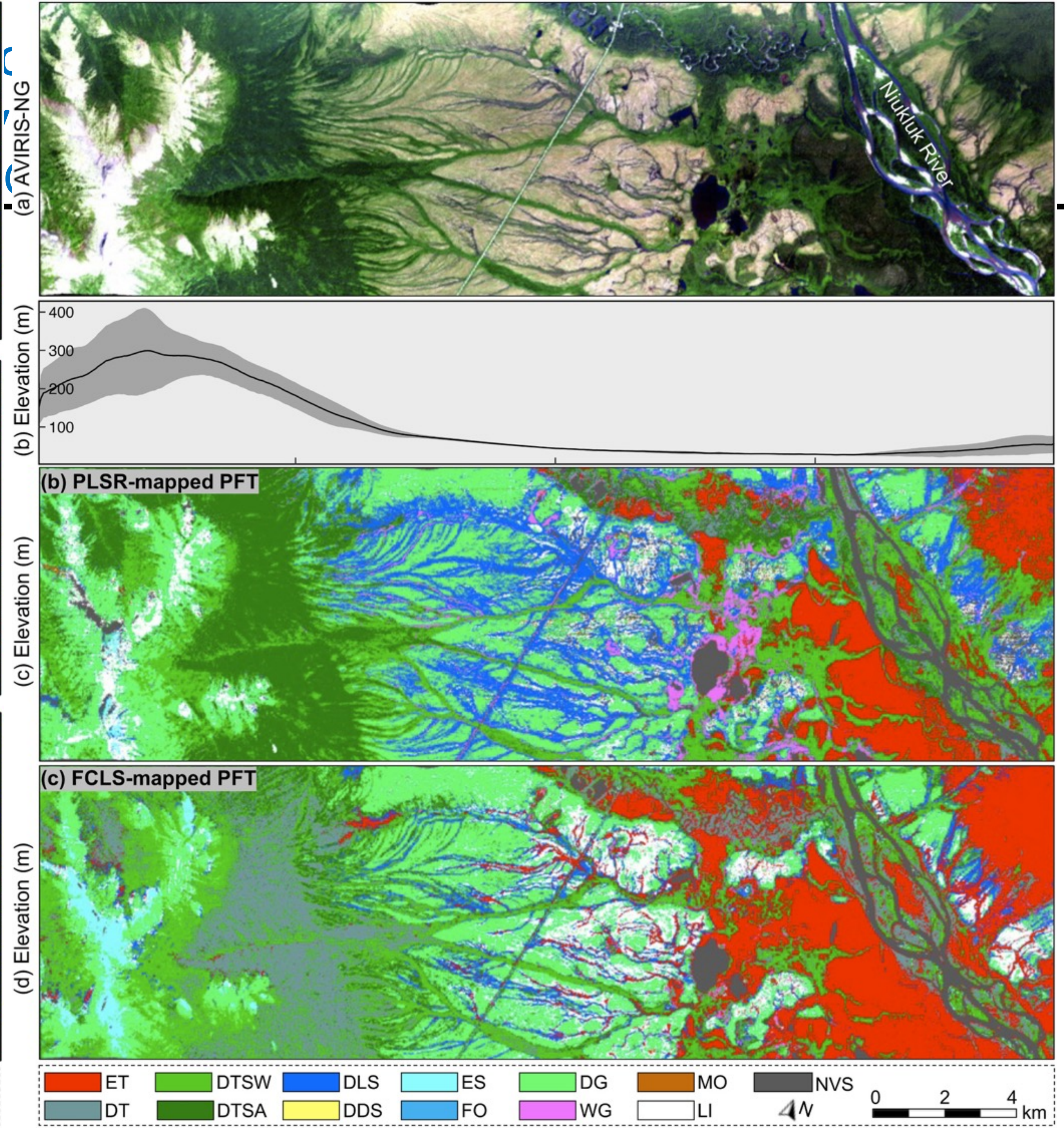
Integrating very-high-resolution UAS data and AVIRIS-NG imaging spectroscopy to map Arctic PFTs (NGEE-Arctic)

Yang *et al*. 2023, *Remote Sensing of Environment*



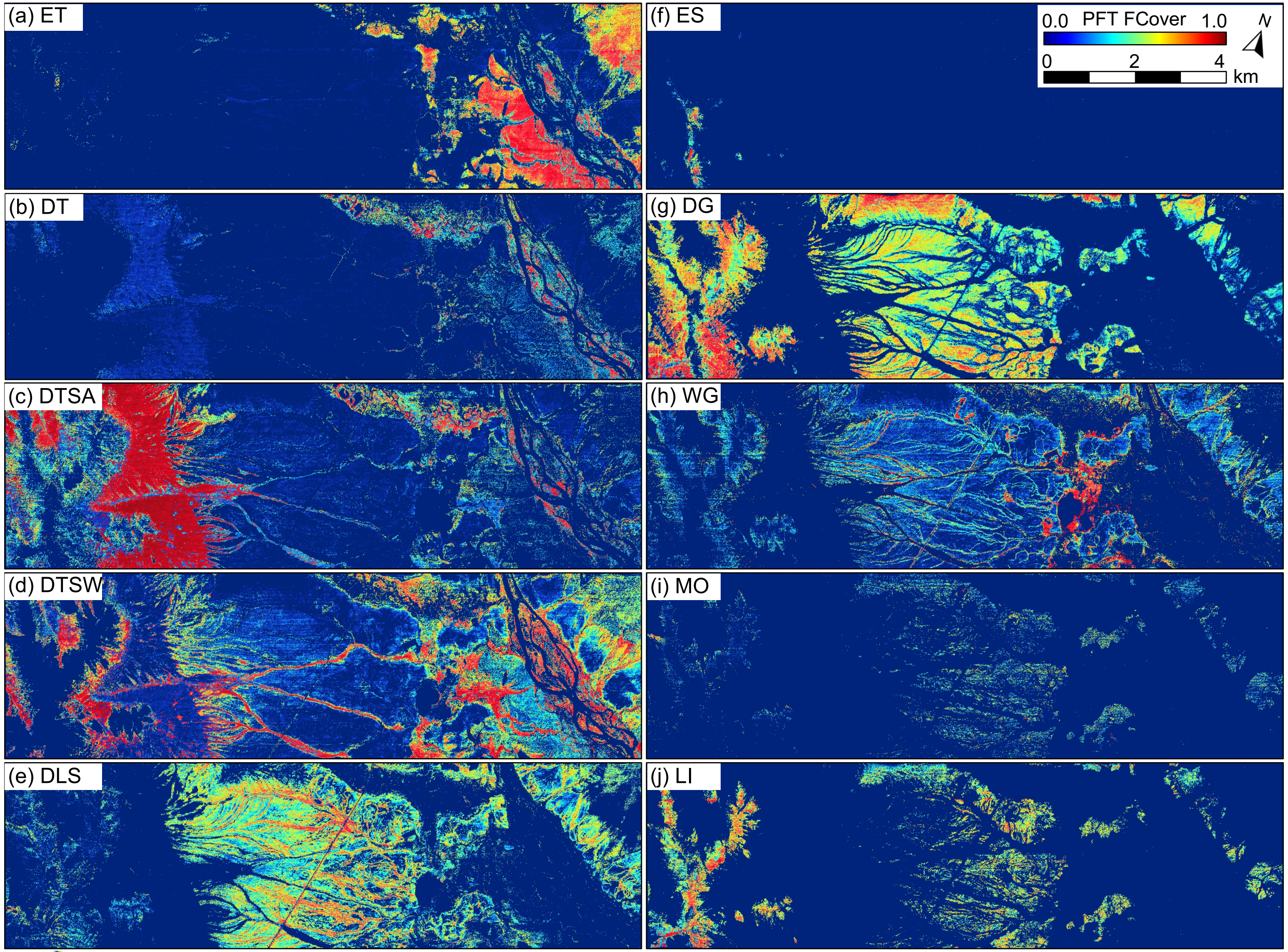


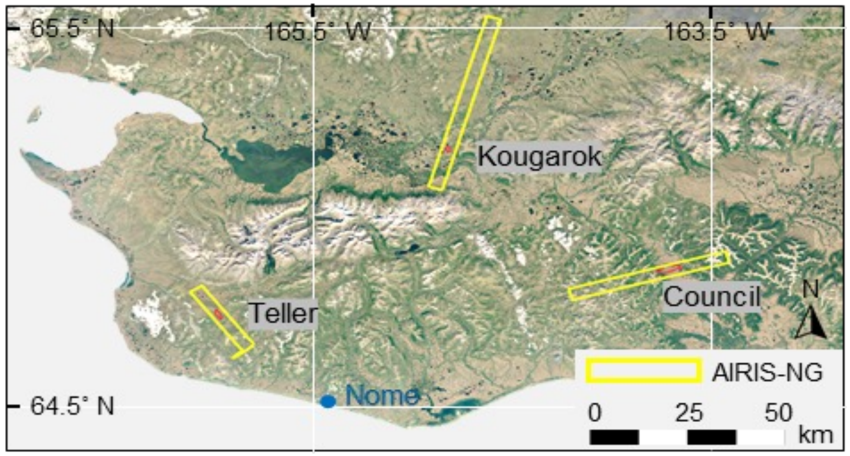
(a) Teller
0 0.15 0.3 km
0 60 120 m
(b) Council
0 0.2 0.4 km
0 70 140 m
(c) Kougarok
0 0.15 0.3 km
0 50 100 m
ET
DTSA
DLS
ES
DG
MO
NVS
DT
DTSW
DDS
FO
WG
LI



(a) AVIRIS-NG
Niukluk River
(b) Elevation (m)
400
300
200
100
(b) PLSR-mapped PFT
(c) Elevation (m)
(c) FCLS-mapped PFT
(d) Elevation (m)
ET
DTSW
DLS
ES
DG
MO
NVS
DT
DTSA
DDS
FO
WG
LI
N
0 2 4 km

Combining UAS and AVIRIS-NG data to create regional-scale maps of Arctic tundra vegetation composition and factional cover (example shown below, Council site on Seward Peninsula)





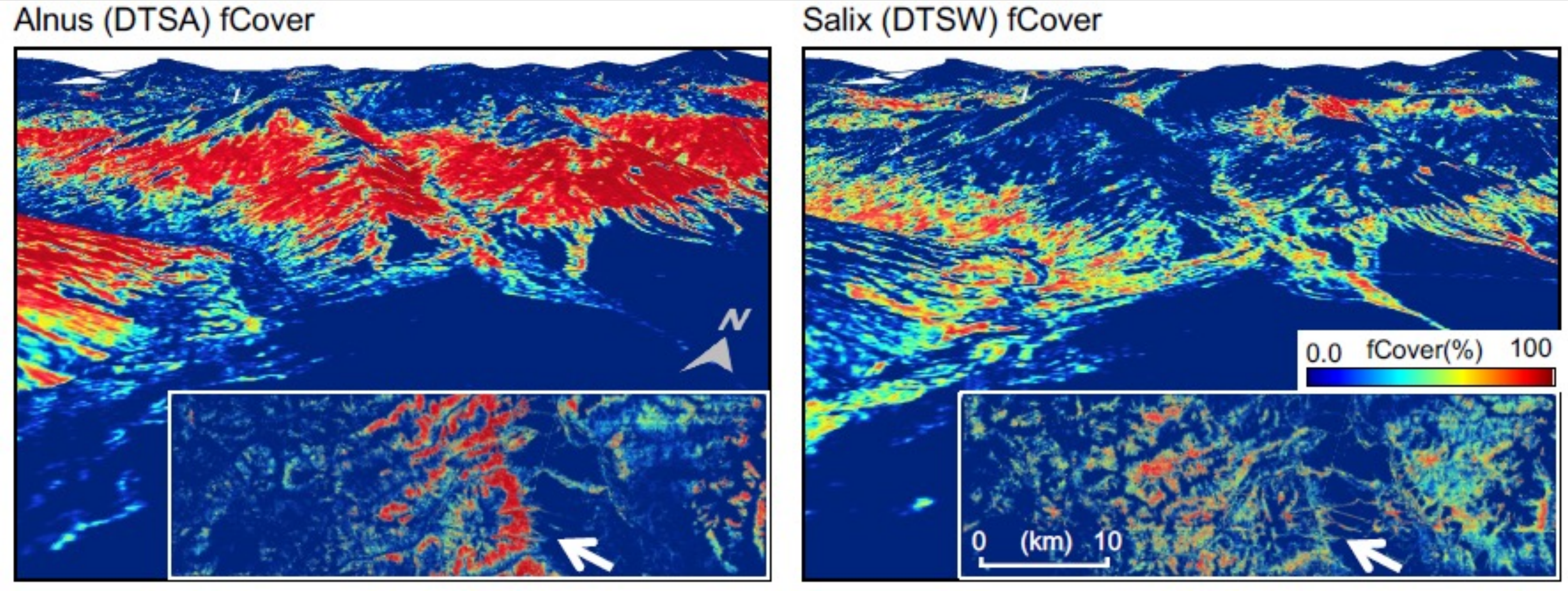
Findings:

- The fractional cover of 12 Arctic PFTs are accurately captured with the UAS-based upscaling.
- The developed scaling method is highly capable of differentiating the composition of spectrally similar PFTs, e.g., alder, willow, and poplar trees.
- UAS-based upscaling is superior to traditional spectral mixing-based mapping of vegetation composition

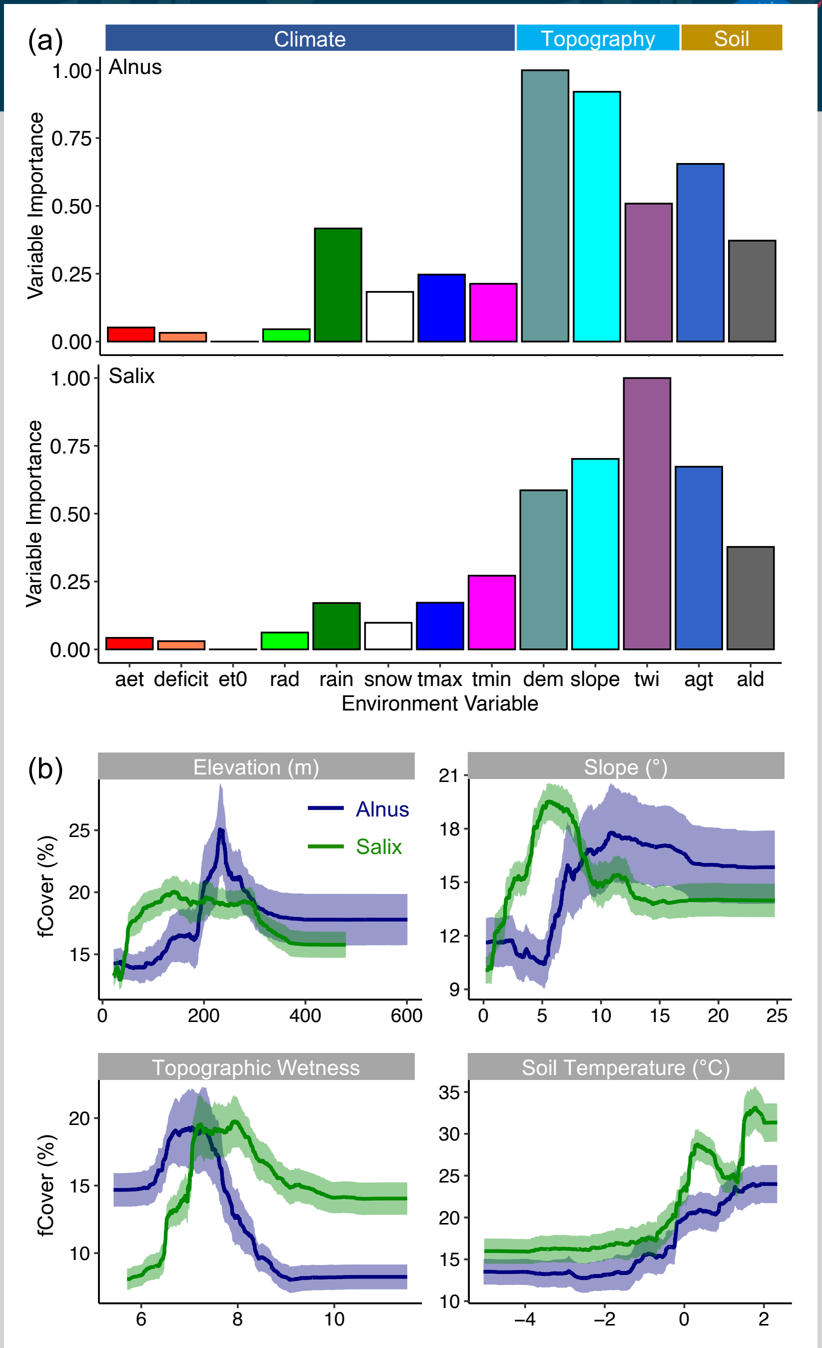
Yang et al., (2023)

Shrub expansion in the Arctic is limited by unfavorable abiotic or biotic factors.

Topography-controlled processes (e.g., hydrology, snow distribution, and micro-scale disturbance) strongly control tall shrub expansion, but this control varies by species (e.g., alder and willow). Alder moves uphill and willow expands along water resources down slope.

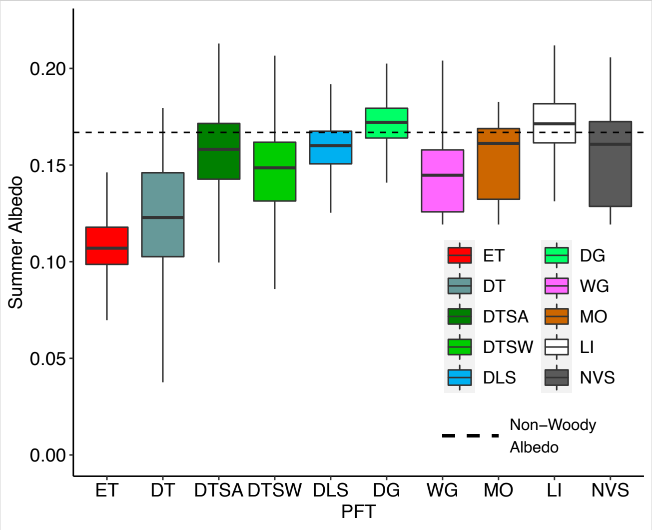


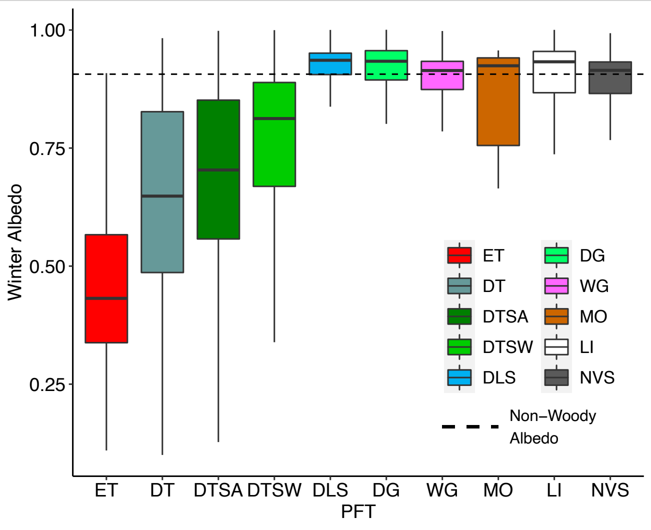
Alnus and Salix fCover derived from AVIRIS-NG (Yang et al., 2023)

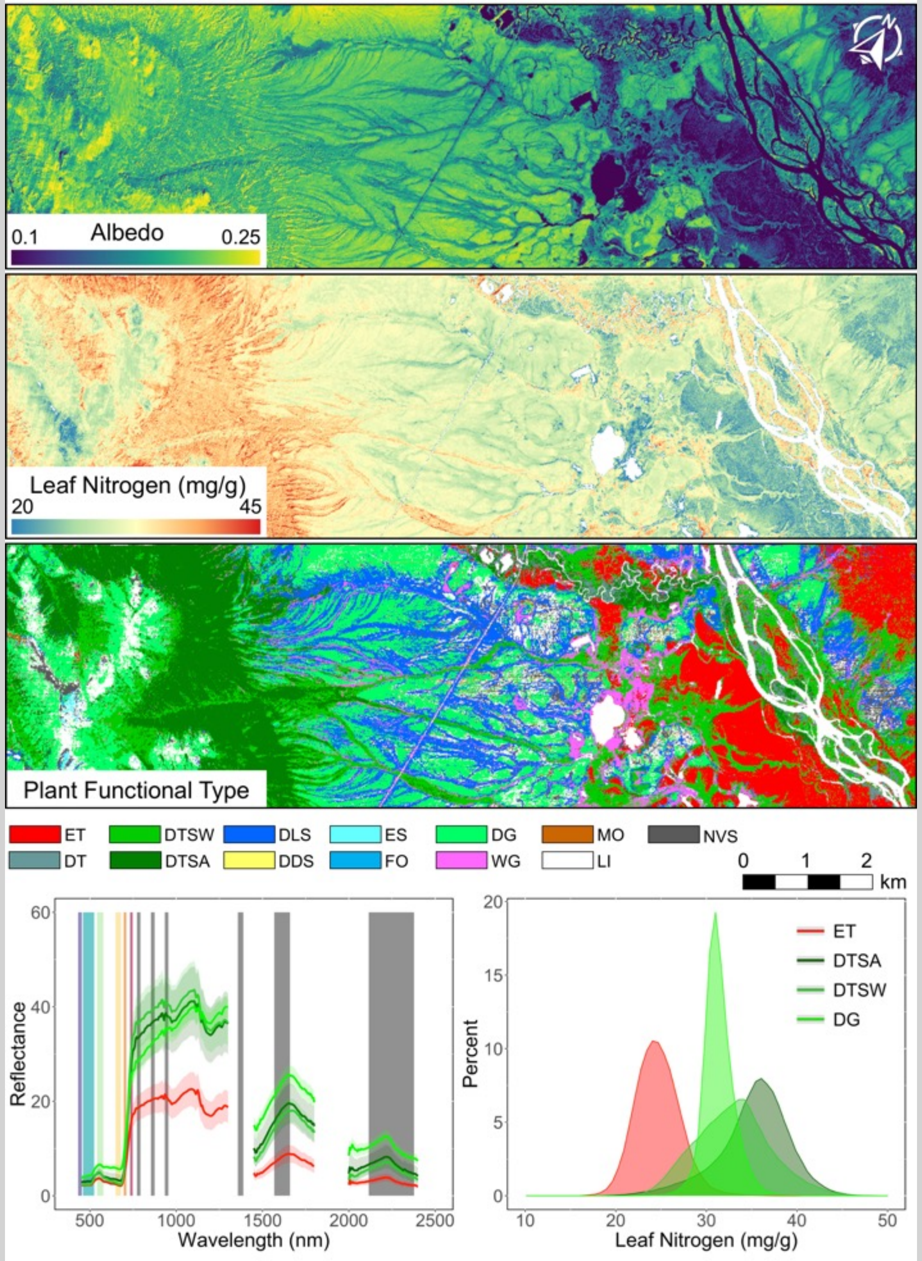


- A high spatial variation in canopy traits and albedo driven by vegetation composition

- Differences across PFTs imply that replacing other non-woody PFTs with tall shrubs will decrease winter-time albedo by **2-38%** and increase ecosystem nitrogen by up to **18%**.







Serbin *et al.* (in preparation)

Peter Nelson, Schoodic Institute at Acadia National Park

- Ground to UAV spectroscopy for transferrable mapping of plant functional types (PFTs) in the ABoVE domain
  - Map PFTs in 32 AVIRIS images using ground and UAV spectra to improve transfer across sites and imaging conditions
- What are in the dimensions of AVIRIS ABoVE data? Team paper leading towards scaling efforts (see Spectroscopy WG presentation)

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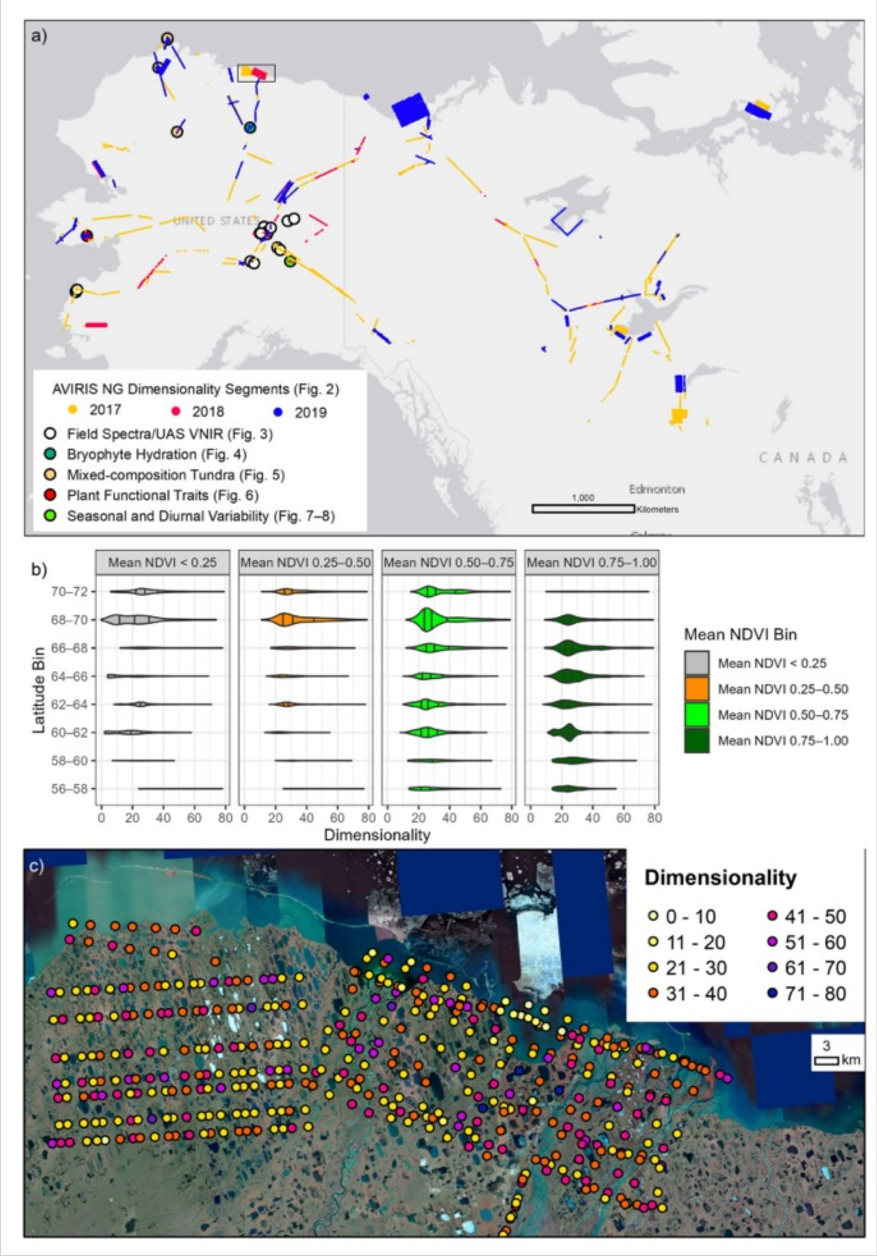
RESEARCH ARTICLE
10.1029/2021JG006697

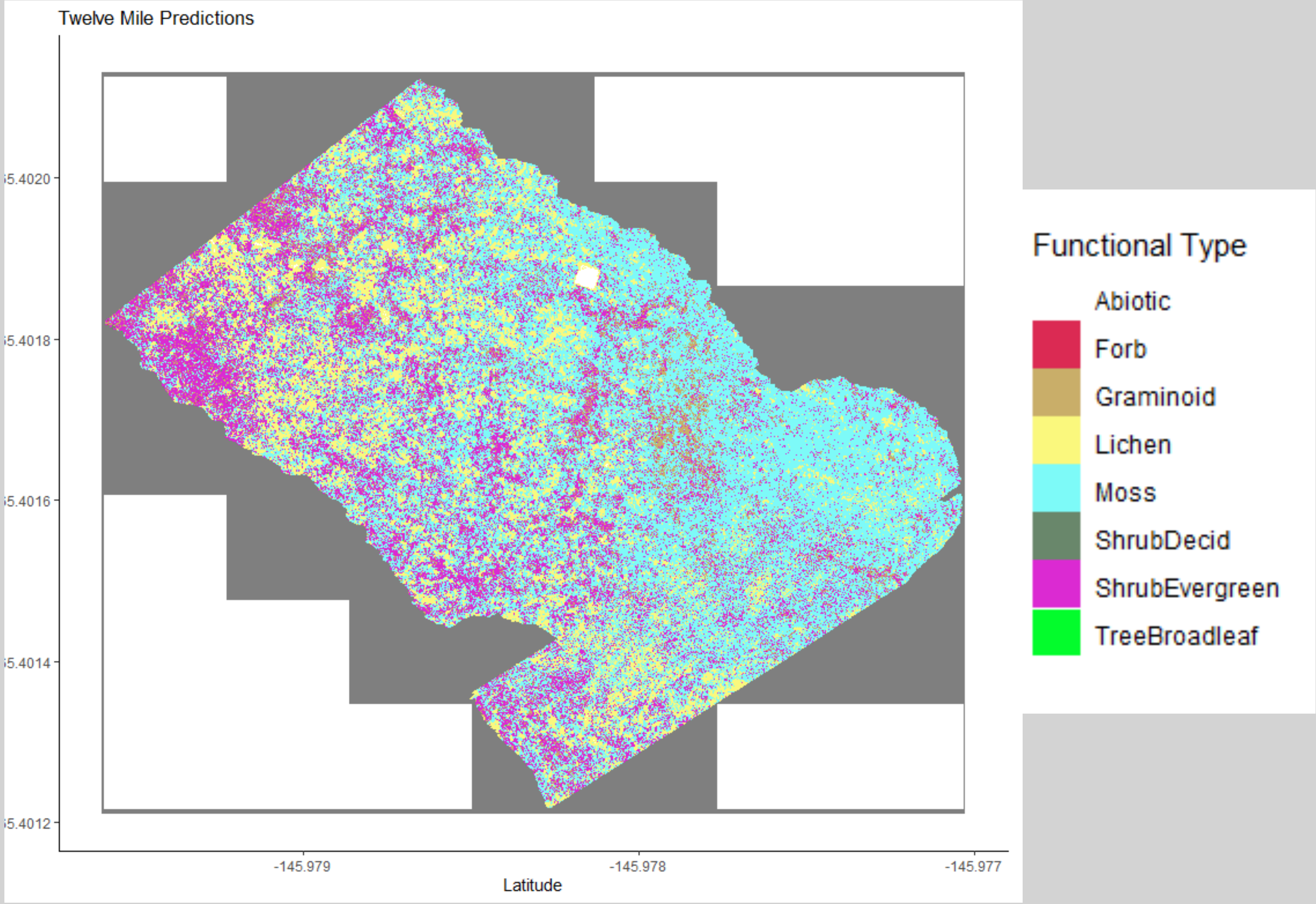
Special Section:
The Earth in living color: spectroscopic and thermal imaging of the Earth: NASA's Decadal Survey Surface Biology and Geology Designated Observable

Remote Sensing of Tundra Ecosystems Using High Spectral Resolution Reflectance: Opportunities and Challenges

Peter R. Nelson[1], Andrew J. Maguire[2], Zoe Pierrat[3], Erica L. Orcutt[4], Dedi Yang[5], Shawn Serbin[5], Gerald V. Frost[6], Matthew J. Macander[6], Troy S. Magney[4], David R. Thompson[2], Jonathan A. Wang[7], Steven F. Oberbauer[8], Sergio Vargas Zesati[9], Scott J. Davidson[10,11], Howard E. Epstein[12], Steven Unger[8], Petya K. E. Campbell[13], Nimrod Carmon[2], Miguel Velez-Reyes[9], and K. Fred Huemmrich[13]

ABoVE 9th SCIENCE TEAM MEETING
WYNDHAM SAN DIEGO BAYSIDE 23-26 JANUARY 2023



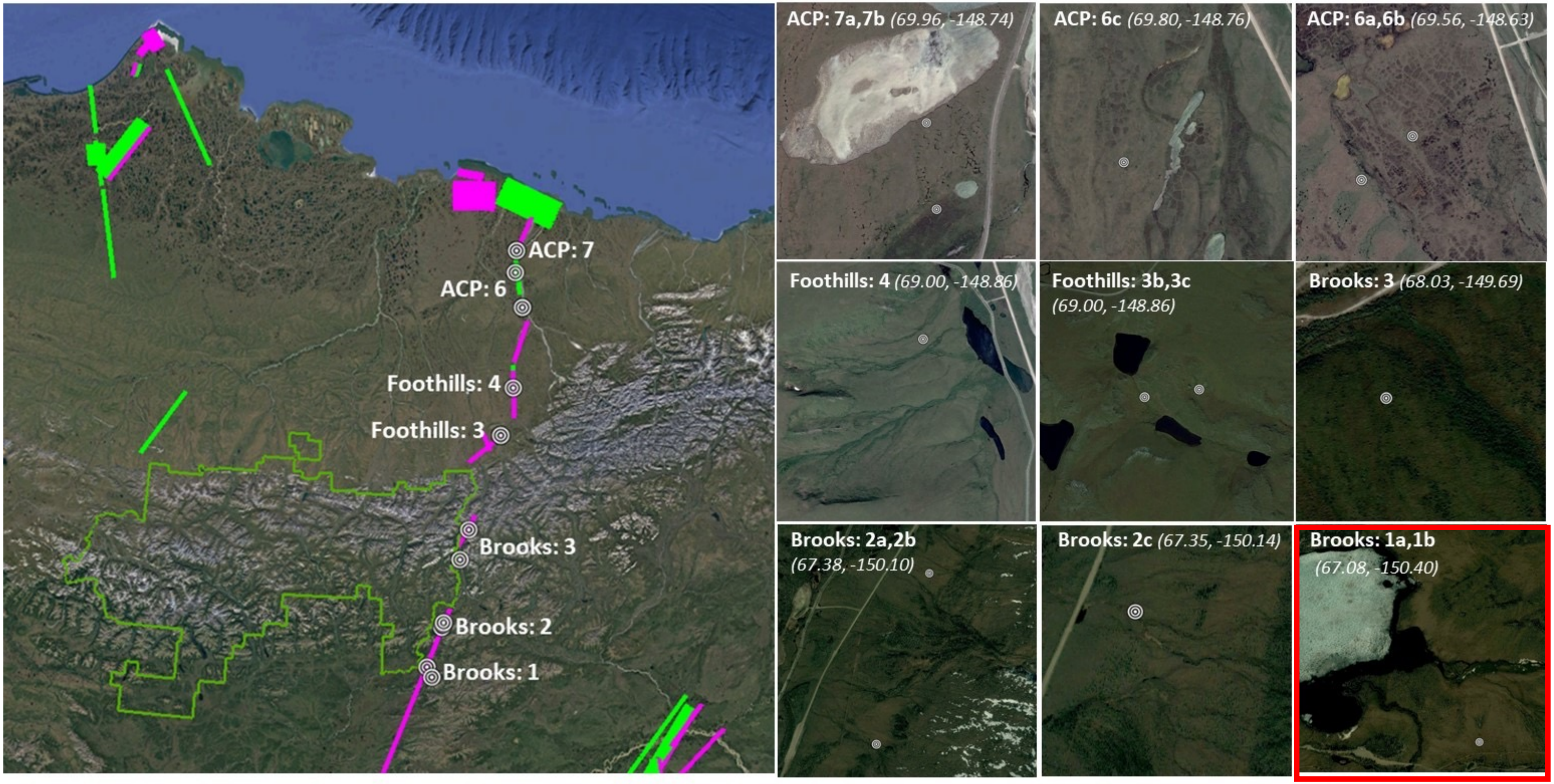


Key Result: Coupling ground and UAV-based spectra for PFTs with AVIRIS reflectance enables subpixel fractional cover estimation.

Wenqu Chen, Mark Lara and Jennifer Fraterrigo (University of Illinois)

- Multiscale Mapping of Tundra Plant Traits Using Hyperspectral Data from UAS and AVIRIS-NG
- Testing optimal plant trait scaling approach across overlapping Airborne Visible Infrared Imaging Spectrometer-Next Generation (AVIRIS-NG) flight lines (ground to UAS to AVIRIS-NG).
- Department of Energy, Grant DE-SC0021094

Multiscale Mapping of Tundra Plant Traits Using Hyperspectral Data from UAS and AVIRIS-NG



Data from site 1B shown on next slides

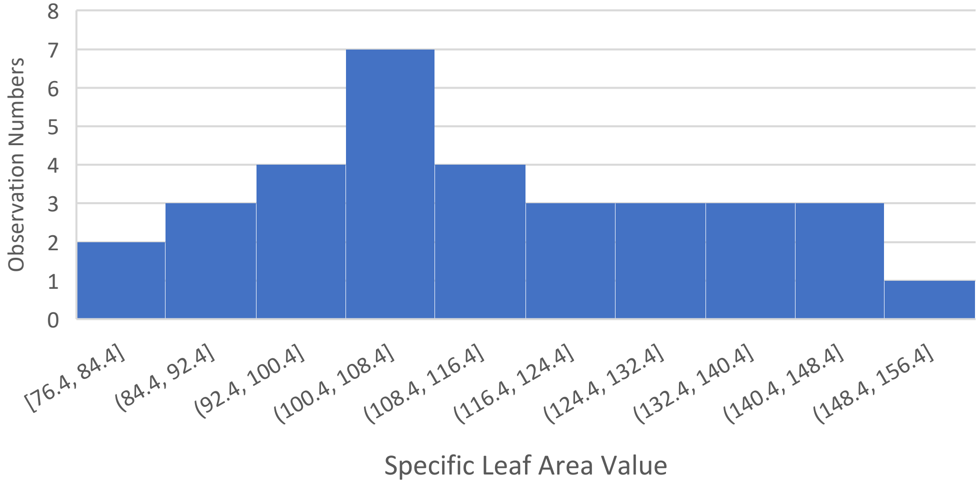
Plant Trait Data Collection



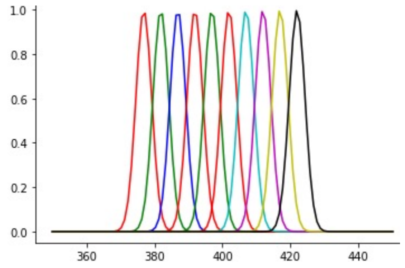
Measured above and below ground plant traits include:

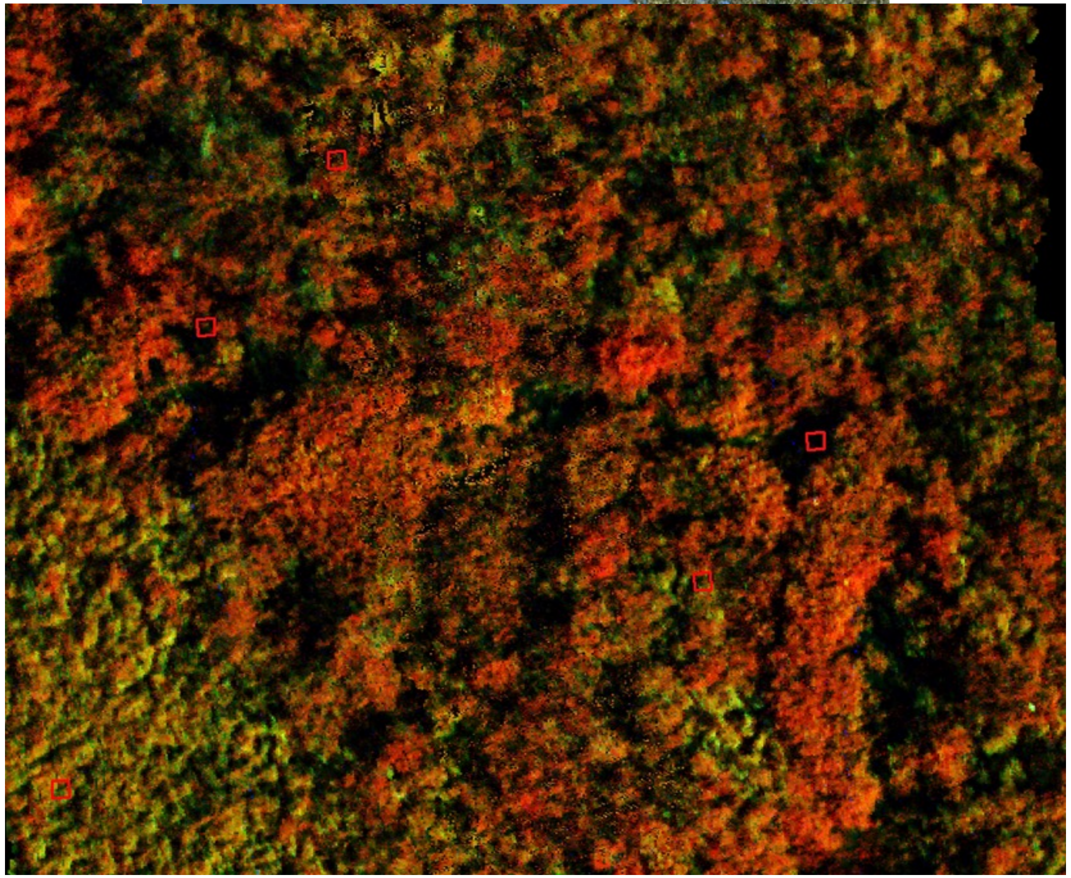
- Specific leaf area (SLA)
- Leaf dry matter content
- Leaf N and $\delta^{15}N$ (N source)
- Leaf $\delta^{13}C$ (plant water stress)
- Height
- Specific root length (SRL)
- Root tissue density
- Root N and $\delta^{15}N$
- Mycorrhizal colonization

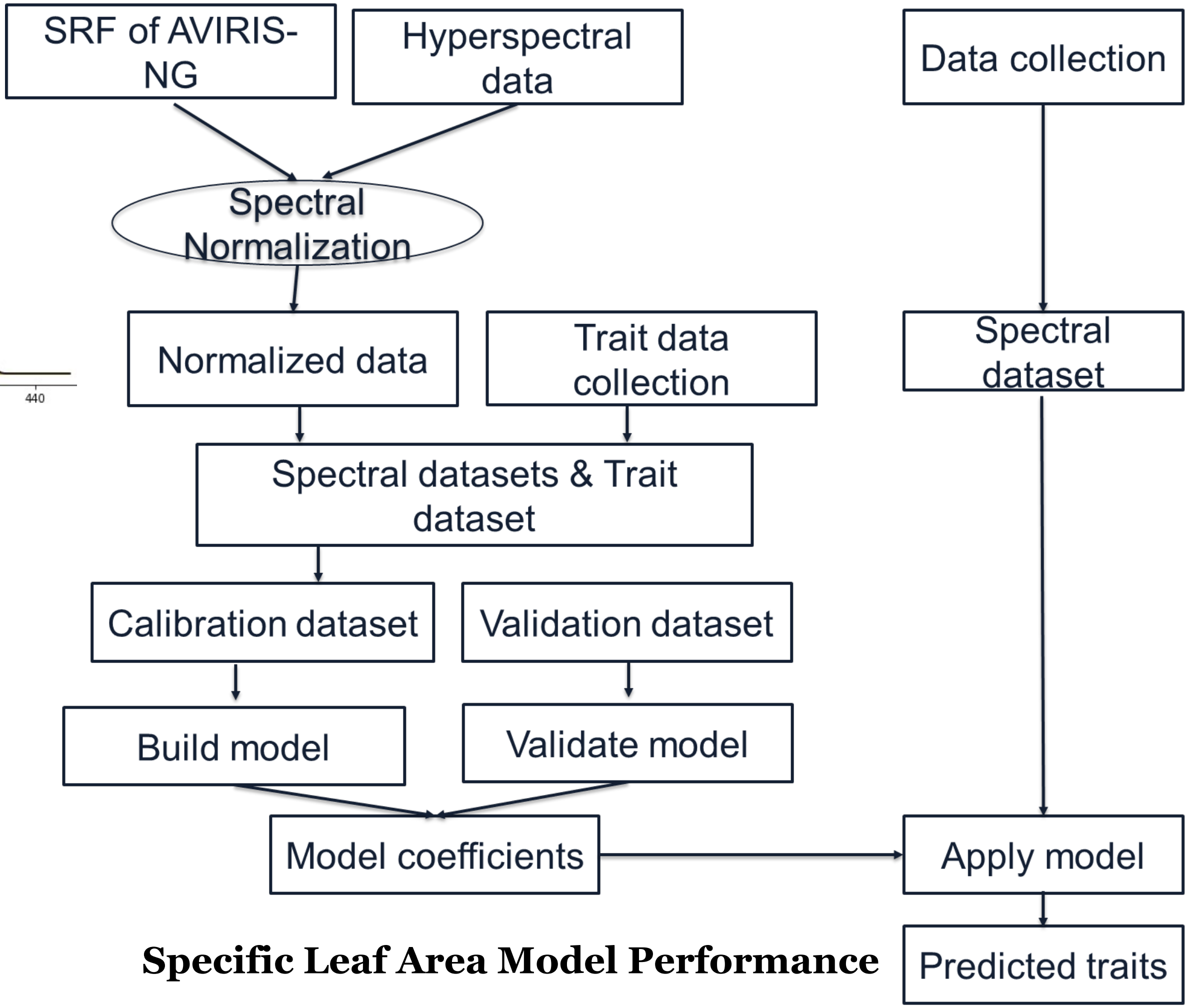
Example: Site 1B, Specific Leaf Area Data



Plant Trait Mapping and Upscaling

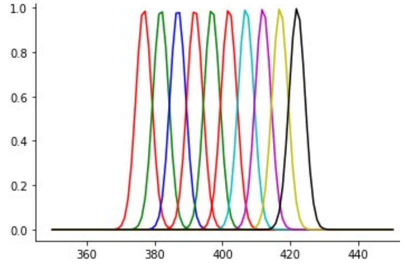


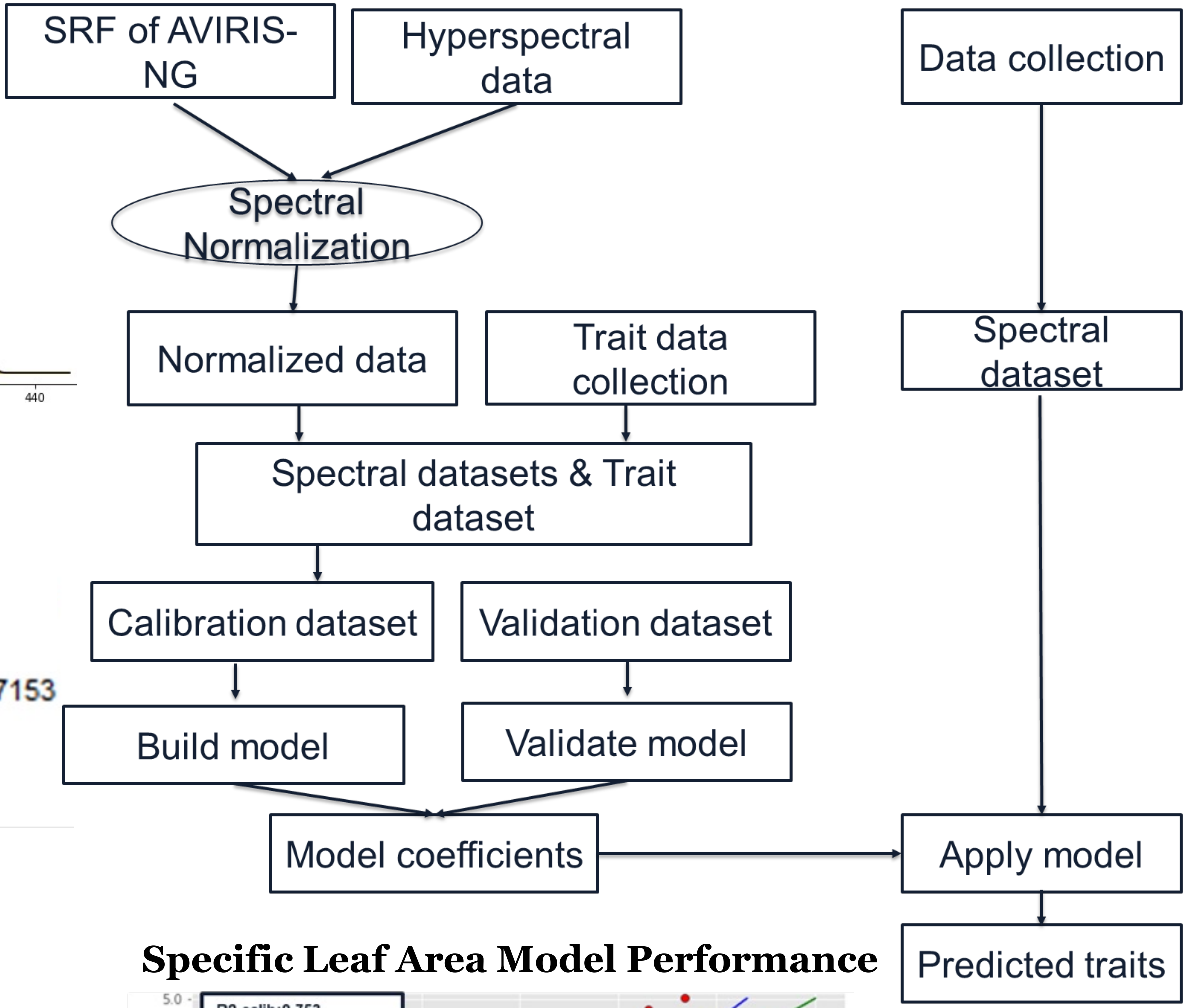


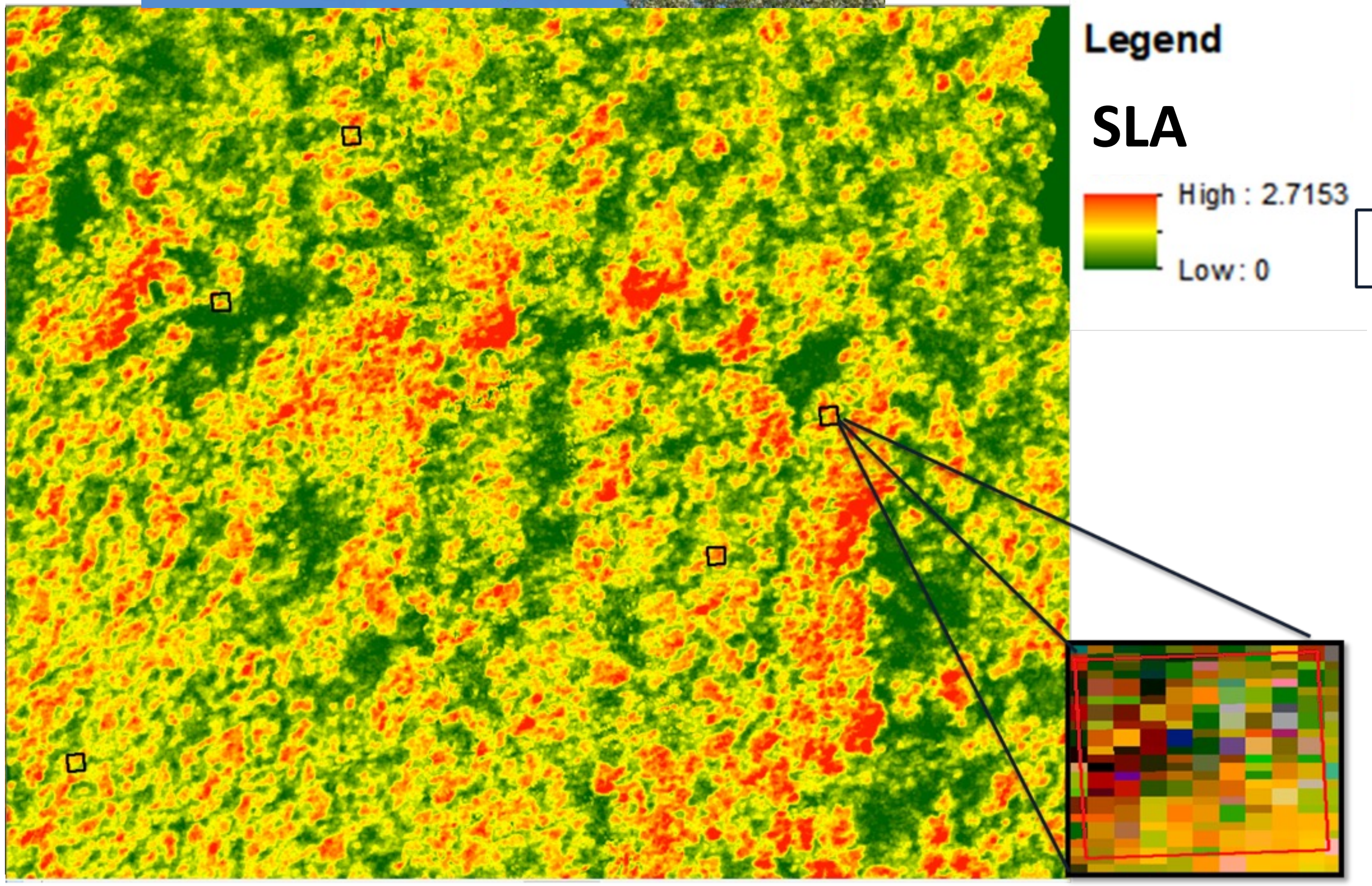


Specific Leaf Area Model Performance

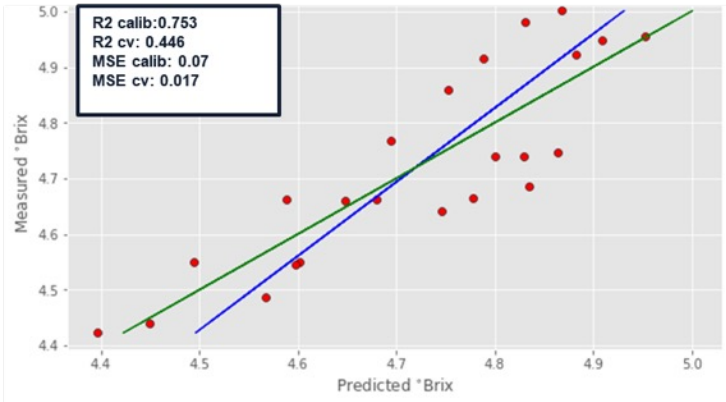
Plant Trait Mapping and Upscaling







Specific Leaf Area Model Performance



Kovach, Townsend, Pavlick et al., Mapping traits across all AVIRIS-NG flight lines

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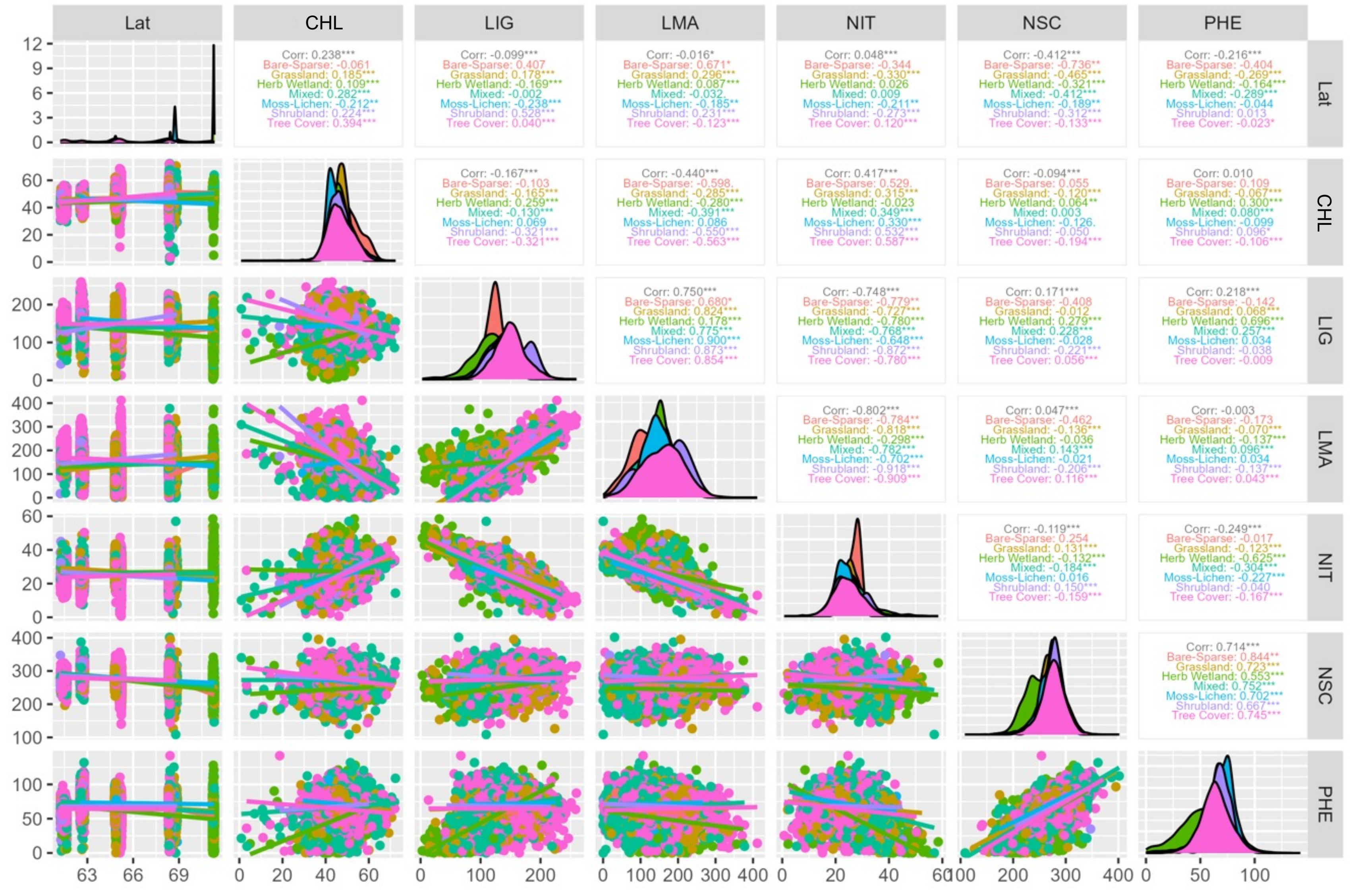
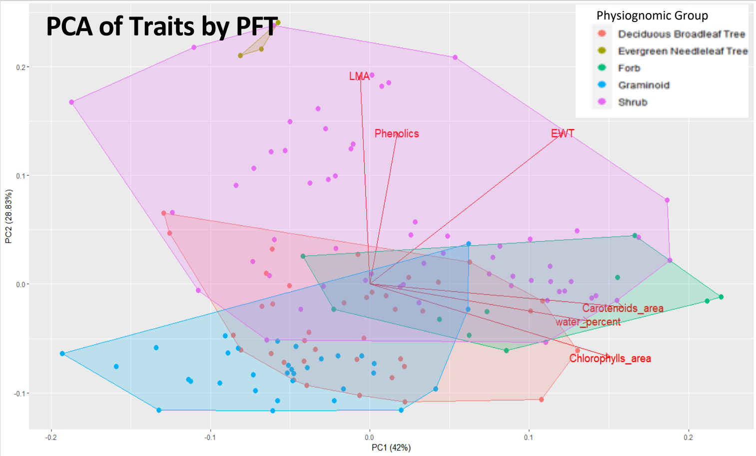
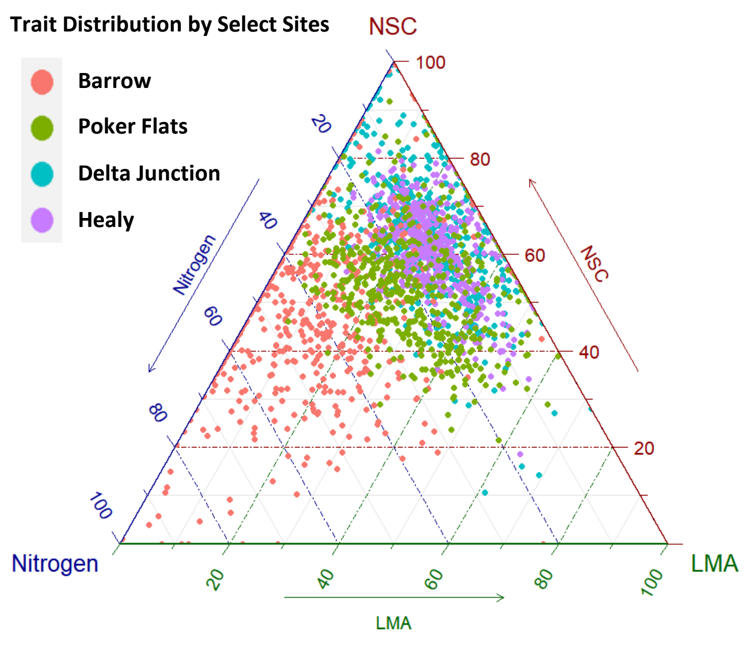
WISCONSIN UNIVERSITY OF WISCONSIN-MADISON

Jet Propulsion Laboratory
California Institute of Technology

Trait Relationships and Distributions Across ABoVE Domain, within PFT Variation





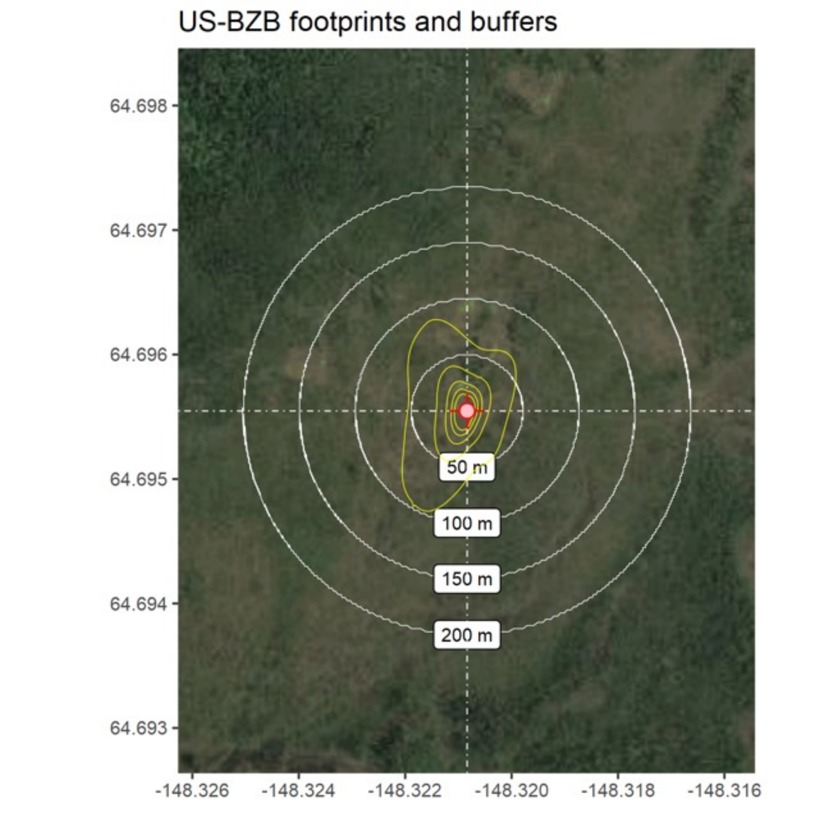


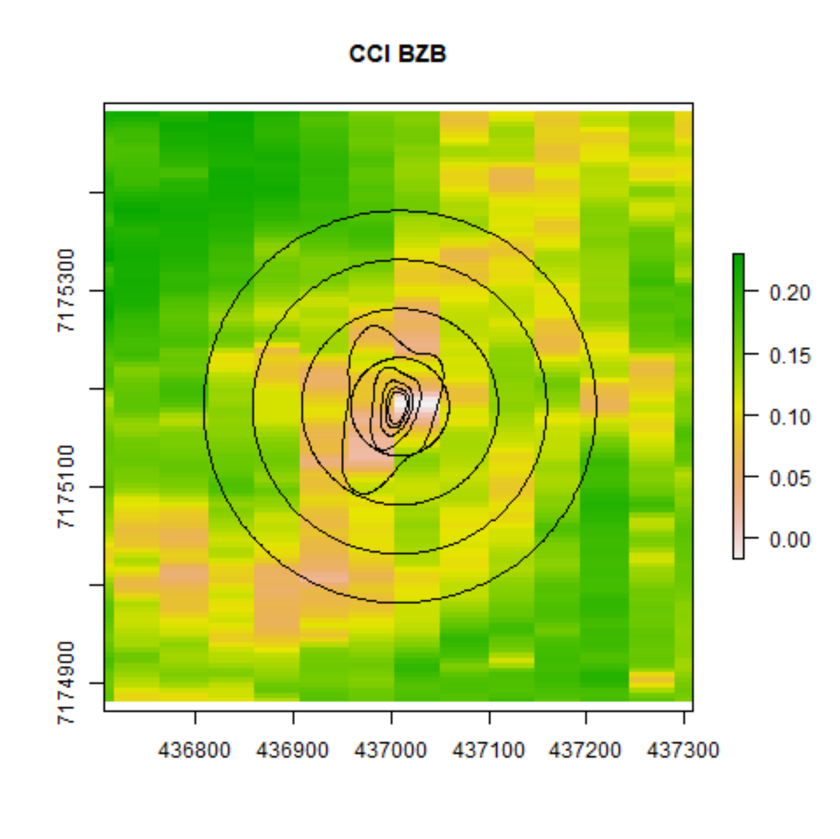
Linkage to Flux Towers

- Erica Orcutt (Sacramento State), Troy Magney (UC-Davis), Christian Frankenburg (Caltech) + collaborators

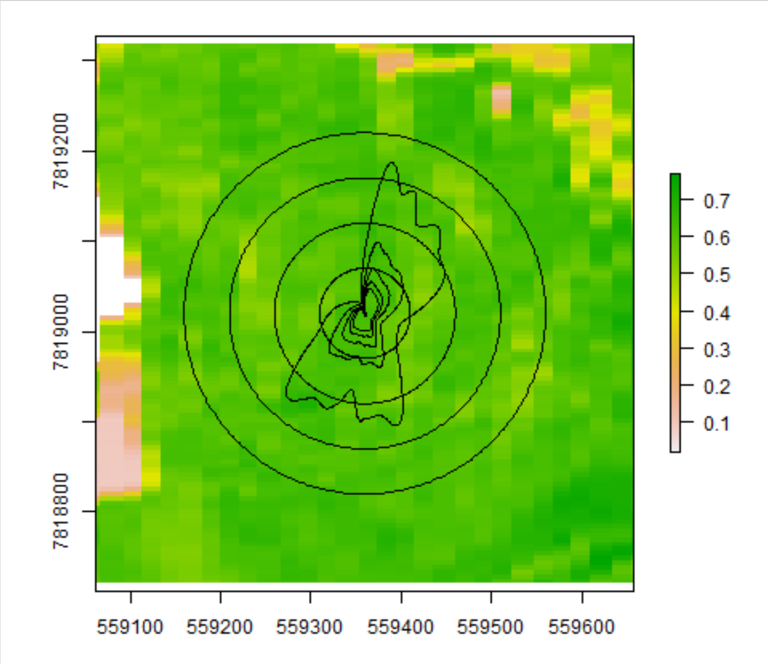
Assessing the variability of aircraft remote sensing products (CFIS and AVIRIS-NG) within flux tower footprints

- Question: What is the hyperspectral variability around flux towers at 14 sites within ABoVE domain?
- Looked at both radii contours (50-200m) and weighted averages of flux tower footprints



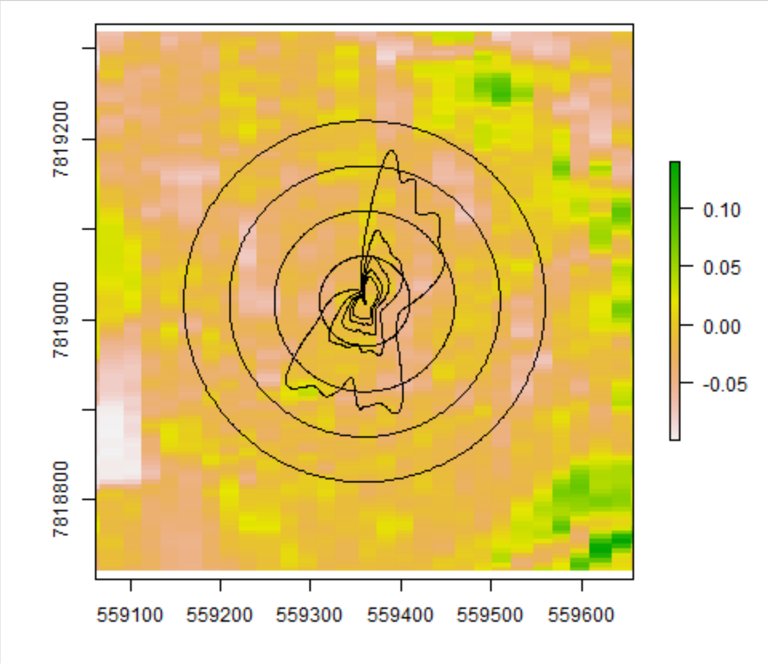


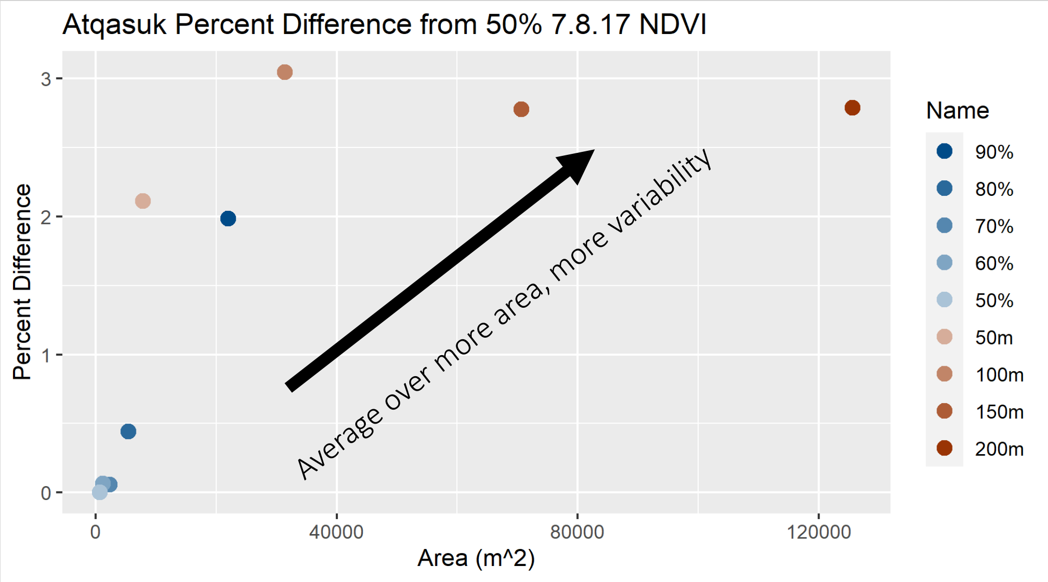
Erica L. Orcutt*, Christian Frankenberg, Housen Chu, Kyle A. Arndt, Eugenie S. Euskirchen, Gabriel Hould Gosselin, Manuel Helbig, Hiroki Ikawa, Hideki Kobayashi, Andrew J. Maguire, Philip Marsh, Gesa Meyer, Walter C. Oechel, Ryan Pavlick, William L. Quinton, Adrian V. Rocha, Christopher Schulze, Oliver Sonnentag, Donatella Zona, & Troy S. Magney

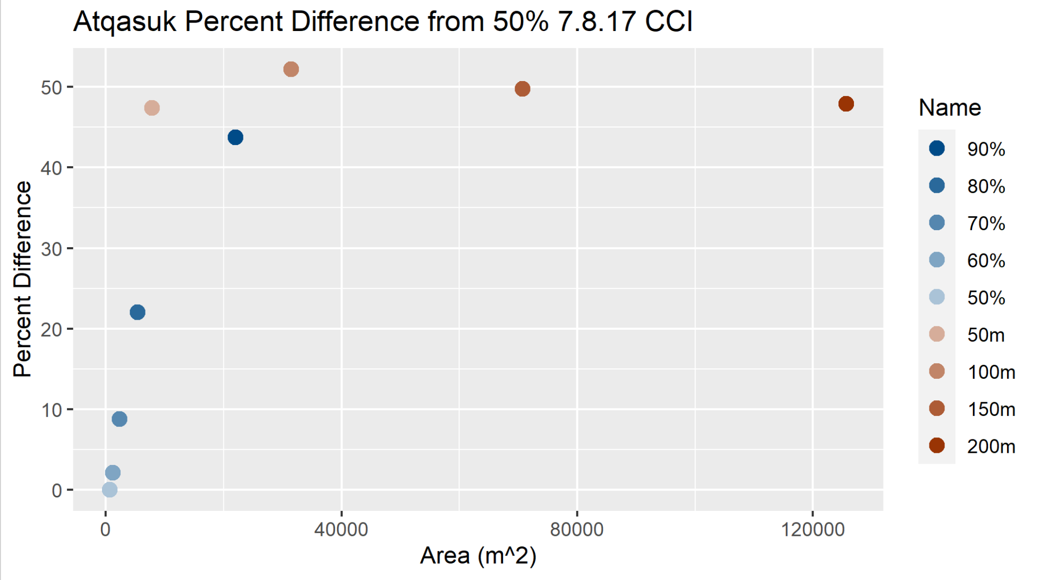


Atqasuk

NDVI and CCI vary 5-50% depending on footprint method

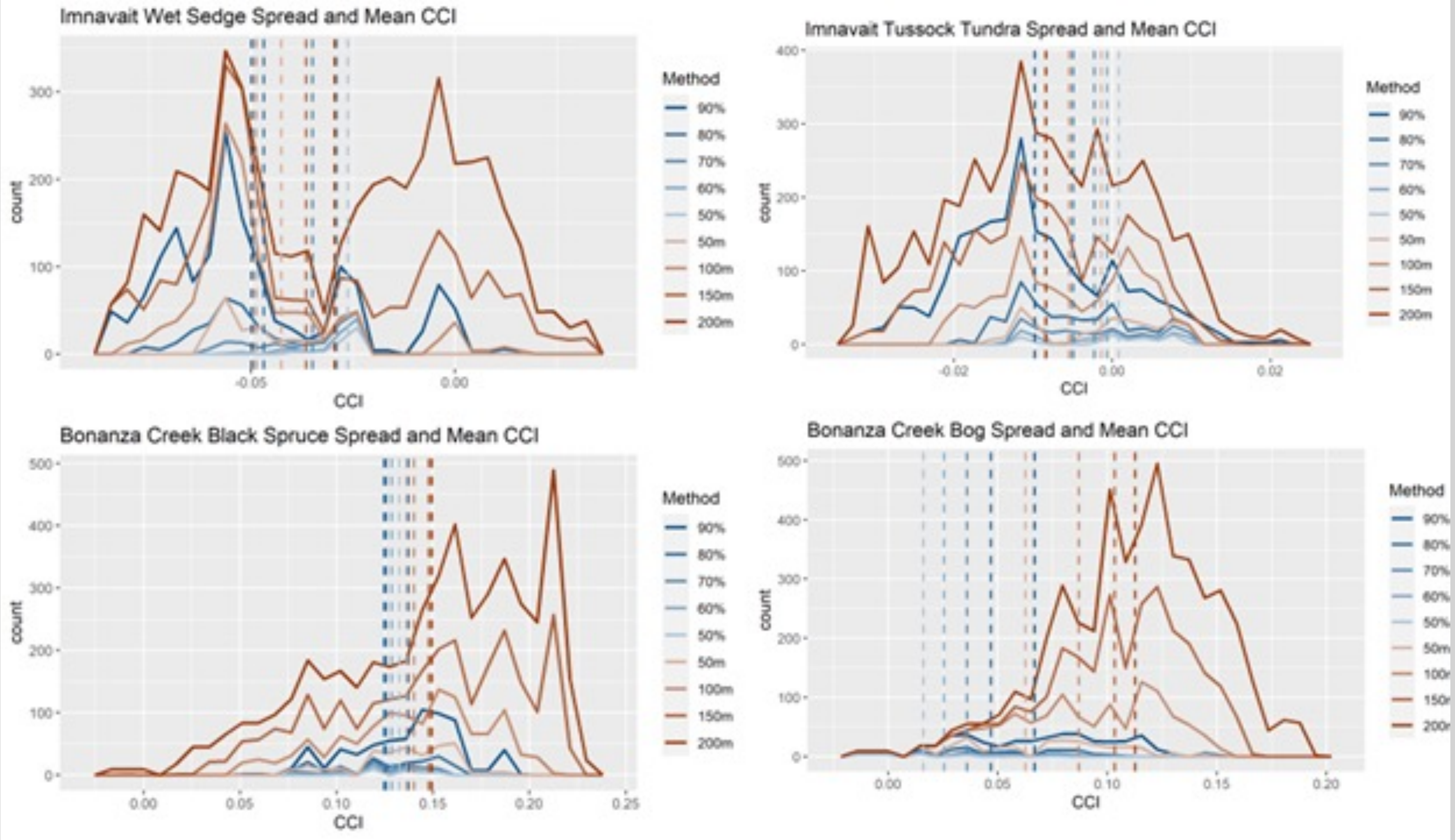


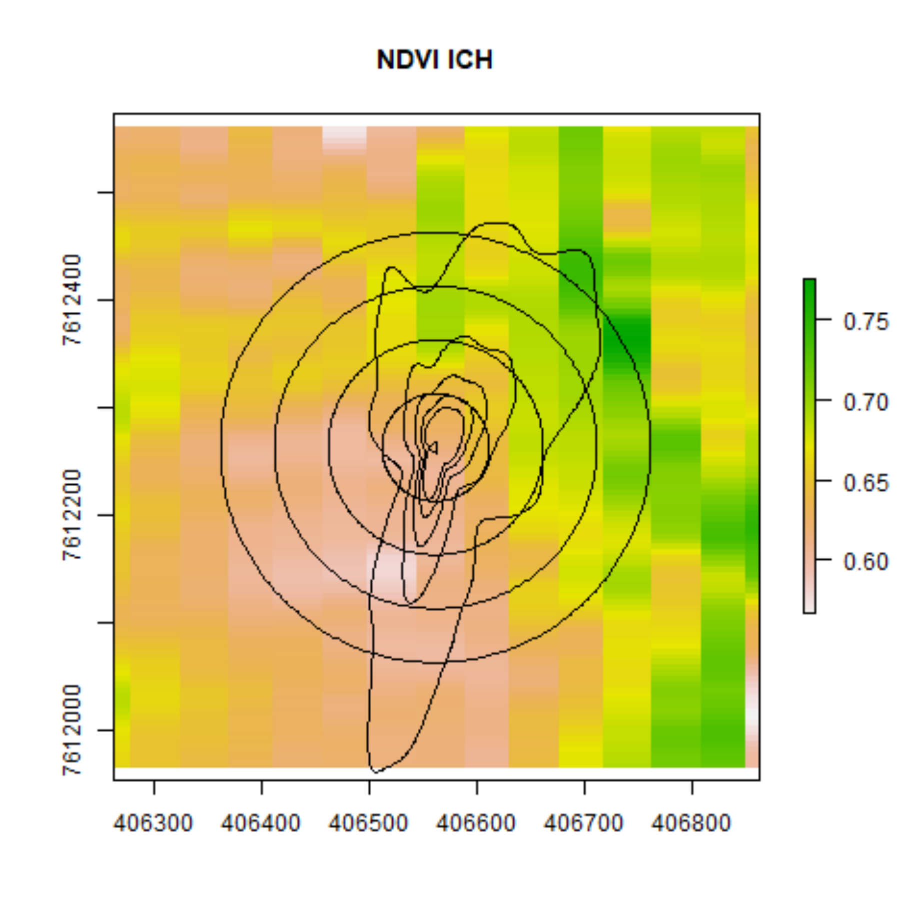




An example from 4 sites shows pixel counts using different footprints.

Take home: How you compare flux tower data to remote sensing data matters.
Recommend using weighted footprints.





Y-axis = % contour or radii distance from tower

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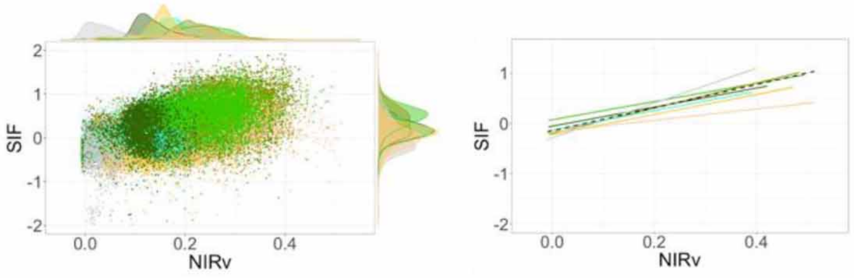
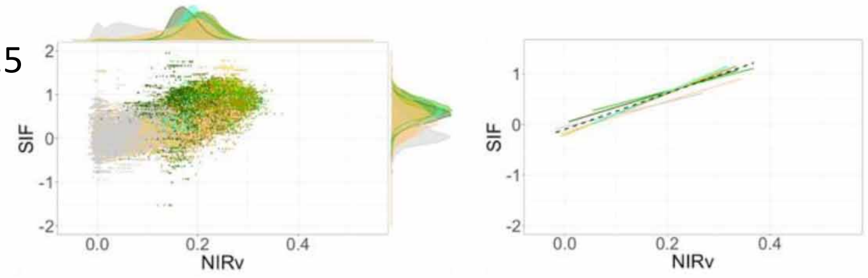
R^2air (NIRv) = 0.26



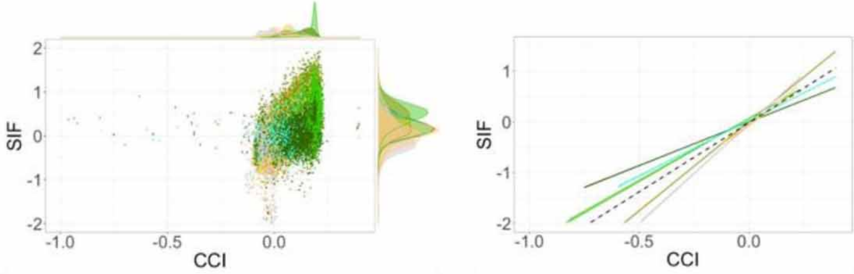
Landcover	R2	slope	% n
ALL	0.26	2.32	1.00
Evergreen Forest	0.13	1.91	0.29
Deciduous Forest	0.16	1.83	0.17
Shrubland	0.20	2.53	0.29
Herbaceous	0.08	1.12	0.05
Sparsely Vegetated	0.09	1.99	0.07
Barren	0.44	3.51	0.04
Fen	0.14	1.92	0.09

R^2space (NIRv) = 0.5



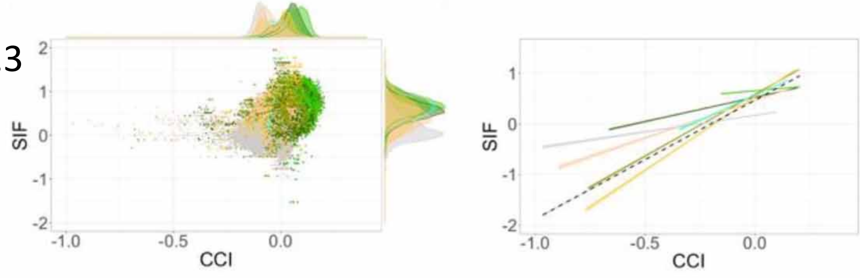
Landcover	R2	slope	% n
ALL	0.50	3.57	1.00
Evergreen Forest	0.18	3.09	0.35
Deciduous Forest	0.18	2.66	0.11
Shrubland	0.32	4.05	0.18
Herbaceous	0.39	3.07	0.09
Sparsely Vegetated	0.50	4.13	0.06
Barren	0.24	2.45	0.18
Fen	0.27	4.29	0.04

R^2air (NIRv) = 0.18



Landcover	R2	slope	% n
ALL	0.18	1.48	1.00
Evergreen Forest	0.09	1.08	0.29
Deciduous Forest	0.02	0.46	0.17
Shrubland	0.25	2.35	0.29
Herbaceous	0.39	3.54	0.05
Sparsely Vegetated	0.33	3.01	0.07
Barren	0.04	0.43	0.04
Fen	0.09	0.96	0.09

R^2space (NIRv) = 0.3



Landcover	R2	slope	% n
ALL	0.30	2.35	1.00
Evergreen Forest	0.04	0.95	0.35
Deciduous Forest	0.01	0.39	0.11
Shrubland	0.24	2.44	0.18
Herbaceous	0.09	1.48	0.09
Sparsely Vegetated	0.35	2.97	0.06
Barren	0.02	0.67	0.18
Fen	0.16	1.96	0.04

Spatial Covariation between Solar-induced Fluorescence and Vegetation Indices from Arctic-Boreal Landscapes

AJ Maguire, JUH Eitel, TS Magney, C Frankenberg, P Kohler, EL Orcutt, NC Parazoo, R Pavlick, and ZA Pierrat. 2021.

Environmental Research Letters

What is the scale dependance among remote sensing metrics commonly used to infer productivity?

- SIF (TROPOMI, CFIS), CCI and NIRv (AVIRIS, MODIS)

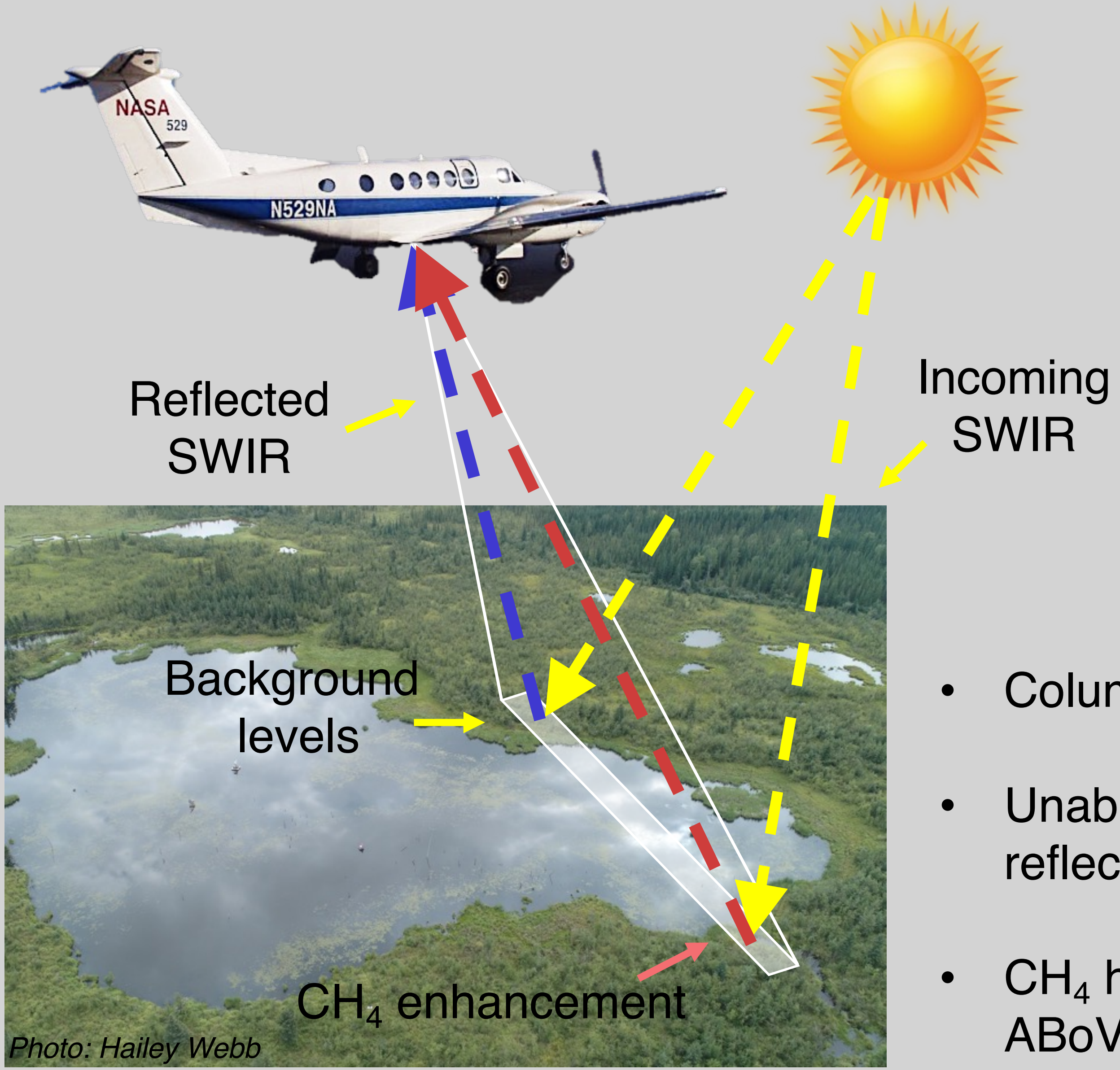
Finding: Linearity of SIF-CCI and SIF-NIRv relationship generally degrade as you move from satellite to airborne scale, with considerable variation among cover types.

Limitation of moderate resolution observations to capture spatial variance in photosynthetic activity.

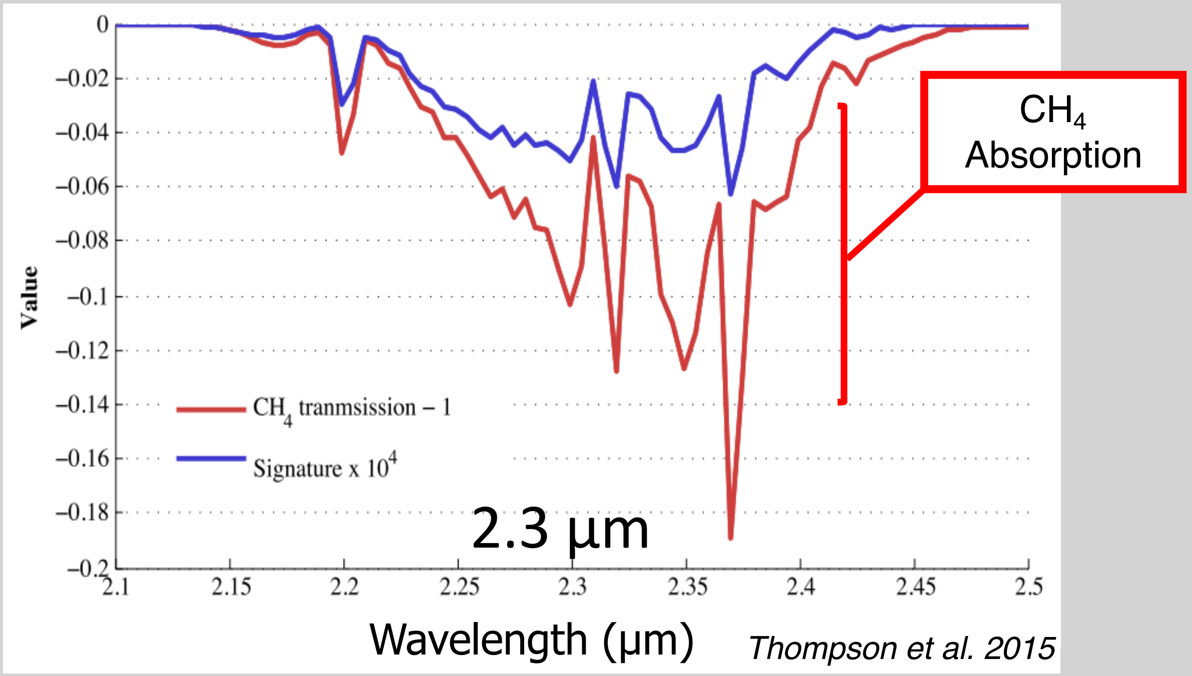
Methane Emissions

- Detection of CH_4 hot spots in permafrost landscapes (wetlands)
  - Related to geomorphology: talik and thermokarst undercutting features
- Chip Miller, Clayton Elder, Latha Baskaran, Andrew Thorpe, David Thompson + collaborators

- Elder et al. 2020, *Geophysical Research Letters*, https://doi.org/10.1029/2019GL085707
- Elder *et al*., 2021, *Global Biogeochemical Cycles*, https://doi.org/10.1029/2020GB006922
- Baskaran et al., 2022, Environmental Research Letters, https://doi.org/10.1088/1748-9326/ac41fb

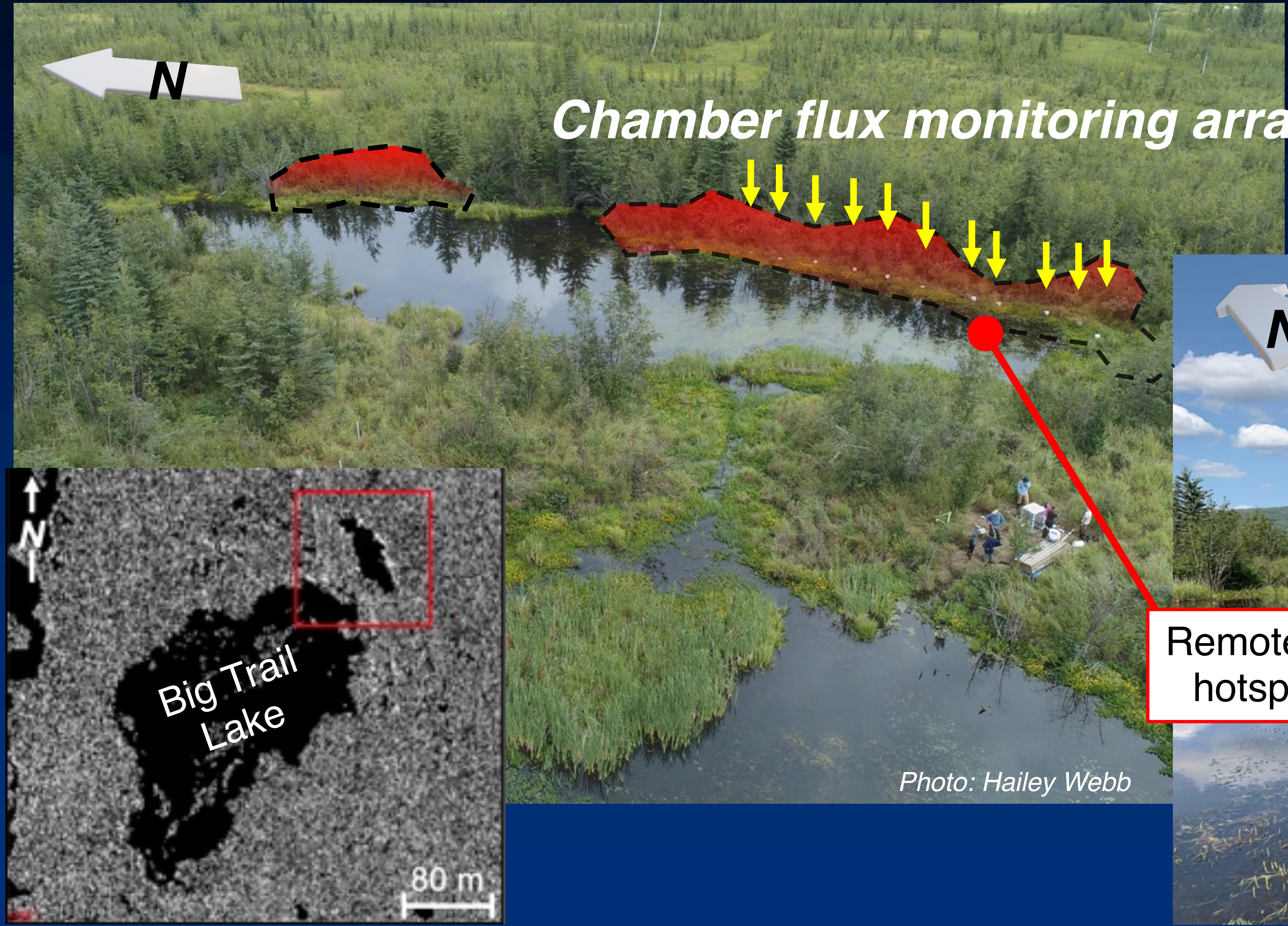


Column CH4 Enhancement due SWIR apsorption

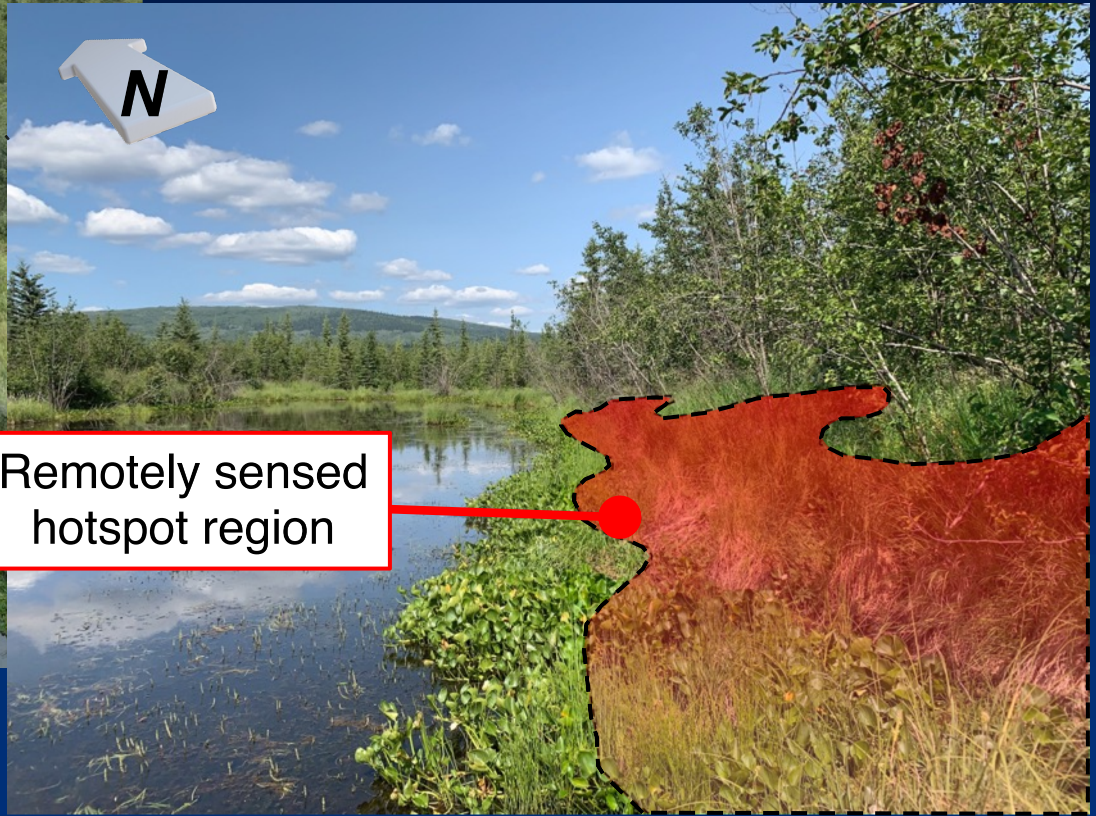


- Column-integrated path-length units of ppm m
- Unable to detect CH_4 over water surfaces (no SWIR reflection)
- CH_4 hotspot detection threshold 2000 – 3000 ppm m in the ABoVE domain

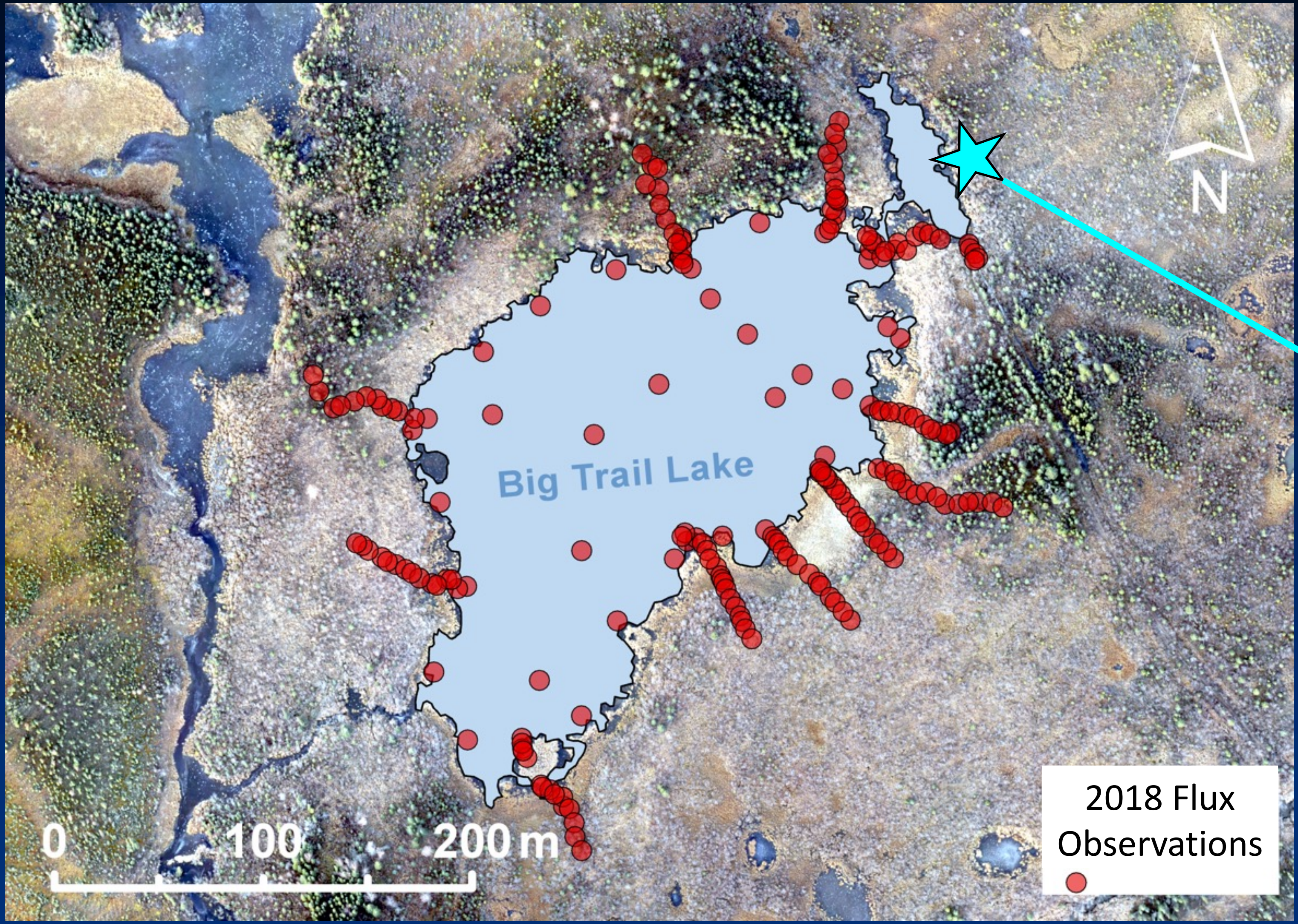
Overnight processing of initial 2019 AVIRIS-NG overflight data confirms persistent hotspot and motivates ground investigation



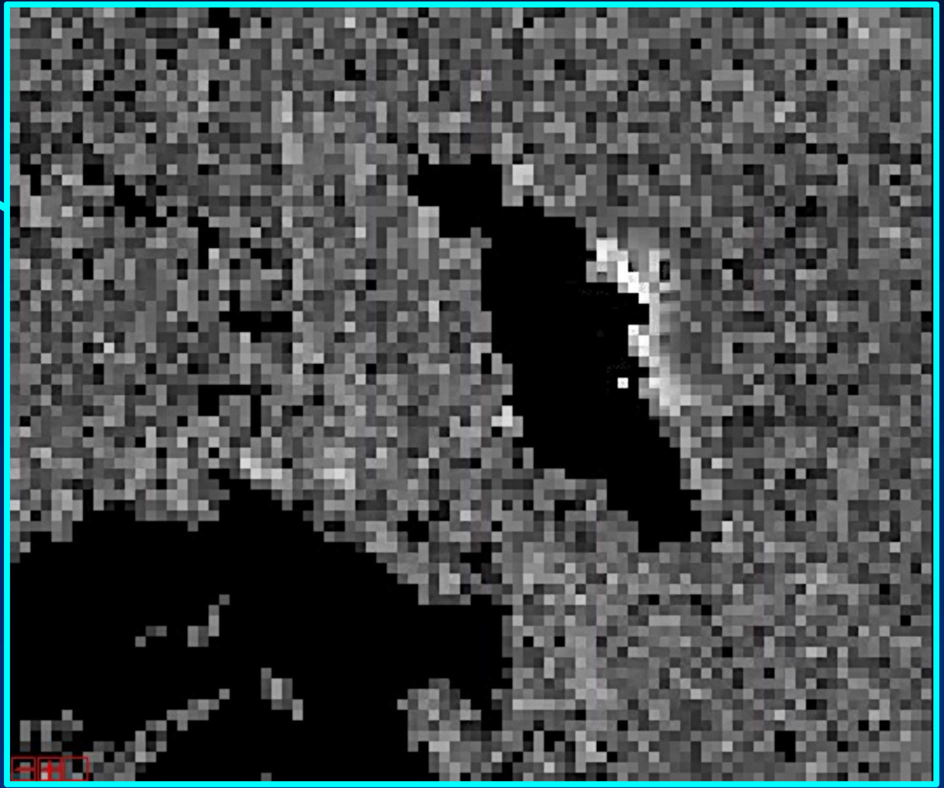
Flux dataset: n = 74 measurements from 08/19 – 12/19



AVIRIS-NG detects CH_4 hotspot at field site in 2018



2018 AVIRIS-NG CH_4 Hotspot at Big Trail Lake

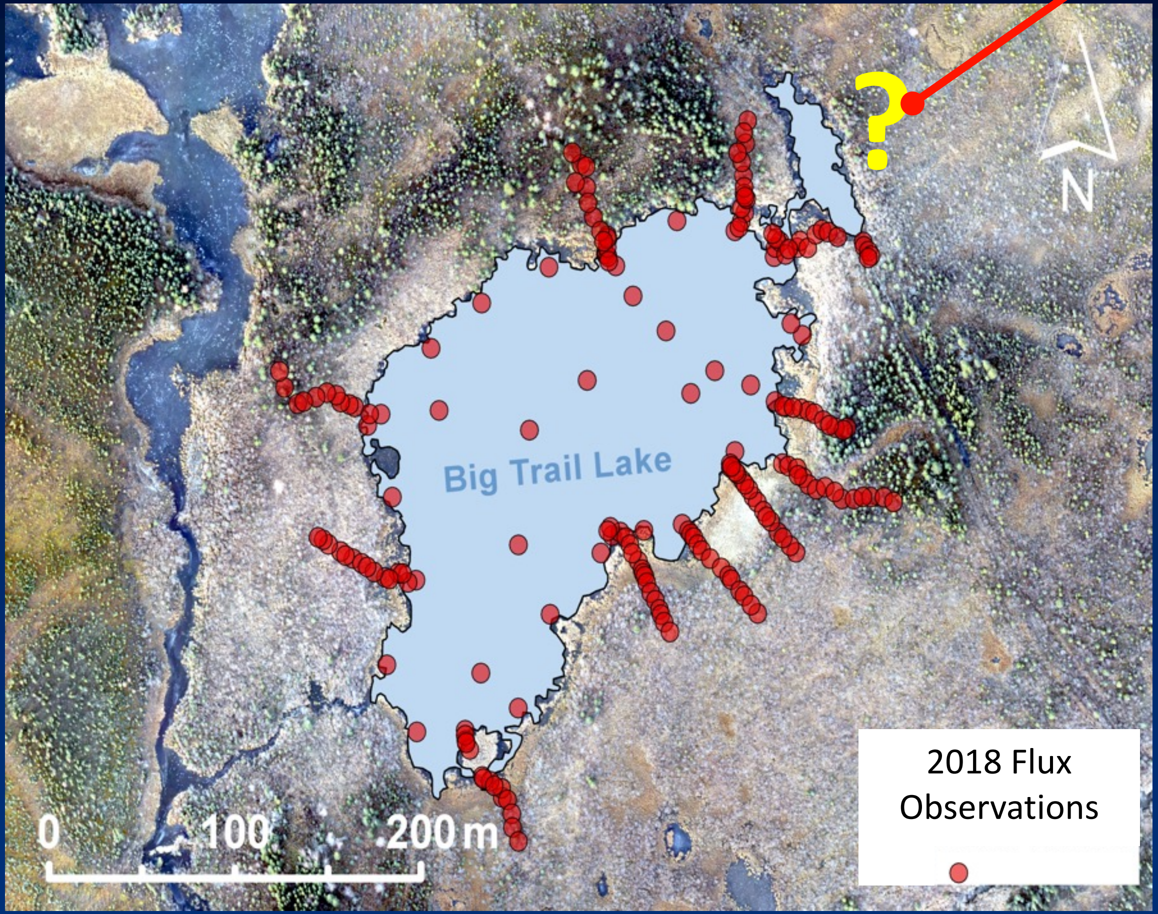


Bright pixels = enhanced CH_4

Ground validation of CH_4 hotspot patterns and fluxes at Big Trail Lake, AK

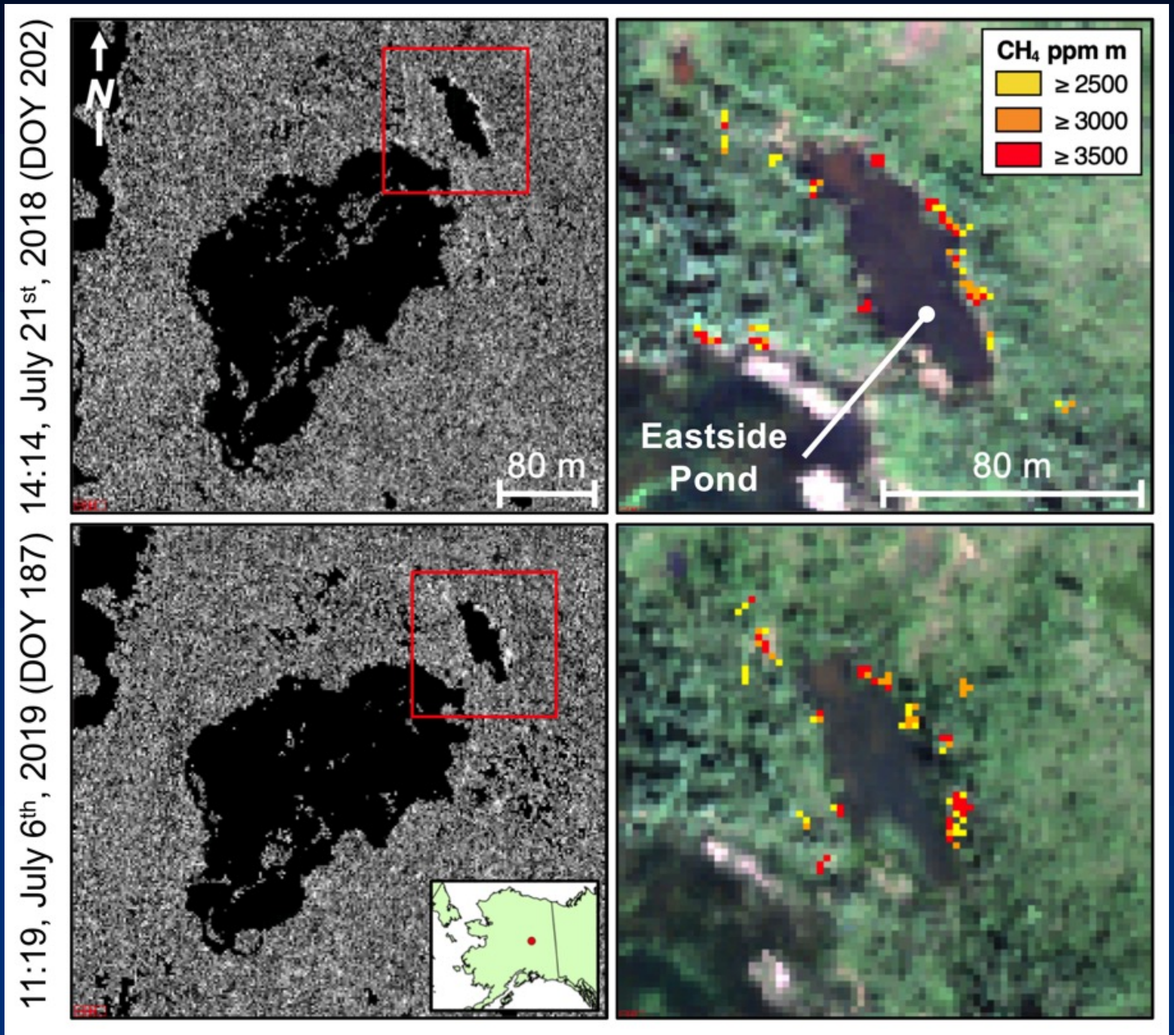
In-situ chamber flux monitoring initiated in 2018

without prior knowledge, 2018 ground survey misses hotspot



Elder et al. 2020

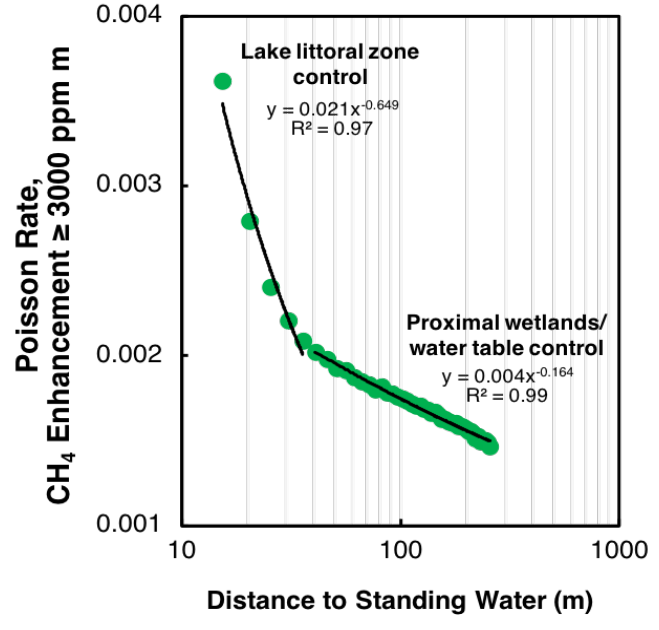
Persistent hotspot identified post 2018 field season and in subsequent 2019 surveys



Elder et al. (In Review)

CH_4 Hotspots follow spatial power law with respect to distance from water, mirroring wide-ranging in situ fluxes

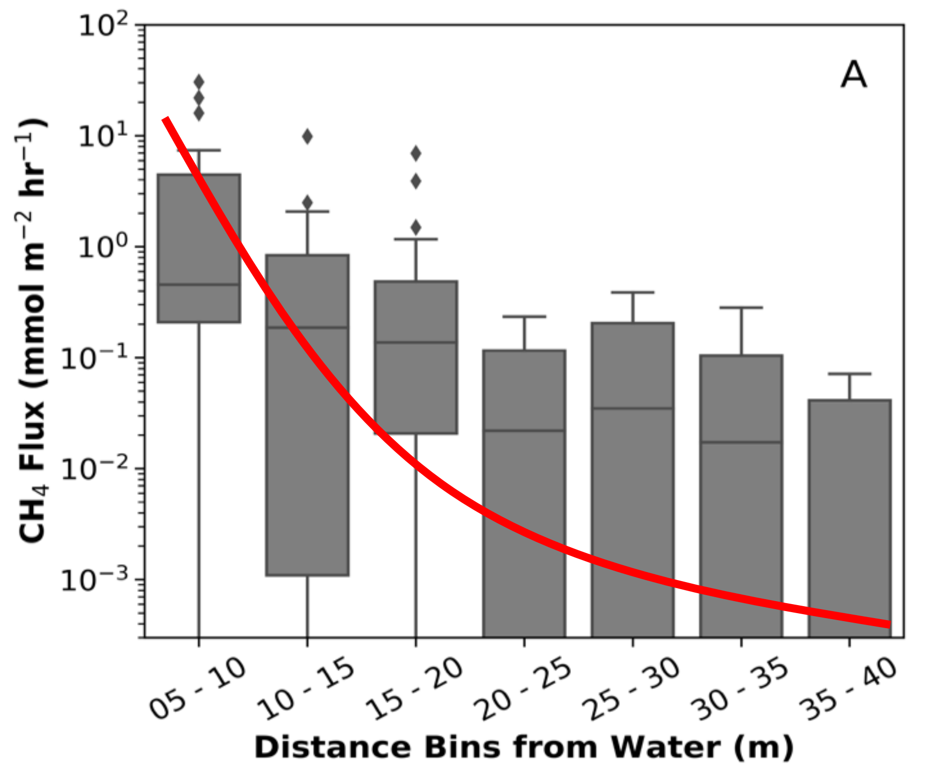
AVIRIS-NG Domain-wide Hotspot Pattern

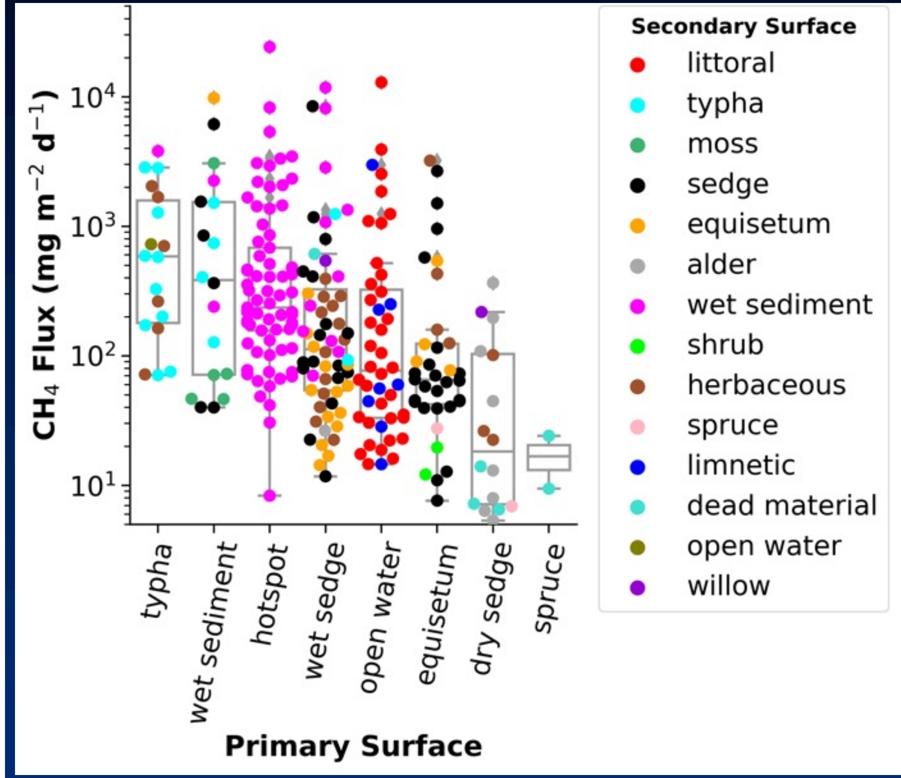


Remote power exponent

$\alpha_{remote} = 0.65$

In-Situ Flux Monitoring

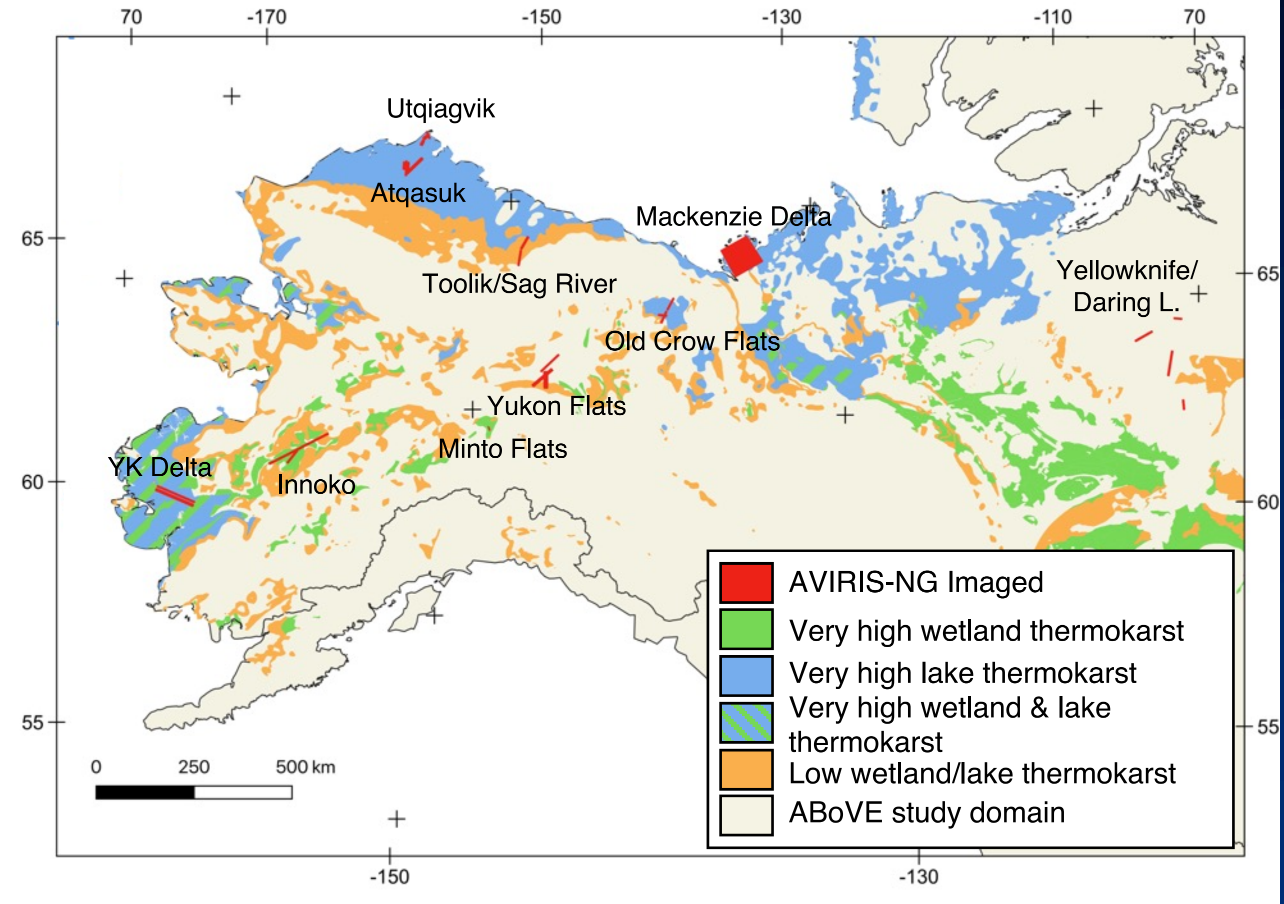


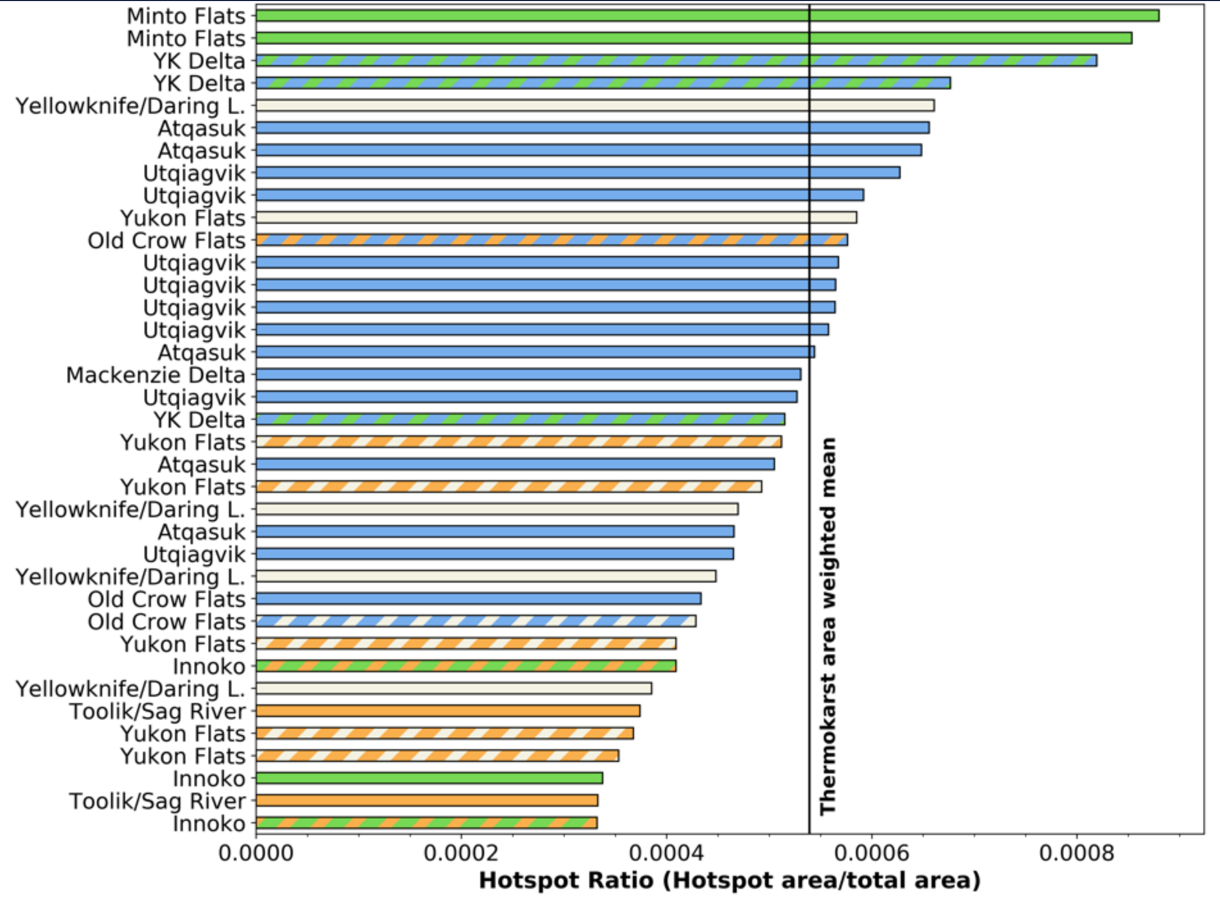


Elder et al. (In Review)

Domain-wide AVIRIS-NG hotspot occurrence correlates with landscape-scale levels of thermokarst activity

Hotspot occurrence ratio was determined for a subset of 65 flight lines spanning variable levels of thermokarst.





Elder et al. (Submitted)

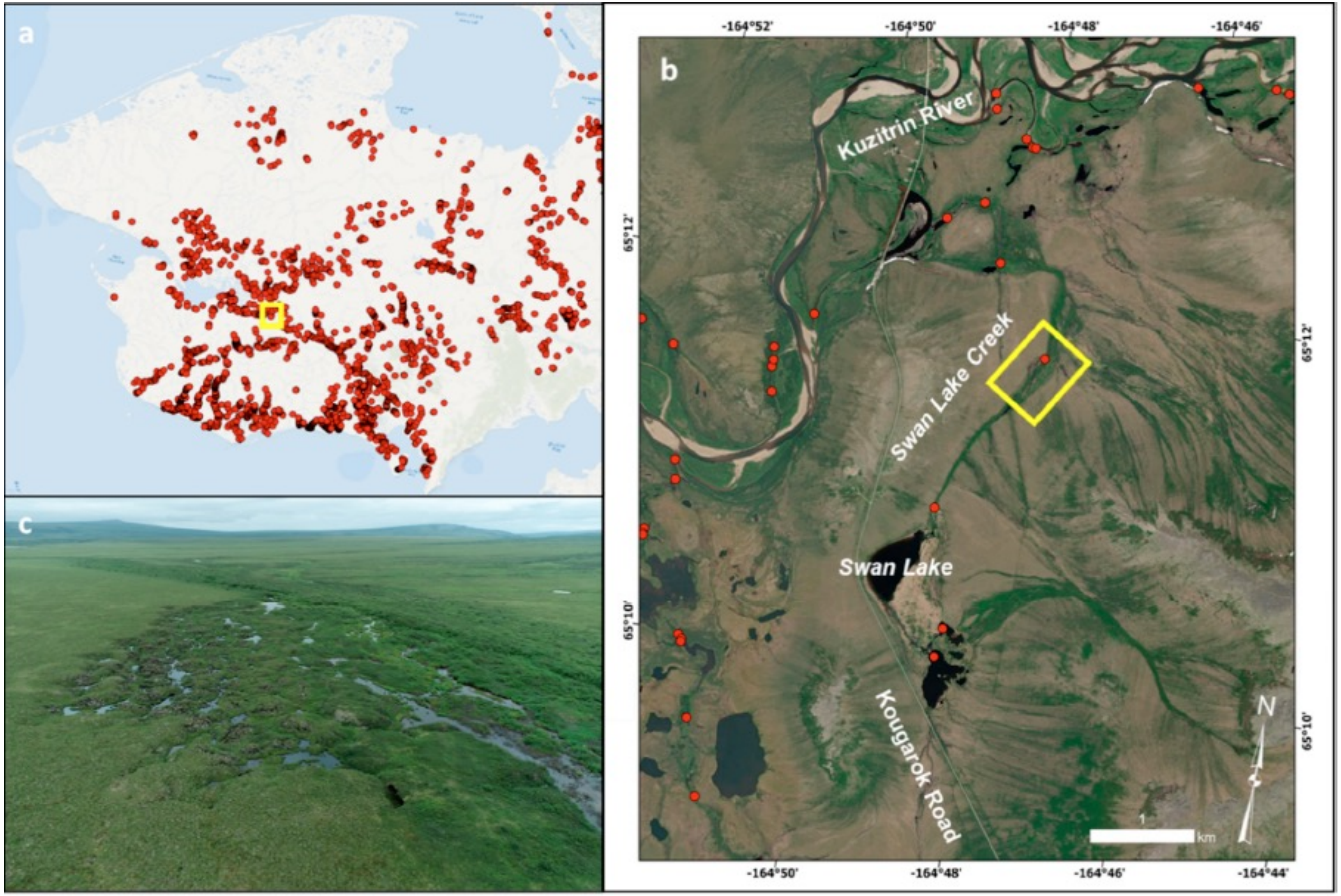
Hotspots were more prevalent in regions with very high wetland and lake thermokarst.

Using AVIRIS to study Beaver Engineering Disturbance and CH4 Hotspots in NW Alaska

ABoVE ARCTIC BOREAL VULNERABILITY EXPERIMENT

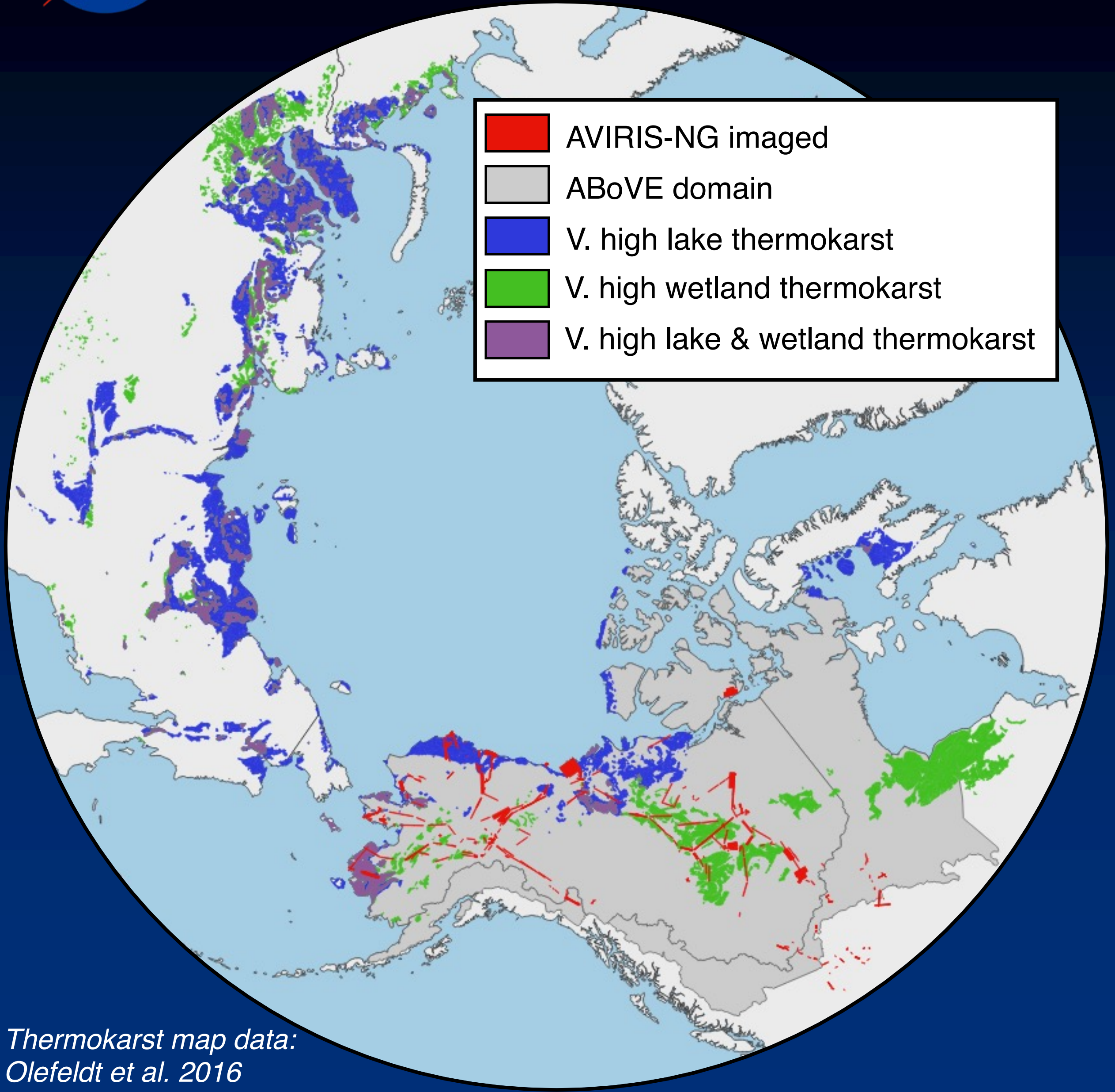
Similar tundra beaver disturbance – CH_4 hotspot studies are under way on the Seward Peninsula near Swan Lake and the NGEE-Arctic Kougarok site

Correlating hydrologic changes with AVIRIS methane hotspots



Jones et al., Remote Sens (2021)

Upscaling CH_4 hotspot occurrence ratios across pan-Arctic regions of very high lake and/or wetland thermokarst



Thermokarst map data: Olefeldt et al. 2016

Upscaling Parameters

- Two upscaling area approaches: discrete features, areas highly susceptible to thermokarst
- Two hotspot occurrence ratios: discrete features, broad area
- Mean, mean of daily max, max in-situ observed flux rates
- 200 days of emissions (growing + cold season fluxes)

Upscaling area description	Upscaling area (m^2)	Hotspot occurrence ratio (%)	CH_4 flux ($mg\ m^{-2}\ d^{-1}$)	flux days^{-yr}	Pan-Arctic Hotspot Flux ($g\ CH_4\ yr^{-1}$)	% of total wetland flux > 45° N*
Very high lake and/or wetland thermokarst occurrence	$^{\delta}1.978 \times 10^{12}$	0.054^{Ψ}	1168^{a} 7984^{b} 24227^{c}	200	2.5×10^{11} 1.7×10^{12} 5.2×10^{12}	0.8 5.3 16.2
Active lake and wetland thaw features	$^{\beta}1.498 \times 10^{11}$	0.243^{Φ}	1168^{a} 7984^{b} 24227^{c}	200	8.5×10^{10} 5.8×10^{11} 1.8×10^{12}	0.3 1.8 5.5
Median					1.14×10^{12}	3.6

pan-Arctic thermokarst hotspots emit roughly 1.0 Tg CH_4 yr^{-1}, or 4% of the pan-Arctic wetland CH_4 budget from < 0.005% of the northern permafrost region

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