

Understanding the Pattern and Drivers of Plant Communities across the Arctic Tundra Landscape

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Background - NGEE Arctic project



- The Next-Generation Ecosystem Experiments (NGEE Arctic) is a US Department of Energy supported project to improve our predictive understanding of carbon-rich Arctic ecosystem processes and feedbacks to climate.
- Activities include experiments, observations, and modeling datasets.
- Data will be incorporated into process representation and parameterization of DOE's Energy Exascale Earth System Model (E3SM).

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Greening Trend in Arctic



Since the late 20th century, tundra regions have been greening in response to changing climate and an accelerated disturbance regime [1; 2].

Credits: NASA's Goddard Space Flight Center/Cindy Starr

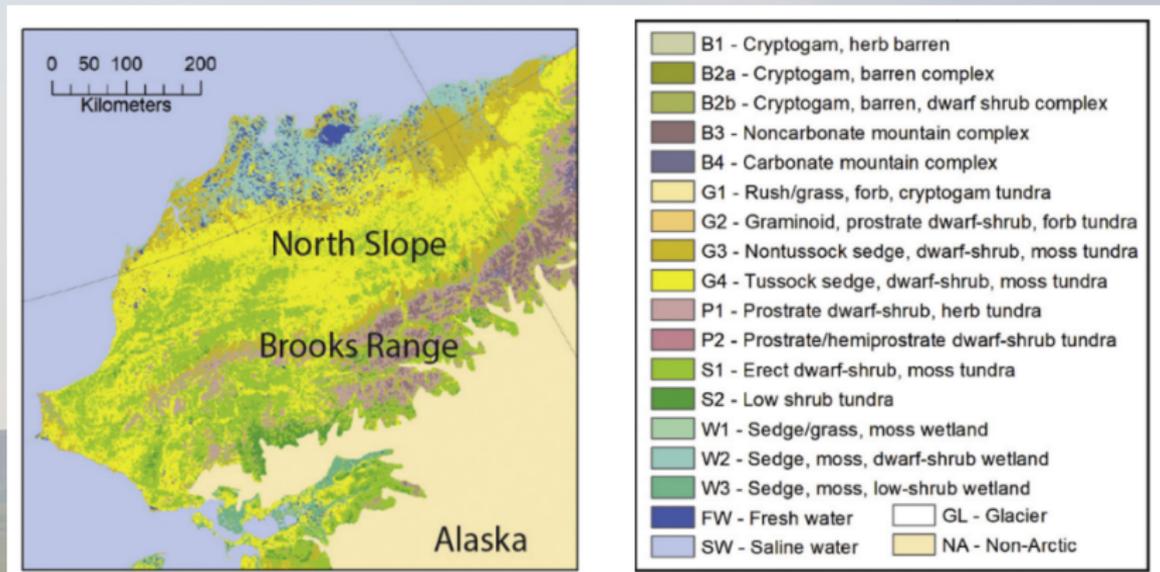
Implications for Arctic Biogeochemistry



Transitioning plant communities have important implications for C and N cycling within tundra ecosystems that have historically been nutrient-limited [3; 4]

Existing maps are coarse

- Circumpolar Arctic Vegetation Map (CAVM) - **1 km spatial res**
- Alaska Existing Vegetation Map (AKEVT) - **30 m spatial res**



Raynolds, Martha K., et al. "A raster version of the Circumpolar Arctic Vegetation Map (CAVM)." *Remote Sensing of Environment* 232 (2019): 111297.

Objectives

- **Landscape Composition** – Create high resolution watershed-scale plant community maps using airborne remote sensing data.
- **Drivers of vegetation distribution** – Identify drivers (topography and climate) drivers of plant community distribution.
- **Landscape Configuration** – How are plant communities arranged spatially?



Intensively Studied Watersheds at Seward, AK

Teller



Kougarak



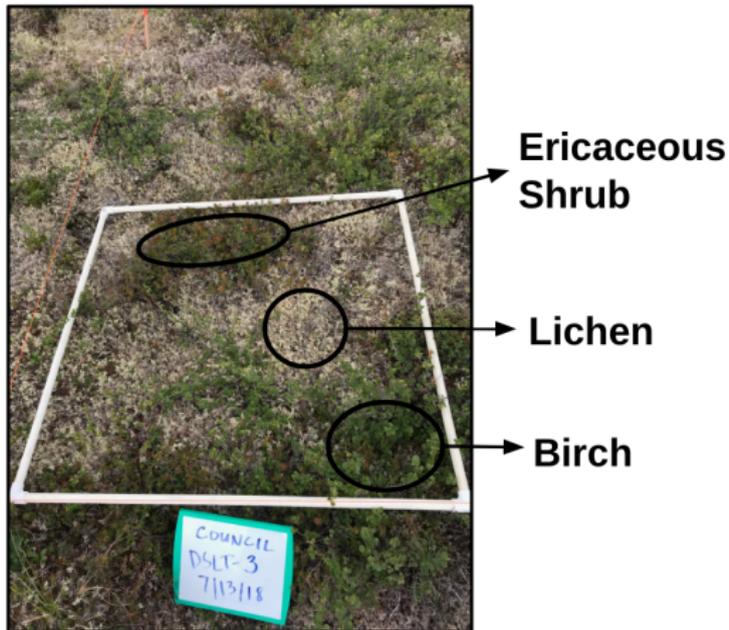
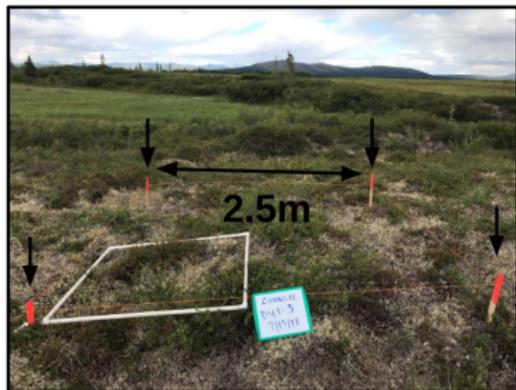
Council



Field vegetation surveys conducted across all watersheds

Plant Community: A collection of plant species within a geographical area, which form a relatively uniform patch

Birch-Ericaceous-Lichen



Field Vegetation Survey (contd.)

12 Plant Communities

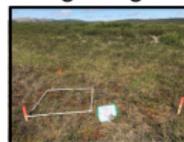
Willow-Birch



Mesic Graminoid-Herb Meadow



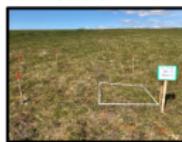
Wet Sedge Bog-Meadow



Dryas-Lichen Dwarf Shrub Tundra



Wet Meadow Tundra



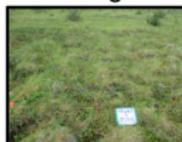
Birch-Ericaceous-Lichen Shrub Tundra



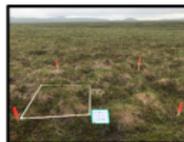
Sedge-Willow Dryas Tundra



Mixed Shrub-Sedge Tussock Tundra



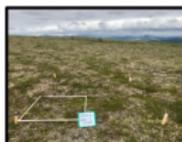
Tussock-Lichen tundra



Willow Shrub



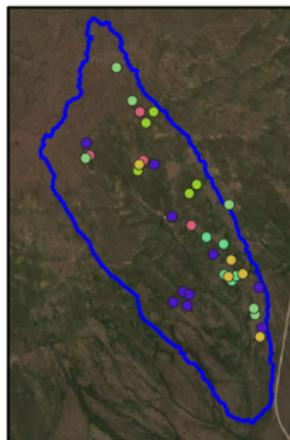
Ericaceous-Lichen Dwarf Shrub Tundra



Alder-Willow Shrub



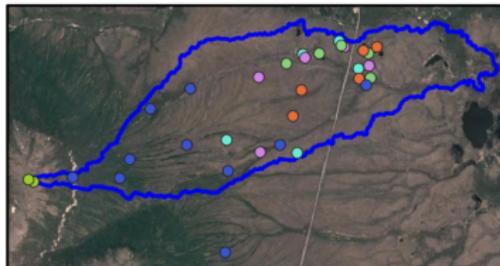
Field Vegetation Survey (contd.)



Teller
(36 plots)



Kougarok
(30 plots)



Council
(32 plots)



Total number of surveys = 98

Airborne Remote Sensing from NASA ABOVE AVIRIS-NG



Sensor Specifications

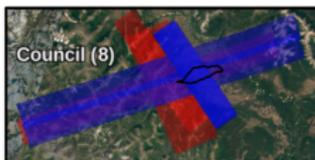
Parameter	Value
Wavelength	380 - 2510 nm
No. of Bands	425
Spatial Res	5 m



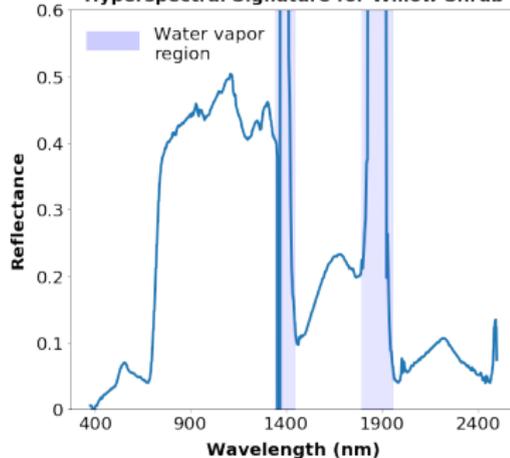
AVIRIS-NG Flight Lines

Legend

- 2017 Flight Lines (red)
- 2018 Flight Lines (blue)



Hyperspectral Signature for Willow Shrub

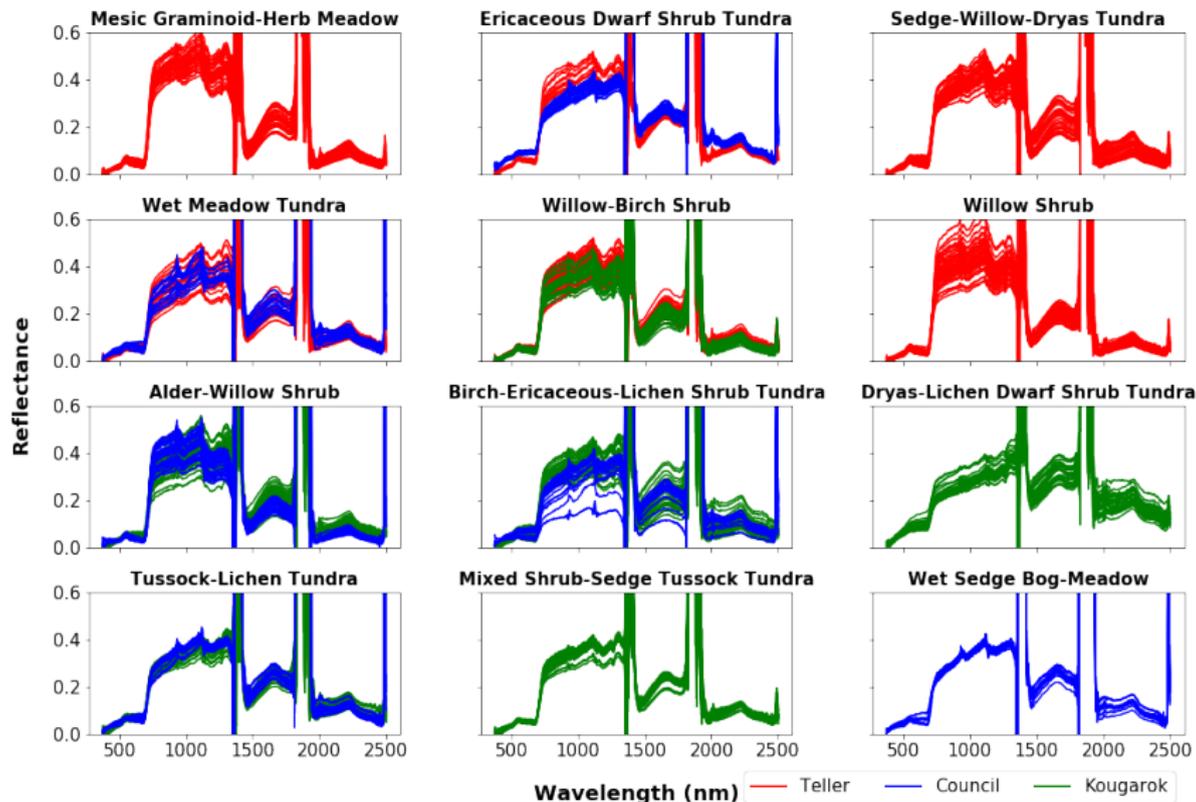


Extent of AVIRIS data collection across ABoVE domain



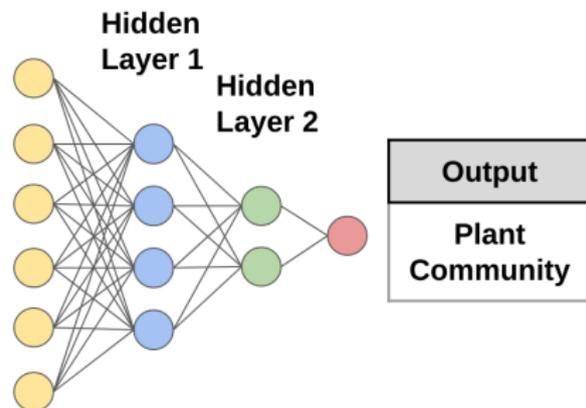
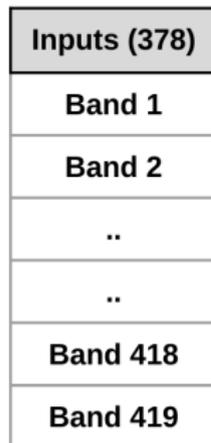
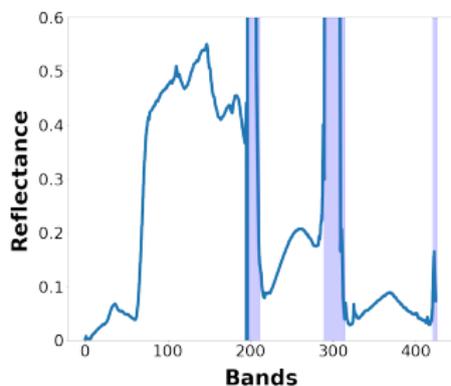
Credits: NASA ABoVE ORNL DAAC website

Spectral signatures of vegetation communities across sites

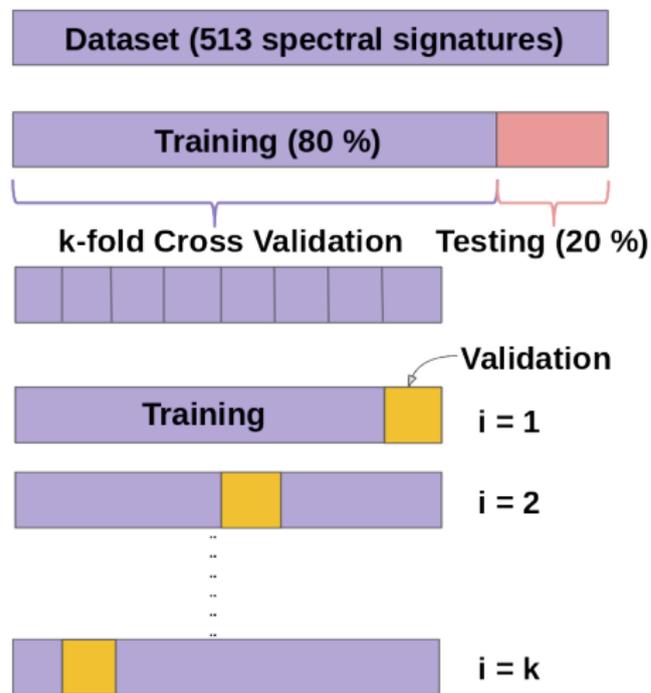


Deep Neural Network-based classifier

5m Airborne
Hyperspectral reflectance
from NASA AVIRIS-NG

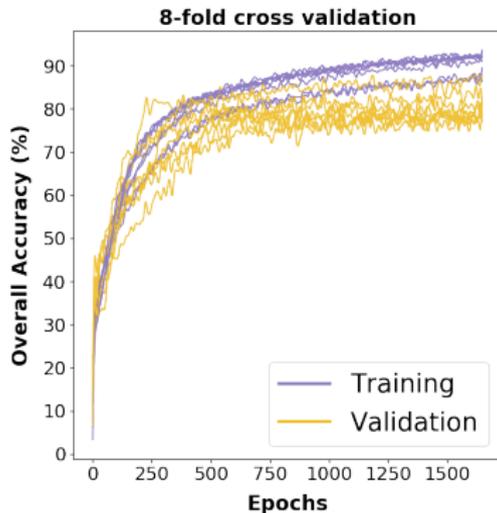


Classification Results



Hyperparameters:

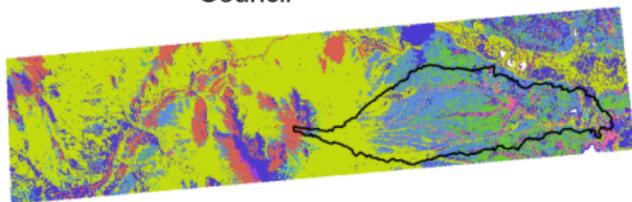
- Number of Hidden Layers: 3
- Number of Units: 200, 100, 50
- Regularization: Dropout (0.1) and L1



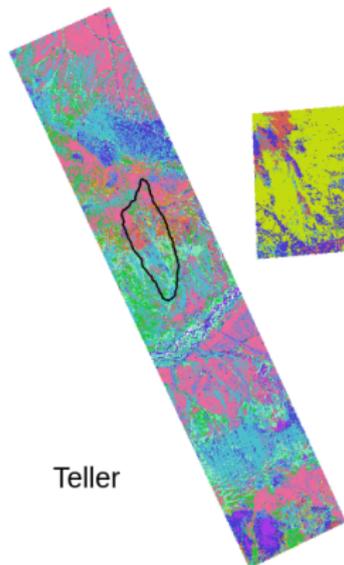
Accuracy on the test set: **80.58%**

5m Plant Community Maps for Watersheds

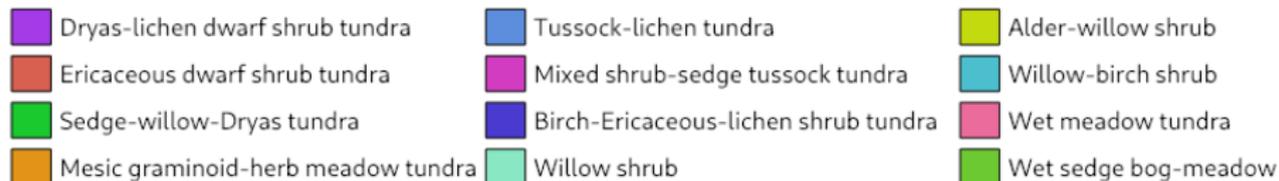
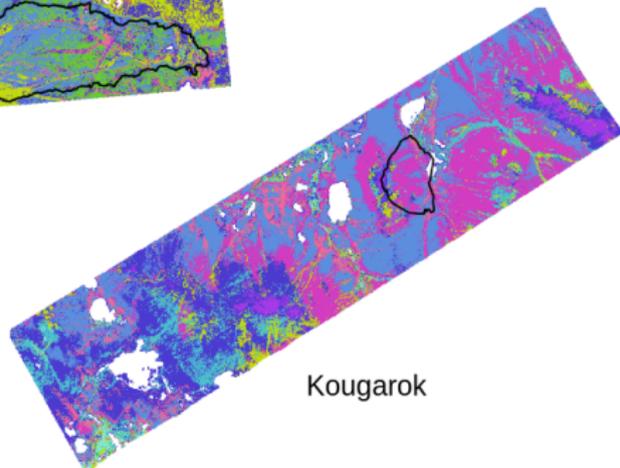
Council



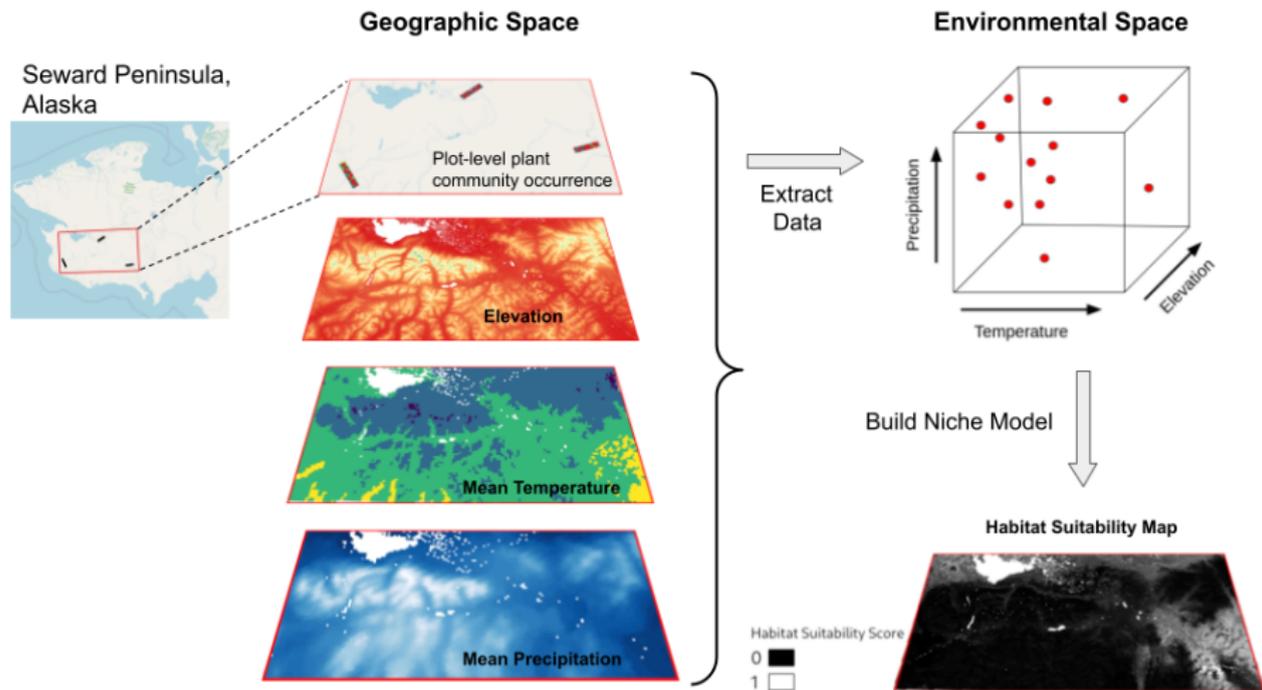
Teller



Kougarok



Environmental Niche Modeling



Environmental Variables

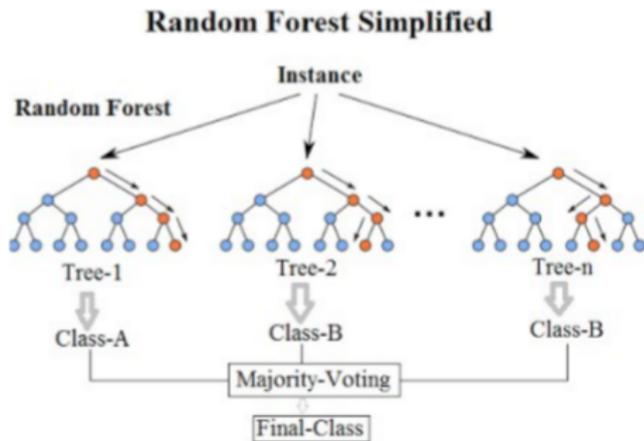
Type	Name	Units	Resolution	Source
Topography	Topographic Wetness Index	-	5m	IfSAR
	Slope	degrees		
	sin(aspect) or "Northness"	-		
	cos(aspect) or "Eastness"	-		
	Avg. Summer and Winter Solar Irradiation*	Wh/m ² /day		
	Elevation	meters		
Climate (Decadal avg. 2000-09)	Mean Annual Temperature	°C	771m	SNAP [†]
	Mean Summer and Winter Temperature*	°C		
	Temperature Seasonality (std deviation)	°C		
	Mean Annual Precipitation	mm		
	Mean Winter and Summer Precipitation*	mm		
	Precipitation seasonality (std deviation)	mm		

* Summer - June, July, August

Winter - December, January, February

[†] SNAP (Scenarios Planning for Alaska Arctic planning) produces downscaled, historical climate data for sub-Arctic and Arctic regions of Alaska and Canada. Downscaled data come from one of 5 top-ranked GCMs or are calculated as a 5-model average.

Niche Modeling using Random Forest



Model Performance

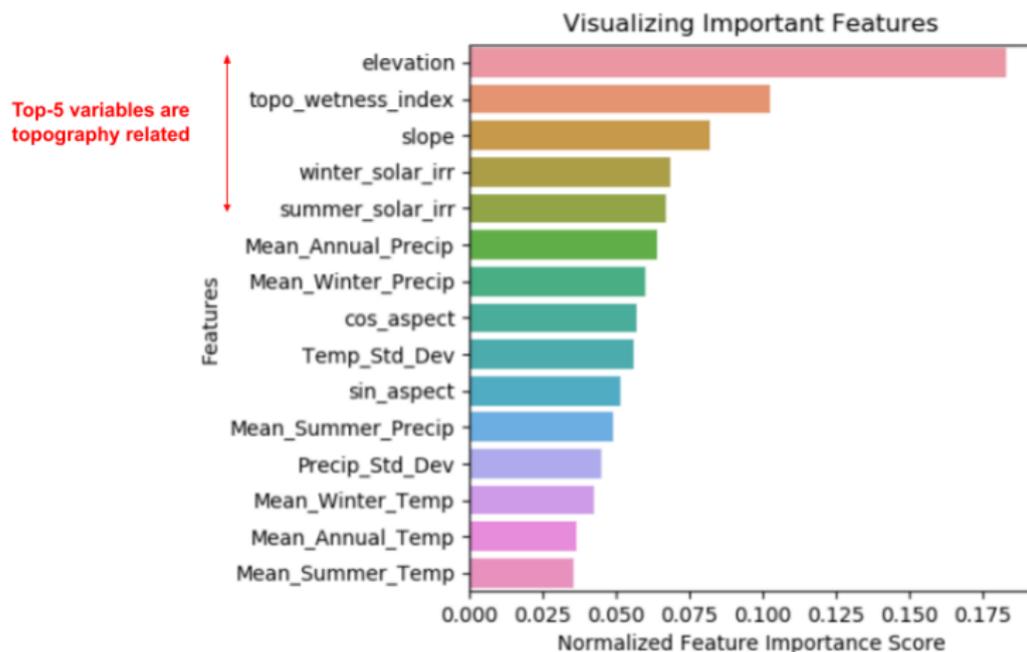
- Dataset divided into training, validation and testing
- Number of trees: 100
- Minimum samples for splitting: 30

	Accuracy on the Independent Test Set (20% of the data)					
	Samples containing all 12 Plant Communities			Samples containing only Top-6 Plant Communities*		
Inputs	Climate only	Topo only	Climate + Topo	Climate only	Topo only	Climate + Topo
Accuracy	41.28%	57.45%	65.45%	64.58%	74.69%	81.53%

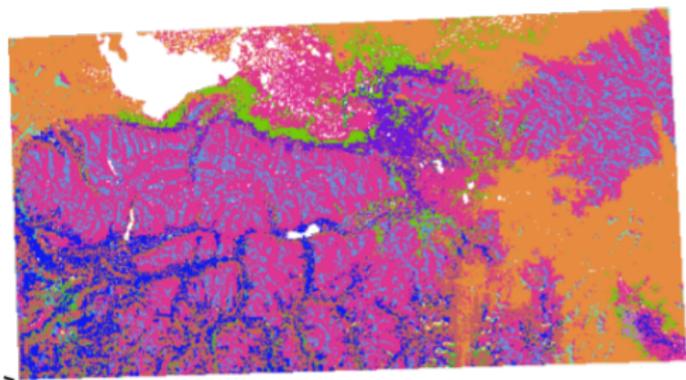
Plant communities with higher accuracy:

Alder-Willow Shrub, Tussock-Lichen Tundra, Dryas-Lichen Dwarf Shrub Tundra, Wet Sedge Bog-Meadow, Mixed Shrub-Sedge Tussock Tundra, Willow-Birch Shrub

Environmental Drivers of vegetation distribution



Regional-scale high resolution (5m) plant community map



-  Dryas-lichen dwarf shrub tundra
-  Ericaceous dwarf shrub tundra
-  Sedge-willow-dryas tundra
-  Mesic graminoid-herb meadow tundra

-  Tussock lichen tundra
-  Mixed shrub-sedge tussock tundra
-  Birch Ericaceous lichen shrub tundra
-  Willow shrub

-  Alder-willow shrub
-  Willow-birch shrub
-  Wet meadow tundra
-  Wet sedge bog meadow

Summary

- Airborne hyperspectral remote sensing data allows mapping of plant communities at watershed scale.
- A Deep Neural Network-based classification of vegetation spectra achieved an accuracy $>80\%$.
- Analysis of environmental drivers provides insights into preferential niche space where plant communities thrive.
- Niche modeling using Random Forest model enables creation of plant community maps over a regional scale.
- Topography-related variables such as elevation seem to be playing a major role in vegetation distribution.
- Niche model could be used to estimate potential changes in niche distribution under predicted future climate.

Thank you!



References

- [1] J. Ju and J. G. Masek, "The vegetation greenness trend in Canada and Alaska from 1984–2012 Landsat data," *Remote Sensing of Environment*, vol. 176, pp. 1–16, 2016.
- [2] G. J. Jia, H. E. Epstein, and D. A. Walker, "Greening of Arctic Alaska, 1981–2001," *Geophysical Research Letters*, vol. 30, no. 20, 2003.
- [3] S. E. Hobbie, "Effects of plant species on nutrient cycling," *Trends in Ecology & Evolution*, vol. 7, no. 10, pp. 336–339, 1992.
- [4] F. S. Chapin III and G. R. Shaver, "Individualistic growth response of tundra plant species to environmental manipulations in the field," *Ecology*, vol. 66, no. 2, pp. 564–576, 1985.