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

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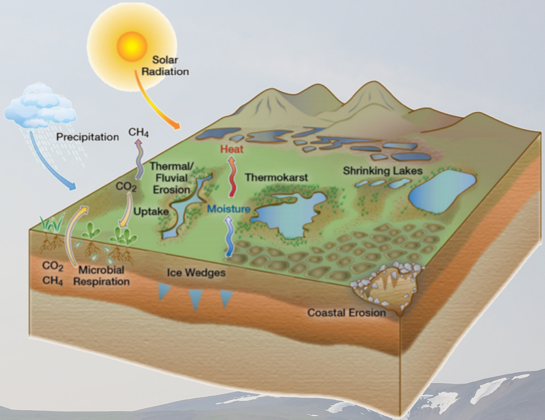
Greening Trend in Arctic

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]

Image provided by Lawrence Berkeley National Laboratory
Edited by: Verity G. Salmon

Objectives

- Create high-resolution, watershed-scale plant community maps – where?

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- Understand the drivers (climatological, topographic and hydrologic) of plant community distribution – why?

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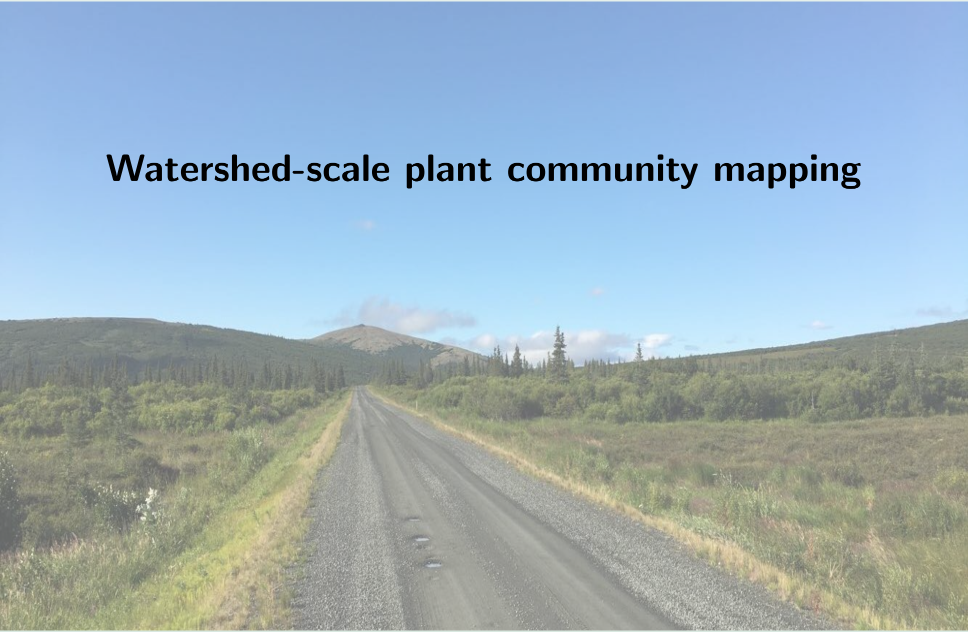
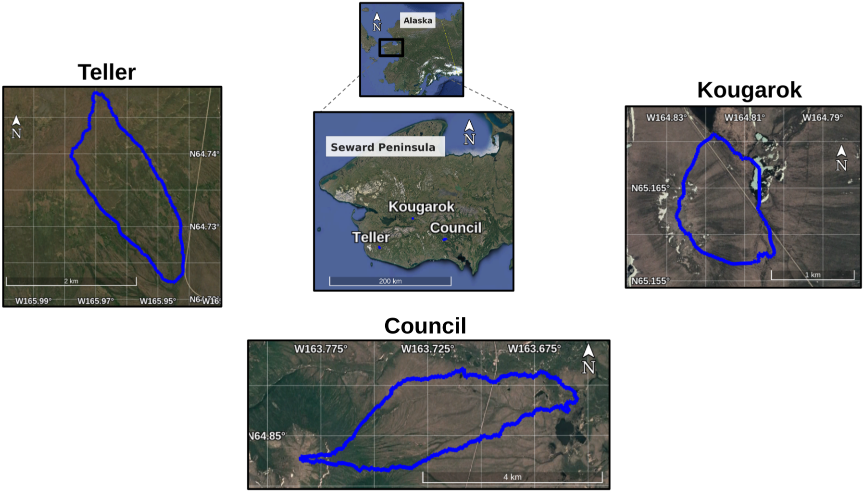
- With the help of Remote Sensing and Machine Learning – how?

Objective 1



Watershed-scale plant community mapping

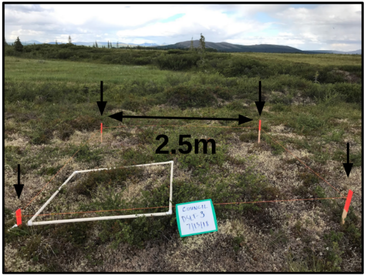
Intensively Studied Watersheds at Seward, AK

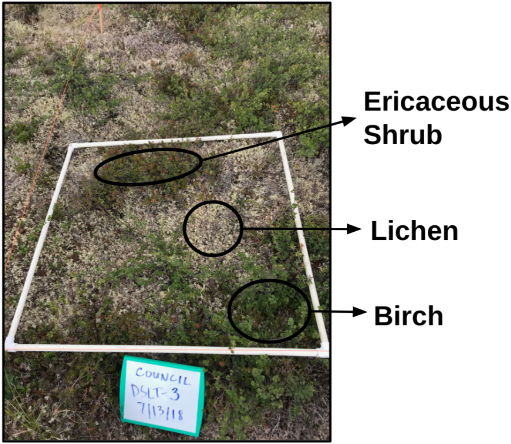


Field vegetation surveys conducted across all watersheds

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

Birch-Ericaceous-Lichen

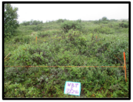




Field Vegetation Survey (contd.)

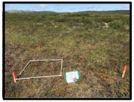
12 Plant Communities

Willow-Birch

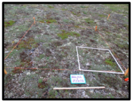


Mesic Graminoid-Herb Meadow

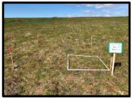
Wet Sedge Bog-Meadow



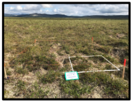
Dryas-Lichen Dwarf Shrub Tundra



Wet Meadow Tundra



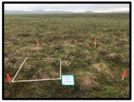
Birch-Ericaceous-Lichen Shrub Tundra



Sedge-Willow Dryas Tundra

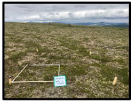
Mixed Shrub-Sedge Tussock Tundra

Tussock-Lichen tundra



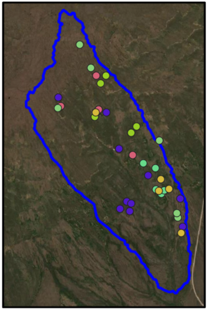
Willow Shrub

Ericaceous-Lichen Dwarf Shrub Tundra

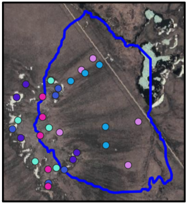


Alder-Willow Shrub

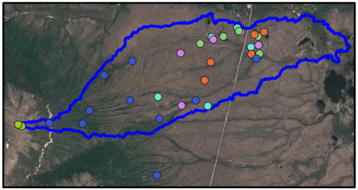
Field Vegetation Survey (contd.)



Teller
(36 plots)



Kougarok
(30 plots)



Council
(32 plots)

Legend

- Alder-Willow Shrub
- Birch-Ericaceous-Lichen Shrub Tundra
- Dryas-Lichen Dwarf Shrub Tundra
- Ericaceous Dwarf Shrub Tundra
- Mesic Graminoid-Herb Meadow
- Mixed Shrub-Sedge Tussock Tundra
- Sedge-Willow-Dryas Tundra
- Tussock-Lichen Tundra
- Wet Meadow Tundra
- Wet Sedge Bog-Meadow
- Willow Shrub
- Willow-Birch Shrub

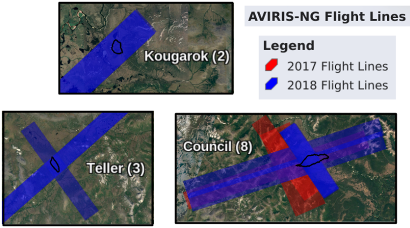
Total number of surveys $= 98$

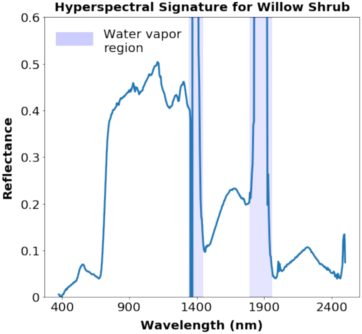
Airborne Remote Sensing from NASA ABOVE AVIRIS-NG

ABoVE
ARCTIC - BOREAL VULNERABILITY EXPERIMENT

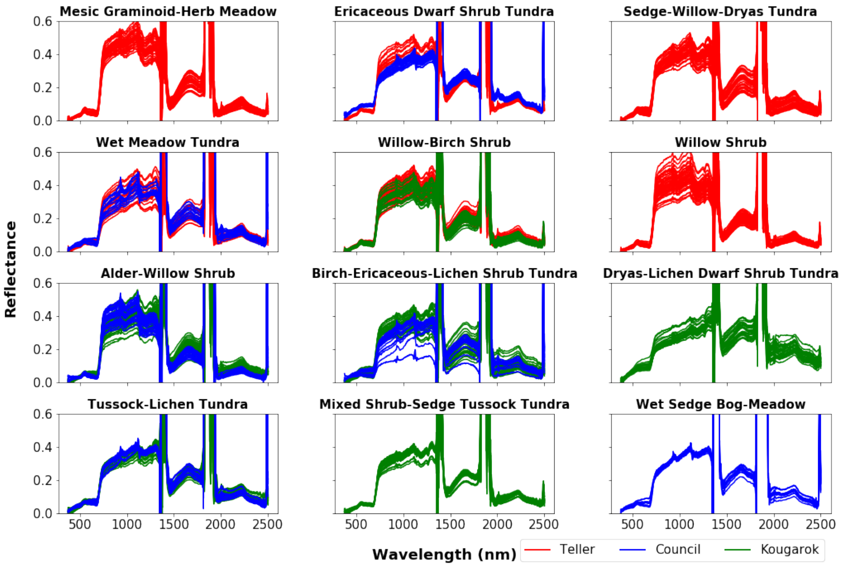
Sensor Specifications

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



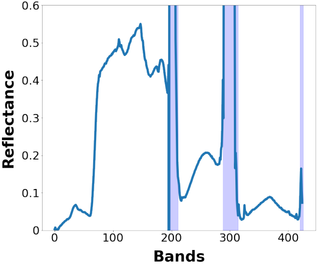


Spectral signatures of vegetation communities across sites



Deep Neural Network-based classifier

For every 5m pixel,



Deep Neural Network-based classifier

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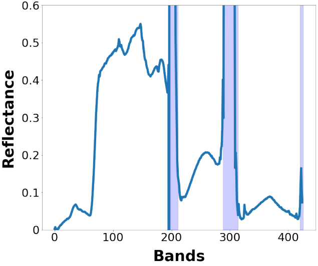
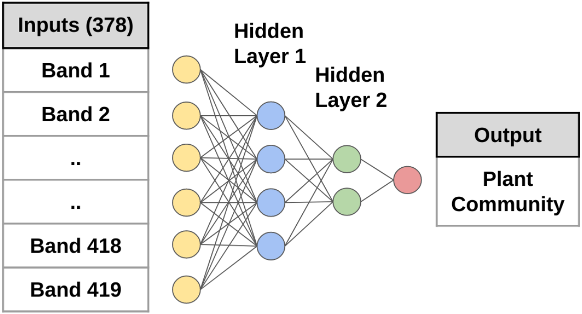
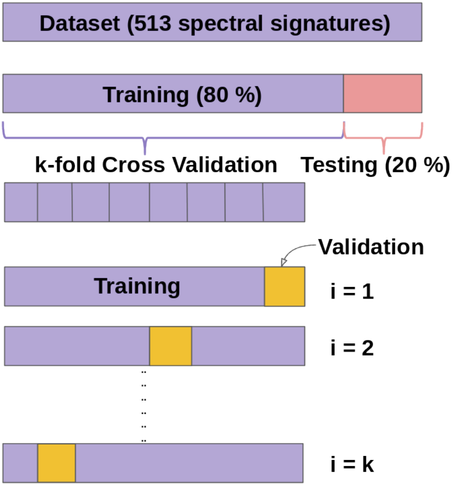
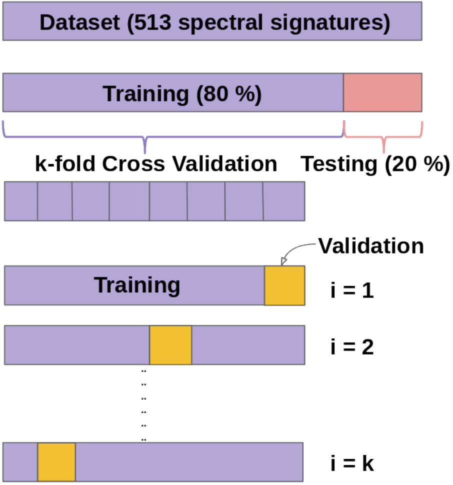




Classification Results

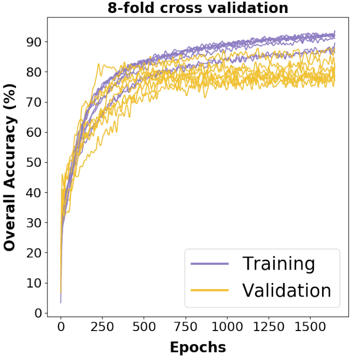


Classification Results



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%**

Errors in Prediction

- Values along the diagonal represent the number of instances when the model predicted correctly.
- Off-diagonal values show errors.

		PREDICTED											
	Ald-Wil	Bir Eric	Dry Lic	Eric Dwrf	Mes Gram	Mix Shrb	Sed-Wil	Tuss Lich	Wet Mead	Wet Sed	Wil Shrb	Wil Bir	Recall (%)
OBSERVED Ald-Wil	12	2	-	-	-	-	-	-	-	-	-	1	80
Bir Eric	-	6	-	1	-	-	-	1	1	-	-	-	67
Dry Lic	-	-	5	-	-	-	-	-	-	-	-	-	100
Eric Dwrf	-	-	-	5	-	-	-	-	-	-	-	2	71
Mes Gram	-	-	-	-	5	-	-	-	-	-	2	-	71
Mix Shrb	-	-	-	-	-	6	-	-	-	-	-	-	100
Sed-Wil	-	-	-	-	-	-	6	-	2	-	1	-	67
Tuss Lich	-	-	-	-	-	-	-	9	-		-	-	100
Wet Mead	-	1	-	-	-	-	-	-	5	-	-	-	83
Wet Sed	-	-	-	-	-	-	-	-	-	3	-	-	100
Wil Shrb	-	-	-	-	1	-	1	-	-	-	8	-	80
Wil Bir	2	-	-	-	-	-	-	-	-	-	2	13	76
Precision (%)	86	67	100	83	83	100	86	90	62	100	62	81	80.58

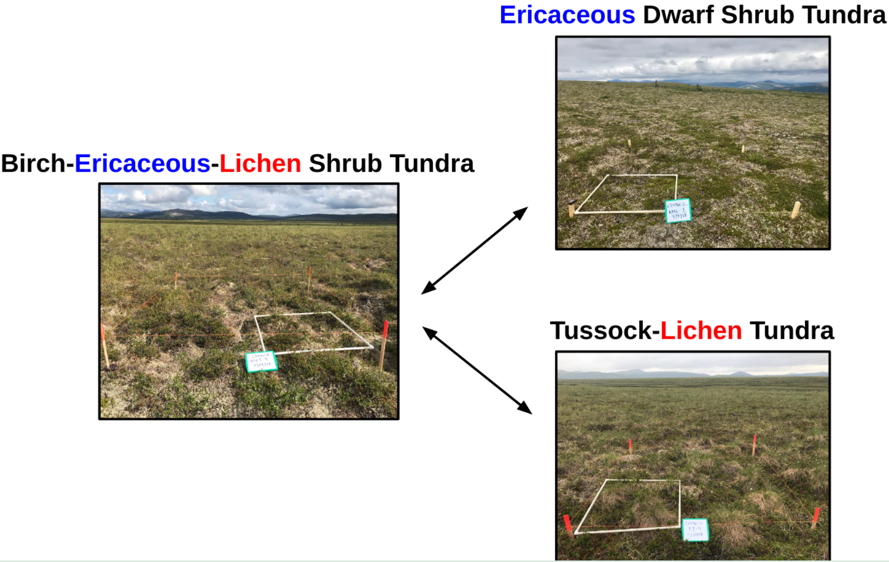
Birch-Ericaceous-Lichen Shrub Tundra

Confused with other plant communities

		PREDICTED												
		Ald-Wil	Bir Eric	Dry Lic	Eric Dwrf	Mes Gram	Mix Shrb	Sed-Wil	Tuss Lich	Wet Mead	Wet Sed	Wil Shrb	Wil Bir	Recall (%)
OBSERVED	Ald-Wil	12	2	-	-	-	-	-	-	-	-	-	1	80
	Bir Eric	-	6	-	1	-	-	-	1	1	-	-	-	67
	Dry Lic	-	-	5	-	-	-	-	-	-	-	-	-	100
	Eric Dwrf	-	-	-	5	-	-	-	-	-	-	-	2	71
	Mes Gram	-	-	-	-	5	-	-	-	-	-	2	-	71
	Mix Shrb	-	-	-	-	-	6	-	-	-	-	-	-	100
	Sed-Wil	-	-	-	-	-	-	6	-	2	-	1	-	67
	Tuss Lich	-	-	-	-	-	-	-	9	-	-	-	-	100
	Wet Mead	-	1	-	-	-	-	-	-	5	-	-	-	83
	Wet Sed	-	-	-	-	-	-	-	-	-	3	-	-	100
	Wil Shrb	-	-	-	-	1	-	1	-	-	-	8	-	80
	Wil Bir	2	-	-	-	-	-	-	-	-	-	2	13	76
	Precision (%)	86	67	100	83	83	100	86	90	62	100	62	81	80.58

Reasons behind confusion

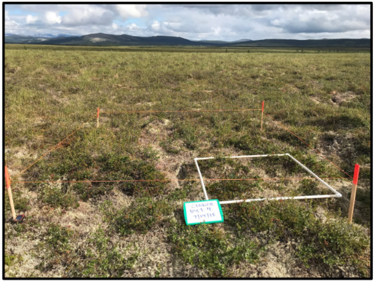
Overlap of constituent species with other plant communities



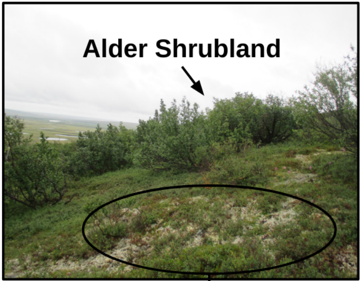
Reasons behind confusion

“Patchiness” of vegetation

Birch-Ericaceous-Lichen Shrub Tundra

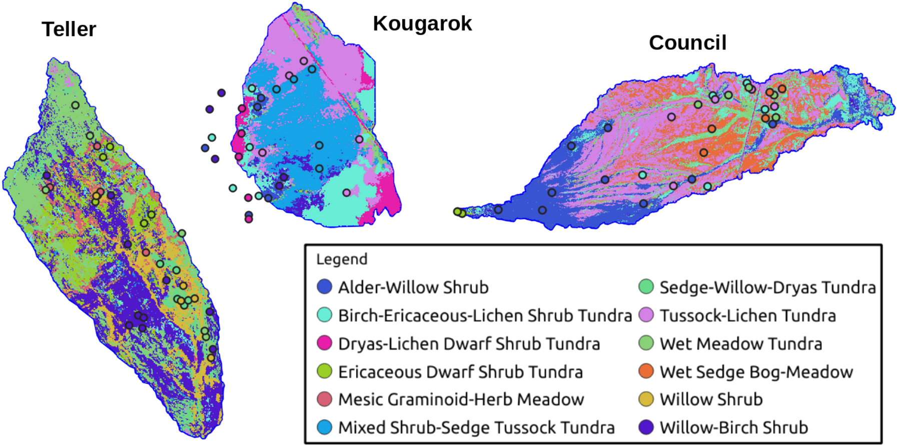


Alder-Willow Shrub



Dwarf Shrub Lichen Tundra

5m Plant Community Maps for Watersheds



Objective 2

Understand the drivers of vegetation distribution

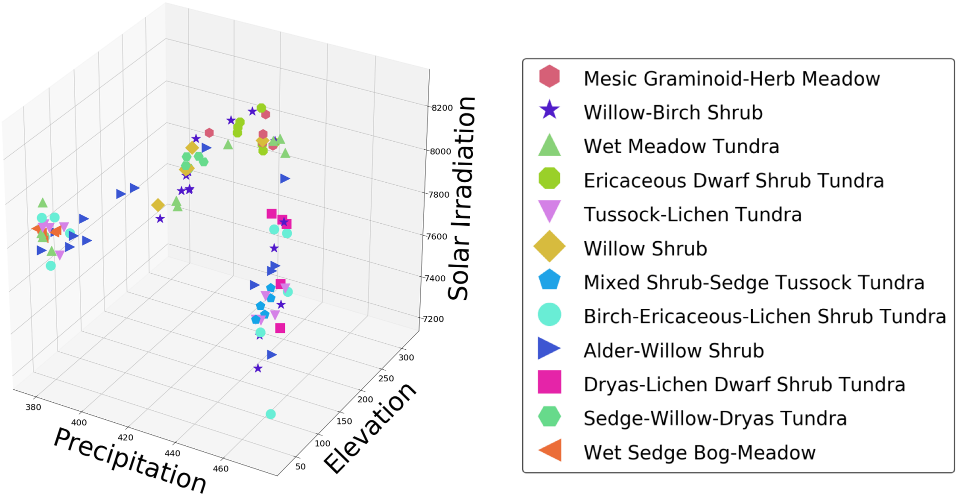
Environmental Variables

Type	Name	Units	Resolution	Source
Topography	Slope	degrees	5m	IfSAR
	Aspect	degrees		
	Elevation	meters		
	Avg. Summer Solar Irradiation*	$Wh/m^2/day$		
	Avg. Winter Solar Irradiation*	$Wh/m^2/day$		
	Topographic Convergence Index	-		
	Distance to stream	meters		
Climate (Decadal avg. 2000-09)	Avg. Summer Temperature*	^oC	771m	SNAP†
	Avg. Winter Temperature*	^oC		
	Precipitation	mm		
	Growing Season Length	days		
	Snowfall Equivalent	mm		

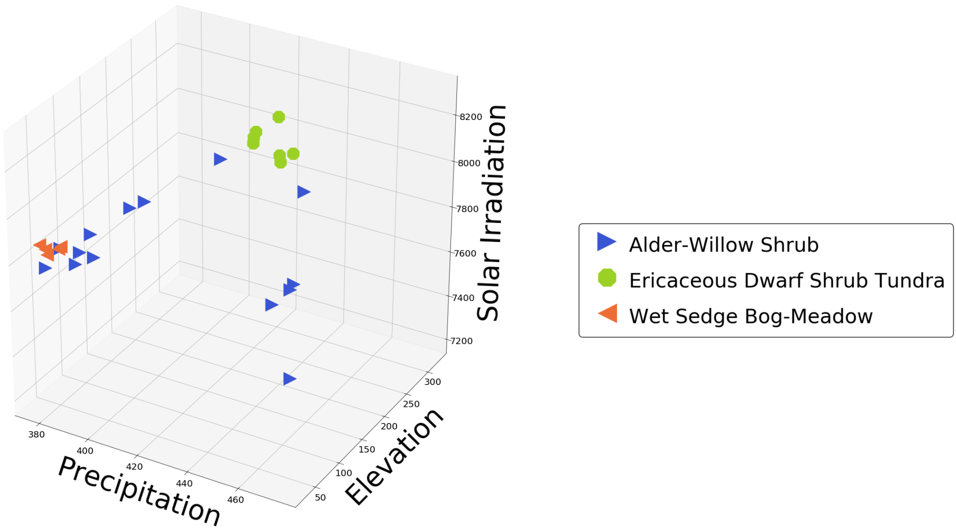
* Summer - June, July, August
Winter - December, January, February

† 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.

Multidimensional Environmental Space



Specialists v/s Generalists



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 $>80\%$.
- Common reasons behind predictions errors:
    - Overlap of constituent species across vegetation communities
    - High heterogeneity of landscape ("patchiness")
- Analysis of environmental drivers provides insights into preferential niche space where plant communities thrive.

References

[1] J. Ju and J. G. Masek, "The vegetation greenness trend in canada and us 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.