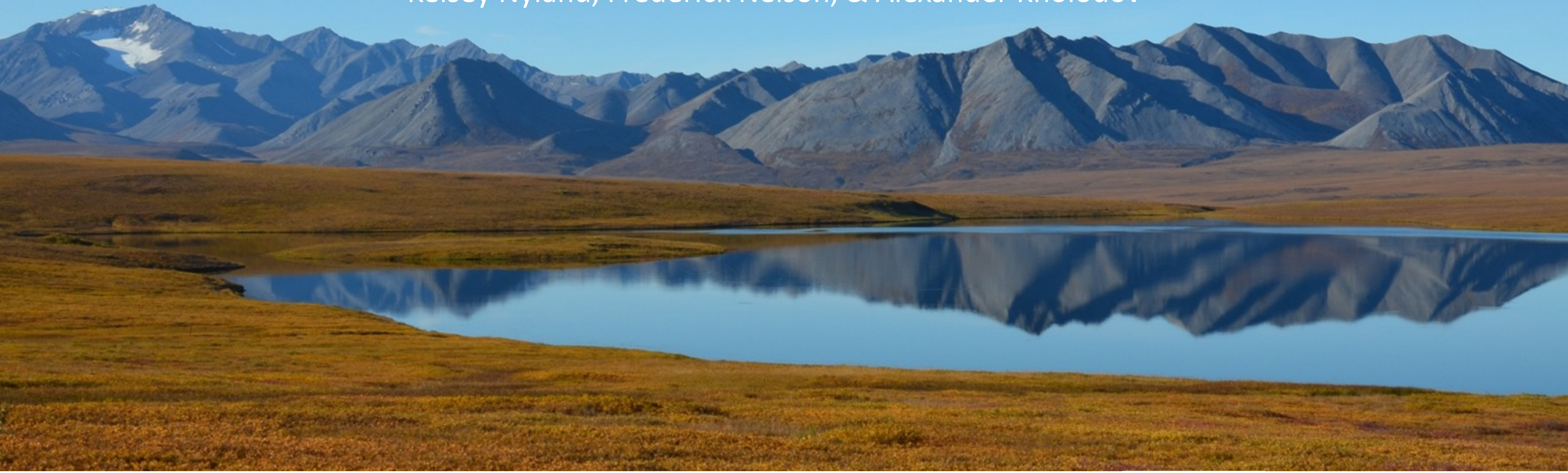
# 30 years of Toolik CALM: Active layer trends in the Kuparuk River Basin

Circumpolar Active Layer Monitoring

Anna Klene, Nikolay Shiklomanov, Dmitry Streletskiy,

Kelsey Nyland, Frederick Nelson, & Alexander Kholodov



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GTN-P Global Terrestrial Network for Permafrost

CALM
Circumpolar Active Layer Monitoring


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# Circumpolar Active Layer Monitoring

- **Essential Climate Variables**

50 linked variables identified by the WMO's GCOS and GTOS programs which critically contribute to the characterization of global climate

The Global Terrestrial Network – Permafrost (GTN-P) coordinates all the permafrost-related variables

- **International Biome Program**
- **International Tundra Experiment**
- **NSF's Arctic Observing Networks**

- **CALM:**
  - Established standardized protocols based on spatial sampling & site characterization
  - Data rescue from former Soviet Union & other archives
  - Central data repository
  - Continue to increase variables
  - Increased site co-location
  - Education & Outreach

CALM Circumpolar Active Layer Monitoring

About CALM | Research | Data | Publications | Related Sites

Welcome to the web site for the Circumpolar Active Layer Monitoring Network-CALM: *Long-Term Observations of the Climate-Active Layer-Permafrost System*.

The primary goal of the Circumpolar Active Layer Monitoring (CALM) program is to observe the response of the active layer and near-surface permafrost to climate change over long (multi-decadal) time scales. The CALM observational network, established in the 1990s, observes the long-term response of the active layer and near-surface permafrost to changes and variations in climate at more than 200 sites in both hemispheres. CALM currently has participants from 15 countries. Majority of sites measure active-layer thickness on grids ranging from 1 ha to 1 km², and observe soil temperatures. Most sites in the CALM network are located in Arctic and Subarctic lowlands. Southern Hemisphere component (CALM-South) is being organized and currently includes sites in Antarctic and South America. The broader impacts of this project are derived from the hypothesis that widespread, systematic changes in the thickness of the active layer could have profound effects on the flux of greenhouse gases, on the human infrastructure in cold regions, and on landscape processes. It is therefore critical that observational and analytical procedures continue over decadal periods to assess trends and detect cumulative, long-term changes.

The CALM program began in 1991. It was initially affiliated with the International Tundra Experiment and has been supported independently and continuously since 1998 through grants from the U.S. National Science Foundation*. CALM is funded by the NSF Project OPP-1836377.

This web site contains archived data sets, a table of summary statistics, a map of the sites, measurement protocols, CALM forms, equipment installation instructions, uploading and downloading instructions, and other pertinent information.

*Any opinions, findings, conclusions, or recommendations expressed in on this site or in CALM publications are those of the authors and do not necessarily reflect the views of the NSF. Mention of specific products or manufacturers does not constitute endorsement by NSF.

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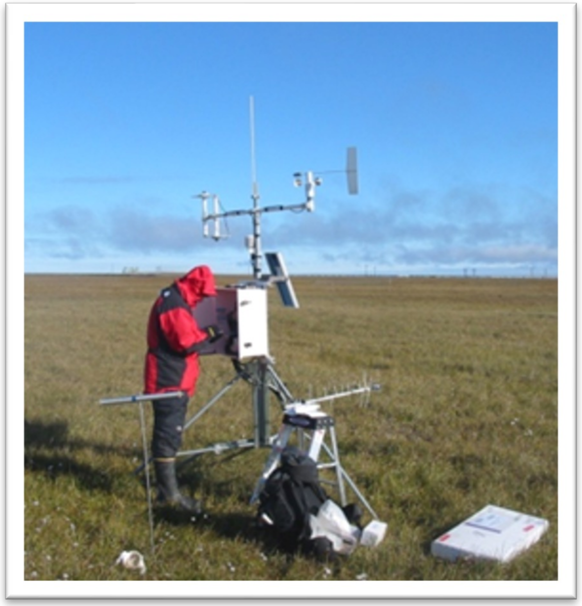
# Active Layer Monitoring

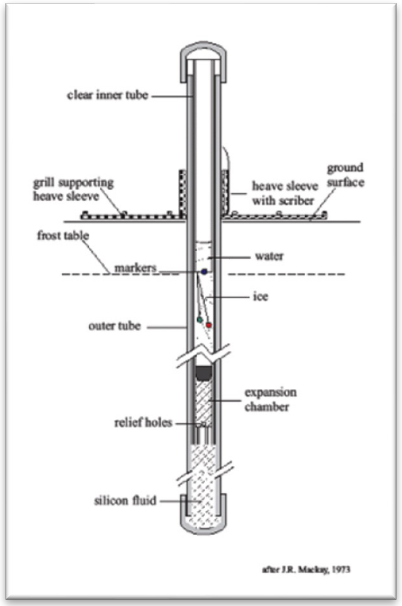
- CALM sites primarily employ gridded sampling (a few use transects) where ALT is measured at regular intervals by mechanical probing (1 ha & 1 $km^2$).
- Some sites interpolate ALT from the maximum seasonal depth of the 0°C isotherm using shallow boreholes or thaw tubes

Probing

Borehole



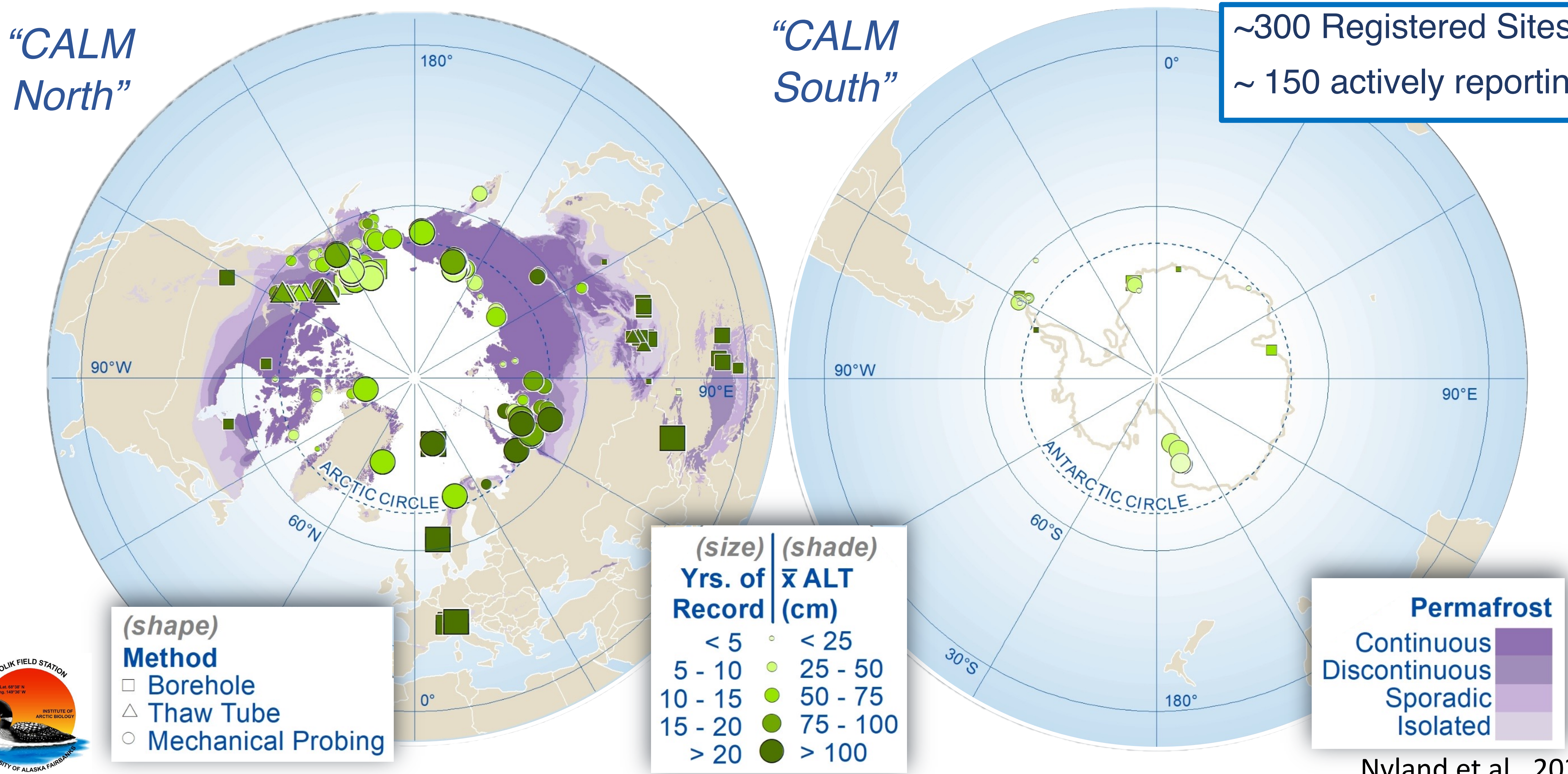
Thaw Tube



# Circumpolar Active Layer Monitoring

~300 Registered Sites

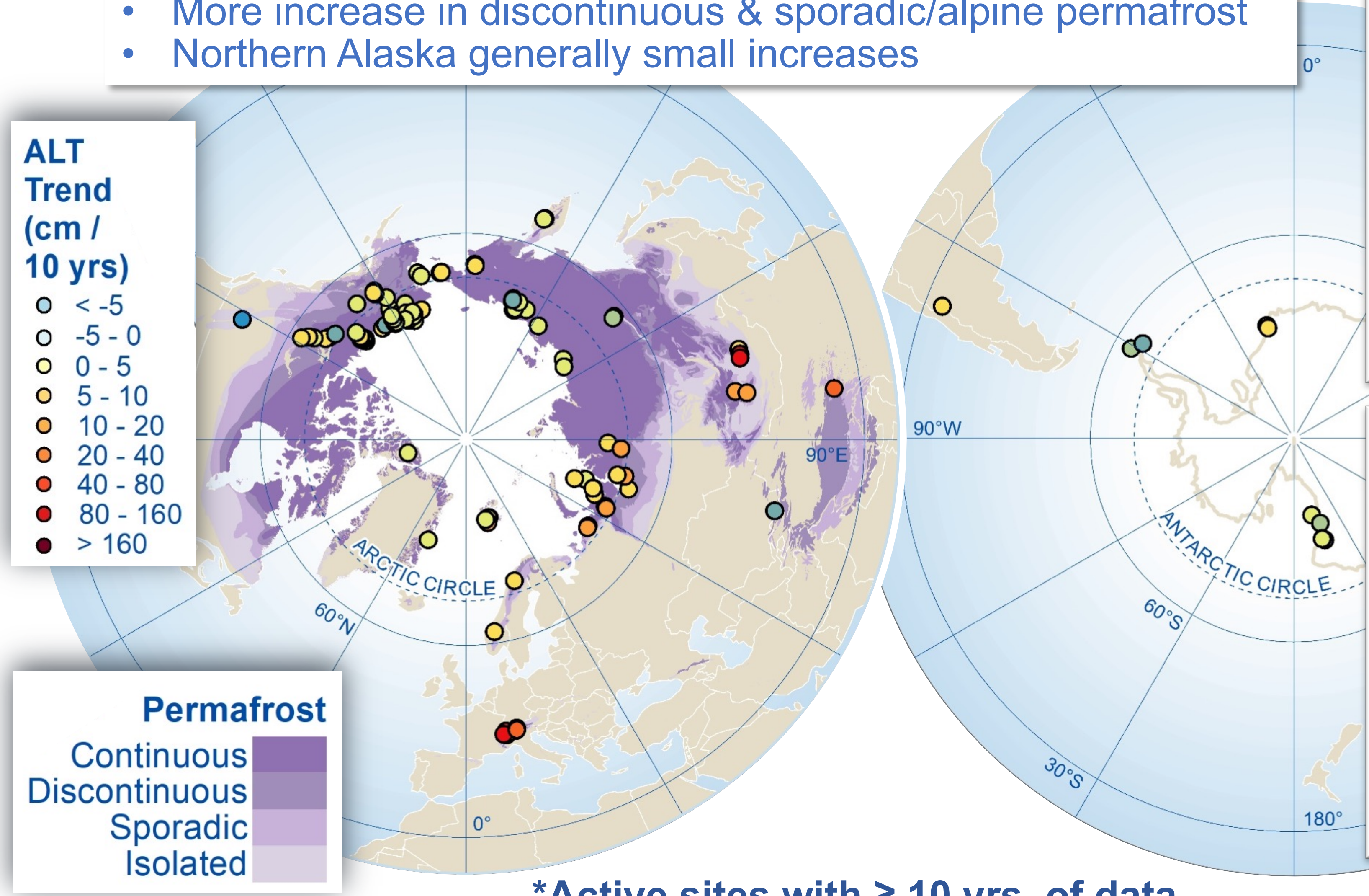
~ 150 actively reporting

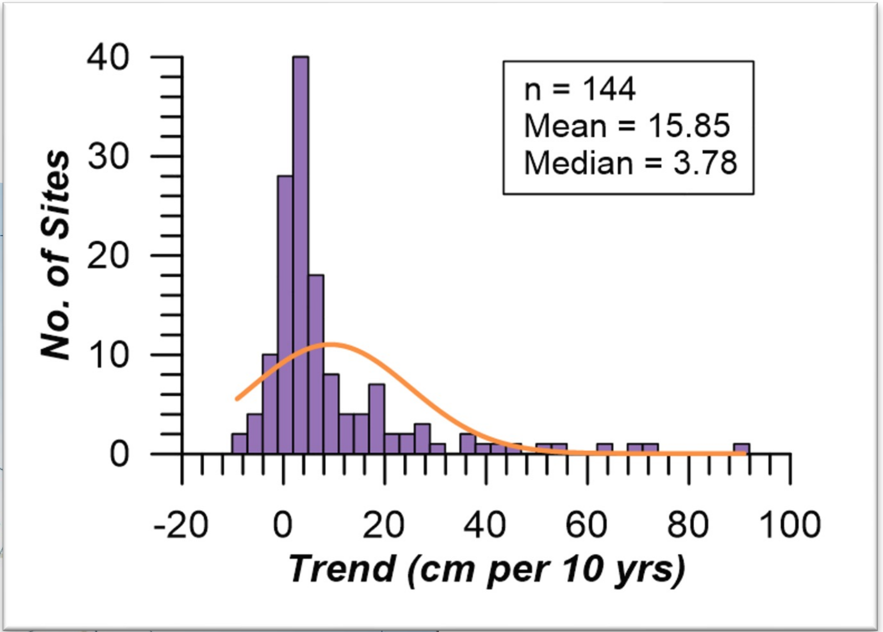


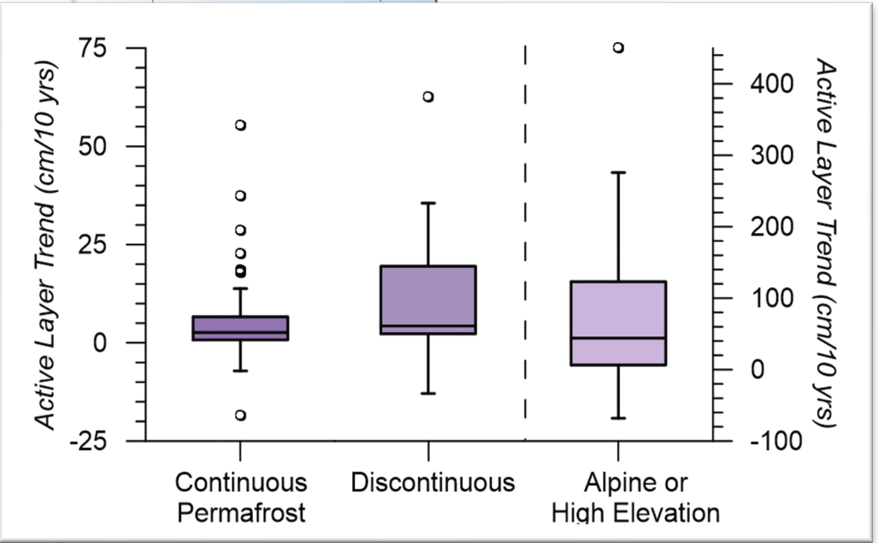

Nyland et al., 2021

# Long-Term ALT Trends

- Global variability but generally increasing
- More increase in discontinuous & sporadic/alpine permafrost
- Northern Alaska generally small increases



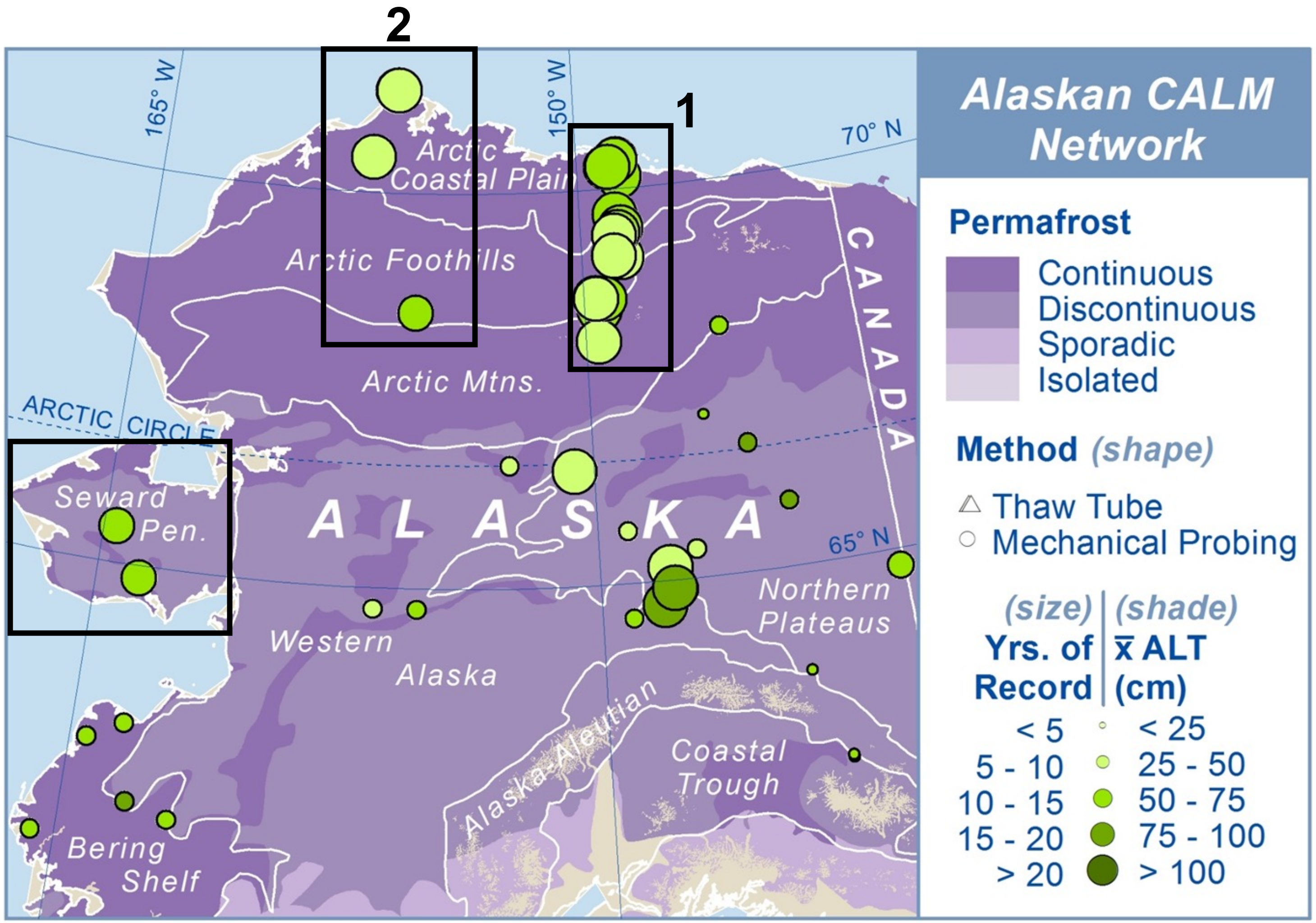



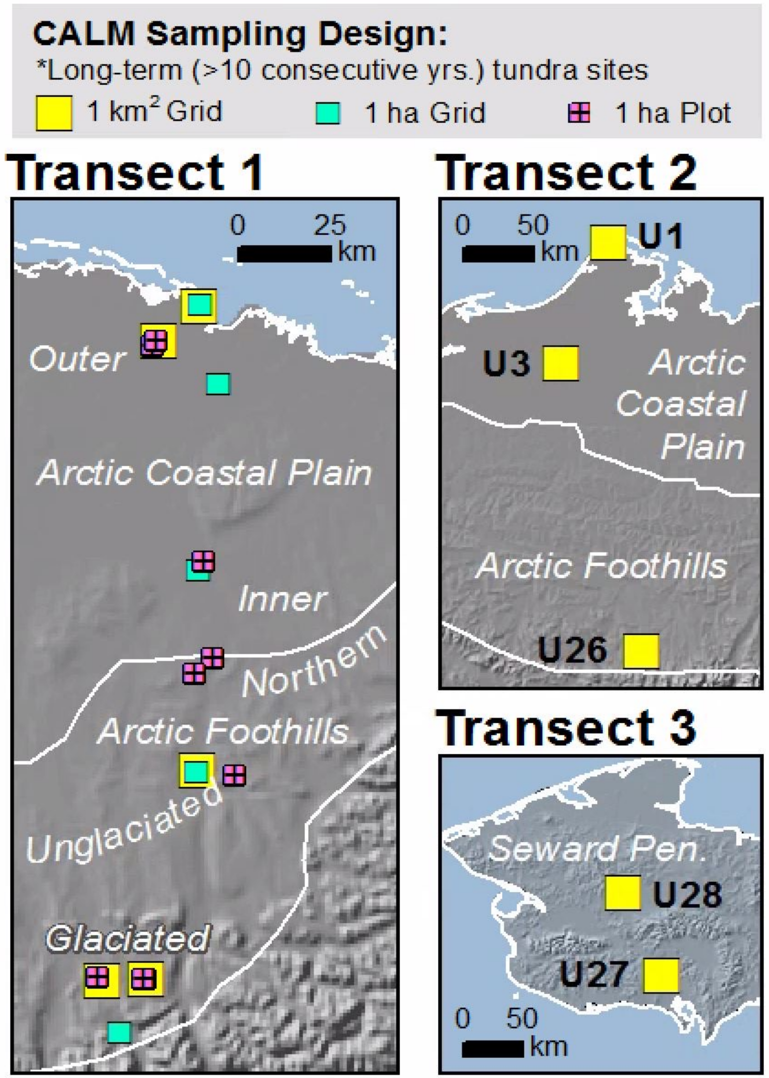




***Active sites with ≥ 10 yrs. of data**

Nyland et al., 2021

# Alaskan CALM Sites

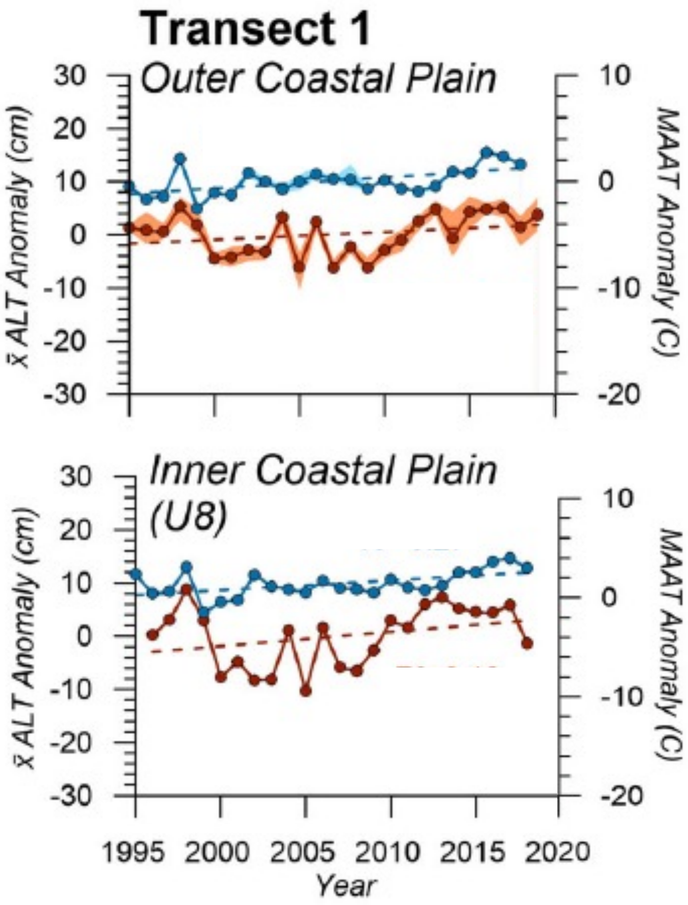



- The 100×100 m grids/plots are established within relatively homogeneous landscape units.
- The 1000×1000 m grids usually encompass several characteristic landscapes within the area.

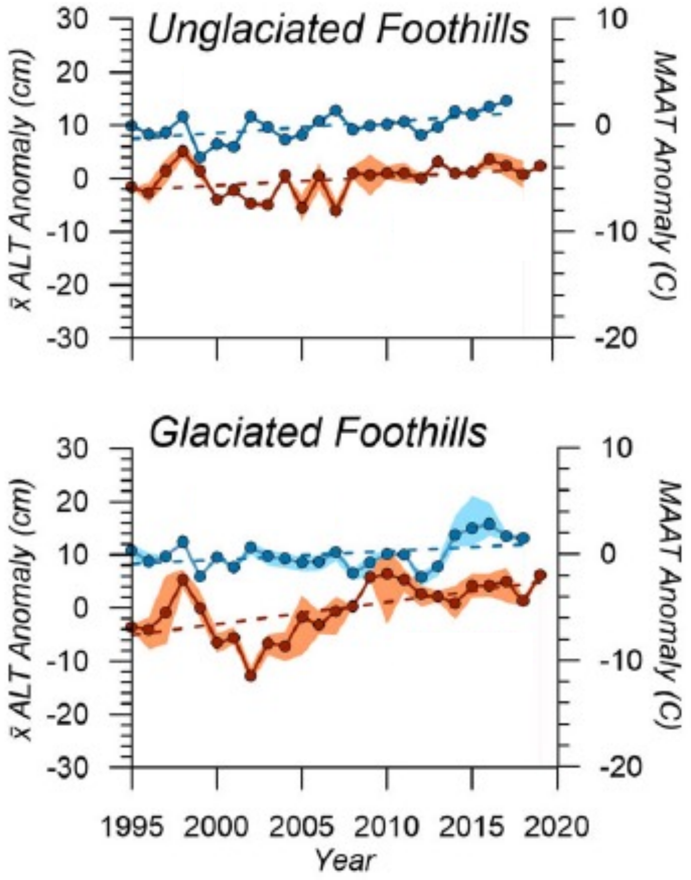
Nyland et al., 2021

# Kuparuk CALM Sites




**Transect 1**


**ALT Anomaly (cm)**
**MAAT Anomaly (°C)**




- Generally increasing ALT and increasing Mean Annual Air Temperatures

Nyland et al., 2021

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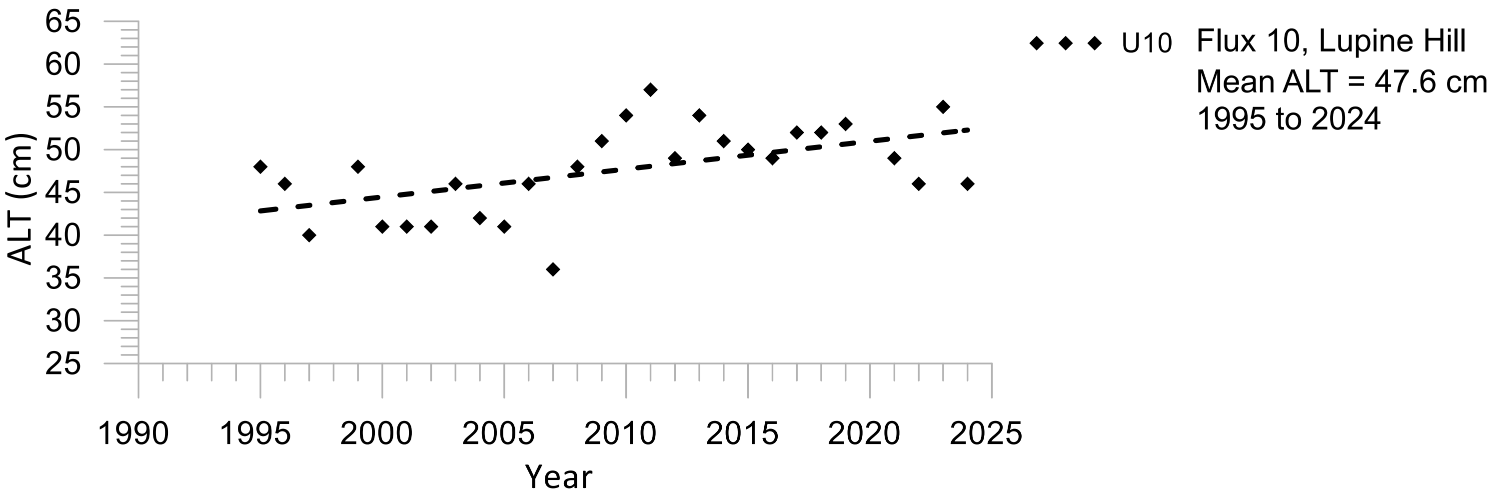


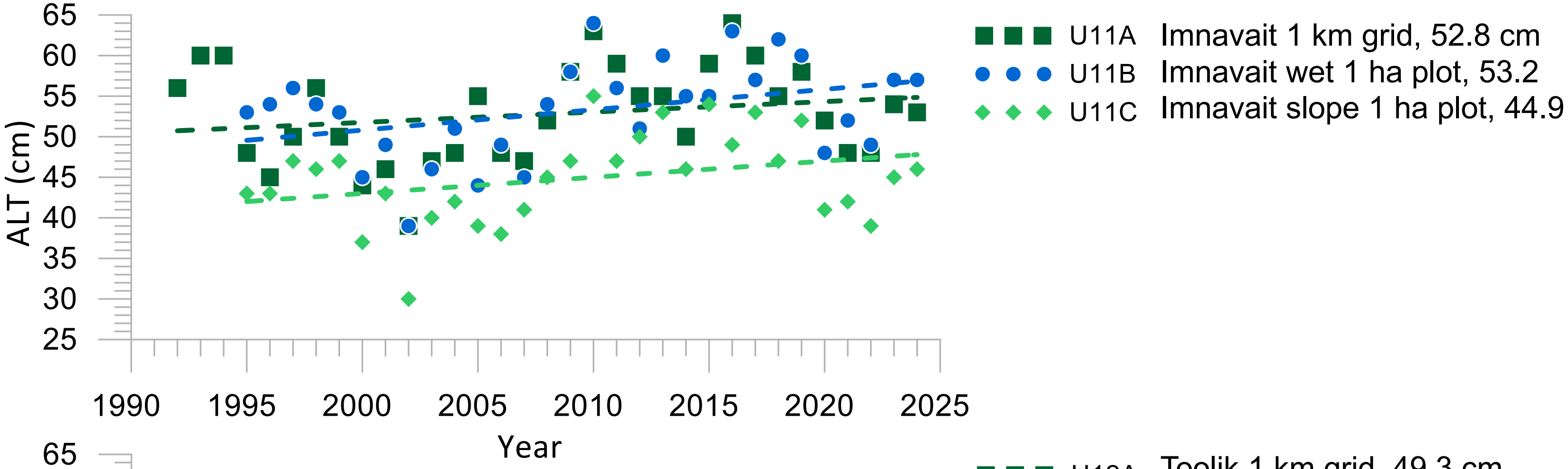


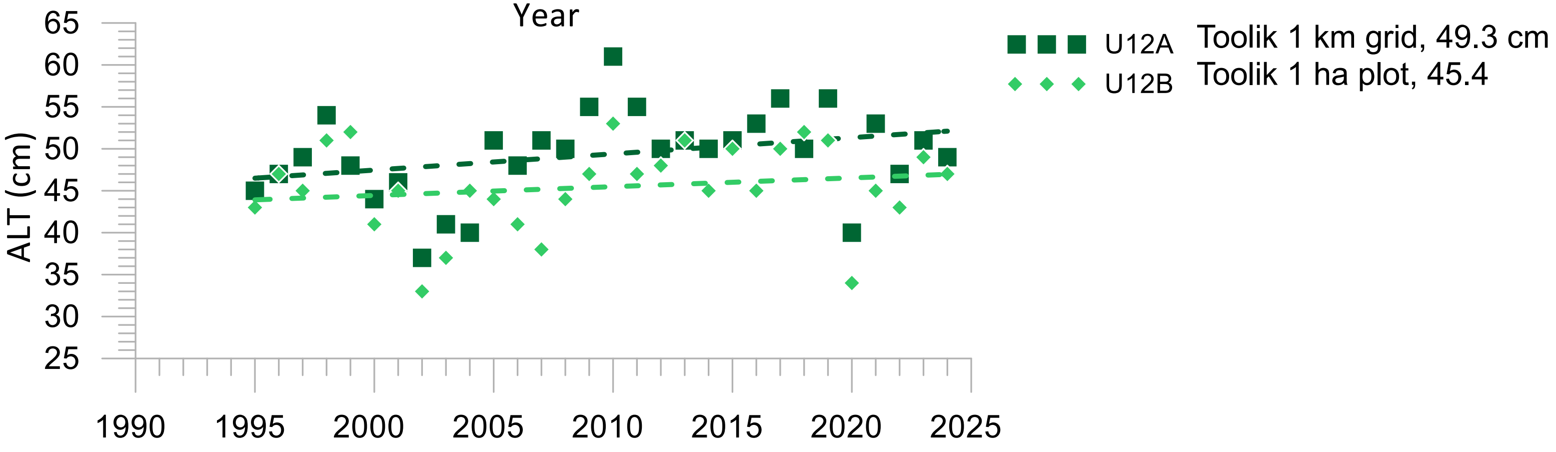


- At Toolik & Imnavait 1 km grids ALT is increasing
- Lupine Hill water track is increasing faster

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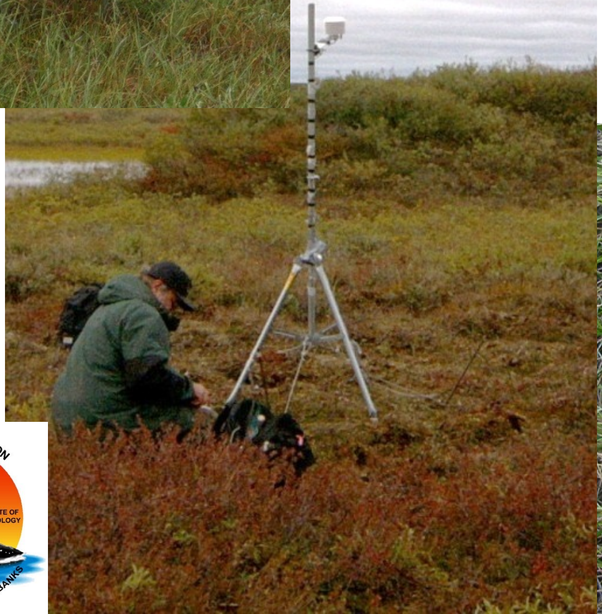
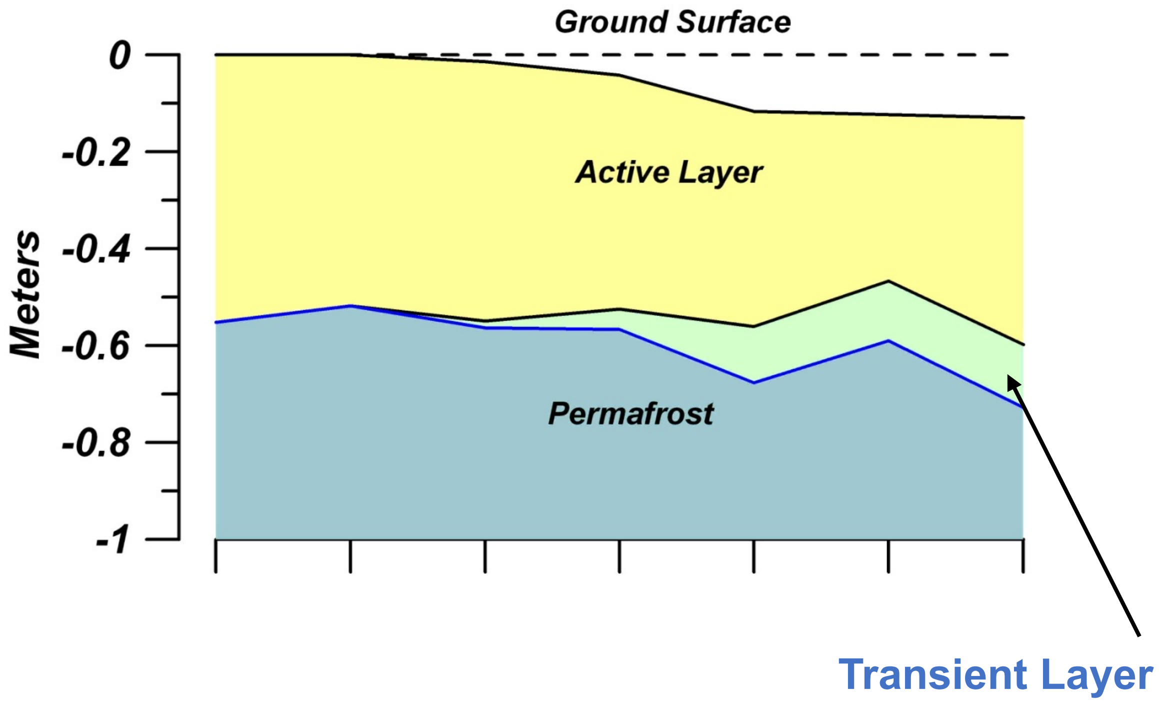
# Alaska CALM Observations

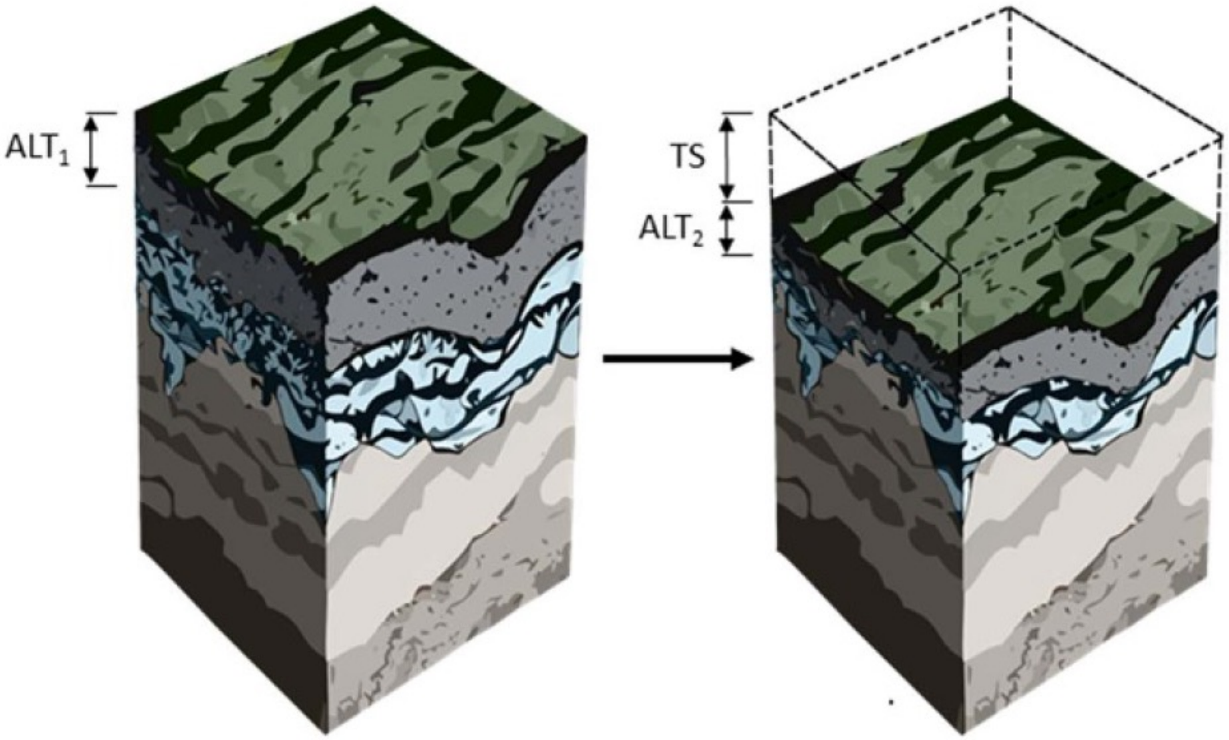
- Active Layer Thickness (thaw depth)
- Vertical position of the Ground
- Air and Ground Temperatures
- Vegetation & Snow
- Soil Moisture



# Subsidence

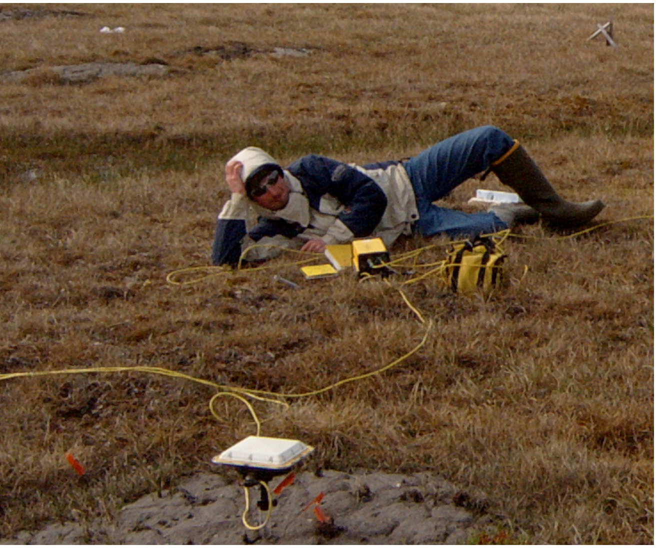


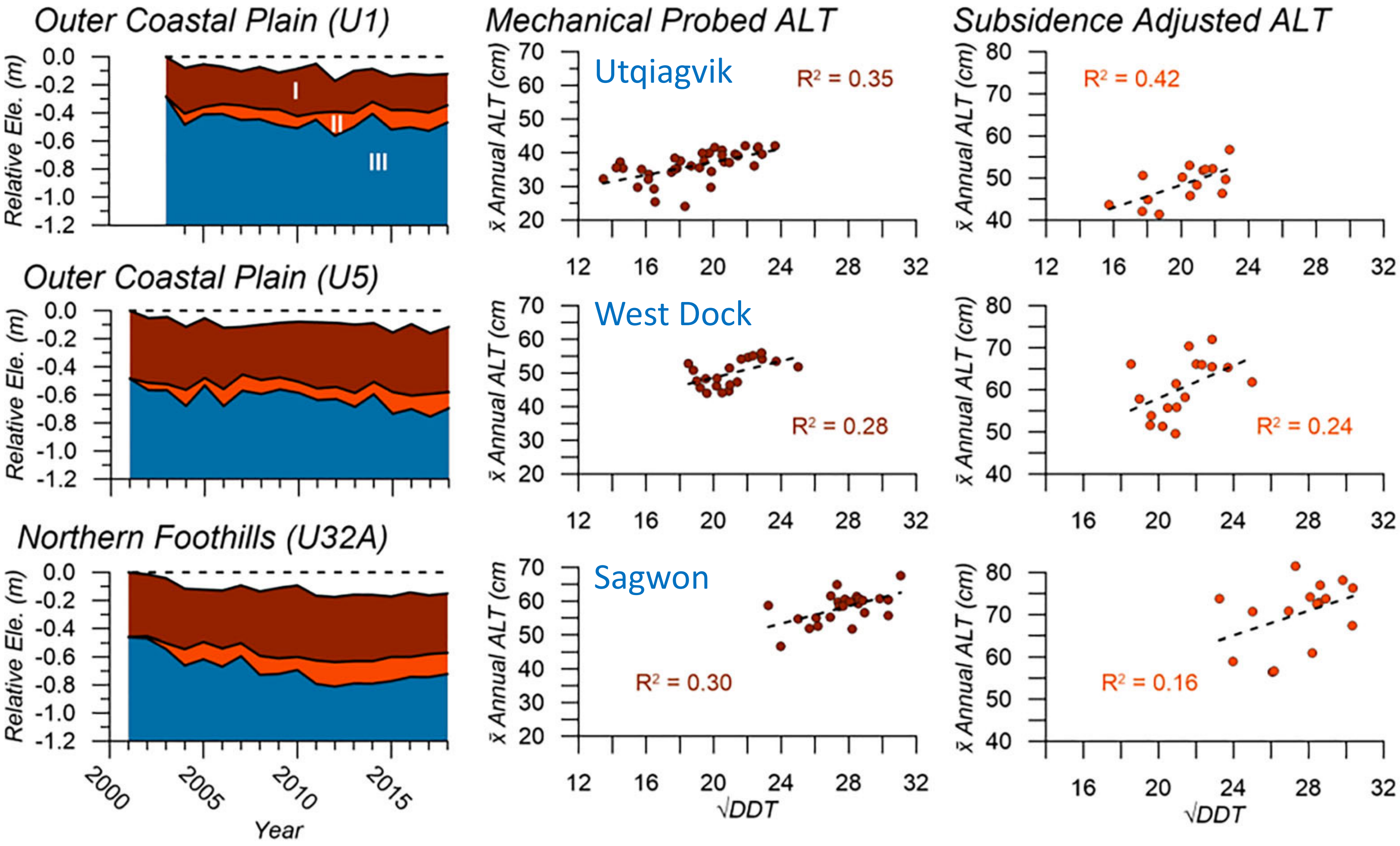
Ground Surface
0
-0.2
-0.4
-0.6
-0.8
-1
Meters
Active Layer
Permafrost
Transient Layer

$ALT_1$
TS
$ALT_2$

# Subsidence





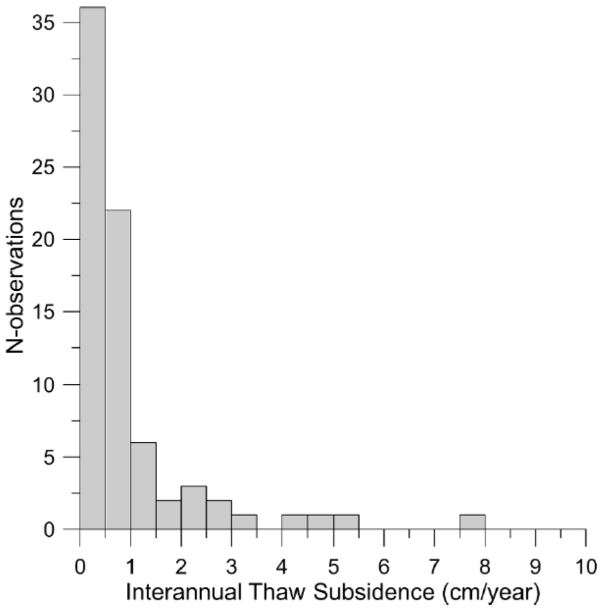

- West Dock: -0.8 cm/yr
- Sagwon: -0.7 cm/yr

Nyland et al., 2021

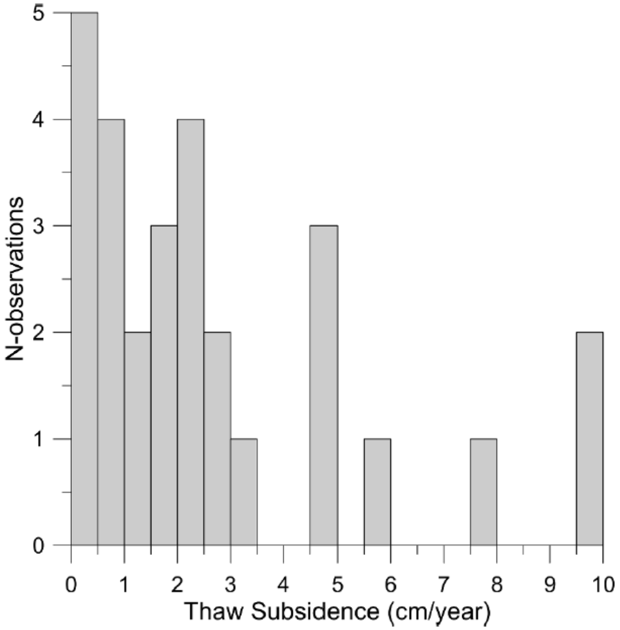
# Subsidence

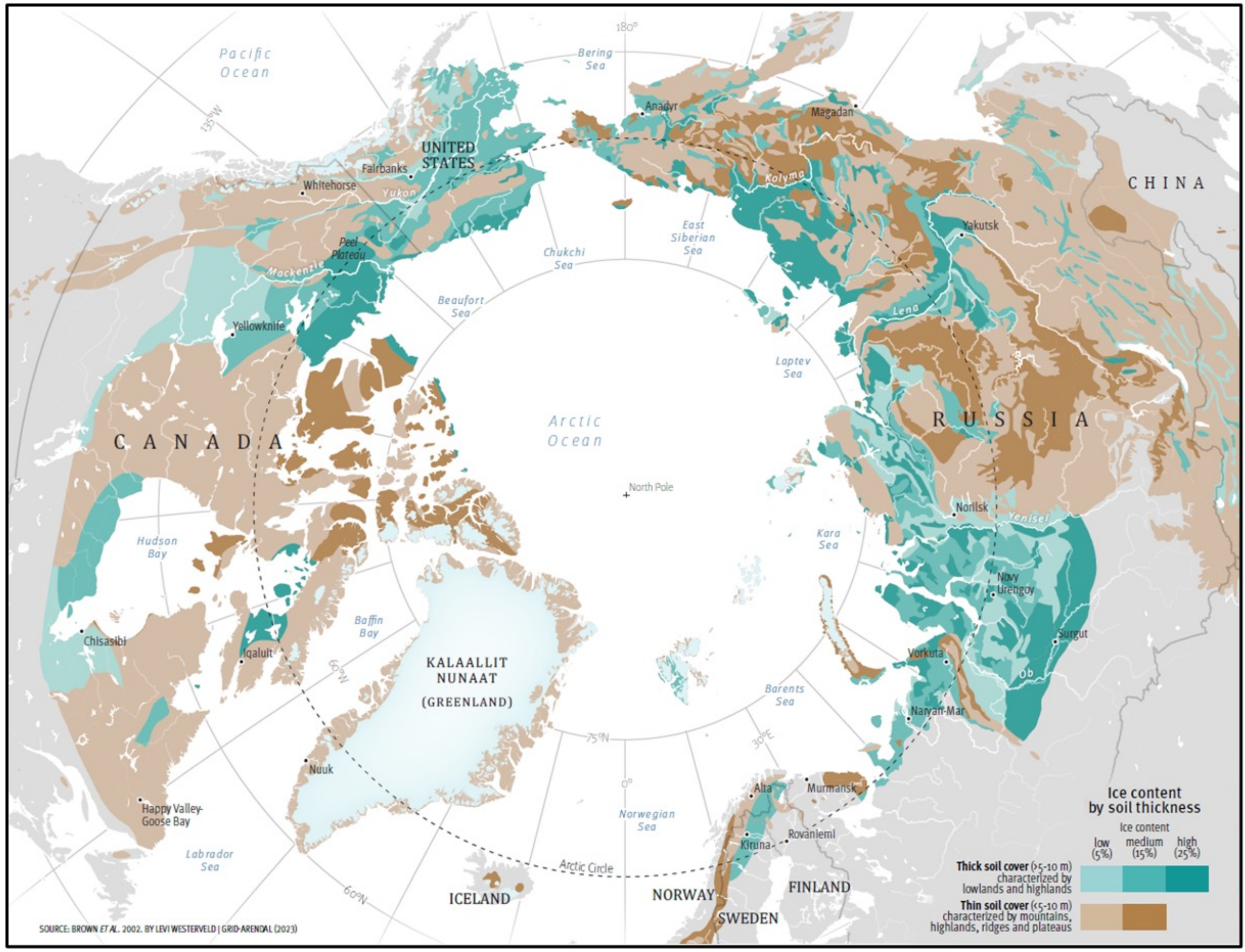
Ice Content, Permafrost Atlas (2023)

North America




Eurasia

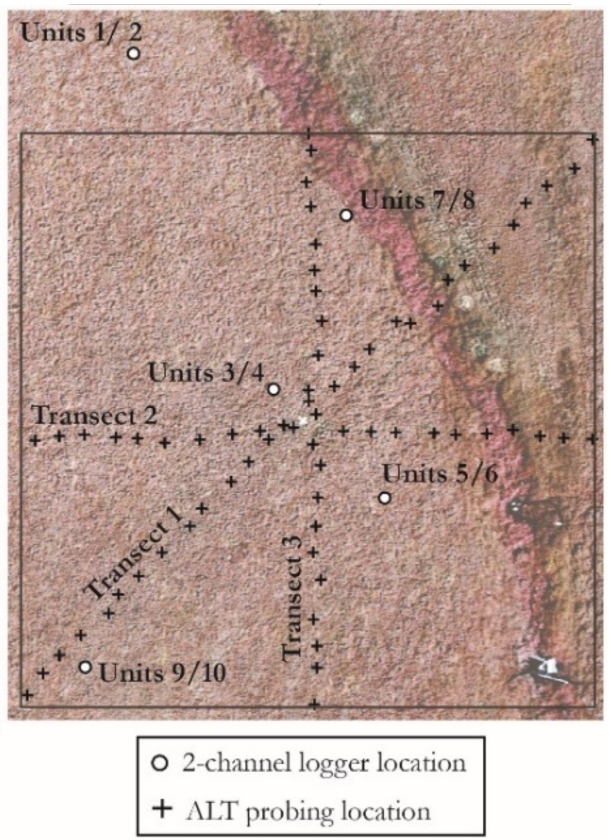



- Widespread subsidence in Arctic permafrost with rates of up to 2 cm/yr in the areas with low ice content and more than 3 cm/yr in regions with ice-rich permafrost (green shades).
- More coordination on standard protocols is needed.

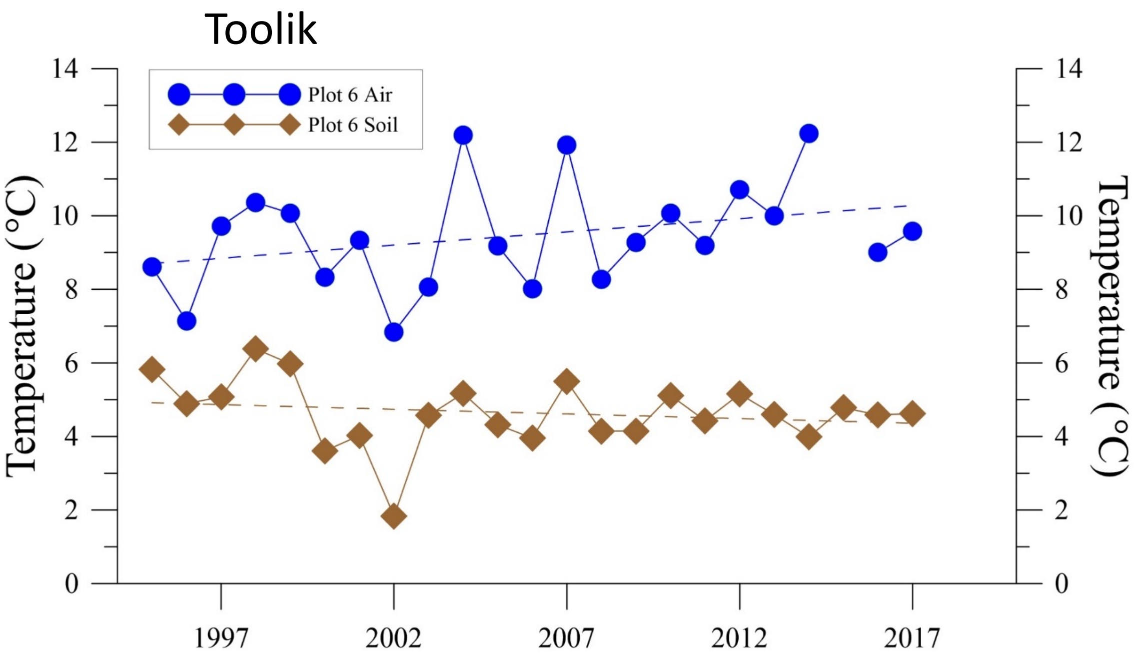
Streletskiy et al., 2025

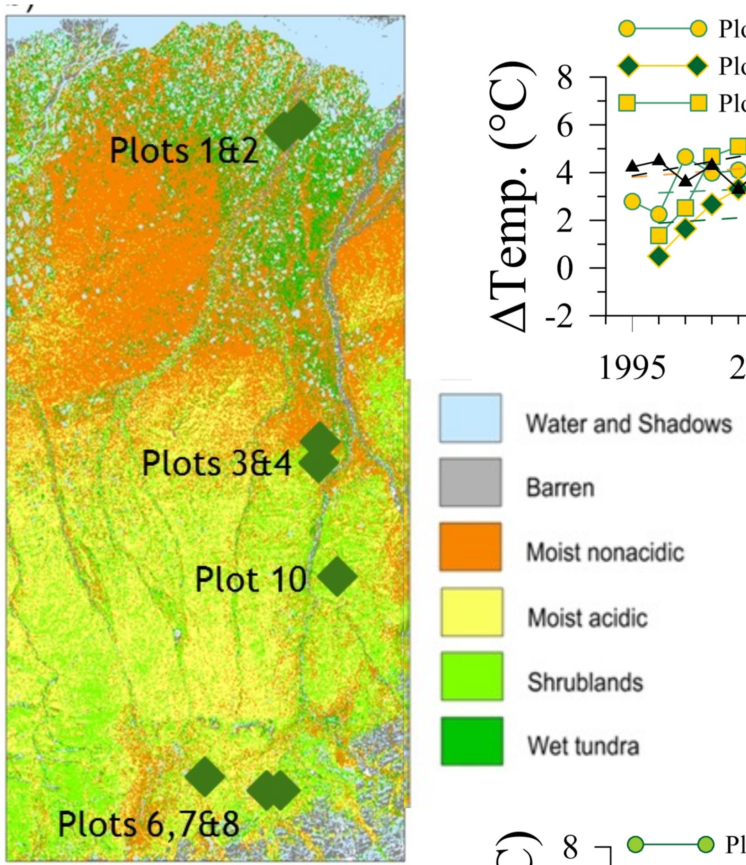
# Flux Plot Air & Soil Temperatures

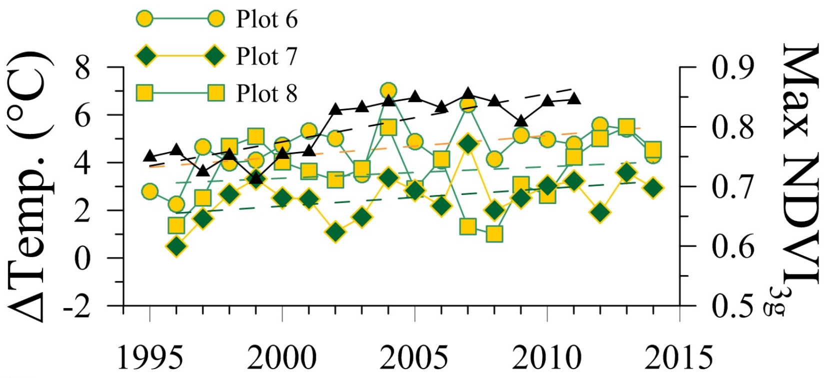



- 5 Onset TM Hobo Pro/V2/U23 2-channel data loggers per site.
- 9 thermistors are place under the vegetation in representative micro topographic locations
- 1 thermistor is placed on the radiation shield mounted on the mast at ~2m height.
- Period of observation 06/1995 – Present.  Data is available for 06/1995 – 08/2024 period

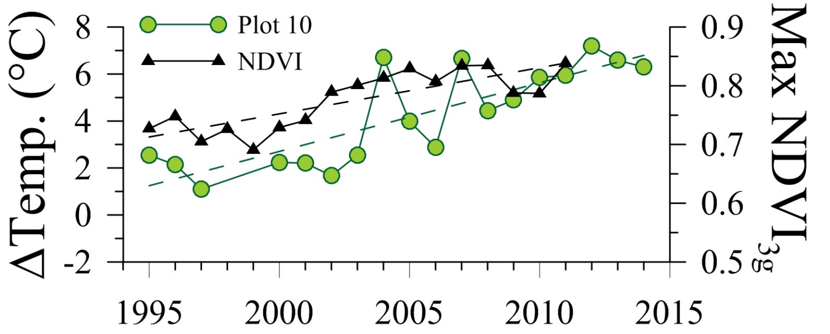
# Increasing Difference in Air & Soil T’s




| Site | ΔT Trend (°C/yr) |
|---|---|
| Site 6 Toolik | 0.10 |
| Site 7 Imn Cr Wet | 0.05 |
| Site 8 Imn Cr Wet | 0.07 |
| Site 10 Lupine Hill | 0.27 |




- Difference is Summer Air – Soil-Surface Temperature
- Increasing difference at all plots, most in for shrub tundra
- Is this real? Is vegetation burying the soil sensor?
- Is our vegetation increasing biomass or height (trapping snow)

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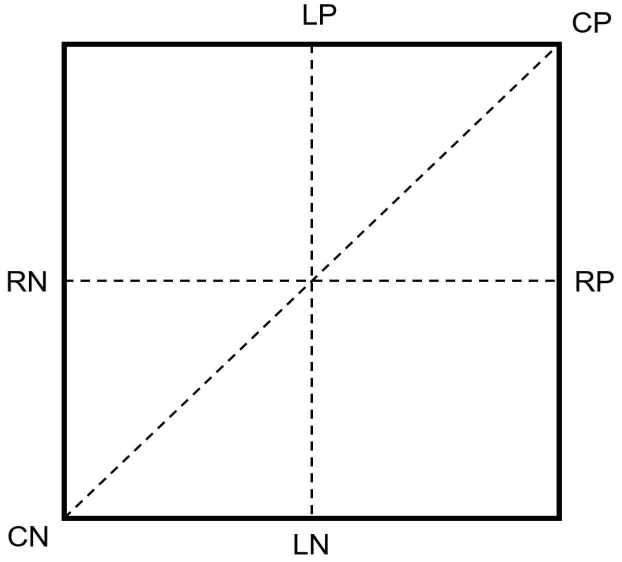
# 3 Theses: Bri, Shira, & Anna M

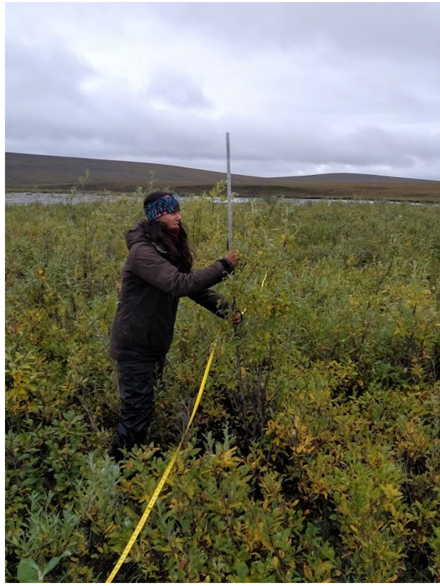
- Can we replicate Skip Walker’s 1995 vegetation height measurements?
- Can we use 1995 Stereopairs & modern UAV imagery to map across a plot?
- Do not attempt this during a pandemic!


- Is the vegetation taller?  YES
- Has the composition changed? YES
- Can we map it?  YES

# Mapping Height Increases




- 100 m x 100 m plot with 3 or 6 transects
- 1995 & 2021/23 Survey:
  - Functional Group Occurrence
  - Canopy Height
  - Maximum Shrub Height



## Results: Canopy Heights (cm)

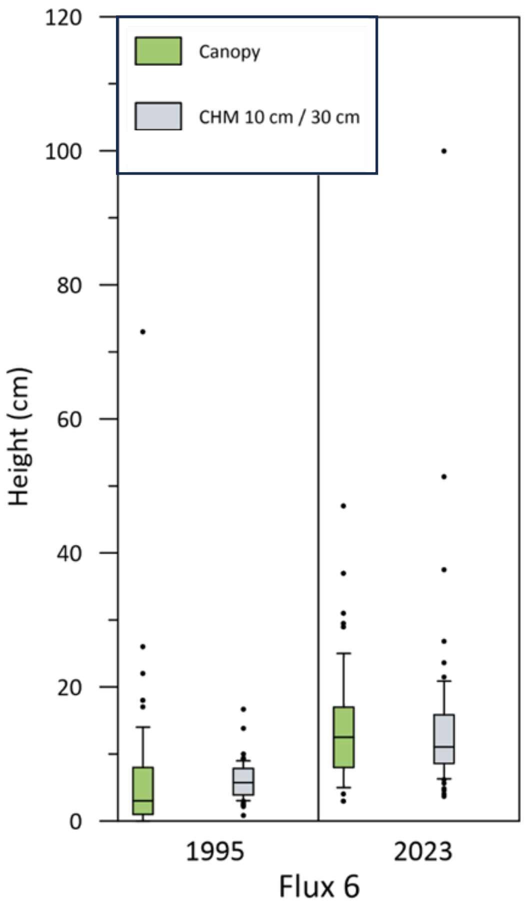
| Plot | 1995 Mean | 2021 & 2023 Mean | Percent Change (%) |
|---|---|---|---|
| Flux 6 | 6.2 | 13.7 | 123 |
| Flux 7 | 3.0 | 11.1 | 275 |
| Flux 8 | 3.9 | 9.2 | 135 |

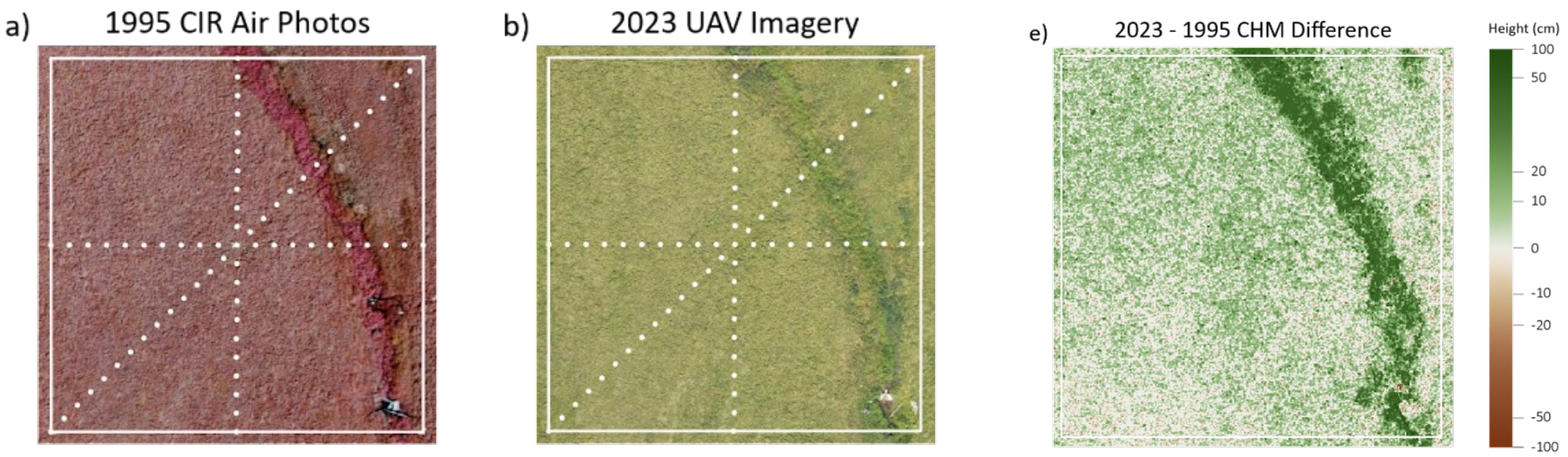
Table 5. Mean canopy heights and percent change for the baseline (1995) and modern (2021 & 2023) data. Canopy heights were recorded every 5 m along the left, right and center transects for a total of ~68 observations per site. P-values were derived from a two-sample t-test. Values <0.005 are in bold, indicating a significant difference between the baseline and modern mean canopy heights.

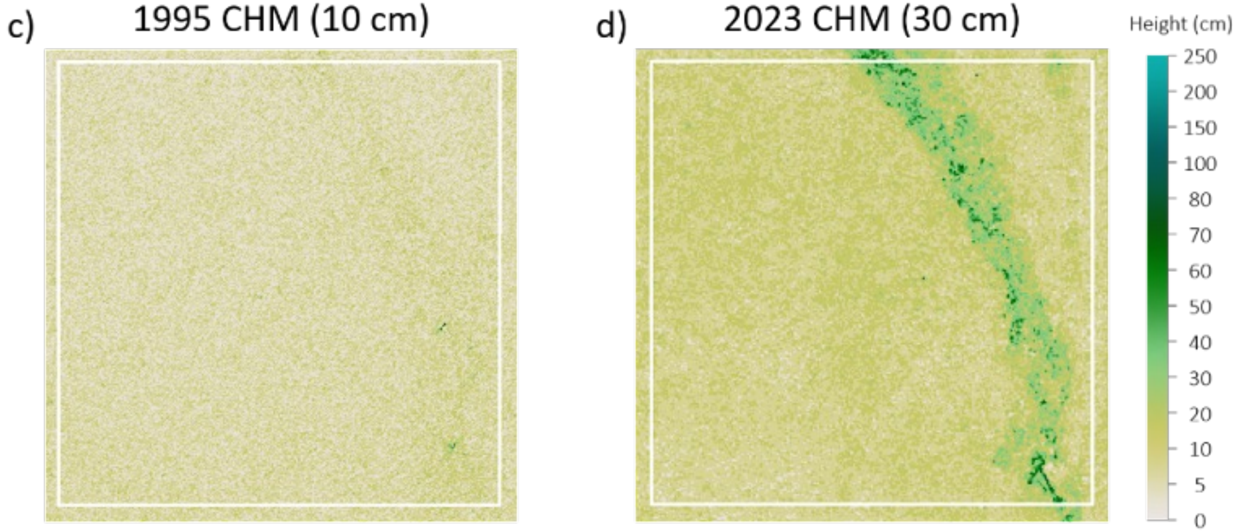
Toolik Lake
Imnavait Creek Wet
Imnavait Creek Slope

Ellenson et al. In Prep for the Special Issue

# Mapping Height Increases




- Canopy height estimates were reasonable despite short tundra vegetation
- Modern UAV estimates captured the range of heights better than the traditional stereopairs

Moser et al. In Prep for the Special Issue

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# Spatial Variability

- Number of papers looking at differences in spatial variability in ALT on the coastal plain and foothill provinces
- Physiographic province, landform, & vegetation all influence

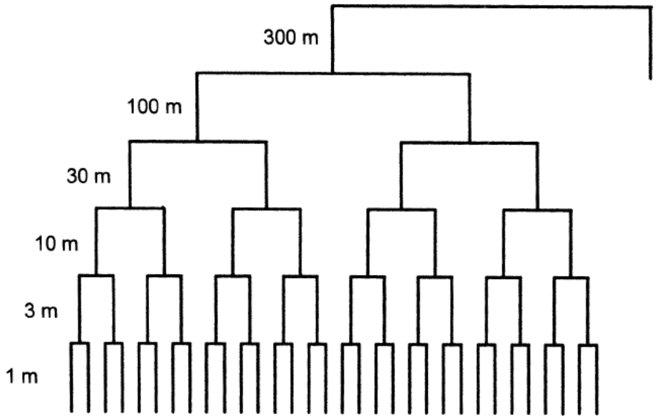



*FIGURE 2. Dendrogram illustrating conceptual branching structure of balanced hierarchical sampling design used at each of nine primary stations on ARCSS grids.*

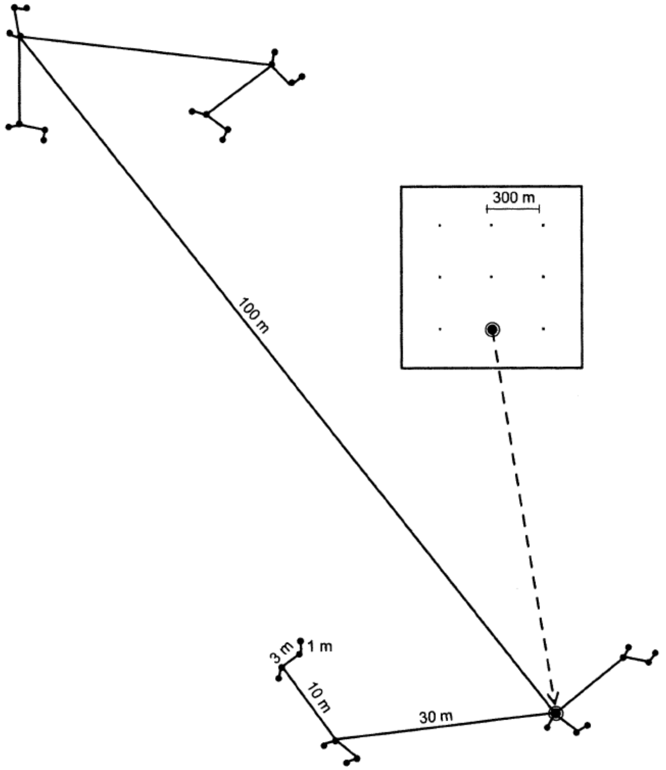
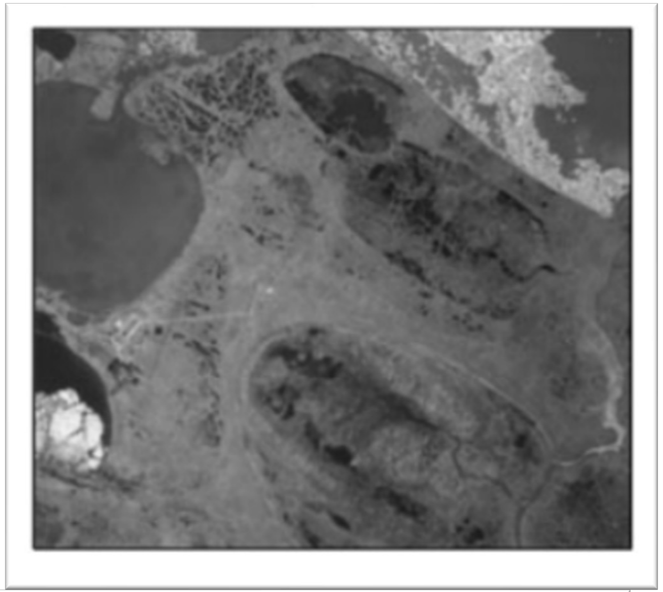
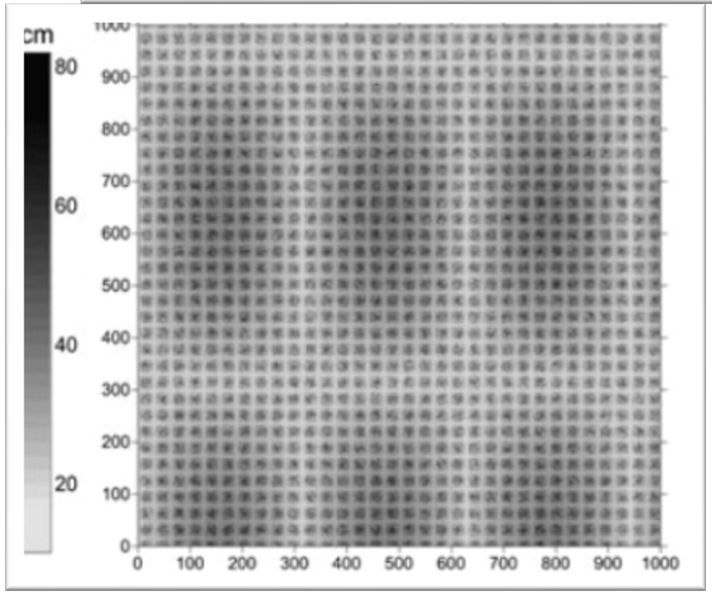



*FIGURE 3. Geographical arrangement of sampling points at one of the nine primary stations on ARCSS grid.*






Nelson et al., 1999; Fagan & Nelson, 2017

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# Conclusions

- Active Layer is deepening slowly in northern Alaska & near Toolik
- Subsidence is occurring slowly in northern Alaska
- Complex interactions between landscape, vegetation & hydrology influence ALT from one meter to the next

# My Favorite Toolik Memory

# Acknowledgements

Toolik, 1997

We thank the numerous students, researchers, and community residents who have assisted with the data collection over the years. This research was supported by the U.S. National Science Foundation (grants OPP-0095088, OPP-0352958, OPP-0856421, OPP-1304555, OPP-1836377). Any opinions, findings, conclusions, or recommendations expressed in this study are those of the authors and do not necessarily reflect the views of the NSF. Mention of specific product names does not constitute endorsement by NSF.

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# Questions?

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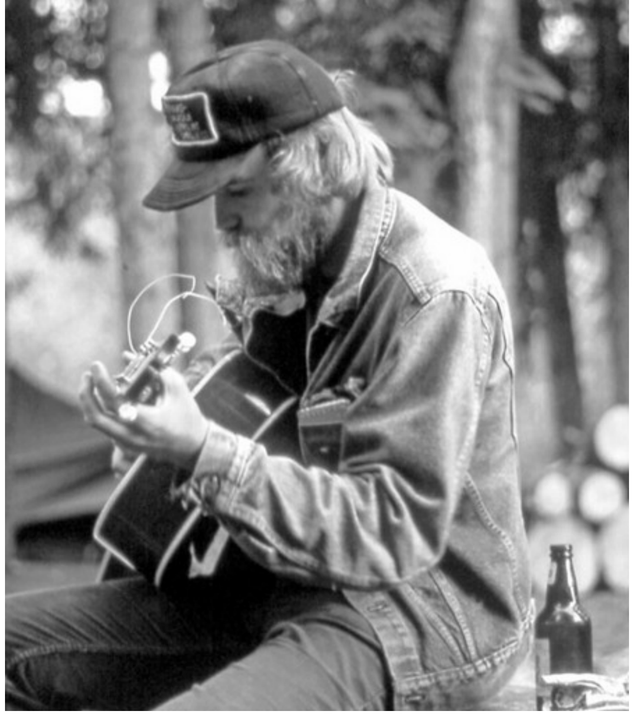
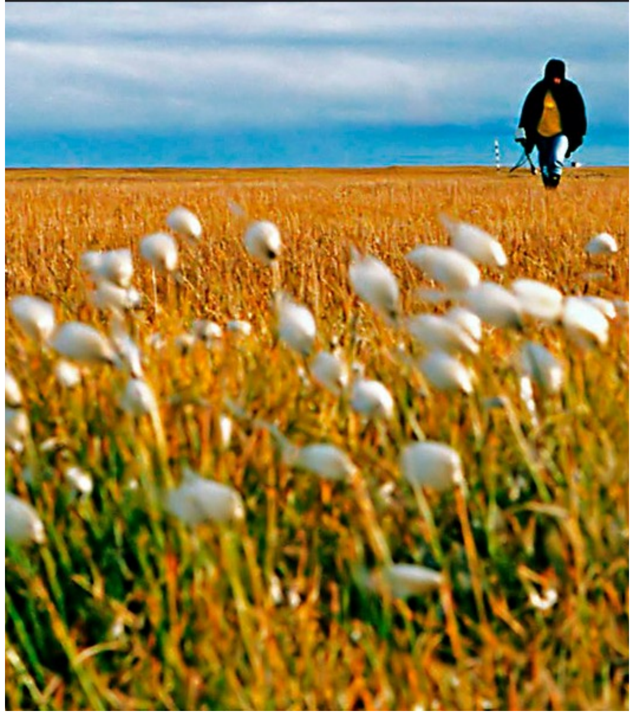
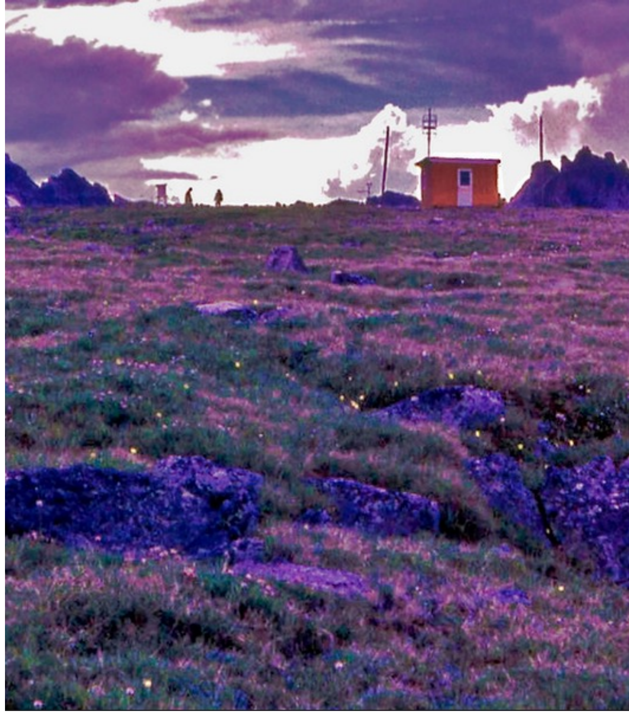

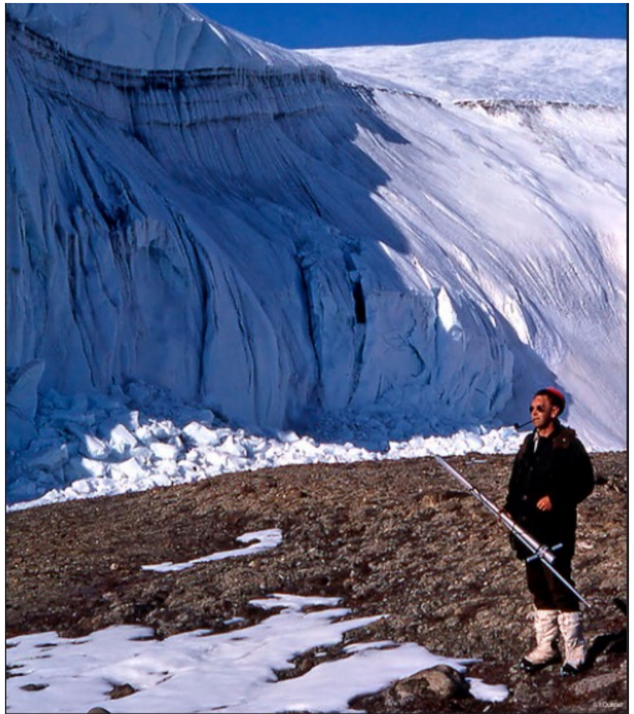

# Sam’s Flicker Account

- >1000 images
- Eclectic, no dates, global distribution
- https://www.flickr.com/photos/sam_outcalt

Please see the regional analyses in the 2021 special issue of ***Polar Geography*** on the CALM program…

Nyland et al., 2021 is the one on Northern Alaska

Full article: Cool, CALM, collected

tandfonline.com/doi/full/10.1080/1088937X.2021.1988001

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Research Article

# Cool, CALM, collected: the Circumpolar Active Layer Monitoring program and network

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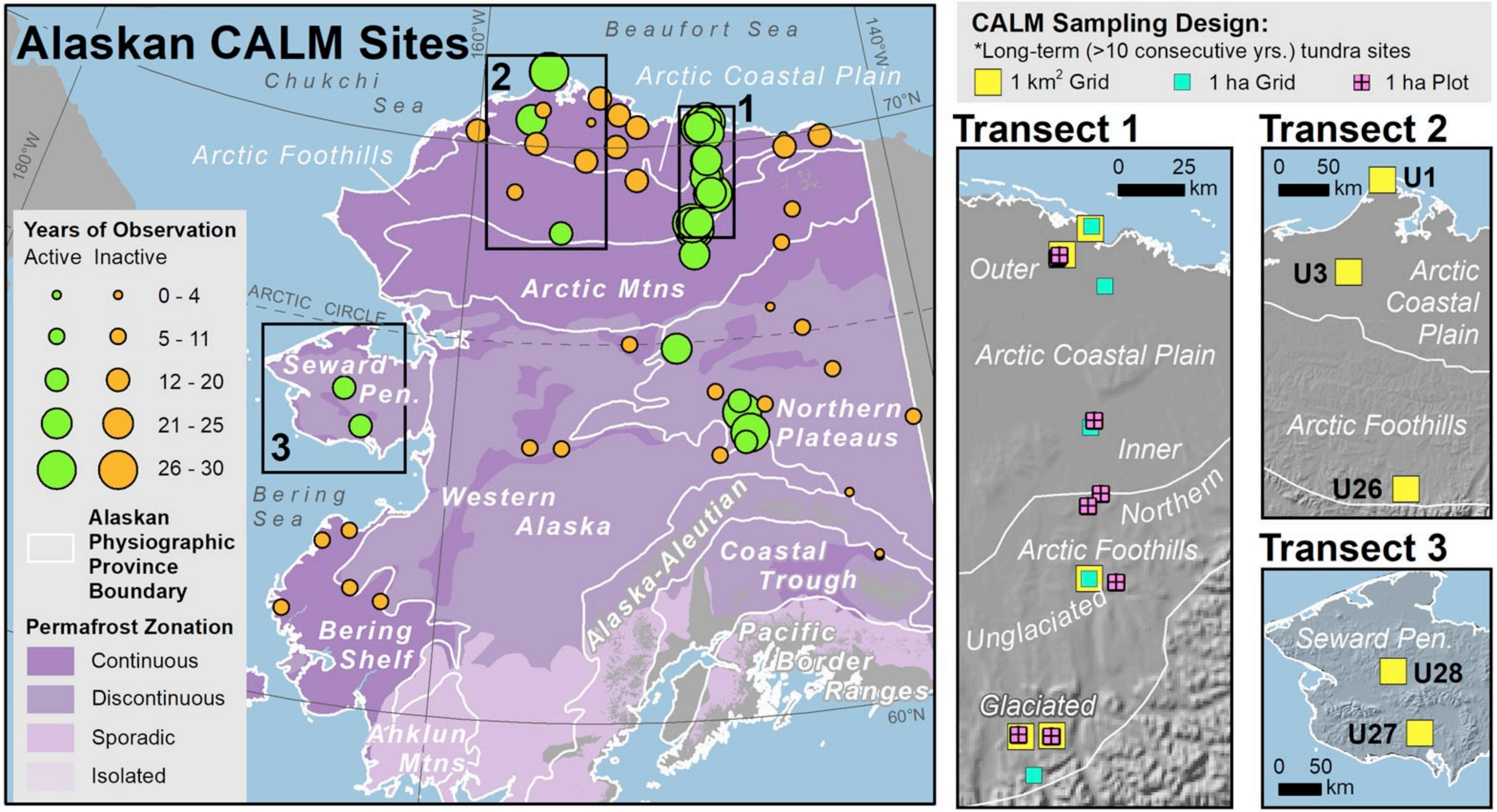
## ABSTRACT

The Circumpolar Active Layer Monitoring (CALM) program is the primary global-change monitoring program concerned with the seasonally frozen active layer above permafrost. The active layer has been designated by the Global Climate Observing System and the Global Terrestrial Observing Network as an 'Essential Climate Variable'. CALM was launched in 1991 on a volunteer basis in cooperation with the International Tundra Experiment. CALM observatories in Russia and Alaska have been supported since 1998 by the U.S. National Science Foundation through five consecutive five-year funding cycles. In its current configuration, the CALM network includes observation sites throughout the circum-Arctic region and a substantial number of sites in Antarctica. Open access to data and data harmonization are hallmarks of the program. In addition to its ongoing emphasis on field observations of active-layer thickness, temperature, soil moisture, and thaw subsidence are currently being monitored at many sites. Increased emphasis is being placed on

# Active Layer Thickness

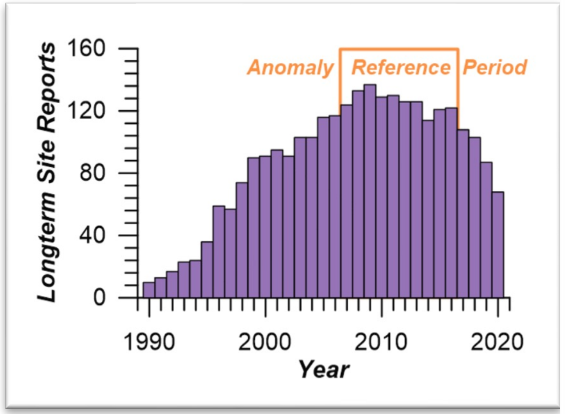


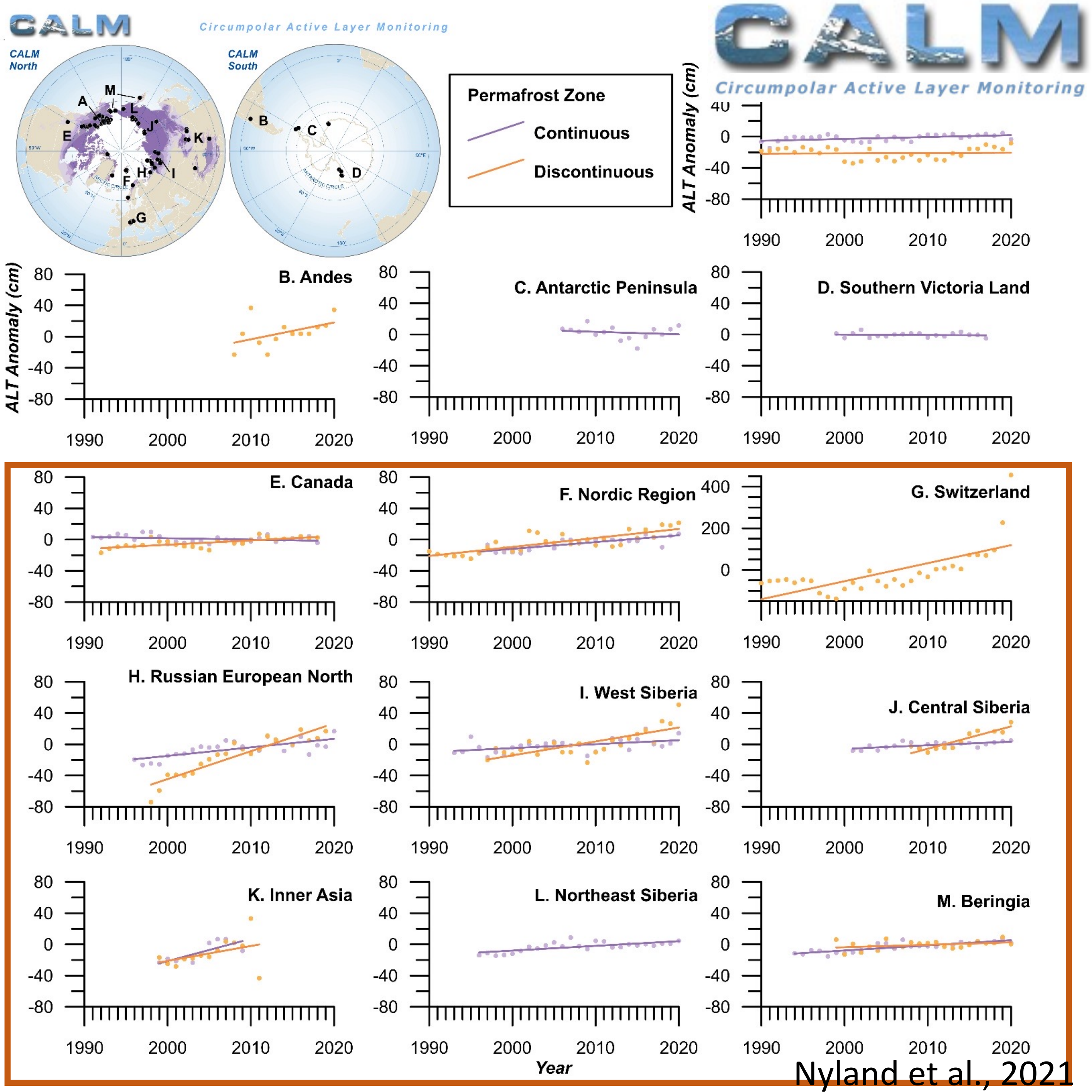

Nyland et al., 2021

# Long-Term Trends

***Regional differences***

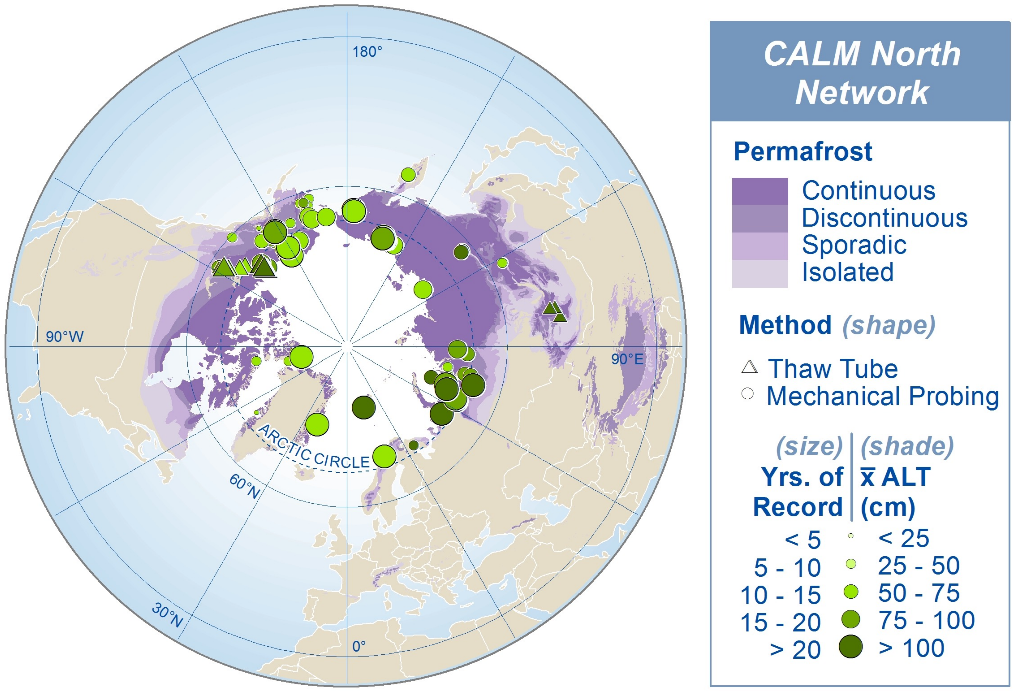
- Sites with data since 1970 thickening at rates of 2.5 to 13 cm per decade
- Active layer thickened most in discontinuous permafrost in the Alps and Russian European North
- Areas with low to insignificant trends include Alaska and all of CALM South.

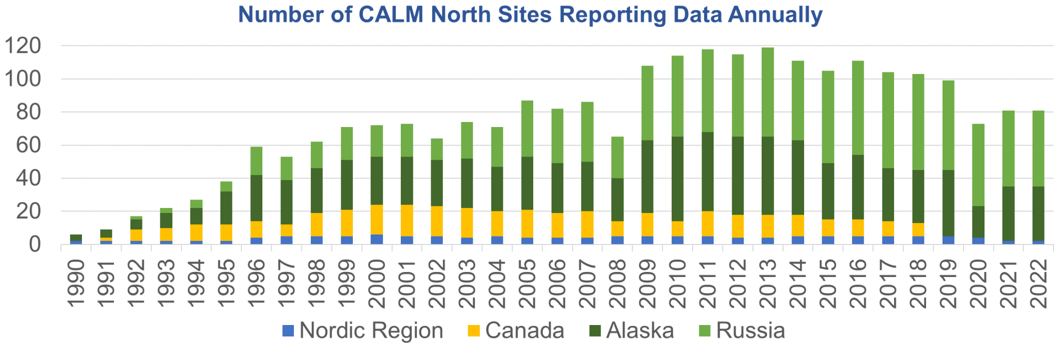



Nyland et al., 2021

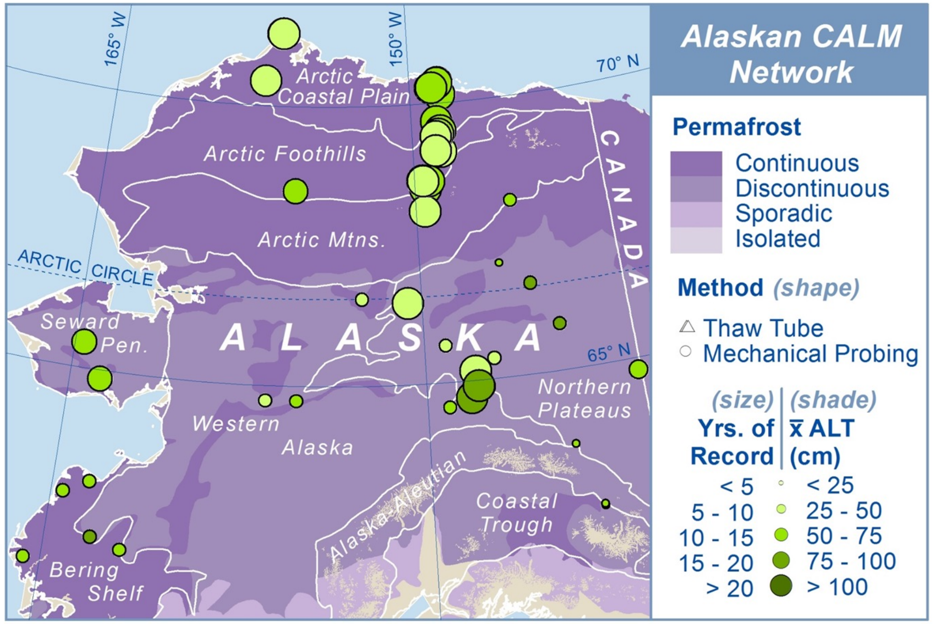
# ACTIVE CALM NETWORK
# (Northern Hemisphere Component )

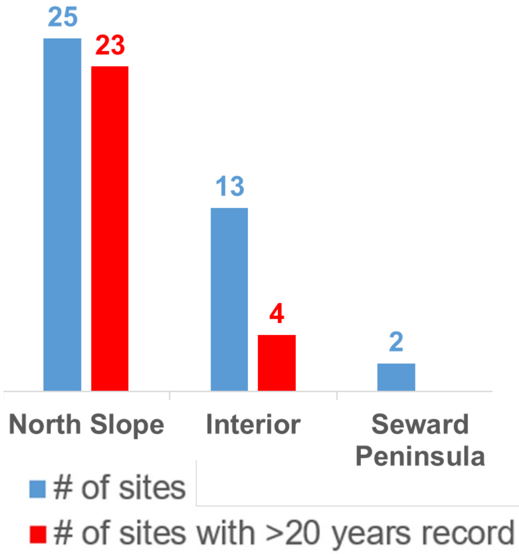



# CALM ALASKA

CALM
Circumpolar Active Layer Monitoring




## CALM METHODS

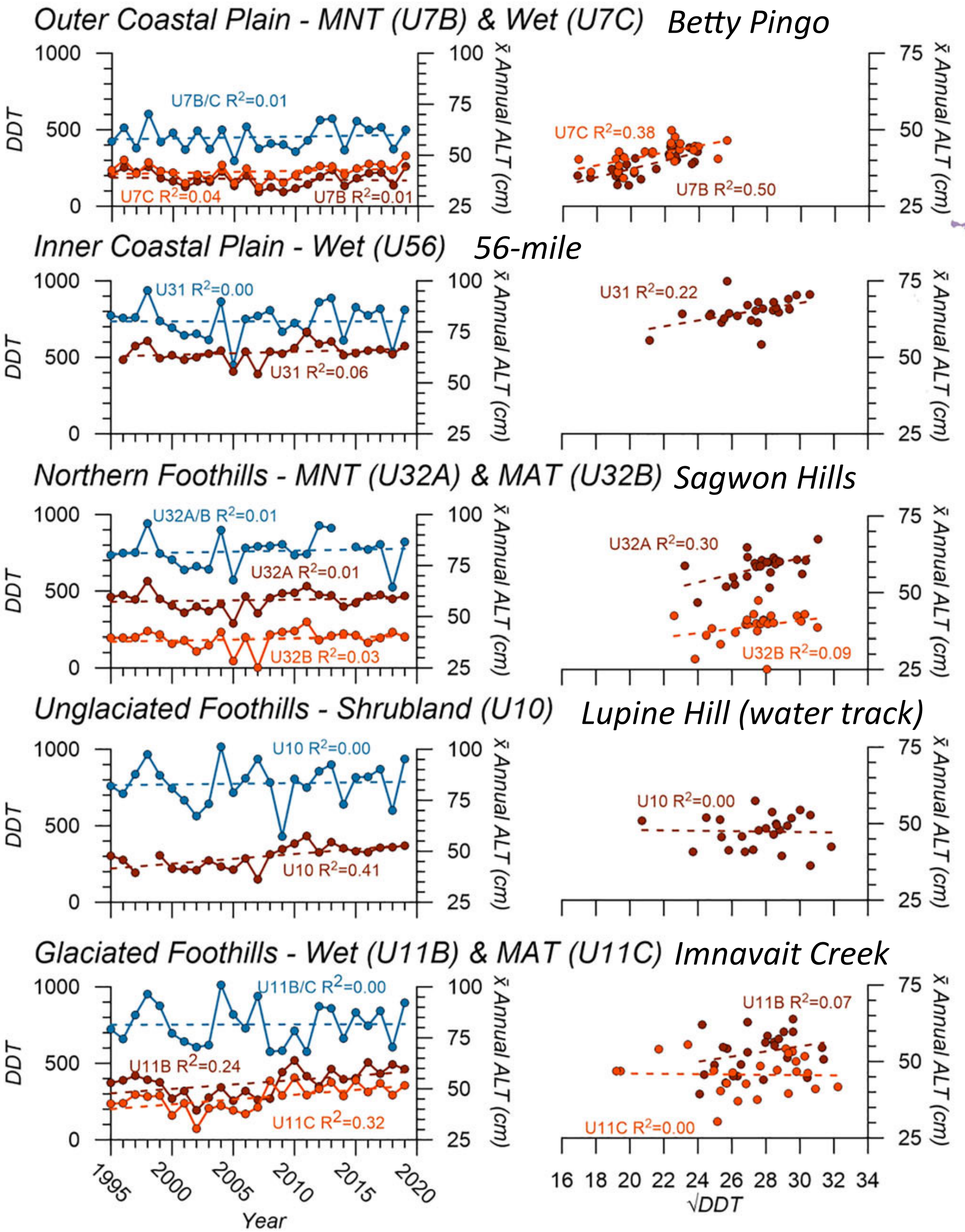
- *Each site cover 1 ha to 1 km$^2$ area.*
- *71 to 121 individual observations per site.*
- *Direct thaw depth measurements by mechanical probing.*
- *At each site observations are made consistently within the same calendar week at the end of the thawing season*

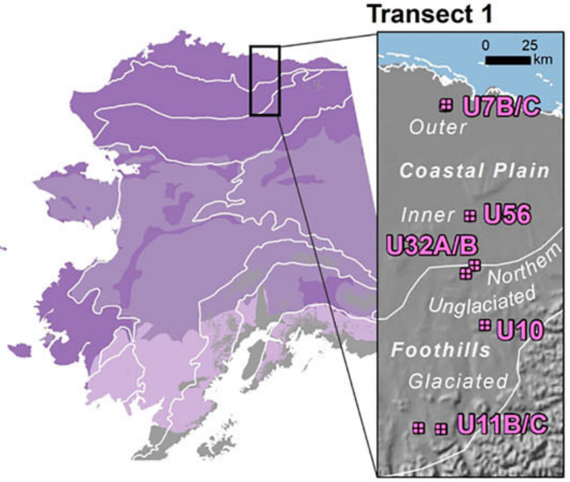
Nyland et al., 2021

**Table 1.** Summary statistics for individual site records. Figure 3 inset map shows locations of sites in Transect 3 regional groups.

| Geographic Name | Observation Type | Data Source | Site | *n* | Min. | $\bar{x}$ | Max. | $\sigma$ | Trend | Site |
|---|---|---|---|---|---|---|---|---|---|---|
| *Transect 1* | | | | | | | | | | |
| Prudhoe Bay (Outer Coastal Plain) | MAAT | CALM/NRCS | U5 U7B/C | 24 | −13.02 | −10.43 | −7.54 | 1.39 | 0.11*** | |
| | ALT | CALM | U4 | 23 | 24.71 | 31.49 | 37.27 | 3.58 | 0.83** | West Dock 1 ha |
| | ALT | CALM | U5 | 25 | 43.94 | 50.72 | 57.70 | 4.23 | 0.11 | West Dock 1 km |
| | ALT | CALM | U6 | 22 | 55.50 | 65.70 | 72.81 | 5.18 | 0.31* | Deadhorse 1 ha |
| | ALT | CALM | U7A | 25 | 46.27 | 52.71 | 59.73 | 3.89 | 0.01 | Betty Pingo 1 km |
| | | | Regional ALT $\bar{x}$ | 25 | 42.61 | 50.16 | 56.88 | 6.99 | 0.36* | |
| Franklin Bluffs (Inner Coastal Plain) | MAAT | CALM/TSP | U8 U31 | 24 | −12.96 | −10.22 | −7.81 | 1.25 | 0.09*** | |
| | ALT | CALM | U8 | 23 | 52.82 | 63.05 | 71.85 | 5.68 | 0.27 | Franklin Bluffs 1 ha |
| Happy Valley (Unglaciated Foothills) | MAAT | CALM/TSP | U9A/B | 23 | −12.75 | −9.82 | −7.45 | 1.27 | 0.11*** | |
| | ALT | CALM | U9A | 19 | 32.91 | 40.83 | 47.18 | 4.21 | 1.03** | Happy Valley 1 ha |
| | ALT | CALM | U9B | 25 | 39.56 | 44.32 | 48.75 | 2.76 | 0.09 | Happy Valley 1 km |
| | | | Regional ALT $\bar{x}$ | 25 | 36.24 | 42.58 | 47.97 | 8.65 | 0.47** | |
| Upper Kuparuk Watershed (Glaciated Foothills) | MAAT | CALM/NRCS | U11B U12B U14 | 24 | −9.81 | −7.56 | −5.70 | 1.12 | 0.07** | |
| | ALT | CALM | U11A | 25 | 38.81 | 52.22 | 62.89 | 6.04 | 0.54*** | Imnavait Cr 1 km |
| | ALT | CALM | U12A | 25 | 38.27 | 49.45 | 60.99 | 5.53 | 0.43*** | Toolik Lake 1 km |
| | ALT | CALM | U14 | 20 | 39.00 | 52.85 | 60.00 | 5.60 | 0.20 | Galbraith Lake 1 ha |
| | | | Regional ALT $\bar{x}$ | 25 | 38.69 | 51.51 | 61.29 | 5.08 | 0.42** | |

Nyland et al., 2021

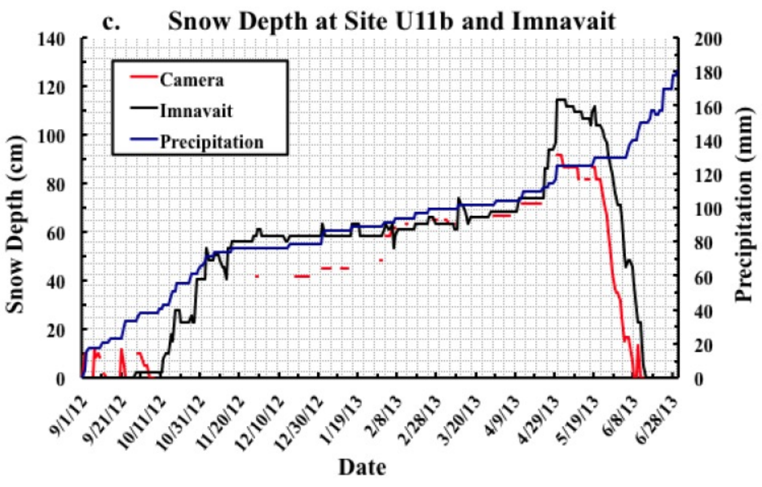


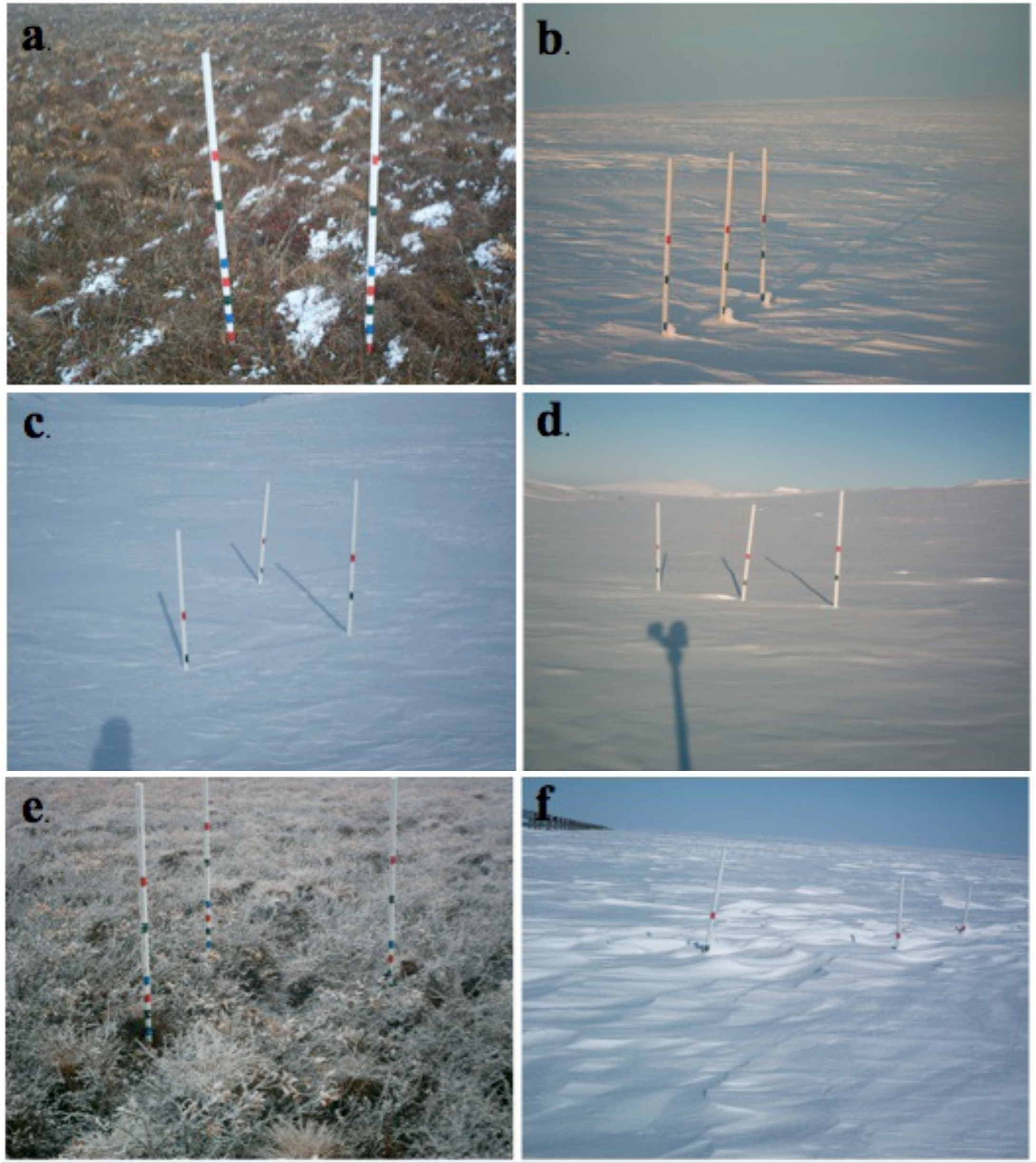



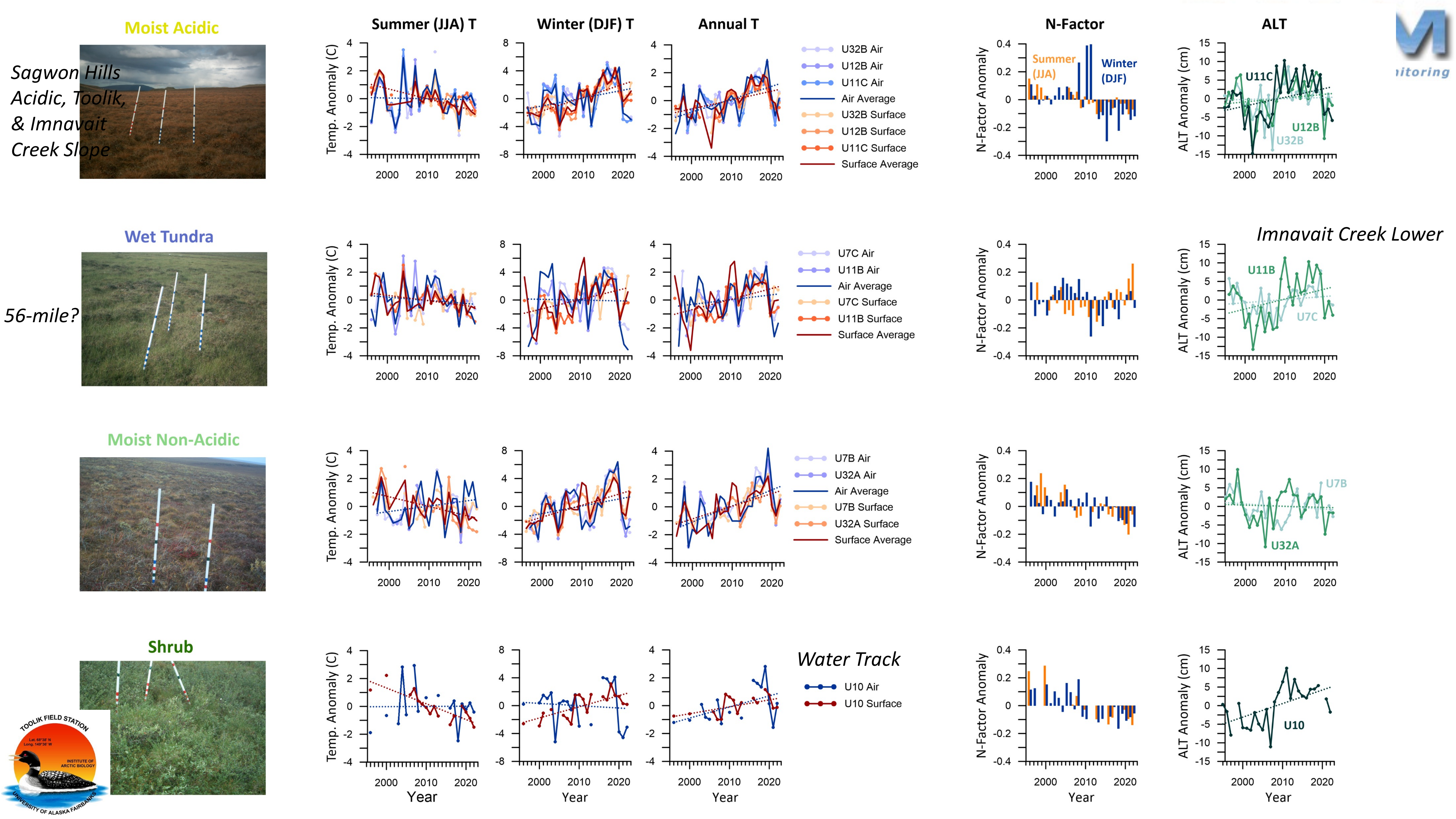

- Increasing but not statistically significant and not nearly as much as some regions

Nyland et al., 2021

# Snow Cameras





Moist Acidic
Sagwon Hills Acidic, Toolik, & Imnavait Creek Slope
Summer (JJA) T
Winter (DJF) T
Annual T
U32B Air
U12B Air
U11C Air
Air Average
U32B Surface
U12B Surface
U11C Surface
Surface Average
N-Factor
Summer (JJA)
Winter (DJF)
ALT
U11C
U12B
U32B
Wet Tundra
56-mile?
Imnavait Creek Lower
U7C Air
U11B Air
Air Average
U7C Surface
U11B Surface
Surface Average
U11B
U7C
Moist Non-Acidic
U7B Air
U32A Air
Air Average
U7B Surface
U32A Surface
Surface Average
U7B
U32A
Shrub
Water Track
U10 Air
U10 Surface
U10
Temp. Anomaly (C)
N-Factor Anomaly
ALT Anomaly (cm)
Year
TOOLIK FIELD STATION
Lat. 68°38' N
Long. 149°38' W
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- Data show that overall, ALT trends in northern Alaska are similar to other CALM sites located in the Arctic regions on cold continuous permafrost.  Rates of air temperature increase ranged from 0.07°C to 0.11°C/yr in the Kuparuk River basin.  Since 2000, ALT in the Kuparuk has increased on average at 0.4 cm/yr, . In the Arctic Coastal Plain ALT increased at 0.2 to 0.5 cm/yr rate, and in the Arctic Foothills at 0.3 to 0.6 cm/yr  Sites dominated by shrubs had higher rates of increasing ALT. Two sites with thaw subsidence measurements, one located near West Dock and one located in the northern foothills show 0.8 cm/yr and 0.7 cm/yr of thaw subsidence since 2003.

- Temperature measurements show an increase in temperature differences between the air and soil surface. Our recent work quantifying changes in vegetation height and snow depth should allow further quantification of what portion of the active-layer trends are attributable to increased  summer and winter thermal insulation.

| Site Code | Site Name | Locat |
|---|---|---|
| | | LAT |
| U1 | Barrow | 71.31667 |
| U2 | Barrow, CRREL Plots | 71.31667 |
| U3 | Atkasuk | 70.45 |
| U4 | West Dock 1 ha grid | 70.3745 |
| U5 | West Dock 1 km grid | 70.36667 |
| U6 | Deadhorse | 70.1613 |
| U7 A | Betty Pingo 1 km grid | 70.28333 |
| U7 B | Betty Pingo MNT | 70.2835 |
| U7 C | Betty Pingo WET | 70.275 |
| U8 | Franklin Bluff | 69.6739 |
| U9 A | Happy Valley | 69.1466 |
| U9 B | Happy Valley 1 km grid | 69.1482 |
| U10 | Lupine Hill | 69.12883 |
| U11 A | Imnavait Creek  1 km grid | 68.6114 |
| U11 B | Imnavait Creek WET | 68.611 |
| U11 C | Imnavait Creek MAT | 68.611 |
| U12 A | Toolik 1 km grid | 68.6215 |
| U12 B | Toolik MAT | 68.624 |
| U13 | Toolik LTER | 68.61667 |
| U14 | Galbraith Lake | 68.4774 |
| U15 | Chandalar Shelf | 68.0691 |
| U26 | Ivotuk  1 km grid | 68.48333 |
| U56 | 56 Mile | 69.5006 |
| U32 A | Sagwon Hills MNT | 69.441 |
| U32 B | Sagwon Hills MAT | 69.401 |
| U20 | Drew Point | 70.8645 |