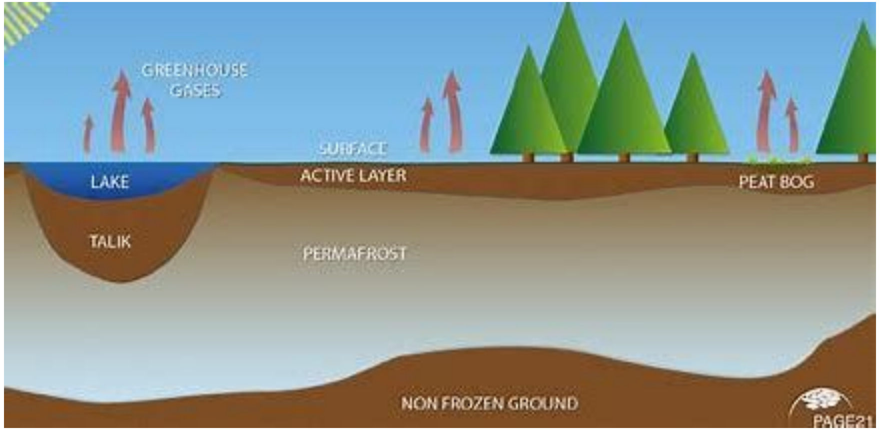
“Frozen” shoreline change and predictions linked to climate change

Philipp Barthelme, Jess Payne, Samuel Fielding and Penny Clarke

Background

Permafrost generates an impermeable layer between the surface and subsurface, the melting of excess ground ice leads to the formation and expansion of a lake.

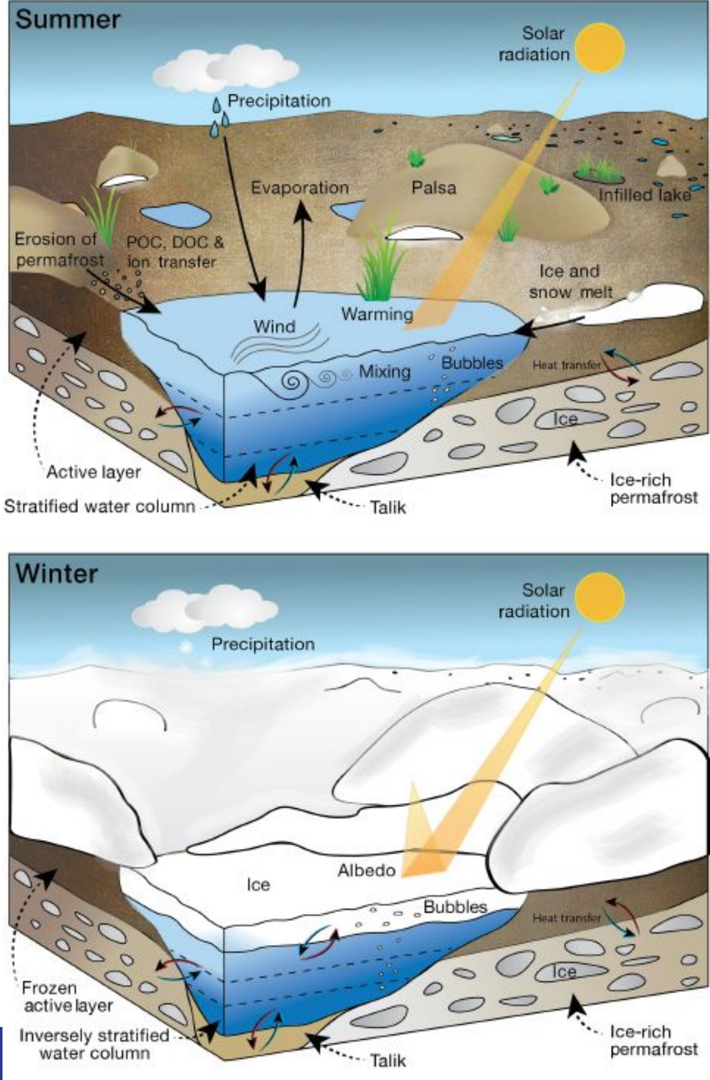


Muster et al. 2013

Background

Necsoiu et al. 2013 found lake surface area in Kobuk Valley National Park decreased 0.5% 1951-1978 and 5.5% 1978-2005

- Can we replicate these results at a higher latitudes, 300km north?

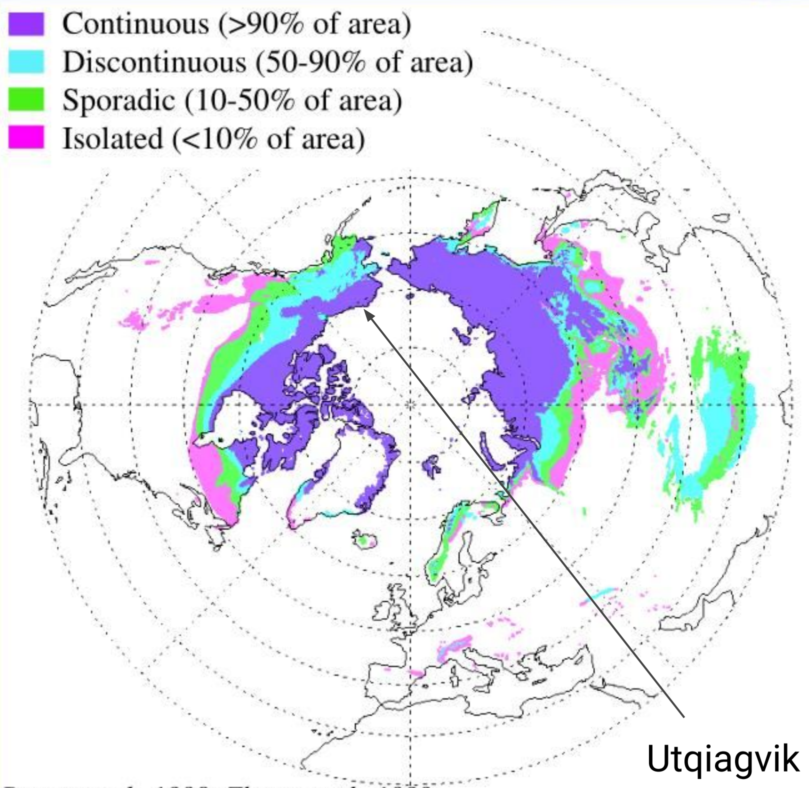


Location of Study Area

Utqiagvik, Alaska:

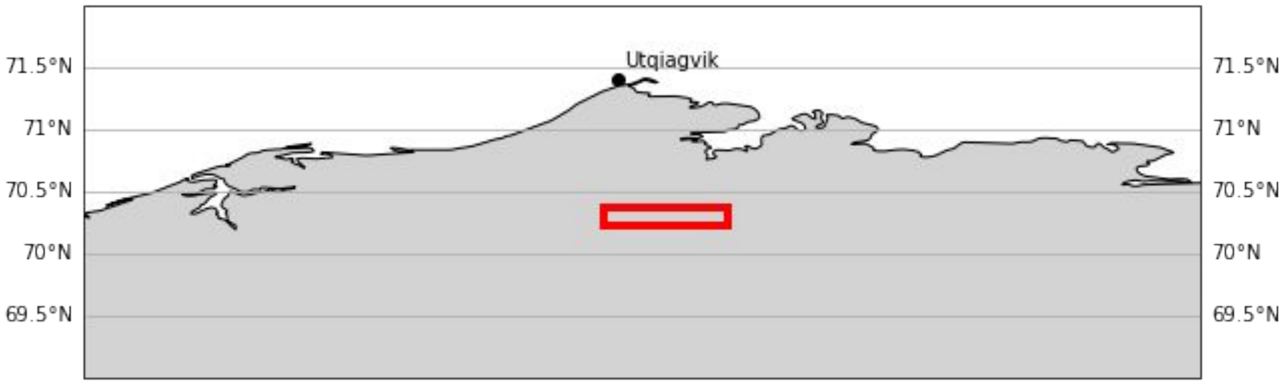
1. In a continuous permafrost zone
2. Has a large sample size of lakes in a small area
3. Is located close to a temperature measurement station

...also most Northern city in the USA



Brown et al., 1998; *Zhang et al.*, 1999

Location of Study Area



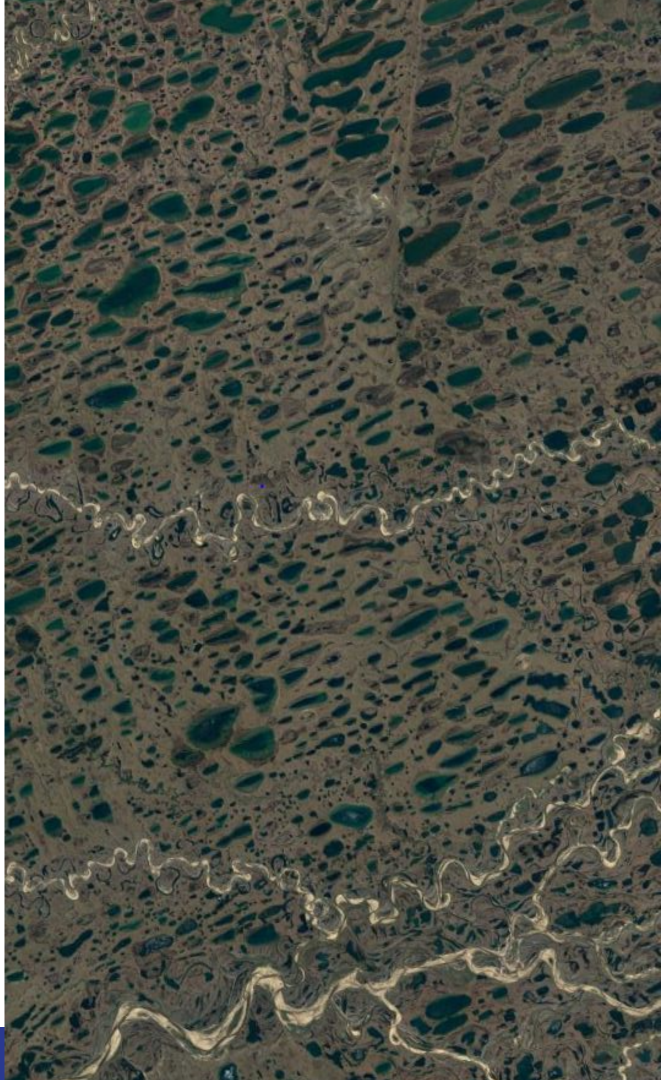
Objectives

The objectives of this project are:

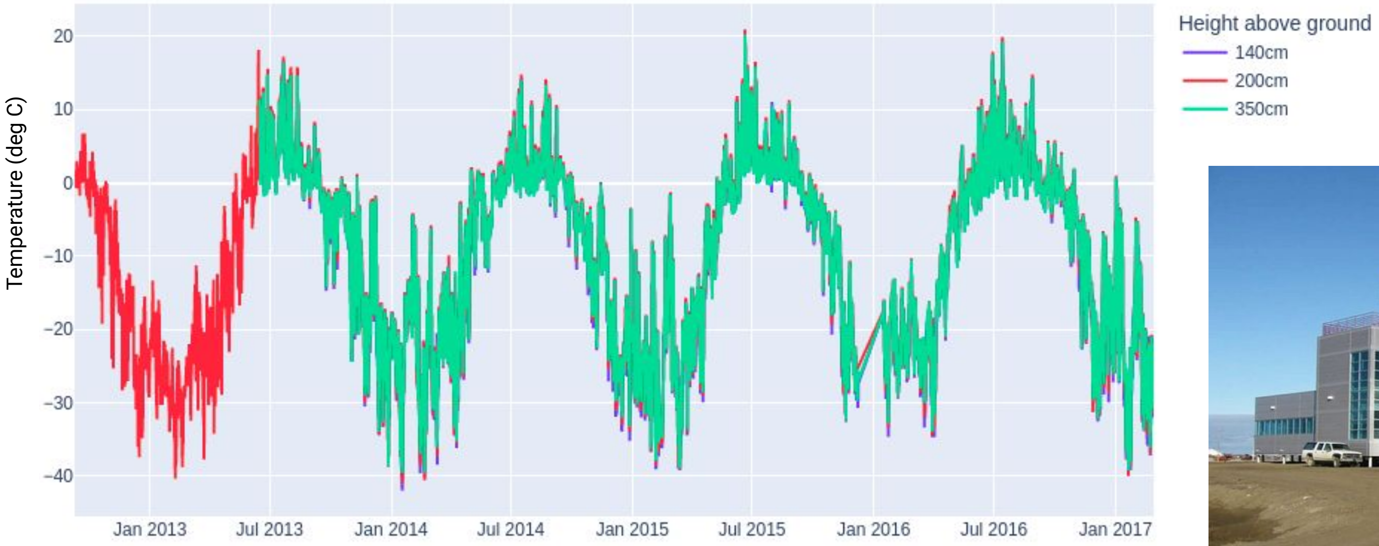
(1) to identify changes in the size and abundance of lakes in permafrost regions by looking at a study location near Utqiagvik, Alaska.

(2) to determine if lake size and abundance vary with temperature changes over time

(3) to predict future lake size and abundance based on 2013-2021 data

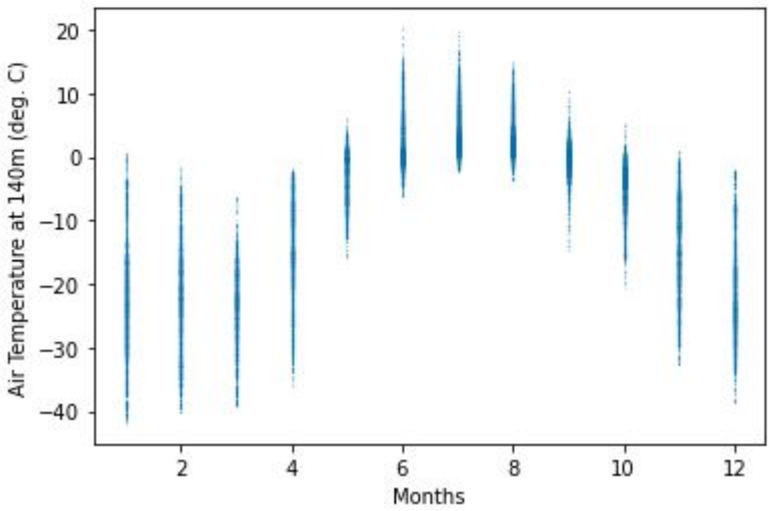


Raw temperature data



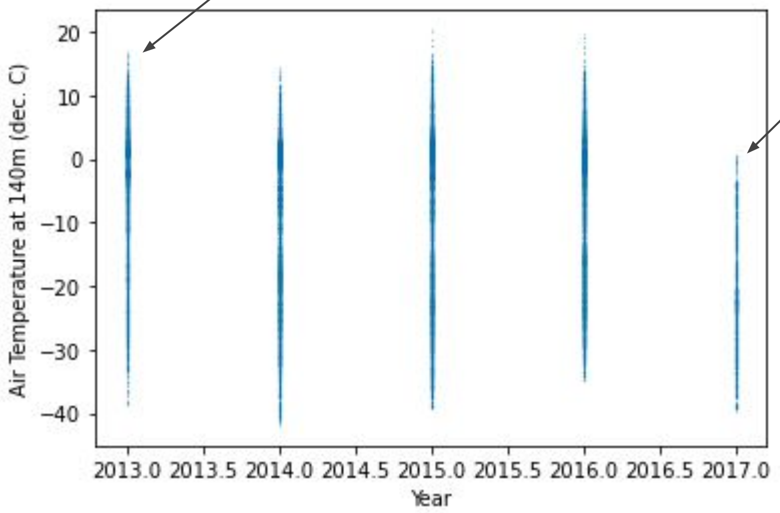
Data from Hinzman et al. 2014, recorded at Site A, Barrow Environmental Observatory

Monthly and annual temperature variation



Data starts June 2013

Data ends Feb 2017

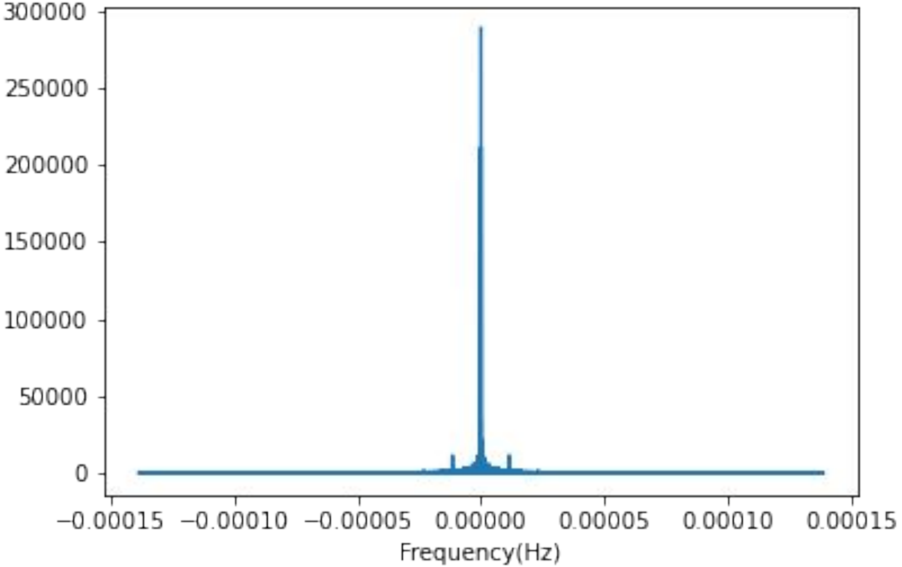


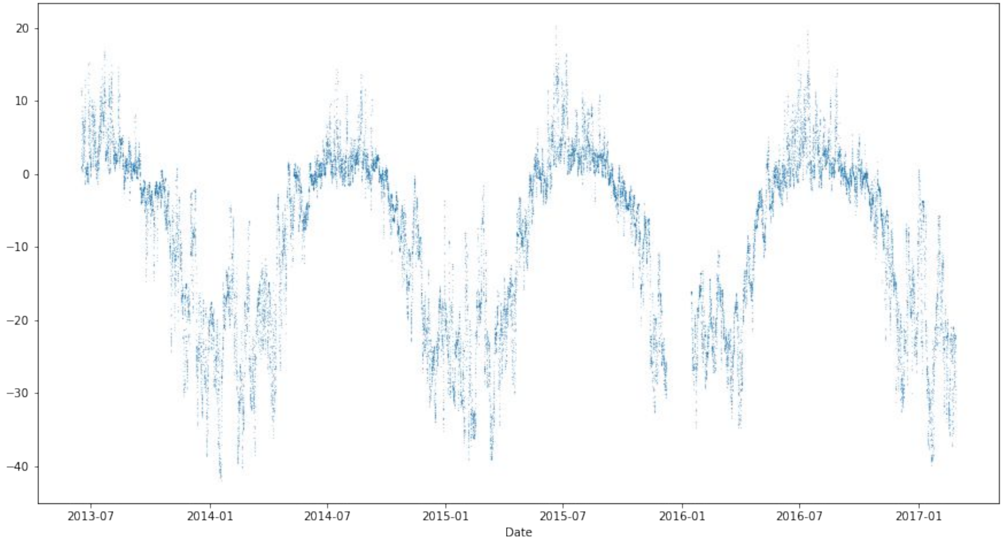
Hinzman et al 2014 hourly data 2013-2017

Time Series Analysis-Temperature

Hinzman et al. 2014 hourly temperature data at 140cm.

Fourier transform applied to data (right).

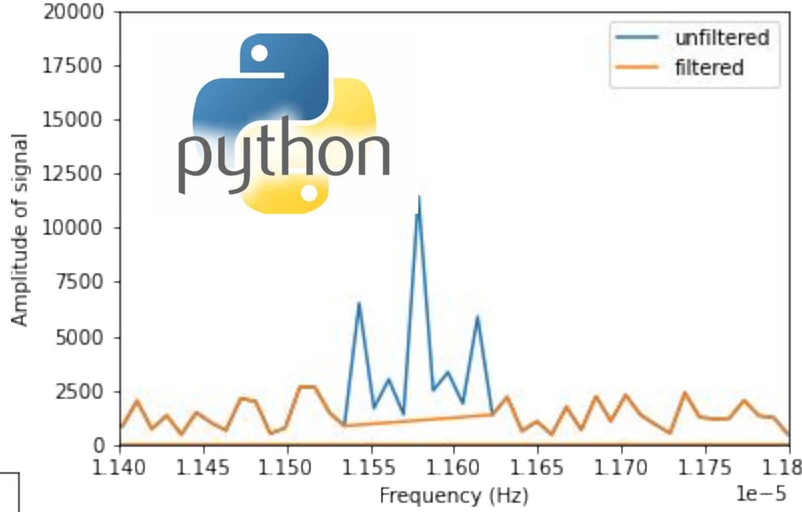


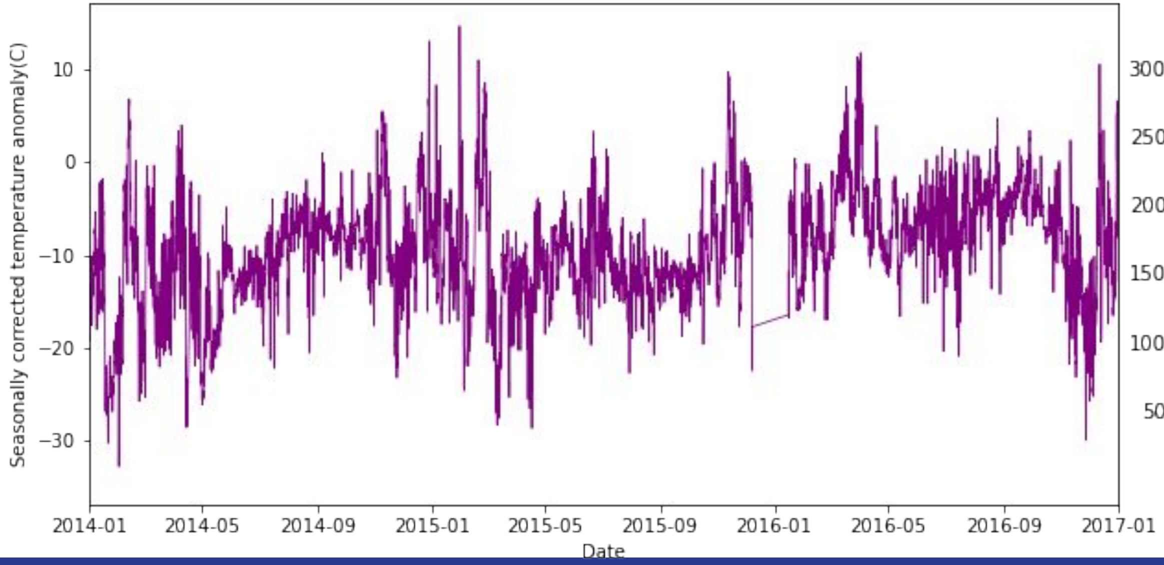


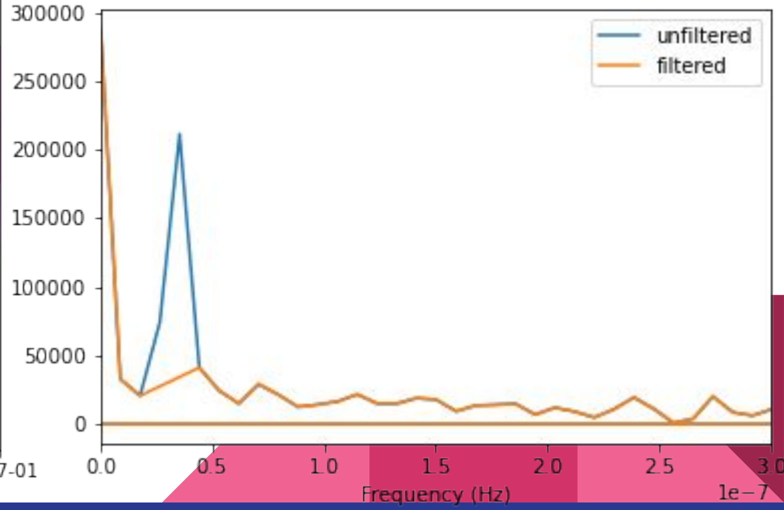
Eliminating periodic variations

(Day variation top right, year bottom left)

Day: 1.16*10^-5Hz, Year: 3.17*10^-8Hz





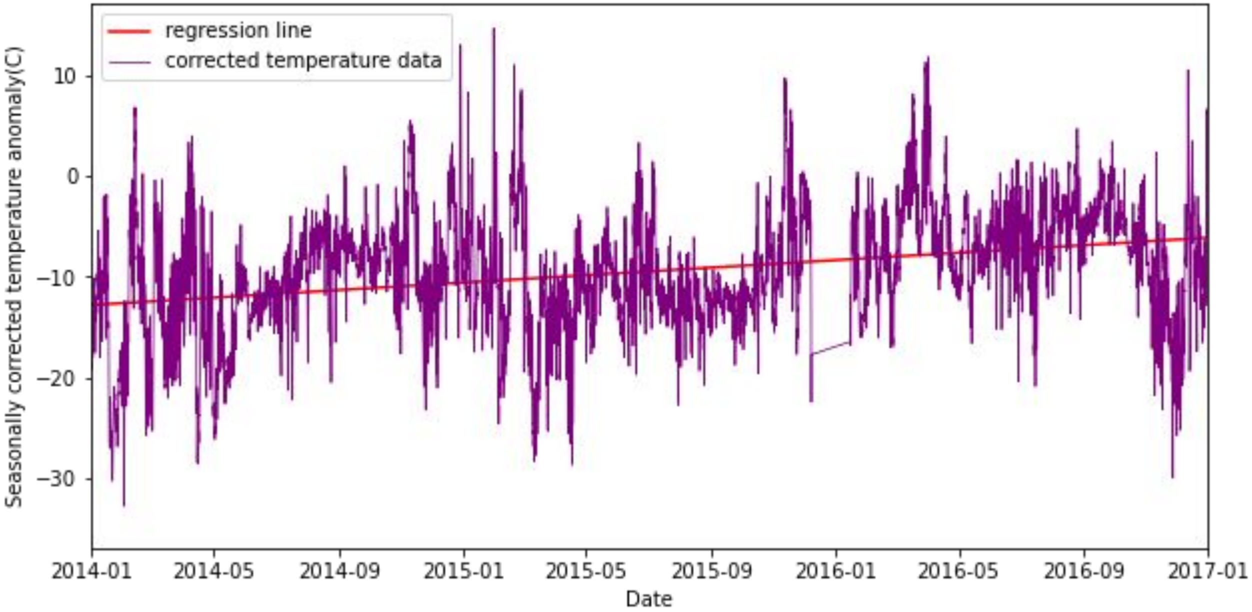


Regression Plots

Clear temperature increase- 4 degree increase from 01 Jan 2014-01 Jan 2017

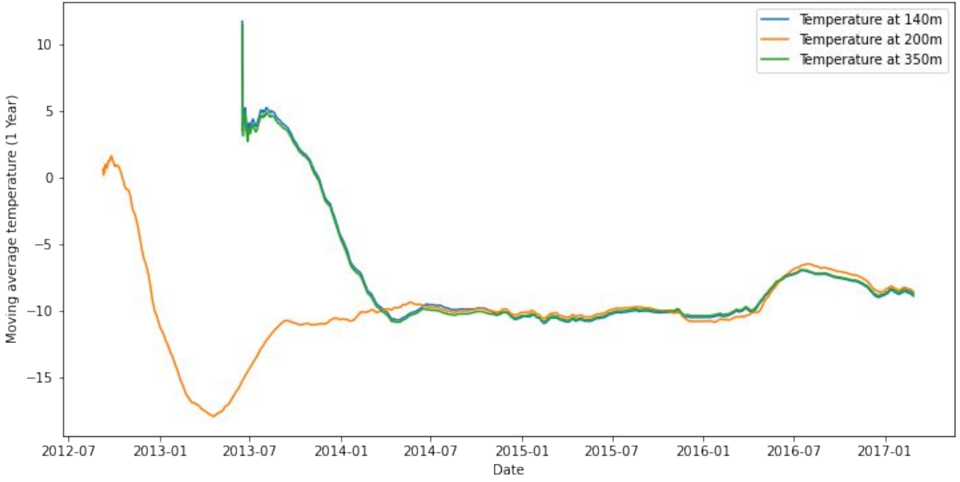
May be exaggerated:

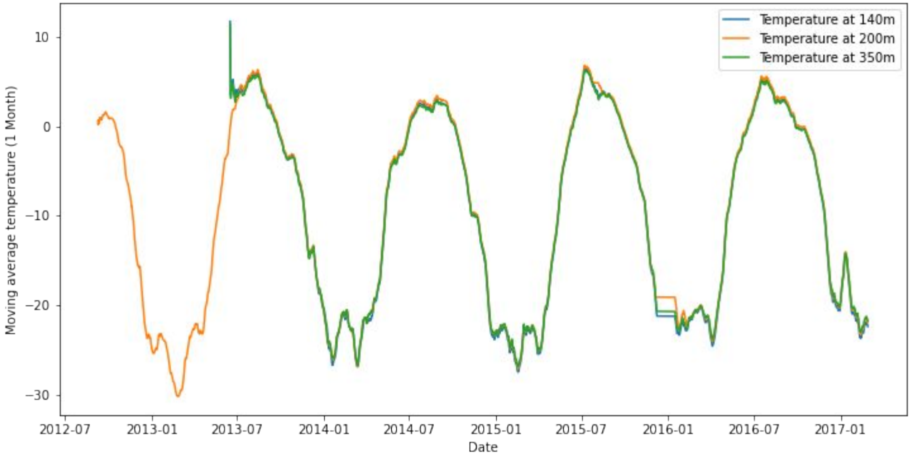
1. Not long enough time series, so removal of periodic variation may not be efficient
2. Slight lag in temperature over year



Moving Average

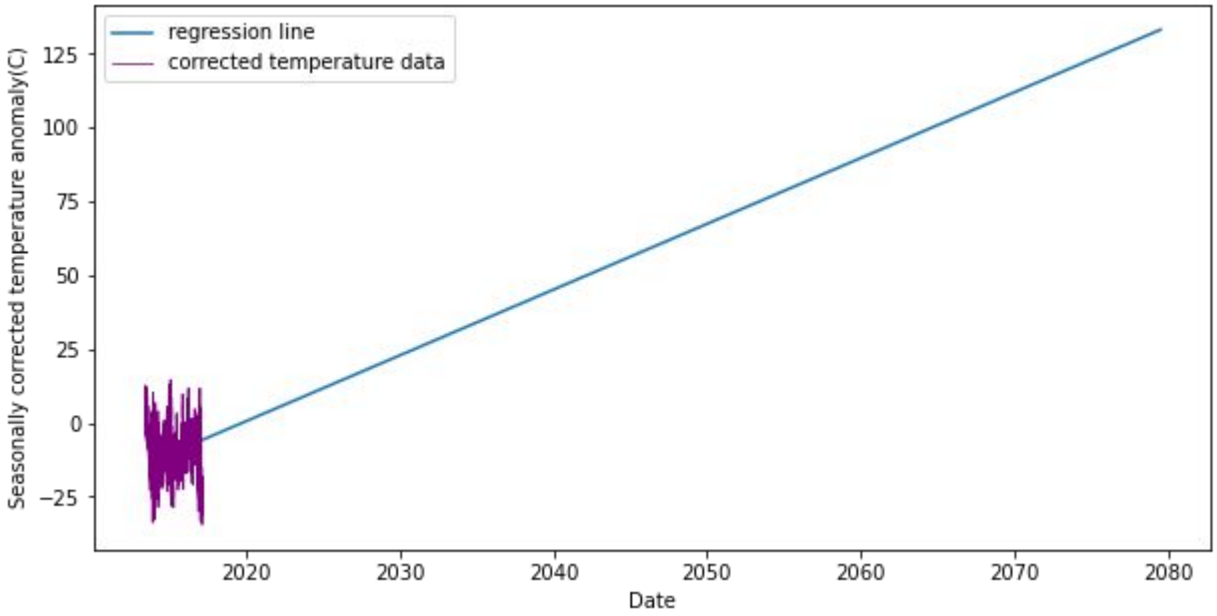
Moving average of temperature was computed for the average over one month and one year.





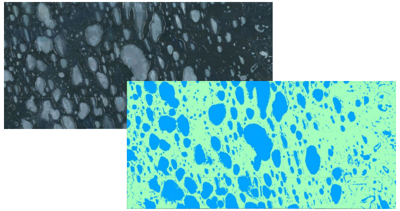
Prediction for the future

Extrapolating our temperature anomaly, the water will start to boil in about 2070, leading to likely dramatic reduction in lake surface area as a percentage of total area

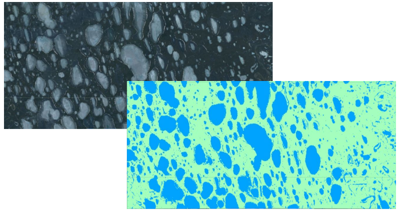


How long until Utqiagvik can market itself as a blue lagoon?

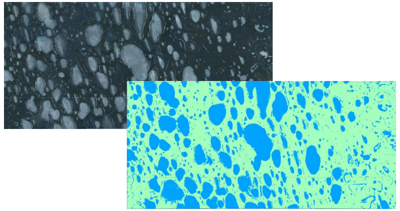
Lake Prediction: Unsupervised



2013



2014



2021

Water

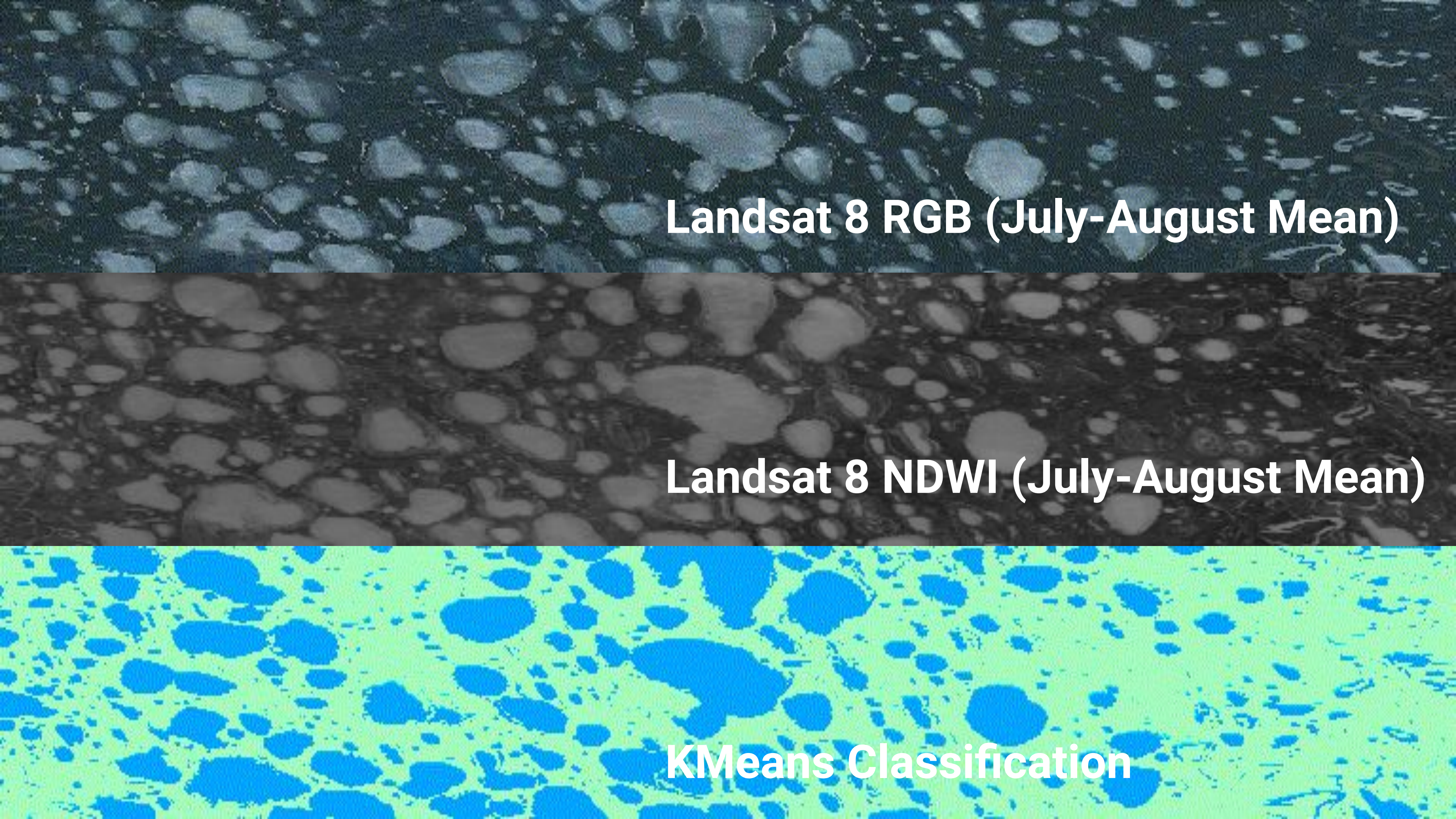
Non-Water

Data: Landsat 8 TOA
Processing:

- Calculate cloud mask and NDWI (normalized difference water index) for each image
- Calculate yearly mean NDWI over cloud-free pixels for all images in June-August (least snow/ice during that time period)

Clustering: KMeans with 2 classes (GEE Implementation)
Result: % of area covered by lakes by year

Google Earth Engine

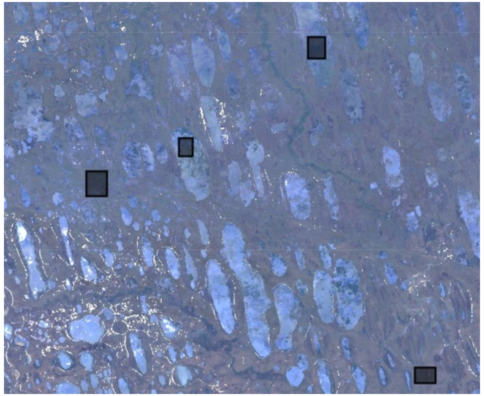

Landsat 8 RGB (July-August Mean)
Landsat 8 NDWI (July-August Mean)
KMeans Classification

Lake Prediction: Supervised

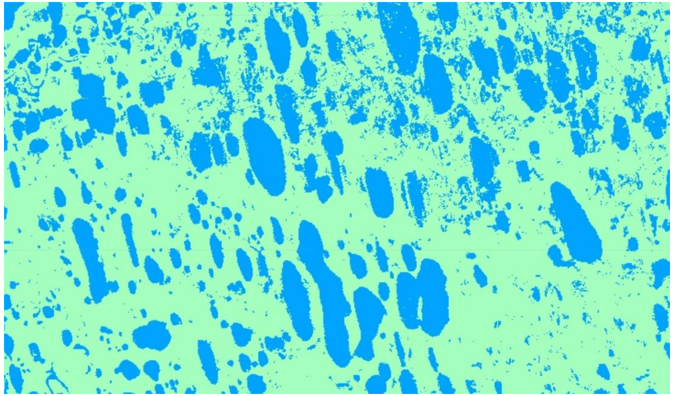
Training Area

Non-Water

Water



Train



Classify

Data: Landsat 8 raw

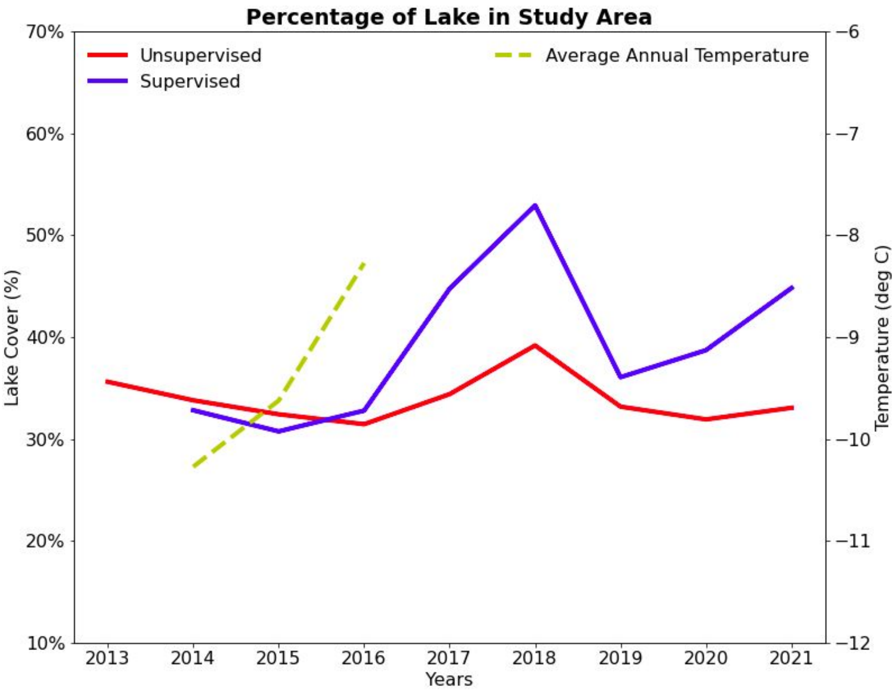
Processing:

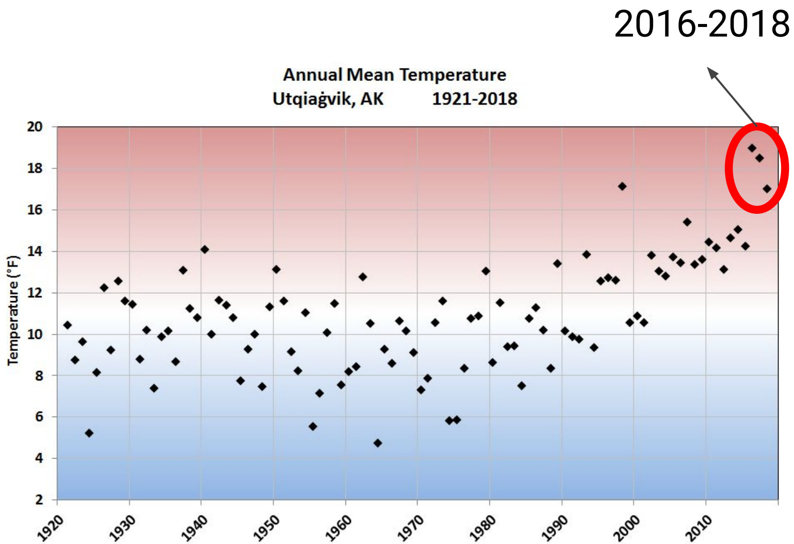
- GEE Landsat SimpleComposite function
- Processes and selects least cloudy scene (Jun-Aug) for each year

Classification: SVM (Support Vector Machine)

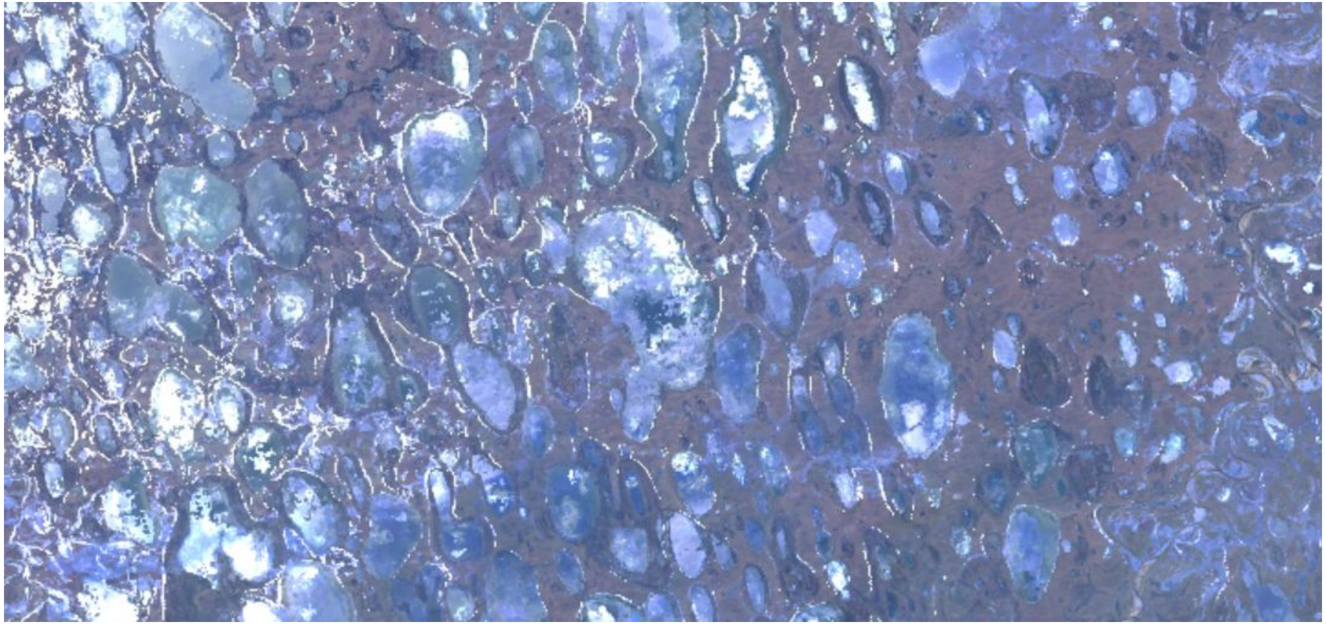
Result: % of area covered by lakes by year

Comparison of classification results



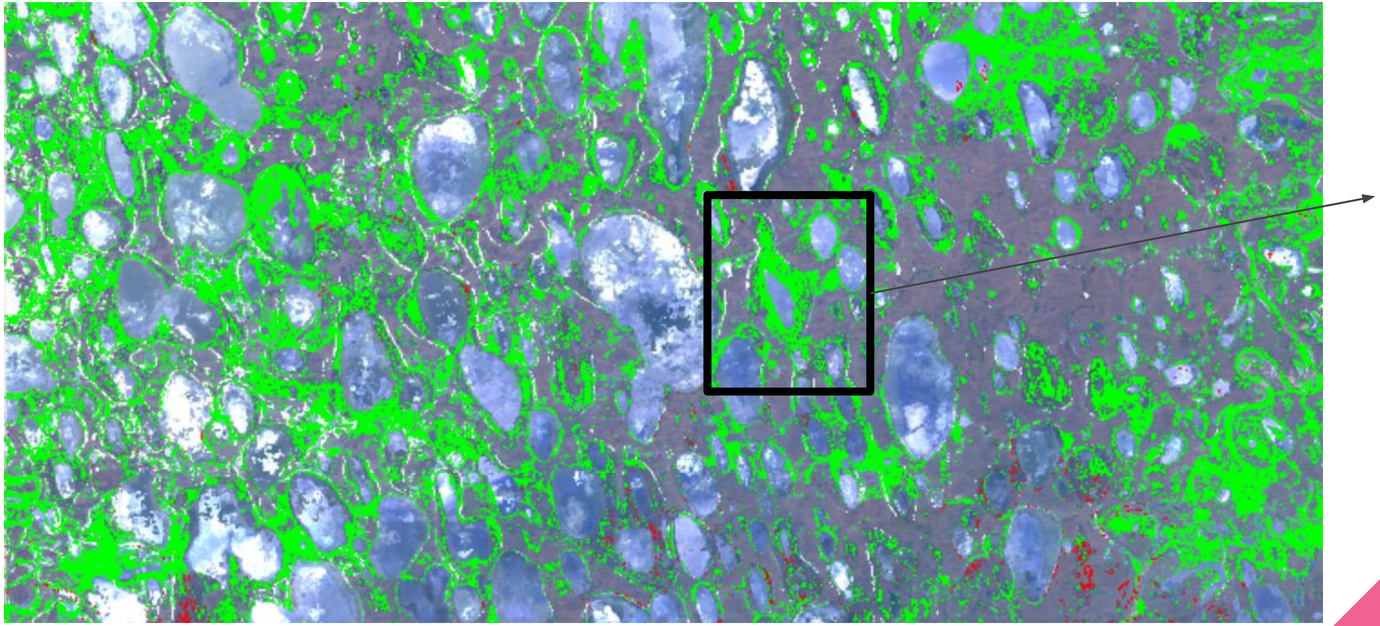


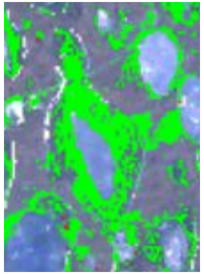
Spotlight 2018 Spike

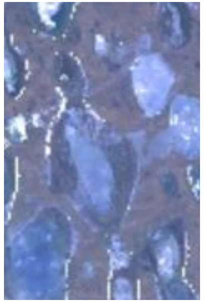


Google Earth Engine

Spotlight 2018 Spike



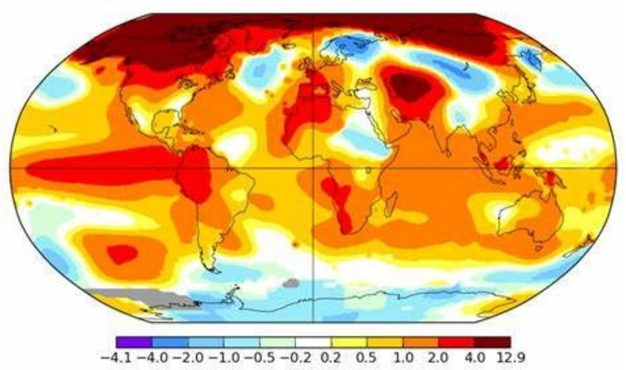


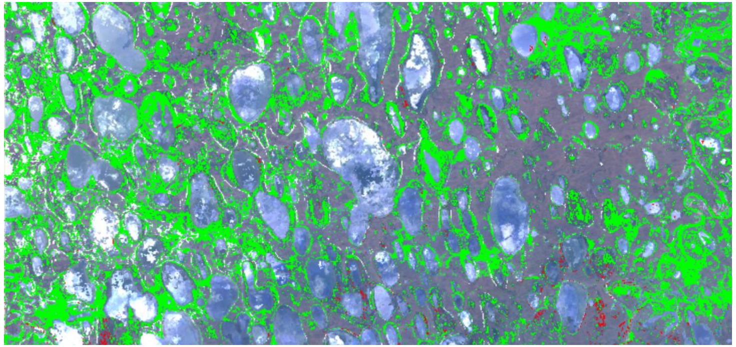


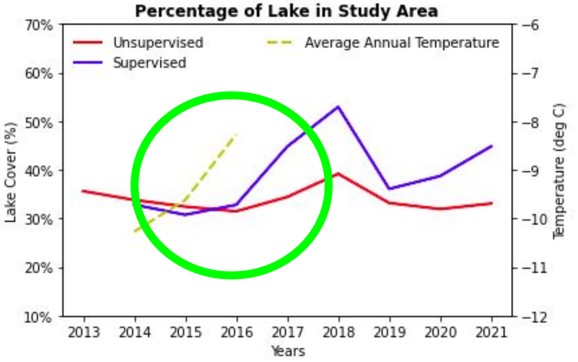
Water Loss Water Gain

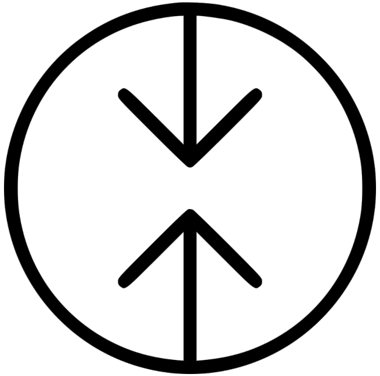
Google Earth Engine

Discussion

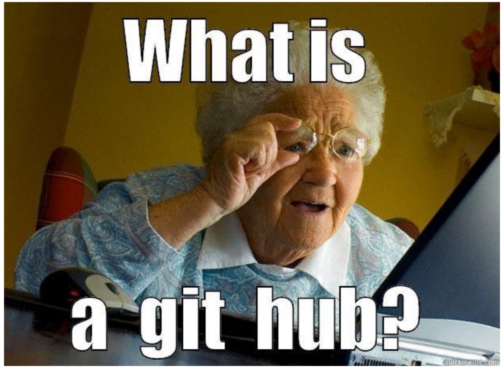

−4.1 −4.0 −2.0 −1.0 −0.5 −0.2 0.2 0.5 1.0 2.0 4.0 12.9



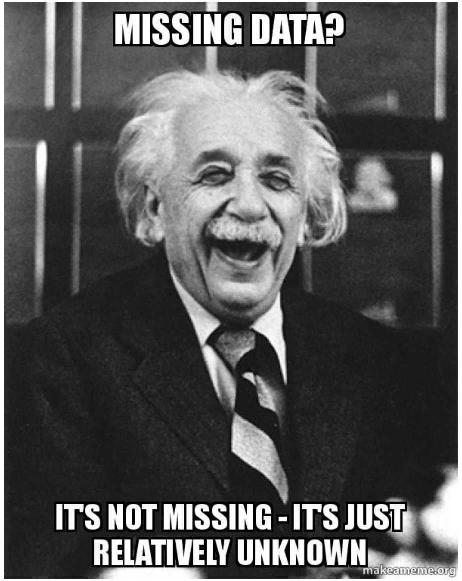

Percentage of Lake in Study Area
Unsupervised
Supervised
Average Annual Temperature
Lake Cover (%)
70%
60%
50%
40%
30%
20%
10%
Temperature (deg C)
−6
−7
−8
−9
−10
−11
−12
2013 2014 2015 2016 2017 2018 2019 2020 2021
Years



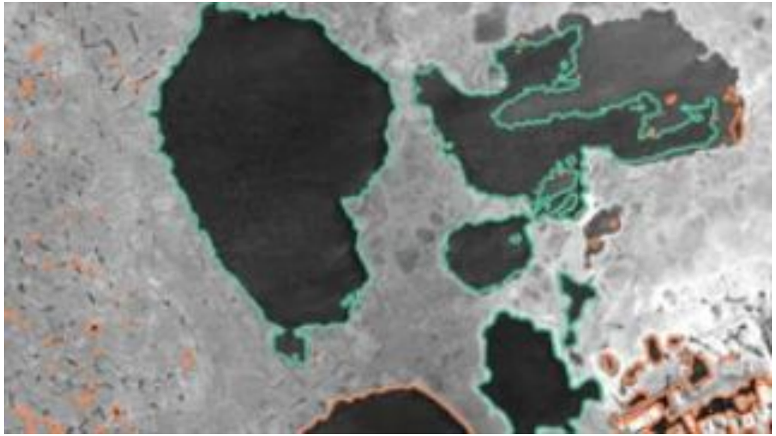
What did we learn?

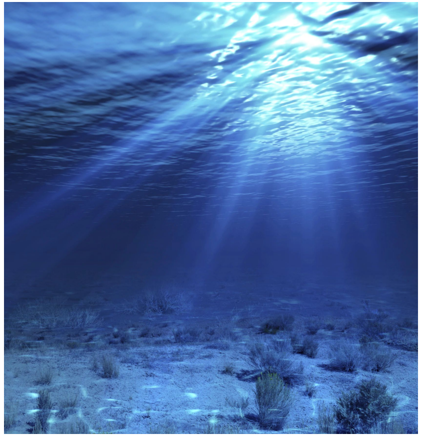


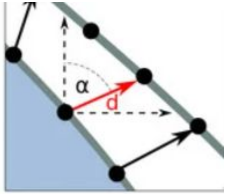
Challenges

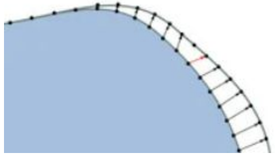

MISSING DATA?
IT'S NOT MISSING - IT'S JUST RELATIVELY UNKNOWN
makeameme.org

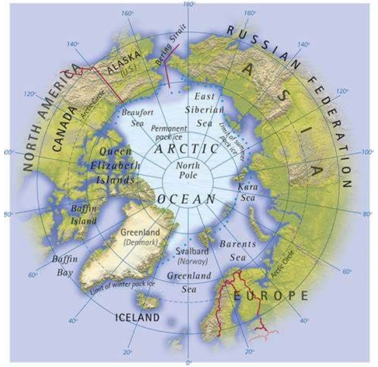
Future Directions











Conclusion

References

Brown, J., O. J. Ferrians Jr., J. A. Heginbottom, and E. S. Melnikov (1998), 211 Circum-Arctic map of permafrost and ground-ice conditions, http://nsidc.org/ 212 data/ggd318.html, Natl. Snow and Ice Data Cent., Boulder, Colo

Hinzman, L., Busey, B., Cable, W., Romanovsky, V., 2014. Surface Meteorology, Barrow, Alaska, Area A, B, C and D, Ongoing from 2012. https://doi.org/10.5440/1164893

Kaiser, S., Grosse, G., Boike, J., Langer, M., 2021. Monitoring the Transformation of Arctic Landscapes: Automated Shoreline Change Detection of Lakes Using Very High Resolution Imagery. Remote Sensing 13, 2802. https://doi.org/10.3390/rs13142802

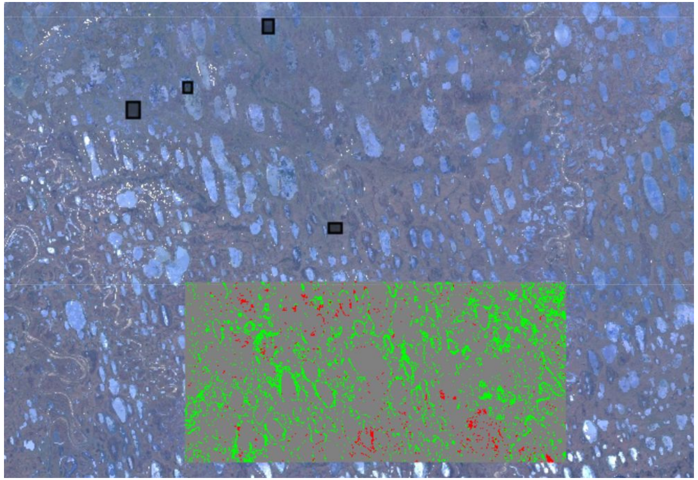
Muster, S., Heim, B., Abnizova, A., Boike, J., 2013. Water Body Distributions Across Scales: A Remote Sensing Based Comparison of Three Arctic Tundra Wetlands. Remote Sensing 5, 1498–1523. https://doi.org/10.3390/rs5041498

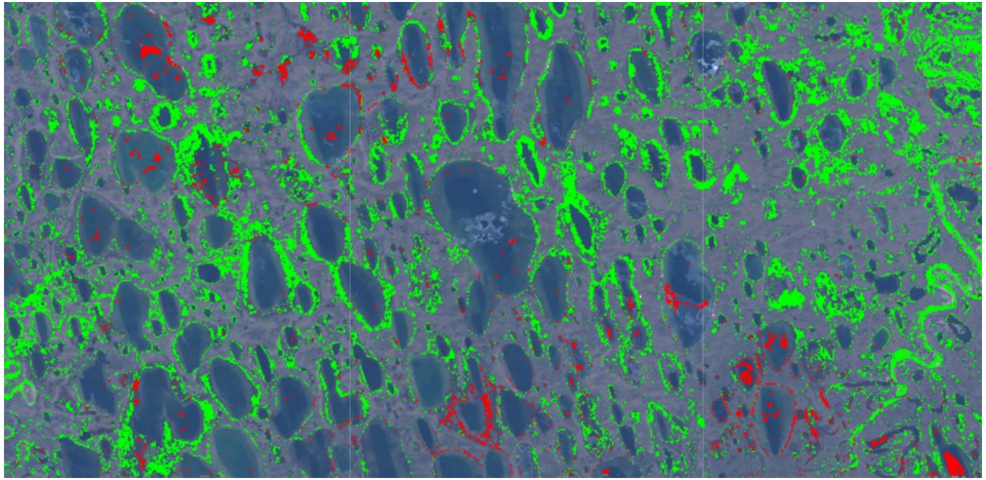
Necsoiu, M., Dinwiddie, C.L., Walter, G.R., Larsen, A., Stothoff, S.A., 2013. Multi-temporal image analysis of historical aerial photographs and recent satellite imagery reveals evolution of water body surface area and polygonal terrain morphology in Kobuk Valley National Park, Alaska. Environ. Res. Lett. 8, 025007. https://doi.org/10.1088/1748-9326/8/2/025007

Shah, C.A., 2011. Automated Lake Shoreline Mapping at Subpixel Accuracy. IEEE Geoscience and Remote Sensing Letters 8, 1125–1129. https://doi.org/10.1109/LGRS.2011.2157951

Zhang, T., Barry, R. G., Knowles, K., Heginbottom, J. A., and Brown, J.: Statistics and characteristics of permafrost and ground ice distribution in the Northern Hemisphere, Polar Geogr., 23, 147–169, 1999.

Machine Learning: Supervised





Training Area | Water Loss | Water Gain

Google Earth Engine