EARTH LAB

EXPLORING THE RELATIONSHIP BETWEEN PERMAFROST DEGRADATION AND REMOTELY SENSED SNOW SEASONALITY IN THE NORTH SLOPE OF ALASKA

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INTRODUCTION

Permafrost, a significant part of the northern region, is a notable indicator of climate change. While the discontinuous permafrost zone (the area in which the subsurface layer is not entirely frozen) marches north, the continuous zone, becomes less dominant. As speculated by others, the variation in the duration of the snow free period is likely one of the causes of such change.

BACKGROUND

A thick subsurface layer of soil that remains permanently frozen throughout the year, permafrost, and its active layer that experiences annual freeze/thaw cycles can have a particularly large impact on the environment. As the active layer melts and refreezes, it causes damage to infrastructure, construction, and challenges maintenance. Permafrost also stores a large amount of carbon beneath its surface. When organic materials beneath the surface decompose and the permafrost that holds it begins to melt, carbon dioxide and methane could be released. These greenhouse gases have been shown to be contributors to climate change.

Though there has been an extensive amount of research concerning the causes of the fluctuation in the active layer, there has been a gap in the research pertaining to the cause(s) of the changes over time. Many have predicted that the changes in snow seasonality impact active layer dynamics, but very few have quantified this relationship at different locations. It is likely that snow is a cause of the variability because it acts as an insulator. At first the snow slows the rate at which the active layer is melting, but at a certain point begins causing the melt. This presents a challenge. Not only does the snow-free period cause the active layer to melt, but the insulating characteristics of the snow also cause the active layer to melt. Project Permafrost believes there could be a correlation between the duration of the snow free period and the variation of active layer depth over time.

METHODS

In order to research this problem we chose to investigate the North Slope of Alaska since it is a fairly homogeneous environment and is in the continuous permafrost zone. We began by extracting and cleaning data. The project used Moderate Resolution Imaging Spectroradiometer (MODIS) derived snow metrics to grab data for snow seasonality, and data from the Circumpolar Active Layer Monitoring Network (CALM) for the collection of active layer depth data points. Project Permafrost used primarily R, and some QGIS and MATLAB for this research project. The first task was to crop the original raster stack, obtained from GINA's (Geographic Information Network of Alaska) MODIS satellite, from the entirety of Alaska to the North Slope of Alaska as seen in Figure 1.

(a) Alaska

(b) North Slope of Alaska

Figure 1: Cropping of raster stack.

Next, it was necessary to extract the most significant layers of the twelve layers contained in the stack. Project Permafrost extracted the start and end of the full snow season, the total number of snow days, the start and end of the longest continuous snow period, and the total number of days in that segment. The full snow season is derived by observing the first snow day and the last snow day and the continuous snow period is described as the longest period of continuous snow; a subset of the full snow period. The snow data was comprised of a time span from 2001-2016.

After extracting the data from those six rasters, the following task was to obtain and import the active layer data. The CALM data spanned a time frame of 1996-2016. There were 42 locations in the North Slope area, out of the many the CALM dataset contained.

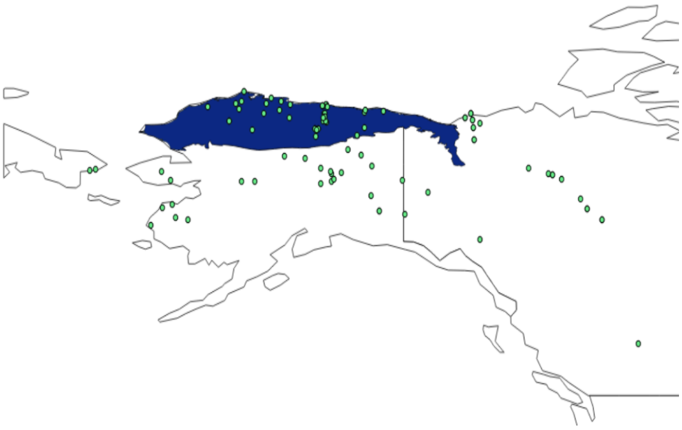


Figure 2: Active layer points (green); North Slope (blue).

Once all datasets had been placed into separate data frames in R, we were able to find the snow seasonality descriptors at each of the active layer points.

ANALYSIS AND RESULTS

Throughout this investigation, we chose to observe the results in terms of the continuous snow period versus the full snow period. The values for the full snow period and the continuous snow period are very close, duration wise, so rather than using two similar datasets, we used the continuous snow.

Since the duration of the snow free period was unknown, Project Permafrost used two different methods to calculate it. The snow season takes place in parts of two years, so for example, if we were looking at the year 2002, the day count would begin 2001. In this example, the snow seasonality data would start in August 1, 2001 and ends July 31, 2002. The data for 2003 would start August 1, 2002 and end July 31, 2003 and so on. The two methods we used to calculate the snow free period were the "Snow Year" and the "Calendar Year". The "Snow Year" snow free period was found by:

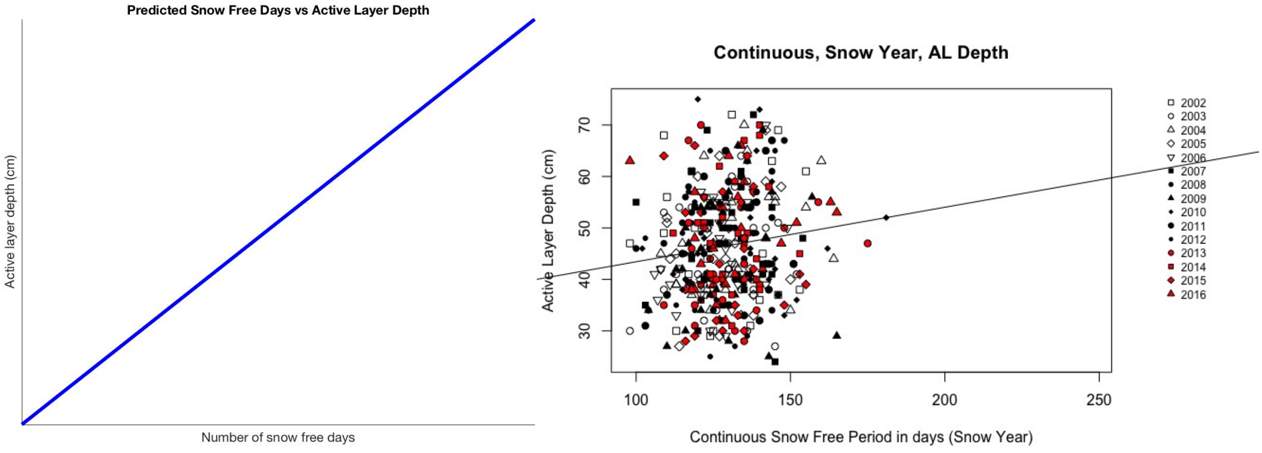
$$\text{Snow Free Period} = 365 - (\text{last day of snow} - \text{first day of snow}) \tag{1}$$

The "Calendar Year" snow free period was found with a series of if/else statements:

$$\begin{aligned}
&\text{if start(year)} < 365 \text{ and end(year-1)} > 365 \\
&\qquad\qquad \text{Snow Free Period} = \text{start(year)} - (\text{end(year-1)} - 365) \\
&\text{if start(year)} < 365 \text{ and end(year-1)} < 365 \\
&\qquad\qquad \text{Snow Free Period} = \text{start(year)} \\
&\text{if start(year)} > 365 \text{ and end(year-1)} > 365 \\
&\qquad\qquad \text{Snow Free Period} = 365 - (\text{end(year-1)} - 365) \\
&\text{if start(year)} > 365 \text{ and end(year-1)} < 365 \\
&\qquad\qquad \text{Snow Free Period} = 365
\end{aligned} \tag{2}$$

The value of the start or end of the snow period may be above 365 because their values are the number of days from January 1. Returning to the example above, if we are looking at data for 2002, the lowest value would be 213 (August 1, 2001) and the largest value would be 577 (July 31,2002).

Choosing the "Snow Calendar" snow free period as the more accurate calculation, we began by comparing our predicted model of active layer depth versus number of snow free days, to the data. Though there appears to be a positive correlation (Figure 3b), it is much weaker than what we predicted (Figure 3a). Our prediction is linear because it is thought that the duration of the snow free period should have a 1:1 relationship with active layer depth. In order to determine our accuracy, we used the R^2 value. It is a statistical measurement of how close the data are to the fitted regression line. The value determines the proportion of the variance in the dependent variable that is predictable by the independent variable. We assumed a linear least squared regression. With these facts in mind, we found that the R^2 value, in Figure 3b, was around 1.37%; far from ideal.



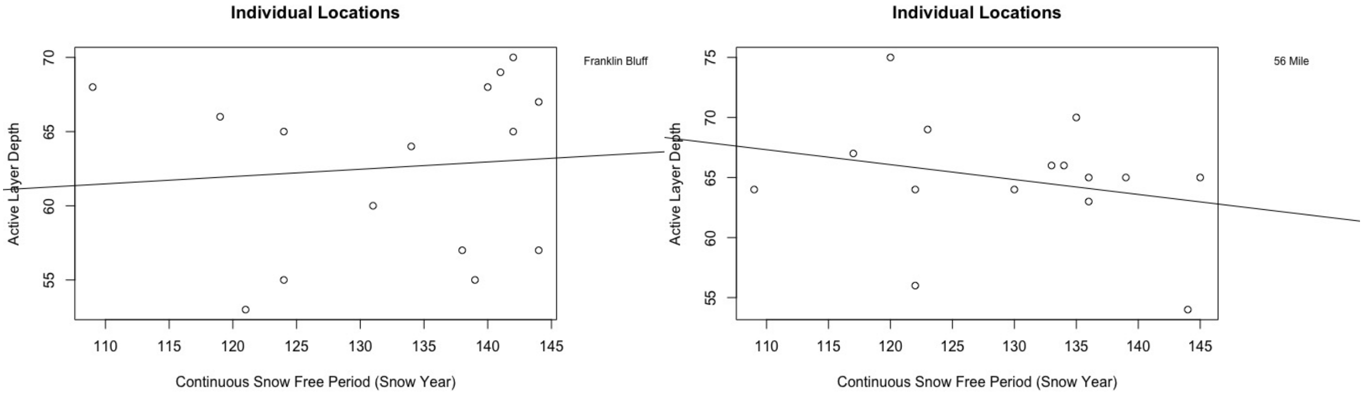
(a) Predicted

(b) Actual

Figure 3: Predicted and actual results.

Figure 3b was, also, a test to see if there was potentially a better fit in certain years. However, upon observing each year on separate plots, the R^2 value was not much better for any particular year. The values ranged from 0.9% to about 4%. Our prediction was largely exaggerated since a rate of 1 cm per every 10 days would be rather alarming. Though our prediction plot is not entirely realistic, Project Permafrost was expecting a larger correlation in the data than a percent. As it appeared in this plot, the data appeared almost random.

The following idea was to investigate whether there would be a better correlation between a different factor rather than years. We observed whether there was a correlation in active layer depth at each location.



(a) Positive correlation **(b)** Negative correlation

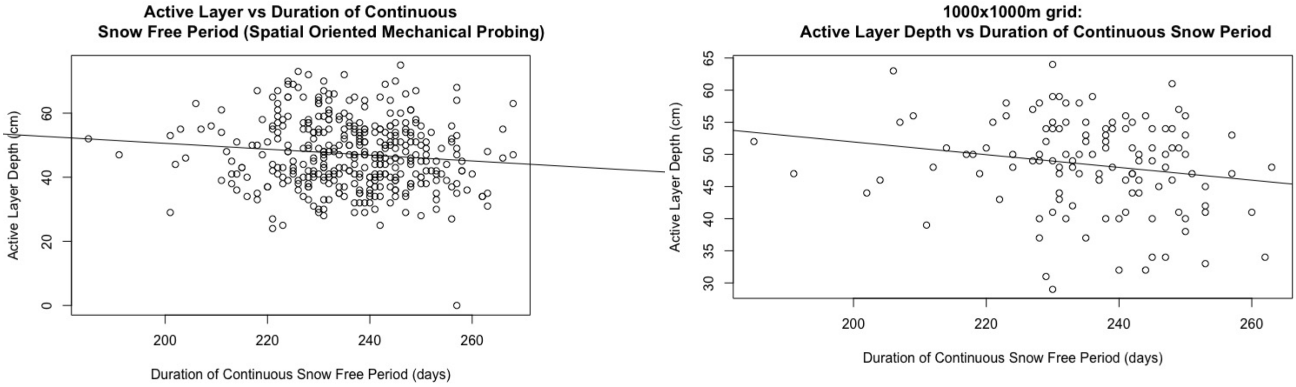
Figure 4: Individual location correlation.

There was not. In fact, the data appeared to be even more sporadic than when all of the points were viewed at once. Some of the locations, such as Franklin Bluff (Figure 4a), demonstrated a more positively fitted correlation, though weak. Whereas other locations, such as 56 Mile, were clearly negatively correlated (weakly).

Figure 5: Proximity of above locations: ≈ 1 mile.

The result may have made sense if the locations were not in relatively close proximity of one another. However, some locations, such as Franklin Bluff and 56 mile were around 1 mile apart (Figure 5). The coordinates were around (69.683, -148.717) and (69.697, -148.682) respectively.

Not every location had a complete record so each plot had a varying number of points. Some locations were not able to produce plots because of the missing data. Since the active layer data was collected using various methods (spatially oriented mechanical probing, thaw tubes, inferred from ground temperature), we hypothesized that the results might be better with one method.



(a) Spatial oriented mechanical probing method.

(b) 1000x1000m grid.

Figure 6: One method and grid size.

As can be seen in Figure 6a, observing data collected using one consistent method does not prove to be a better result. The R^2 for the data collected with the probe, is 0.9%. The spatial oriented mechanical probing method takes many sample points over a particular grid, so the data that we used was an average of those points. This could present an error, since some of the data was collected over various grid sizes. Figure 6b shows a a subset of the previous plot. It looks at a 1000x1000 m grid while still using the probing method. Looking at a constant grid size, there is a marginally better R^2 value, 3.88%. However, it is still a negative correlation and still poorly matches the regression line.

At this point, we had reduced our original dataset of 42 locations down to 8 locations (probe data). Perhaps there isn't actually a strong correlation between active layer depth and snow seasonality. Returning to a simple plot of active layer depth versus time (Figure 7), we were able to report a result, though not pertaining to snow seasonality.

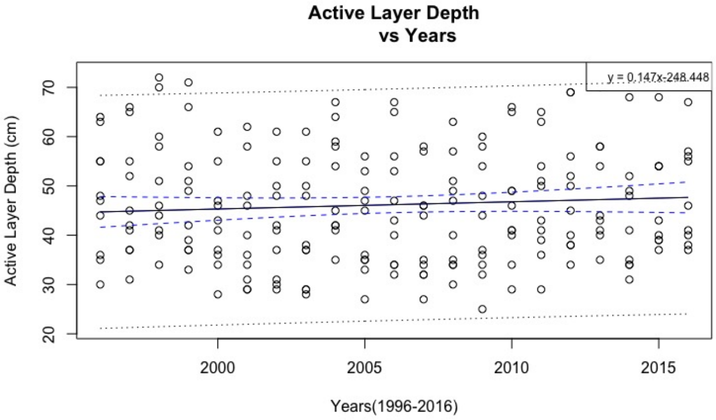


Figure 7: Ten locations with the most complete record.

Figure 7 took 10 locations at which the active layer data had the most complete record (no missing data over 20 years). Each year on the plot has all 10 active layer depths. There appears to be a weak positive regression line. The dotted blue curves show the confidence interval of the regression line, and the dotted black lines are the prediction interval. Since the regression line is in such a spot within the confidence interval, there could be a positive or a negative trend in the data depending on how the regression line is tilted in the interval.

CONCLUSION

Since the slope is slightly positive in the plot of active layer depth over time, it appears that the active layer is getting deeper over time. Specifically, it is deepening at a rate of about 1.47 cm per decade. However, it could also not be changing at all depending on how the regression line is positioned within the confidence interval. Perhaps a time span of 20 years is not enough time to investigate.

Some potential sources of error in this investigation could be due to factors in the active layer data as well as factors within the snow data. The active layer data is missing values in many locations and years. In particular, the depths that were inferred from ground temperature and the earlier years (before 2000) are lacking a majority of their data. It is unknown whether the data was taken at the same time each year. The documentation states that the points were collected at the end of the thaw period, however there is no documented date. Another potential error, was that the data was taken using different methods and over varying grid sizes. The data that was taken using the probe method took the average of all points collected within varying grid sizes whereas the remainder of the data was simply inferred from ground temperature.

The snow seasonality imagery data could be misinterpreting clouds as snow. The MODIS satellite uses moderate resolution imagery so it is unknown whether there is confusion between the two. It is also unknown whether the imagery was compared to ground based data. The ground based snow period could be longer than what the satellite detects depending on the resolution of the imagery. For example, the satellite may not detect snow at the end of the snow season when the snow is nearly completely melted due to its resolution. From the documentation, it is unknown whether there was filtering for view angle. As the satellite orbits the Earth, it views the same location at slightly different angles daily. If there is no filtering for view angle the pixel sizes in the images can vary by a factor of 4.

So, what is next? Project Permafrost hopes to investigate the discontinuous permafrost region as opposed to the continuous zone that was investigated in this paper. The discontinuous zone is said to be the one that is demonstrating the greater change, however, it will be more difficult to research since the region is no longer homogeneous and contains more vegetation.

REFERENCES

1. Circumpolar Active Layer Monitoring Network. 2016. "CALM Summary Table". Retrieved February 2017. (`https://www2.gwu.edu/~calm/data/north.html`)

2. Geographic Information Network of Alaska. 2016. "MODIS-derived Snow Metrics". Retrieved January 2017.(`http://www.gina.alaska.edu/projects/modis-derived-snow-metrics`)

3. National Geographic. 2007. "Permafrost". Retrieved April 2017. (`http://ngm.nationalgeographic.com/geopedia/Permafrost`)

4. Alexander, Cherry, and Symon, Carolyn, and Corell, Robert. 2004. "Impacts of a Warming Arctic".

5. Lawrence, David M. and Slater, Andrew G. 2005. "A projection of severe near-surface permafrost degradation during the 21st century". *Geophysical Research Letters*: 1-5.

6. Slater, Andrew G. and Lawrence, David M. 2013. "Diagnosing present and future permafrost from climate models". *Journal of Climate*: 5608-5623.