An Analysis of Glacier Retreat in Southcentral Alaska using Remote Sensing Techniques

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Introduction

Glaciers are large accumulations of ice, snow, and other materials that form on land. They exist in areas where the mean annual temperature is close to or below freezing, where there is significant snow accumulation, and where temperatures are not too warm to completely melt the year's snow accumulation (USGS, 2017).

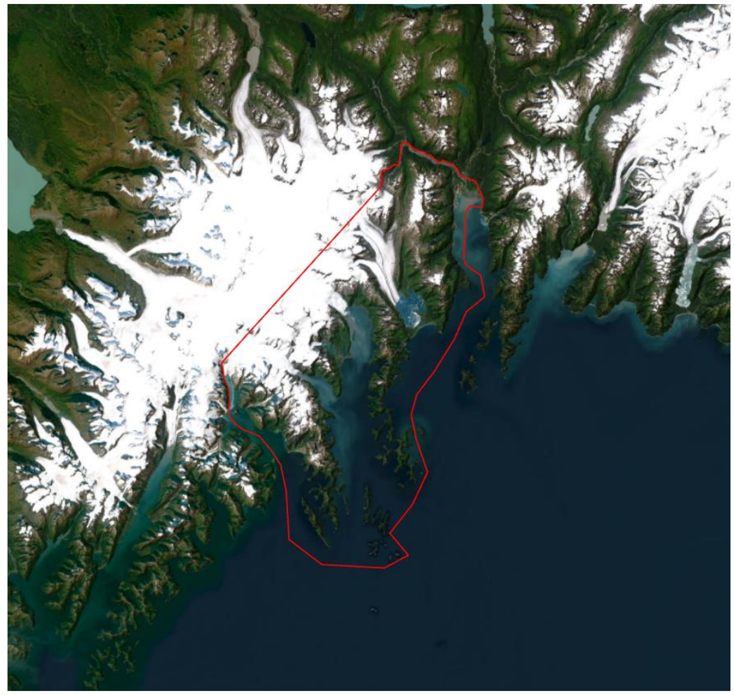
A typical place for glaciers to form are mountains. Mountain glaciers are well known to be heavily affected by our current global warming crisis. A study done by Sommer et al. (2020) found that glaciers in the European Alps have been on the decline due to global warming. This applies to glaciers all over the globe, where things like water resource management and tourism are critical to the area (Sommer et al., 2020).

In Alaska, United States, there is a national park by the name of Kenai Fjords National Park. It was established on December 2, 1980, and is the smallest national park in the state at 607,000 acres. The name "Kenai" comes from the region, which was named by the Athabaskan indigenous people who have historically lived in the area, and the name "Fjords" comes from an Old Norse word that means "long, glacier-carved inlet" (National Geographic, 2021).

A 2022 study done by Black and Kurtz found that of the 19 glaciers they studied, 13 have substantially retreated since 1984. This has led to massive landscape changes, with lake and ocean terminating glaciers retreating from the ocean and lakes, and land-terminating glaciers retreating into the alpine (Black & Kurtz, 2023). The goal of this study is to quantify that change in a smaller study area of the Kenai Fjords National Park.

Methods

Study Area

Kenai Fjords National Park is located in Southcentral Alaska along the coast of the Pacific Ocean. This study will take a smaller portion of the park (outlined in red in the image) including the Northwestern, Holgate, Pederson, Addison, Aialik, Skee, and Bear Glaciers and analyze them to quantify the changes in glacial area. The study area polygon seen in this map was created in ArcGIS Pro and the area was calculated to be 1570.794206 km^2. The most notable glacier is Bear Glacier, which is known to have retreated extensively (Black & Kurtz, 2023).

Data Acquisition

Year	**1972**	**1982**	**1992**	**2002**	**2012**	**2022**
Satellites	Landsat 1	Landsat 4	Landsat 5	Landsat 5 & 7	Landsat 7 & 8	Landsat 8
Range	1972-1973	1982-1983	1992	2001-2003	2012-2013	2020***

Landsat Data was acquired from USGS Earth Explorer in intervals specified in the above chart across 50 years, for 6 total samples. Similar to Sommer et al. (2022), images were taken from between August and September to avoid excess snow cover. Images were picked based on minimal cloud cover and clarity. For the 2022 sample, images from 2020 were used due to snowfall in 2021-2022 that had not melted fully and was distorting the collection. Calculations were adjusted accordingly.

Classification

Each image was converted to the WGS 1984 UTM 6 projection to avoid any distortion. The initial plan going into this study was to use a Red/SWIR (shortwave infrared) band ratio to extract the glaciers from their surroundings (Sommer et al., 2020). However, SWIR imagery was not available until Landsat 7 which was launched in 1999, so a red band grayscale image was used for the 1972-1992 images, which best replicated the Red/SWIR ratio with the data that was available. The Red/SWIR ratio is optimal for glacier extraction because snow and ice have a high reflectance of red light. Conversely, SWIR wavelengths can go through atmospheric aerosols and shadows of clouds for a clearer image. When not available, red band grayscale is the next option due to ice and snow’s high reflectance, as previously mentioned.

After the ratios or grayscales were created, the Unsupervised ISODATA Classification on the program ENVI was used to classify glaciers from their surroundings. Mosaics were created as needed to get the most accurate possible classification. With these classified and grayscale images ready, they were exported into ArcGIS Pro to calculate the area.

Calculations – Area

In ArcGIS Pro, both the classified and grayscale images were imported for clipping to the study area polygon. The grayscale images were only needed for the visual comparison model.

The classified images, however, were needed to calculate the area of glacier pixels. Each clipped image was vectorized into a polygon shapefile, then the area was calculated using ArcGIS Pro's "Calculate Geometry" function.

The area of each sample year was used to calculate the rate of retreat per year with the equation (Area2 – Area1)/10. The percentage of the study area for each sample year was calculated using the equation (Glacial Area / Total Area) * 100. The total area of the study area is 1570.794206 km^2.

After the calculations with area were completed, the clipped classification and grayscale rasters were exported to create gifs to help visualize the area change. The clipped classification rasters went back into ENVI to calculate the pixel numbers.

Calculations – Pixels

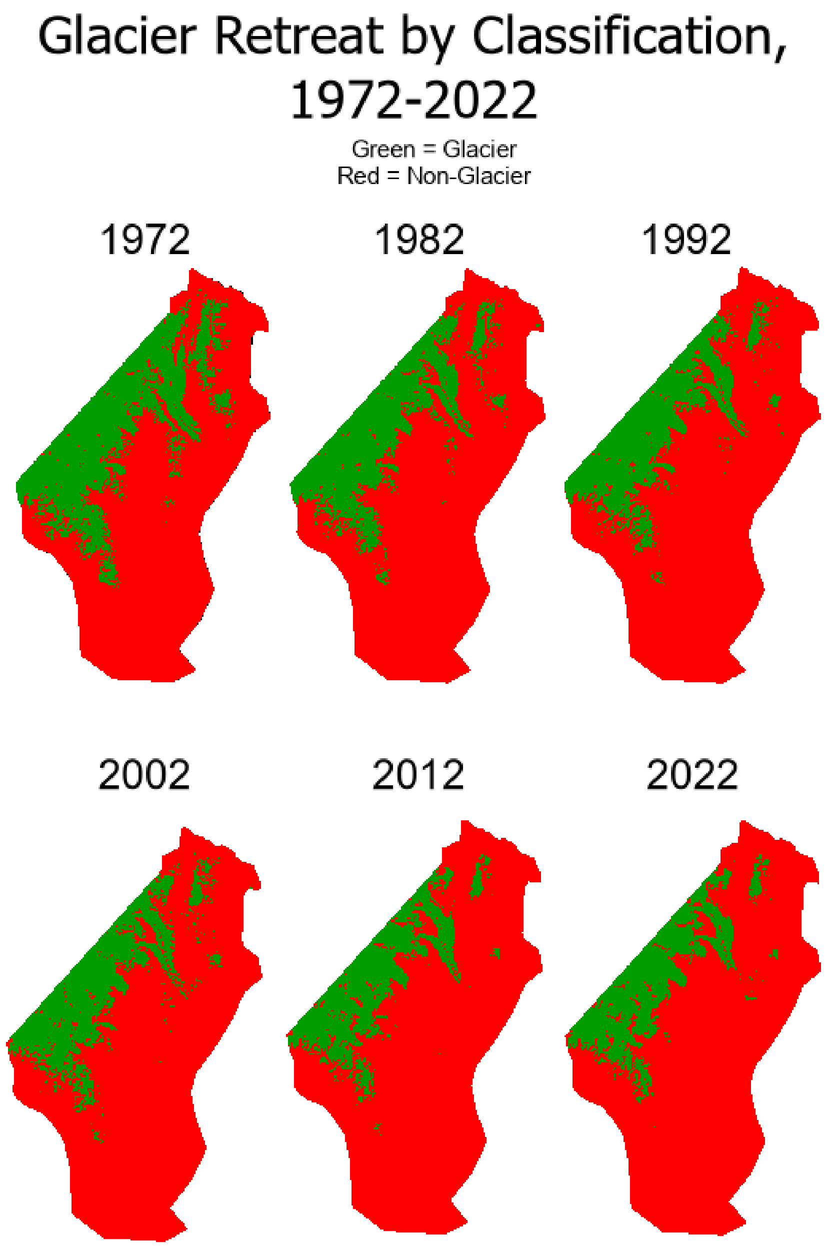
After the clipped classification rasters were put back into ENVI, they needed to be reclassified due to exporting them as a TIFF file. For a second time, Unsupervised ISODATA Classification was used to re-attain the previous classifications, but this time with just the study area and not the entire Landsat image. With this, the number of pixels of glacial area within the study area and the total pixel count of the study area could be acquired. Each sample had a different pixel count due to satellite differences. Once acquired, the pixel count was used in a similar fashion to the area calculation. The percentage of study area was calculated the same way, using the equation (Glacial Pixels / Total Pixels) * 100. Pixel depletion per year was not calculated due to the drastic differences in total pixel count between Landsat 5 and 7.

Other Calculations

After the area and pixel calculations were complete, the last calculations needed were the following: first, the average percent of study area; next, the average percent retreat per year, followed by the 50-year average of both aforementioned, and finally the standard deviation and error of the 50-year average. Those were calculated using Excel and were put into a chart along with all other data collected.

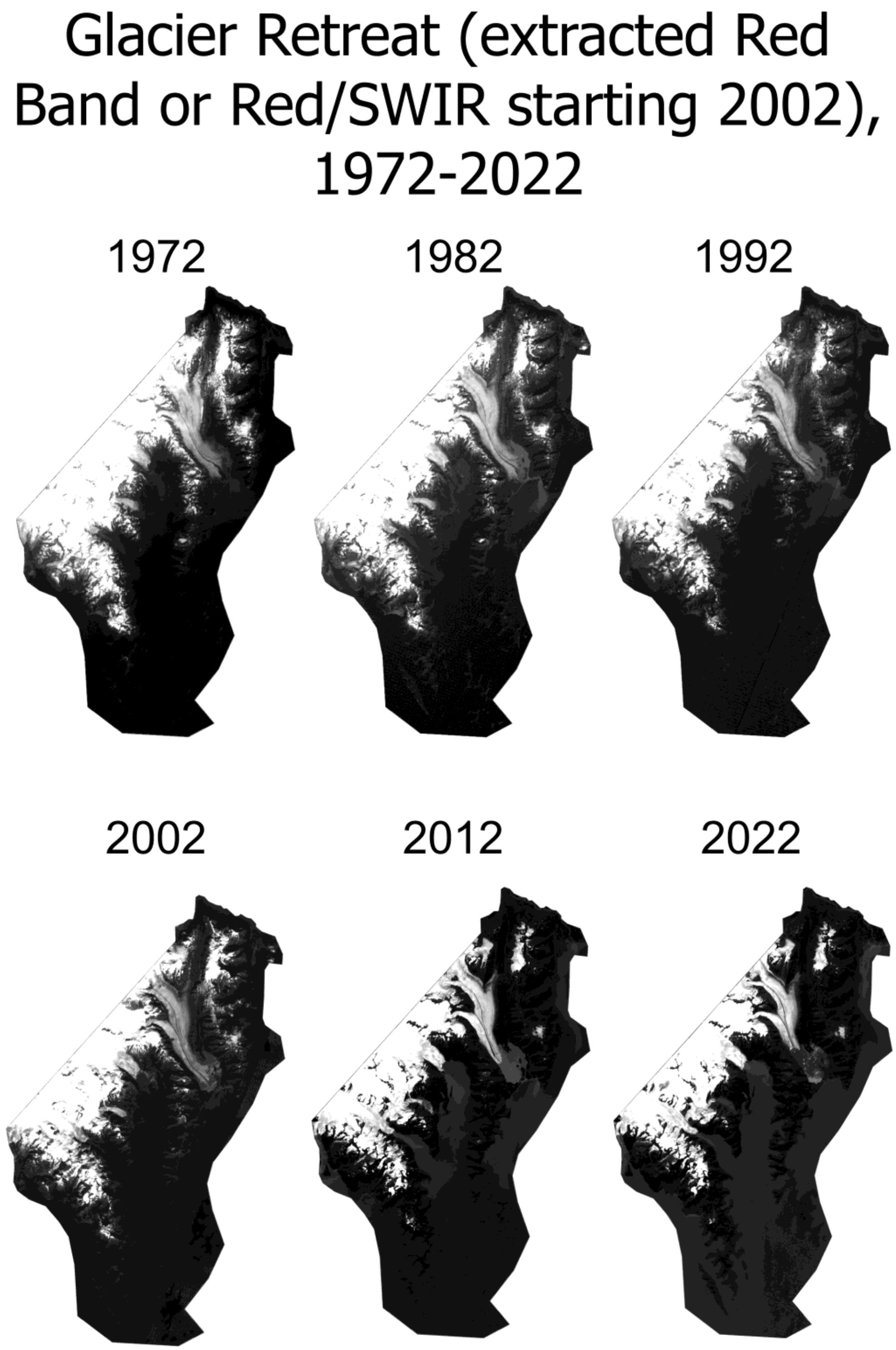
Results

Classifications



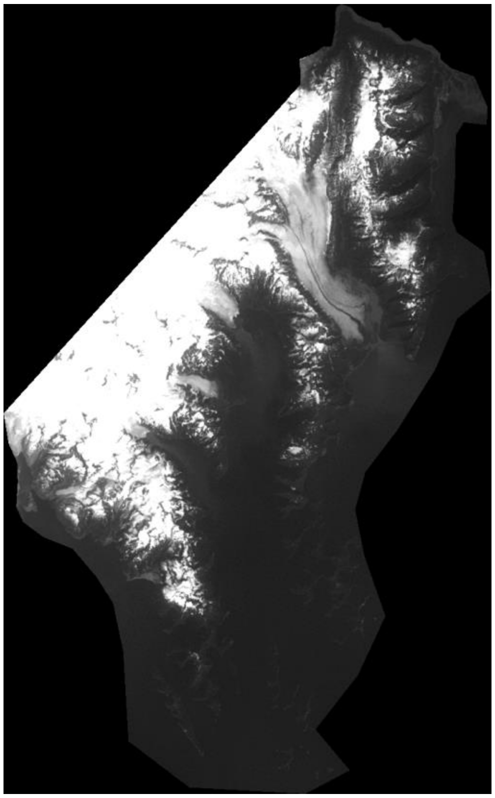
This layout contains the six Unsupervised ISODATA Classification clipped rasters.

Grayscale Images



This layout contains the six Red/SWIR ratio or Red Band grayscale clipped rasters.

Classification and Grayscale Gifs



These are gifs of both the classification and grayscale images, with each frame being one of the decadal images.

Chart

Year	Pixel Count	Total Pixels	Calculated Area (km^2)	Rate of Retreat (km^2/yr)	% of Study Area (by Pixel)	% of Study area (by area)	Average %	Average % Retreat per Year
1972	129159	437886	464.82629	N/A	29.50%	29.59%	29.54%	N/A
1982	105357	436237	378.80376	-8.60225	24.15%	24.12%	24.13%	-0.54%
1992	96132	436527	354.55412	-2.42496	22.02%	22.57%	22.30%	-0.18%
2002	364449	1746461	327.92476	-2.66294	20.87%	20.88%	20.87%	-0.14%
2012	323988	1745762	291.70945	-3.62153	18.56%	18.57%	18.56%	-0.23%
2022	315257	1750010	283.56898	-1.01756	18.01%	18.05%	18.03%	-0.07%
50 yr avg				-3.66585				-0.23%
STDEV				2.91244				0.16%
ST ERR				0.58249				0.03%

This chart contains the quantitative data collected from the classification.

Discussion

Average Retreat

Based on these findings, the most aggressive rate of retreat occurred between 1972 and 1982, at roughly 8.602 km^2 per year, while every other decade has between 1-4 km^2 of retreat per year. It is possible that there is some snow cover in the 1972 images that account for this drastic change, but it could be glacial material since it only disappears after 2002. Because it appears in multiple decades before disappearing, there is a possibility that it is glacial material, but there is no way to be certain.

This makes for an average of 3.625 ± 0.592 km^2 of retreat per year. However, the 50-year averages were slightly skewed by the 1972-1982 rate of retreat. The rate of retreat seems to remain at a similar rate excluding the 1972-1982 decade. The average percentage of glacial area in the study area decreased between 0.5-2% almost every decade, with an average of 0.23% ± 0.03% every year.

Bear Glacier

There is an obvious change in Bear Glacier, which is the largest lake-terminating glacier in both the study area and park. It is in the northern half of the image and is flowing into a lake. The most drastic change appears to have taken place between 2002 and 2012, although minimal changes are still visible in other years. It doesn’t appear that the 2002 classification picked up all the Bear Glacier pixels, so that may not have been quantified.

Other Visual Differences

It is apparent that the glaciers in this area have been steadily retreating. Both visually and numerically, there have been extreme changes in the landscape over the last 50 years. Other smaller lake and ocean-terminating glaciers have shrunk almost completely back to land. It’s also interesting to see the gradual increase in quality of the Landsat images through the years due to the progression of remote sensing technology. This is especially noticeable in the gif after the switch to Landsat 8 in 2012 and the use of Red/SWIR ratio instead of just the Red Band grayscale.

Conclusions

Based on this analysis, the glaciers in Kenai Fjords National Park are shrinking at an alarming rate. While there is not conclusive evidence from this study of its connection to global warming, it is important to remember that global warming is an established cause of glacier retreat (Sommer et al., 2020). Further research would be needed and has already been done by Black and Kurtz (2023). Their research is far more extensive than the research done here, as there was not enough time to do research that detailed.

Further research would also need to be done to determine the cause of the drastic change between 1972 and 1982. It could have been human error in this analysis, but it could also have been caused by excessive heat in that period or some other climate anomaly. This study has confirmed what we already know: the glaciers in Kenai Fjords National Park have been shrinking and will continue to shrink.

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