

A Historical Aerial Imagery Analysis of Glacier and Open Water Change for the Pedersen Glacier and Pedersen Lagoon Wildlife Sanctuary in Kenai Fjords National Park, Alaska

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Keywords: Pedersen Glacier, Pedersen Lagoon, Pedersen Lagoon Wildlife Sanctuary, Remote Sensing, Image Analysis, Glacier Reduction, Glacier, Glacial Lake, Climate Change, Kenai Fjords National Park

Abstract

This study used historical aerial imagery to study the change and reduction rate of the Pedersen Glacier in Kenai Fjords National Park, Alaska. Fourteen black and white aerial images, three color infrared aerial images, and two GeoEye satellite images were used in this study covering the time period from 1950 to 2005. Each image was used as reference to digitize glaciers, open water, and uncorrelated areas. Uncorrelated areas consisted of areas that were not open water or glacier areas, or areas that could not be determined with certainty. A trend analysis was performed to show past change and forecast future glacier reduction and open water expansion. Results showed a large decrease in the glacier from the 1950s to the 1980s and then an additional decrease during the remainder of the study. An average glacier reduction rate of 81,130 square meters per year occurred, with a total decrease of 4,462,150 square meters during the 55 years studied.

Introduction

Glaciers are a tremendously important cultural, recreational, economic, and ecological resource in the state of Alaska. As a first step towards better understanding glacial and shoreline change, scientists need to have accurate, detailed information about historic patterns of glacier and shoreline change.

The National Park Service of Alaska has been using aerial imagery since the 1950s to document change within Kenai Fjords National Park in Alaska. Pedersen Glacier specifically has been documented using land-based photographs by the United States Department of the

Interior and the United States Geological Survey (USGS) since the early 1900s. Historical photographs can be used to quantitatively and qualitatively determine similarities and differences in the state of the Pedersen Glacier and the Pedersen Lagoon Wildlife Sanctuary between time periods (USGS, 2010a).

Using aerial photography that spans fifty-five years, and with the more recent introduction and use of satellite imagery, it is possible to show the evolution of Pedersen Glacier. The research reported here was designed to provide such information for a study site centered on the Pedersen Glacier and Pedersen Lagoon Wildlife Sanctuary in

Kenai Fjords National Park.

The Value of Historical Imagery

There is a need to create digital scans of historical hard copy images; they provide a valuable resource and glimpse into an area's past. Historical photographs and film are among the most fragile record formats, and adverse storage conditions may hasten their deterioration. Placing them in close contact with materials that may cause chemical reactions, mishandling, and other abusive treatment can damage them beyond repair, causing catastrophic loss of valuable information.

Historical aerial photography is an essential component of condition assessments and provides a visual record of the condition of an area. "These photos are a valuable source of information regarding vegetation and landform conditions that can be assessed against current imagery in order to examine processes that are impacting the landscape" (Robertson, Knopf, Johnson, and Maffitt, 2014). Uses for historical imagery may include: "local and regional vegetation gain/loss studies; glacial advance and retreat; ice condition assessment; identification of landform change processes; [and] climate change studies" (Knopf, Johnson, Good, Maffitt, and Robertson, 2013).

Study Area

Pedersen Glacier and Pedersen Lagoon Wildlife Sanctuary formed in a natural valley within the Kenai Fjords National Park with mountain peaks and open water to the east. The study area (Figure 1) located within the Kenai Fjords National Park extends approximately 4.71 miles into the Kenai Fjords National Park from the coastline and includes 3.06 miles of coastline. The study area is within the

borders of Kenai Fjords National Park. The study area borders consist of the Kenai Mountains to the north and south and Aialik Bay to the east (Figure 2). The study area is subject to the daily tides, wave events, and storms that can impact the flow of glaciers and sediment deposits in the bay area.



Figure 1. Pedersen Glacier location in the state of Alaska.

Methodology

Data Collection and Orthorectification

Historical aerial photographs from three separate time periods were acquired from GeoSpatial Services; they were originally provided to GeoSpatial Services from the National Park Service. After researching the area, these were the only three time periods of historical imagery that were found to show the Pedersen Glacier study area. Only 1:12,000 scale or larger, vertical, and survey quality aerial photographs were used.

Of the 1950s time period of photographs, fourteen images were used; the imagery was procured from air photo

flying missions conducted by the U.S. Air Force in 1950, 1951, and 1952. The photo emulsion was black and white and the scale of the final hardcopy photo print products was 1:40,000.

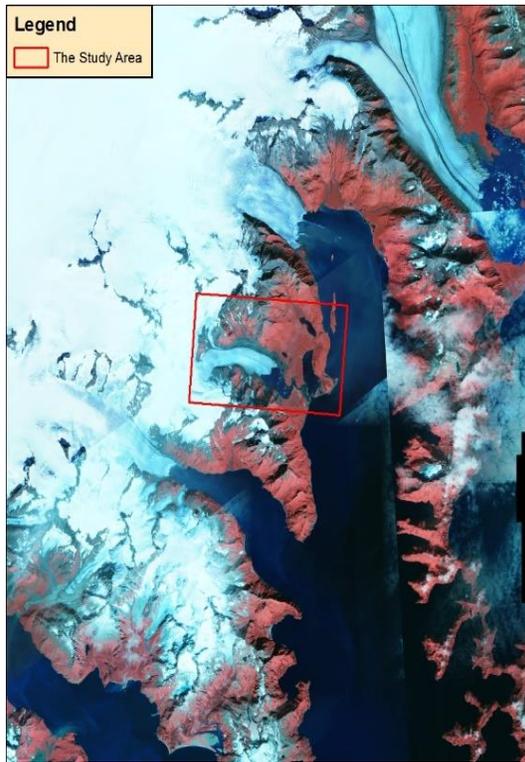


Figure 2. Pedersen Glacier location in Kenai Fjords National Park, Alaska.

Three images from the 1980s time period were used, and the imagery was procured from air photo flying missions conducted by the NASA Ames Research Center in 1984 and 1985. The photo emulsion was color infrared and the scale of the final hardcopy photo print products was +/- 1:62,000. The imagery was one meter resolution, pan-fused multispectral, 16 bit pixel depth. Scanned digital imagery at a resolution of 1200 dots per inch was provided by the National Park Service to GeoSpatial Services.

Scanned images of the photographs were corrected for distortion errors by GeoSpatial Services. GeoSpatial Services used a minimum of twelve ground control

points (GCP's) per image when orthorectifying each image. By using a minimum of twelve GCP's, GeoSpatial Services was able to ensure that the imagery had at least one GCP in each main area of the image (Figure 3). Rectification utilized the GCPs, the principle point of a photograph, and information about the camera. The process oriented each image so that true north was oriented up, assigned it a common map projection (Universal Transverse Mercator) and datum (World Geodetic System 1984), and rubber sheeted it to best fit the GCPs.

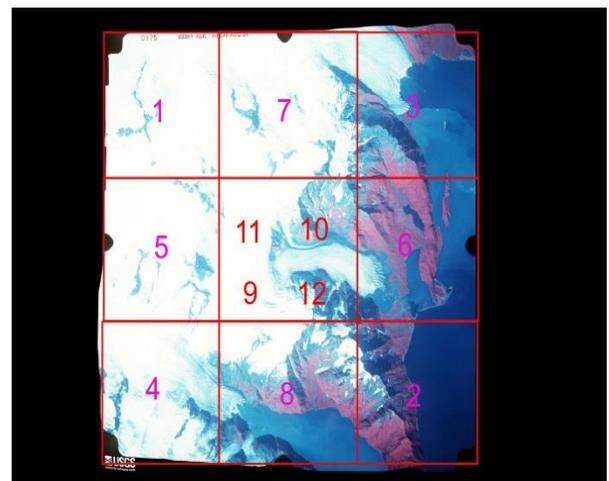


Figure 3. Locations of control points for georeferencing an image.

Two photos were used for the 2005 time period, one color-infrared (CIR) seamless image database (SID) image and one RGB (red, green, and blue) SID image. Both images were obtained from GeoEye. The original input imagery consisted of standard geometrically corrected IKONOS-2 one meter ground sample distance, 11-bit, dynamic range adjusted, pan-sharpened natural color orthorectified images. Three of the four source imagery bands (Green, Red, and Near-infrared) were merged to create a CIR orthorectified mosaic of Kenai Fjords National Park, Alaska.

Creation of Image Mosaics

ArcGIS 10.2 was the primary software used for this study; it was used for the creation of the geodatabases, mosaic datasets, and feature classes. Prior to loading the images into the ArcGIS 10.2 mosaic dataset, no statistical or color manipulation was performed on the images. Following orthorectification by GeoSpatial Services, the aerial images from 1950, 1951, 1952, 1984, and 1985 were placed in separate mosaic datasets in a common file geodatabase. This geodatabase was created to store the imagery data for the study. Polygon feature classes for each year were created within the geodatabase. Three attribute fields were created in each polygon feature class: Attribute (string type), Area (long integer), and Year (short integer). To ensure accuracy, all data was projected to the same coordinate system (Albers Conical Equal Area) (Esri, 2014b).

The satellite imagery from 2005 was not placed into a mosaic dataset, since the images already had adequate coverage of the study area, and was excluded from the mosaic and color balancing process. The CIR and RGB 2005 satellite images, having a coordinate system already applied when the images were taken, only had to be projected into the same coordinate system as the rest of the imagery.

Scanned historical images and previously orthorectified images were imported into Esri's ArcGIS 10.2 software. Within the existing geodatabase, a mosaic dataset was made for each of the corresponding decades (1950s and 1980s), and the matching imagery was added to each decade's mosaic dataset (Figure 4). Historical images were chosen for the mosaic dataset that were able to overlap each other to add coverage to an area that

needed better image quality, more coverage, or enhancement. This was done to ensure the main images of the study group had the coverage needed to make a seamless mosaic image. If an image had skewing after being orthorectified, holes, or flaws within the original image, it was blended out of the image by using other images to cover the problem areas. The 1950s dataset had fourteen images, the most historical images used for a single time period, due to the smaller area covered by each image and to ensure that the mosaic had little or no skewing within the mosaic image. When building a mosaic image, the middle of a rectified image has better position accuracy than the edges, so the center of each image was desired to be used when joining rectified images together.

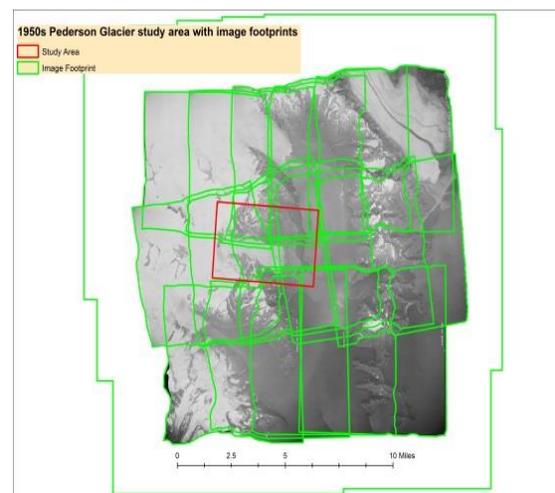


Figure 4. 1950s black and white mosaic dataset showing the study area (red) with the overlaying footprint outlines (green).

When creating a mosaic image, modifications to the default settings in the mosaic dataset process were required to get a seamless, color matched mosaic. These modifications affected how the mosaic image would be presented; they can also impact the performance of the server (Esri, 2014c).

The footprints of the images used in both the 1950s (Figure 4) and 1980s (Figure 5) mosaic datasets were sampled for unwanted anomalies in the image edges. These unwanted anomalies included fiducials, time and date stamps, and any handwritten notes in the margins of the image. Once a minimum distance was established that captured these anomalies from the image edge, the shrink distance parameter value for each mosaic was determined. For both the 1950s and 1980s time periods, a 400 meter shrink distance was applied to each footprint. This setting ensured that the final mosaic would be clean from outside intrusions and would use the center of each image more predominately (Table 1).

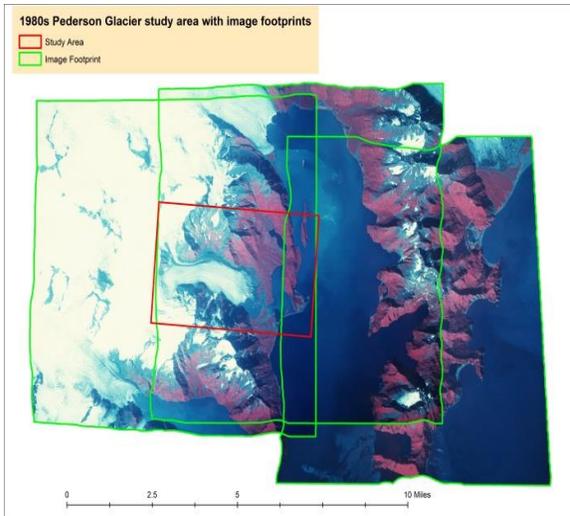


Figure 5. 1980s CIR mosaic dataset showing the study area with the overlapping footprint outlines.

To ensure that all the colors of the images were represented, the minimum data value was set to 1 and the maximum data value was set to 255. The number of vertices was set to 400. Several tests were done to find the appropriate number of vertices to use to get the clearest and seamless mosaic image. The lowest number of vertices tested was 25 and the highest was 600. The higher the number of vertices, the longer it took for the mosaic

image to render. Four hundred vertices created a very smooth image with little to no visible seam lines within the mosaic (Esri, 2014f).

Table 1. Settings used for shrinking a footprint in Esri’s ArcCatalog.

Build Footprints	
Query Definition	Blank
Computer Method	Radiometry
Minimum Data Value	1
Maximum Data Value	255
Approximate number of Vertices	400
Shrink Distance	400 Meters
Do not check	Maintain Sheet Edges
Check	Skip Overviews
Check	Skip Overviews
Simplification Method	None

Building pyramids and statistics in the mosaic dataset was required for color balancing to work (Esri, 2014d). When running the Build Pyramids and Statistics tool, it was necessary to select the following options: Include Sub-Directories, Build Pyramids, and Calculate Statistics (Table 2).

Table 2. Building Pyramids and Statistics in ArcCatalog.

Build Pyramids And Statistics	
Input Data or Workspace	The path to the mosaic dataset
Input Data	Include Sub-Directories
Check	Build Pyramids
Check	Calculate Statistics
Check	Skip Existing

Multiple trials were made when color balancing the mosaic image (Figure 6) (Esri, 2014d). Color balancing can be complicated with the variations in images. Images have differences in color due to differences in atmospheric conditions,

cameras, and the timing of acquisition. The processing of the original hard copy photos also affects the coloring of an image. A trial and error process was used, drawing on previous work experience, Esri ArcGIS help files, and educated reasoning acquired while researching and applying multiple mosaicking techniques in order to choose the right method to apply on each of the mosaic datasets for the study group (Esri, 2014a).

There are three color balancing methods available when using Esri software: Dodging, Histogram, and Standard Deviation. Using these three methods, multiple test mosaic datasets and mosaics were generated before choosing a suitable mosaic for use in this study. Standard deviation works when the same values or colors are distributed throughout the image. Histogram works well when there is a similar shape to all the rasters. For the 1950s and 1980s time periods Dodging color balance method was used in which “each of the pixel’s values change toward the target color” (Esri, 2014e). Options for the color surface type were available when using the Dodging color balancing method (Esri, 2014e). The target color surface type that was chosen for both of the mosaics datasets was “single color.” With this setting, all the pixels are dodged toward a single color point, which is the mean. A single color surface works well when there are only a small number of rasters and there are only a few different types of ground objects. “If there are too many rasters or there are too many types of ground surfaces, then the output color may become blurred”(Esri, 2014e). “Dodging balancing tends to give the best result in most cases” (Esri, 2014e). The Dodging color balancing method could be applied to both the CIRs and the black and white historical imagery.

Spatial Analysis

Polygons in each feature class were initially onscreen digitized at a scale of 1:1500 for all feature types: open water, glacier, and uncorrelated. The ‘Year’ attribute field was populated according to the time period the images were taken: the 1950s, 1980s, or 2005. The Attribute field values consisted of glacier, open water, or uncorrelated (Figure 7; Yavaslı and Olgen, 2008). Then, the feature classes had their lines cleaned and checked for consistency, spikes, ghost polygons and miscellaneous anomalies at a scale of 1:500 for all of the attribute classifications (Figure 6).

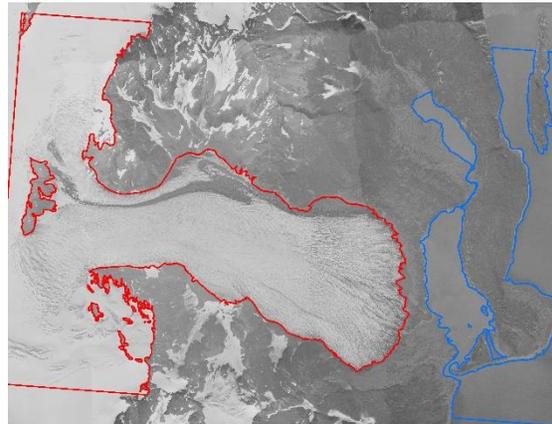


Figure 6. Pedersen Glacier in the 1950s black and white image. The Pedersen glacier is outlined in red and open water is outlined in blue.

Multiple conditions were used when deciding where the glacier ended. One condition was that the glacier was visibly ending at open water. A moraine or stagnation on the sides of the glacier, trimlines or striations in the glacier, and proximity to a rock wall were also utilized when deciding the termination area of the glacier (Figure 7).

Open water consisted of pit ponds and other areas where free-flowing or open water was visible and not covered by free-floating ice. Uncorrelated areas consisted of any area that was not glacier

or open water. Various land cover types were classified as uncorrelated, including vegetation-free bedrock around the margin of a retreating glacier showing the recent loss of ice and outwash plains. Within the uncorrelated areas vegetation may be visible. Free flowing channels of water and outwash plains were included in the uncorrelated area due to the visible inconsistency of the area (Figure 8). A visible inconsistency included any formations that could not be determined to be uncorrelated or open water areas due to the time the imagery was taken. A defined process could not be established to separate the water and sediment build up; therefore, all of the outwash areas were included in the uncorrelated area. Tidal areas were also included in the uncorrelated area since the metadata did not include a timestamp of when the image was taken. Without a timestamp, high or low tide was indeterminable.

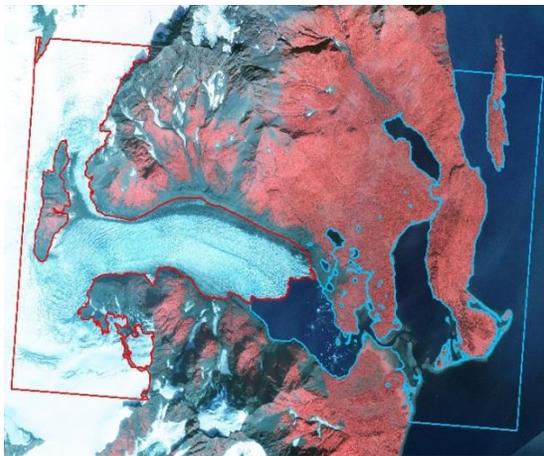


Figure 7. A CIR image of Pedersen Glacier with the red boundary depicting the size and shape of the glacier and blue depicting open water in 2005.

If it would have been possible to determine whether the images were taken at high or low tide, this information would have helped in making an informed decision about shoreline areas that were of questionable determination. It could adjust

the edge of the open water polygon as little as one meter in some locations or as much as 137 meters in other areas. This would have decreased the uncorrelated area size significantly (Figure 8).



Figure 8. Examples of uncorrelated areas in the 1980s photos that may have been classified as open water if the timing of the photos relative to low and high tide was known.

The Area attribute field consisted of the size of the feature in square meters. The area was determined using the Calculate Geometry function in ArcMap using the coordinate system of the data source, Albers Conical Equal Area, and the units of square meters.

Trend Analysis

Once the fields were populated, a quality assurance / quality control (QA/QC) examination of all the feature classes checked for variances. The purpose of the QA/QC was to identify any variations in the feature classes, spikes in the line delineations, any areas that may be overlapping, or any polygons that may be ghost polygons or have a null value. After the QA/QC was performed and any variances were corrected, the data was exported into a Microsoft Excel Pivot Table to perform a trend analysis on the data.

Results

A comparison of all three time periods is depicted in Figure 9 and Figure 10. The starting point for the trend analysis was the 1950s information: glacier (13,439,472 square meters (m²)), open-water (5,281,920 m²), and uncorrelated fields (18,631,722 m²) (Table 3).

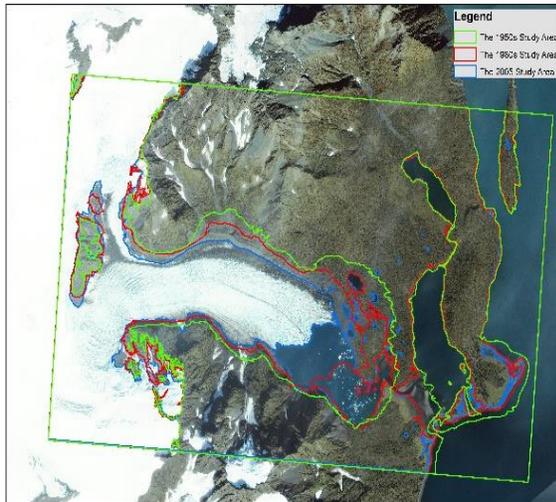


Figure 9. Pedersen Glacier RGB image from 2005 with a comparison of all three study time periods (blue representing 2005, red representing the 1980s, and green representing the 1950s).

The data obtained from the trend analysis shows that the Pedersen Glacier decreased in size from 13,439,472 m² in 1950s to 10,975,978 m² in the 1980s to 8,977,322 m² in 2005. There was a 4,462,150 m² decrease in size from the 1950s to 2005, an average reduction of 81,130 m² per year over the 55 years (Table 4).

Table 3. Summary totals of the areas for glacier, open water, and uncorrelated (m²).

Sum of AREA	Column Labels		
Row Labels	GLACIER	OPEN WATER	UNCORRELATED
1950	13,439,472	5,281,920	18,631,722
1980	10,975,978	6,807,947	19,589,095
2005	8,977,322	7,574,140	20,723,820

Table 4. Summary of the total change in glacier, open water, and uncorrelated areas within the study area (m²).

Change	Glacier Decrease	Open Water Increase	Uncorrelated Increase
1950 to 2005	4,462,150	2,292,220	2,092,098
Yearly Change	81,130.00	41,676.73	38,038.15

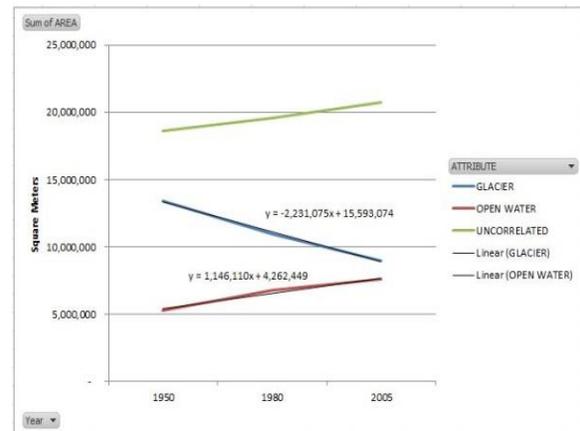


Figure 60. Graph of the trend line analysis. The blue line represents the glacier change, the red line represents the open water areas, and the green line represents the uncorrelated areas. There are two black lines that appear on top of the glacier and open water lines. The black lines are the linear trend lines.

The open water area increased from 5,281,920 m² in the 1950s to 6,807,947 m² in the 1980s to 7,574,140 m² in 2005. There was a 2,292,220 square meter increase in size from the 1950s to 2005, growing an average of 41,677 m² per year over the 55 year period (Table 4).

The uncorrelated areas also increased over the years, increasing from 18,631,722 m² in the 1950s to 19,589,095 m² in the 1980s to 20,723,820 m² in 2005. There was a 2,092,098 m² increase in size from the 1950s to 2005, growing 38,038.15 m² per year over the 55 years (Table 4) (Figure 10).

Conclusions

If the Pedersen Glacier Park glacial reduction trend continues within the

designated study area at the rate this study shows (81,130 m² per year), the Pedersen Glacier will be completely gone within the next 111 years.

Acknowledgements

I would like to thank Jeff and Kris Knopf for mentoring me while I interned at GeoSpatial Services for a great learning and life experience. I would like to thank Dr. David McConville, John Ebert, Greta Poser, my friends, and Saint Mary's University of Minnesota classmates for their support throughout my studies.

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