**Lab Report**

Title: Estimating Glacial Melt in Iceland & Alaska
Notice: Dr. Bryan Runck
Author: Taylor Andersen-Beaver
Date: 12/21/2022

**Project Repository: https://github.com/and03449/GIS5571_FinalProject.git**
**Google Drive Link:**
**https://drive.google.com/drive/u/0/folders/119hLFEzfokOZSYcxa4gYqNPnugd9e0Ec**
**Time Spent: 52 hours**


## Abstract

Glaciers are large ice formations that have developed over time in areas that are generally at or near freezing temperature year round (*What Is a Glacier? | U.S. Geological Survey*, n.d.). The ebb and flow of a glacier begins with the annual snow accumulation that gets impacted over time and turns to ice which adds to the volume of the glacier but is balanced with the amount of snow and ice that melts each year in the warmer months (US EPA, 2016b). The melted snow and ice create a slow-moving, river-like path from the tip of the glacier typically into a lake or ocean which is what is called the 'tongue' of the glacier (Brandon et al., 2017). This balance of impacted and melting snow has been changing over the last century with the climate: "glaciers are sensitive indicators of changing climate" (*What Is a Glacier? | U.S. Geological Survey*, n.d.). Major changes in glacial melt were observed in the 1950s when glaciers were melting more than in the past and although it was first observed in the 1950s it was likely occurring decades before as well (US EPA, 2016b).

Two glaciers that have been studied and observed since these changes were first noticed are Vatnajökull in SE Iceland and Gulkana in Alaska, USA. Vatnajökull, because of its seven active volcanoes with overlying subglaciers all beneath the ice cap, which if too much of the ice cap melts it could cause significant sea-level rise as well as serious flooding of the region (Hugonnet et al., 2021). One of the volcanoes beneath Vatnajökull Glacier erupted in 1996 and the amount of glacial melt as well as flooded subglaciers created a river which was briefly the second largest river in the world and caused approximately 14M USD of damage from the flood (Kristmannsdóttir et al., 1999). The second glacier in this study is Gulkana Glacier in Alaska, USA. I chose this glacier because it is one of only two glaciers that have been studied in Alaska since 1950 as it was one of the first observed receding glaciers (Le Bris & Paul, 2015). For this study I am focusing on the visual recession of ice over a six-year time frame using data from Planet and estimating the areal change of the two glaciers over this six-year time frame using two different methods.


## Problem Statement

Glacier melt accounts for 21% of the annual sea-level rise with an increase of 6-19% each decade (Hugonnet et al., 2021). The observed sea-level rise is approximately 0.12 - 0.14 inches per year, which may not seem like an incredibly significant amount however it amounts to approximately 6 inches since 1950 with it rapidly increasing each year (US EPA, 2016a). Glacial melt is observed in two different ways: surface area of the glacier and volume of ice in the glacier. Using satellite imagery from Planet Explorer I will compare surface area over time using two different methods of two known-receding glaciers - Vatnajökullin SE Iceland and Gulkana in Alaska, USA - using Planet imagery.

*Table 1. Requirements Needed for Estimating Glacial Melt In Iceland & Alaska*

| # | Requirement | Defined As | (Spatial) Data | Attribute Data | Dataset | Preparation |
|---|---|---|---|---|---|---|
| 1 | Area of Interest (AOI) | Because raster data is large an AOI will need to be identified to optimize the amount of data storage | Coordinates of AOI | N/A | Link to GeoJSON-Iceland, Link to GeoJSON - Alaska | Determine an AOI based on glacial research |
| 2 | Data Acquisition | Raster data of the glacier to analyze ice melt over time | 4 or 8 band rasters | N/A | Link to Planet Explorer | Search Planet Explorer for the best images |
| 3 | Build ETL | Use the Planet API to extract the Planet data | 4 or 8 band rasters | N/A | Link to Planet API Documentation | Research how to use Planet API |
| 4 | Combine Planet Scenes | Each extraction contains multiple clips that needs to be combined to a single image | 4 or 8 band rasters | N/A | Planet Imagery | Research combinations techniques for optimal results |
| 5 | Reclassify Combined Rasters | Reclassify the new combined rasters to have a consistent classification and visualization between rasters | Combined Rasters | Cell Values & Statistics | Planet Imagery | Determine the number of classifications needed for analysis |
| 6 | Calculate Change | Using pixel count of ‘ice’ pixels and ‘not ice’ pixels to calculate change over time | Combined Rasters | Cell Values & Statistics | Planet Imagery | Research compute change techniques |
| 7 | Create Visualization | Create a graphic or chart to show change over time of each of the glaciers | Combined Rasters | Cell Values & Statistics | Planet Imagery | Determine which visualization would represent the results the best |

**Input Data**
The data used for this study is a set of raster images from Planet Explorer. Because these are medium-resolution images (3-7 m) of relatively large geographic areas, I have chosen to scale down the scope of the images based on research done about these two specific glaciers: Breiðamerkurjökull in Iceland and Gulkana in Alaska.

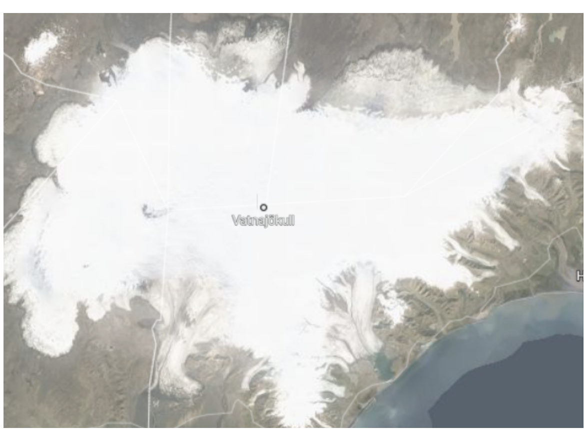
I have chosen Breiðamerkurjökull Glacier, highlighted in Figure 1, because it is the part of Vatnajökull Glacier that melts directly into the Glacier Lagoon. The Glacier Lagoon, or Jökulsárlón, is actually a product of climate change as the lagoon did not exist prior to 1935 and only developed from the excessive glacial melt (Brandon et al., 2017). Since the development of Glacier Lagoon it has quadrupled in size and is approximately 11 km² and growing (Brandon et al., 2017).

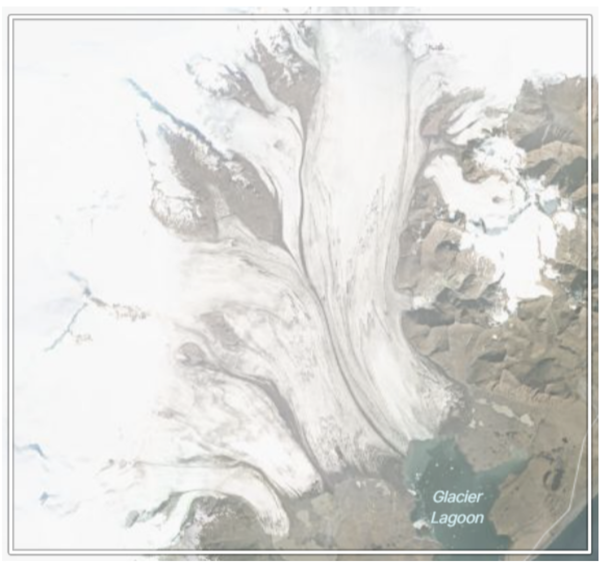
Gulkana Glacier, also in Figure 1, is one of thousands of glaciers in the Alaska Range (Park et al., n.d.). I have chosen Gulkana Glacier for this study because it is one of only two glaciers that have been observed and tracked since the 1950s when rapid glacial melt was first identified in Alaska (US EPA, 2016b). Since 1966 the USGS has been tracking “glaciological data…combined with weather and geodetic data to estimate the seasonal and annual mass balance” of these glaciers (Mcneil et al., 2016).

*Table 2. Datasets Needed for Tracking Glacial Melt in Iceland & Alaska*

| # | Title | Purpose in Analysis | Link to Source |
|---|---|---|---|
| 1 | Planet Imagery - Iceland | Multiple raster datasets from Planet Explorer to track glacial melt over time of Breiðamerkurjökull Glacier | Planet Explorer |
| 2 | Planet Imagery - Alaska | Multiple raster datasets from Planet Explorer to track glacial melt over time of Gulkana Glacier | Planet Explorer |

*Figure 1. Visualization of Geographical Scope and Area of Interest*

| *Vatnajökull Glacier, Iceland, 14,076 km²* | *Alaska Range*, USA, 223,498 km²* |
|---|---|
|   |  |

| *Setting the Area of Interest* | *Setting the Area of Interest* |
|---|---|
|  |  |
| *Breiðamerkurjökull Glacier, Iceland, 736 km²* | *Gulkana Glacier, Alaska, 15 km²* |
|  |  |
| **The image above does not show the full Alaska Range* | (*Planet Explorer*, n.d.) |

**Methods**

The first step in the analysis will be to extract the Planet images from the Planet API. Planet has fantastic documentation on how to search, filter, and extract images from their API (*Planet Data API Reference*, n.d.). To begin the extraction process, as seen in Figure 2, it is first important to access the API key, which is unique to each user, authenticate access to the API, and set the base URLs needed for searching and placing the order to the API. Once those elements have been set then the filters can be placed to search through the Planet images.

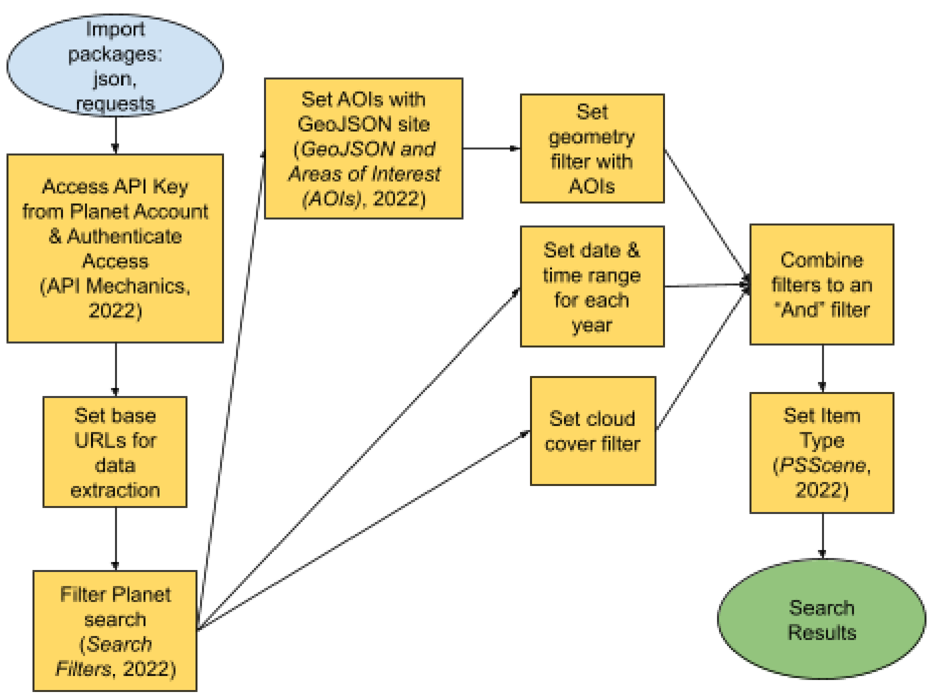
As stated above, Planet has great documentation on each element of the API process and there are multiple criteria that can be searched; for this study I am filtering for a set area of interest, as established above, a set date range, and a set percentage of cloud coverage I am willing to allow

(*Search Filters*, 2022). I located the bounding box coordinates for each of the glaciers and used them to set the geometries respectively as directed by the Planet documentation (*GeoJSON and Areas of Interest (AOIs)*, 2022; Mapbox, n.d.). Next I set the date range I am interested in for the study which is August 1 - September 15 for Iceland and July 20 - August 31 for Alaska both starting at 12:00 AM and ending at 11:59 PM. I chose these date ranges because of a visual scan of the images in Planet Explorer that showed those were the times of year where most of the snow had melted from the glacier exposing the ice and areas where there was no ice. Another filter I used is the cloud coverage filter for obvious reasons: with too much cloud coverage of the image, very little analysis can be done. I set the cloud filter to only allow 15% cloud coverage of the image. The only filter I am missing that is available on Planet Explorer but not available in code is the area coverage; area coverage is the amount of area within the area of interest that is covered by scenes. Typically I would set a filter for 85% coverage for this filter when using the Planet Explorer GUI however since this is not an option using code I am unable to filter for this element.

The last element to establish in the search is the item type; the item type is the specific class of satellites used for the images which in this case are PlanetScope Scenes (PSScenes). "PlanetScope images are from three different sensors: PS2, PS2.SD, PSB.SB" (*PSScene*, 2022). For this study the images are from all three sensors depending on the year the image is captured; 2017 - 2018 images are PS2, 2019 is PS2.SD, and 2020 - 2022 is PSB.SD. The reason the images are all captured using different scenes is because as new sensors are released, the API will automatically use the most current sensor; it is possible to request a certain sensor although depending on when the images were captured, the sensors may be discontinued or not yet available. The only difference between the sensors, other than the updated technology, are the bands. "Sensors PS2 and PS2.SD deliver four bands: red, green, blue, and near-infrared" while PSB.SD "has an additional four bands: green I, yellow, coastal blue, and red edge" (*PSScene*, 2022).

Using the combination "And" filter, there are about 5 - 8 viable images that meet all of the criteria listed above. To consolidate data storage space I decided to visually select one image per year to use for this study which are pictured below in Figure 4 for Iceland and Alaska, respectively.

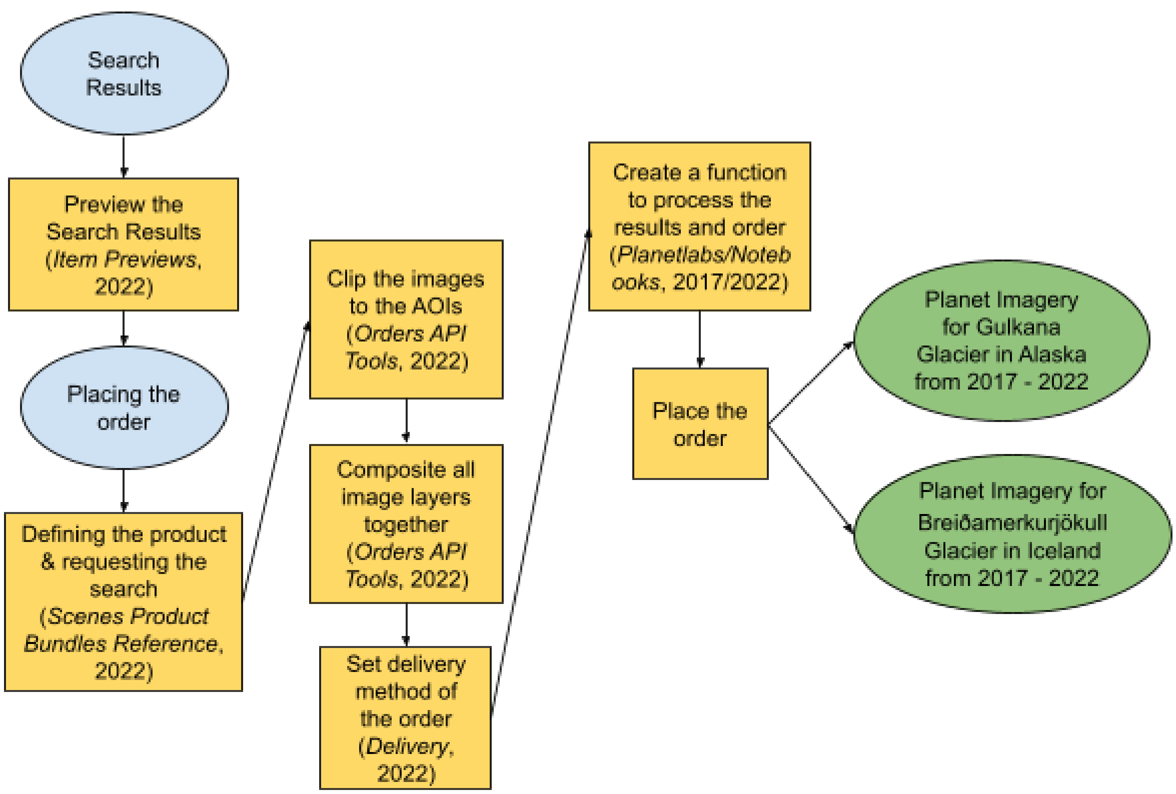
*Figure 2. Searching the Planet API*



Once the search criteria are set the results can be previewed to select the best images for analysis before the final steps to place the orders (*Item Previews*, 2022). The selected images will also need to be assigned a product bundle to determine the orders that will be delivered. “Product bundles comprise of a group of assets for an item” - an item is a single image or a ‘scene’ and the assets are derived from the data source (*Scenes Product Bundles Reference*, 2022). For the selected images used in this study I have chosen to use ‘analytic_udm2’ as my product bundle as it is a consistent bundle used for PlanetScope Scenes capturing 4 band images as well as UDM2 (*Scenes Product Bundles Reference*, 2022). UDM2 or Usable Data Masks is the assigned mask given to each cell individually based on a supervised machine learning technique to generalize all Planet visualizations globally (*UDM 2*, 2022).

While defining the product with the product bundle, certain tools can also be used to edit the images before ordering them. The tools I have chosen to use for the images in the study are to clip the images to the areas of interest as selected above and to composite all of the scenes together into one single image (*Orders API Tools*, 2022). I chose to composite the images because when first learning how to manipulate Planet images in ArcGIS Pro, I attempted to combine scenes using multiple different tools with no success so was pleased to find the ‘composite’ option right from the Planet API. The delivery method is set to deliver the images directly to my Planet account where they will be stored and downloadable (*Delivery*, 2022). I did attempt to deliver the images to a Google Cloud Service to avoid storing them directly on my machine but was unsuccessful and eventually decided to use the generic Planet delivery (*Delivery*, 2022).

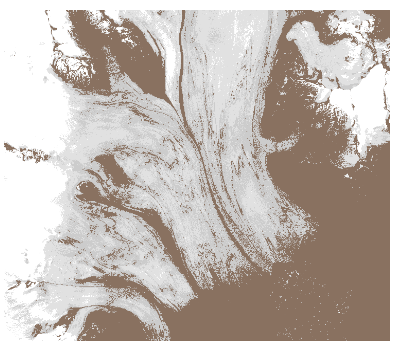
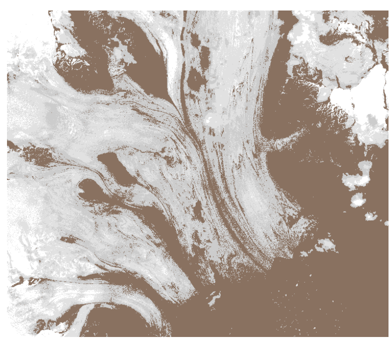
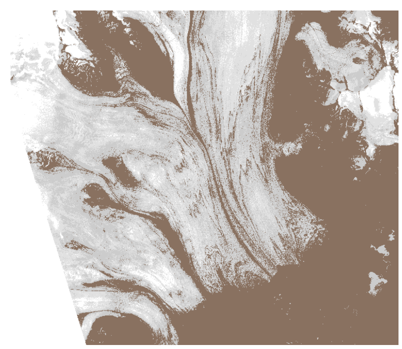
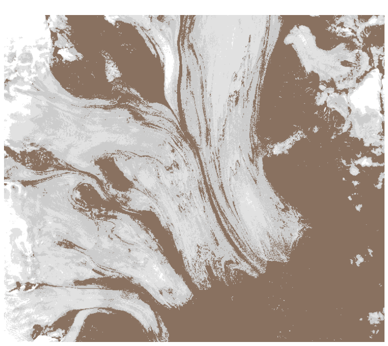
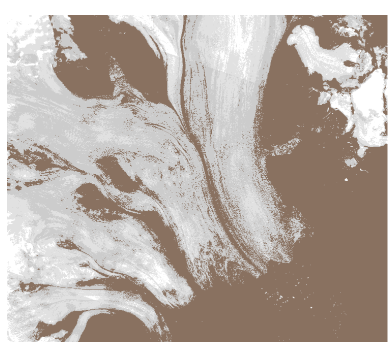
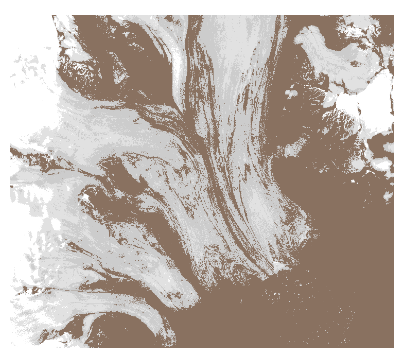
*Figure 3: Extracting the Filtered Planet Images*

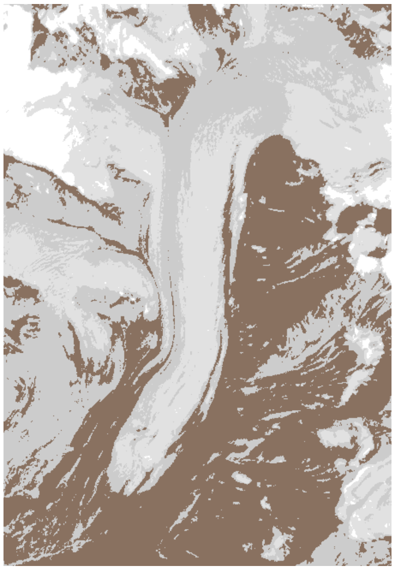
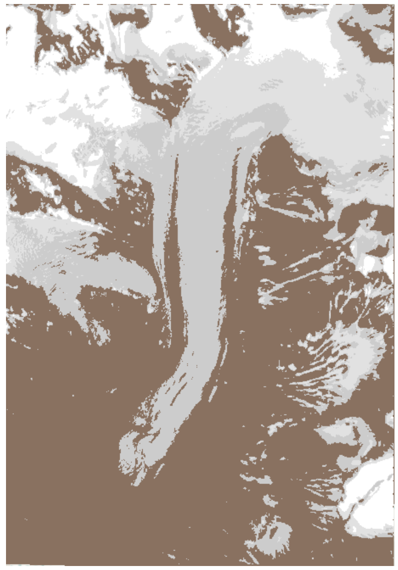
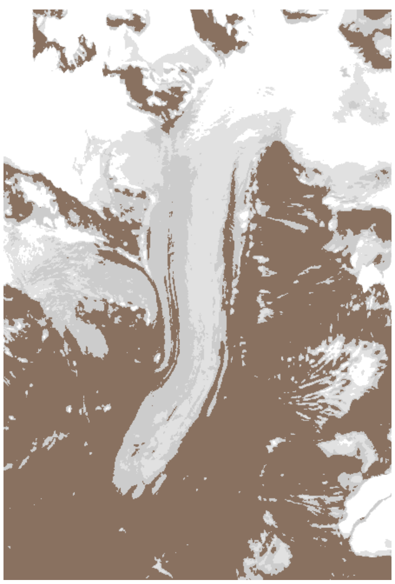
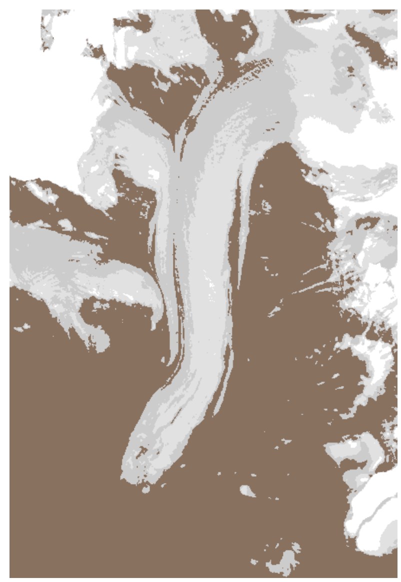



After unsuccessfully delivering the data to the Google Cloud Storage, I decided to import the data into a Google Drive manually to store in the cloud versus on my machine. Reading much about how to import data to ArcGIS Pro directly from a Google Drive and unfortunately finding it unsuccessful, I decided to use the Planet plug-in for ArcGIS Pro to import the images (Palazzi, 2017/2022; Windahl, n.d.).

To visualize the newly imported Planet images, I reclassified the data to have 4 classes: Not Ice, 2 classes of Ice, and Snow. This reclassification is not for analysis but rather to visualize the images with a consistent classification, as seen in Figure 4. Just upon visual inspection I can see that there are certain images that still have a significant amount of snow, such as Breiðamerkurjökull Glacier in 2017, which for this study I am going to assume that this snow is over ice because it most likely would have melted if it was not on ice. Another discrepancy to consider in the images is the "Not Ice" areas clearly in the center of the glacier - these are most likely avenues where the melted glacier has flowed before and has carried dirt, and silt, and pebbles with it causing the ice to appear darker. There can also be ice beneath the thick rock surface which would be hidden to satellite images and can be very difficult to observe and research (*Dirty Glaciers Melt Just as Fast as Clean Ones*, 2015). For the purposes of this study I am going to focus on the visible surface ice.

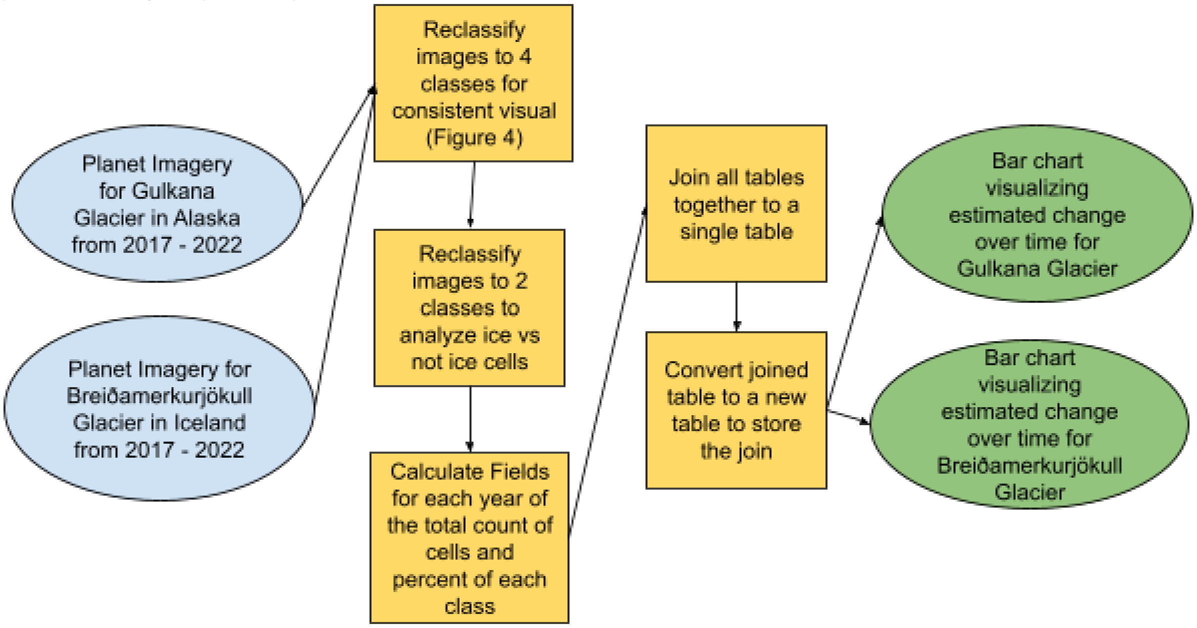
*Figure 4. Reclassification of Planet Images*

| *Breiðamerkurjökull Glacier, Iceland* | | |
|---|---|---|
| *2017* | *2018* | *2019* |
|  |  |  |
| *2020* | *2021* | *2022* |
|  |  |  |

| *Gulkana Glacier, Alaska* | | |
|---|---|---|
| *2017* | *2018* | *2019* |
|  |  |  |
| *2020* | *2021* | *2022* |
|  |  |  |

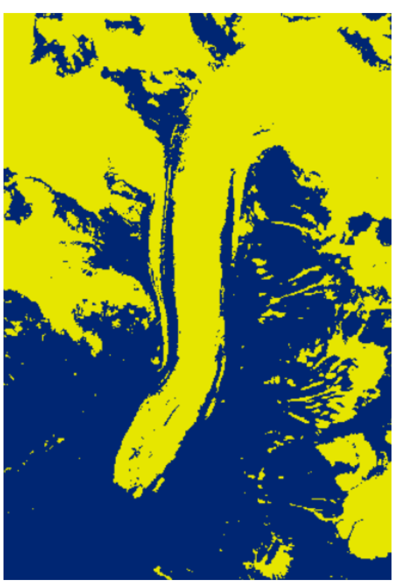
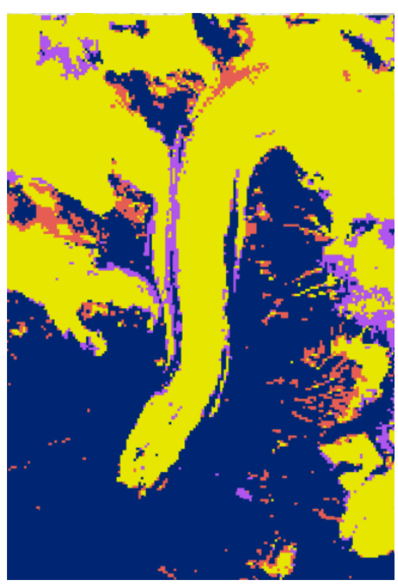
To start the analysis, as seen in Figure 5, I reclassified the cells again into two classes: “Ice” and “Not Ice” so I can clearly see a change over time in cell type. Once classified, I calculated two new columns with the “Calculate Field” function: total count of cells per raster and percentage of cells per classification. To calculate the total count of all cells I manually selected the values of each of the classifications and summed them. Once all cells were calculated for each year, I joined all of the tables to two tables: one for Iceland and the other for Alaska. I then converted the joined tables to new tables to store the join. With the new joined and converted tables, I created bar charts to visualize the changes from year to year, as seen in Charts 1 & 2.

*Figure 5: Analyzing Change Over Time with Calculated Fields*



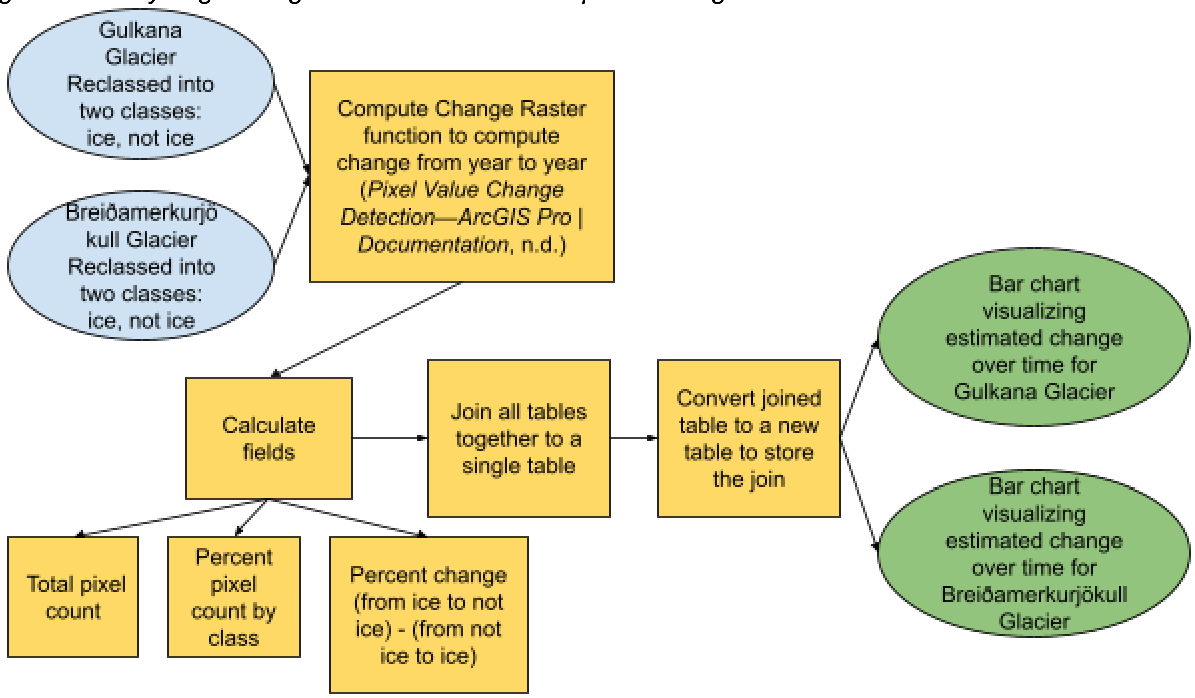

Similar to the process in Figure 5, I calculated the change from year-to-year for each glacier but this time using the ‘Compute Change’ function with Arcpy in Figure 7. This function takes a raster (Gulkana Glacier, 2017, for example) and compares it to another raster (Gulkana Glacier, 2018) and highlights the changes from each raster. Since I am only using two classifications, the changes that are being observed are Class 1: Not Ice (navy blue), Class 1 > Class 2: Not Ice to Ice (purple), Class 2 > Class 1: Ice to Not Ice (red), and Class 2: Ice (yellow), as seen in Figure 6.

*Figure 6. Example of Computing Change from Year to Year*

| *First Reclassification* | *Compute Change* | *Reclassify Changes from Compute Change* |
|---|---|---|
|  |  |  |

I used this function to compute changes for 2017-2018, 2018-2019, 2019-2020, 2020-2021, 2021-2022 for each glacier then used calculated fields to find the percentage of each of the classes, similar to the process in Figure 5, and then created bar charts to visualize the results of change over time.

*Figure 7: Analyzing Change Over Time with Compute Change Function*




**Results**

Over the course of six years, both Gulkana Glacier and Breiðamerkurjökull Glacier have shown an increase in ice melt using the Calculated Fields method, as seen in Charts 1 & 2 below. One exception is Gulkana Glacier in 2020 where there was a jump in the amount of ice visible but then continued to decrease in the following years. The reclassified image of Gulkana Glacier in 2020 in Figure 4 does have a significant amount of snow compared to other years which could account for the jump in visible, classified snow but there is not enough evidence to be able to tell definitively if that is the cause. Breiðamerkurjökull Glacier also has a very small jump in visible ice in 2020, but not nearly as much as Gulkana Glacier, 2% vs 9% increase. Another possible explanation of the jump in increased ice and snow is the global COVID-19 pandemic in 2020 - due to the drastically reduced travel, manufacturing, shipping, etc there was as significant change in many environmental impacts in 2020 (Rasmussen, 2021). Regardless of the cause of the increase in ice and snow in 2020, both Breiðamerkurjökull and Gulkana Glaciers continued to decrease in the following years. Ideally, these percentages would be consistent from year to year if these glaciers were balanced, meaning they are acquiring as much ice as what is melting, but they are continuing to lose more ice than they are acquiring.

*Chart 1. Percent Change of Cell Type from Year to Year Using Calculated Fields, Gulkana Glacier, Alaska*

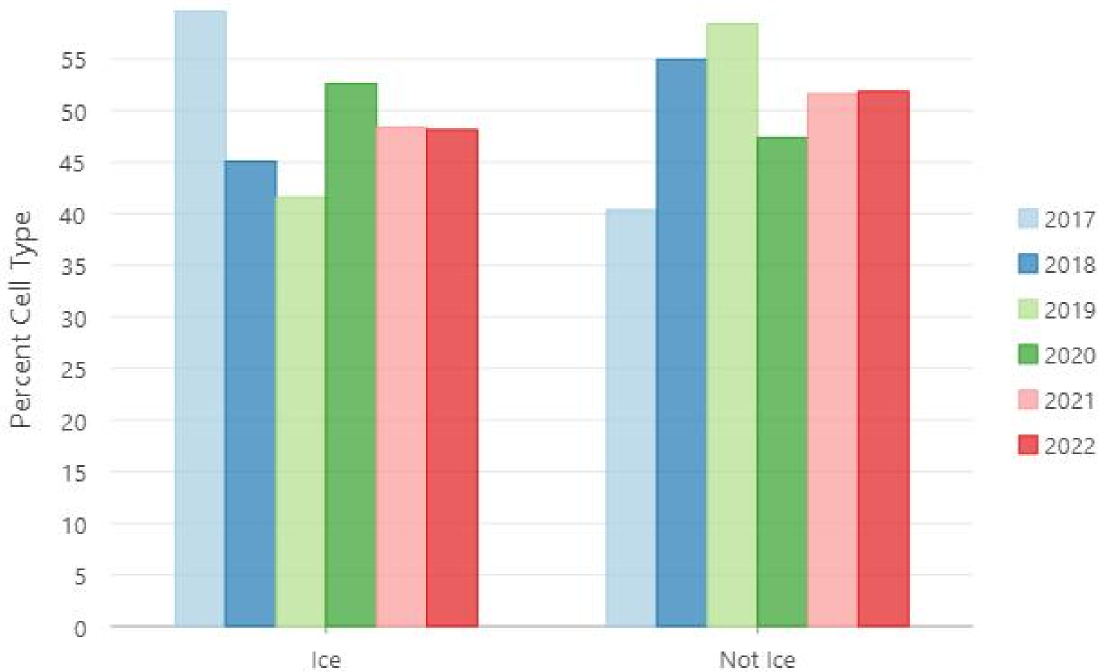
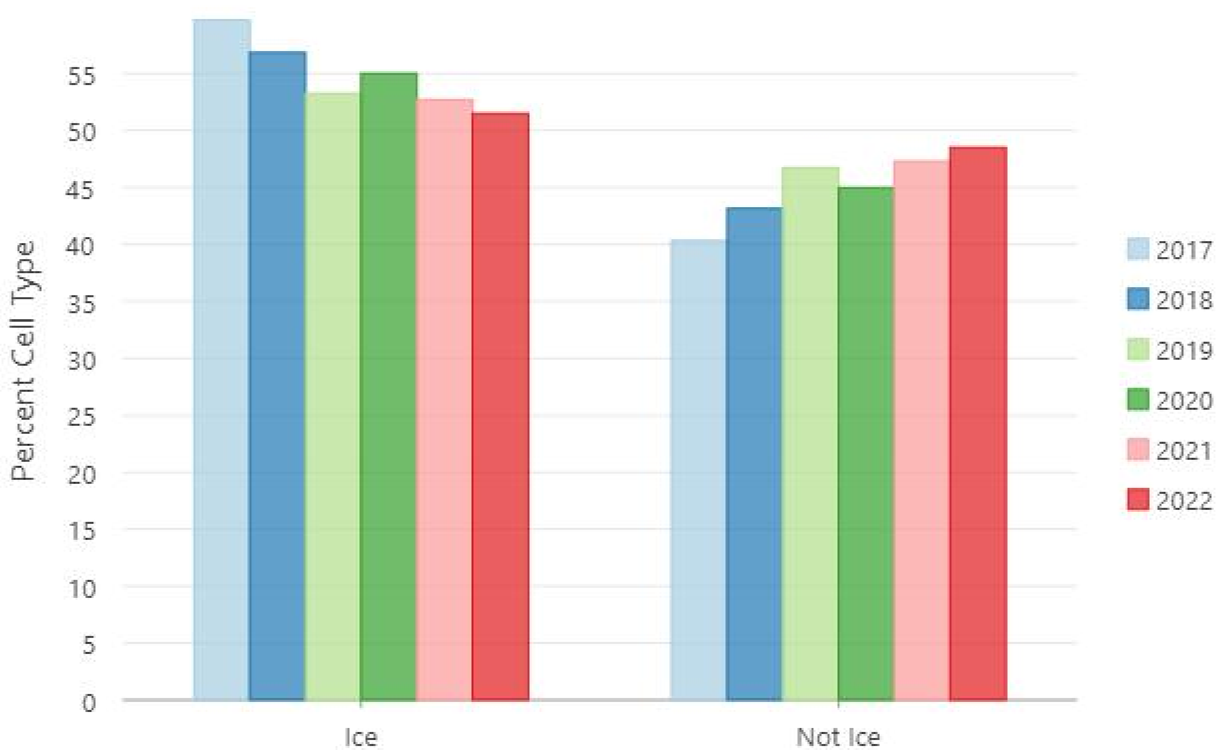



*Chart 2. Percent Change of Cell Type from Year to Year Using Calculated Fields, Breiðamerkurjökull Glacier, Iceland*



Similar to the results from Charts 1 & 2 using Calculated Fields, the Compute Change method also shows an increase in glacial melt, as seen in Charts 3 & 4. The interesting aspect of the Compute Change method is seeing the change from Ice to Not Ice and vice versa on the charts. For Gulkana Glacier, the Ice to Not Ice classification shows a decrease over time, meaning that more Ice is changing to Not Ice over time with the exception of 2020 again. This is even more prominent in the Not Ice to Ice classification where there is a significant jump of cells that were Not Ice in 2019 and were Ice in 2020. Interestingly, Breiðamerkurjökull Glacier does not show as consistent results of steady decrease of ice coverage as it does in Chart 2. The change of Ice to Not Ice over time seems more consistent than in Chart 2, however the change is more gradual than that of Gulkana Glacier so it may just appear more steady - though it is still decreasing over time.

*Chart 3. Percent Change of Cell Type from Year to Year Using Compute Change Method, Gulkana Glacier, Alaska*

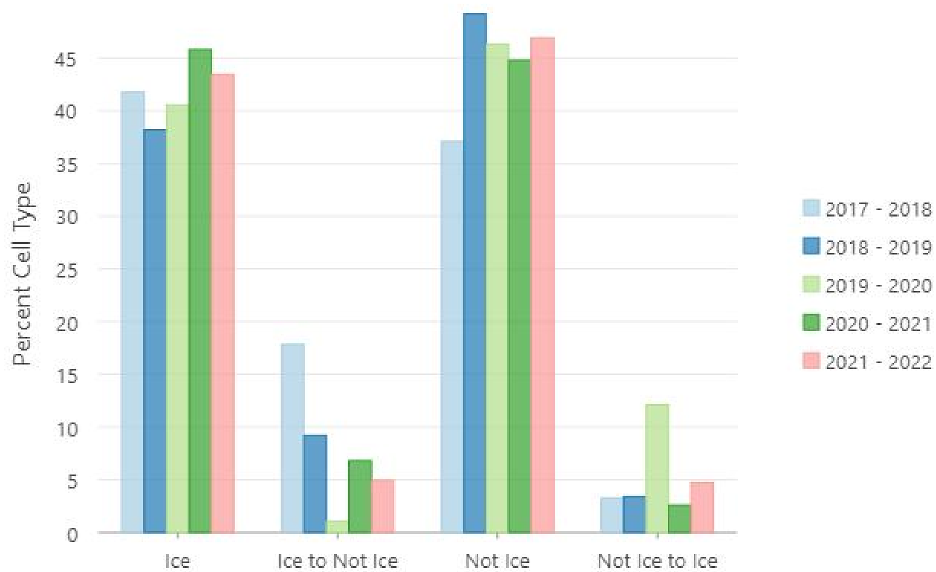
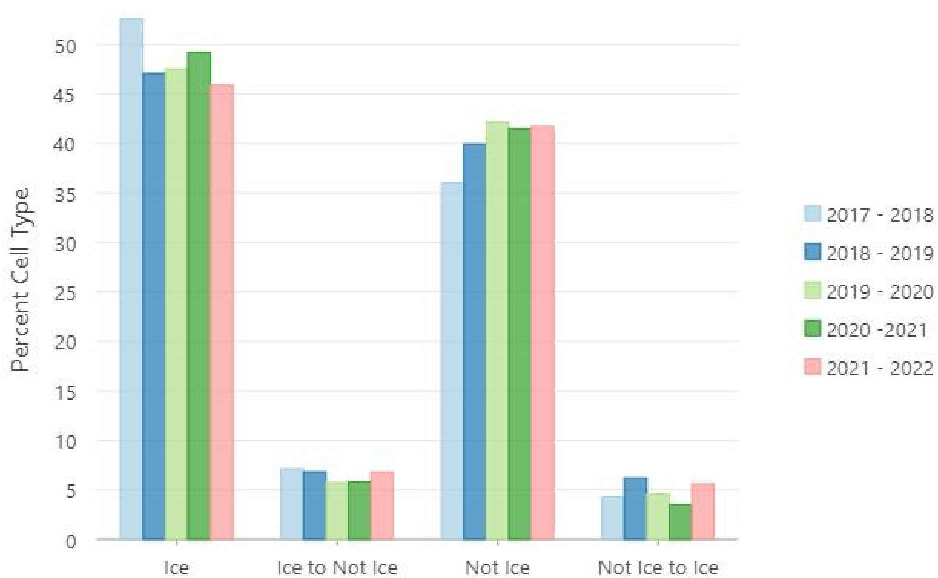



*Chart 4. Percent Change of Cell Type from Year to Year Using Compute Change Method, Breiðamerkurjökull Glacier, Iceland*



**Results Verification**

To verify my results, I summed the change from Ice to Not Ice and vice versa from the results in Figure 7 to create two classifications once again: Ice and Not Ice. I used Calculated Fields once again to find the total count of each of the rasters and found the percentage of each of the classifications for each year. The results from this calculation are very similar to the results from the Calculated Fields method in Figure 5 which tells me that the results are consistent. There is still a consistent decrease over time of the amount of visible ice for both Gulkana and Breiðamerkurjökull Glacier with the exception of 2020 and with Breiðamerkurjökull Glacier being more consistent and having fewer drastic jumps than Gulkana Glacier, as seen in Charts 5 & 6.

*Chart 5. Summing the Changes from Year to Year from the Compute Change Method, Gulkana Glacier, Alaska*

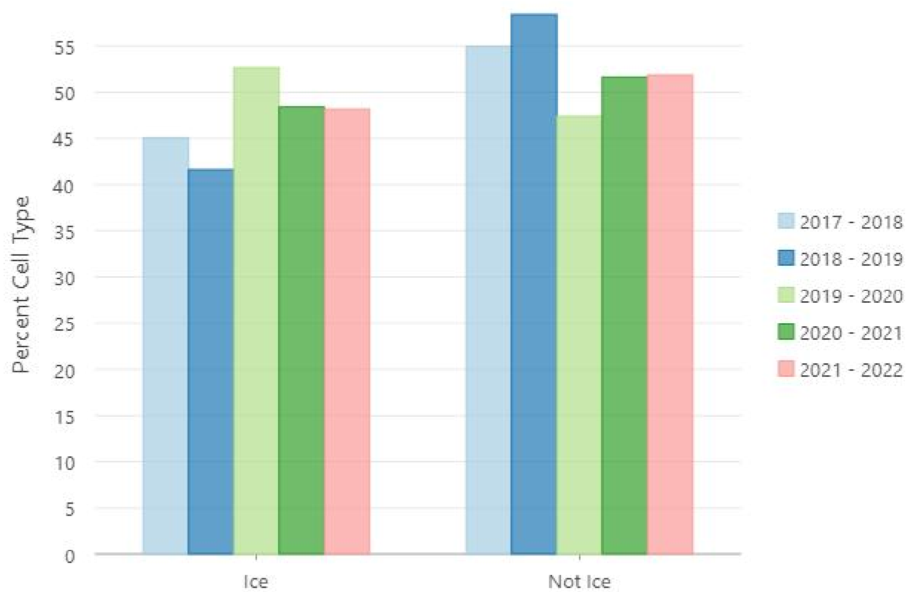
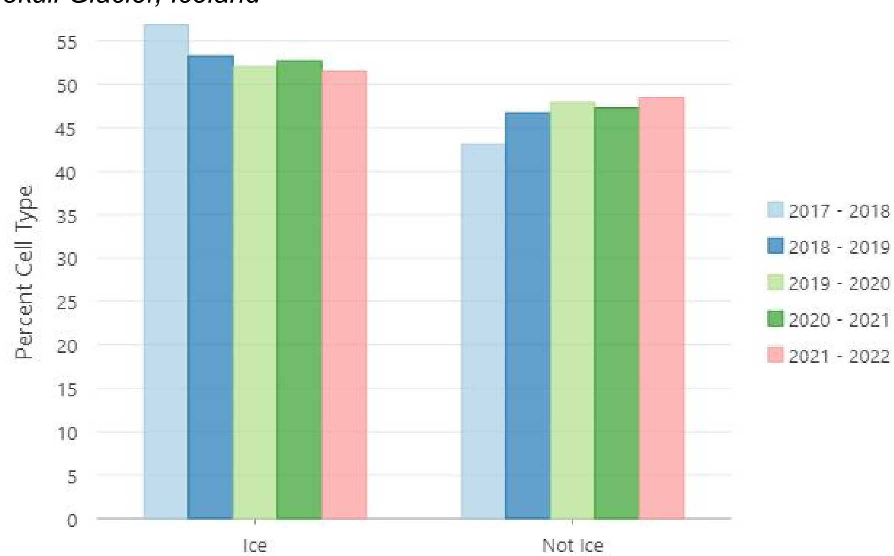



*Chart 6. Summing the Changes from Year to Year from the Compute Change Method, Breiðamerkurjökull Glacier, Iceland*



## Discussion and Conclusion

As I stated above, glacial melt is measured by surface area covered by ice as well as the volume of ice within a glacier - in this study I only focused on the surface area covered by ice. In future studies, it would be helpful to see if the same results I found are true when estimating the volume of ice within a glacier using DEM data, for example. Another way to estimate the volume of ice within a glacier would be to estimate the amount of snow on the glacier - unfortunately this could not be done with Planet or DEM data because a volume of ice would not be visible within a raster and the overall elevation of the snow would be inconsistent with the amount that truly contributes to the glacier. One way this study could be done would be with weather data estimating the amount of snow on the glacier annually and calculating based on historical data how much of that snow becomes ice and contributes to the glacier. Glacial melt could also be estimated using weather data by analyzing temperatures and seeing how many days would be ‘melt’ days per year and seeing if the amount of ‘melt’ days increase over time.

For this study I used a very small sample size of data: two glaciers with one snapshot per year over a span of six years. I limited this sample size because of a lack of time but also because of a lack of available storage and quotas. As stated above, extracted Planet data is large, and with glaciers being geographically large areas the data extracted is exceptionally large. If I had unlimited storage and Planet quotas available, I would capture multiple images per year or multiple glaciers and continuously be calculating change as new images are available.

In the analysis, specifically when calculating fields, I ended up having to calculate some fields manually which defeats the purpose of using Arcpy. Too far into my project did I come across a function called “SearchCursor” and “UpdateCursor” that I could have used to automate more of the analysis and reduce the processing time. In any future analysis, I would further investigate these functions to be able to automate more of the process especially if I were to add more years and more glaciers in the future.

For the results, I would be interested in further investigating the true global impact of receding glaciers. Specifically, with the results I got for Gulkana and Breiðamerkurjökull Glacier where they both are melting more each year, how much water is being outputted by the melt each year and is contributing to the sea-level rise? Glaciers are a significant contributor to glacial melt, but they are not the only contributor. Another major contributor are the ice sheets in the Antarctic, these have a similar ebb and flow to glaciers but have a far greater impact globally if they melt versus glaciers. If all of the global glaciers melted the sea-level would rise “just under half a meter (1.6 feet)” (*Glacier Quick Facts*, n.d.). “If the entire Antarctic Ice Sheet melted, sea level would rise about 60 meters (197 feet)” (*Glacier Quick Facts*, n.d.).

Research has just begun on the impacts that the global COVID-19 pandemic had on the world as a whole but also on the environmental impacts, as I mentioned briefly above in the results. The results of the pandemic - reduced travel, manufacturing, shipping, etc - caused an environmental anomaly as most environmental impacts - temperatures rising, air pollution increasing, sea-level rise, etc - seemed to improve in 2020. Again, these are new studies about the true impacts the COVID-19 pandemic had on the environment but would be willing further investigation on their impact of glacial melt as well.

In this study I found an increase in glacial melt in only two glaciers; in the world there are over 200,000 glaciers - some of which are balanced or even decreasing in glacial melt, but most are similar to Gulkana and Breiðamerkurjökull and are increasing in glacial melt. Glacial melt is an important contributor to sea-level rise to be sure to continue monitoring and observing. The climate impacts of significant glacial melt can be drastic as seen briefly during the eruption of Vatnajökull Glacier in 1996 - though this eruption was not due to climate change, it did cause significant damage and an increase of water at the surface that contributes to the overall sea-level rise. Glaciers contain a significant amount of the world's water inventory and can quickly impact civilization with a rapidly increasing sea-level rise and rising temperatures.

**References**


*API Mechanics*. (2022, November 1). https://developers.planet.com/docs/apis/data/api-mechanics/

Brandon, M., Hodgkins, R., Björnsson, H., & Ólafsson, J. (2017). Multiple melt plumes observed at the Breiðamerkurjökull ice face in the upper waters of Jökulsárlón lagoon, Iceland. *Annals of Glaciology*, *58*(74), 131–143. https://doi.org/10.1017/aog.2017.10

*Delivery*. (2022, November 16). https://developers.planet.com/apis/orders/delivery/

*Dirty glaciers melt just as fast as clean ones*. (2015, January 28). https://www.science.org/content/article/dirty-glaciers-melt-just-fast-clean-ones

*GeoJSON and Areas of Interest (AOIs)*. (2022, November 1). https://developers.planet.com/docs/planetschool/geojson-and-areas-of-interest-aois/

*Glacier Quick Facts*. (n.d.). National Snow and Ice Data Center. Retrieved December 19, 2022, from https://nsidc.org/learn/parts-cryosphere/glaciers/glacier-quick-facts

Hugonnet, R., McNabb, R., Berthier, E., Menounos, B., Nuth, C., Girod, L., Farinotti, D., Huss, M., Dussaillant, I., Brun, F., & Kääb, A. (2021). Accelerated global glacier mass loss in the early twenty-first century. *Nature*, *592*(7856), 726–731. https://doi.org/10.1038/s41586-021-03436-z

*Item Previews*. (2022, November 1). https://developers.planet.com/docs/apis/data/item-previews/

Kristmannsdóttir, H., Björnsson, A., Pálsson, S., & Sveinbjörnsdóttir, Á. E. (1999). The impact of the 1996 subglacial volcanic eruption in Vatnajökull on the river Jökulsá á Fjöllum, North Iceland. *Journal of Volcanology and Geothermal Research*, *92*(3–4), 359–372. https://doi.org/10.1016/S0377-0273(99)00056-6

Le Bris, R., & Paul, F. (2015). Glacier-specific elevation changes in parts of western Alaska. *Annals of Glaciology*, *56*(70), 184–192. https://doi.org/10.3189/2015AoG70A227

Mcneil, C. J., Sass, L., Florentine, C. E., Baker, E. H., Peitzsch, E. H., Whorton, E. N., Miller, Z. S., Fagre, D. B., Clark, A. M., & O'Neel, S. R. (2016). *Glacier-Wide Mass Balance and Compiled Data Inputs: USGS Benchmark Glaciers* [Csv,zip]. U.S. Geological Survey. https://doi.org/10.5066/F7HD7SRF

*Orders API Tools*. (2022, November 16). https://developers.planet.com/apis/orders/tools/

Palazzi, A. (2022). *Google-drive-downloader* [Python]. https://github.com/ndrplz/google-drive-downloader (Original work published 2017)

Park, M. A. G. B. N., Gustavus, P. P. B. 140, & Us, A. 99826 P. 907 697-2230 C. (n.d.). *Glaciers / Glacial Features—Glacier Bay National Park & Preserve (U.S. National Park Service)*. Retrieved December 16, 2022, from https://www.nps.gov/glba/learn/nature/glaciers.htm

*Pixel value change detection—ArcGIS Pro | Documentation*. (n.d.). Retrieved December 15, 2022, from https://pro.arcgis.com/en/pro-app/latest/help/analysis/image-analyst/pixel-value-change-detection.htm

*Planet Data API Reference*. (n.d.). Retrieved December 16, 2022, from https://developers.planet.com/docs/apis/data/reference/

*Planet Explorer*. (n.d.). Planet. Retrieved December 16, 2022, from https://www.planet.com/explorer/

*Planetlabs/notebooks*. (2022). [Jupyter Notebook]. Planet Labs. https://github.com/planetlabs/notebooks (Original work published 2017)

*PSScene*. (2022, November 9). https://developers.planet.com/docs/data/psscene/

Rasmussen, C. (2021, November 9). *Emission Reductions From Pandemic Had Unexpected Effects on Atmosphere*. Climate Change: Vital Signs of the Planet. https://climate.nasa.gov/news/3129/emission-reductions-from-pandemic-had-unexpected-effects-on-atmosphere

*Scenes Product Bundles Reference*. (2022, November 1). https://developers.planet.com/apis/orders/product-bundles-reference/

*Search Filters*. (2022, November 1). https://developers.planet.com/docs/apis/data/searches-filtering/

*UDM 2*. (2022, November 9). https://developers.planet.com/docs/data/udm-2/

*UpdateCursor—ArcGIS Pro | Documentation*. (n.d.). Retrieved December 15, 2022, from https://pro.arcgis.com/en/pro-app/latest/arcpy/data-access/updatecursor-class.htm

US EPA, O. (2016a, June 27). *Climate Change Indicators: Sea Level* [Reports and Assessments]. https://www.epa.gov/climate-indicators/climate-change-indicators-sea-level

US EPA, O. (2016b, July 1). *Climate Change Indicators: Glaciers* [Reports and Assessments]. https://www.epa.gov/climate-indicators/climate-change-indicators-glaciers

*Visit Iceland*. (n.d.). Retrieved December 12, 2022, from https://www.visiticeland.com/article/vatnajokull

*What is a glacier? | U.S. Geological Survey*. (n.d.). Retrieved December 19, 2022, from https://www.usgs.gov/faqs/what-glacier

Windahl, E. (n.d.). Check out Esri's new tools for managing Planet imagery in ArcGIS. *ArcGIS Blog*. Retrieved December 4, 2022, from

https://www.esri.com/arcgis-blog/products/imagery/imagery/check-out-esris-new-tools-for-managing-planet-imagery-in-arcgis/

**Self-score**

| **Category** | **Description** | **Points Possible** | **Score** |
|---|---|---|---|
| **Structural Elements** | All elements of a lab report are included **(2 points each)**: Title, Notice: Dr. Bryan Runck, Author, Project Repository, Date, Abstract, Problem Statement, Input Data w/ tables, Methods w/ Data, Flow Diagrams, Results, Results Verification, Discussion and Conclusion, References in common format, Self-score | 28 | **28** |
| **Clarity of Content** | Each element above is executed at a professional level so that someone can understand the goal, data, methods, results, and their validity and implications in a 5 minute reading at a cursory-level, and in a 30 minute meeting at a deep level **(12 points)**. There is a clear connection from data to results to discussion and conclusion **(12 points)**. | 24 | **24** |
| **Reproducibility** | Results are completely reproducible by someone with basic GIS training. There is no ambiguity in data flow or rationale for data operations. Every step is documented and justified. | 28 | **28** |
| **Verification** | Results are correct in that they have been verified in comparison to some standard. The standard is clearly stated **(10 points)**, the method of comparison is clearly stated **(5 points)**, and the result of verification is clearly stated **(5 points)**. | 20 | **20** |
| | | 100 | **100** |