

Monitoring Changes in Glaciers over time Using Remote Sensing Imagery from Landsat 4 MSS and Landsat 8 OLI

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ABSTRACT: In this work, Landsat 4 MSS and Landsat 8 OLI imagery was used to quantitively and qualitatively assess changes in glaciers over time using ENVI tools such as regions of interest, ruler, unsupervised and supervised classifications, band math, and preprocessing tools. The Normal Difference Snow Index was also calculated for the OLI images, but not accurately for the MSS images because the spectral resolution is not optimal to obtain a desirable result. The area of interest was the Wrangell-Mt. Elias National Park in Alaska where the Bering and Malaspina Glaciers, alpine and piedmont glaciers, respectively, are located and were the focus of this project. The major goal was to comprehend the interrelationship between climate change factors and the rapid retreat of glaciers.

Introduction

Glaciers are massive bodies of ice that form when snow piles up in high elevation areas known as accumulation zones. The overlying snow exerts pressure over the snow underneath forcing air pockets to escape, thereby causing the snow to undergo a recrystallization process where the final product is dense glacial ice. Due to gravity, this dense ice located at high elevations will slowly begin to flow to lower elevations. As the ice flows downwards, it eventually reaches areas where there is no longer accumulation, but ablation, in other words, melting, calving, evaporation, sublimation, etc. Glaciers are dynamic bodies that experience a natural process of mass gain over the winter and mass loss over the summer. Although they experience these fluctuations in their mass, they are useful climate change indicators when analyzed over an extensive period of time. An effective concept for assessing changes of glaciers over time is the mass balance given by *Equation 1:*

Mass Balance = Input – Output

where input refers to the mass received by the system and output refers to the mass lost. In a particular case study for Himalayan glaciers, Racoviteanu et al. 2008 use ASTER imagery to find glacier thickness and volume estimations, determine volumetric changes at decadal time scales using digital elevation models (DEMs) on a pixel by pixel basis and AAR-ELA methods to calculate yearly mass balances of glaciers from multispectral data. In this paper, their methods are used as a basis for looking at changes in the mass balance over time, instead of calculating specific current mass balances of the Bering and Malaspina glaciers in Alaska. Even though there are fluctuations of mass balance on a year to year basis, if a glacier has lost area and mass and has retreated over a period of decades, then the conclusion is that the average mass balance over that period of time was negative. On the contrary, if the glaciers advances and gains mass, the conclusion is that the average mass balance has been positive. To find the answer to this question, Landsat 4 MSS and Landsat 8 OLI imagery is used.

Data Collection

The images used for this project were taken from USGS EarthExplorer and Global Visualization Viewer (GLOVIS). The images for Landsat 4 MSS correspond to September 1983. The images for Landsat 8 OLI correspond to September 2015-2016. The time passed between these images is 32-33 years. All the images contain 0-10% cloud cover and were taken during the day time.

Methodology

Pre-processing

The glaciers of interest were not in the same images in the case of both sensors, therefore the images were mosaicked. Once the mosaic was done, a subset was created to isolate the areas of interest that contained the Bering and Malaspina glaciers. Both images were radiometrically corrected and validated using cursor value.

Processing

- ISODATA was used to conduct an unsupervised classification in order to look at the spectral diversity within both images. It is not necessarily useful in assigning classes like a supervised classification tool would.
- Neural Net was used to conduct a supervised classification. The classes water, dirty ice, clean ice, vegetation, and shadows projected by mountains were used to train the program using the ROI tool.
- Calculate area of both glaciers in 1983 and 2015-2016 using the ROI tool.
- Find distance of retreat or advance using ruler tool.
- Calculate Normal Difference Snow Index using *Equation 2:*

$$NDSI = \frac{Green - SWIR}{Green + SWIR}$$

where green corresponds to the green band values and SWIR to the short wave infrared band values. This algorithm is useful because of its effectiveness in distinguishing between clouds, snow and ice.

Results



B



Figure 1. A) ISODATA unsupervised classification for Landsat 4 MSS 1983 image. B) ISODATA unsupervised classification for Landsat 8 OLI 2015-2016 image.



B



Figure 2. A) Neural Net supervised classification for Landsat 4 MSS 1983 image. B) Neural Net supervised classification for Landsat 8 OLI 2015-2016 image.

A



B



Figure 3. A) Normalized Difference Snow Index calculation attempt for Landsat 4 MSS 1983 image. B) Normalized Difference Snow Index calculation for Landsat 8 OLI 2015-2016 image.

Discussion

The area calculated for the Bering glacier from the 1983 and 2015-2016 images was 812.39 km² and 616.58 km², respectively. The change in area for this glacier was 195.81 km². The area calculated for the Malaspina glacier from the 1983 and 2015-2016 images 918.37 km² and 795.86 was km². respectively. The change in area for this glacier was 122.51 km². The Bering glacier retreated 4.66 km and the Malaspina glacier retreated 1.61 km. A probable reason why the Bering glacier lost much more area and retreated more dramatically than the Malaspina glacier was because the Bering glacier's terminus position ends at a water body which causes the ice to melt much faster than a glacier that is insulated by land. Figure 2 shows the supervised classifications for this area in 1983 and 2015-2016 using the classes water, dirty ice, clean ice, shadow and vegetation to qualitatively assess changes in clean ice coverage. Dirty ice refers to areas that have a mixture of sediments as well as ice. It is a useful tool because it provided an easy, visual way to notice the change in loss of clean ice coverage over the period between 1983 and 2015-2016. Another useful way to quantitively asses change in ice coverage was the NDSI calculation because it shows how ice and snow is distributed in area and provides specific values. Unfortunately, NDSI is only useful when using a sensor that has the SWIR band. Figure 3B shows the NDSI calculation for the 2015-2016 mosaic. which fits the supervised classification satisfactorily. Figure 3A shows an NDSI calculation attempt for the MSS sensor, but the final product does compare positively with the supervised classification. This result is to be expected because the MSS sensor does not have the SWIR band values necessary for this calculation.

Conclusion

Remote sensing proved to be a very useful tool in the assessment of glacier change over time in the Wrangell-Mt. Elias National Park region in Alaska. The ENVI program was a user-friendly interface in which the calculations of area and distance. NDSI. supervised and unsupervised classifications were easy to do in a fast, efficient way. We found that glaciers have, indeed, reduced and retreated over time most likely because of the rise in temperatures caused by the greenhouse gases that are increasing in concentration. By looking at the reduction of these glaciers, we can conclude their mass balance has been negative on average over the past three decades. These glaciers along with others will most likely keep reducing in size over time.

Recommendations

It would be quite interesting if students had the opportunity to calculate current mass balances of different glaciers with digital elevation models that they can process in ENVI, as well as looking at surface elevation changes and estimating volumes. It would also be quite helpful if an algorithm can be developed where Landsat 4 MSS imagery can be used to calculate NDSI because even though it is an older sensor, it provides historical data that other sensors cannot. To fully understand the change in snow and ice coverage, it would be useful to have the NDSI values from both 1983 and 2015-2016.

References

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