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Visualizing NDWI Change for Glacial Lakes in the Patagonia Mountains

For the final project of this course, I was interested in using remote sensing data to calculate Normalized Difference Water Index (NDWI) values and visualize glacial lake area change. It is estimated that between 1990 and 2018, the area of glacial lakes increased globally by 51% due to rising temperatures and increased glacial melt (Shugar, D. H. et al., 2020). My interest for this topic stems from an ongoing research opportunity with faculty member Johnny Ryan, where we have been trying to quantify the length of the Greenland ice sheet that is in contact with proglacial lakes. I decided that I wanted to focus on the southern hemisphere for this project, more specifically on three lakes in particular: Lago O'Higgins/San Martín, Lago Viedma, and Lago Argentina, all of which are located in the Patagonia mountains on the border between Chile and Argentina (Figure 1). The objective of this study is centered around the concern of climate change impacts on high latitudes and how increasing proglacial lake levels can help to understand glacial retreat.

The first steps of this project entailed collecting cloud free image mosaics for the years of 2001 and 2021. I decided on this 20 year range as I wanted to focus on recent changes leading up to the present and show the trends of the 21st century at the study site. Additionally, I wanted to create a mosaic belonging to the same time of year for both images. Given that glacial lakes in the Patagonia mountains are subject to high levels of seasonal variation in both atmospheric conditions and glacial discharge, it was important to compare images of the same seasonality (Sugiyama, S., Minowa, M., Fukamachi, Y. et al., 2021). I decided to compare late summer to early autumn time periods (March - April) as this time period provided more consistently cloud free images and the least snow cover. The next decision involved selecting the dataset to use. This decision was made easier given that Landsat data is one of the only publicly available datasets offering multispectral images within this desired time range. For the 2001 image collection, I elected to use Landsat 5, the longest operating earth observation satellite which captured images from 1984-2013 (USGS, 2022). To create a cloud free image collection for 2021, I used Landsat 8 data. This satellite launched in 2013 and continues to provide images every 16 days for nearly the entire globe (USGS, 2022). The execution of the process was straightforward within Google Earth Engine (GEE), and involved filtering the image collections to only contain images with less than 20% cloud cover, and then calculating the median value for each pixel. With two cloud free image mosaics created for 2001 and 2021, it was possible to create true color RBG visualizations (Figure 2, Figure 3).

Calculating NDWI values was the next step for the images. The NDWI formula uses the NIR and Green band in the equation (G - NIR)/(G + NIR) in order to calculate a difference value from -1 to 1 where 1 represents water and -1 represents vegetation (Sahu, Abhay Sankar, 2014). This difference is due to the higher absorption of NIR energy in water bodies when compared to vegetation (Sahu, Abhay Sankar, 2014). After the NDWI images were calculated, the data was exported as tif files from GEE and into QGIS to calculate and style an NDWI difference image (Figure 4). After inspecting the histograms of each image, a water mask was produced for both images where NDWI values are greater than 0.6 (Figure 5). These two visualization methods help to understand areas of NDWI change between the two years and identify areas of glacier retreat as seen in Figures 4 and 5.

The next step in this analysis involved collecting climate average data for the months of March and April in both 2001 and 2021. This was important in order to understand how atmospheric and lake temperatures are affecting glacial melting, as temperature in the upper layer of glacial lakes follows a seasonal variation of air temperature (Sugiyama, S., Minowa, M., Fukamachi, Y. et al., 2021). Along with this, precipitation differences evidently influence lake area, and percent snow cover in the summer months aids in understanding the climate behaviors of a given year and if more water is stored in snowpacks for one year more than another. The process of data collection for climate data was similarly conducted within GEE using ERA5 data collected at a 11132m resolution for average temperature and snow cover statistics. The Global Precipitation Measurement (GPM) constellation of satellites provided hourly precipitation rate in mm/hr for each pixel at the same spatial resolution of 11132m. The resulting temperature data was then averaged for the months of March and April, and another layer was produced to include the maximum temperature value for each pixel within the two month period. Snow cover data was averaged for each pixel of the two months, and the precipitation data was aggregated to get precipitation sums for each pixel. The precipitation values are very large numbers due to the fact that it is aggregating hourly precipitation for each pixel over a two month time period.

The findings for this analysis show the increase in area for the three glacial lakes between 2001 and 2021 using an NDWI difference image (Figure 4) and a water mask (Figure 5). The increase in lake area is evident, especially around areas with glacial interaction. The two figures show a zoomed in area of Lago Argentina, where the lake area has extended toward the retreating glacier. Looking at the differences in climate between the two years, it is likely that increasing glacial melt as a result of higher temperatures increased lake area in 2021 (Table 1). This increase in area can be further attributed to glacial influences, as total precipitation values for 2021 during March-April are less than half of the precipitation totals for 2001 during the same months. Of course, there are likely many other factors that are influencing the lake area change (such as snow cover) which decreased from 2001 to 2021 signifying there is less water being stored as snow.

Research of glacial lakes is important in order to understand the complex dynamics between glaciers and water bodies. Expanding on this project, I would like to continue looking at other years in the 20 year time range as well as other seasons to understand seasonal variability. This project was a fantastic opportunity for me to dive deeper into a subject that I am passionate about and learn more about the capabilities of a cloud computing platform such as Google Earth Engine.

Figures and Tables

<u>Figure 1:</u> Study area showing Lago O'Higgins/San Martín, Lago Viedma, Lago Argentina top to bottom

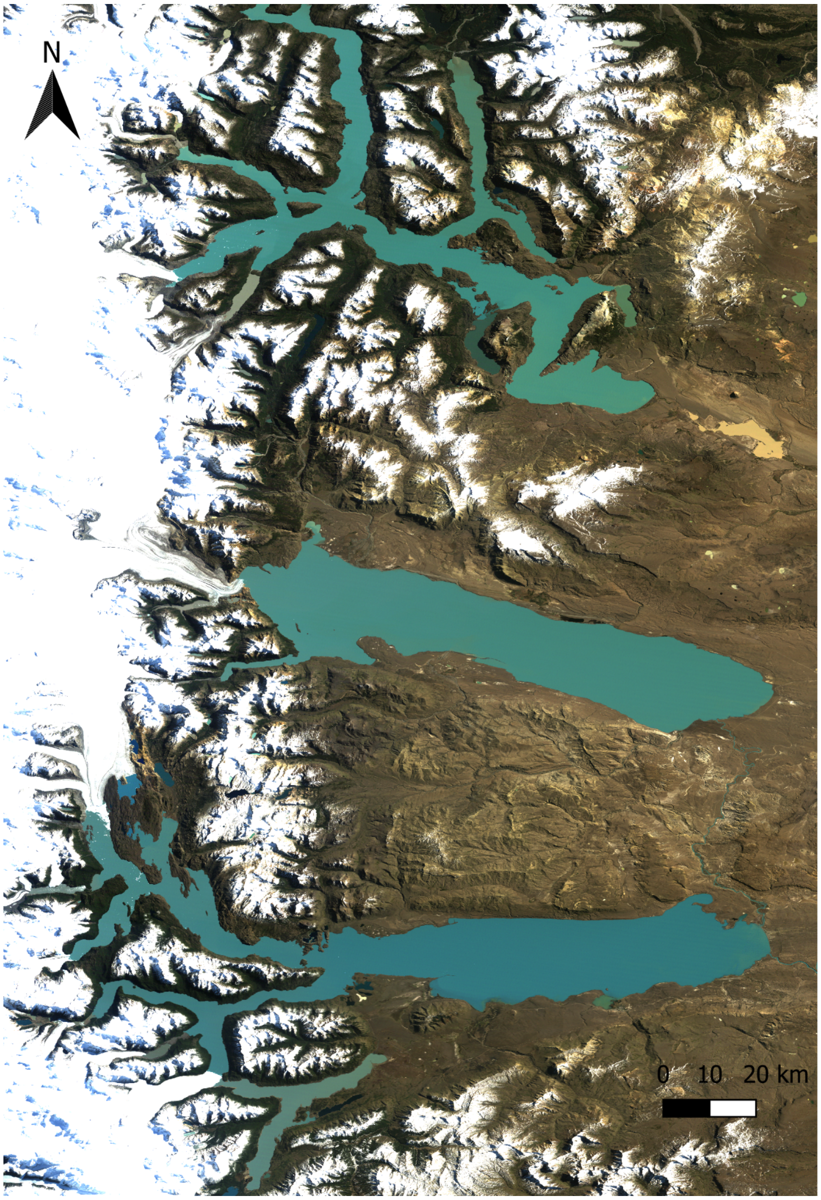


Figure 2: Landsat 5, 2001 RGB

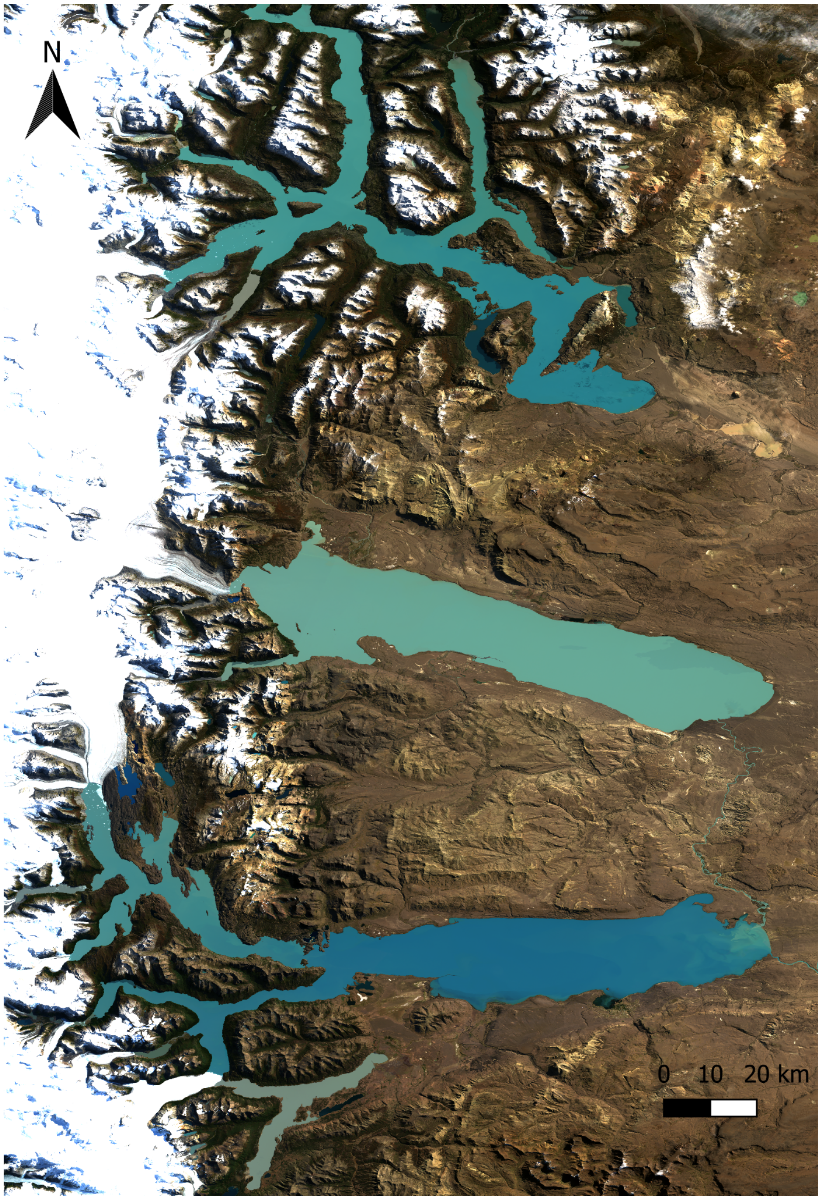
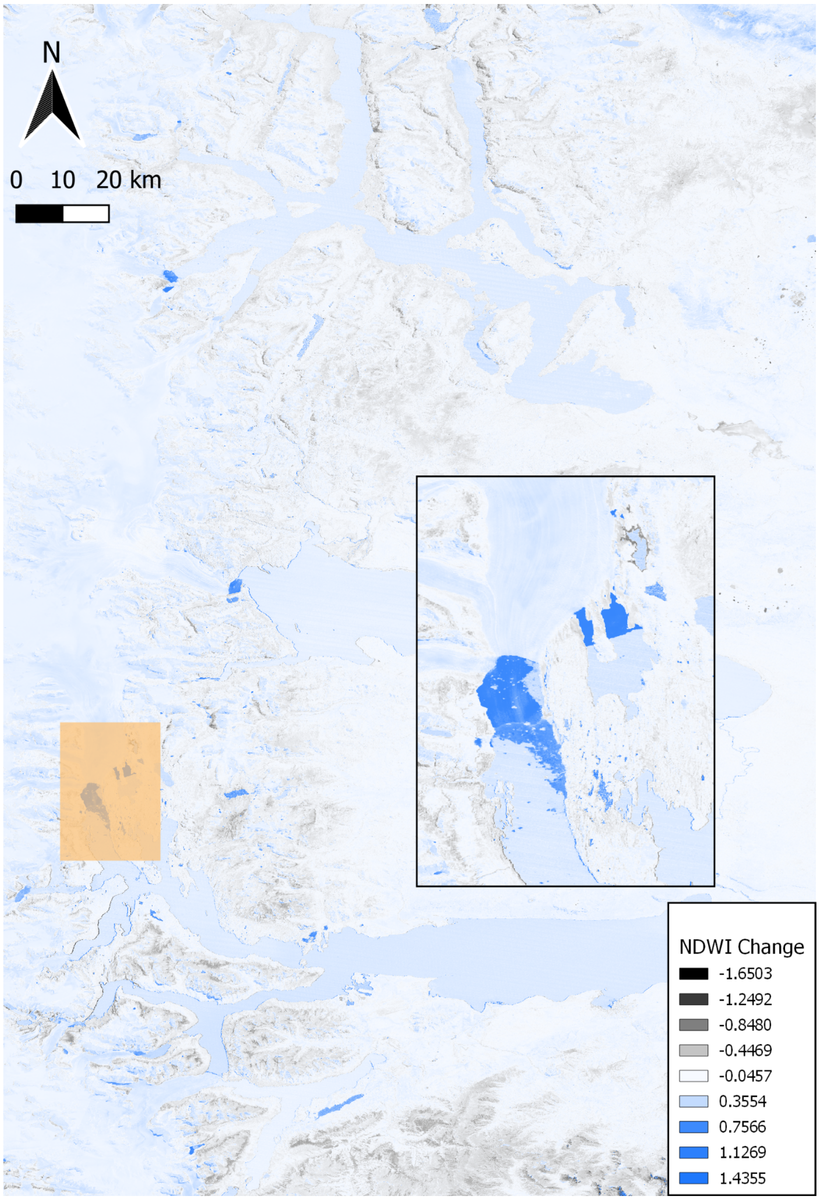


Figure 3: Landsat 8, 2021 RGB



<u>Figure 4:</u> NDWI Difference between 2001 and 2021

<u>Figure 5:</u> Water Mask (NDWI > 0.6) for 2001 and 2021

	2001	**2021**
Average Temperature (℉)	36.23	41.07
Max Temperature (℉)	48.49	53.45
Average Snow Cover (%)	48.77	32.63
Total Precipitation (mm)	12389051.49	6073201.18

Table 1: Climate variables (March-April) for 2001 and 2021 study area

Works Cited

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Shugar, D. H. et al. (2020). Rapid worldwide growth of glacial lakes since 1990, Nature Climate Change, doi:10.1038/s41558-020-0855-4

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