Impact of Climate Change on Mountain Glaciers

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Abstract

Glaciers are important climate change indicators as changes in physical features such as their area give measurable evidence of fluctuating temperature, precipitation, and other climate factors. The remote nature of glaciers renders direct measurement impractical. Our project uses satellite imagery, taken at regular intervals since the Landsat project began, to quantify changes in the terminal point and area of the Franz Josef and Gorner glaciers. We find local temperature, CO2, and precipitation as significant factors for predicting changes in the area of the Franz Josef glacier and movements in the terminal point of both glaciers using generalized additive models. Area fluctuations in the Gorner glacier were best predicted by a generalized additive model including local and global temperature, CO2, and precipitation.

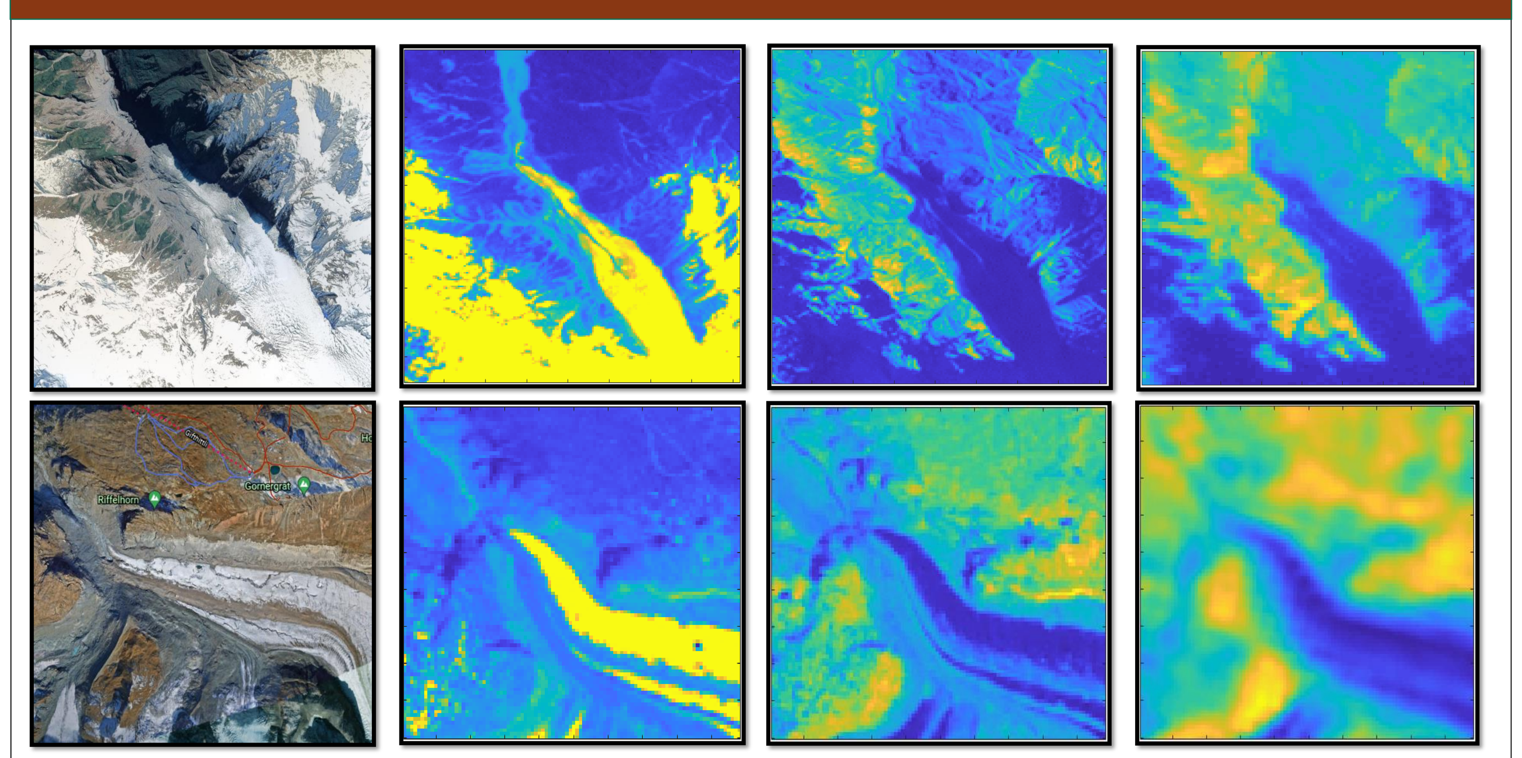
Introduction

Glaciers gain mass during periods of accumulation and lose mass in the ablation period. The net result of accumulation and ablation gives the glacier's mass balance. The mass of a glacier is relevant as glacial melting has effects on sea level and surrounding ecosystems. It is therefore important to quantify changes in glacial size, particularly as it relates to climate factors.

Physical features that can indicate changes in a glacier's size are its area and terminal point (the end of a glacier's flow path). Previous literature has measured changes in glaciers' termini using satellite imagery [1]-[3]. For both the Franz Josef and Gorner glaciers, we will use Landsat imagery to detect termini and quantify changes in glacial area. Area quantification is especially sensitive to data quality. The area was measured using image segmentation and object detection methods.

Once terminal points and surface area data were collected, we modeled them as a function of climate factors (collected by NOAA). We started with multiple regression model. Because multiple regression was not relevant due to nonlinear trends, we chose Generalized Additive Models [4].

Datasets



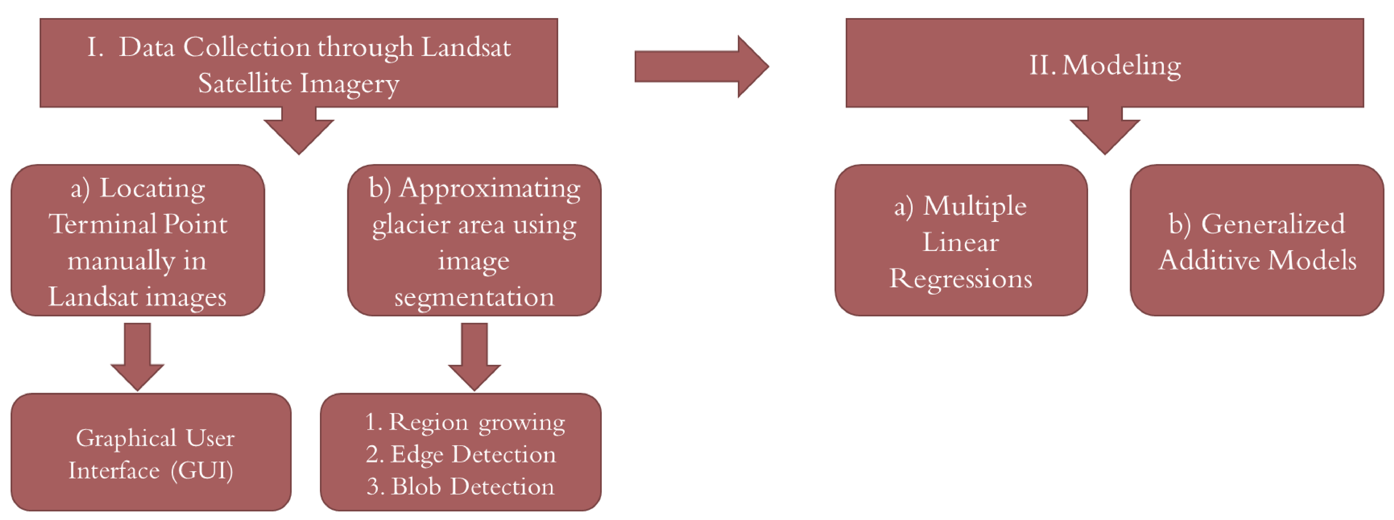
Landsat imagery – Franz Josef glacier (top), Gorner glacier (bottom) -- from left to right: color image from Google Earth; Landsat band 1, Landsat band 5, Landsat band 6

Satellite imagery received across eight different bands (42 scenes for FJ, 1973-2009) (17 scenes for Gorner, 1984-2009)

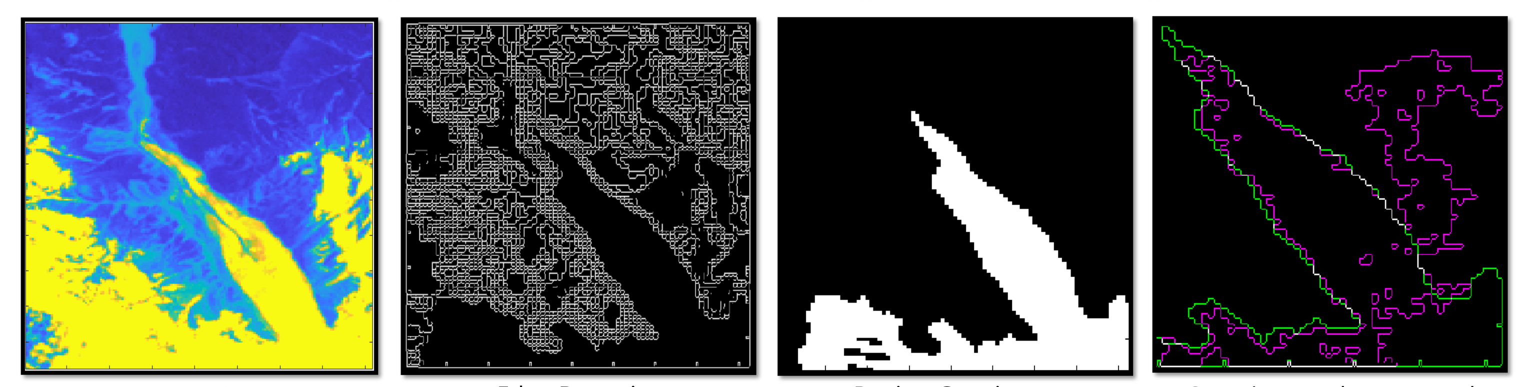
Climate data from NOAA Physical Sciences Laboratory (https://psl.noaa.gov/boulder/)

Bands	Wavelength (µm)	Resolution (m)
Band 1 – Blue	0.45 – 0.52	30
Band 2 – Green	0.52 – 0.60	30
Band 3 – Red	0.63 – 0.69	30
Band 4 – Near Infrared	0.77 – 0.90	30
Band 5 – Shortwave Infrared 1	1.55 – 1.75	30
Band 6 – Thermal	10.40 – 12.50	60
Band 7 – Shortwave Infrared 2	2.09 – 2.35	30
Band 8 – Panchromatic (entire visible)	0.52 – 0.90	15

Methods

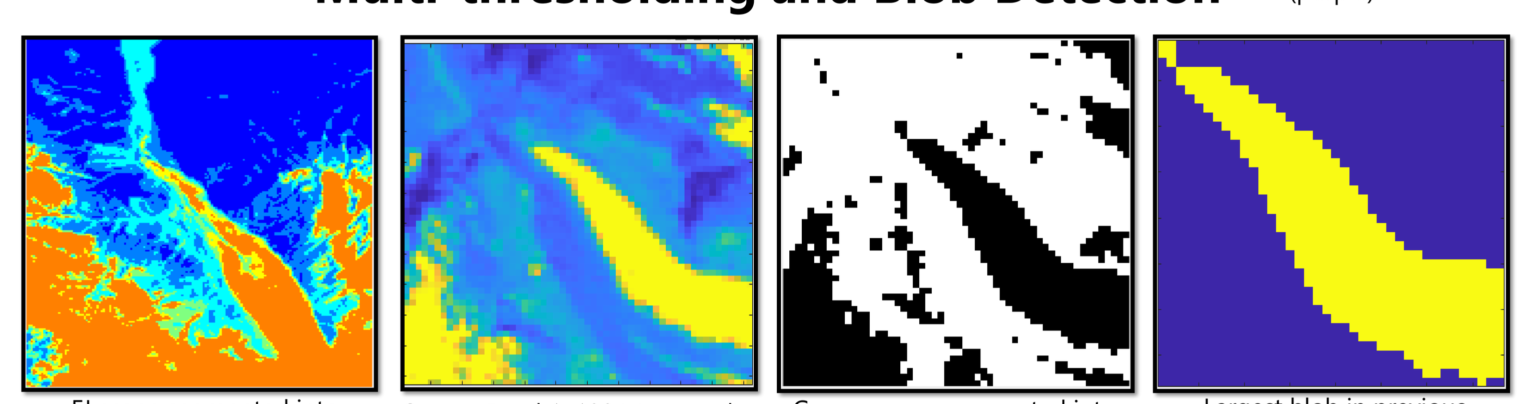


Edge Detection and Region Growing



Franz Josef, Band 1, 1990 | Edge Detection | Region Growing | Superimposed segmented scenes, 1990 (green), 2009 (purple)

Multi-thresholding and Blob Detection



FJ scene segmented into five regions | Gorner, Band 1, 1984 (cropped) | Gorner scene segmented into two regions (binarized) | Largest blob in previous image, represents glacier

Linear Regressions: Single linear models were created to understand each factor's relationship to the two response variables. Then various combinations of all the climate factors were considered in our multivariate linear model.

Generalized Additive Models: A linear combination of the smoothed functions of each factor was considered next. General additive models were performed, in which f represents our two response variables (terminal point and area).

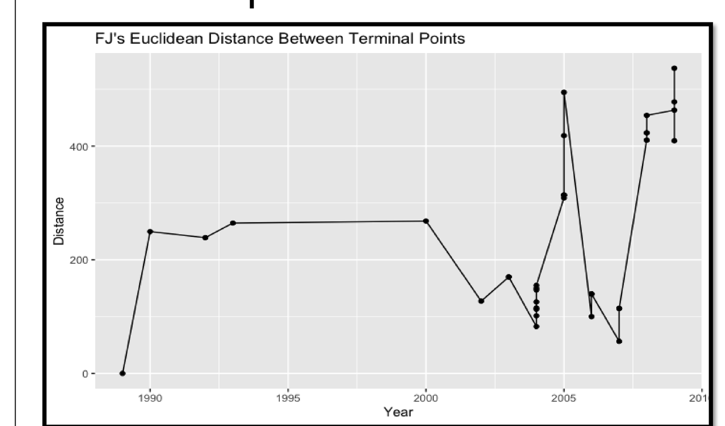
$$f = s_o + \sum_{1}^{p} s_j(X_j)$$

Each of the smoothed functions were estimated using the local log likelihood method, in which the coefficients maximize the local log likelihood.

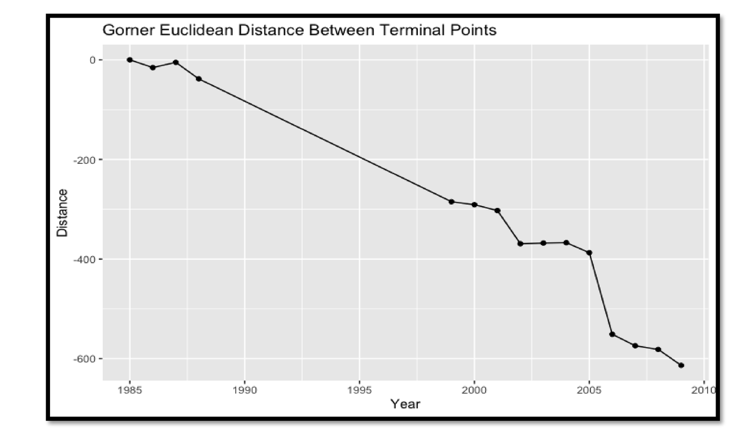
$$\hat{s}(x_i) = \hat{\beta}_{0i} + \hat{\beta}_{1i} x_i$$

Results

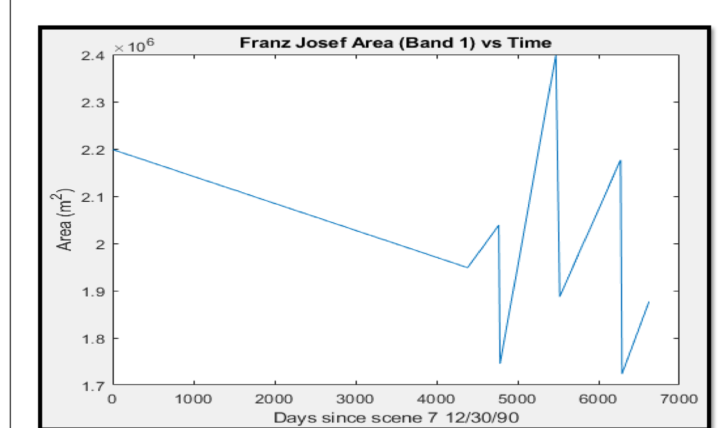
Time series for the changes of the Franz Josef and Gorner glacier's terminal point and area were created from our collected data.



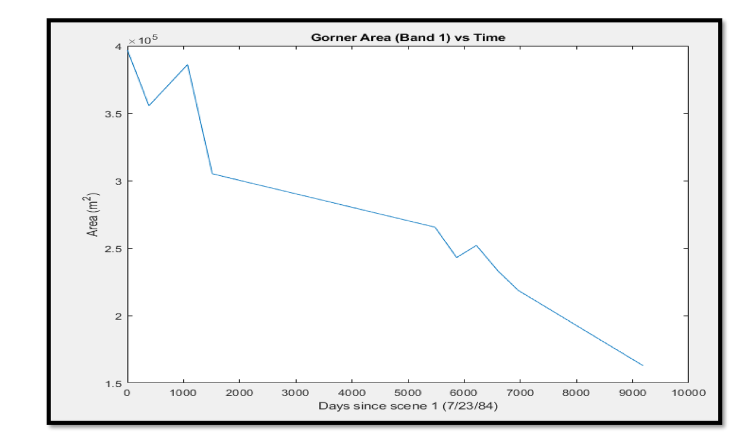
Time Series of Changes to Franz Josef's Terminal Point



Time Series of Changes to Gorner's Terminal Point

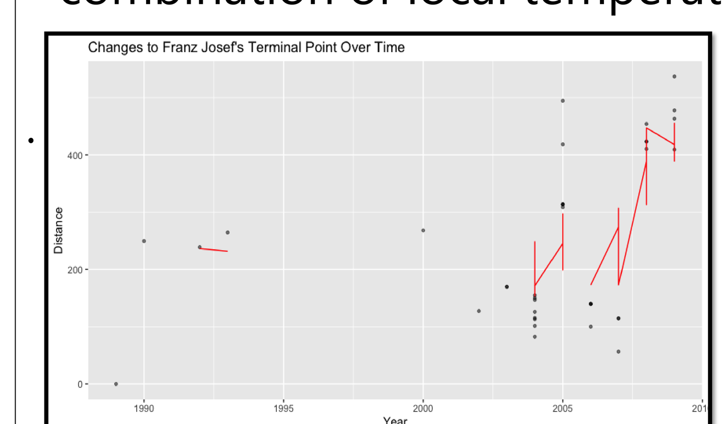


Time Series of Changes to Franz Josef's Area

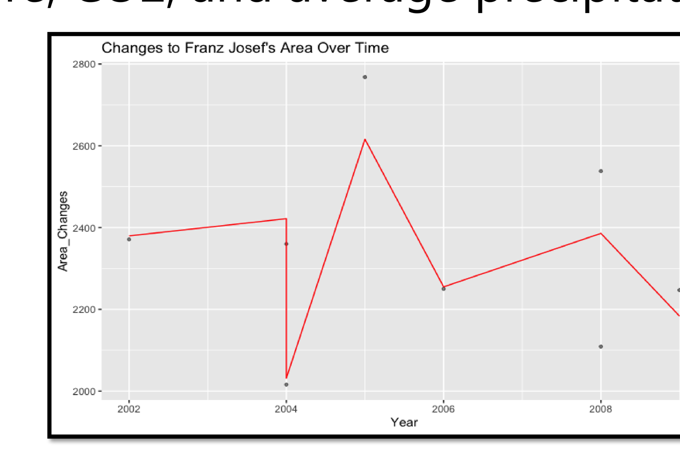


Time Series of Changes to Gorner's Area

The final additive model that worked best for Franz Josef was a combination of local temperature, CO2, and average precipitation.

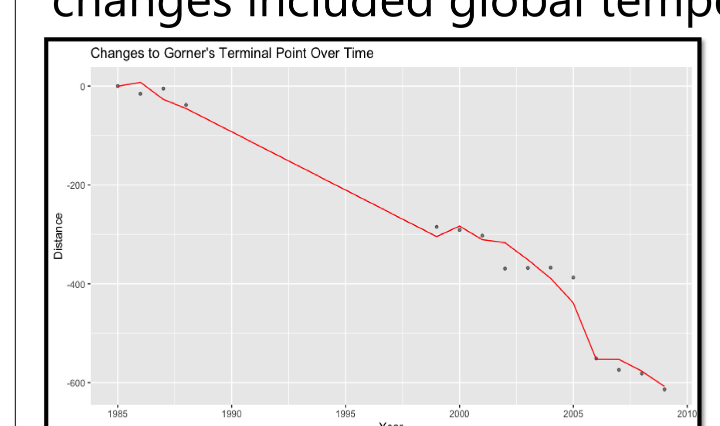


Generalized Additive Model on Franz Josef's Terminal Point

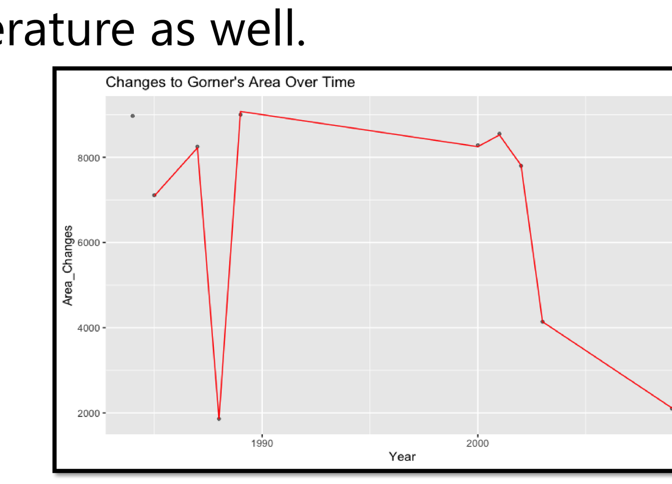


Generalized Additive Model on Franz Josef's Area

For Gorner, the optimal additive model of terminal point was local temperature, average precipitation, and CO2, while area changes included global temperature as well.



Generalized Additive Model on Gorner's Terminal Point



Generalized Additive Model on Gorner's Area

Conclusion and Discussions

Generalized additive model identified CO2, temperature, and precipitation as significant factors in explaining the variations of terminal point and area for both glaciers. We will consider including the interaction terms between the climate factors in model in our future work.

We also plan to develop an automated method for terminal point detection and glacier area quantification. To improve image segmentation, processed bands, composed of multiple Landsat bands, are being considered as a means of increasing contrast within an image. This would lead to better segmentation and more accurate pixel counts. Differences in pixel intensity distributions between bands and scenes demand a method for selecting segmentation thresholds specific to each image. Filling in gaps within segmented glacier areas is important as to have more accurate pixel counts and therefore area measurements. The computational cost of the entire process demands a method for efficient data cleaning in the preprocessing phase.

References

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(2) Kachouie, N., Gerke, T., Huybers, P. and Schwartzman, A., 2015. Nonparametric Regression for Estimation of Spatiotemporal Mountain Glacier Retreat From Satellite Images. *IEEE Transactions on Geoscience and Remote Sensing*, 53(3), pp.1135-1149.

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(4) Hastie, T. and Tibshirani, R., 1986. Generalized Additive Models. *Statistical Science*, 1(3).