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 multipated regression was not relevant due to nonlinear trends, we chose Generalized Additive Models [4].

### Datasets

| Datasets |
|-----------------|-----------------|
| Landsat imagery - Franz Josef glacier (top) | Landsat imagery - Gorner glacier (bottom) |
| Sentinel-2 imagery (left to right) | Google Earth Imagery (left to right) |

### Methods

#### I. Data Collection through Landsat Satellite Imagery

- a) Locating Terminal Point manually in Each Image
- b) Apprxiimating glacier area using image segmentation
- c) Region growing
- d) Generalized Additive Model

#### II. Modeling

- a) Multiple Linear Regressions
- b) Generalized Additive Models

### Edge Detection and Region Growing

- **Franz Josef Band 1 1996**
- **Edge Detection**
- **Region Growing**
- **Superimposed segmented image, 2009 (purple)**

### Results

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

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

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

### 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 a generalized model for the 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.