# GLACIER RECESSION

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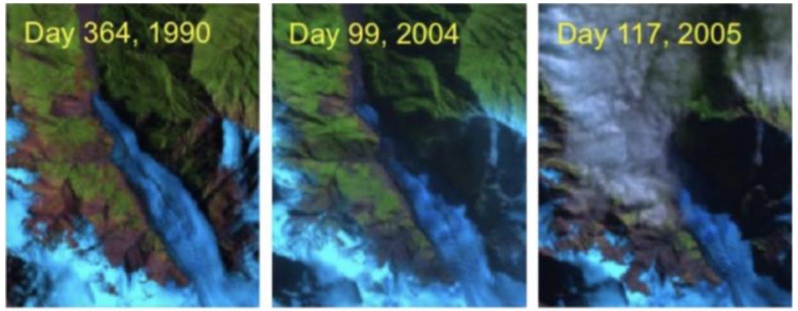
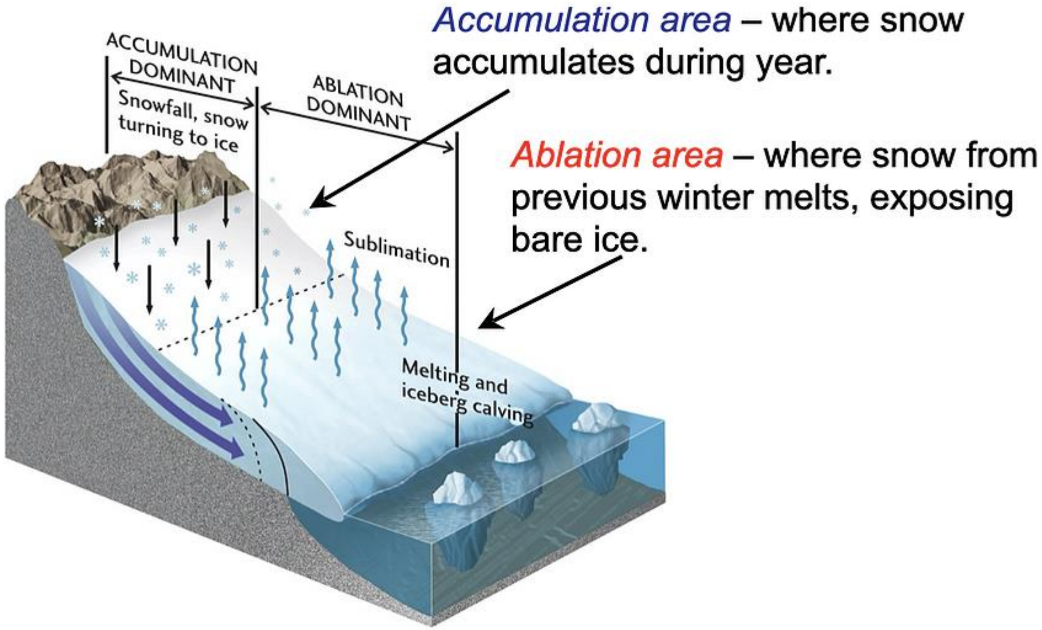
# INTRODUCTION

Using satellite images to analyze the mountain glaciers' variation over time and investigate the potential relation to climate factors, including temperature, $CO_2$, and precipitation.



# GLACIER BASICS

## Accumulation vs. Ablation Periods




## Glacier Terminal Point

# LITERATURE REVIEW

**Quantifying Area:**" *Localization of mountain glacier termini in Landsat multi-spectral images* "

ARTICLE IN PRESS

Pattern Recognition Letters

Localization of mountain glacier termini in Landsat multi-spectral images

Nezamoddin N. Kachouie, Peter Huybers, Armin Schwartzman

**Modeling :**"*Multivariate models for predicting glacier termini*"

Environmental Earth Sciences (2017) 76:807
https://doi.org/10.1007/s12665-017-7135-2

ORIGINAL ARTICLE

## Multivariate models for predicting glacier termini

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**Abstract**
Concerns over the rapid retreat rates of mountain glaciers have been rising as global temperatures have continued to increase. The extent of variation in the retreat of mountain glaciers can provide information about changes to different climatic conditions. Assessing the retreat rates of glaciers is crucial to assess the continuing existence of mountain glaciers and the ramifications of those retreats on water security for human societies. Therefore, mathematical and statistical models for the quantification of glacier dynamics in response to climate change are in high demand. In this research, we propose a multivariate regression model that estimates glacier change and predicts the location of glacier terminus over time, based on observed climate factors. The proposed method is applied to temporal sequences of ground observations for a number of glaciers around the globe. This model can potentially be used for monitoring glacier systems using climatic factors.

**Keywords** Climate change · Mountain glaciers · Statistical analysis · Regression · Multivariate models · Correlation · Prediction · Terminus location · Climate factors

### Introduction

In our previous work (Kachouie et al. 2013, 2015) we proposed a statistical method for estimating the location of a glacier terminus over time, from a sequence of Landsat multispectral satellite images, by identifying an inflection point in the glacier's path intensity profile. A new processed band (NDTSI) was introduced using B62 and NDSI for glacier studies via remote sensing that provides a better estimation than any individual Landsat spectral band. A constrained bandwidth selection method using local polynomial regression was also introduced for the detection of glacier terminus. Here we propose a model for predicting the glacier terminus location over time based on observed climatic factors. This is achieved by applying multivariate regression to the temporal sequence of observed terminus locations using climatic factors.

The definition of climate change varies from any change in climate over time (Solomon et al. 2007) to changes in climate that result from human activity (UNFCCC 1995). Climate change is used synonymously with global warming, referring to the observed rise in global surface air temperatures during the past century (Hansen et al. 2010). In their most recent and Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), a body of work by thousands of scientists worldwide concluded that "Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems" (Pachauri et al. 2014). These impacts include global sea-level rise; ocean acidification; shrinking glaciers; changes to hydrologic cycles; smaller crop yields; more heat waves, droughts, and floods; and numerous other changes to natural and biological

**Electronic supplementary material** The online version of this article (https://doi.org/10.1007/s12665-017-7135-2) contains supplementary material, which is available to authorized users.

Osita Onyejekwe, Bryan Holman, and Nezamoddin N. Kachouie have contributed equally to this work.

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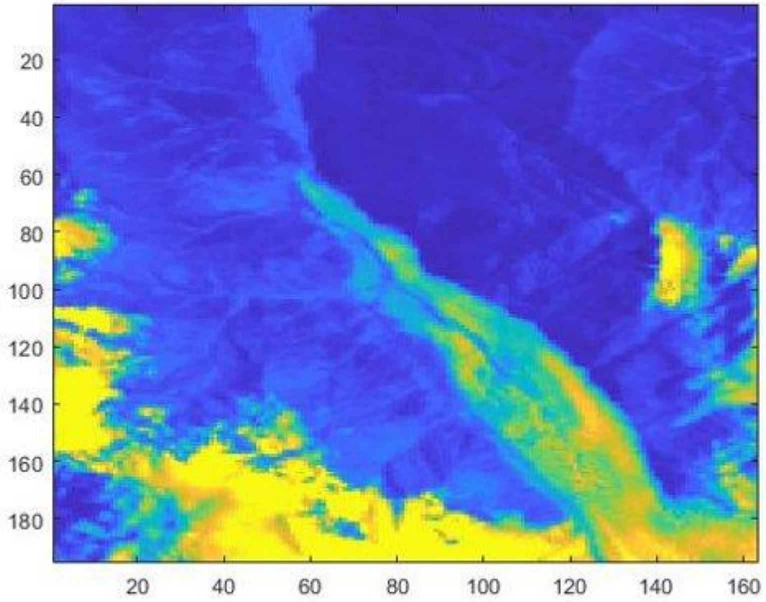
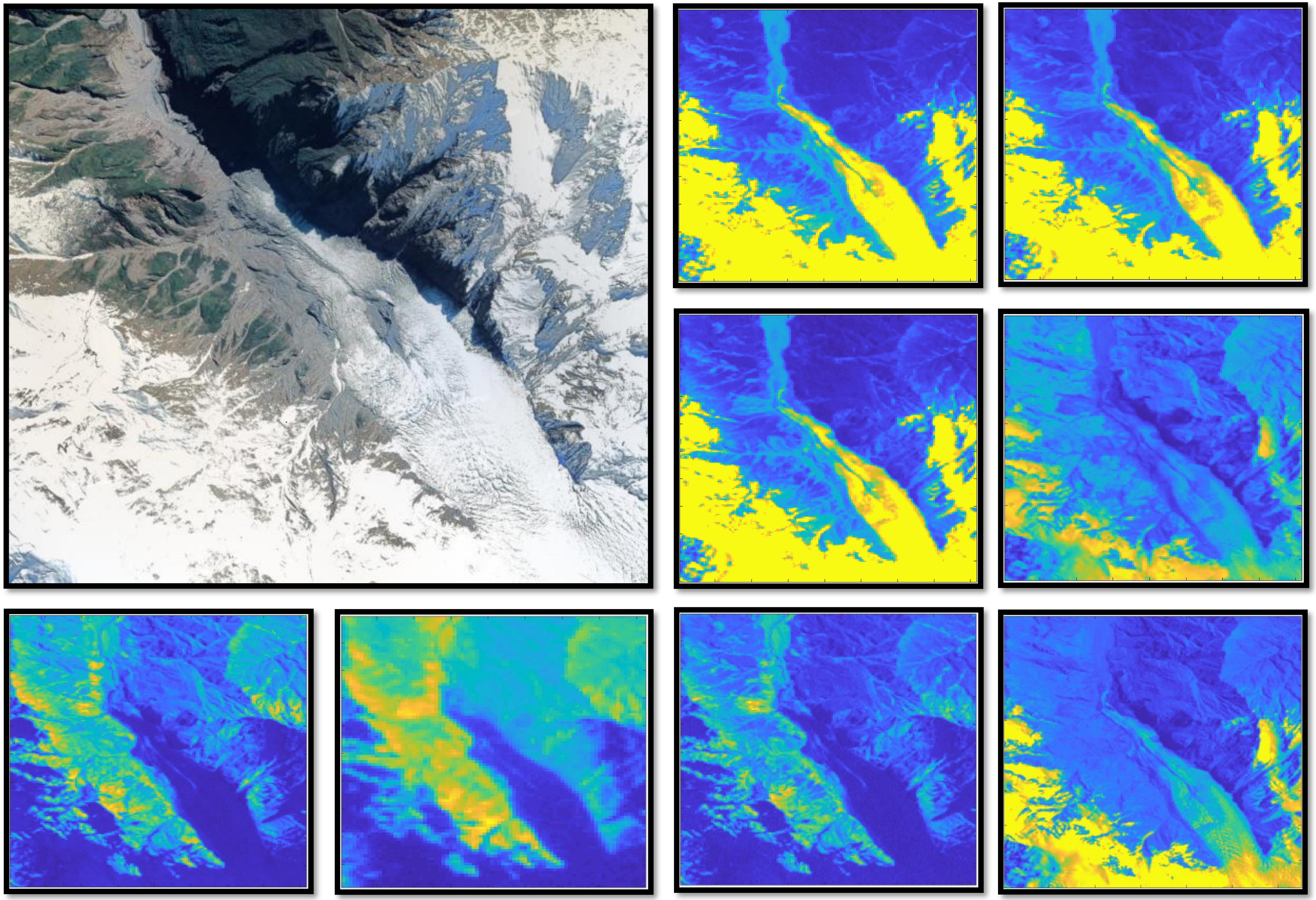
# DATASETS

**Landsat 8 Satellite Images**

Processed as a tif file without geographical information




| 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 |



L to R: Google Earth image of Franz Josef, blue band, green band

L to R: red band, near infrared (IR) band

L to R: shortwave (SWIR) band 1, thermal band, SWIR band 2, panchromatic band (entire visible spectrum)

# CLIMATE DATA

We gathered daily climate data from a weather station closest to each glacier from NOAA.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NOAA
U.S. DEPARTMENT OF COMMERCE

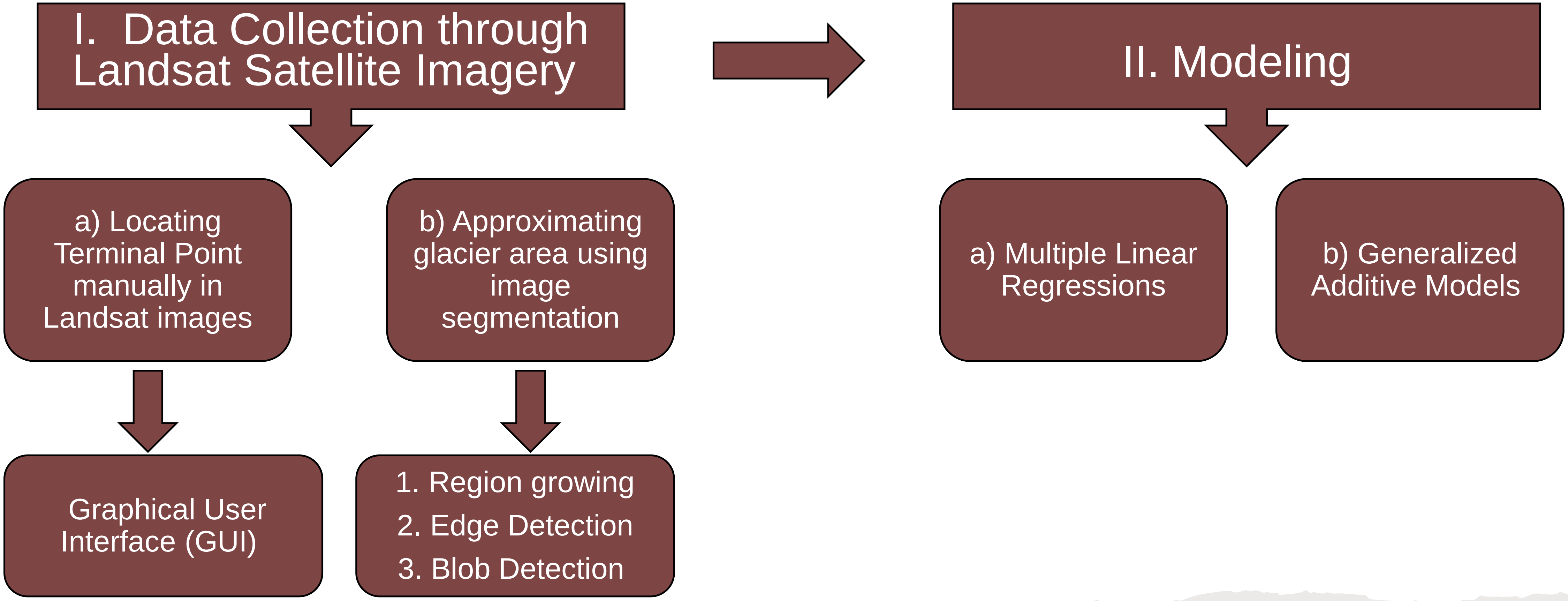

Daily Temperature Data

Daily Precipitation Data

# HYPOTHESIS

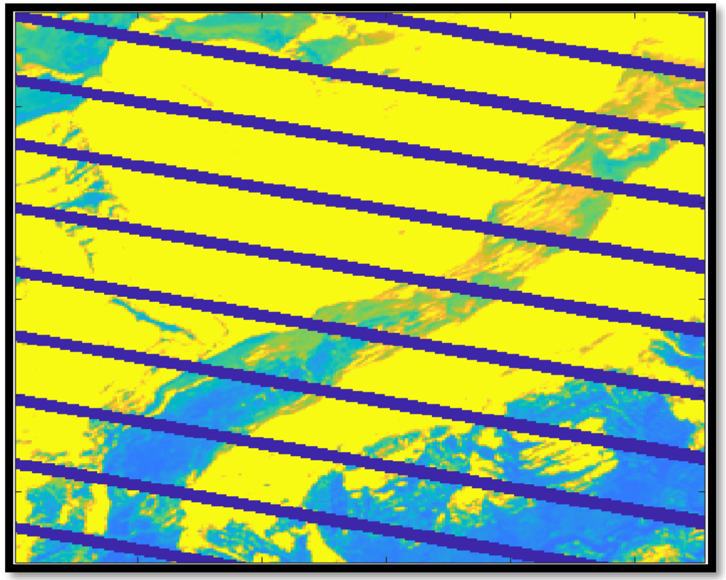
Whether mountain glacier variation is correlated with global temperature, local temperature, precipitation, and $CO_2$ (climate factors).

# SCHEMATICS

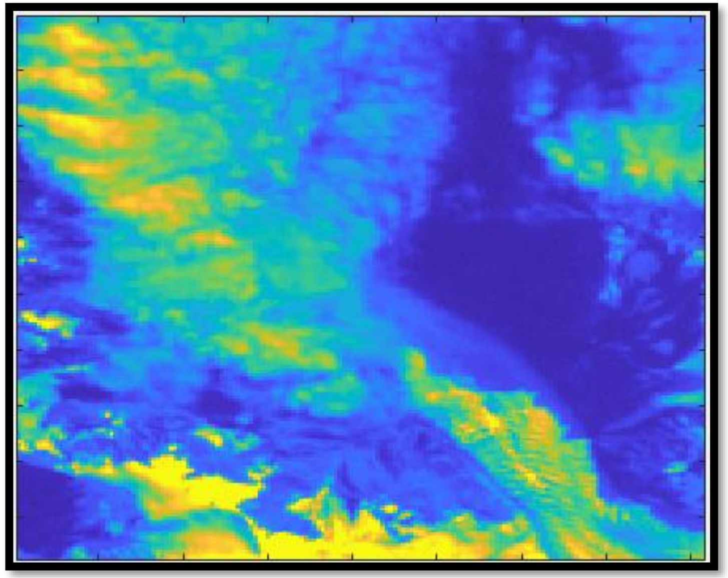

I. Data Collection through Landsat Satellite Imagery
II. Modeling
a) Locating Terminal Point manually in Landsat images
b) Approximating glacier area using image segmentation
a) Multiple Linear Regressions
b) Generalized Additive Models
Graphical User Interface (GUI)
1. Region growing
2. Edge Detection
3. Blob Detection

# PART I. DATA COLLECTION

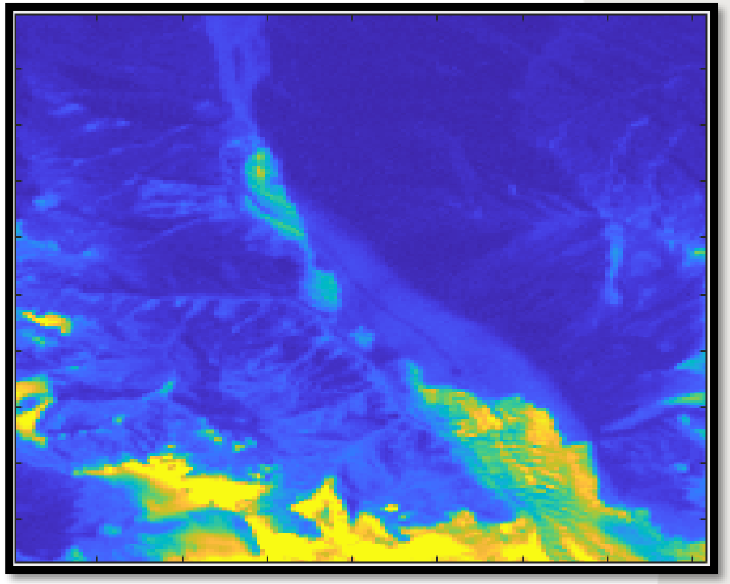
# DATA QUALITY



Gorner, corrupted by a sensor malfunction



Franz Josef, obscured by clouds



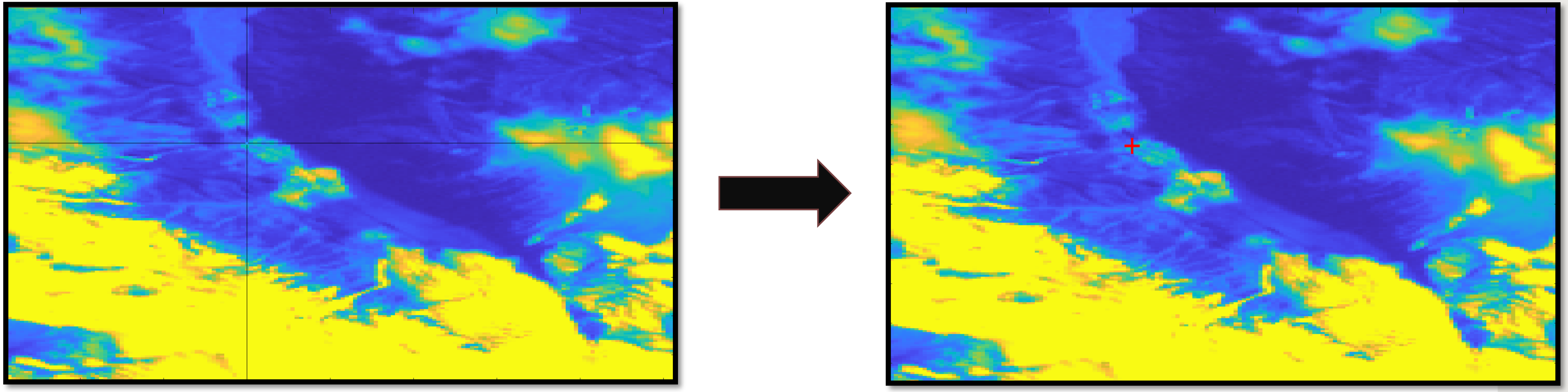
Franz Josef, obscured by shadows

Franz Josef – 42 scenes, 37 usable for terminal point detection, 9 usable for area measurement

Gorner – 17 scenes, 15 usable for terminal point detection, 10 usable for area measurement


TERMINAL
POINT

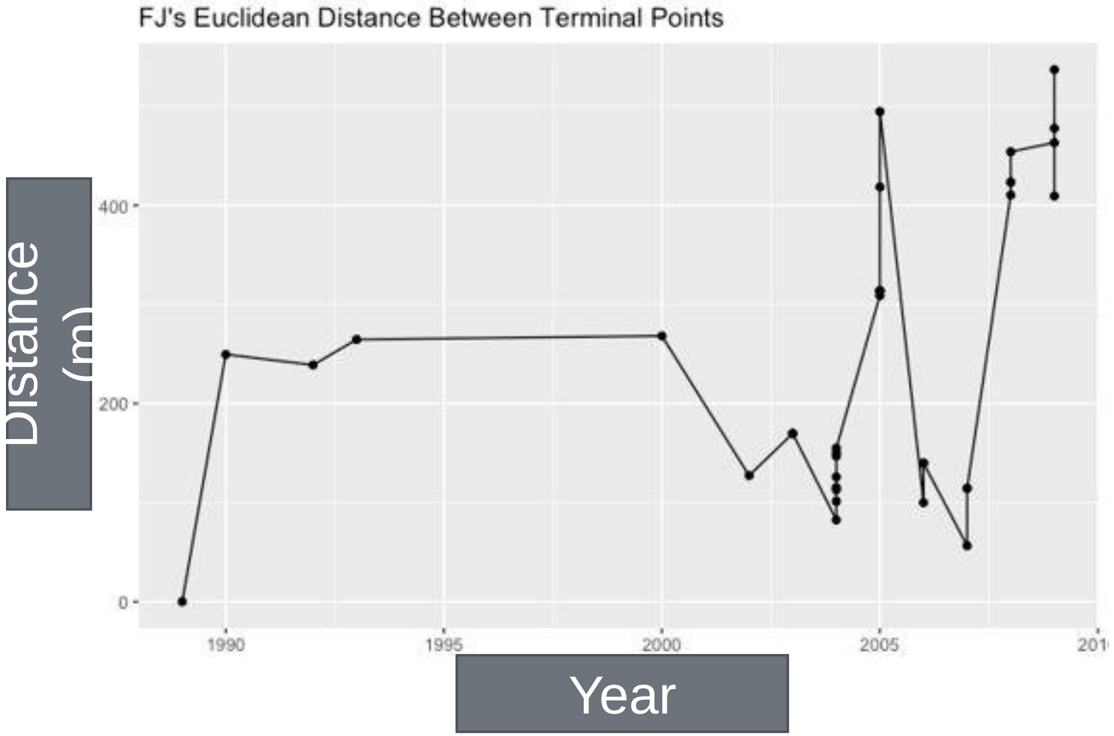
# MATLAB GUI

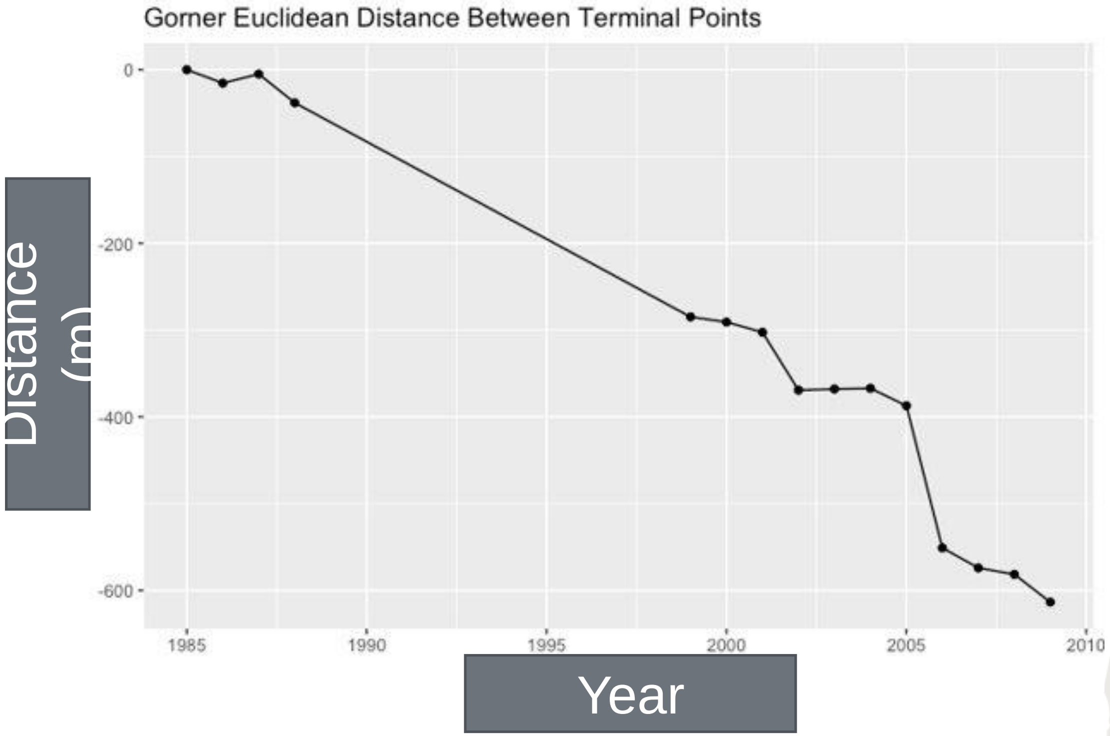


A graphical user interface (GUI) allows us to plot the satellite images against an arbitrary graph and manually estimate the location

# TERMINAL POINT VARIATIONS

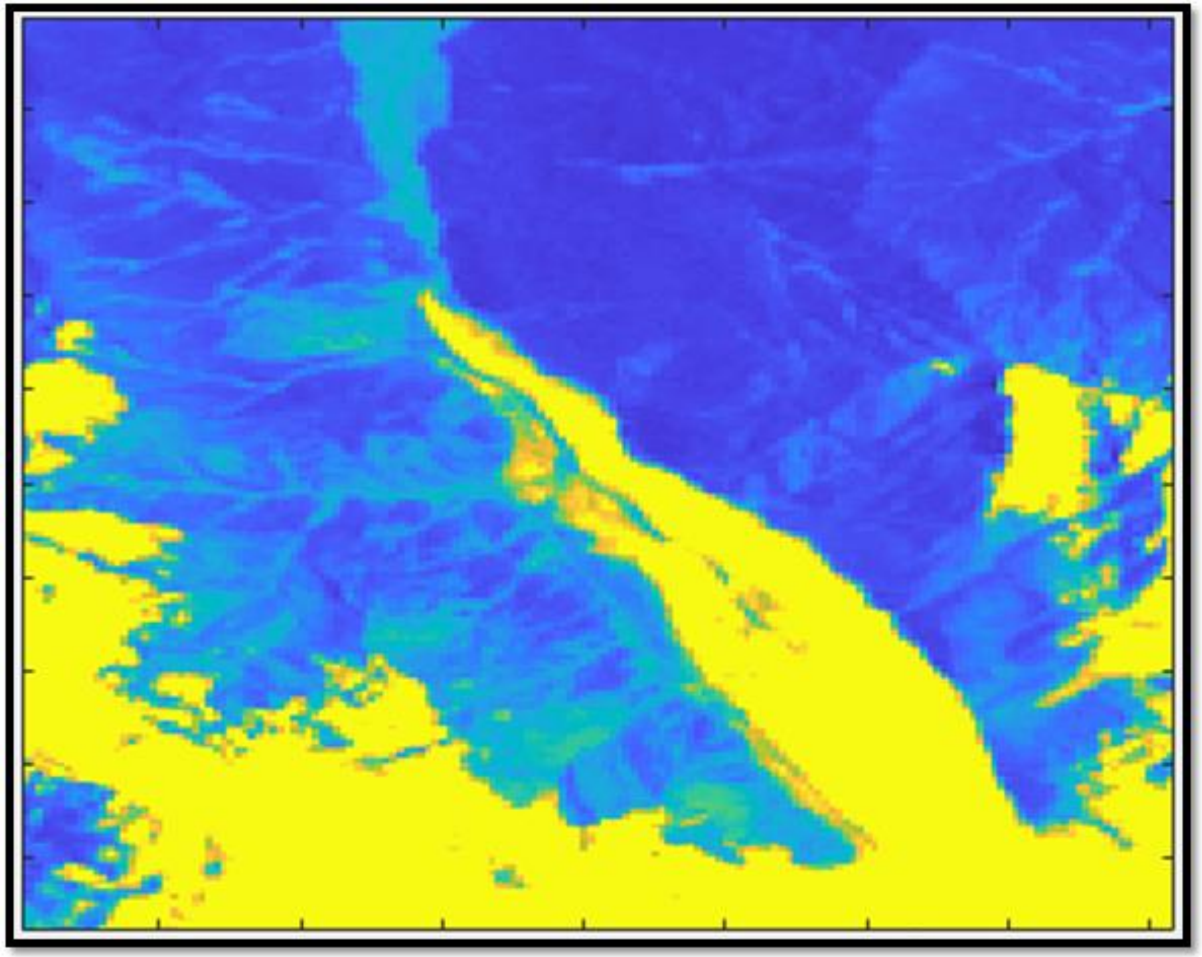
We plotted a time series of the distances between consecutive terminal points for both glaciers



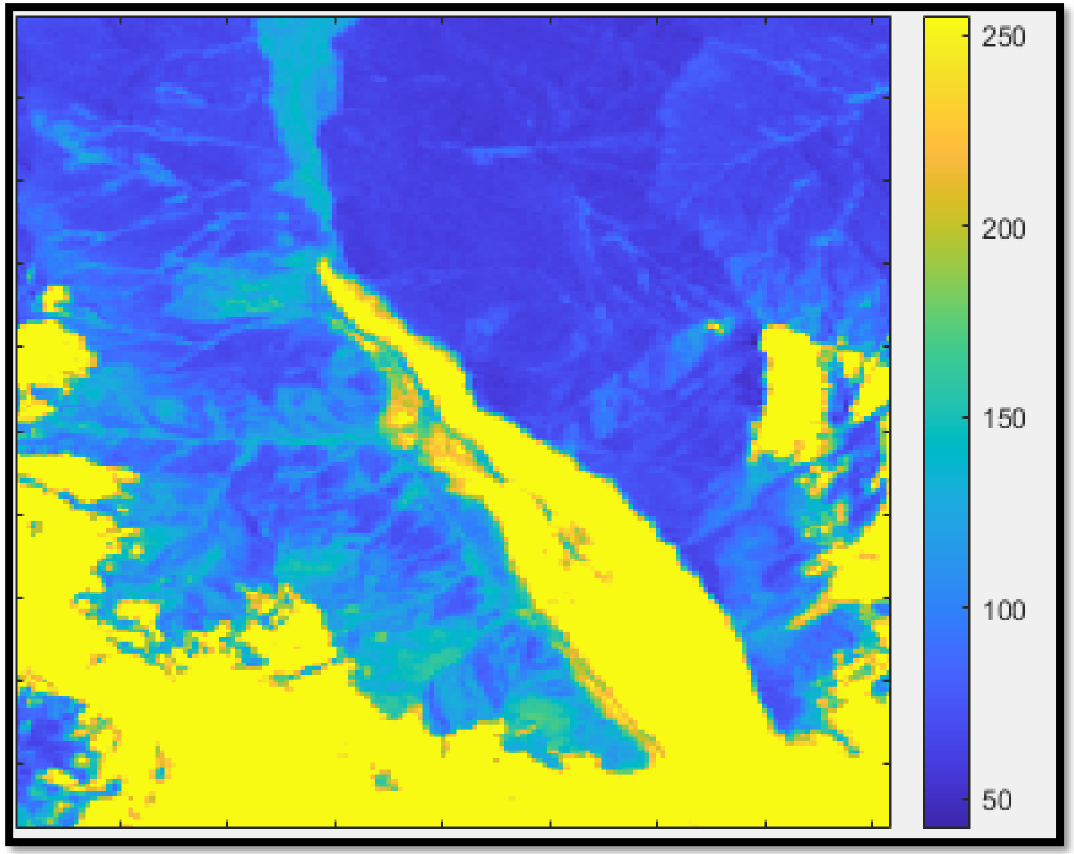
# AREA

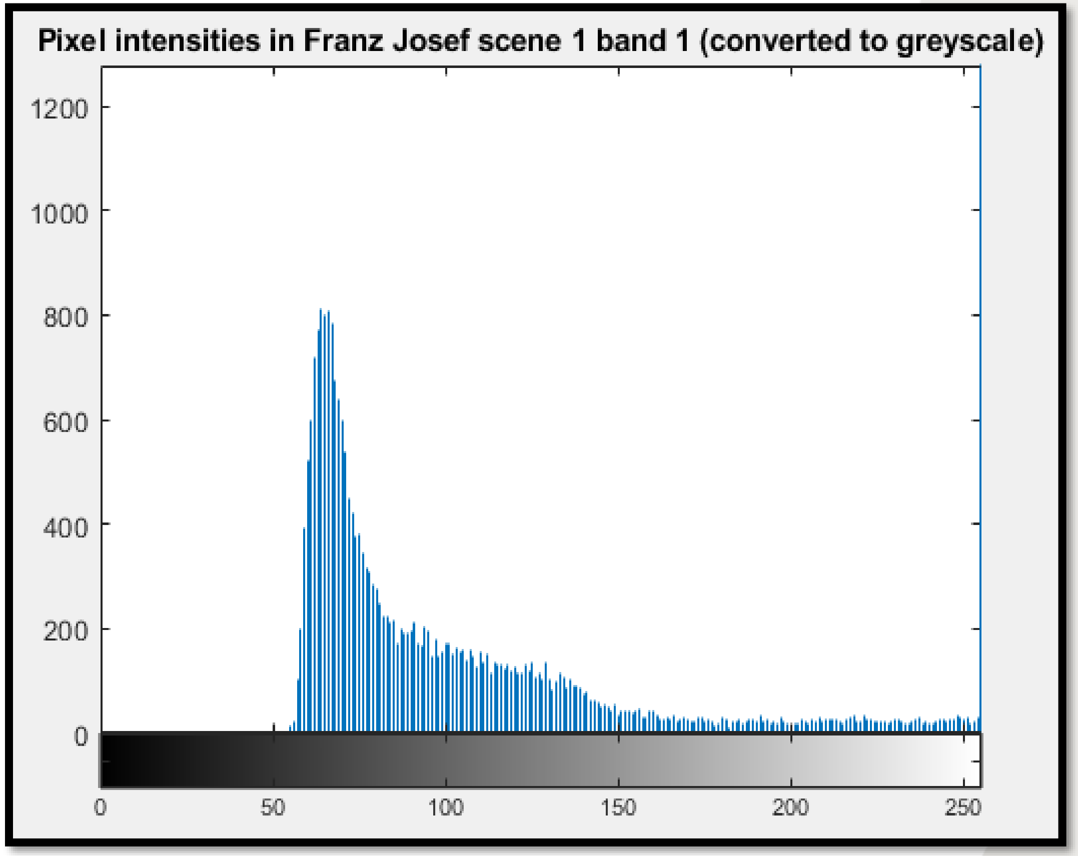
# MEASURING AREA



Simple idea – count pixels that make up the glacier and multiply by image resolution to get area

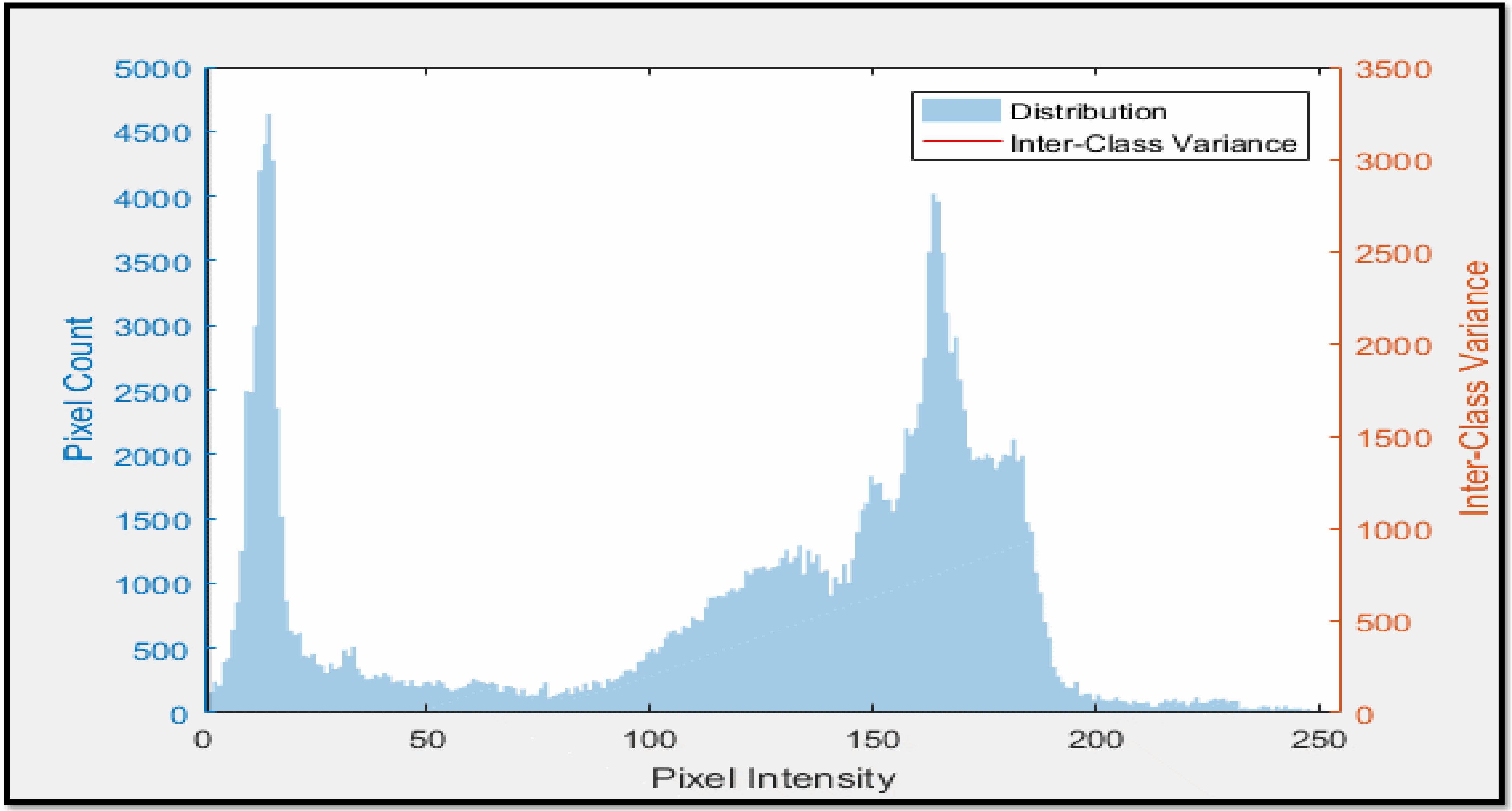
# IMAGE SEGMENTATION



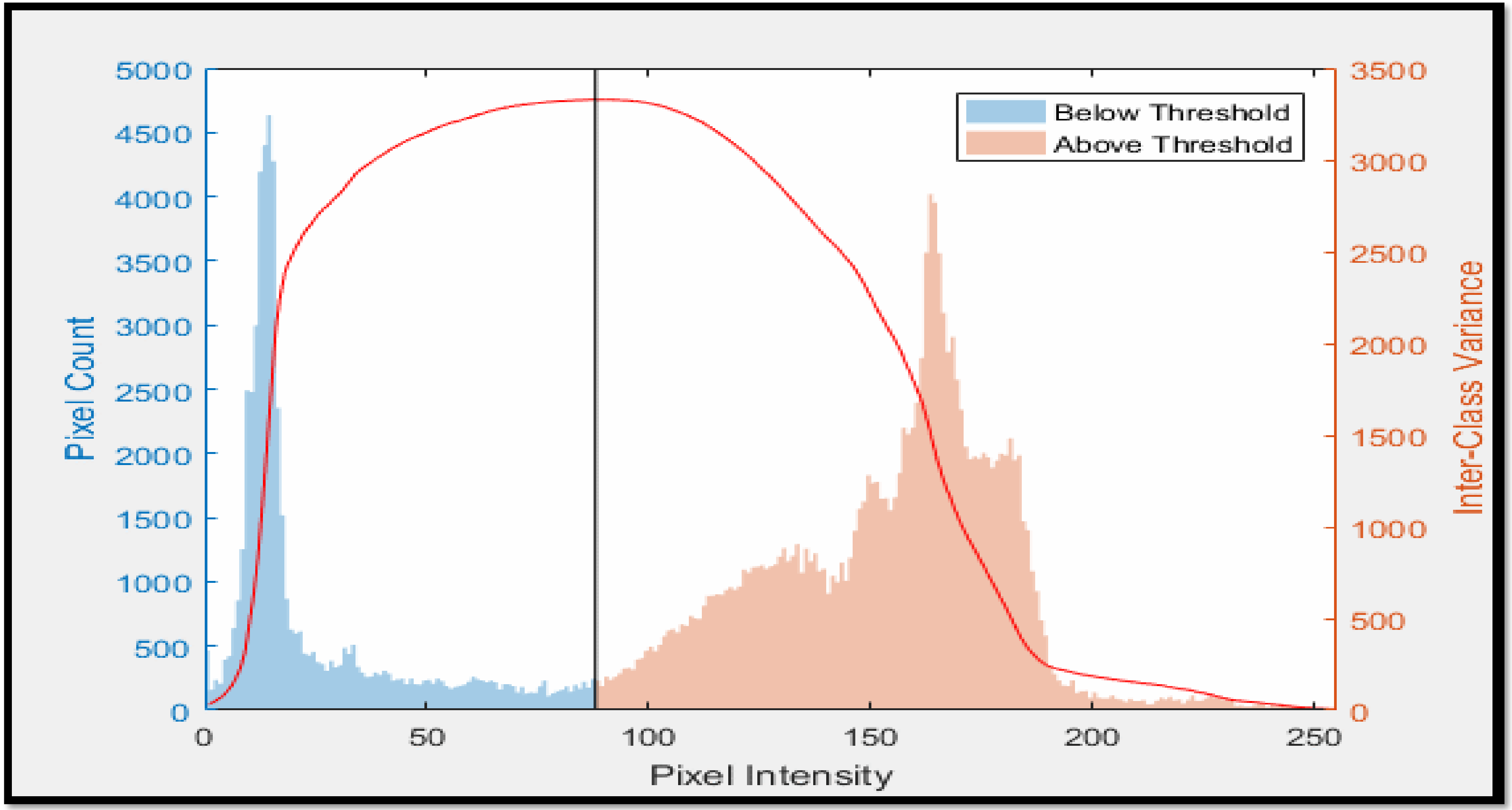

Images exist as matrices of pixel intensities

# IMAGE SEGMENTATION



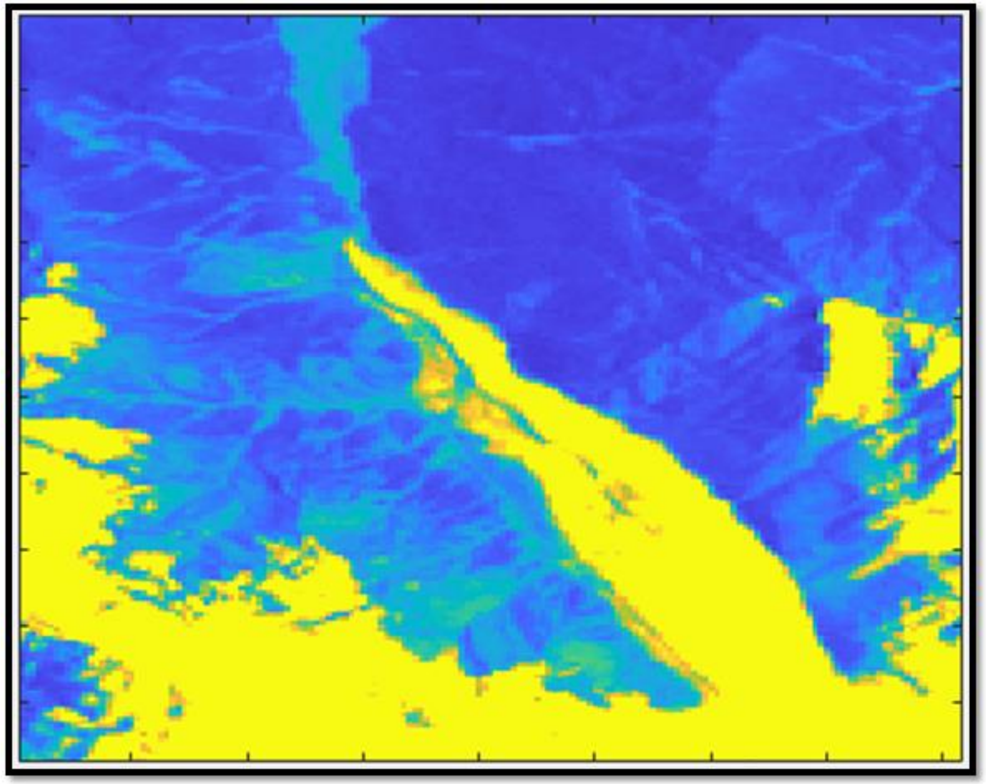

Otsu's method

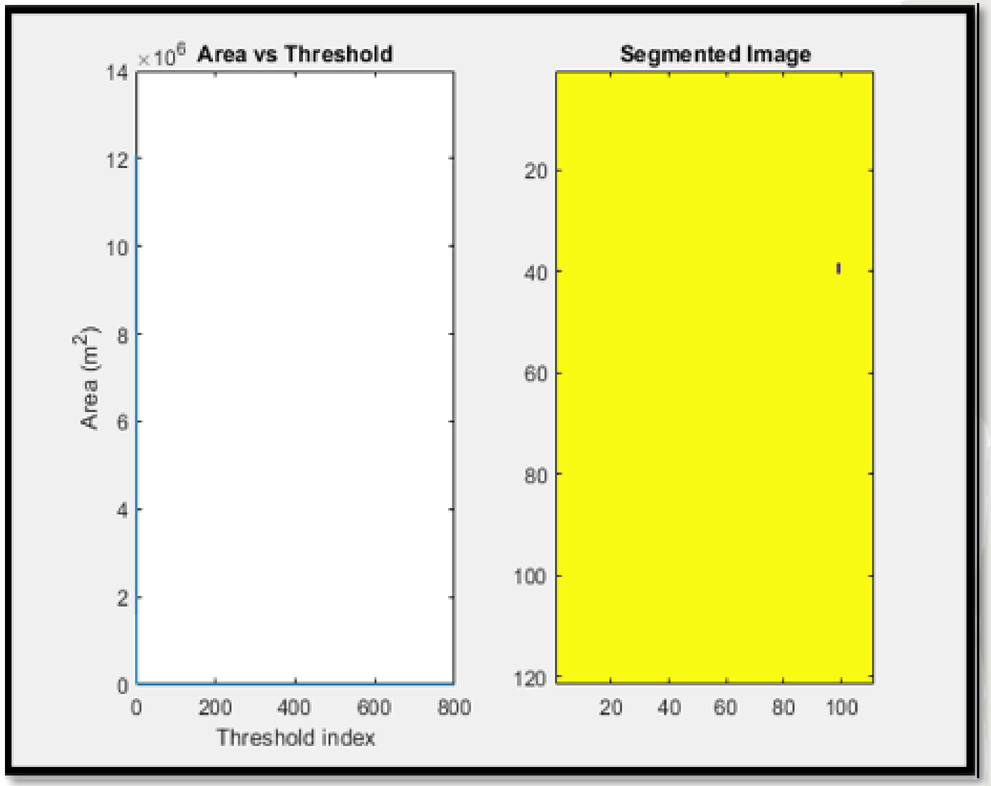
# IMAGE SEGMENTATION




Otsu's method

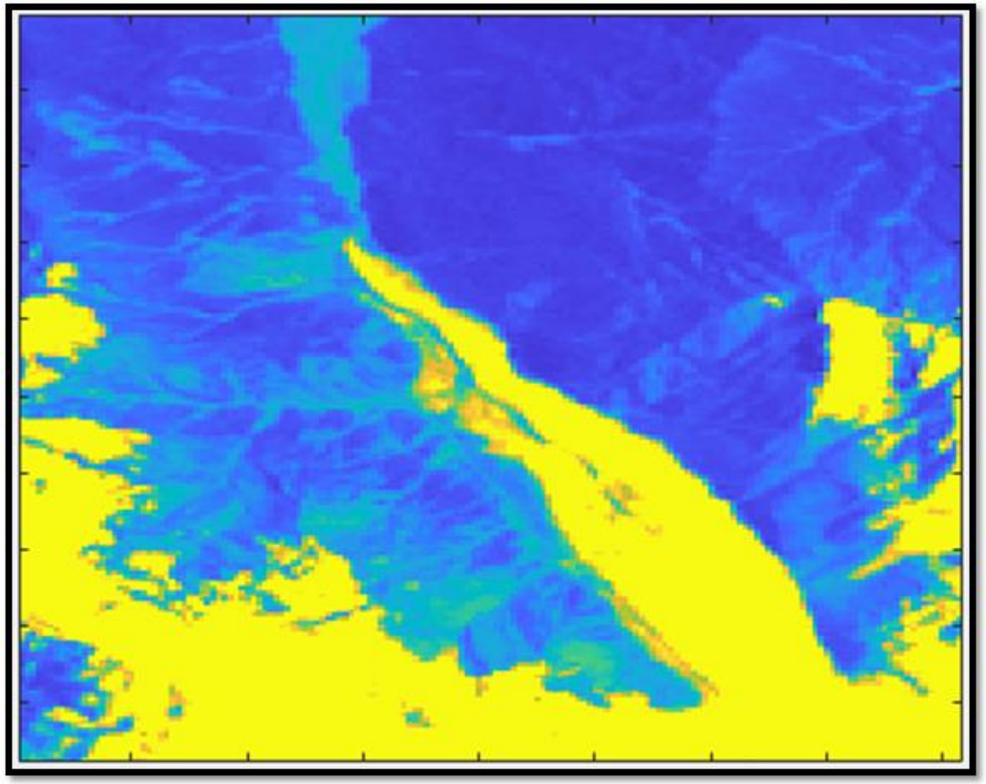
# IMAGE SEGMENTATION

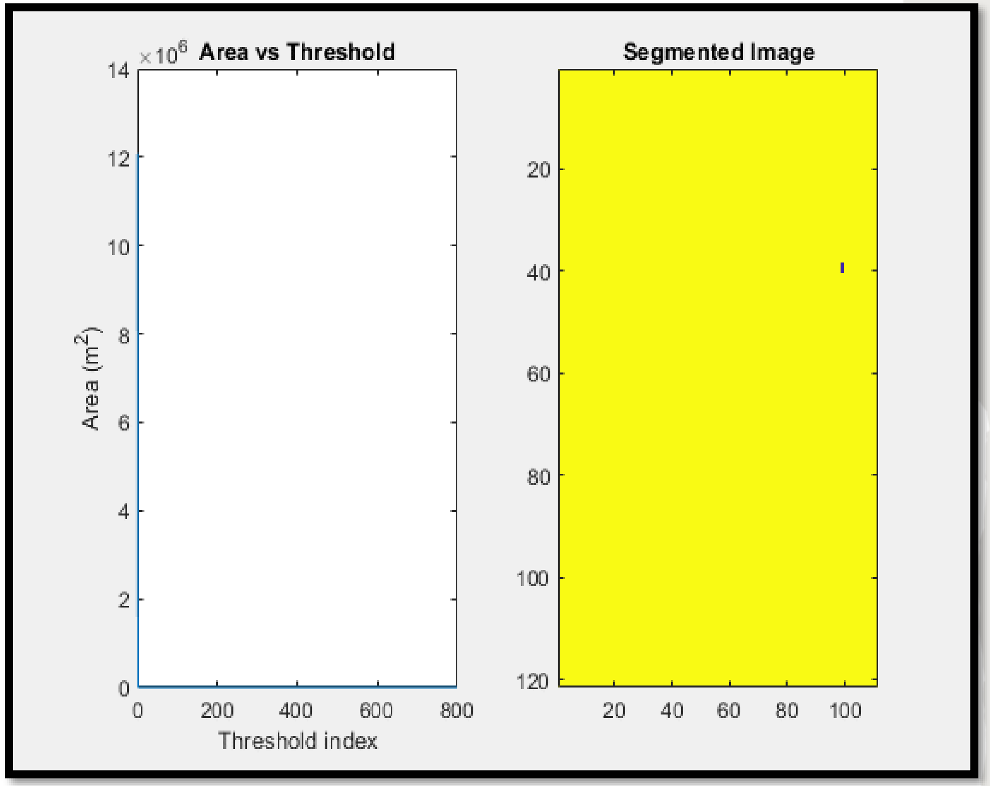





Images are segmented into different regions based on a threshold for the difference between pixel intensities in those regions

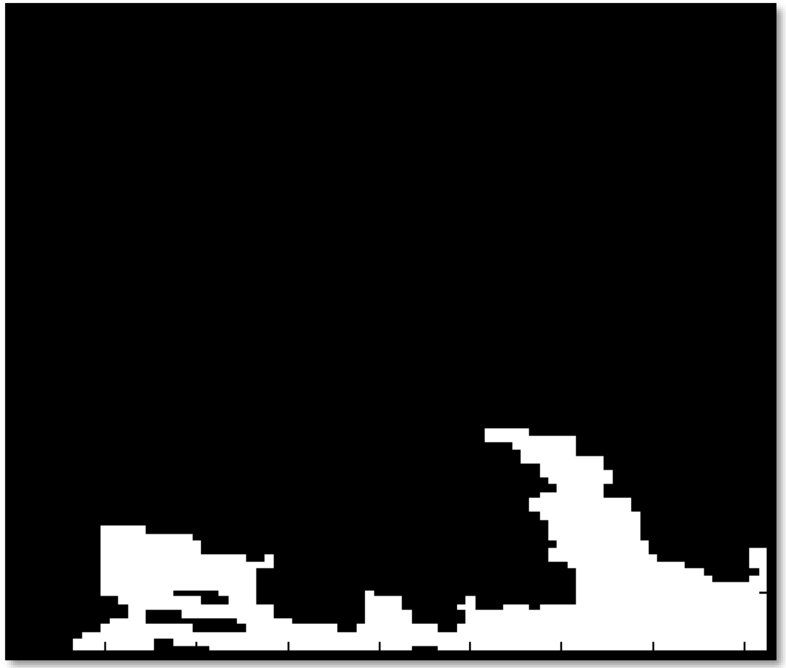
# IMAGE SEGMENTATION





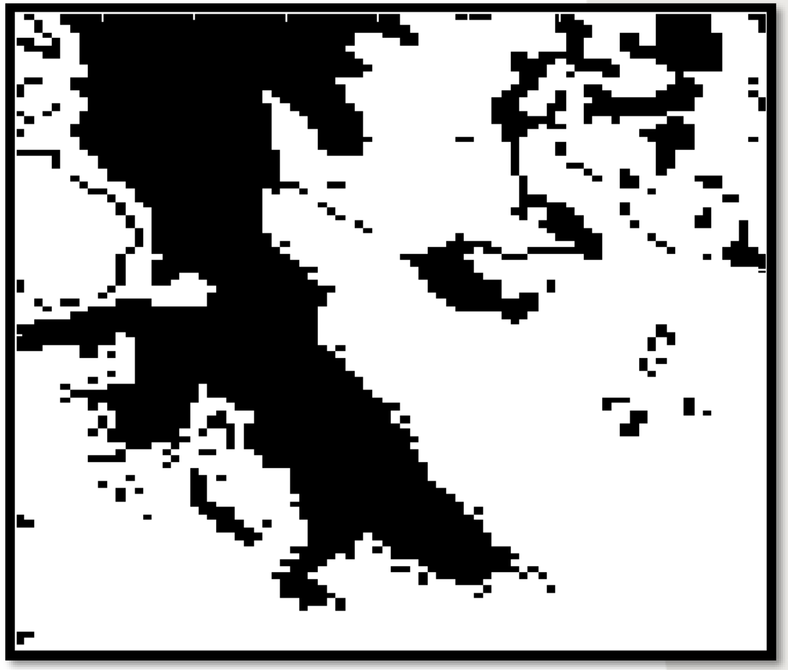

Images are segmented into different regions based on a threshold for the difference between pixel intensities in those regions

# REGION GROWING



Too little glacier

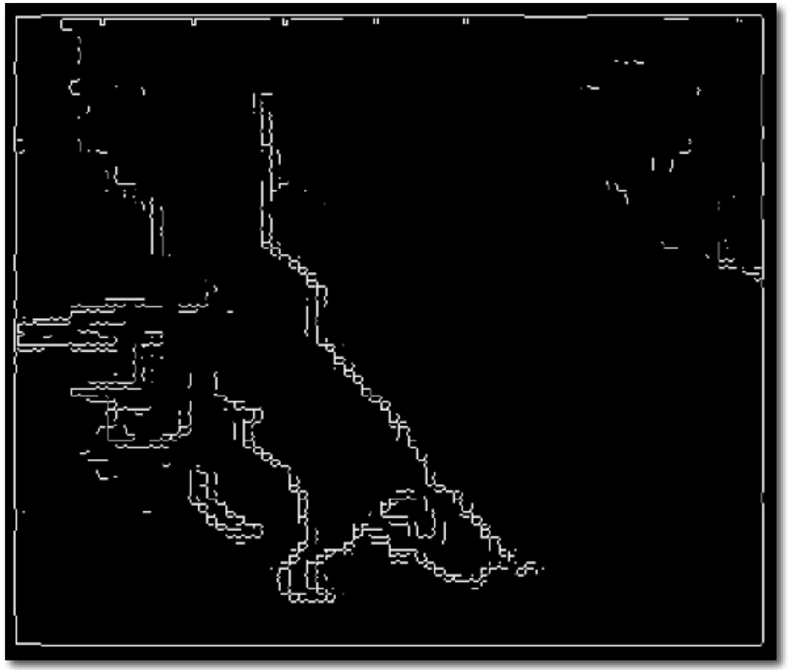
Good segmentation!



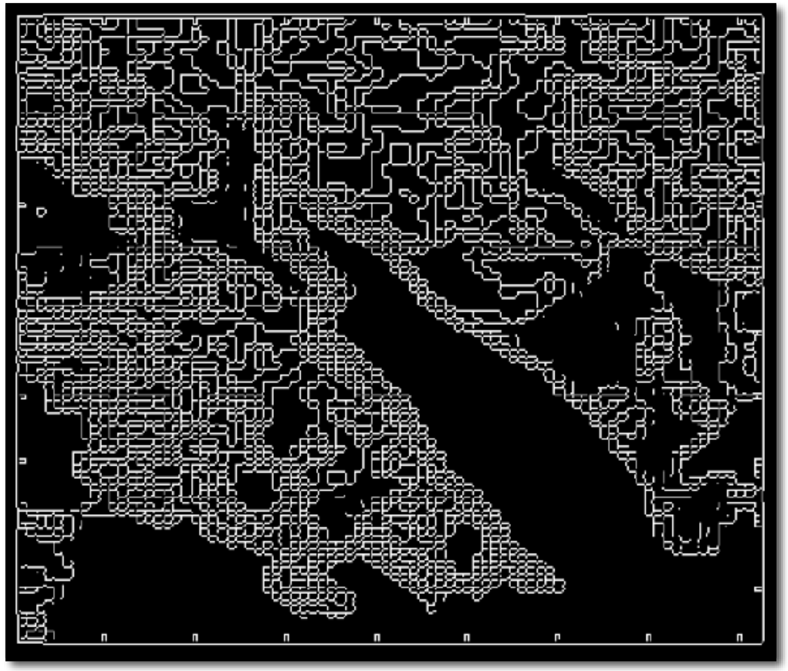
Too many surroundings

Pick a pixel within the glacier and have it grow based on differences in pixel intensity

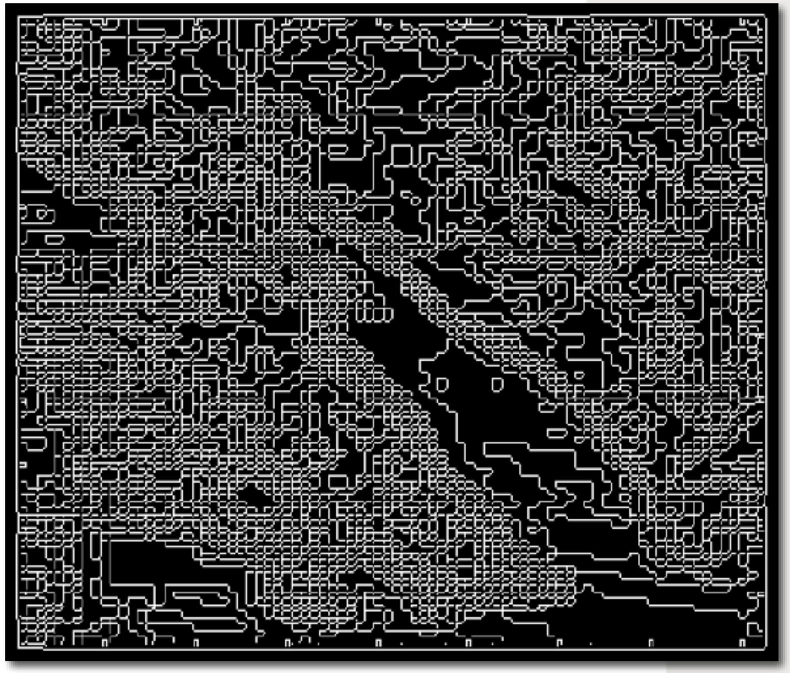
# EDGE DETECTION



Glacier not fully outlined



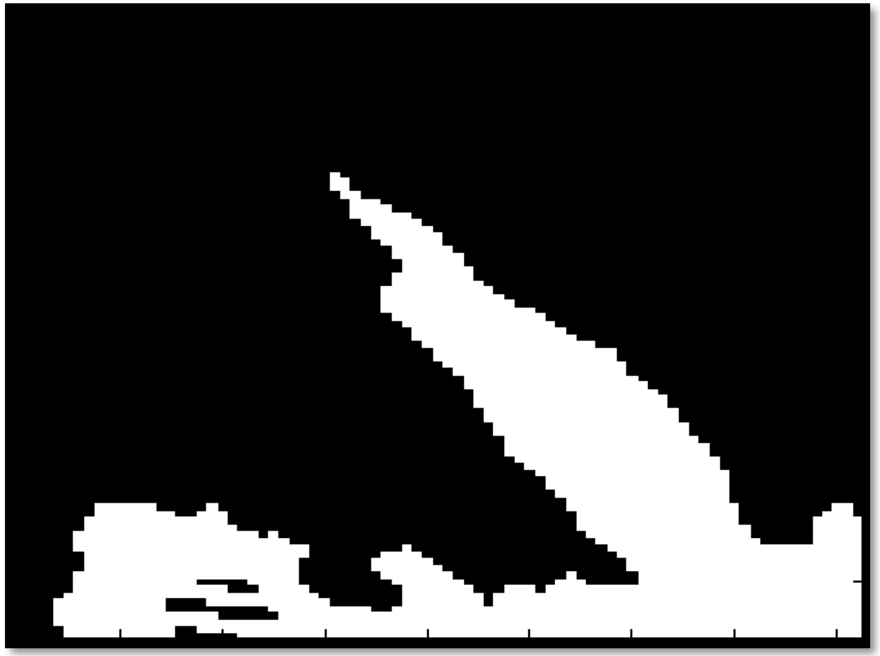
Good outline!

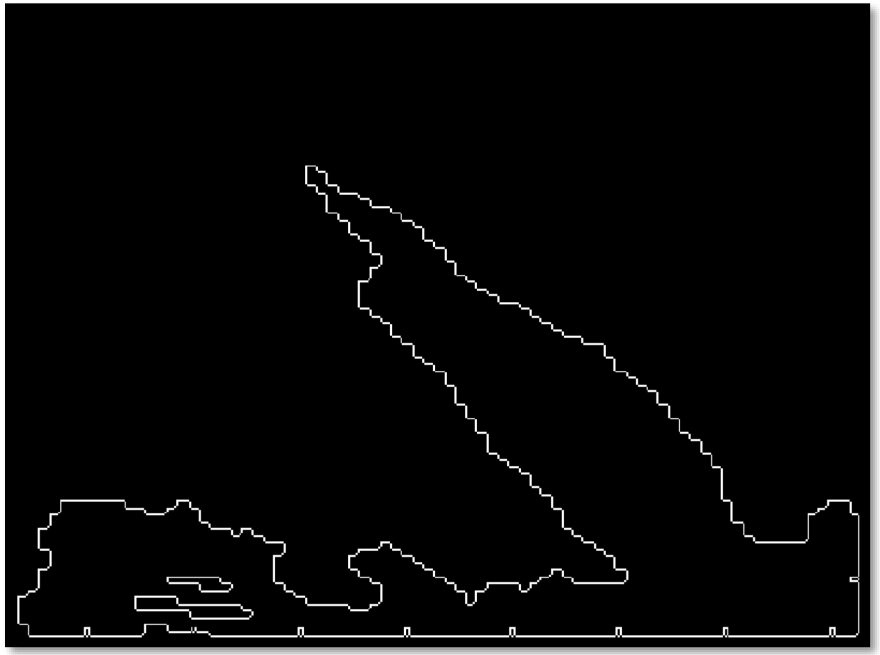


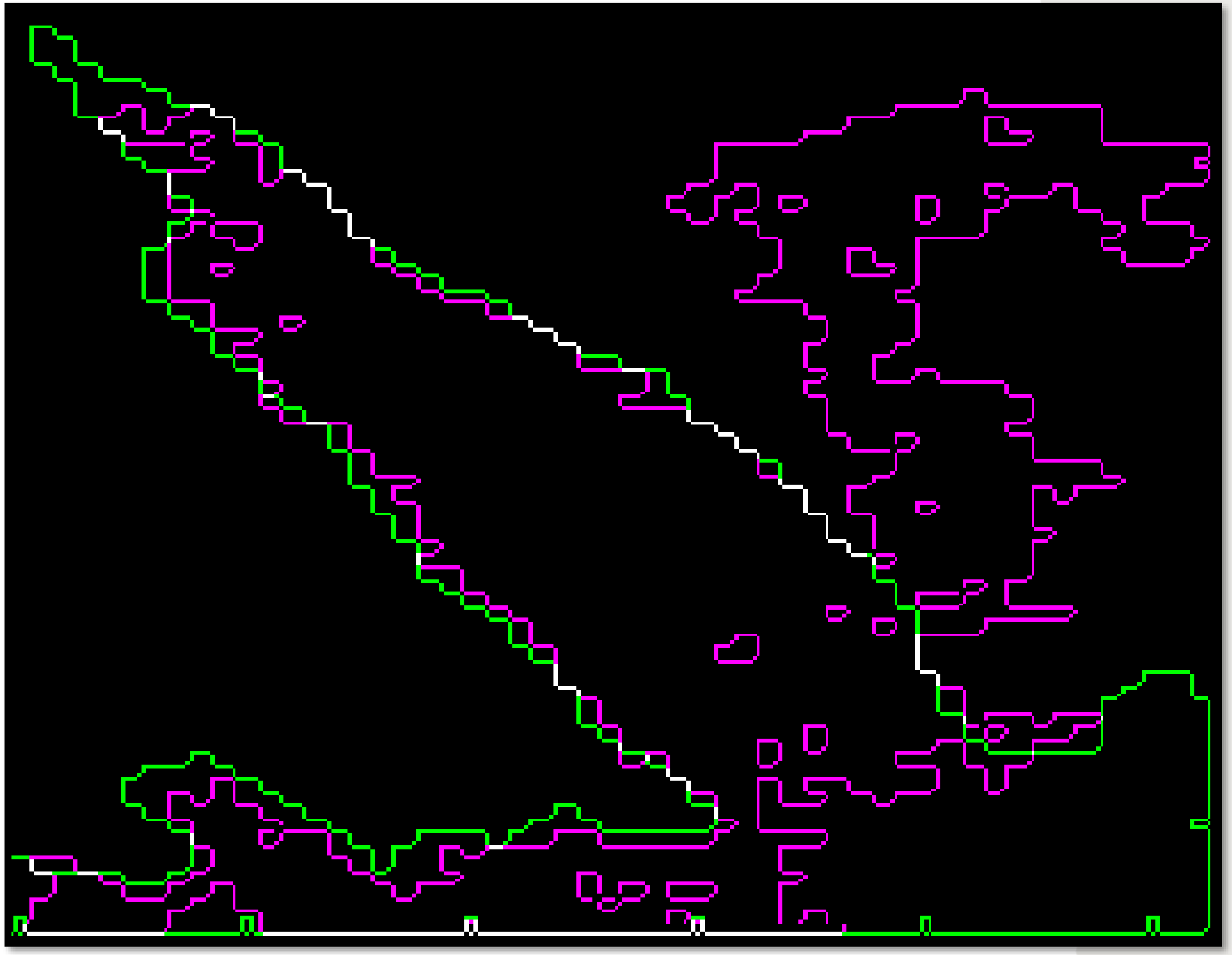
Glacier is broken up

Edges are defined by differences in the intensities of adjacent pixels

# COMBINING METHODS

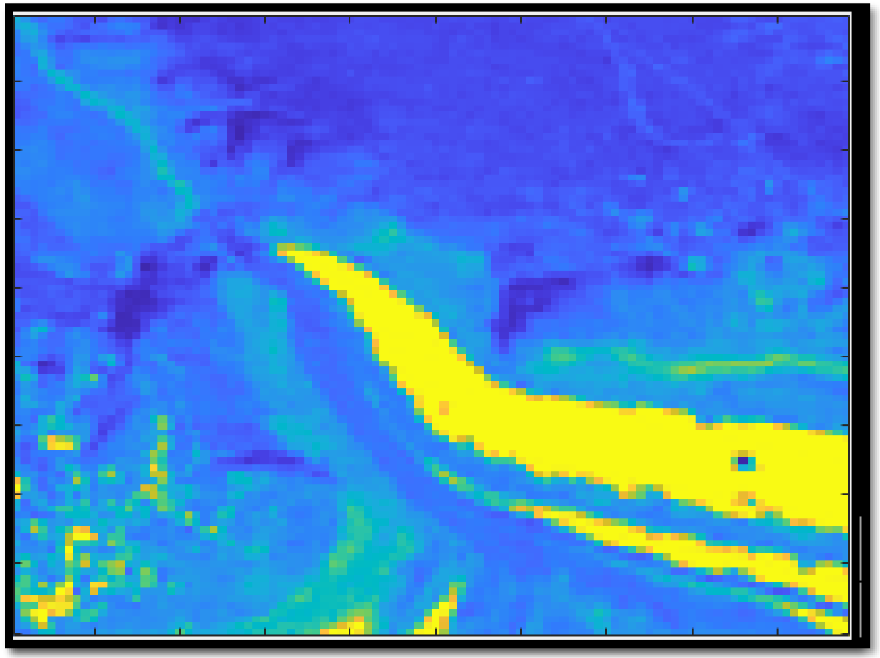




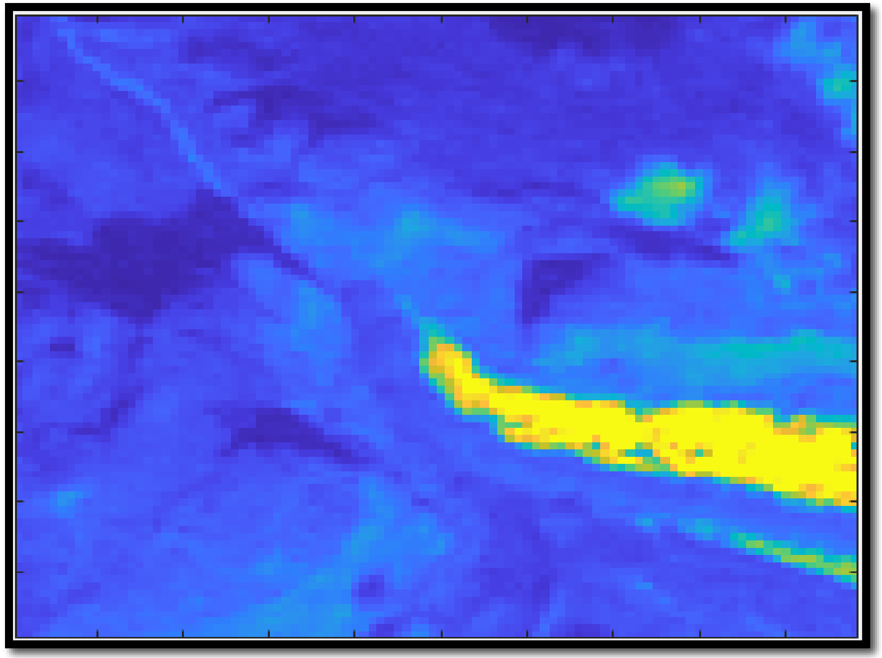


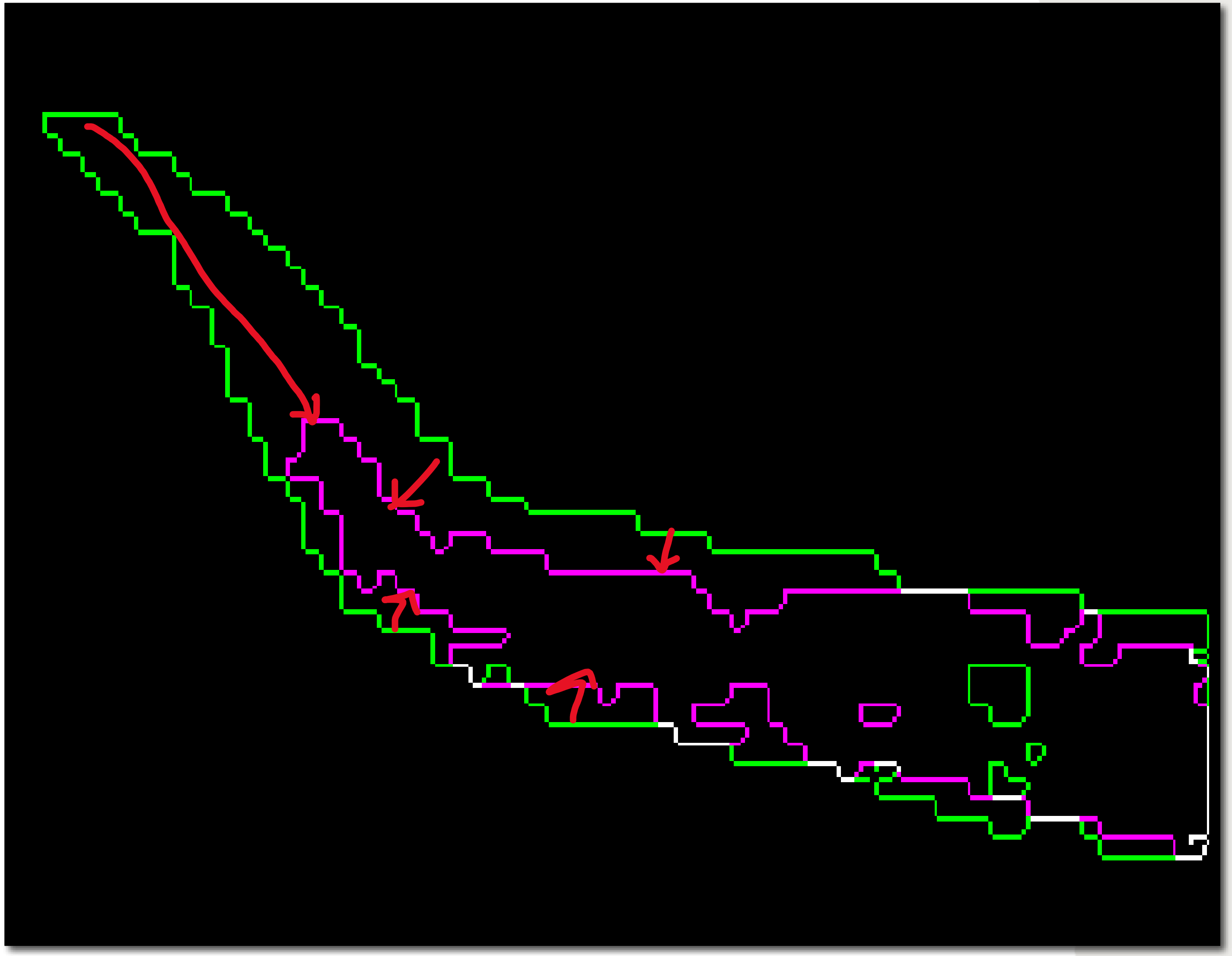
Superimposed scenes show area change – Franz Josef glacier
1990 (green), 2009 (purple)

# COMBINING METHODS



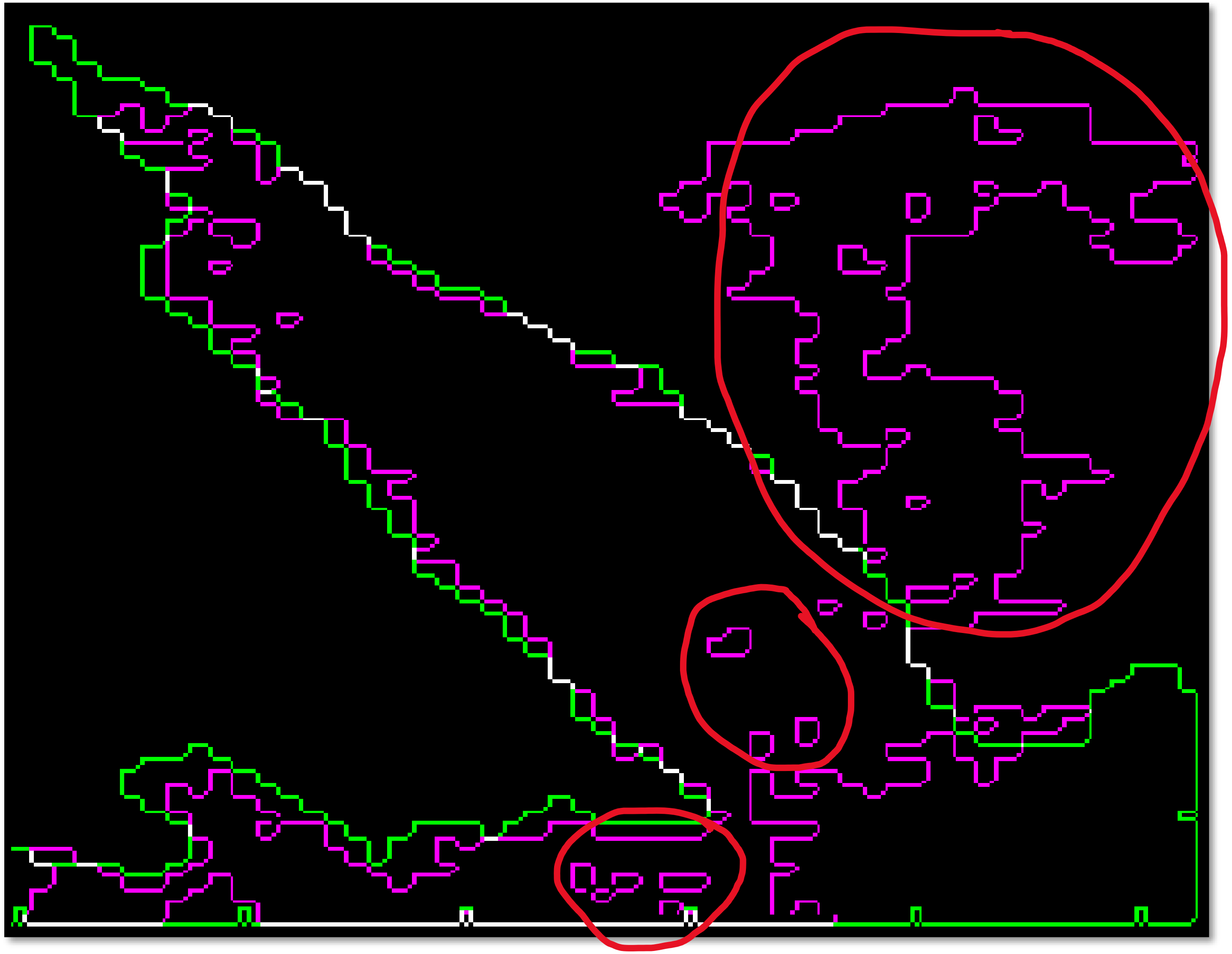
Gorner blue band, 1985 (top), 2009 (bottom)





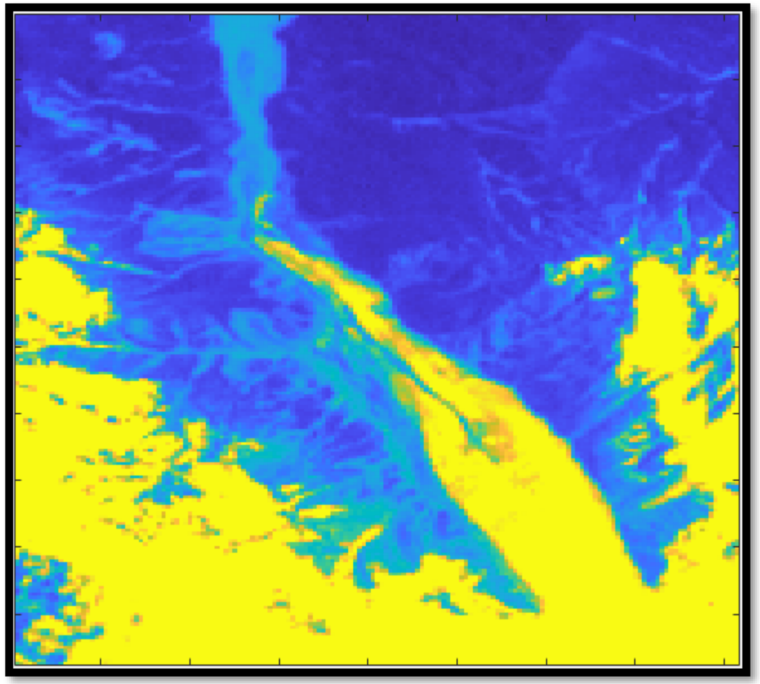
Superimposed scenes show area change – Gorner glacier
1984 (green), 2009 (purple)

# PROBLEMS

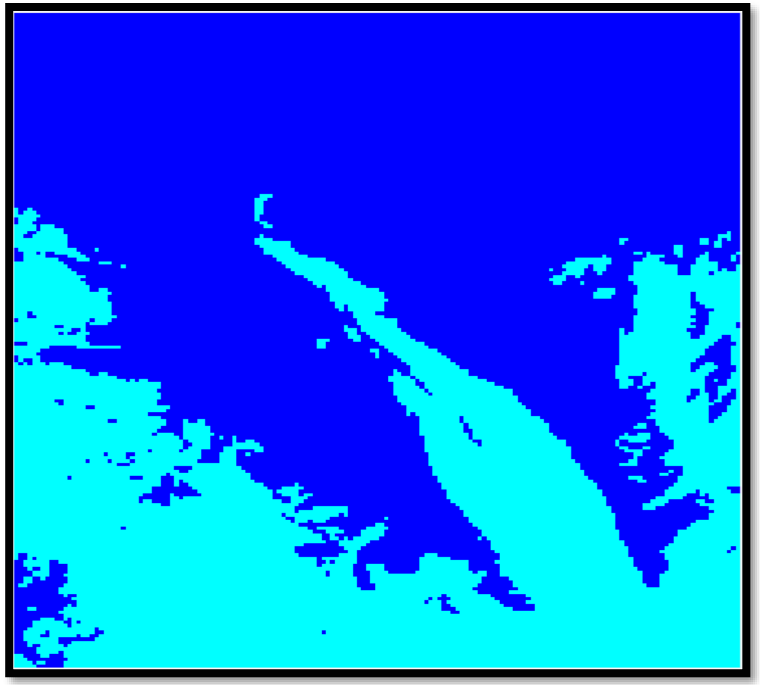


This method allows us to visualize change over time, but leaves holes in glaciers and includes snow or ice outside the glacier

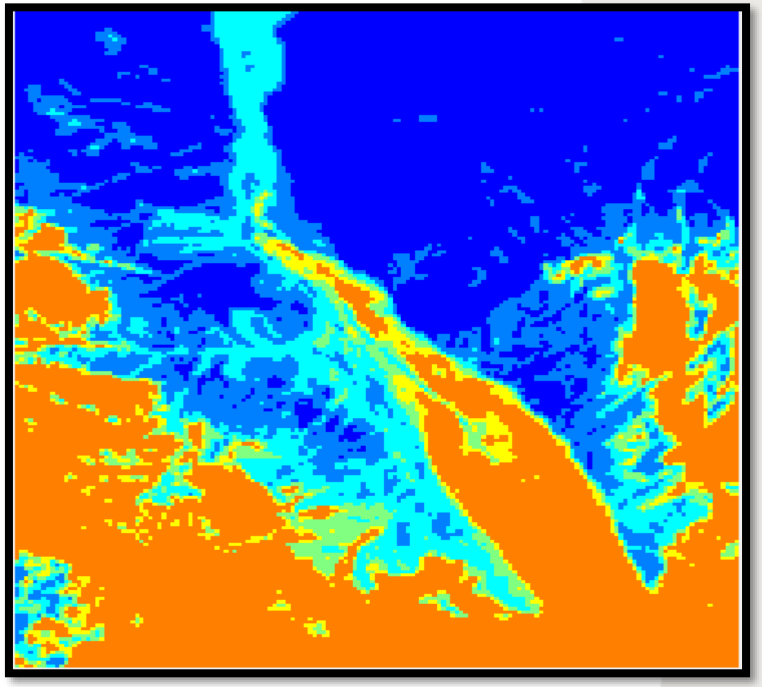
# MULTI-THRESHOLDING



Franz Josef blue band



Two segments

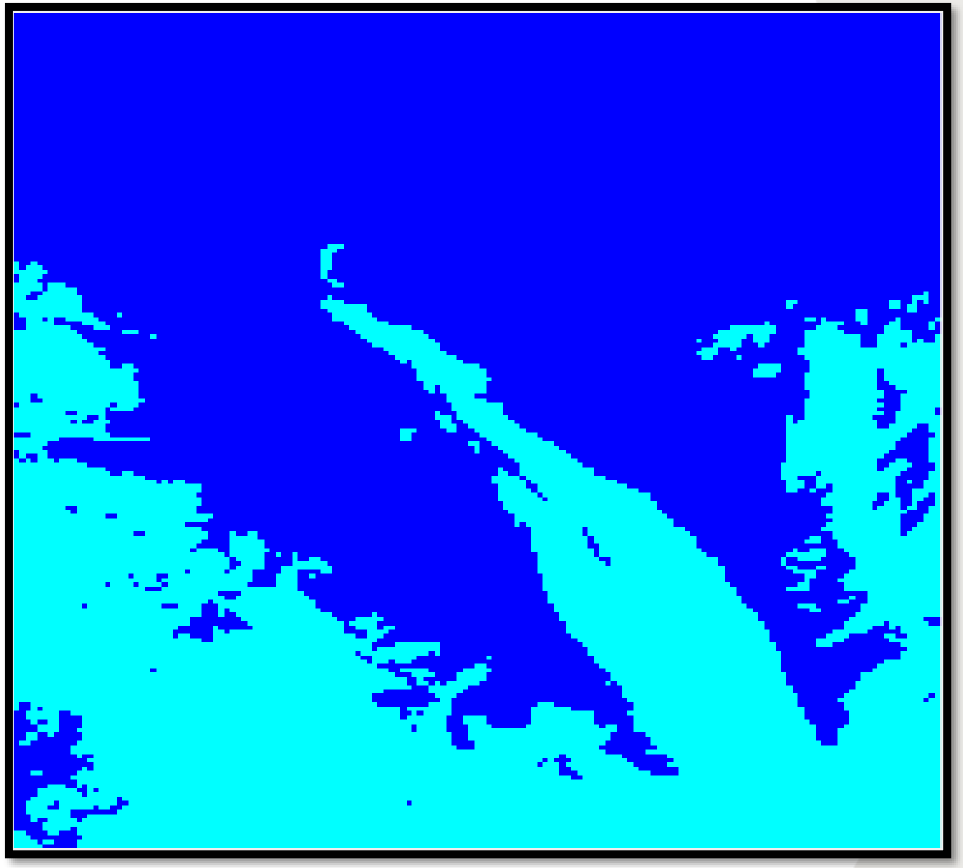


Five segments

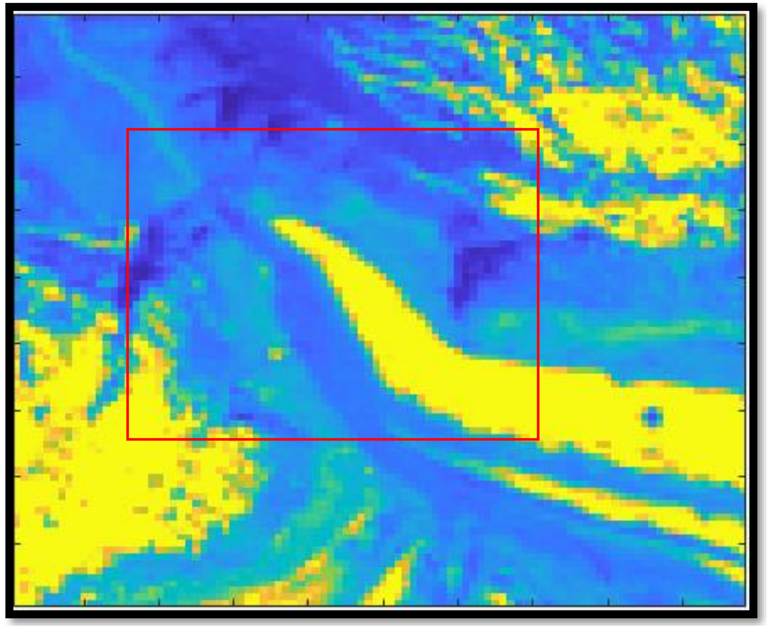
Segmentation is good but having the glacier broken into multiple segments actually makes the problem harder

# BINARY SEGMENTATION

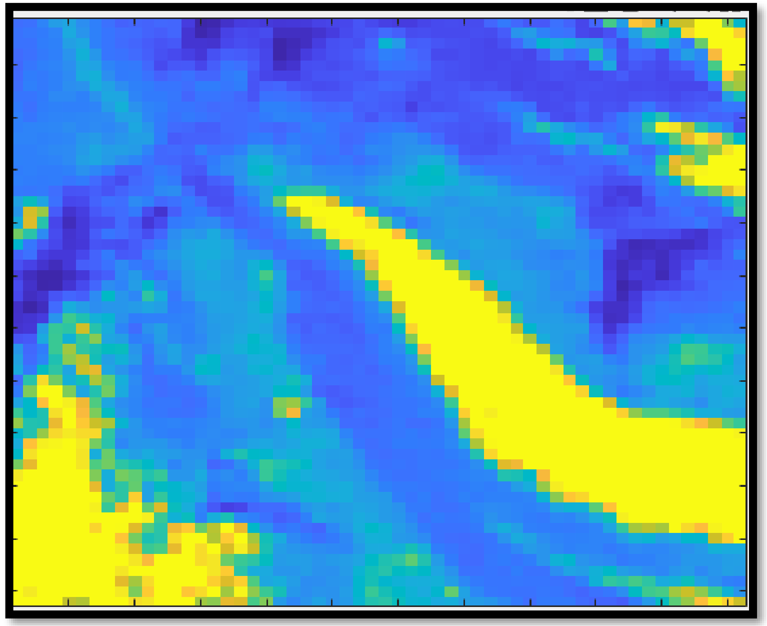
We need a method that segments images into only two regions (glacier and background) and does not leave holes inside the segmented glacier area or include pixels from the background



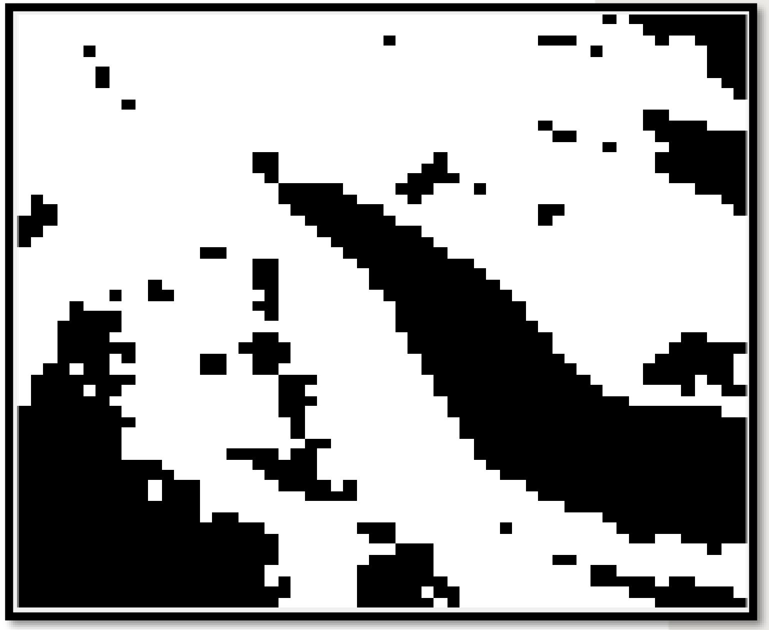
# BLOB DETECTION



Gorner blue band



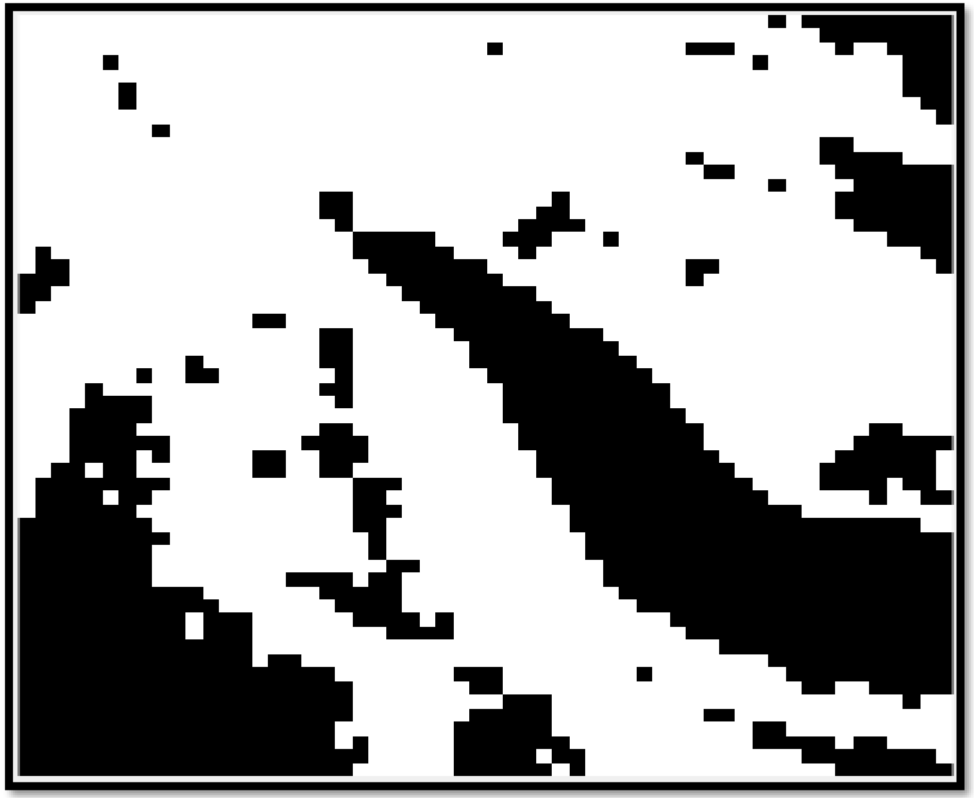
Gorner blue band (cropped)



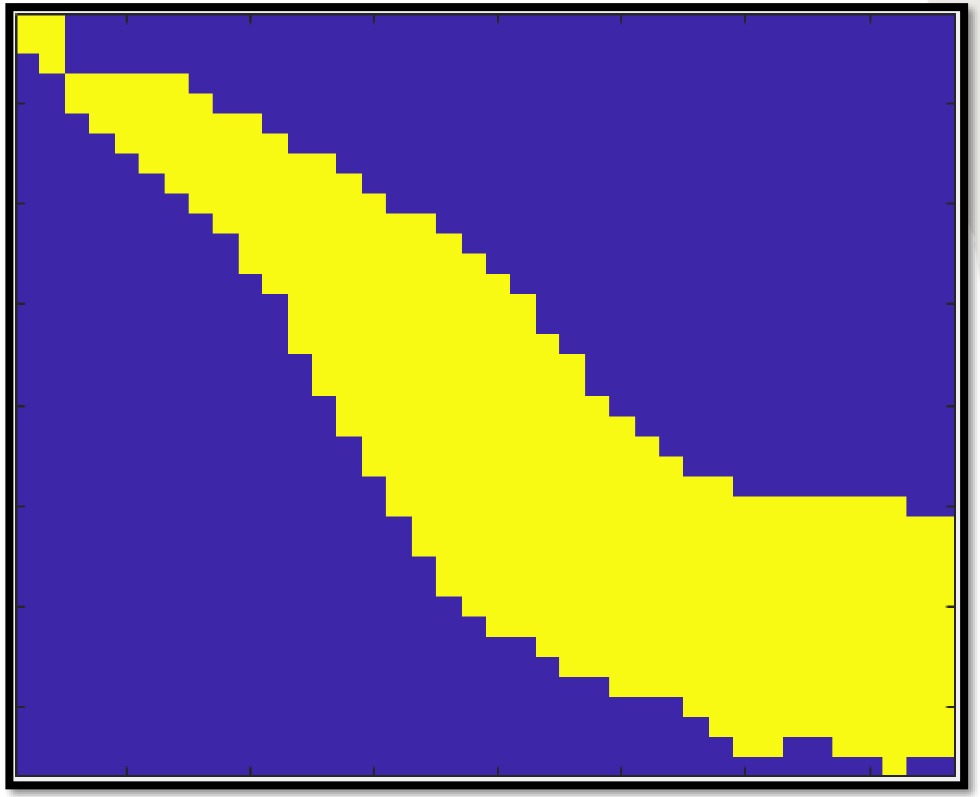
Binarized

Crop the region of interest and then segment it into two regions

# BLOB DETECTION



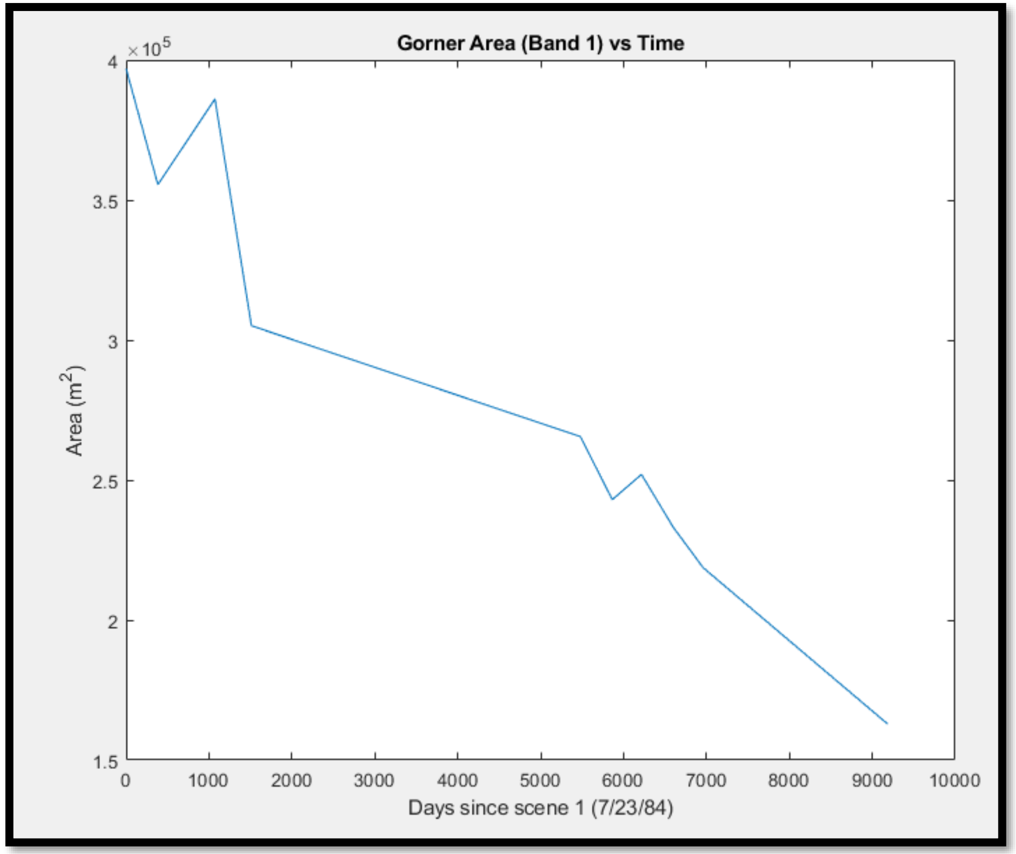
Binarized



Largest blob

Find the largest blob in the binarized image
that represents the glacier area

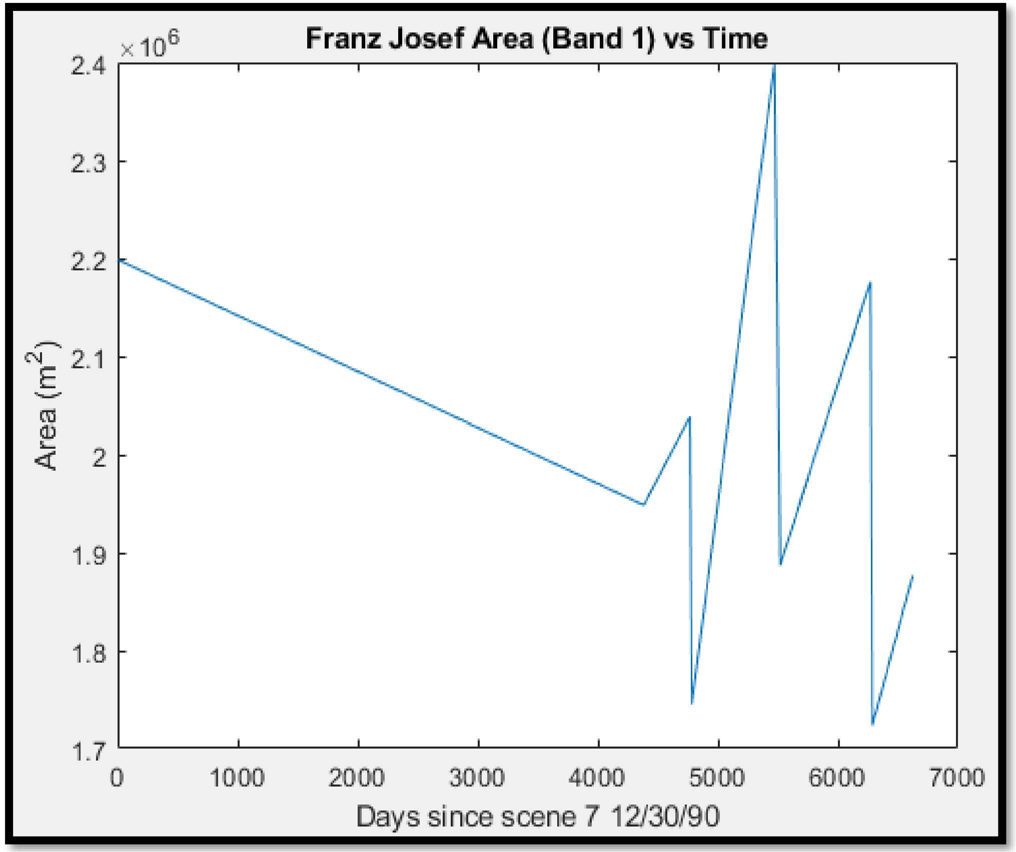
# SEGMENTED AREA



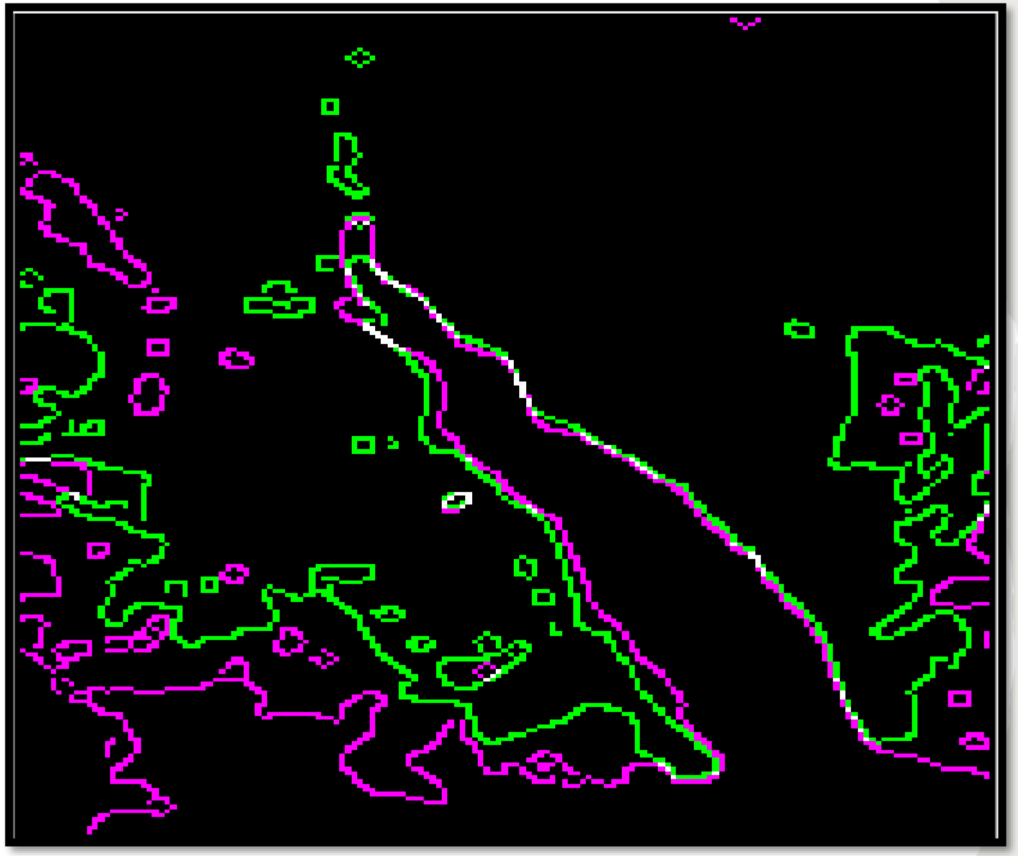

Gorner Area vs Time from 1984 to 2009

Superimposed scenes show area change – Gorner glacier 1984 (green), 2009 (purple)

# SEGMENTED AREA

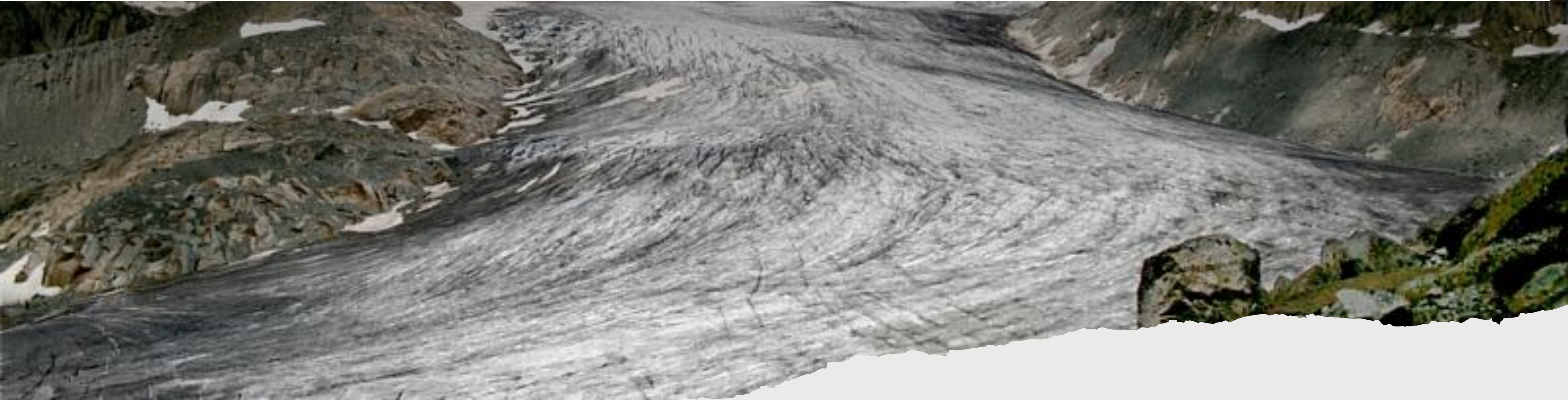



Gorner Area vs Time from 1990 to 2009

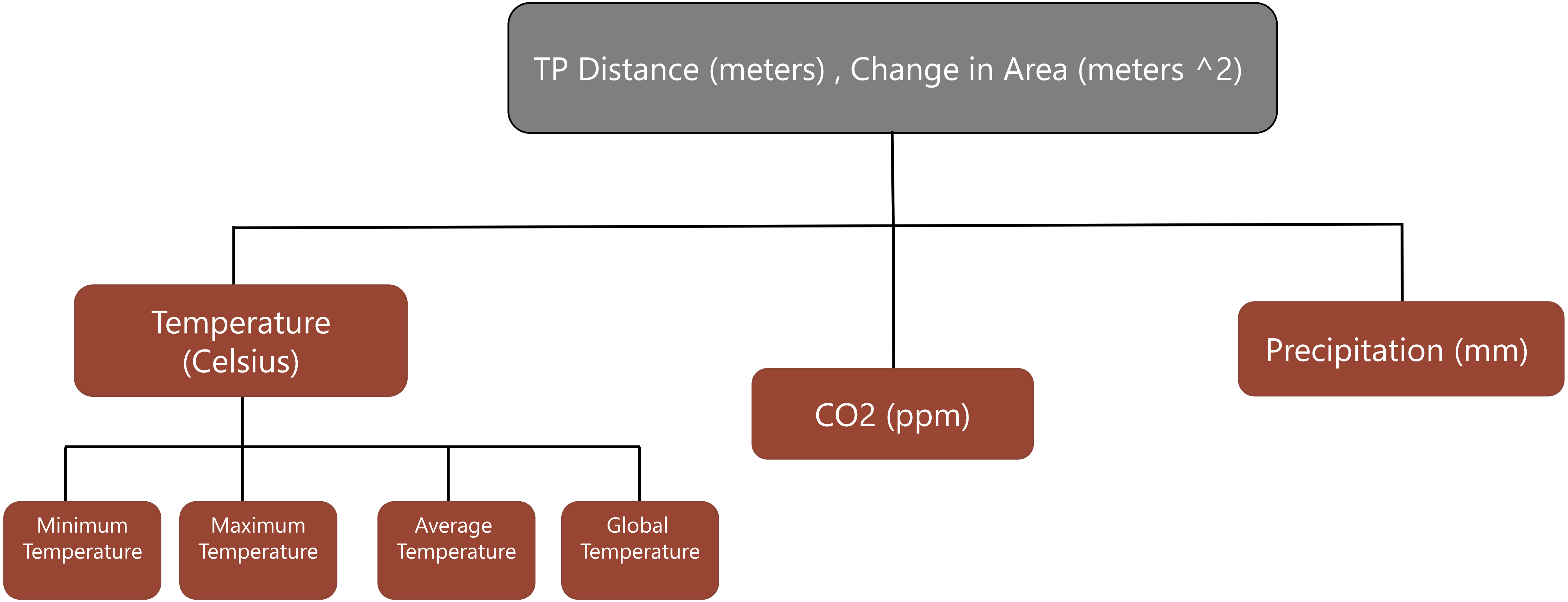


Superimposed scenes show area change – Franz Josef glacier 1990 (green), 2009 (purple)

# PART II. MODELING



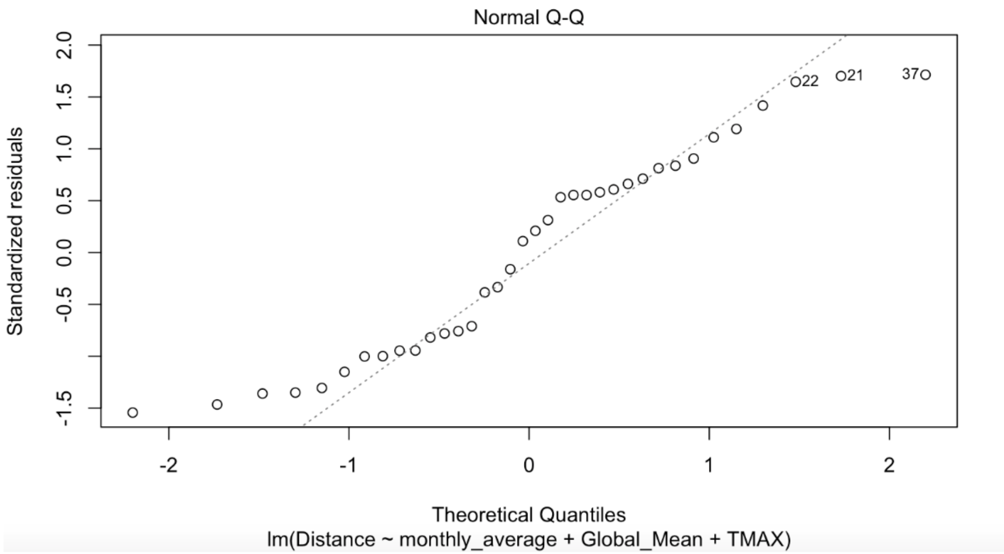
# CLIMATE FACTORS



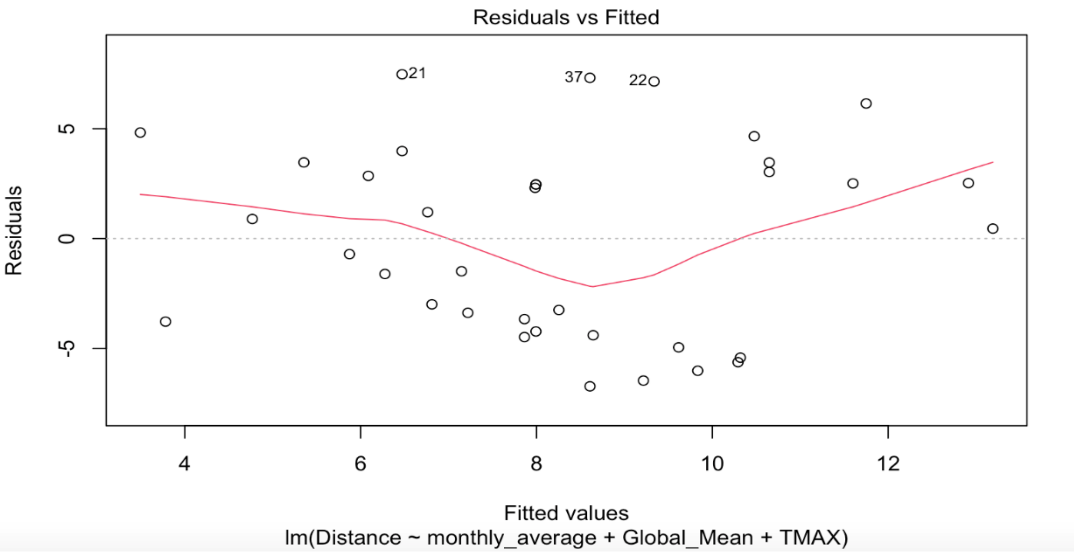

FRANZ
JOSEF'S
TERMINUS

# MULTIPLE REGRESSION

## Plots for checking residual normality




## Plots for checking Homoscedasticity

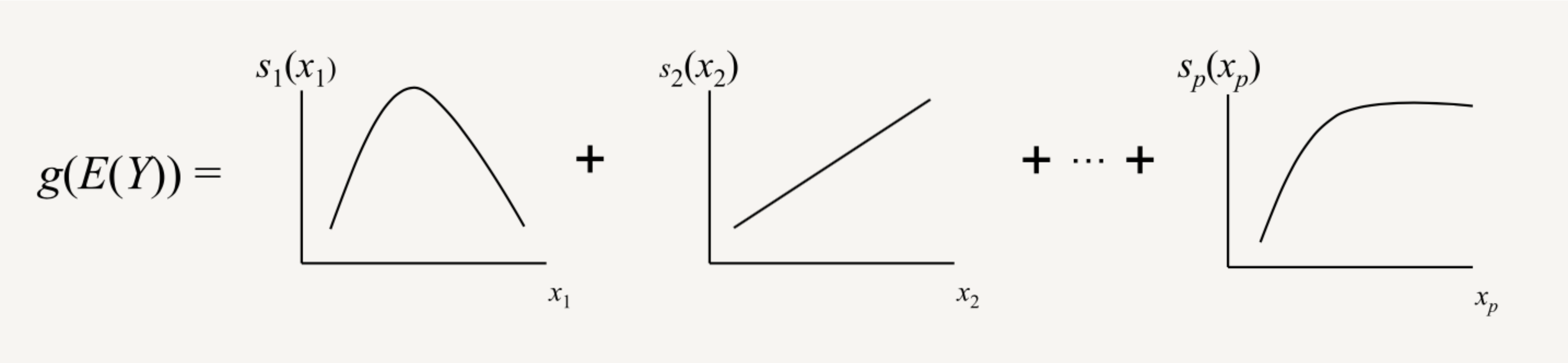



| Factors | # of Factors | R^2 | AIC | SBIC |
|---|---|---|---|---|
| TMAX + PRCP + CO2 | 3 | 0.0864 | 180.1562 | 99.0866 |
| TMAX + CO2 | 2 | 0.1278 | 217.1768 | 116.2774 |
| TMAX + PRCP | 2 | -0.0513 | 183.3642 | 101.7315 |
| Global_temp + PRCP +CO2 | 3 | 0.055 | 187.367 | 103.4142 |
| Global_temp + CO2 | 2 | 0.086 | 224.7852 | 120.9909 |
| Global_temp + PRCP | 2 | -0.0737 | 190.3286 | 105.8343 |
| TMAX + Global_temp + PRCP + CO2 | 4 | 0.1147 | 180.0575 | 99.7556 |
| TMAX + Global +PRCP | 3 | -0.0933 | 185.3631 | 104.2935 |
| TMAX + Global + CO2 | 3 | 0.152 | 217.0579 | 116.8533 |
| TMAX + Global | 2 | -0.0139 | 222.5972 | 121.8789 |

# GENERALIZED ADDITIVE MODEL SUMMARY

Response variable is modeled based on smoothed functions of predictor variables where smoothed functions are obtained using a non-parametric method.

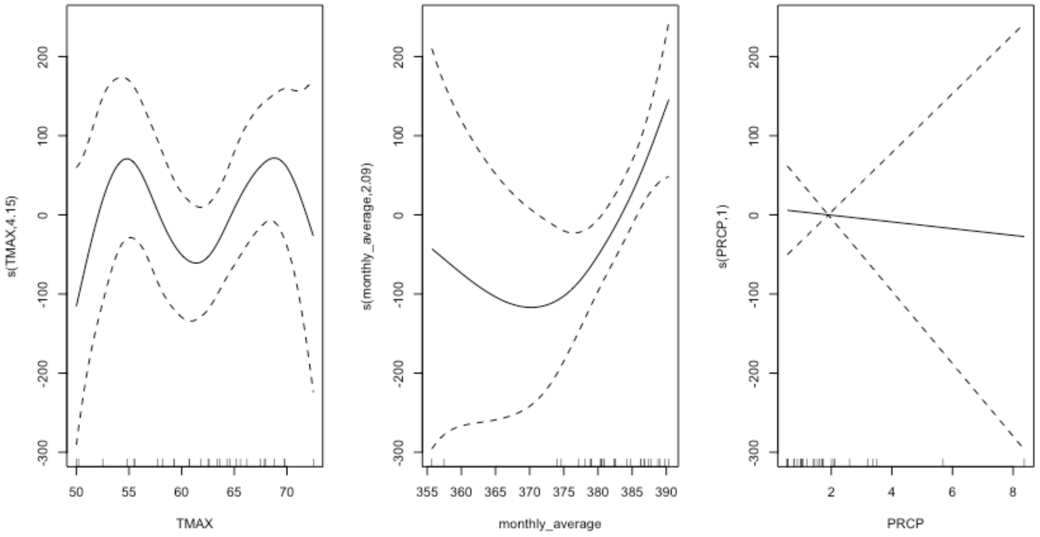
$$g(\mathrm{E}(Y)) = \beta_0 + f_1(x_1) + f_2(x_2) + \cdots + f_m(x_m).$$



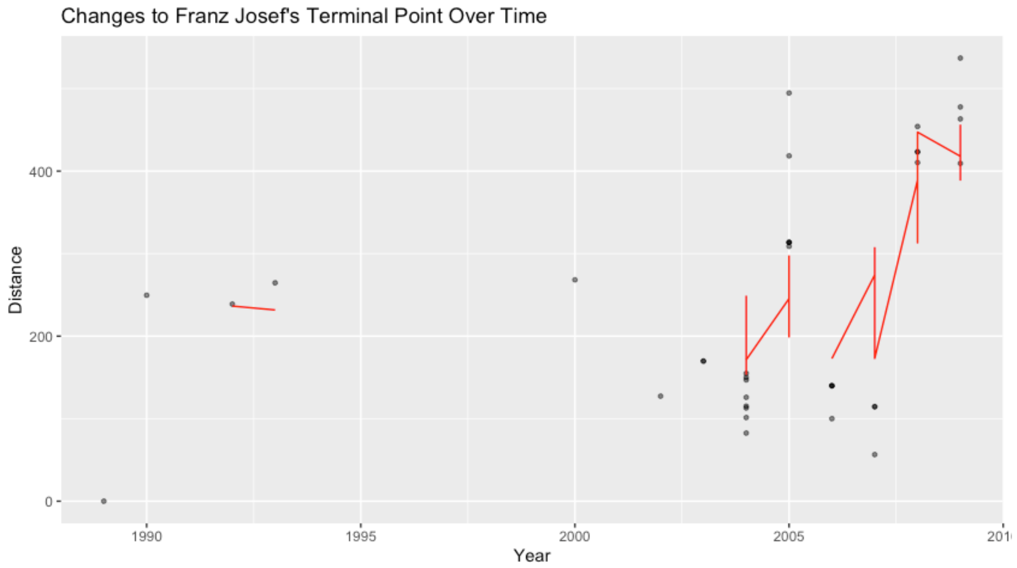

~ "GAM: The Predictive Modeling Silver Bullet",*MultiThreaded*

# GENERALIZED ADDITIVE MODEL

**Plots of the Factors in the Multiple Additive Model**




**Graph of Predicted Values from the Model**

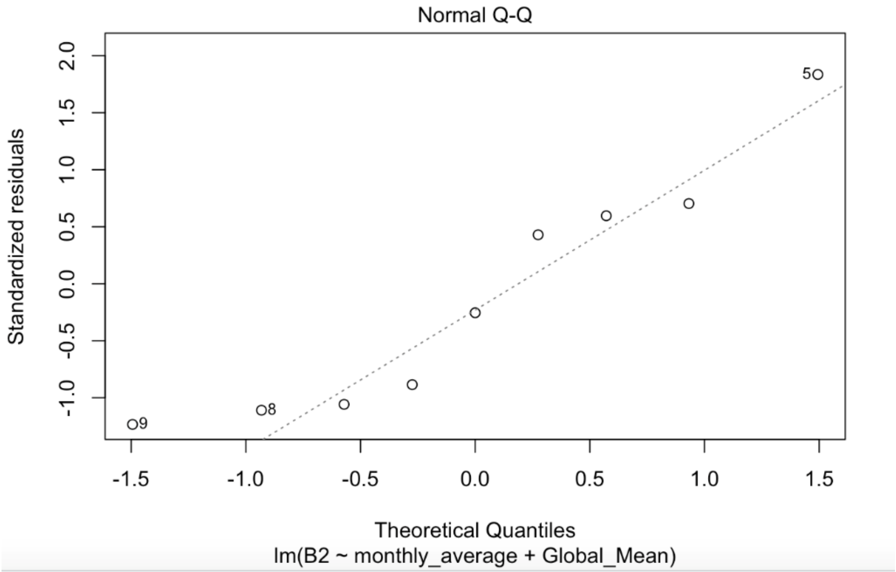



| Factors | # of Factors | R^2 | AIC |
|---|---|---|---|
| TMAX + PRCP + CO2 | 3 | 0.422 | 369.8605 |
| TMAX + PRCP | 2 | 0.216 | 376.764 |
| TMAX + CO2 | 2 | 0.296 | 457.4287 |
| Global_temp + PRCP +CO2 | 3 | 0.244 | 386.8718 |
| Global_temp+ PRCP | 2 | -0.0737 | 394.4011 |
| Global_temp + CO2 | 2 | 0.268 | 471.386 |
| TMAX + Global_temp + PRCP + CO2 | 4 | 0.201 | 375.3042 |
| TMAX+Global_temp + PRCP | 3 | -0.0591 | 382.9207 |
| TMAX+Global_temp + CO2 | 3 | 0.253 | 459.6973 |
| TMAX+Global_temp | 2 | -0.012 | 467.5875 |

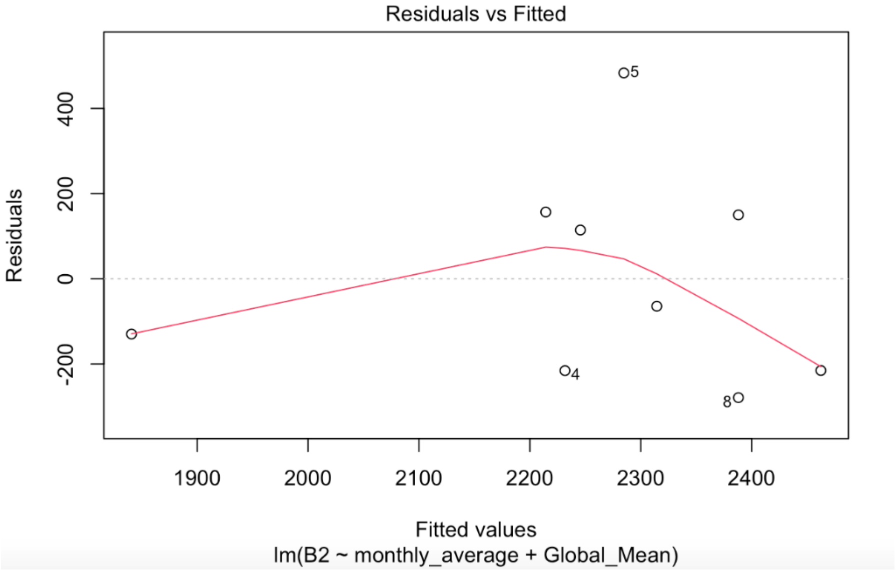
# FRANZ JOSEF'S AREA

# MULTIPLE REGRESSION

## Plots for checking residual normality



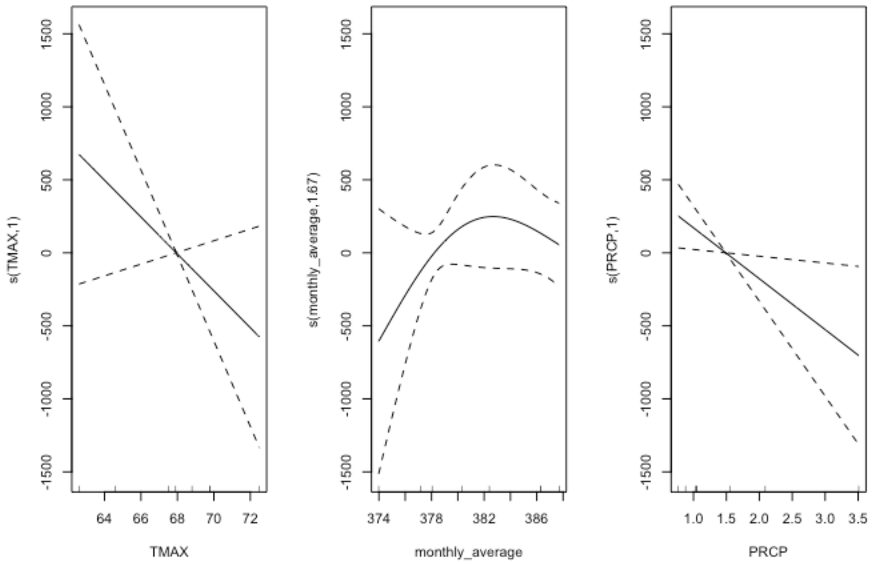

## Plots for checking Homoscedasticity



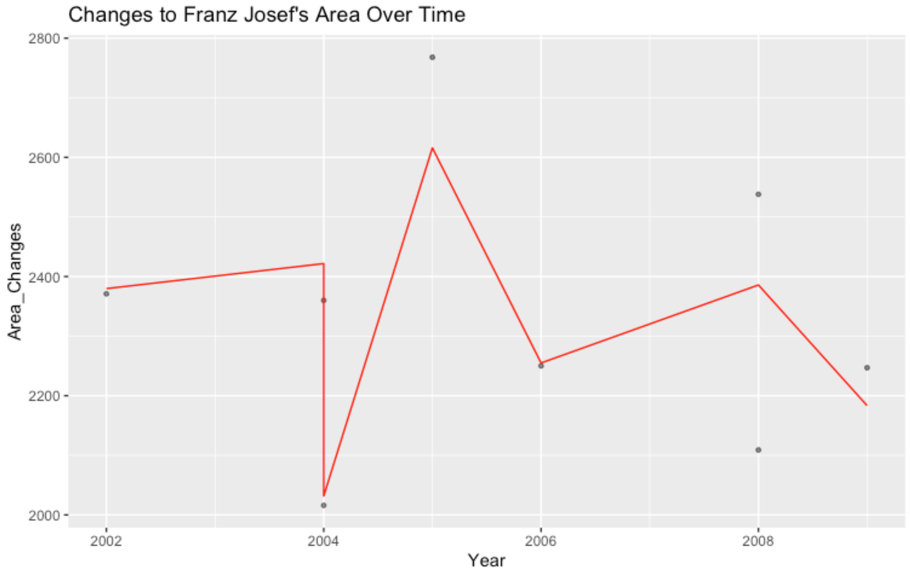

| Factors | # of Factors | R^2 | AIC | SBIC |
|---|---|---|---|---|
| TMAX + PRCP + CO2 | 3 | -0.0342 | 115.0206 | 98.3176 |
| TMAX + CO2 | 2 | 0.1218 | 131.6565 | 108.6156 |
| TMAX + PRCP | 2 | 0.1718 | 113.0285 | 94.3215 |
| Global_temp + PRCP +CO2 | 3 | -0.0897 | 115.4389 | 98.7359 |
| Global_temp + CO2 | 2 | 0.1271 | 131.602 | 108.5611 |
| Global_temp + PRCP | 2 | 0.1074 | 113.628 | 93.805 |
| TMAX + Global_temp + PRCP + CO2 | 4 | -0.3572 | 116.8935 | 105.3016 |
| TMAX + Global +PRCP | 3 | -0.0222 | 114.9274 | 99.9869 |
| TMAX + Global + CO2 | 3 | -0.0381 | 133.5215 | 113.1006 |
| TMAX + Global | 2 | -0.0756 | 133.481 | 110.4401 |

# GENERALIZED ADDITIVE MODEL

## Plots of the Factors in the Multiple Additive Model




## Graph of Predicted Values from the Model

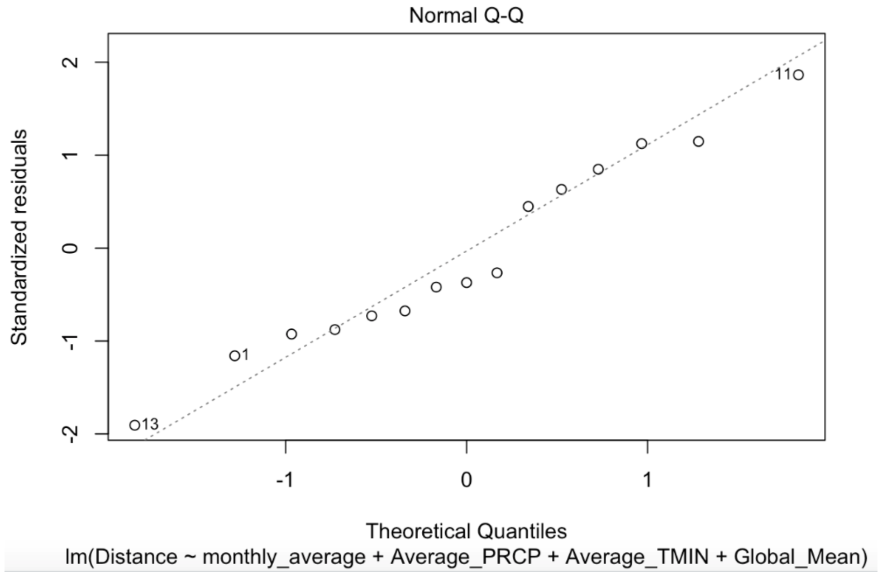



| Factors | # of Factors | R^2 | AIC |
|---|---|---|---|
| TMAX + PRCP + CO2 | 3 | 0.309 | 112.1162 |
| TMAX + PRCP | 2 | 0.172 | 113.0287 |
| TMAX + CO2 | 2 | 0.193 | 131.5022 |
| Global_temp + PRCP +CO2 | 3 | -0.0897 | 115.4391 |
| Global_temp+ PRCP | 2 | 0.107 | 113.6282 |
| Global_temp + CO2 | 2 | 0.167 | 131.6321 |
| TMAX + Global_temp + PRCP + CO2 | 4 | NA | NA |
| TMAX+Global_temp + PRCP | 3 | -0.0222 | 114.9275 |
| TMAX+Global_temp + CO2 | 3 | 0.0867 | 132.9009 |
| TMAX+Global_temp | 2 | -0.0121 | 133.4584 |

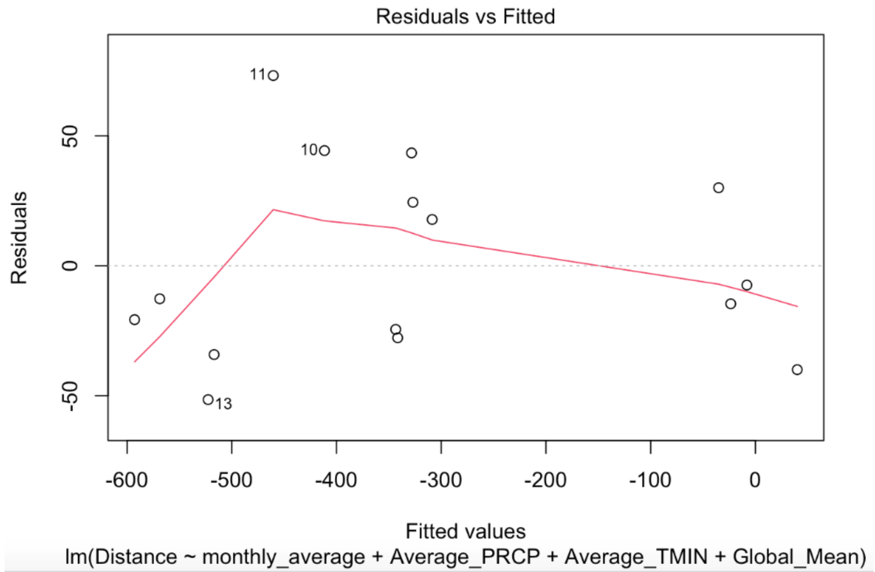
# GORNER GLACIER’S TERMINUS

# MULTIPLE REGRESSION

## Plots for checking residual normality



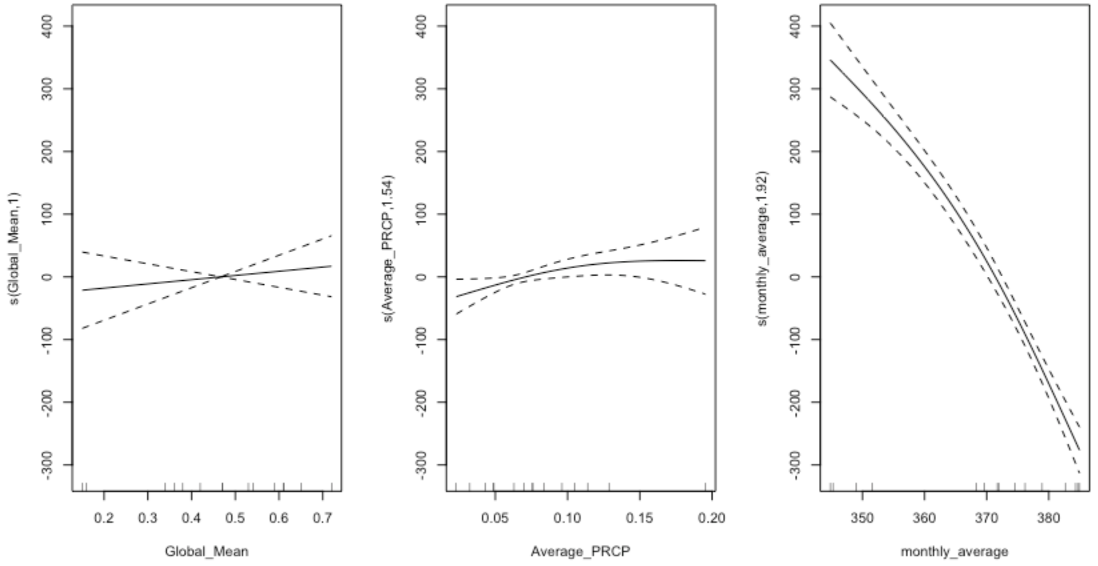

## Plots for checking Homoscedasticity



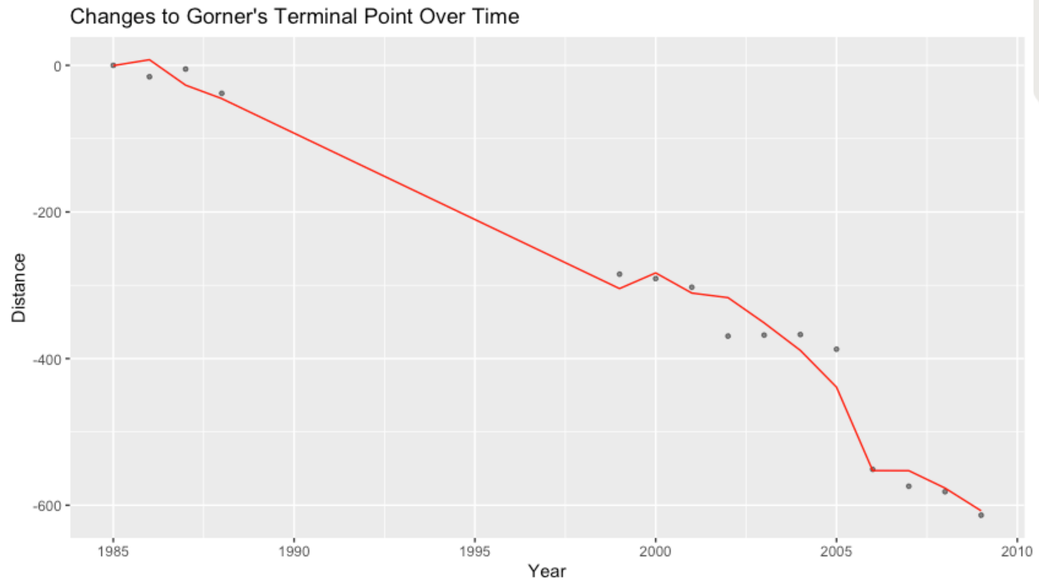

| Factors | # of Factors | R^2 | AIC | SBIC |
|---|---|---|---|---|
| TMIN + PRCP + CO2 | 3 | 0.9592 | 161.3541 | 121.4306 |
| TMIN + CO2 | 2 | 0.9576 | 161.2273 | 119.7976 |
| TMIN + PRCP | 2 | 0.3306 | 202.6117 | 161.4185 |
| Global_temp + PRCP +CO2 | 3 | 0.9532 | 163.3948 | 123.4713 |
| Global_temp + CO2 | 2 | 0.9526 | 162.9085 | 121.7153 |
| Global_temp + PRCP | 2 | 0.6122 | 194.4261 | 153.233 |
| TMIN + Global_temp + PRCP + CO2 | 4 | 0.9604 | 161.4673 | 123.3991 |
| TMIN + Global +PRCP | 3 | 0.6285 | 194.4752 | 154.5516 |
| TMIN + Global + CO2 | 3 | 0.9586 | 161.5526 | 121.6291 |
| TMIN + Global | 2 | 0.6591 | 192.4898 | 151.2966 |

# GENERALIZED ADDITIVE MODEL

**Plots of the Factors in the Multiple Additive Model**




**Graph of Predicted Values from the Model**

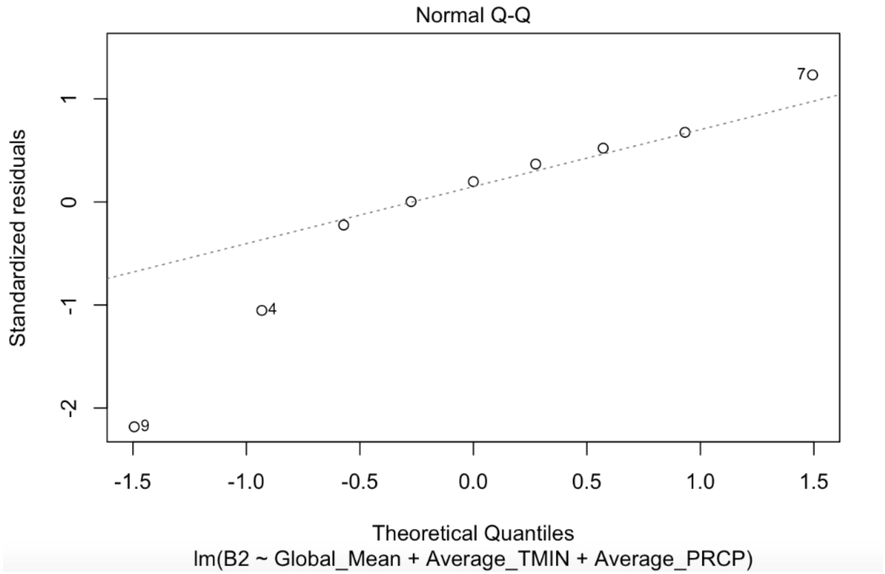



| Factors | # of Factors | $R^2$ | AIC |
|---|---|---|---|
| TMIN + PRCP + CO2 | 3 | 0.982 | 151.2125 |
| TMIN + CO2 | 2 | 0.974 | 154.8016 |
| TMIN + PRCP | 2 | 0.419 | 201.4022 |
| Global_temp + PRCP +CO2 | 3 | 0.982 | 150.8067 |
| Global_temp+ CO2 | 2 | 0.974 | 154.4909 |
| Global_temp + PRCP | 2 | 0.612 | 194.4265 |
| TMIN + Global_temp + PRCP + CO2 | 4 | 0.979 | 152.8832 |
| TMIN+Global_temp + CO2 | 3 | 0.972 | 156.5745 |
| TMIN+Global_temp + PRCP | 3 | 0.644 | 194.4644 |
| TMIN+Global_temp | 2 | 0.659 | 192.49 |

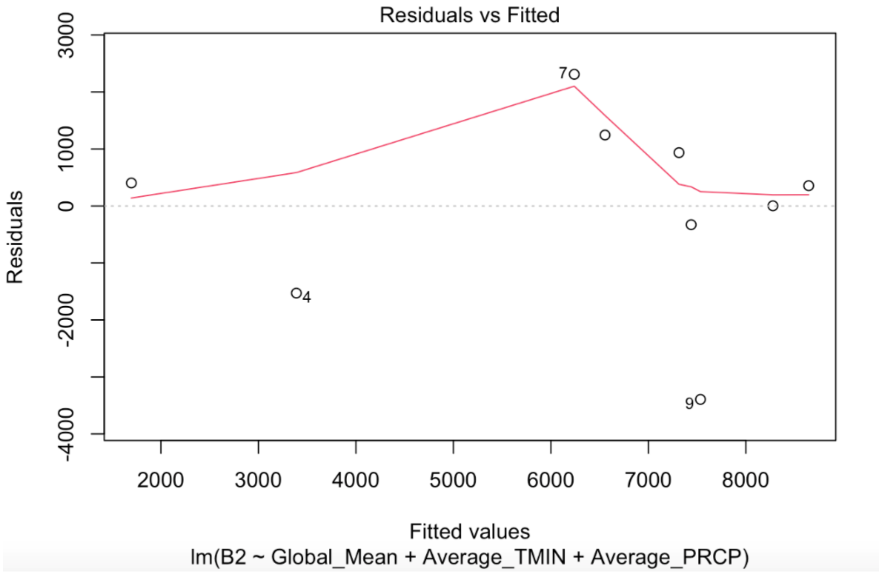
# GORNER GLACIER’S AREA

# MULTIPLE REGRESSION

## Plots for checking residual normality



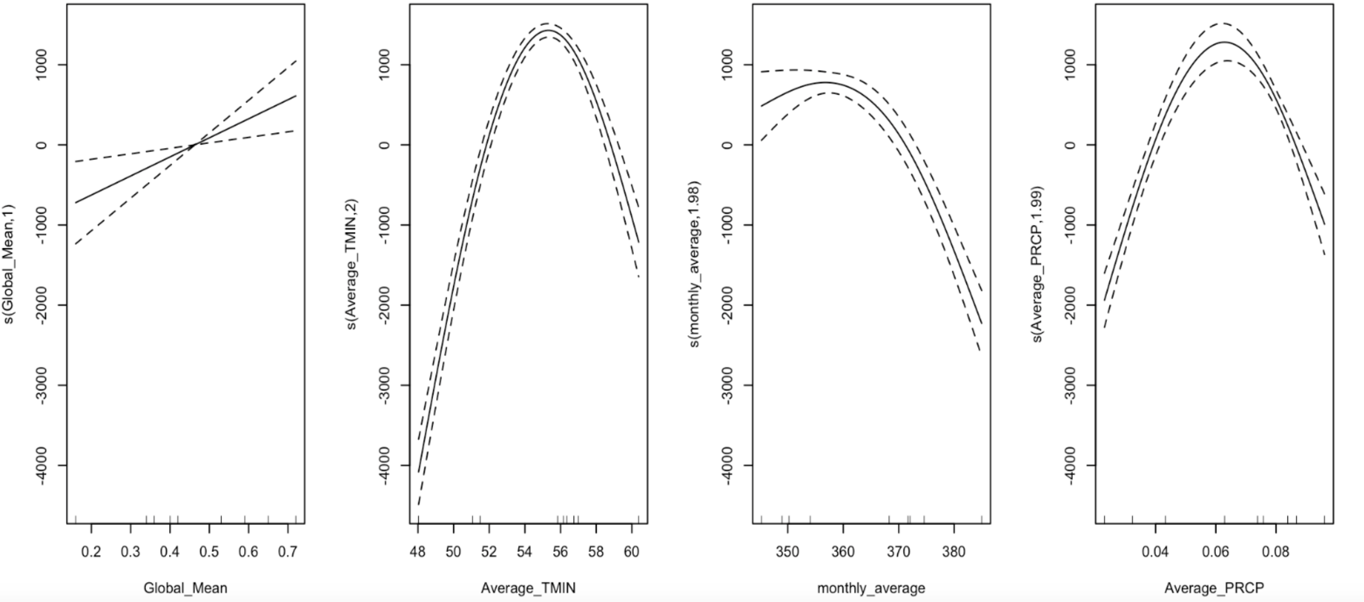

## Plots for checking Homoscedasticity



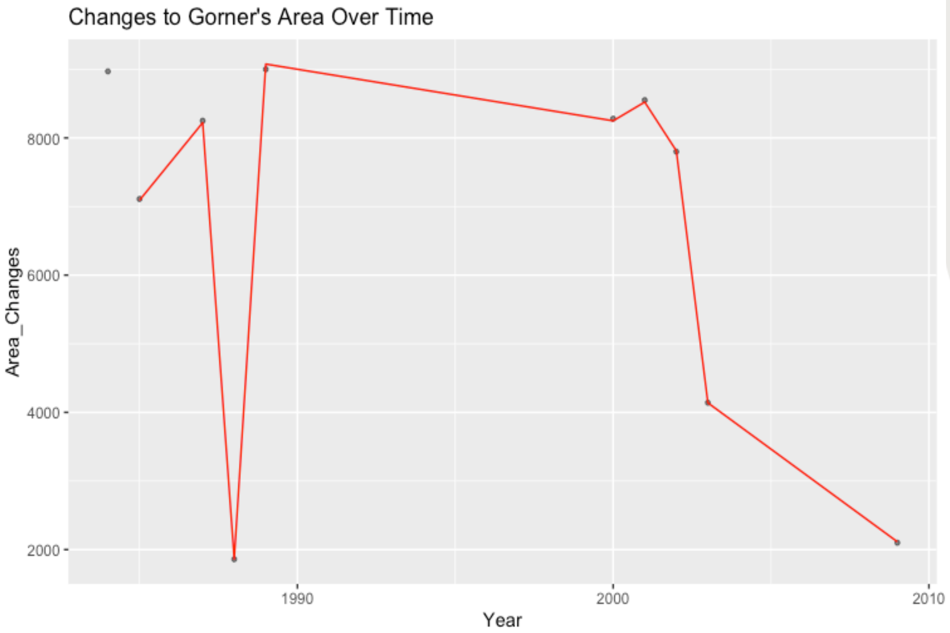

| Factors | # of Factors | R^2 | AIC | SBIC |
|---|---|---|---|---|
| TMIN + PRCP + CO2 | 3 | 0.2727 | 170.5771 | 150.1562 |
| TMIN + CO2 | 2 | 0.3597 | 169.0711 | 146.7626 |
| TMIN + PRCP | 2 | 0.1241 | 171.891 | 148.8501 |
| Global_temp + PRCP +CO2 | 3 | 0.3655 | 169.349 | 148.9281 |
| Global_temp + CO2 | 2 | 0.0396 | 191.245 | 165.0703 |
| Global_temp + PRCP | 2 | 0.2573 | 170.4059 | 146.3961 |
| TMIN + Global_temp + PRCP + CO2 | 4 | 0.3618 | 169.3921 | 153.2262 |
| TMIN + Global +PRCP | 3 | 0.4579 | 167.9325 | 147.5116 |
| TMIN + Global + CO2 | 3 | 0.4892 | 167.3962 | 148.7272 |
| TMIN + Global | 2 | 0.5338 | 166.2156 | 144.0324 |

# GENERALIZED ADDITIVE MODEL

## Plots of the Factors in the Multiple Additive Model




## Graph of Predicted Values from the Model




| Factors | # of Factors | R^2 | AIC |
|---|---|---|---|
| TMIN + PRCP + CO2 | 3 | 0.995 | 123.5698 |
| TMIN + CO2 | 2 | 0.947 | 147.3274 |
| TMIN + PRCP | 2 | 0.954 | 145.8929 |
| Global_temp + PRCP +CO2 | 3 | 0.699 | 163.3429 |
| Global_temp+ CO2 | 2 | 0.306 | 188.7458 |
| Global_temp + PRCP | 2 | 0.728 | 162.1333 |
| TMIN + Global_temp + PRCP + CO2 | 4 | 0.999 | 105.9211 |
| TMIN+Global_temp + CO2 | 3 | 0.937 | 148.577 |
| TMIN+Global_temp + PRCP | 3 | 0.993 | 126.458 |
| TMIN+Global_temp | 2 | 0.902 | 152.9688 |

# SUMMARY AND CONCLUSION

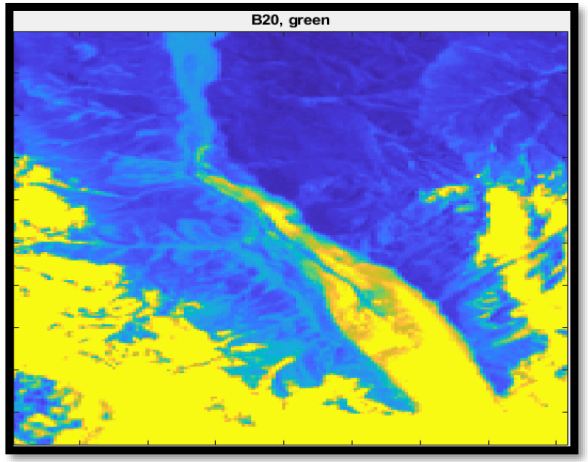
# SUMMARY OF WHAT WE DISCOVERED

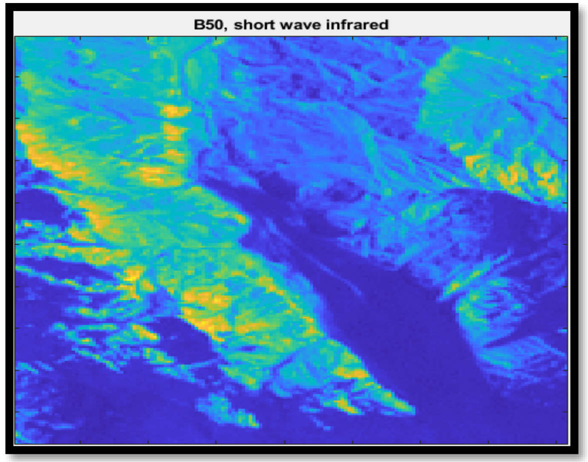
- Multi-spectral Landsat images and climate factors were used to study glacier variations over time.
- Image processing methods were developed to detect and segment glacier area.
- Our models identified the relationship between glacier changes and some climate factors including global temperature, local temperature, precipitation, and $CO_2$.
- Investigate and model the relationship between $CO_2$ and other climate factors to better understand the impact of $CO_2$ on glacier changes.

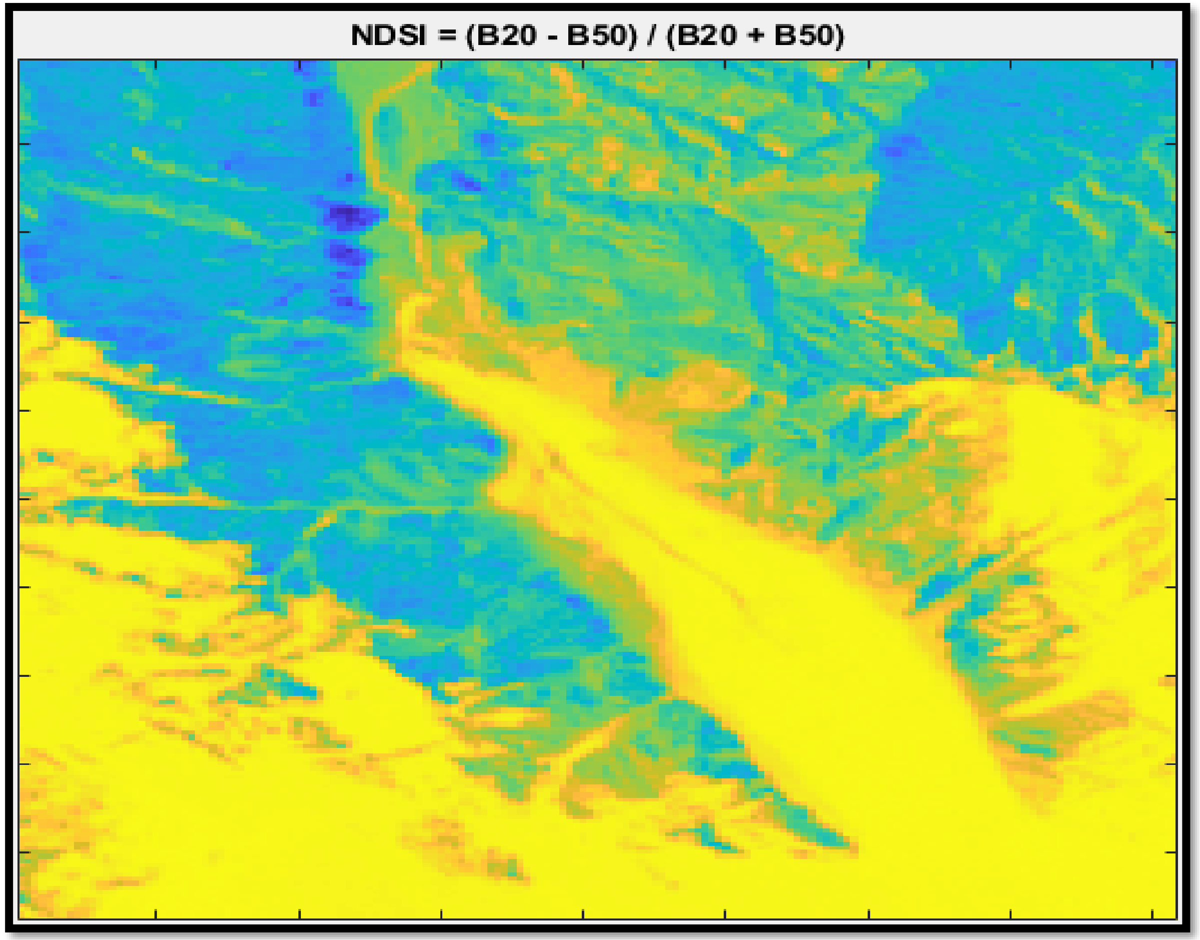
# FUTURE PLANS FOR AREA MEASUREMENT

- Our work has brought us to a good basic method, blob detection
- Segmentation can always improve
- Problems:
  - Thresholding
  - Gap filling
  - Preprocessing

# PROCESSED BANDS

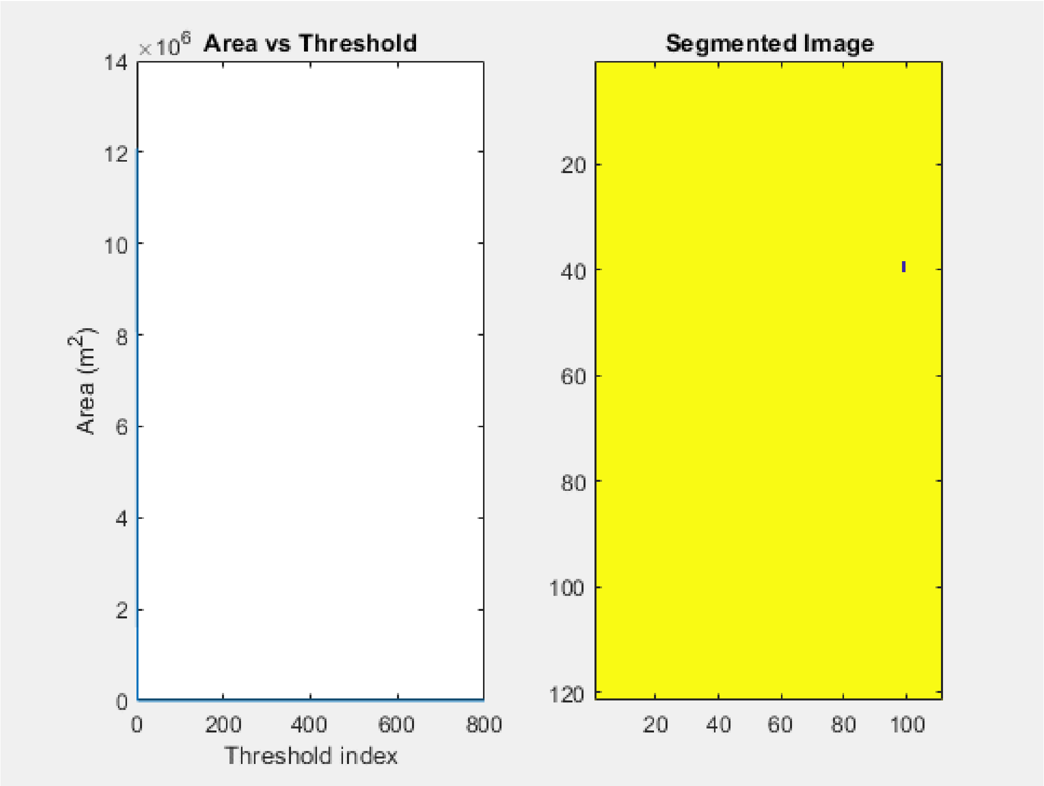


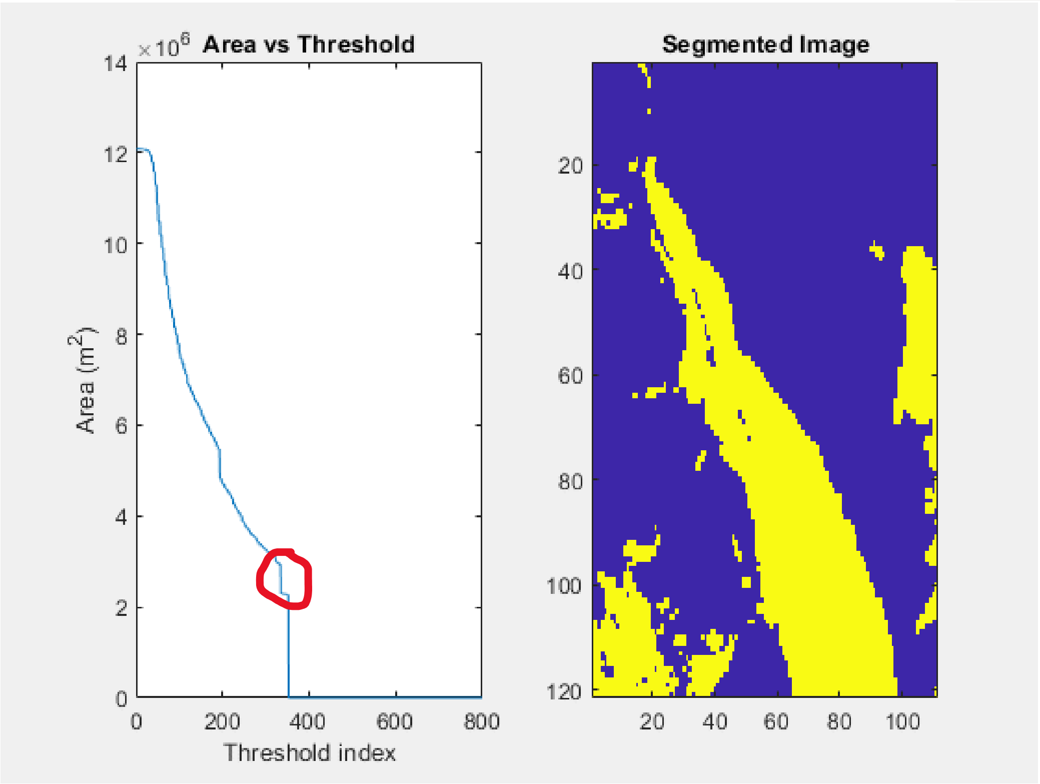




Higher contrast allows for better segmentation and better area measurements

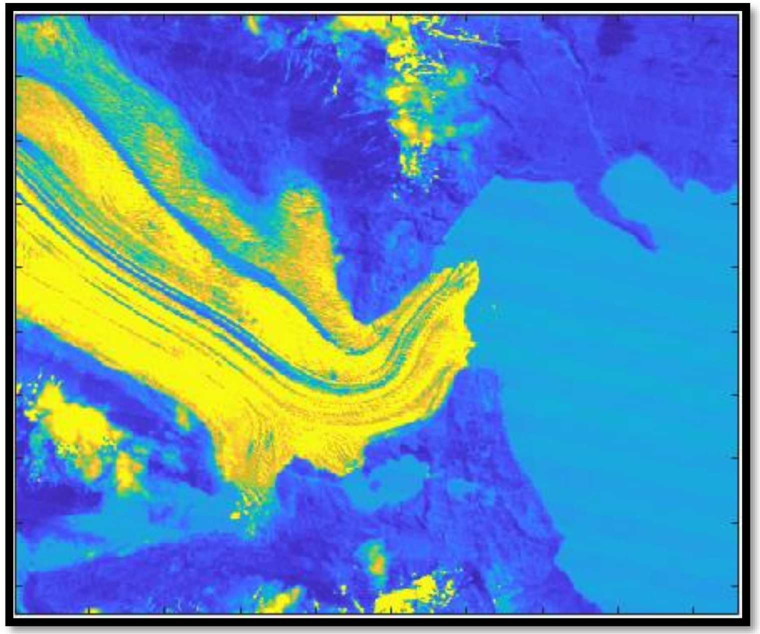
# THRESHOLDING

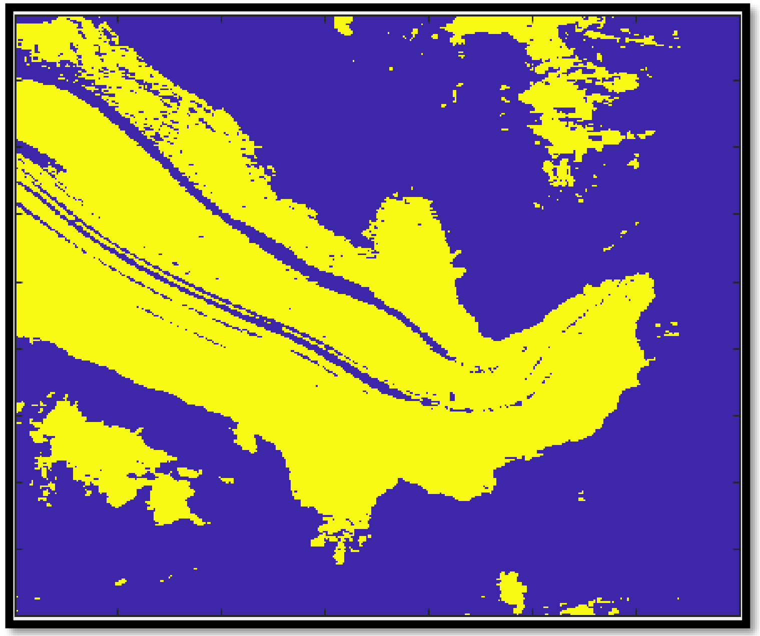


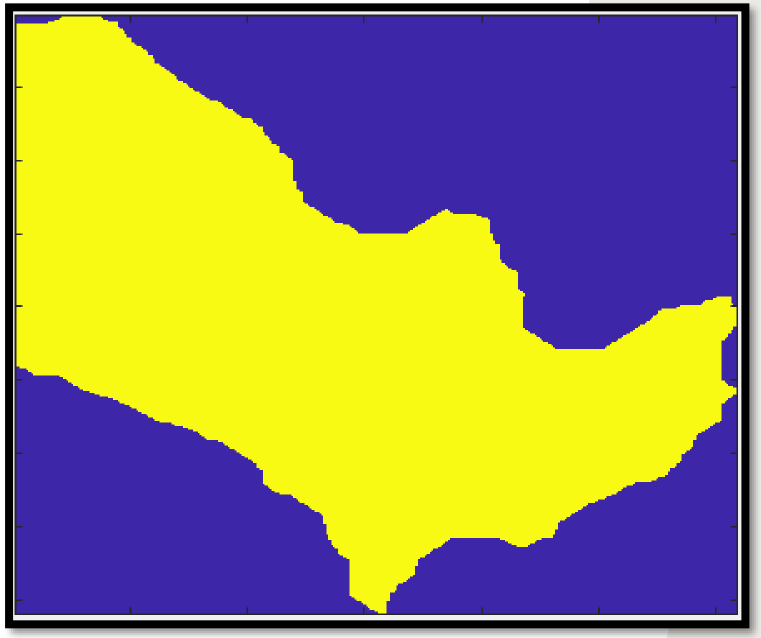




Each image needs its own threshold

# GAP FILLING

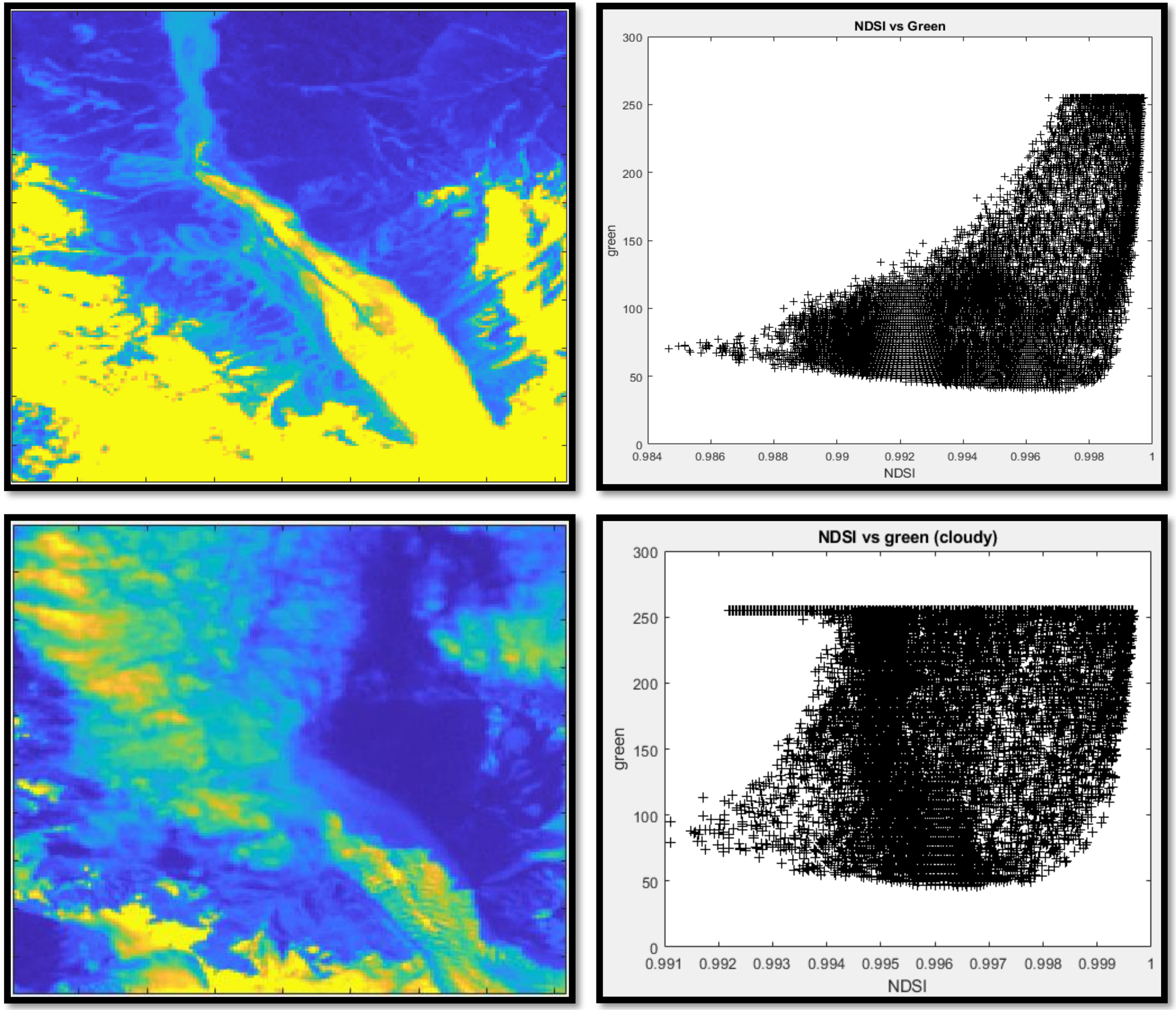

Viedma glacier blue band


Binarized


Example of gap filling

We need a method to fill holes in glaciers while minimizing non-glacier pixels added

# PREPROCESSING




We can train a neural network to classify images by plotting different bands' pixel intensities against each other

Clockwise from top left: FJ green band (good image), NDSI plotted against green for good image, NDSI plotted against green for cloudy image, FJ green band (cloudy image)

# RESEARCH TEAM

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Florida Institute of Technology

Jonathan Webb, University of Idaho

Edmund Robbins, Florida Institute of Technology

# REFERENCES


(1) Oerlemans, J., 2005. Extracting a Climate Signal from 169 Glacier Records. *Science*, 308(5722), pp.675-677.

(2) Huybers, K. and Roe, G., 2009. Glacier response to regional patterns of climate variability. *Journal of Climate*, 22(17), pp.4606-4620.

(3) Roe, G., 2011. What do glaciers tell us about climate variability and climate change?. *Journal of Glaciology*, 57(203), pp.567-578.

(4) Gao, J. and Liu, Y., 2001. Applications of remote sensing, GIS and GPS in glaciology: a review. *Progress in Physical Geography*, 25(4), pp.520-540.

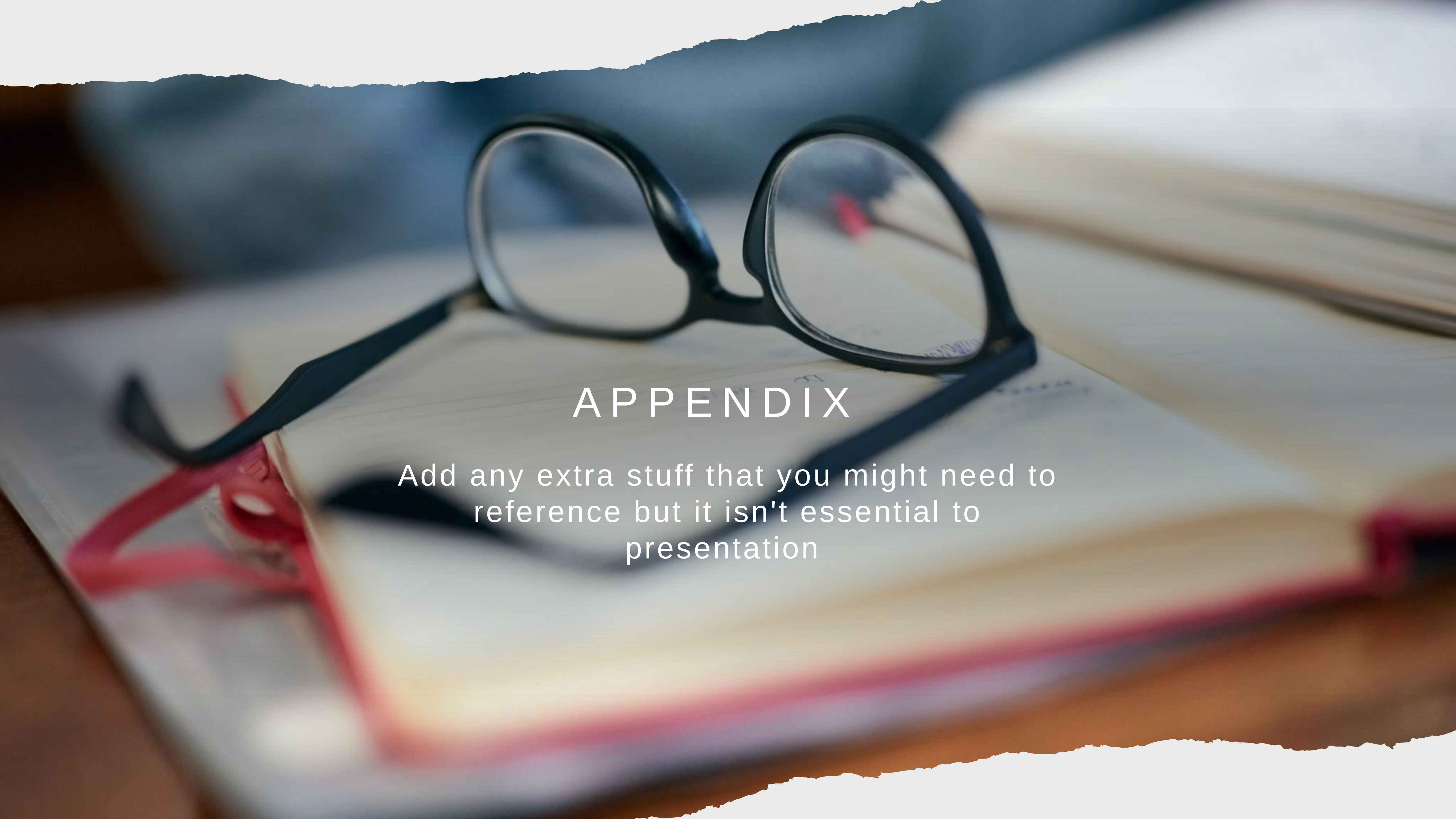
(5) Kachouie, N., Huybers, P. and Schwartzman, A., 2013. Localization of mountain glacier termini in Landsat multi-spectral images. *Pattern Recognition Letters*, 34(1), pp.94-106.

(6) 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.

(7) Onyejekwe, O., Holman, B. and Kachouie, N., 2017. Multivariate models for predicting glacier termini. *Environmental Earth Sciences*, 76(23).

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

# QUESTIONS?

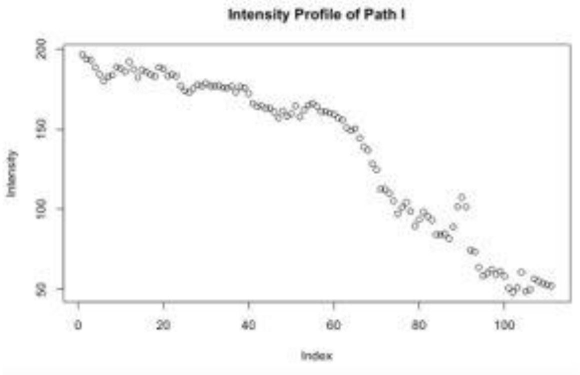


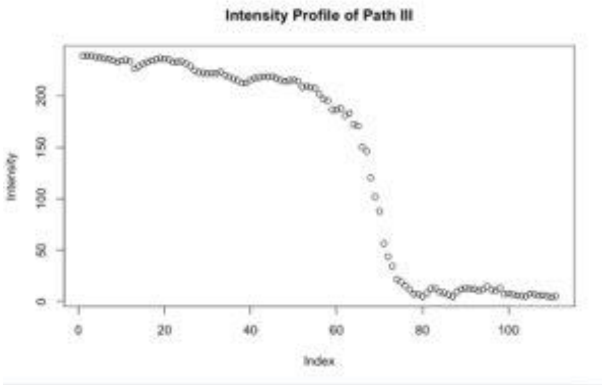
# APPENDIX

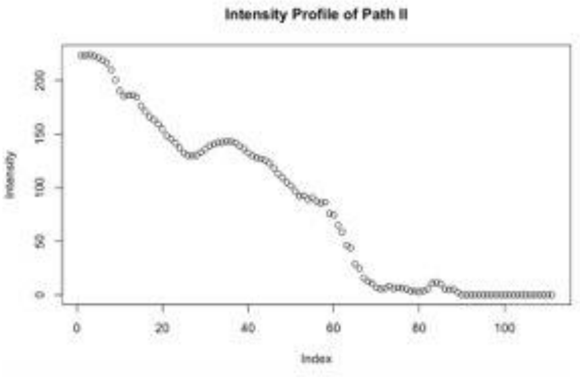
Add any extra stuff that you might need to reference but it isn't essential to presentation

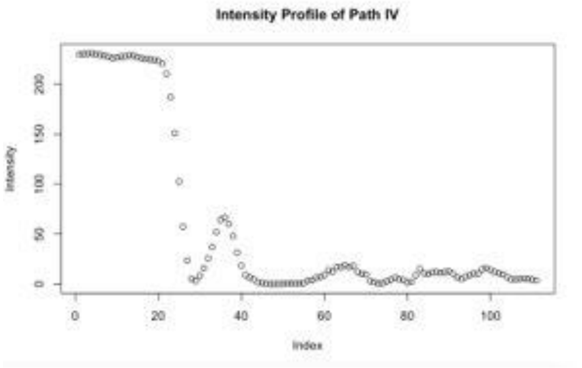
# WHAT ARE THEY?

- The set of intensity values from regularly spaced points along a line segment (in our example, that is the glacier path)
- From the Landsat Data, we graphed each separate column and got the intensity profiles for glacier path on each image



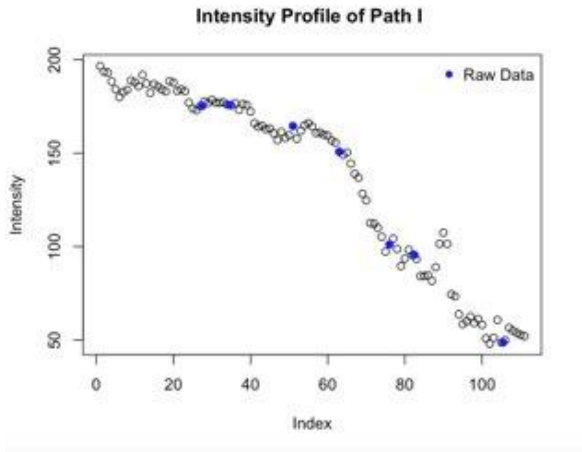



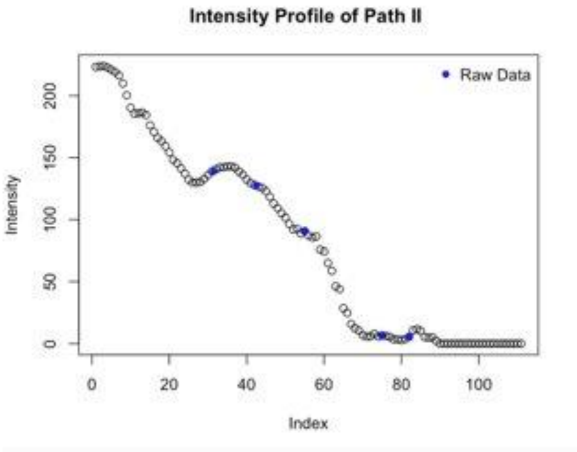



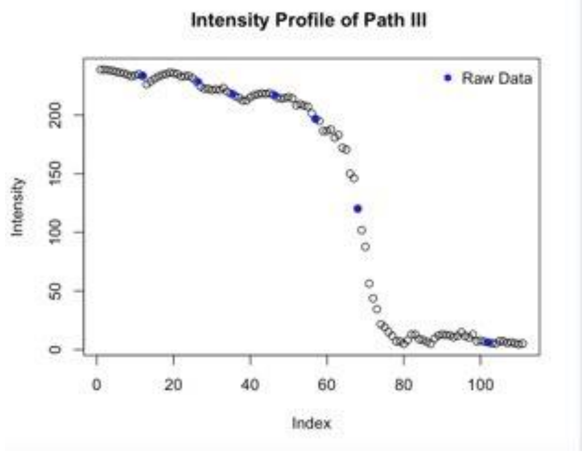



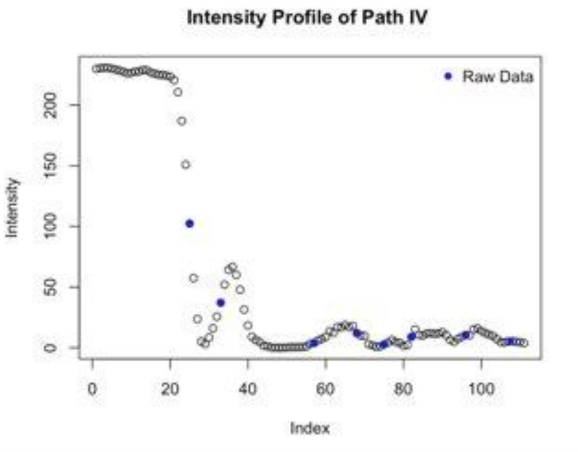
# INFLECTION POINTS

- We found the candidate points from the raw data for the first four paths.



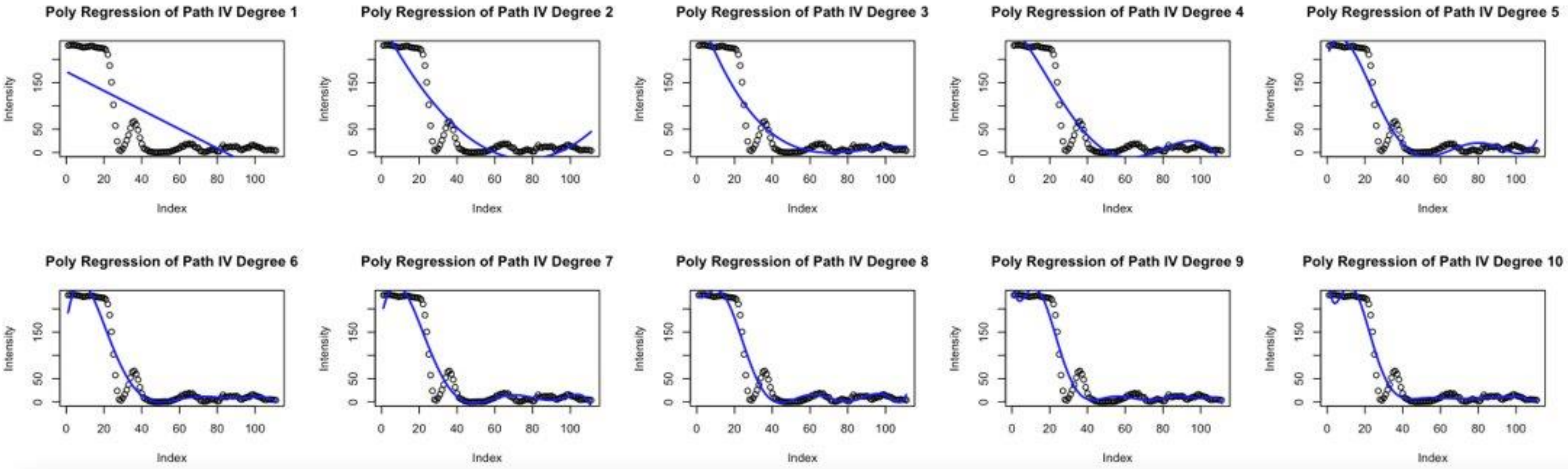



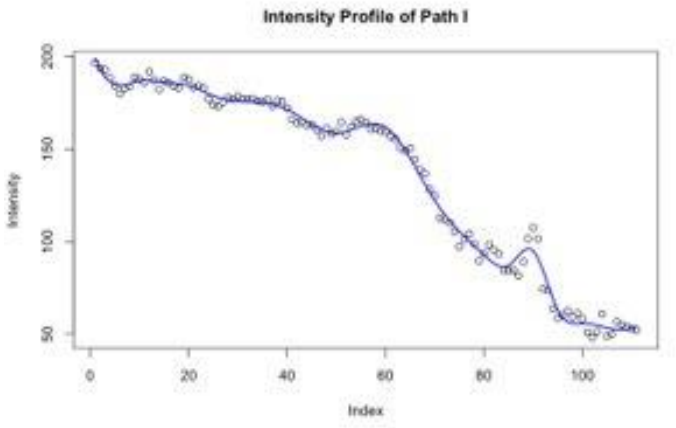
# POLYNOMIAL REGRESSION

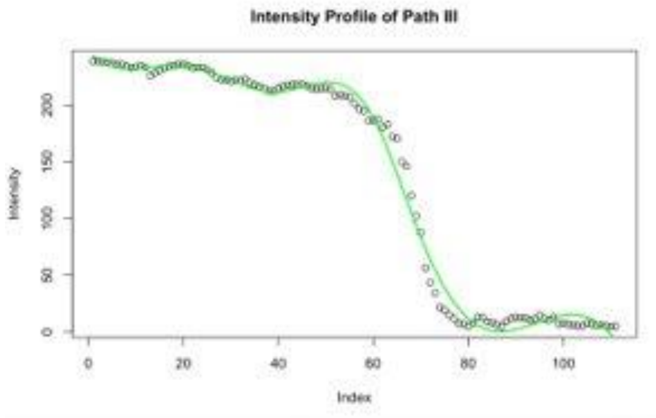
- On the first four paths, we ran polynomial regressions of degree 1 to 10.

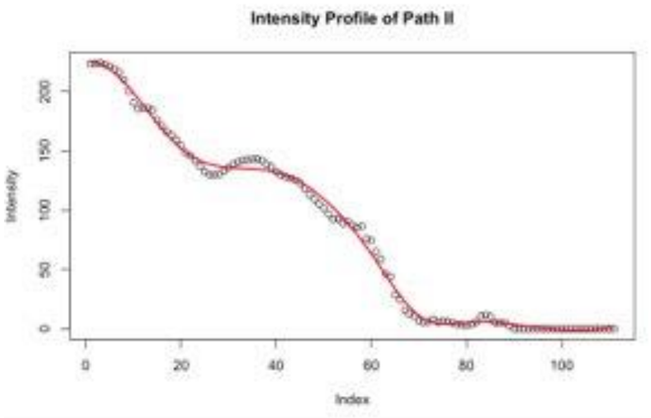


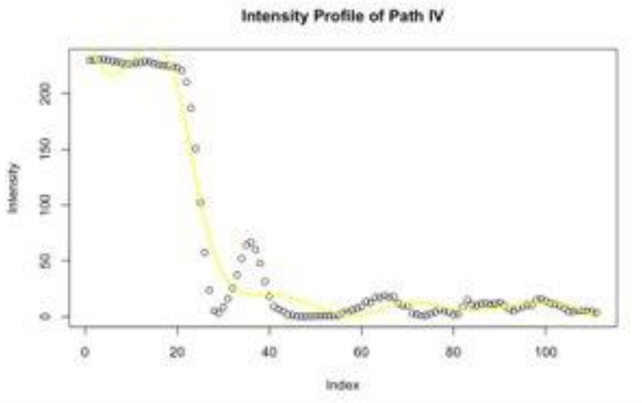
# CUBIC SPLINES

- On the first four paths, we fit cubic splines.



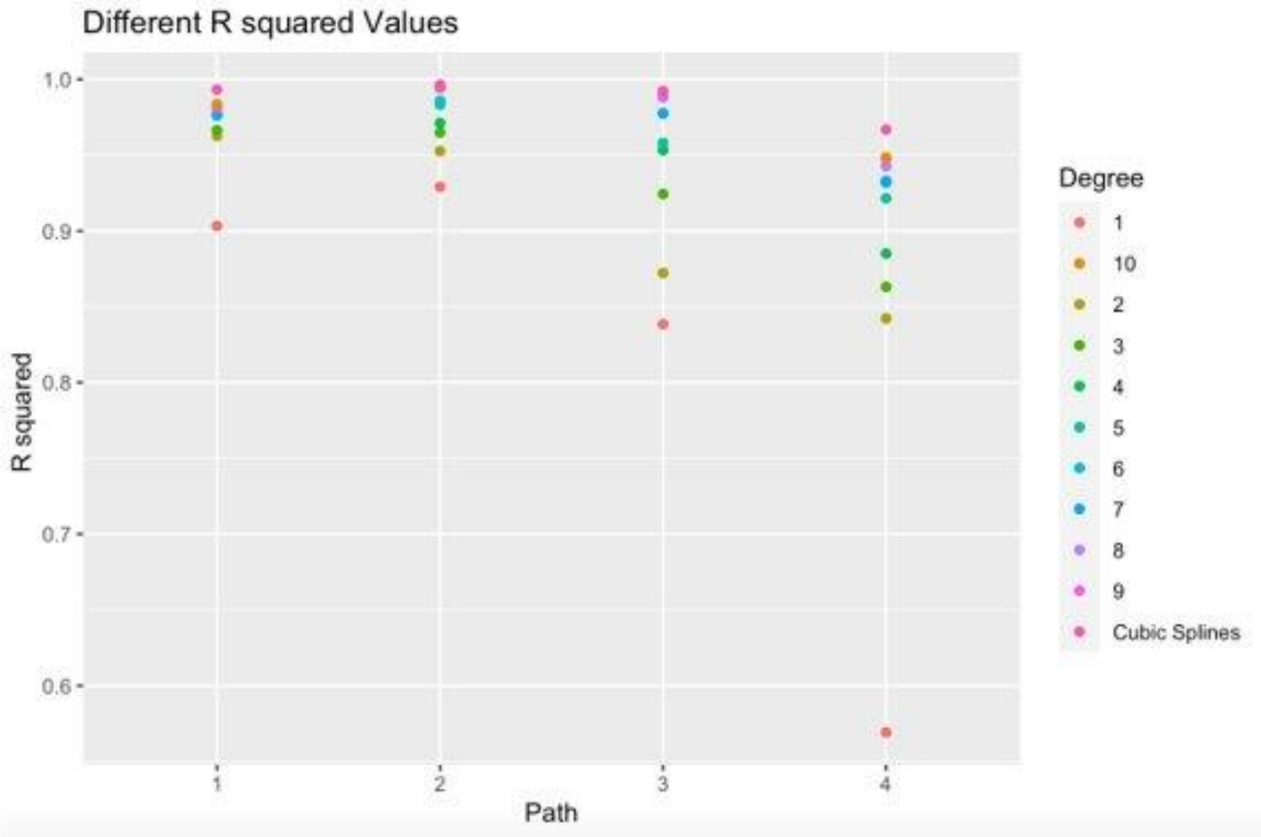



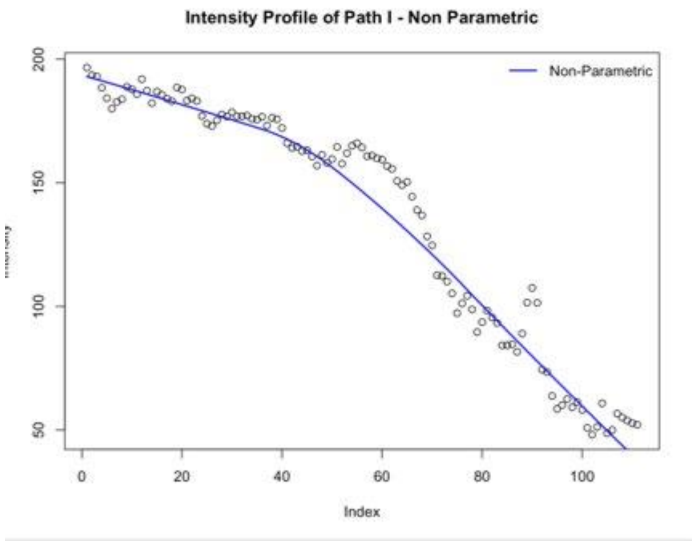
# COMPARISON OF THE PARAMETRIC REGRESSIONS

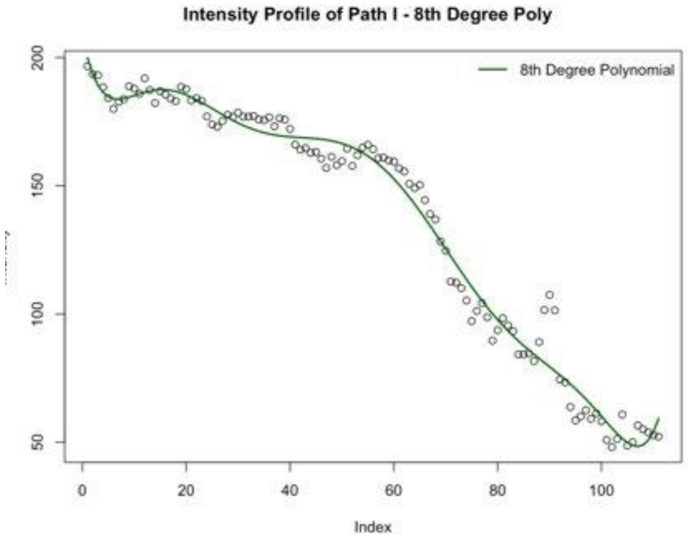
- We wanted to compare each regression's performance of estimating the intensity profile using R^2.

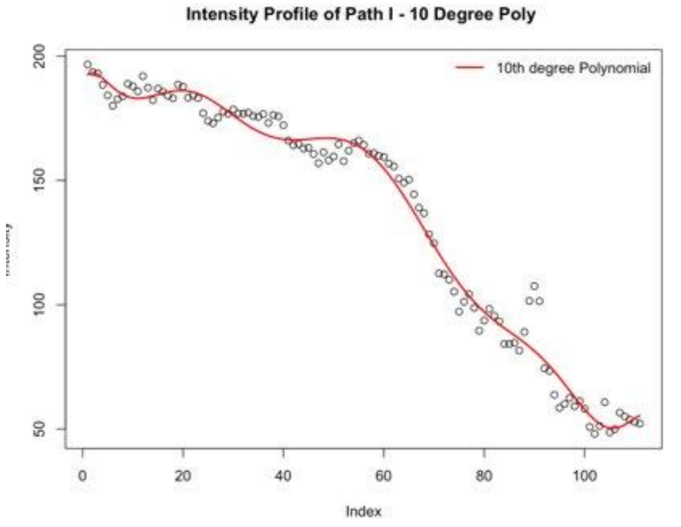


# NON-PARAMETRIC REGRESSIONS

- We specifically chose the LOESS method in R when creating our non-parametric regression.

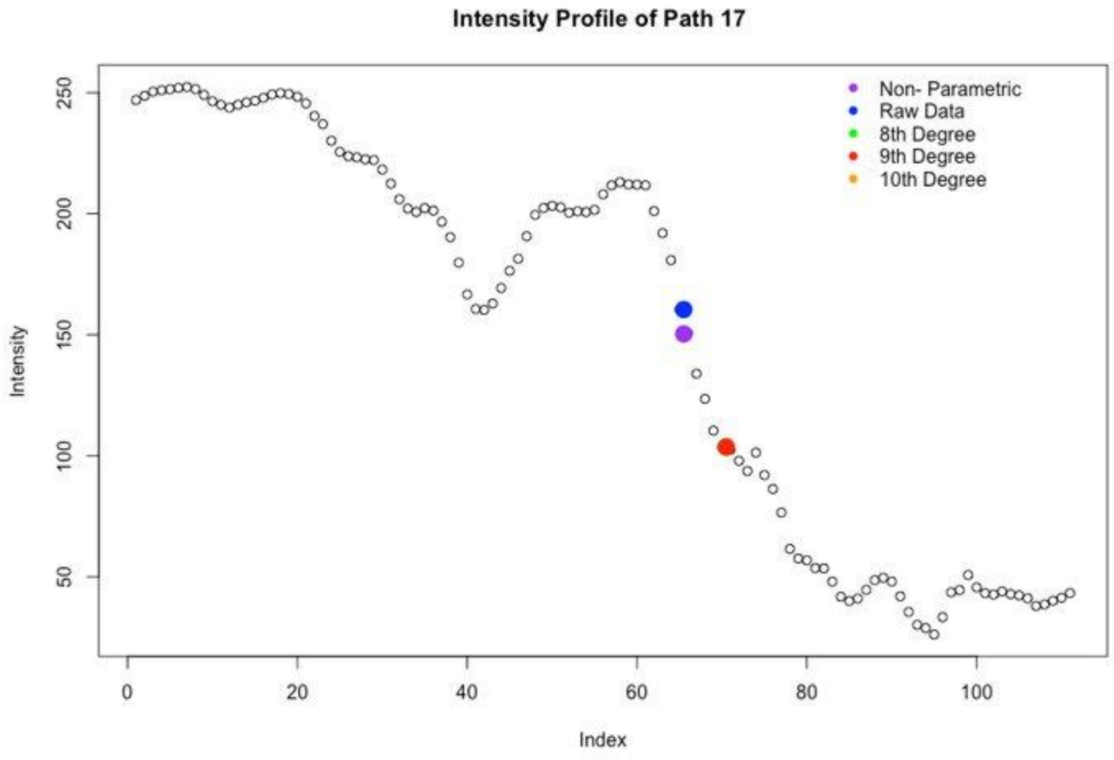


# REGRESSION'S INFLECTION POINTS

- We see that the non-parametric regression finds a more closer approximation for the terminal point than other regressions.



# SUMMARY OF INTENSITY PROFILES

01

I. We can find the terminal point in intensity profile by using inflection points.

02

II. It is better to find terminal points from regressions than from the raw data for future predicting purposes.

03

III. A non-parametric regression is the best method of estimating and prediciting future terminal point locations.

# LINEAR MODELS FOR FRANZ JOSEF

### *Terminal Point*

| Factor | P-value | R^2 |
|---|---|---|
| Average Monthly Temperature | 0.993 | 3.77E-06 |
| Average Minimum Temperature | 0.872 | 0.001327 |
| Average Maximum Temperature | 0.278 | 0.03453 |
| Average Precipitation | 0.94 | 0.000204 |
| Average Monthly Co2 | 0.0382 | 0.117 |
| Average Global Temperature | 0.485 | 0.01405 |

### *Area*

| Factor | P-value | R^2 |
|---|---|---|
| Average Monthly Temperature | 0.131 | 0.5872 |
| Average Minimum Temperature | 0.0939 | 0.0939 |
| Average Maximum Temperature | 0.239 | 0.1913 |
| Average Precipitation | 0.128 | 0.3422 |
| Average Monthly Co2 | 0.0991 | 0.3405 |
| Average Global Temperature | 0.34 | 0.1301 |

# LINEAR MODELS FOR GORNER

### *Terminal Point*

| Factor | P-value | R^2 |
|---|---|---|
| Average Monthly Temperature | 0.0176 | 0.3623 |
| Average Minimum Temperature | 0.00858 | 0.4238 |
| Average Maximum Temperature | 0.0331 | 0.3039 |
| Average Perciptation | 0.645 | 0.01681 |
| Cumulative Monthly Perciptation | 0.6178 | 0.01971 |
| Average Monthly Co2 | 3.22e-10 * | 0.9563, |
| Average Global Temperature | 0.000201 | 0.6674 |

### *Area*

| Factor | P-value | R^2 |
|---|---|---|
| Average Monthly Temperature | 0.166 | 0.2541 |
| Average Minimum Temperature | 0.125 | 0.3028 |
| Average Maximum Temperature | 0.323 | 0.1392 |
| Average Perciptation | 0.117 | 0.3138 |
| Cumulative Monthly Perciptation | 0.112 | 0.3211 |
| Average Monthly Co2 | 0.363 | 0.104 |
| Average Global Temperature | 0.20391 | 0.193 |

# ADDITIVE MODELS FOR FRANZ JOSEF

**Terminal Point**

| Factor | P-value | R^2 |
|---|---|---|
| Average Monthly Temperature | 0.59 | 0.0238 |
| Average Minimum Temperature | 0.733 | -0.00962 |
| Average Maximum Temperature | 0.387 | 0.0159 |
| Average Precipitation | 0.94 | -0.0355 |
| Average Monthly Co2 | 0.0103 | 0.29 |
| Average Global Temperature | 0.285 | -0.0141 |

**Area**

| Factor | P-value | R^2 |
|---|---|---|
| Average Monthly Temperature | 0.13 | 0.45 |
| Average Minimum Temperature | 0.127 | 0.587 |
| Average Maximum Temperature | 0.239 | 0.0757 |
| Average Precipitation | 0.127 | 0.233 |
| Average Monthly Co2 | 0.149 | 0.295 |
| Average Global Temperature | 0.38 | 0.137 |

# ADDITIVE MODELS FOR GORNER

## Terminal Point

| Factor | P-value | R^2 |
|---|---|---|
| Average Monthly Temperature | 0.0173 * | 0.313 |
| Average Minimum Temperature | 0.00832 | 0.379 |
| Average Maximum Temperature | 0.0329 * | 0.25 |
| Average Precipitation | 0.646 | -0.0588 |
| Cumulative Monthly Precipitation | 0.618 | -0.0556 |
| Average Monthly Co2 | <2e-16 | 0.986 |
| Average Global Temperature | 0.000139 *** | 0.642 |

## Area

| Factor | P-value | R^2 |
|---|---|---|
| Average Monthly Temperature | 0.0221 | 0.638 |
| Average Minimum Temperature | 0.0136 | 0.686 |
| Average Maximum Temperature | 0.04 | 0.566 |
| Average Perciptation | 0.0113 | 0.704 |
| Cumulative Monthly Perciptation | 0.00954 | 0.718 |
| Average Monthly Co2 | 0.254 | 0.213 |
| Average Global Temperature | 0.204 | 0.0922 |