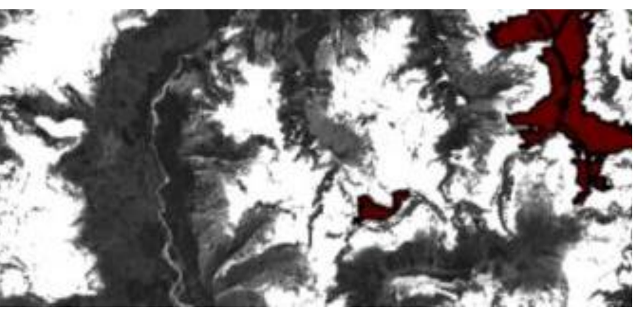
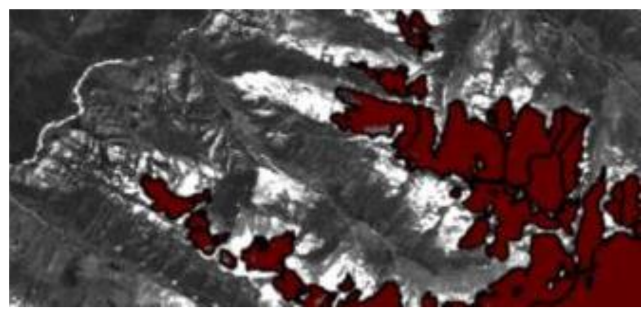
GLACIER AREA CHANGE IN BRITISH COLUMBIA, CANADA OVER 31 YEARS OF SATELLITE IMAGERY

Alexandre Bevington[1,2], B. Menounos[1] and M. Geertsema[1,2]
[1] University of Northern British Columbia, Prince George, BC, Canada
[2] Ministry of Forests, Lands and Natural Resource Operations, Prince George, BC, Canada



Poster Abstract *(preliminary results)*

Analysis of glacier extent though time provides one method to assess the magnitude and spatial pattern of recent climate change. Previous work in British Columbia, Canada used semi-automatic methods to delineated glacier extents from Landsat satellite imagery for the years 1985 and 2005. Over that time period rates of glacier area change averaged -0.55 % yr^{-1}. We build upon that work by providing post 2005 area change assessment and also increase the number of years over which glacier change is evaluated. Our workflow runs in Google Earth Engine that analyzes publically available satellite imagery [Landsat Thematic Mapper (TM), Enhanced Thematic Mapper (ETM+) and Operational Land Imager (OLI) sensors] for all available late-summer scenes between 1985-2016. Our algorithm employs a semi-automated method based on band ratios, a normalized difference snow index (NDSI) and a green band threshold. Areas of recent deglaciation are delineated and trends in glacier extents are compared to change in energy and mass flux present in climate stations and reanalysis products. We also discuss preliminary results of a 2016 British Columbia, Canada glacier extent produced from Sentinel-2A Multispectral Instrument (MSI) imagery. Sentinel-2A offers a higher spatial resolution (10 m) than Landsat satellites (15-30 m). Validation and uncertainty estimates have not yet been completed. The validation process will include comparison to air photos, LiDAR and high resolution satellite imagery for different environmental settings. Debris-covered glacier ice still presents a challenge to this mapping and will only be manually corrected for the 2016 Sentinel-2 glacier inventory.



Introduction

The analysis of glacier area though time provides one method to assess the magnitude and spatial pattern of recent climate change. Moderate resolution satellite based multispectral imagery is often used to delineate glacier extents using manual, automated, or semi-automated techniques (Kääb et al. 2010). Previous work in British Columbia, Canada used semi-automated methods to delineate glacier extents from Landsat imagery for the years 1985 and 2005 (**Fig. 1**; Bolch et al. 2010). Over that time period rates of glacier area change averaged -0.55 % yr^{-1}. Efforts such as the Randolph Glacier Inventory compile such glacier extents into global glacier inventories that are used to model climate and the cryosphere.

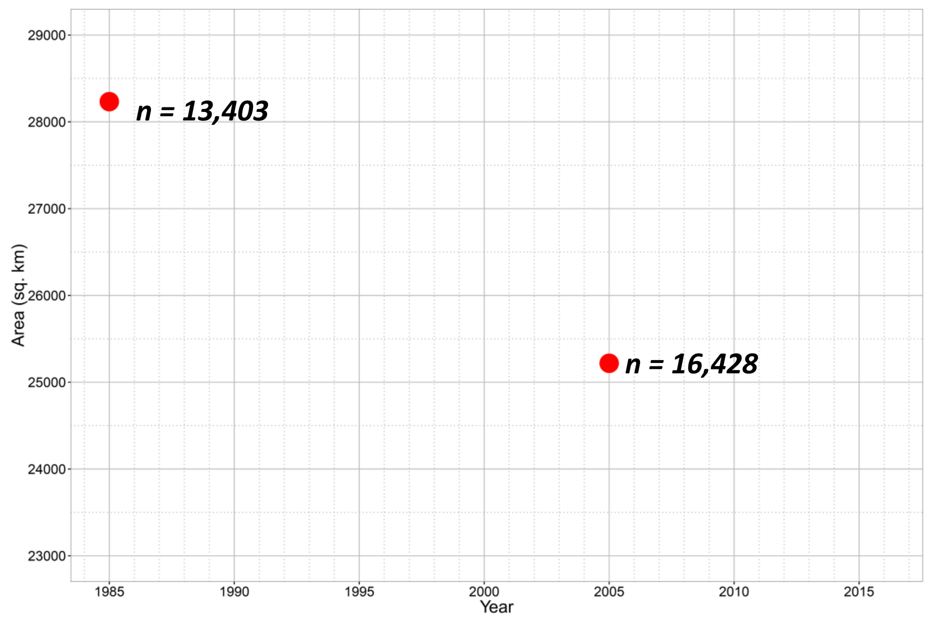


Fig 1. *Previously published glacier area measurements for British Columbia, Canada. Glacier area decreased from 28,349 km2 to 25,852 km2 between 1985 and 2005, and the total number of glaciers increased from 13,403 to 16,428 over the same period. As deglaciation occurs large glaciers divide into two or more smaller glaciers.*

Objectives

1. **Update glacier inventory**
   The last glacier inventory of British Columbia, Canada was for the year 2005. One of the objectives of this study is to complete a 2016 glacier inventory using semi-automated techniques.

2. **Conduct time-series analysis**
   In order to better understand the relationship between climate changes and glacier extent changes, we investigate annual glacier area change. One of the objectives of this study is to quantify glacier area for all years from 1985-2016. We hope to optimize this methodology by conducting a sensitivity analysis. We hope to leverage free data and free cloud computing to add temporal resolution to glacier change studies.

Study Area

British Columbia is located in western Canada. It is bordered to the west by the Pacific Ocean and the Alaskan Border, to the north be the Yukon and Northwest Territories, To the east by Alberta, and to the south by the United States. The province covers approximately 1 million square kilometers, and has three broad mountain chains: The Coast Mountains to the west, the Rocky Mountains to the east and the Interior Ranges in the center. All regions have seen a decrease in glacier area from 1985-2005 (**Fig. 2**).

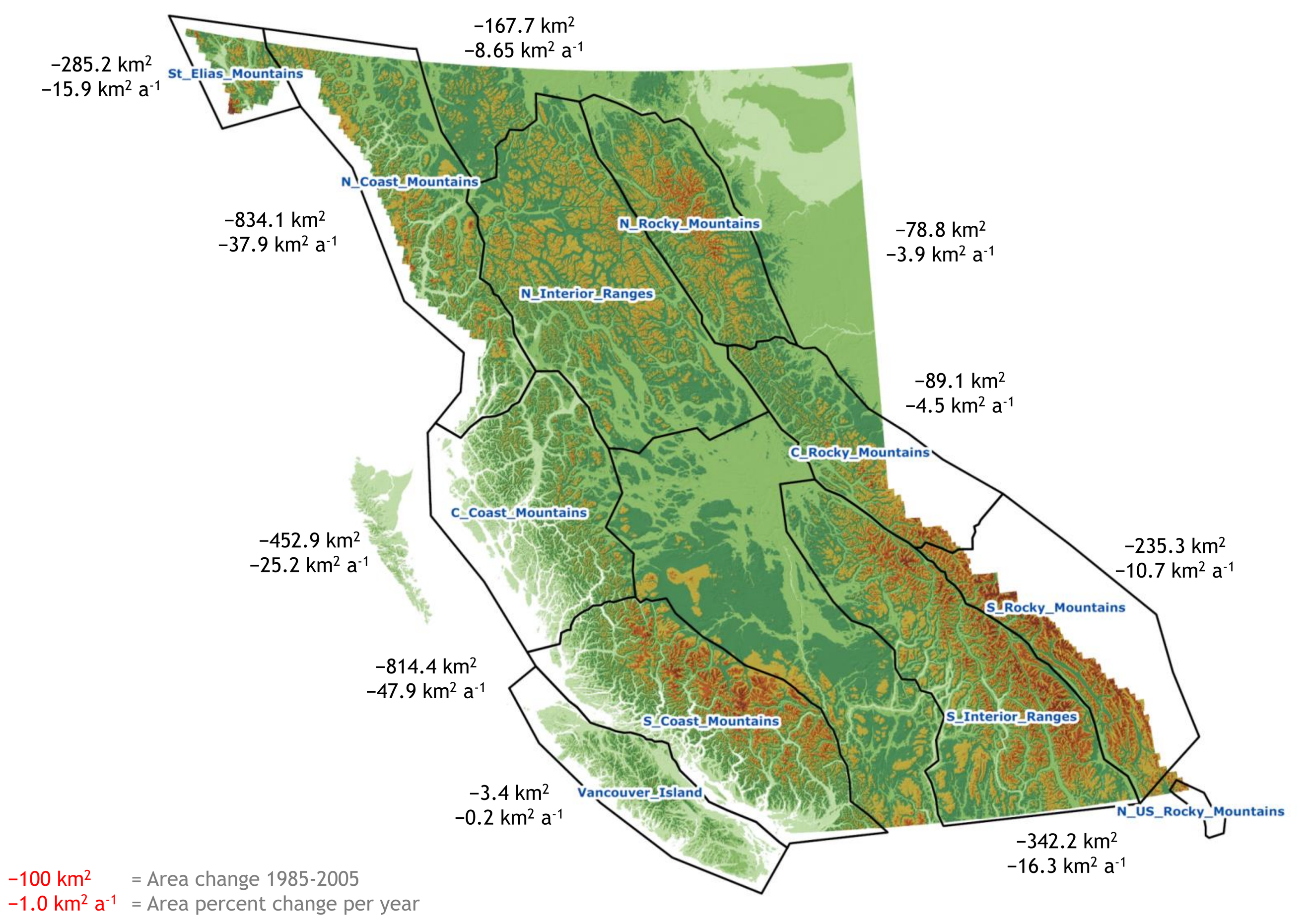


Fig 2. *Map of the study area with previously published retreat rates (Bolch et al. 2010). Regions are described as South, Central or North, Rocky, Coast or Interior*

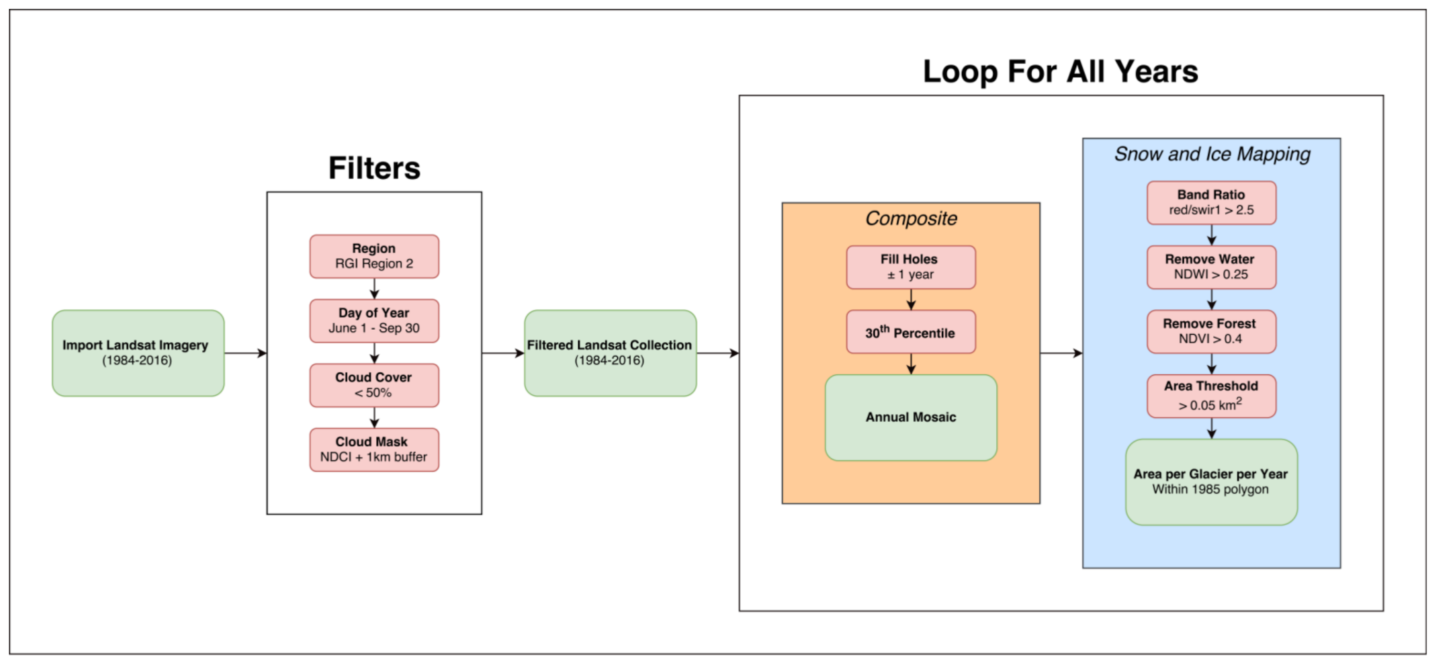


Fig 3. Flowchart describing methodology employed on Google Earth Engine to delineate glacier area.

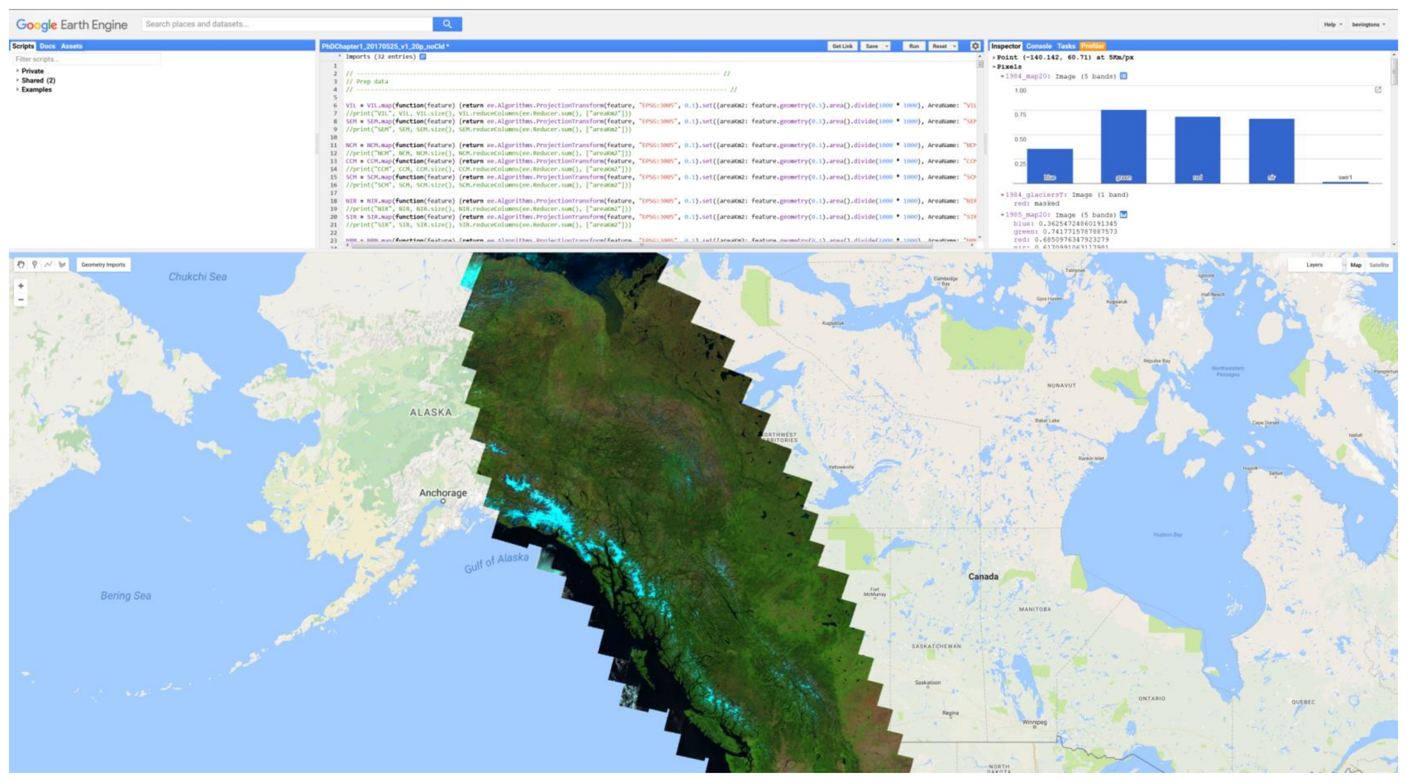


Fig 4. Screenshot of a 30th percentile image mosaic over western Canada. The screenshot includes a view of the Google Earth Engine platform and code editor.

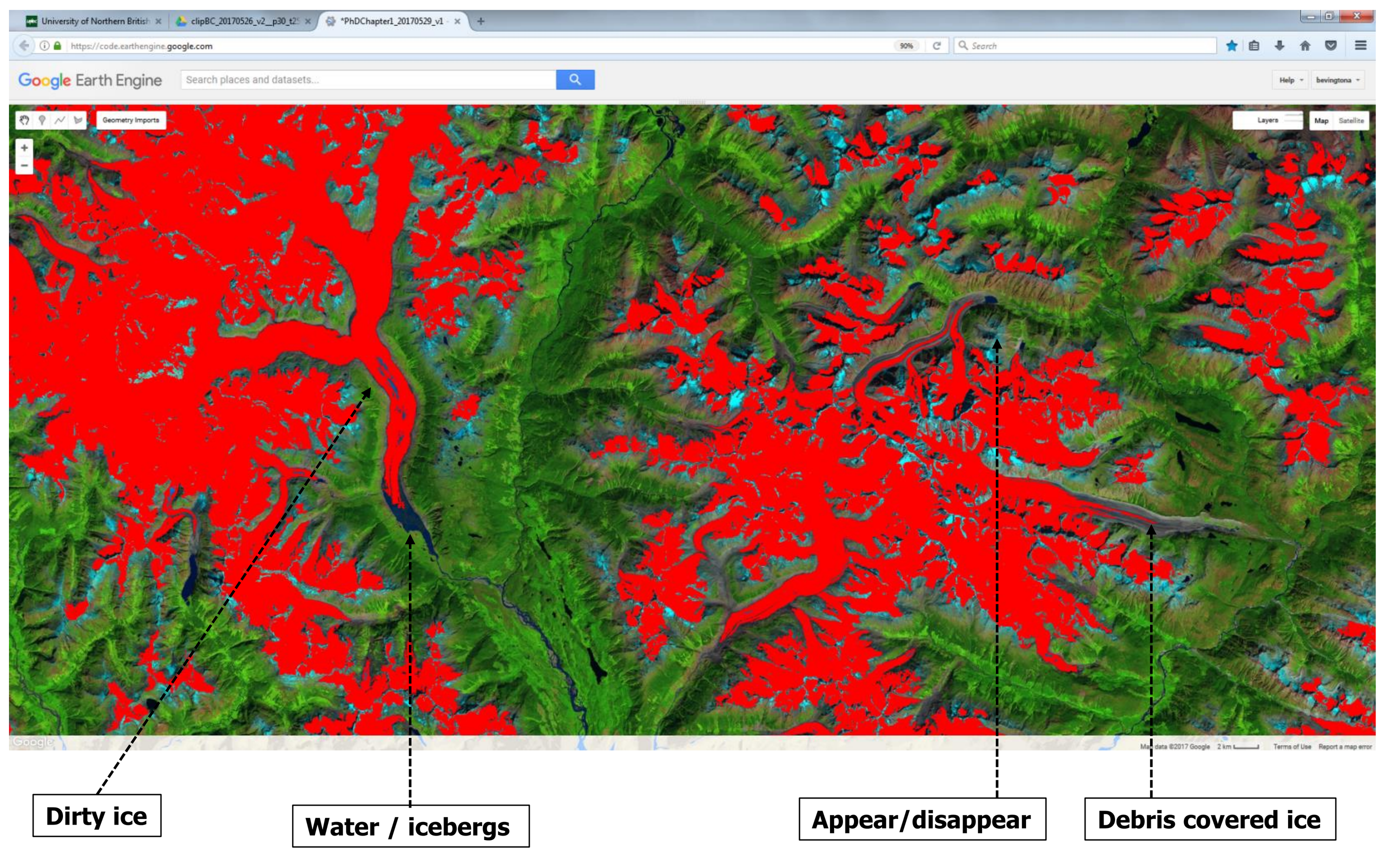


Fig 5. Image of challenges relating to misclassifications in our algorithm. Dirt ice, icebergs, area threshold, and debris covered ice.

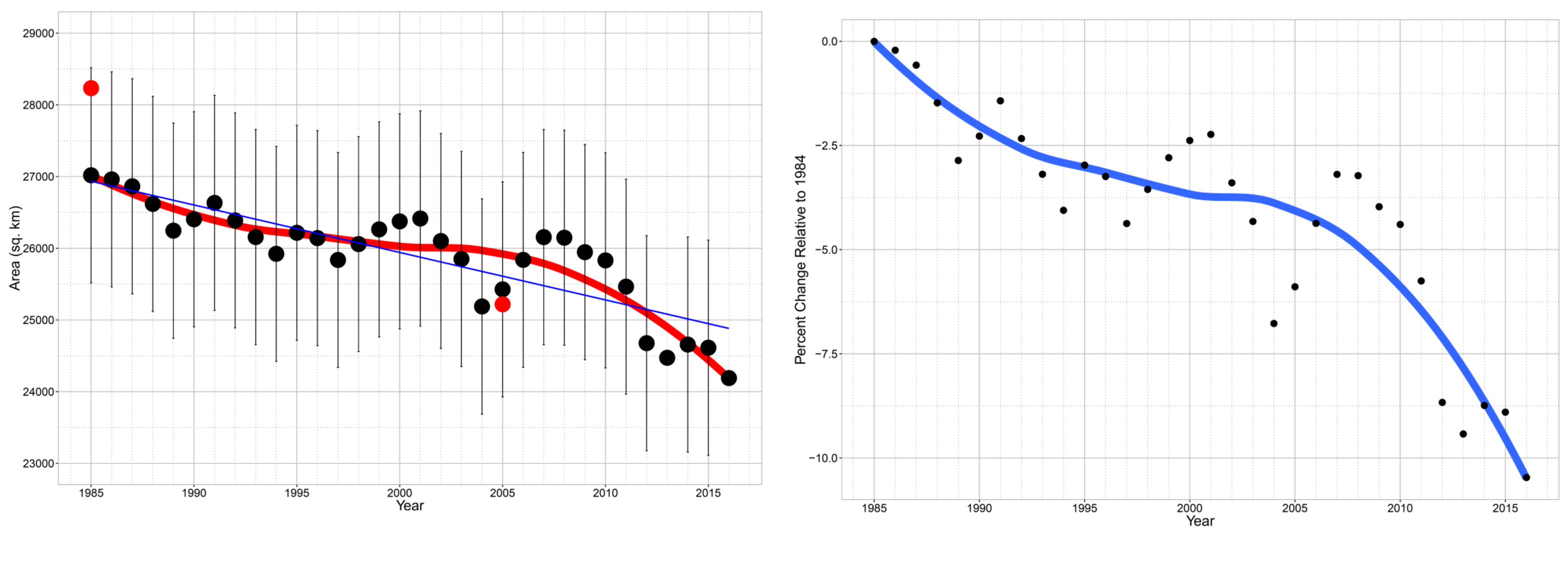


Fig 6. [left] Glacier area change over time. Black dots show decreasing trend in glacier area. Error bars estimated in grey, red dots show previously published glacier area estimates. [right] Cumulative glacier area percent change over time from 1985-2016.

Methods

Our workflow analyzes publically available satellite imagery [Landsat Thematic Mapper (TM), Enhanced Thematic Mapper (ETM+) and Operational Land Imager (OLI) sensors] for all available late-summer scenes between 1985-2016. We use the Google Earth Engine (GEE) platform to process the imagery. GEE is a free online cloud computing platform that rapidly loads and processes satellite imagery from a variety of satellite image datasets (Google, 2010).

Our methodology has three main components: 1) Combine and filter the Landsat 4, 5, 7 and 8, and Sentinel-2A image collections; 2) Create annual cloud free composite mosaics of the study area; and 3) Map snow and ice within the published 1985 glacier outlines. See **Fig. 3**, and additional details below:

Step 1: The Landsat 4, 5, 7 and 8, and Sentinel-2A image collections are filtered spatially, by day of year (June 1 – Sep 30) and cloud cover percent (< 50%). A cloud mask is then applied using the Normalized Difference Cloud Index (NDCI), a threshold, and a spatial buffer.

Step 2: For every year a 30th percentile mosaic is calculated using imagery from the previous year to fill in any gaps. The 30th percentile mosaic is chosen based on a preference for darker pixels in glacier mapping and to exclude late snow and unmasked clouds (**Fig. 4**).

Step 3: We calculate a band ratio threshold to map snow and ice (red / swir1 > 2.5), remove water bodies (NDWI > 0.25) and forests (NDVI > 0.4), then filter out resulting snow and ice with an area threshold to remove small outliers (>0.05 km2). See **Fig. 5**.

Preliminary Results

1. Total glacier area decreased from 27,034 km2 to 24,235 km2 from 1985-2016. Error bars are estimated at 1200 km2.
2. Two periods of rapid ice loss have occurred, one in 1985-1997 and one in 2008-2016. The most rapid ice loss is between 2010 and 2016 (**Fig. 6**)
3. The parameter optimization between manual and automated techniques has not yet been completed

Preliminary Discussion

1. Errors possibly due to water, icebergs, late lying snow and debris cover (**Fig. 5**). Debris-covered glacier ice still presents a challenge to this mapping and is only manually corrected for the 2016 Sentinel-2 glacier inventory. Other challenges remain and require iteration and parameter optimization. Our goal is to have better agreement between manual and automated techniques and more realistic glacier area change trend lines over rich time series data.
2. Two periods of rapid glacier area loss (~1985-1997 & ~2008-2016) consistent with air temperature record (**Fig. 6 & 7**).

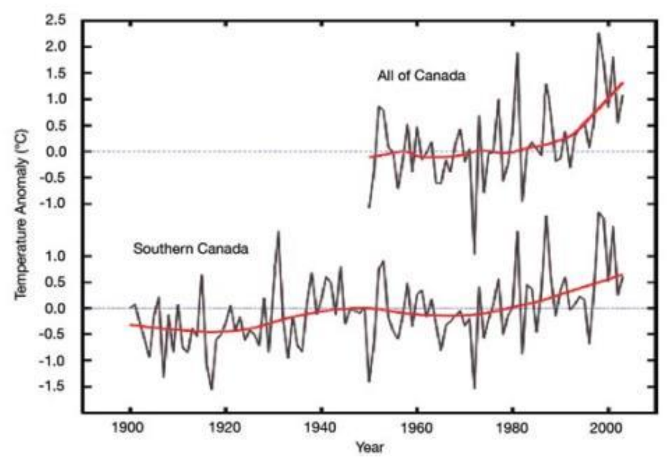


Fig 7. Air temperature trends for western Canada match well with two periods of rapid warming. (Bolch et al. 2010)

References

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Acknowledgements

The Google Earth Engine developer community, the university of northern BC and the Forest Service research branch.