Changes in the Extent of Baffin Island’s Penny Ice Cap in Response to Regional Warming, 1985-2010

Mary Cox1, Heather Cormier2, Alex Gardner1
Clark University1; Jet Propulsion Laboratory-NASA2

1. OVERVIEW

Glaciers are retracting globally in response to warmer atmospheric temperatures, and the largest glaciated region and present-day contributor to sea level rise outside of the ice sheets is the Canadian Arctic. The Penny Ice Cap, one of the last remnants of the Laurentide Ice Sheet, is the last. This study recently experienced accelerated rates of ice loss. This study examines spatial and temporal variations in the extent of the Penny Ice Cap from 1985 to 2010. Regional climate patterns are investigated as contributors to the differences in rates of change across the ice cap.

2. DATA & METHODS

As cloud cover and seasonal snow are common challenges to working with Arctic data, three summertime Landsat 5 TM scenes were downloaded from USGS EarthExplorer, in an attempt to analyze two 5-10 year periods of change over the last few decades. For each scene, atmospheric corrections were performed using the cloud-only method, which includes dark object subtraction (Humes and Nolin 2014). Normalized difference snow indices (NDSI) values were then calculated for each image separately, using the equation, NDSI = (Green - SWIR)/(Green + SWIR). With Landsat 5 TM bands 2 and 3. An NDSI threshold of 0.4 was then used consistently across all images to distinguish ice from land (Hall et al. 1995). Each year’s near-infrared-based band was then used to incorporate an appropriate threshold for distinguishing water from ice, in order to mask water out of the area calculation of the ice cap. Water mask thresholds used were 0.219, 0.233, and 0.154 for the years 1985, 1995, and 2010, respectively. Outliers were then manually corrected for shadows, seasonal snow, and debris (Svoboda and Paul 2009). A SPOT IRS scene of higher spatial resolution from 2009 was also obtained, and outlines were similarly thresholded by digital number value, then manually corrected. This outline was used to assess the accuracy of the outlines derived from the lower resolution Landsat imagery.

3. RESULTS

Area Change

Results of the area change analysis show overall decrease in area for the entire ice cap over the full study period as well as an increase in the rate of change over time. Between 1985 and 1995, and 1995 and 2010, the rate of change was 2.15 km²/yr, but between 1995 and 2010, this rate increased to 5.3 km²/yr.

This study also explored regional patterns in area change across the Penny Ice Cap by dividing the ice cap into two sections, west and east, along a major drainage divide. The western portion of the Penny Ice Cap experienced a rate of change of -1.48 km²/yr between 1985 and 1995 and -3.99 km²/yr between 1995 and 2010, while the eastern section saw a rate of -0.67 km²/yr between 1985 and 1995 and -1.99 km²/yr between 1995 and 2010.

Climate

Climate is often identified as a driver for area loss of glaciers (Gardner et al. 2012). Throughout the Penny Ice Cap, positive degree days have increased over the past three decades as annual precipitation has decreased. Over the same time period, the rate of area loss between time periods has increased, which is consistent with the findings of Oerlemans et al. (1998) that higher summer temperatures and lower annual precipitation both contribute to area loss. Since positive degree days (PDD) compounds the effects of higher temperatures, it can be used as a proxy for energy available for melt, so ice will be warmer for longer. Due to observed higher PDD and lower precipitation in the west, both area and length were expected to experience greater retreat than the east; however, this was not the case for changes in area. This indicates there are other possible drivers affecting length change of individual glaciers. Additionally, as there was not much change between the west or east length across time periods, measuring changes in length is a poor proxy for a retreat signal that might not capture the full story.

Hypsometry

In order to explore other possible drivers of regional differences in rates of area and length change, we conducted a hypsometry analysis of the Penny Ice Cap. Elevation was classified into 100 m bins within 1 km of the perimeter of the Ice Cap and was extracted for the west and east sides. This analysis showed the following:

- The eastern region, excluding tidewater glaciers, contains the lowest elevations (118 m).
- The western region has more area (620 km²) at low elevations than the eastern region (570 km²).

Elevations below the mean of the buffered perimeter were considered “low.” Increasing temperatures have more impact on ice that is already at the melting point since all energy from solar to canopy degree goes toward melt, while colder ice remains unaffected until it reaches a certain point. Ice at low elevations tends to be closer to the melting point and therefore more sensitive to even slight temperature increases (Gardner et al. 2012, Paul and Svoboda 2009). Although this study used a small (21 total) and unevenly sample plot (9 eastern and 12 western) of individual glacier lengths, our results may still have implications for investigating drivers of ice loss.

As expected, with more peripheral area at low elevations in the west, this region also experienced higher rates of area retreat than the east starting both during time periods, including tidewater glaciers, and also did not change considerably between time periods. Therefore, solely examining length change of individual glaciers can be misleading, and extrapolation of length changes to area changes across an ice cap may not prove accurate.

4. DISCUSSION

Accuracy Assessment

A novel extent comparison algorithm was developed to quantify the error in the 2010 Landsat 5 TM outline, relative to the 2009 SPOT IRS outline. First, transects were drawn every thirty meters, perpendicular to the SPOT outline. Next, the intersections between the transects and the 2010 outline were identified and assigned a sign indicator (positive if the 2010 outline extended outside the SPOT boundary, negative if it was inside the SPOT boundary). The distance between these two points of intersection was then calculated for each transect and multiplied by the sign indicator. Finally, a graph of error was generated over increasing distances from 30 m to 1.200 m. Due to autocorrelation, error decreases as it is integrated over larger distances and levels off around 17 m when measured over a distance of approximately 1 km.

5. CHALLENGES AND LIMITATIONS

Finding accurate cloud-free imagery at the time scales and intervals of interest presented challenges in this study. Shadows, debris, and seasonal snow, even in summer months, often causes misclassification and limited confidence in their accuracy. Subsequent subjectivity in manual corrections for each year likely also had an influence on findings. Unreliable geographic sampling of glaciers used in the box method could have influenced the average length changes calculated for the eastern (9 glaciers) and western (12 glaciers) sides of the ice cap, and any outliers in the east could skew results. Finally, since climate records from ground weather stations were sparse and inconsistent through time, reanalysis data were used instead of direct observations.

6. SUMMARY AND CONCLUSIONS

Consistent with the mass loss findings of Gardner et al. (2012), this study found that the rate of area loss of the Penny Ice Cap has increased over the past three decades, as PDD has increased and precipitation has decreased. We further determined that the west has experienced greater rates of area loss than the east. Although climate factors appear to play a role in the observed changes, they do not fully explain geographic differences. Larger area at low elevations in the west may be a contributing factor to this regional disparity.

Contrary to some rates, rates of length change of individual glaciers. Additionally, as there was not much change between the west or east length across time periods, measuring changes in length is a poor proxy for a retreat signal that might not capture the full story.

Scale, similar is important to the accuracy of change measurements. The accuracy assessment results from this study showed correlation of error over short distances, but over longer distances, the error began to level off. By measuring change along the entire perimeter of the Ice Cap, error is minimized and results. Any area change to area changes across an ice cap may not prove accurate.

ACKNOWLEDGEMENTS

We would like to thank Clark University’s International Development, Community and Environment Student Association and the Graduate Student Council for their contribution of generous travel funds, which allowed us to present at such a prestigious conference. The input from fellow M.S. Geographic Information Science for Development and Environment candidates was invaluable. Special thanks are extended to Dan Dorigo-Oehme, Himmelberger, and the Clark University Graduate School of Geography. References