Historical Structure from Motion

Automated production of high-resolution DEMs from historical imagery for quantitative analysis of glacier and geomorphological change

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Motivation

- Long-term (50-100 yr) records of quantitative landscape change are often temporally and geographically sparse.
- Historical aerial and satellite photography provide the opportunity to augment these records and study incremental change.
- We present a fully automated photogrammetry approach to generate high-resolution Digital Elevation Models from historical imagery and conduct quantitative change analysis.

Workflow

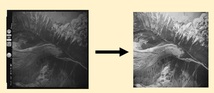
Aerial photograph acquisition

Between 1964 and 1997, Austin Post and the USGS NAGAP program collected >100,000 aerial photographs of glaciers in Western North America. Stereo photographs were acquired with metric aerial cameras (9x9" film) at ~60% along-track overlap, enabling stereo reconstruction. The USGS coordinated efforts with Matt Nolan to scan >20,000 of these images at 20 micron resolution. Today, these images are publically available via NSF's arcticdata.io website.

Scan film into digital format

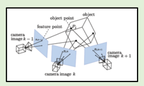
Make public via NSF's arcticdata.io

Image pre-processing and standardization



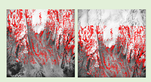
- Automated image download
- Fiducial marker detection
- Frame removal
- Affine transformation
- Histogram equalization

Adjust relative camera positions and orientations



- Approximate camera location and orientation
- Detect and match interest points
- Refine camera positions and orientations

Generate dense point cloud and DEM

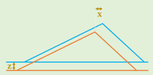


- Dense stereo matching
- DEM generation
- Orthomosaic generation

Agisoft

NASA ASP

Align DEM with modern reference DEM over stable ground



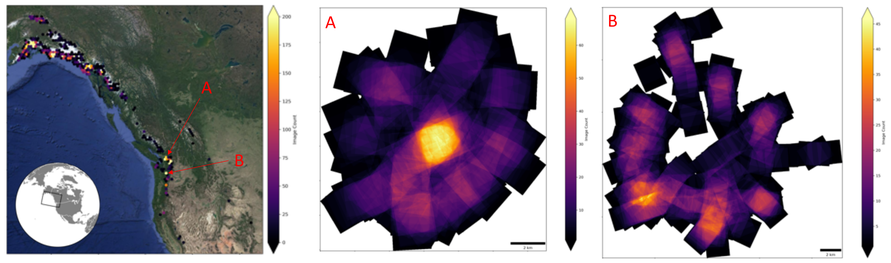
- Iterative point cloud alignment
- DEM co-registration
- Modern point cloud as ground control

Difference DEMs and quantify chance through time

- Subtract DEMs
- Compute volumetric differences
- Analyze change through time

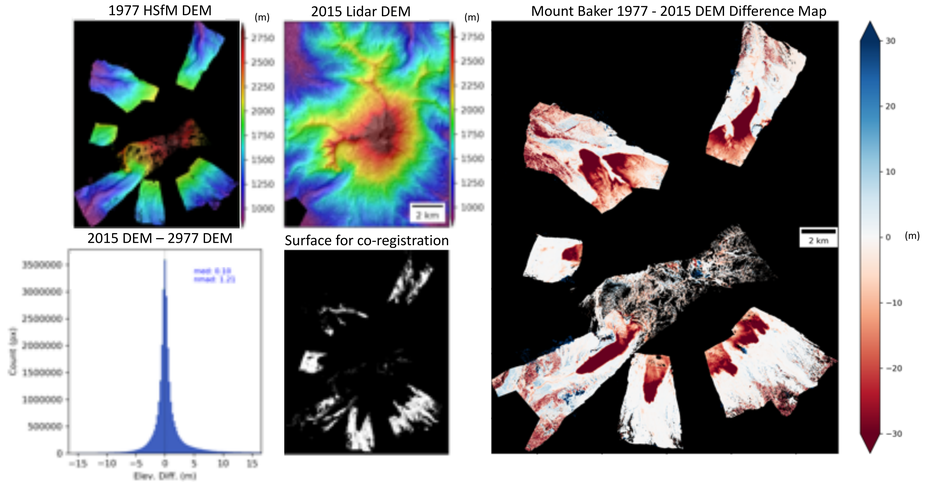
North American Glacier Aerial Photography

(1960s – 1990s coverage)



Mount Baker elevation change

(1977 – 2015 difference)



Example of high-resolution DEM for Easton glacier

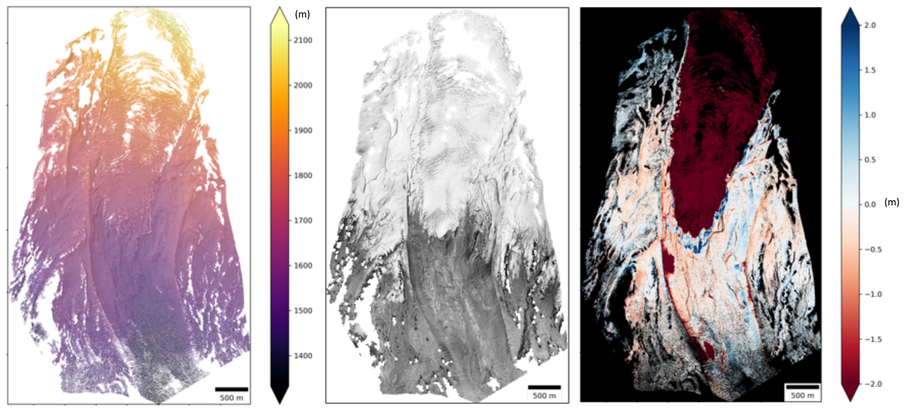
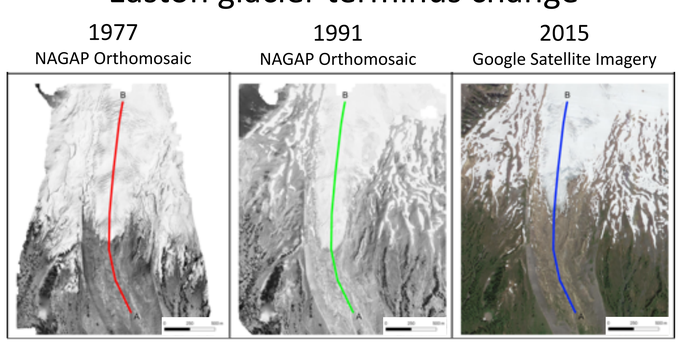


Image Ground Sample Distance	DEM Posting (Resolution)	1977 -2015 Difference (NMAD)
20 cm	50 cm	30 cm

Easton glacier terminus change



Orthomosaics (above) and elevation profiles (below left) at Easton Glacier showing terminus advance between 1977 and 1991 and subsequent retreat. By 2015, the terminus retreated >250 m and the lower glacier thinned by >20 m, compared to its 1977 state. Figure 5. from Harper 1993 (below right) for additional reference.

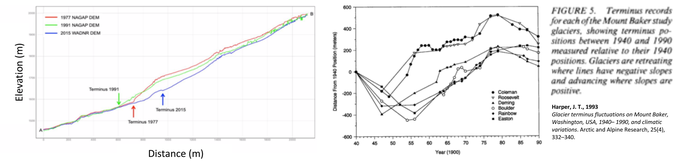


FIGURE 5. Terminus records for each of the Mount Baker study glaciers, showing terminus positions between 1940 and 1990 measured relative to their 1940 positions. Glaciers are retreating where lines have negative slopes and advancing where slopes are positive.

Harper, J. T., 1993
Glacier terminus fluctuations on Mount Baker, Washington, USA, 1940–1990, and climatic variations. Arctic and Alpine Research, 25(4), 332–340.

Quantifying erosion and vegetation change

1977 – 2015

- 5 m average tree growth over 0.26 km² sampled area
- 21 m average tree height loss over 0.58 km² sampled area
- 6 m average degradation along 2.5 km stream profile
- Longitudinal elevation change profile below

Takeaways

- Land, ice, and vegetation changes show significant variability on decadal timescales.
- Our automated approach is modular and can be applied to other archives of historical aerial and satellite imagery.
- Quantifying variability through time provides new insight on regional responses to climate forcing.

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