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

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Abstract

We are developing a fully automated Structure from Motion (SfM) processing pipeline to generate high-resolution digital elevation models (DEMs) from archives of historical aerial and satellite imagery acquired between the 1950s to the 1990s. Scanned images are loaded directly from online archives and processed using open-source software deployed on cloud-computing infrastructure. Modern DEMs with high resolution and accuracy (e.g., airborne lidar, stereo DEMs from sub-meter satellite imagery) are used to iteratively improve historical image geolocation, without manual processing steps involving ground control. We present preliminary DEM and orthoimage time series for glaciers in Washington state, derived from the USGS North American Glacier Aerial Photography (NAGAP) archive. These records document surface elevation change with sub-meter vertical accuracy over decadal timescales. We are using these observations to quantify evolving rates of glacier mass change and proglacial sediment transport. Our aim is to generate long-term, regional records of glacial response to climate forcing on decadal timescales. Better understanding these past responses will help constrain projections of future glacier change under different climate scenarios, as well as impacts on downstream water resources.

Historical Structure from Motion

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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

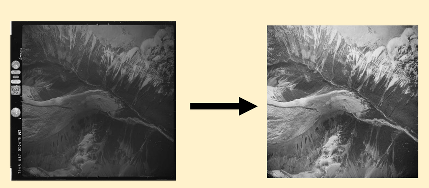
Aerial photograph acquisition

Scan film into digital format

Make public via NSF's arcticdata.io

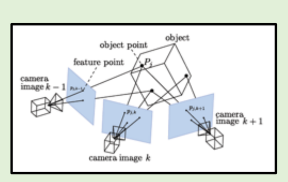
Between 1964 and 1997, Austin Post and the USGS NAGAP program collected >100,000 aerial photographs of glaciers in Western North America. Stereo photographs were acquired with metric aerial cameras (9x9" film) at ~60% along-track overlap, enabling stereo reconstruction. The USGS coordinated efforts with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

Image pre-processing and standardization



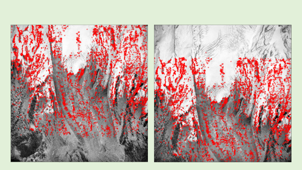
- Automated image download
- Fiducial marker detection
- Frame removal
- Affine transformation
- Histogram equalization

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

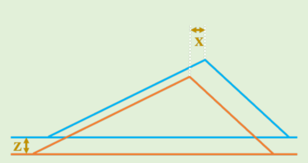


- Dense stereo matching
- DEM generation
- Orthomosaic generation

Agisoft

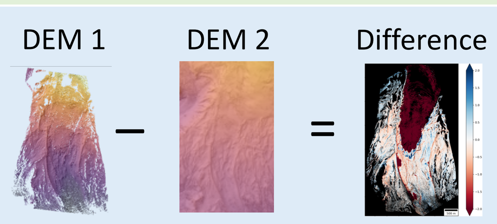
ASP

Align DEM with modern reference DEM over stable ground



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

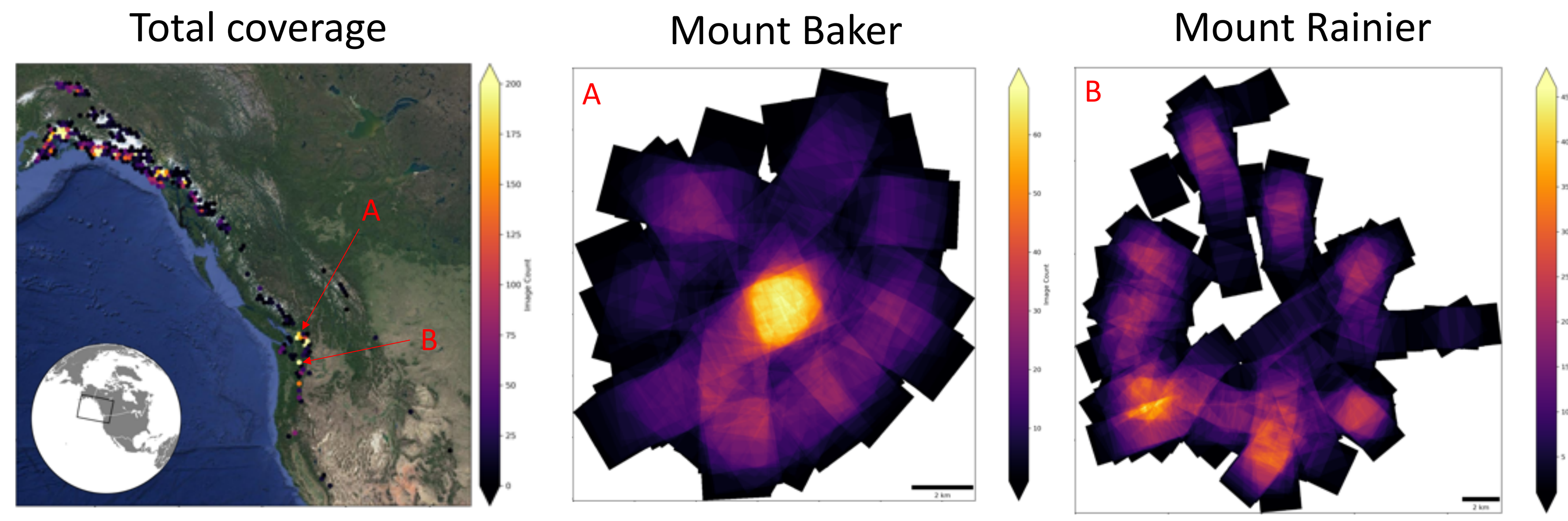
Difference DEMs and quantify chance through time



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

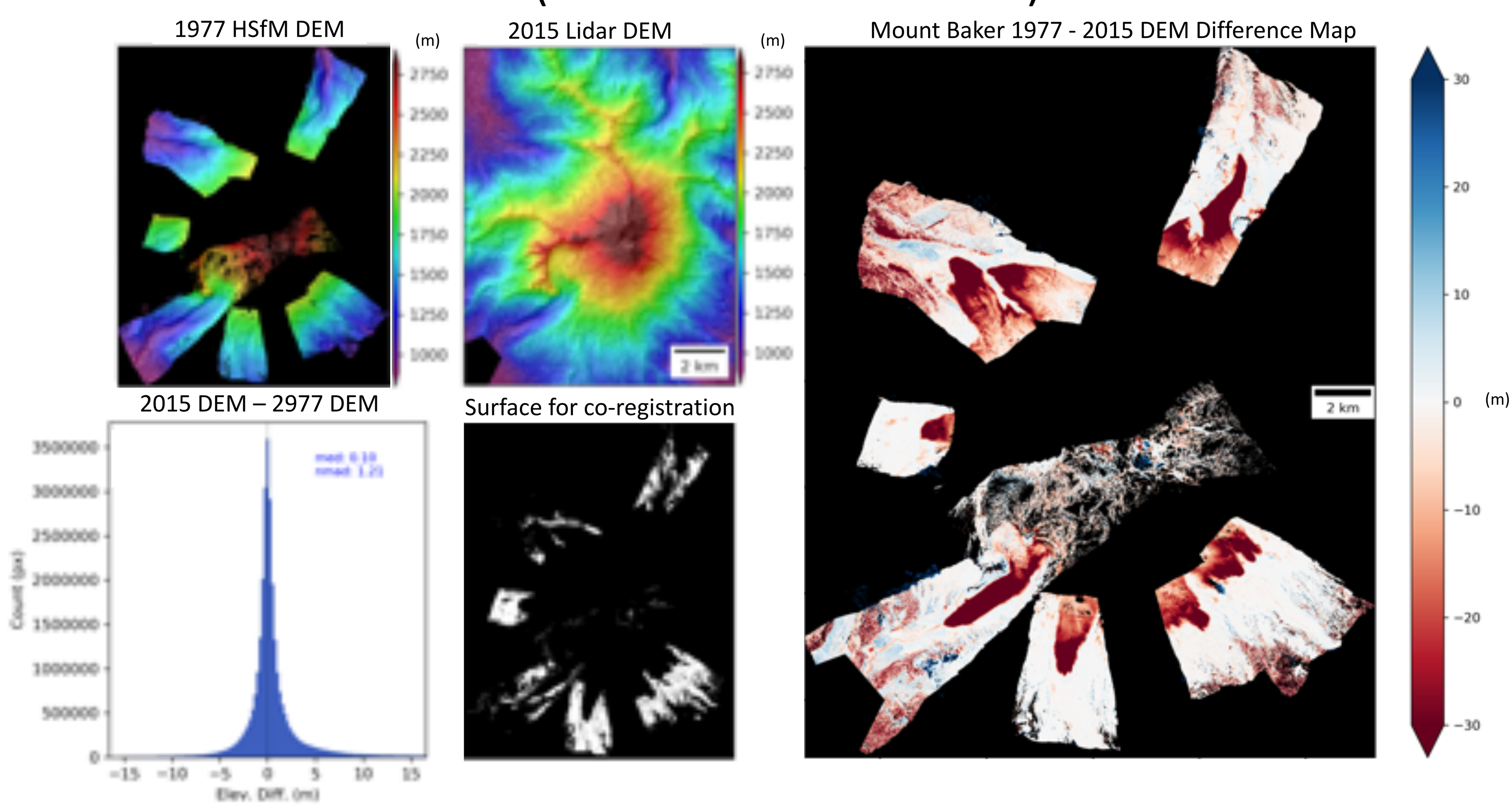
North American Glacier Aerial Photography

(1960s – 1990s coverage)



Mount Baker elevation change

(1977 – 2015 difference)



Example of high-resolution DEM for Easton glacier

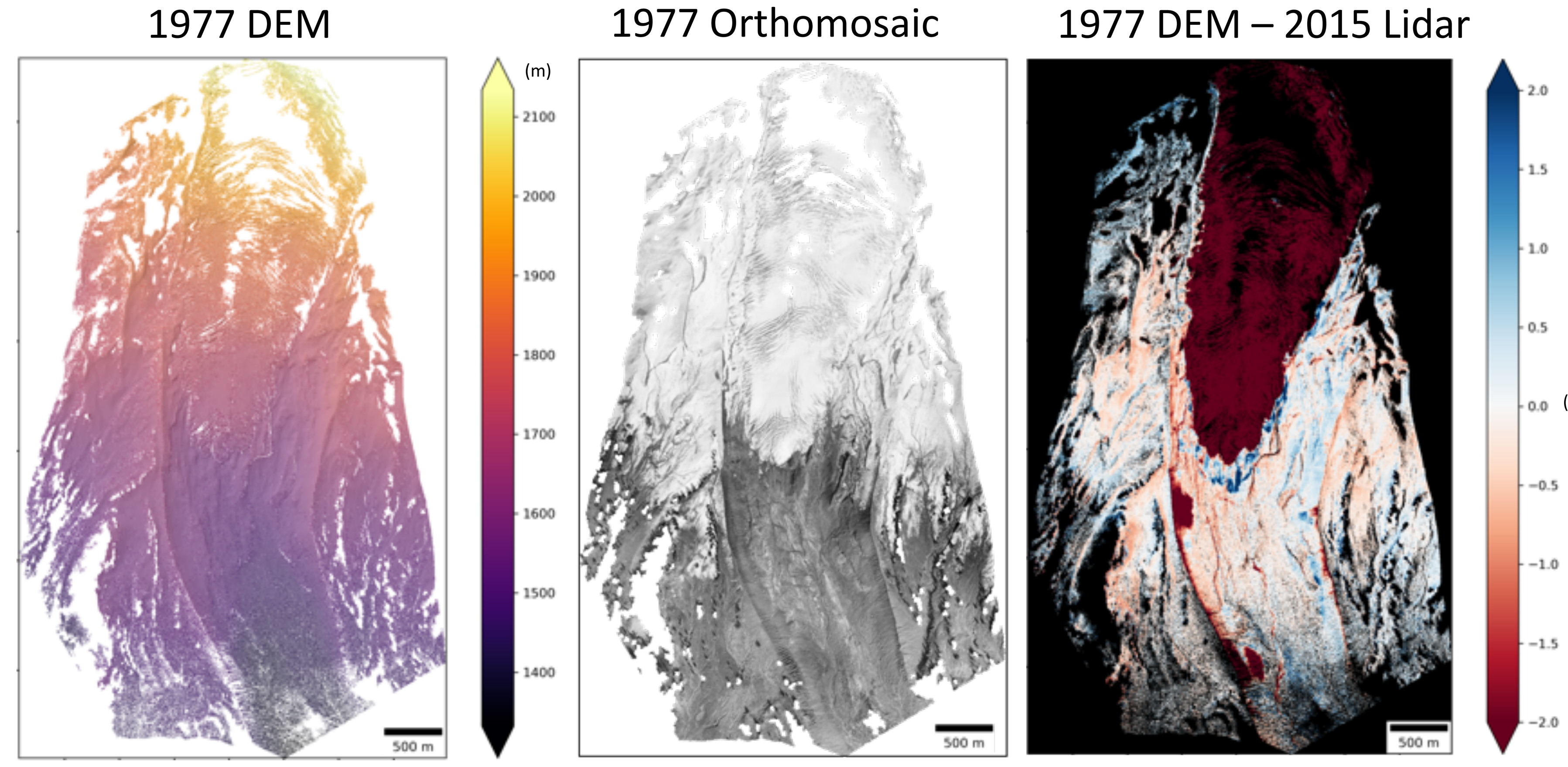
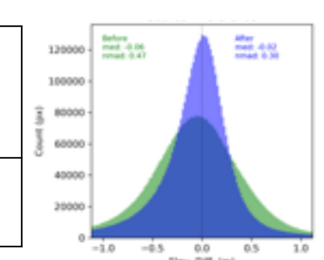
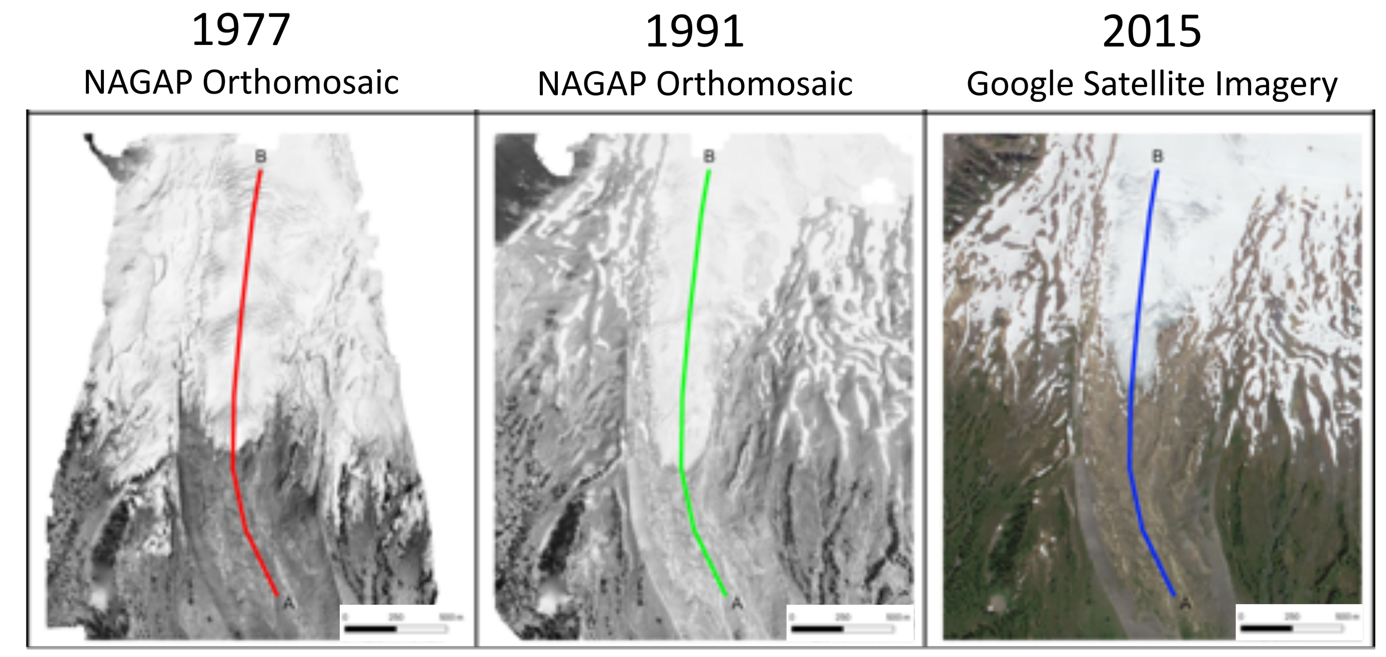


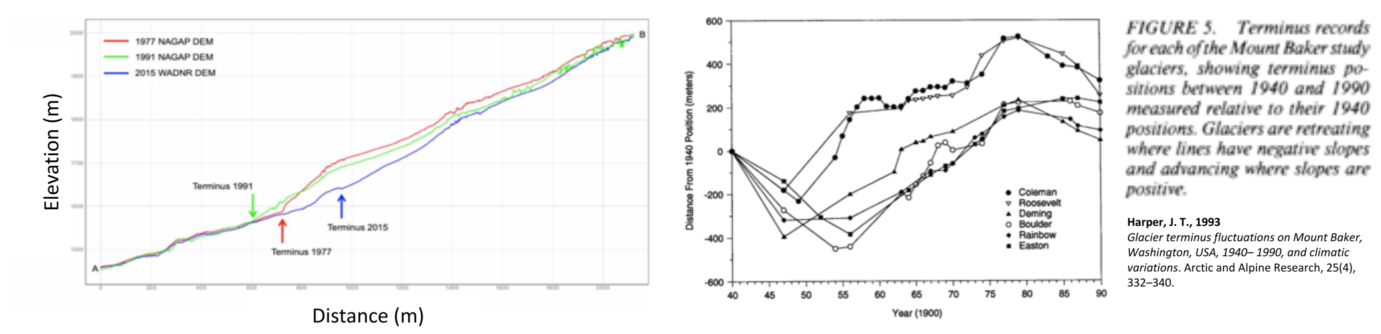
Image Ground Sample Distance	DEM Posting (Resolution)	1977 -2015 Difference (NMAD)
20 cm	50 cm	30 cm



Easton glacier terminus change

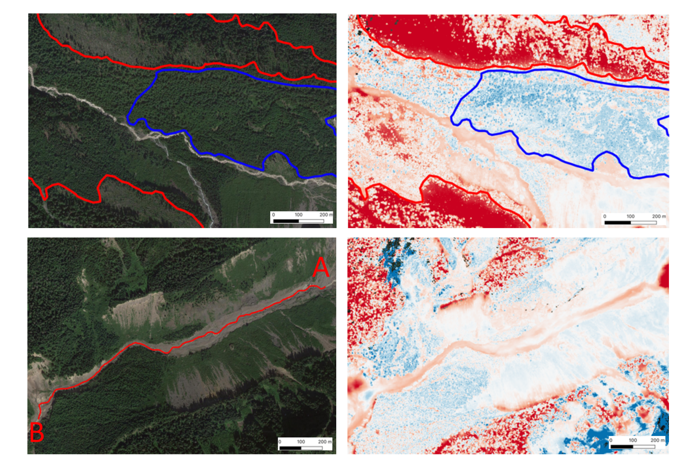


Orthomosaics (above) and elevation profiles (below left) at Easton Glacier showing terminus advance between 1977 and 1991 and subsequent retreat. By 2015, the terminus retreated >250 m and the lower glacier thinned by >20 m, compared to its 1977 state. Figure 5. from Harper 1993 (below right) for additional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



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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