Geovisualisation of Alpine Glacier Elevation Changes in Western Canada

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Abstract. Mapping of glacier changes and specifically downwasting through elevation loss have become increasingly common with the impact of global warming and the wide availability of satellite imagery, digital topographic map data and terrain models and image algebra software options. This paper demonstrates the cartographic options suitable for geovisualisation of glacier elevation change through isarithmic mapping of DTM differences, sequential shaded relief animation and 3D perspective images.

Keywords: Glacier mapping – satellite imagery – DTMs – isarithmic – shaded relief

1. Introduction

Cartographic representation of glacier extents and elevations was largely considered to be static during much of the twentieth century; that is, mapping was presumed to show a stable environmental record. However continued warming over recent decades has generated the need to be able to visualize series of past and present glacier configurations in alpine landscapes. The depiction of retreat and area change is mostly achieved using a sequence of lines or polygons; however this usually results in a set of near overlapping 'spaghetti-like' lines near the glacier front, and can only be minimized where individual glaciers are mapped at relatively large scale (figure 1).

Figure 1. Swiss postage stamp depicting glacier retreat

In contrast glacier thinning or downwasting involving elevation change is experienced throughout the glacier coverage, and represents a more substantial indicator of overall ice loss and the inferred climatic impact. Glacier change is caused by two factors –

precipitation, notably in winter, in the form of snow, and temperature, specifically in the ablation season (summer). However elevation datasets are not as numerous as for glacier extents which can be derived from single air photos, satellite images and maps. Suitable Digital Terrain Models (DTMs) have become more common in the new millennium due to a combination of conversion of historic mapping through digitization of contour lines and software interpolation, and multiple satellite derived DTMs from stereo optical imagery or radar interferometry.

Comparisons between DTM datasets have recently become common in the glaciological literature, and frequently between older photogrammetrically derived surfaces from topographic mapping and later surfaces from satellite observation devices. The difference maps are rendered as isarithmic surfaces and typically use a bichromatic colour scheme from increasing tints of blue for gain, symbolizing more ice and implying more snow or cooler temperatures versus increasing tints of red for greater loss visually implying higher overall temperatures; small amounts of gain or loss are symbolised as neutral grays. An alternate design scheme involves a more complete use of the colour spectrum ranging from blues to reds through yellow and green where the latter represent minimum elevation change, or even reds to greens with yellow as zero change (Table 1). In some cases the legends are not fully utilized as occurrences of elevation gain (increased accumulation) may be limited in areal extent.

Authors	*Region*	*Years of study*	*Ice elevation change (m)*	*Colour scheme*
Berthier et al.2010	Alaska	1957-2007	+150 to -300	Blue/Red
Bolch et al. 2011	Himalayas	1970-2007	+250 to -300	Blue/Red
Clague et al. 2011	BC Coast Mtns	1970-2000	+10 to -300	Blue-green-red
Gardelle et al. 2012	Karakoram	2000-2008	+150 to -150	Red-yellow-green
Larsen et al. 2007	Alaska	1948-2000	+200 to -640	Blue-yellow-red
Paul et al. 2008	Swiss Alps	1985-1999	0 to -80	Blue/Red
Tennant et al. 2013	Canada Rockies	1919-2009	+50 to -200	Blue/Red
Wheate et al. 2013	BC Coast Mtns	1967-2005	+150 to -200	Blue/Red

Table 1. Sample published studies which map glacier elevation change

2. Available DTMs and limitations

Within a funded project to map and inventory the glaciers of western Canada in the provinces of Alberta and British Columbia (2005-2010), we collected multiple glacier extents and elevation models from sources that included analogue topographic and digital mapping, and satellite imagery. For the whole region, we have a minimum of four digital terrain models, two of which are photogrammetric from federal (1950-90) and provincial topographic mapping (1980s), and two are satellite derived from the Shuttle Radar Topographic Mission (SRTM) 2000 and Advanced Spaceborne Thermal Emission and

Reflection Radiometer (ASTER) Global (G)DEM (mid-2000s). In select cases, we also have access to DTMs from older mapping, further satellite imagery and LiDAR.

2.1 National Topographic DataBase (NTDB)

The Canadian provinces were mapped at 1:50,000 scale between 1947-1990. Contour lines (contour interval 40m) can be downloaded by mapsheet from www.geogratis.ca merged for regions, and interpolated to generate a DTM suitable for 25-100 m resolution pixels. For any given portion of the western mountains, the surface date could apply any decade from the 1950s to the 1980s, where the older data are more useful for comparison especially with regards to provincial data. In some cases especially where contours are sparse due to gentle gradients, a terraced surface can result.

2.2 British Columbia Terrain Resource Information Management (TRIM)

The province of British Columbia (BC) completed digital mapping in 1995 at the 1:20,000 scale from aerial photography flown in 1981-1989 through the TRIM program. A province wide DTM was assembled from mass elevation points derived photogrammetrically and interpolated into a continuous surface consisting of 25 m pixels for each 1:250,000 map sheet. A similar program was used to generate DTM data for the limited western portion of the province of Alberta that covers their glaciers in the southern and central Rocky Mountains. Overall, the provincial DTM is the most detailed DTM available for the region, but is more prone than the earlier federal DTM to digital saturation on icefields, and also some discontinuities between adjacent map sheets, which were compiled by a range of consultant companies.

2.3 Shuttle Radar Topographic Mission (SRTM)

The SRTM generated a near global DTM (as far north as 60°N latitude) from data captured in February 2000, and therefore corresponds to the glacier surface from the end of the 1999 summer melt season, as RADAR imagery involves some penetration of surface snow. This DTM has a lower resolution than the others (90m) but avoids errors associated with map sheet boundaries. Data gaps are mostly on steep slopes that do not generally include glaciers.

2.4 ASTER Global DEM (GDEM)

The GDEM was assembled in 2009 from all available ASTER image stereo scenes and subsequently revised. Unlike the SRTM model, it covers the entire globe, but the data range from 2000-2008. Such a range should not cause any variations in a stable landscape, but with a potential annual downwasting of up to 10 metres on glaciers, this may involve uncertainties approaching 100 metres, and often results in a ‘pockmarked’ surface, with adjacent pixel elevations derived up to eight years apart..

2.5 Other DTM sources

DTMs are available from a range of high resolution satellites e.g. SPOT, IKONOS etc., although these usually need to be purchased individually for special interest areas. They can also be acquired from LiDAR and special mapping projects.

2.6 Methods and DTM processing

Difference map layers are generated using image algebra and the subtraction of two surfaces, the latter minus the temporally earlier elevation layer to show loss as negative values and gain as positive. In some cases, investigators need to eliminate potential bias by examining elevation values on selected control points on ice-free locations adjacent to glaciers, which in theory should be constant over time.

The resulting images should be treated with some caution as consideration must be made for both potential bias and data quality. DTMs based on satellite imagery for example include tree canopy height in non-glacier vegetated areas, which infers elevation gains from photogrammetric DTMs. Photogrammetric DTMs may be subject to lack of data due to high reflectance over icefields and accumulation areas, which causes saturation in the visible wavelengths recorded on film or digitally. In contrast satellite imaging often includes errors and data gaps due to shadow and clouds. All DTMs are subject to issues of interpolation especially on steep slopes.

3. Cartographic results

3.1 Isarithmic mapping

From the series of four DTMs, up to four difference maps can be generated using the isarithmic technique: one map for the change between each temporally adjacent pair of DTMs, and one covering the period between the earliest and most recent DTMs. For direct comparison, the mapping unit can be converted from total elevation change in metres to annual average change in metres per year; this compensates for variation in the time interval between each pair of elevation data. The isarithmic sequence is optimized using a bichromate scheme with increasing blue tints for elevation gain and orange-red tints for elevation (figure 2). These are best displayed as a panel of map images, or as an animation of registered images. Typically they show a reduced rate of downwasting between 1970-90 to match the lower retreat and in some cases glacier advance documented in this period, as a result of cooler summer temperatures. In addition the later difference images may reflect the increased rate from global warming since ~1990.

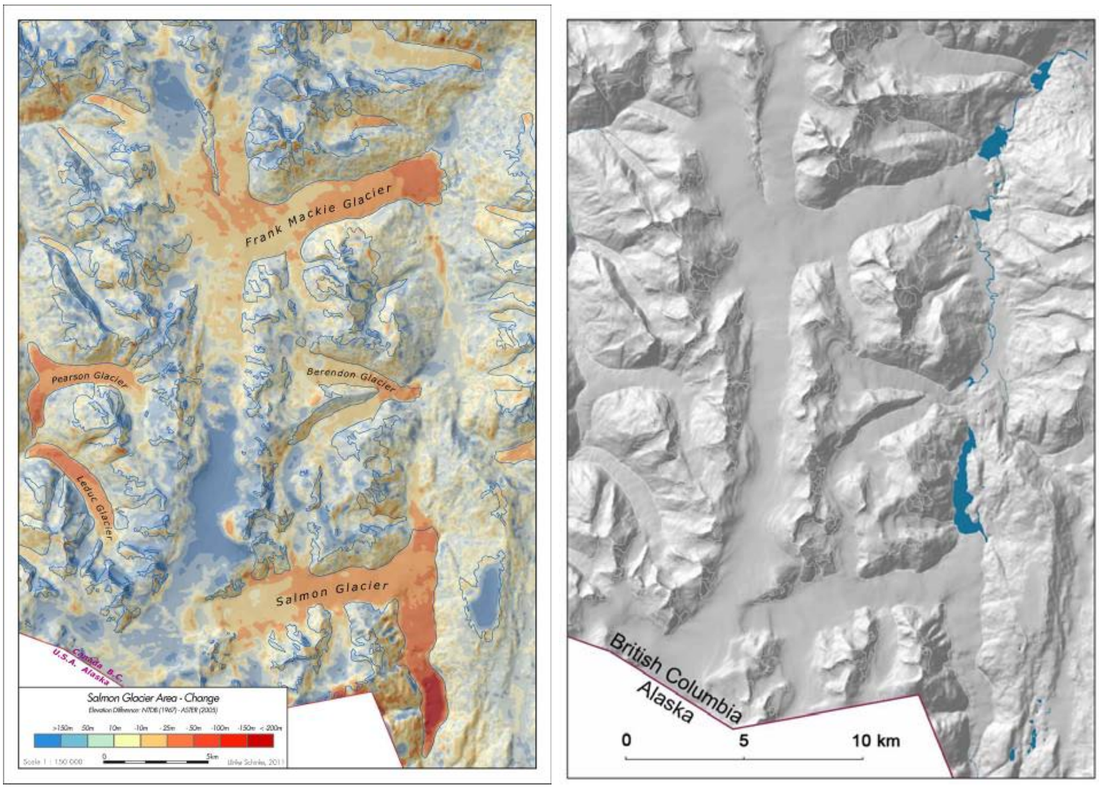

Figure 2: glacier area in the BC coastal mountains adjacent to the Alaska boundary.
a. isarithmic mapping of elevation gain (blue) and loss (red-orange) between 1965-2004;
b. shaded relief model of the NTDB dataset (1965)

3.2 Shaded relief and 3D perspectives

Further geovisualisation involves the display of the sequence of four DTMs as shaded relief models as well as enhanced satellite data, both either as registered planimetric images, or as pseudo-3D images draped on their respective DTMs. These can be highly informative in revealing spatial patterns and minor terrain detail changes, involving both retreat and downwasting at frontal and lateral glacier boundaries.

4. Conclusions

Continued warming, glacier retreat and downwasting ensure that this will remain a focus in glaciology and mountain cartography for the 21st century, along with an ever increasing array of new terrain data available from airborne LiDAR and spaceborne systems, and with improved spatial resolution and accuracy.

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