GIS data capture of glacier change in western Canada

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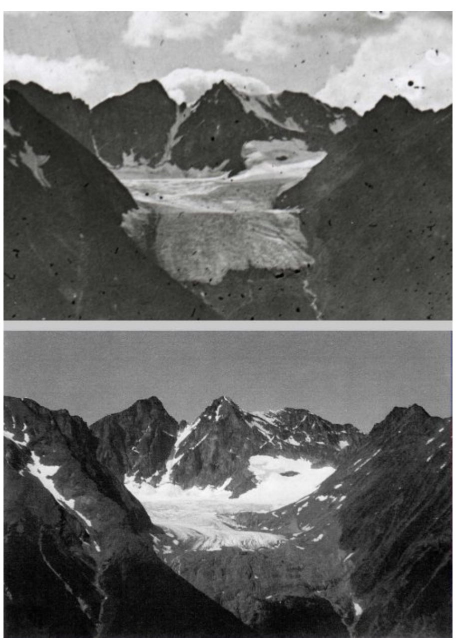
1. Introduction

Alpine glaciers worldwide have experienced accelerated rates of retreat in the new millennium, and continuous retreat in western Canada since at least 1980, largely as a result of higher summer temperatures, which have seen the greatest relative increase outside arctic latitudes in North America. Glaciers are important for many reasons: as 'canaries' of climate change, as reservoirs of freshwater, in providing meltwater for hydro-electric power, to augment late summer river flow, to moderate summer water temperatures in fish-bearing streams, and for their tourism values (Figure 1). The Western Canadian Cryospheric Network (WC2N) is a funded consortium of universities, government institutions and researchers which will map past and present glacier extents and investigate the links between climate and glaciers over 5 years (2006-2010).

Figure 1: the iconic Hudson Bay Glacier at Smithers, BC. 1912 (above) and 2003 (below)



The most recent inventories represented by federal and provincial GIS mapping layers from the 1980s are out of date and not fully reliable in both glacier extents and elevations, where the latter are stored either as mass points, interpolated grids or contour data. A variety of sources are being used in this study to update and monitor both extents and surface elevations, as well as to create historic data layers by incorporating past surfaces where available. Glacier extents have been derived by digitising historic topographic maps, scanning intermediate aerial photographs, importing vector data sets, and digital image processing of current and recent satellite imagery (1982-2006). This paper will focus on data capture methods, integrating historic and current sources, and the processing of digital elevation models in order to estimate and portray rates of change. These include issues of GIS data quality, scale and uncertainty, associated with data capture in remote and extreme mountain environments.

2. Methodology

2.1 Vector data sources

British Columbia is covered by approximately 1100 federal map sheets at 1:50,000 scale (approx. 30% contain glaciers) based on aerial photography ranging from 1948-1990. Many of these have been digitised into the National Topographic DataBase (NTDB), and where they have not, the glacier contours and extents have been digitised from scans by undergraduate students in-house, using GIS software. Later editions include updated glacier extents, but not updated elevation values. Additional federal map sources include early twentieth century maps by alpinist surveyors, using 'photo-topographical' methods triangulating from mountain peak vantage points. A second additional source includes specialised glacier maps produced during the International Hydrological Decade (IHD) 1965-75 (Table 1). The province of British Columbia (BC) has been topographically mapped in 7000 digital tiles from photography 1979-88 through the Terrain Resource Inventory Management (TRIM) program. This has been updated after 1996 via the TRIM II program, involving new glacier vectors (but not contours), as well as 1 metre resolution orthophotos. These form a solid base layer, although not perfect as they were generated from panchromatic aerial photography often saturated in areas of high reflection, and by photo-interpreters more experienced in forestry applications.

2.2 Satellite Image processing

Digital image processing of satellite data has become increasingly appropriate due to the combination of reduced map and vector production by mapping authorities, increasing rates of environmental change, the repetitive nature of image acquisition, the large area covered by image scenes, and the reduced cost and increased availability of image data. Early Landsat (MSS) data are of limited use due to lower resolution and temporal overlap with provincial mapping. Improved resolution from both Landsat and SPOT data have been augmented this century with the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) sensor launched onboard the Terra satellite in 2000, and supporting the Global Land Ice Measurement from Space (GLIMS) project to create an updated worldwide inventory of glaciers via a network of regional stewards and centres (UNBC is the regional steward with responsibility for the Western Canadian Cordillera). Image classification methods for feature extraction of glacier extents and surface morphology build on established techniques (Kaab 2002, Paul 2002, Sidjak and Wheate 1999). These meet challenges posed by debris covered ice and shadows, which may require image overlay and GIS queries incorporating DEM derivative layers

2.3 Digital Elevation Models.

Digital elevation models (DEMs) have been used to generate estimates of volume loss by subtracting current and recent DEMs from historic models. Early elevation models have been created either by digitising contour maps and interpolation to create raster grids, or by stereo photogrammetry (from archival aerial photography). A standard 25 metre gridded DEM is available for the whole province through the TRIM program (1980s), although elevation values are suspect in upper glacier elevations (accumulation areas) due to photographic saturation inhibiting the acquisition of mass points. In some cases, we are going back and recreating these DEMs from optimally processed photographs. Contemporary models include those produced from ASTER and SPOT satellite stereo imagery, and the Shuttle Radar Topographic Mapping - SRTM (Table 1). The latter provides a continuous 90 metre DEM for the western mountains, with some gaps on steeper slopes. Any ASTER scenes also provide a (15 metre) DEM as the sensor includes a backward looking mode band in addition to the nadir mode used for image data collection. This results in some data gaps on steep north facing slopes, but these tend to be non-crucial. The generation of multiple DEMs enables 3D visualisation techniques in addition to volume estimations.

Maps, GIS data or Images	**Dates**	**Polygons**	**DEM**
Historic alpine maps	1890-1950	x	x
Glacier maps- IHD	1965-75	x	x
National Topographic maps	1950-85	x	x
Stereo aerial photography	1948-96	x	x
BC provincial TRIM data	1986-88	x	x
BC provincial TRIM II data	1996-2006	x	
Landsat MSS	1972-82	x	
Landsat TM	1982-2006	x	
Landsat ETM+	1999-2003	x	
SPOT HRV	1986-2006	x	
ASTER	2000-06	x	x
SRTM	2000		x

Table 1: Data sources for glacier (extent) polygons and DEMs

3. Results and analysis

Our deliverables include a province wide assessment of glacier change for three time periods, and over 5 year intervals for seven selected areas of focus. Preliminary results indicate current average rates of retreat approaching 20 metres per year, but these are greater in the southern parts of the cordillera. Overall area loss in ice cover is in the order of 10% province-wide between 1988-2000. As one would expect, smaller glacier polygons have lost a higher percentage of their total area than larger icefields. Potential sources of error include misclassification of perennial and late snow as ice, and incomplete reliability of historic vectors (Hall et al, 2003). Subtraction of historic-current DEMs - indicate a loss of depth of ice between 50-100 metres immediately upslope from the snout in the dozen years between the late 1980s (TRIM data) and 2000 (SRTM). Initial comparison with postwar national topographic mapping indicates a similar volume loss between 1965 and 1988 (that is, over a longer period). We anticipate that in 2007 we will find increased rates of loss in volume and distance retreat since 2000 given the record average temperatures experienced in the new millennium. Apparent gains in the upper accumulation areas since the 1980s are suspect due to potential data errors from photo saturation and will be examined during further analysis using alternatively derived DEMs.

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Biographies

Dr. Wheate is an Associate Professor and GIS co-ordinator at UNBC. He has 20 years experience in geomatics information processing and received his Ph. D from St. Andrews in 1997. His research focuses on information extraction from remotely sensed image data and high mountain cartography.