A New Digital Terrain Model for the Tasman Glacier, New Zealand, using Digital Photogrammetry Techniques

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ABSTRACT

Terrestrial, airborne and spaceborne photogrammetry can be employed in glaciological research to obtain accurate 3D glacier surface information. This information is essential in glaciological modelling, volume change and geomorphological mapping, particularly in those glaciers located in remote and harsh terrain. In this project, vertical aerial photographs of the Tasman Glacier from 2008 were used to derive a new high-resolution Digital Terrain Model (DTM). Results were obtained using a digital photogrammetric workstation. A bundle block adjustment was calculated employing 15 ground control points and 750 semiautomatic tie points distributed over 49 photographs. Customized strategies were employed in different areas depending on the condition of the surface to optimize the performance of the automatic terrain extraction. It is suggested that this DTM needs to be manually inspected and corrected on low contrast areas (high accumulation areas) due to noticeable errors in the surface. This DTM constitutes the newest and highest resolution dataset available for the Tasman Glacier.

KEYWORDS

Digital Terrain Model – photogrammetry

INTRODUCTION

The Tasman Glacier is New Zealand's largest ice body (including its tributary glaciers) with an area of ca. 100 km^2 (Figure 1). It accounts for 10% of the total glacier area and 30% of the ice volume of New Zealand (Chinn, 2001). Since 1890s, this glacier has experienced a sustained decreasing in thickness (Blair, 1994). Thinning has been particularly important in the lower section whereby the Tasman Glacier is heavily debris-covered (Purdie and Fitzharris, 1999). Numerous studies have focused on the Tasman Glacier and characterized the development of the proglacial lake at its front (Dykes et al., 2011; Kirkbride, 1993; Kirkbride and Warren, 1999; Strong, 2008) or the mass balance and downwasting of the glacier (Hochstein et al., 1995; Purdie et al., 2011). Recently, Redpath (2011) provided evidence of the dynamic nature of the surface velocity. It is estimated that this glacier has lost a volume of 3.4 km^3 between 1965 and 2002 by means of calving and melting (Thomas, 2009).

Although the Tasman Glacier is one of the most studied glaciers in New Zealand and the Southern Hemisphere, researchers still rely on relatively old topographical data and lack a recent high resolution DTM. Currently, the Tasman Glacier topography is characterized by 20 m contour lines derived from an aerial photogrammetric survey completed in February 1986, and held by Land Information New Zealand (LINZ) in the NZTopo database (1:50,000 scale) from which DTMs are often interpolated. This topographic database was mainly compiled using stereoplotting equipment for contour and spot elevation plotting (LINZ, 2004). Additionally, the periodic updating process carried out by LINZ has introduced a mixture of data sources (at various points in time) in the area that complicates the study of changes, such as calculating volume change over a well-defined period of time.

This study contributes to New Zealand glaciological research by producing a new 5 metre resolution DTM for the Tasman Glacier. In particular, we triangulated the most recent aerial photogrammetric survey completed over the Tasman Glacier in February 2008. The use of soft copy analytical photogrammetry allowed automatic methods to be used to extract high resolution elevation data over large regions with different glacier surfaces such as debris cover, bare ice and snow. This updated topography will be useful to refine current estimates of the glacier volume change and geometric glacier parameters. It is also anticipated that

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this dataset will be used to update topographical mapping of the region.

The main aims of this contribution are to (i) present the digital photogrammetric method as a useful tool to derive a new DTM for the Tasman Glacier, (ii) describe the DTM product and assess its accuracy, and (iii) discuss the implications and possible uses of this new elevation dataset.

DATA AND METHODS

Aerial survey

The vertical aerial photographs for this study were acquired on February 11, 2008 (from 13:40 to 15:00 local time) by New Zealand Aerial Mapping Ltd (NZAM). Three strips with SW-NE orientation were captured with a Leica RC30 frame camera from an elevation of approximately 6000 m a.s.l., providing a full coverage of the glacier. Colour imagery was obtained with a nominal scale of 1:40,000. Forty-nine frames were scanned using an Intergraph PhotoScan® photogrammetric scanner programmed at 14-µm resolution. This yielded a ground spatial resolution of approximately 50 cm depending on the elevation above the terrain. During the survey, on-board GPS instrumentation provided nominal locations of photographic perspectives centres for initial exterior orientation used for the subsequent triangulation.

Differential GPS survey

No ground control points (GCPs) were collected during the survey in 2008. In order to triangulate the aerial photographs, 10 full GCPs (XYZ) near reliable features were measured adjacent to the Tasman Glacier (Figure 1) during two field campaigns (2011–2012). In particular, all mountaineering huts visible in the imagery were visited and surveyed as they provided the reliable and stable location that could be used as reference for the triangulation. The GCP locations

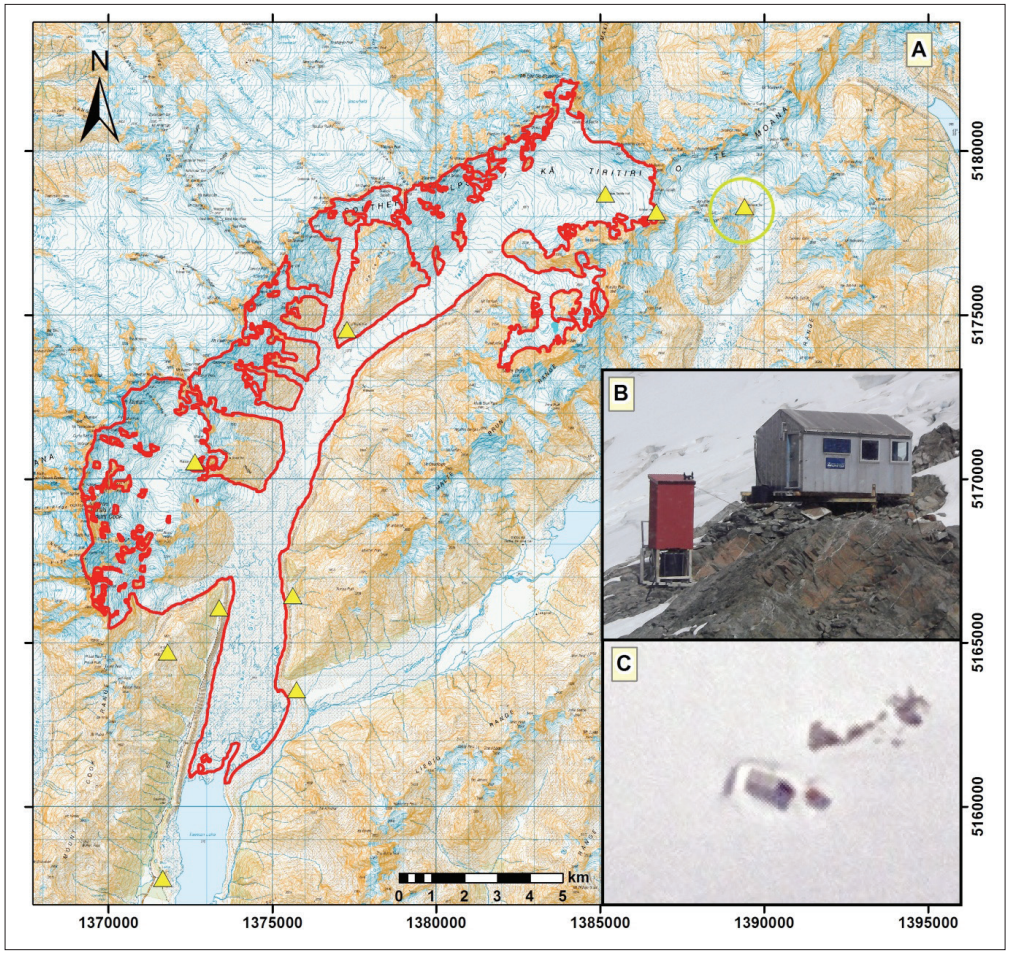

Figure 1. (A) Map displaying the location of GCPs (yellow triangles) and the extent of the Tasman Glacier and its tributaries (continuous red line). The map is extracted from NZ Topo50 sheets BX15 and BX16. Tasman Glacier outline sourced from Sirguey (2010). (B) Photo from the Murchison Hut (yellow circle in A) (21-03-2012). (C) Enlargement of the 2008 aerial photo (frame 7-38) showing the hut and the toilet.

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were measured using a TRIMBLE® R8 differential global position system (dGPS) with occupation times between 10 and 15 minutes. Post processing was conducted within the Trimble Business Center® v2.5 (TBC) yielding a positional average (XYZ) uncertainty of ±0.01 m. Additionally, five well define mountain summit heights extracted from NZ Topo50 sheets BX15 and BX16 were used as vertical GCPs (only Z) in order to provide full altitudinal coverage of the photogrammetric block. These points are expected to fulfil vertical accuracy of ±5 m (LINZ, 2004).

Aerial Triangulation

In the next step, scanned aerial photographs in 8-bit uncompressed TIFF format were imported into the digital photogrammetric workstation Leica Photogrammetry Suite® (LPS) 2011. The camera calibration report from September 2004 (Swissoptic, 2004) was employed to define the interior orientation and to compensate the radial lens distortion.

On-board GPS instrument data was used to record the position of the camera in X, Y and Z coordinates during each exposure. These values were used as initial values for the exterior orientation due their unknown accuracy and lack of accompanying inertial measurements (i.e. attitude angles). The knowledge of initial exterior values is useful to extract automatic tie points. At least 15 semiautomatic tie points were added per stereo pair using image matching techniques (ERDAS, 2010). A bundle block adjustment was performed, yielding a total image unit-weight RMSE of 0.39 pixel, demonstrating a good block adjustment. The RMSE of the GCP positions in the X, Y, and Z directions were 0.26 m, 0.35 m and 0.26 m respectively. The RMSE achieved by the bundle block adjustment is in good agreement with the average photographic pixel size. The main result of the triangulation process was the determination of the X, Y and Z coordinates and the omega, phi and kappa rotation angles of the perspective centre of each aerial photograph, taking into account all possible errors (i.e. bundle adjustment) (Figure 2). In the future, old aerial photographs could be adjusted in absolute coordinates using this photogrammetric bundle block adjustment as reference.

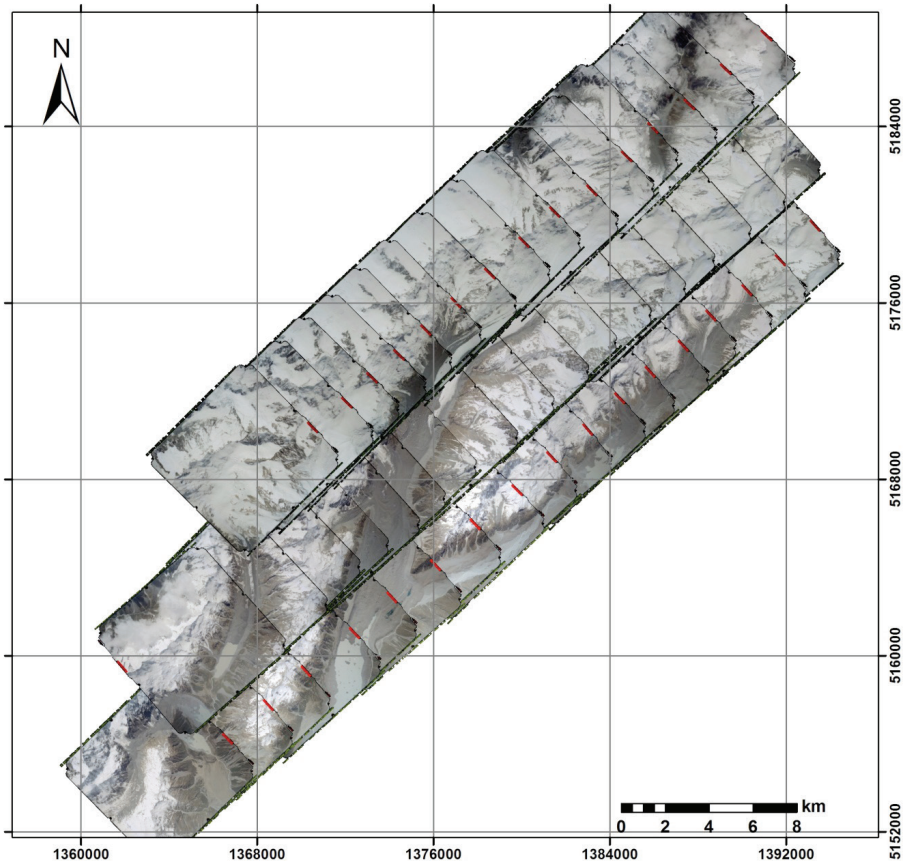

Figure 2. 2008 aerial triangulation. The perspective centre of each photograph is positioned in the ground space coordinate system as it existed when the photographs were captured. The coordinates are with respect to the NZTM projection. Photographs are Copyright NZAM 2010.

Photogrammetric DTM computation

The extraction of the DTM was conducted using the enhanced Automatic Terrain Extraction (eATE) module available on LPS. This module uses all geometric parameters of two or more overlapping photographs to match any point and derive its 3D coordinates. Because of the diverse terrain characteristics involving various contrasts (e.g. debris, ice, snow) four different strategies were configured in order to improve the algorithm performance over various surfaces. Typically, a relatively low correlation coefficient threshold and large search window size were used for snow covered areas, while a high correlation coefficient threshold and small search window size were used for debris covered areas. Finally, areas of interest (AOIs) were delineated over the glacier and its surroundings in order to allocate specific strategies for each terrain.

RESULTS

A seamless DTM was extracted for all stereo pairs through eATE module using a regular sampling distance of 2.5 m (Figure 3). The final pixel size was established at 5 m, due to computational and time constraints. In general, the block triangulation results for Tasman Glacier are well suited for the DTM extraction, even though data artifacts must be expected in areas displaying fresh snow cover and steep slopes that compromise automatic image correlation. In several areas an almost continuous snow cover exists above ca. 1500 m a.s.l. Errors are evident in steep terrain covered by snow where geometric distortion and poor contrast are present. On the lower trunk, thermokarst ponds, arcuate debris ridges, lateral moraines, crevasses and other features in the debris-mantled tongue are well represented by the DTM (Figure 4).

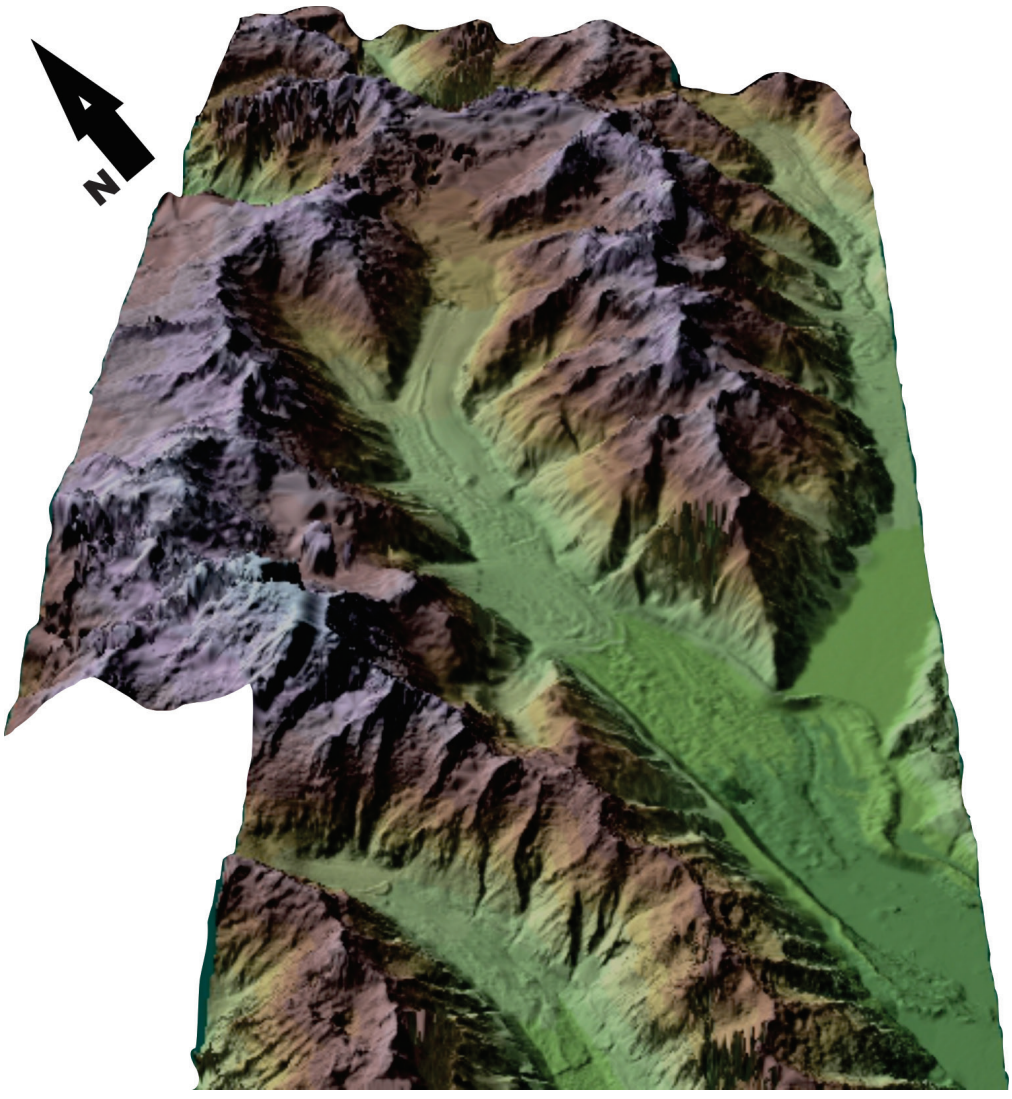

Figure 3. Perspective view of the Tasman Glacier DTM. Moraine walls, arcuate debris ridges, medial moraine and proglacial lake are clearly visible. Errors are present in steep areas such as near Aoraki/Mount Cook.

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DTM Error

Given the hazardous and dynamic terrain of the Tasman Glacier region, possibilities to fully assess the 2008 DTM accuracy remain troublesome. Two validation approaches were employed to overcome this problem. Firstly, we re-triangulated our bundle block model keeping all GCPs as control points but one as an independent check point. This process was iteratively performed on all full GCPs. The results of this leave-one-out cross validation method yielded on RMSE values of 0.88 m, 1.07 m and 2.71 m in the X, Y and Z ground positions, respectively. Secondly, the LINZ geodetic marks available in the area (LINZ, 2012) were used as independent surface references. Geodetic marks affected by the 1991 Mount Cook rock/ice avalanche and other small slips (McSaveney, 2002) were removed from this dataset. Finally, a set of common DTM error descriptors (Fisher and Tate, 2006) were calculate using 6 geodetic marks (Table 1).

Statistics	Values (m)
Root mean squared error (RMSE)	2.970
Mean error (ME)	-1.271
Mean absolute error (MAE)	2.250
Maximum absolute error (MaxAE)	5.841
Error standard deviation (S)	2.940

Table 1. Results of the accuracy assessment for the Tasman Glacier DTM (5 m).

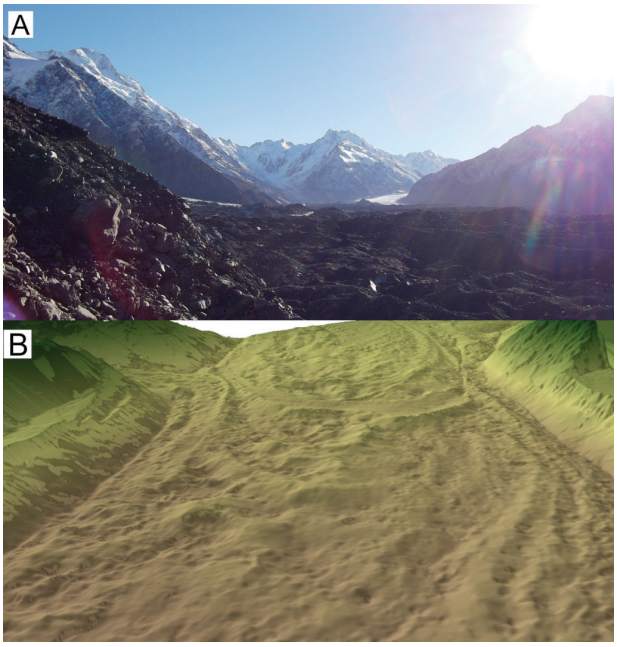

Figure 4. (A) Photograph of the lower glacier taken during the first fieldtrip (2011). (B) Portion of the lower glacier in the DTM. Lateral moraines and arcuate debris features are very finely resolved.

RECOMMENDATIONS AND FUTURE WORK

The results of this study show that the eATE module has the capability to map large areas in complex terrain using custom strategies. However, unbroken snow involves a considerable challenge. Unfavourable conditions are present in the 2008 aerial photographs, due to large areas covered by fresh snow. When a photogrammetric flight is planned over mountain regions, seasonal snow cover should be avoided. Optimal timing to do this in New Zealand is during the end-of-summer (March–April), when seasonal snow cover reaches its minimum and the glacier's snowline position is at the highest elevation (Chinn, 1995). However, this study shows that snow can still be expected in the middle of February that can complicate this task.

The remaining steps in the process can be handled employing manual editing and correction procedures in the problematic areas. LPS has the capability to edit DTMs in a stereo environment, which reduces operational time and increases productivity. The procedure presented on this paper opens new promising perspectives for glacier monitoring in New Zealand, where old photographs are available but have not previously been processed with such techniques. The photogrammetry of the 1986 imagery will be reprocessed in the same digital environment to derive a DTM with similarly high spatial resolution. This will allow the vertical surface displacements and volume changes to be calculated by subtracting the two DTMs (Etzelmüller, 2000; Bamber and Rivera, 2007). Knowing or assuming the mean glacier ice density, this volume represents the cumulative mass balance of the glacier in the given period (1986–2008) which is crucial information to assess the evolution of the glacier over the period.

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