# Recent Ice Wastage on the Tasman Glacier Obtained from Geodetic Elevation Changes

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## 1.0 INTRODUCTION

Mountain glaciers and ice caps cover an area of 740,000 km$^2$ (Radić and Hock, 2010) and store ca. 0.7% of the total ice volume available on the Earth's surface (Dyurgerov and Meier, 2005). Meltwater runoff originated from mountain glaciers can play an essential role for providing water resources for human consumption, irrigation systems and hydroelectric power generation (Barnett *et al*. 2005). Among the 3144 glaciers located in New Zealand the Tasman Glacier is the country's largest glacier with an area of ca. 100 km$^2$ in 1978 (Chinn, 2001). Since the early 1990s it has undergone a rapid frontal retreat associated with the concomitant expansion of a proglacial ice-contact lake. Historical and more recent data indicates an increasing in the thinning rates in the lower glacier (Hochstein *et al*. 1995; Quincey and Glasser, 2008), but the lack of recent glacier-wide information about elevation change precluded a more accurate representation of the contemporaneous ice volume loss.

In this paper, elevation and volume change of the Tasman Glacier and its tributary glaciers were measured between 1986 and 2008 using the photogrammetric processing of vertical aerial photographs, and bathymetric data of Tasman Lake. Detailed analysis of the multitemporal DEM enabled the geodetic surface elevation and mass balance changes to be quantified. Our analysis revealed diverse spatial patterns of thickness and volume change, varying between the tributaries and within and between elevation bins.

## 2.0 DATA AND METHODS

Two sets of vertical aerial photographs were acquired in 1986 and 2008 by New Zealand Aerial Mapping Ltd (NZAM). Forty-nine colour frames and 13 panchromatic frames were scanned at 14 µm resolution, yielding an average ground spatial resolution of 50 cm and 80 cm for the 2008 and 1986 aerial photographs, respectively. In order to perform an aerial triangulation, we measured 10 GCPs near stable features outside the glacier area using a Trimble R8 differential GPS, with occupation times between 10 and 15 minutes. Mt John Observatory tracking station was used during the post processing step, yielding GCP locations with an uncertainty of ±0.01 m. In addition, we employed data from a bathymetric survey of the Tasman Lake performed in 2008 by a research team from Massey University. About 913 discrete water-depth points were measured using a Hummingbird 323 DualBeam Plus echo-sounder and with a vertical accuracy estimated as ±6 m (Dykes *et al*. 2011).

GCPs, tie points and on-board GPS instrument data were used to perform an aerial triangulation in Leica Photogrammetry Suite (LPS) 2011 (Figure 1). The DEMs were generated at 5 m regular grids using a nonlinear interpolator method based on a fifth-order polynomial function. In addition, bathymetric data were interpolated, gridded and adjusted to the 2008 DEM to create a comprehensive ice surface elevation model. Elevation changes were calculated as the difference between the two DEMs on a pixel basis (Etzelmüller, 2000). Errors associated with the differential DEM and the derived volume and mass balance were considered using the method of Barrand and others (2010).

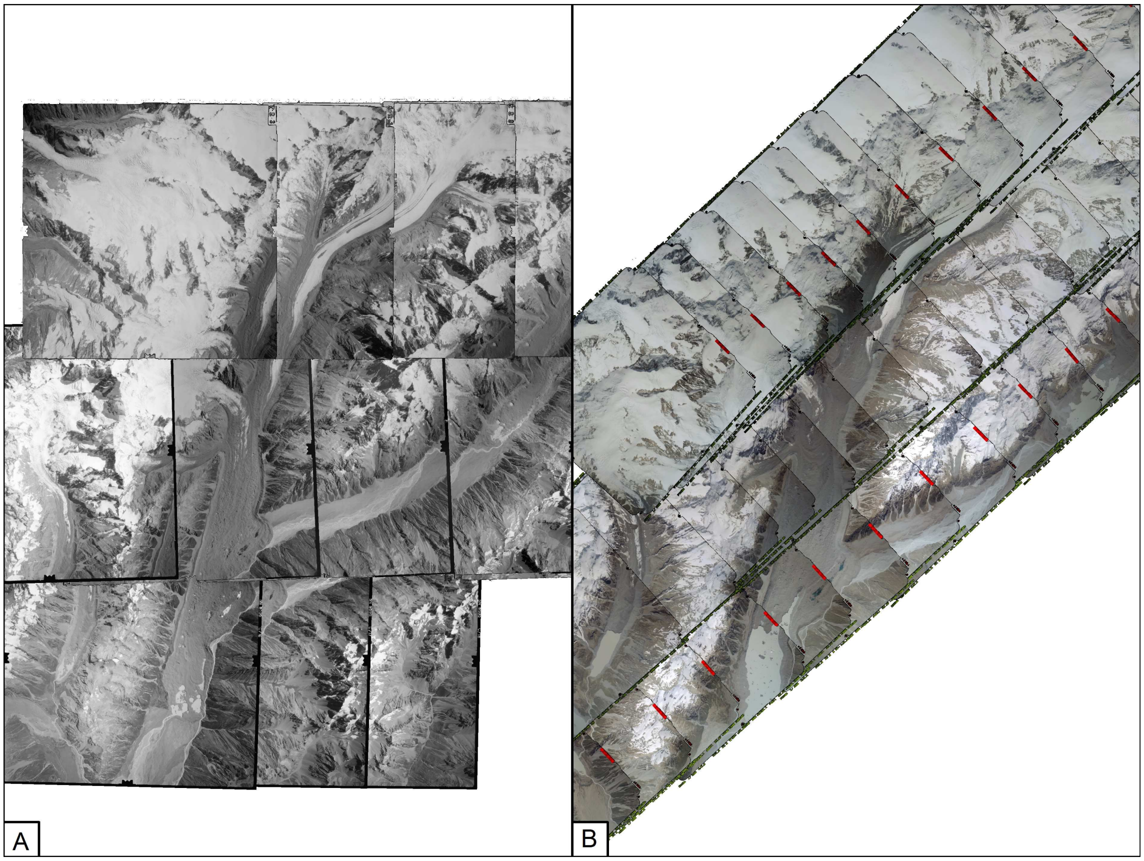


*Figure 1: (A) 1986 aerial triangulation of the study area. (B) 2008 aerial triangulation of the study area.*

## 3.0 RESULTS

Complex elevation changes were found in the debris-covered area below the Hochstetter Confluence. Glacier elevation changes originated from glacier downwasting, ice flow, and local rockfall deposits. In general, high rates of ice loss are found in the lower glacier between the terminus and the upper limit of the Hochstetter Confluence (Figure 2). However, tributary glaciers exhibit contrasting differences in elevation change that appears to be related to the aspect of the tributaries. Thus, tributaries on the western side of the main Tasman Glacier exhibit significantly larger change rate than those on the eastern side. We found that the overall Tasman Glacier and tributaries lost $19.72 \pm 0.05 \times 10^8$ $m^3$ of ice between February 1986 and February 2008. This ice wastage corresponds to an area-averaged geodetic balance of $-0.87 \pm 0.002$ m w. eq. $yr^{-1}$. The main Tasman Glacier accounts for ca. 85% of this ice volume loss. Of the remaining 15% of the total ice loss, the second most important contributor is the Hochstetter Glacier, reaching $1.37 \pm 0.02 \times 10^8$ $m^3$ of ice loss or 7%. The ice volume lost due to the expansion of the Tasman Lake reaches $5.53 \pm 0.015 \times 10^8$ $m^3$, whereas the ice volume lost due to downwasting equates to $14.18 \pm 0.05 \times 10^8$ $m^3$.

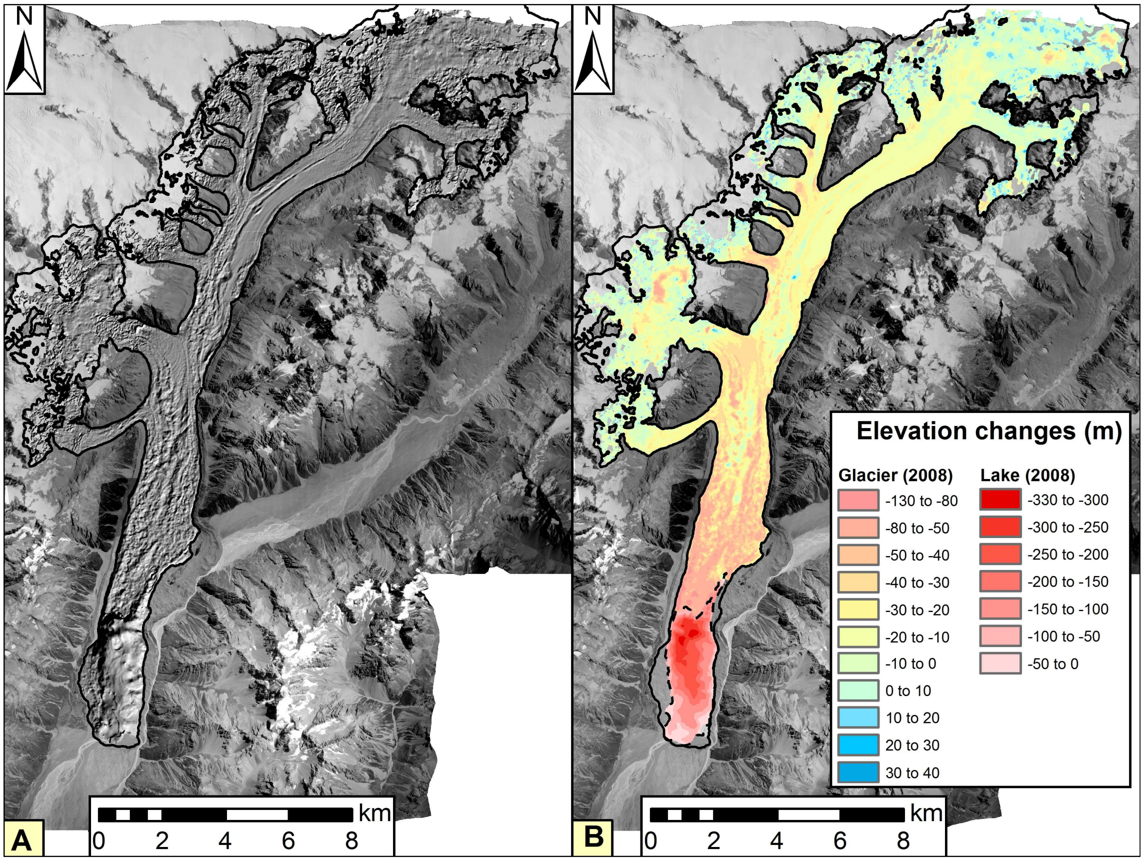


*Figure 2: Glacier elevation changes between 1986 and 2008. (A) Hillshade representation of the elevation changes. (B) Elevation change for the glacier (continuous black line) and lake (dashed black line) areas. White gaps within the glacier represent areas without photogrammetric restitution. The orthophotomosaic from 1986 is displayed as a background.*

## 4.0 CONCLUSIONS

The Tasman Glacier has lost a large mass of ice as the terminus has retreated, calved and thinned. From 1986 to 2008 the average annual rate of terminus retreat was -194 m $yr^{-1}$. For the same period, the loss in volume of the Tasman Glacier and its tributary glaciers corresponds to ca. 2 $km^3$, where the main Tasman Glacier accounts for ca. 85% of this ice loss. The present work has demonstrated the importance of using recent bathymetric data to fully calculated volume change in glaciers with recently developed ice-contact lakes. Although seemingly essential, the inclusion of bathymetric data in geodetic mass balance measurements on calving glaciers has attracted little attention. We estimated that the geodetic mass balance values on calving glaciers reported elsewhere may be biased toward less negative values due the lack of concomitant bathymetric measurements.

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