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Franz Josef and Fox Glaciers, New Zealand: Historic length records

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ABSTRACT

Compilation of modern and historical length change records for Franz Josef and Fox Glaciers demonstrates that these glaciers have lost ~3 km in length and at least 3–4 km^2 in area since the 1800s, with the greatest overall loss occurring between 1934 and 1983. Within this dramatic and ongoing retreat, both glaciers have experienced periods of re-advance. The record from Franz Josef Glacier is the most detailed, and shows major advances from 1946 to 1951 (340 m), 1965–1967 (400 m), 1983–1999 (1420 m) and 2004–2008 (280 m). At Fox Glacier the record is similar, with advances recorded during 1964–1968 (60 m), 1985–1999 (710 m) and 2004–2008 (290 m). Apart from the latest advance event, the magnitude of advance has been greater at Franz Josef Glacier, suggesting a higher length sensitivity. Analysis of the relationship between glacier length and a reconstructed annual equilibrium line altitude (ELA) record shows that the glaciers react very quickly to ELA variations — with the greatest correlation at 3–4 years' lag. The present (2014) retreat is the fastest retreat in the records of both glaciers. While decadal length fluctuations have been linked to hemispheric ocean–atmosphere variability, the overall reduction in length is a clear sign of twentieth century warming. However, documenting glacier length changes can be challenging; especially when increased surface debris-cover makes identification of the 'true' terminus a convoluted process.

1. Introduction

Glaciers are sensitive indicators of climatic variations on all time scales from millennia-long glaciations to decadal and inter-annual variations. Recent work on New Zealand moraine records (e.g. Schaefer et al., 2009; Kaplan et al., 2010; Putnam et al., 2010, 2012; Doughty et al., 2013) has improved our understanding of the timing and magnitude of the climatic events that led to the termination of the Pleistocene, subsequent re-advance during the late-glacial period, and general retreat through the Holocene. On a century scale, glacial retreat is an excellent indicator of the magnitude of warming that has occurred since the end of the Little Ice Age (LIA) (Oerlemans, 2005). On decadal timescales the temporary advance of some glaciers has been interpreted from various changes in meteorological conditions (Fitzharris et al., 1997; Hooker and Fitzharris, 1999; Chinn et al., 2005b). The basis of interpreting past glacial change on all of these time-scales, and its climatic significance, rests on the observation of the fluctuations of present-day glaciers and their climatic causes.

Records of glacier fluctuations are heavily biased towards the Northern Hemisphere and the European Alps in particular (Oerlemans, 2005), where there are historic documents, illustrations and photographs that extend back many centuries (Oerlemans et al., 2007 and references therein). In contrast, the Southern Hemisphere has few historic records of glacier change. There are a few records for South America that combine historic data and tree ring dates (Villalba et al., 1990), but the record from Franz Josef Glacier, in the Southern Alps of New Zealand, stands out. It begins in 1865, within a few years of the earliest written observations of any Southern Hemisphere glaciers, and contains observations at least every decade between then and the present. Fox Glacier has a record of similar duration but of lesser detail.

As well as representing a poorly measured zone of Earth's surface, Fox and Franz Josef Glaciers are also remarkable from a glaciological point of view. Both have similar topographies, descend as far below their equilibrium line altitudes (ELAs) as any glacier worldwide, and both have extremely sensitive and fast responses to climatic variations. The Franz Josef Glacier is the best studied of the two, for example, from Wilson (1896) and Bell (1910) to Oerlemans (1997) and Anderson et al. (2006). Length records at Fox and Franz Josef Glaciers are crucial to understanding links between climatic and glacier length variations. The records exist in a number of published and unpublished sources, and various versions with slight differences are shown by different authors (e.g. Chinn, 1999; Oerlemans, 2005; Anderson et al., 2008; Leclercq and Oerlemans, 2011). The different versions arise because of the varied sources of information and changing datum positions for length measurement. The aim of this paper is to present a coherent set of length change measurements that exist for these extraordinarily sensitive and responsive glaciers.

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2. Study site

The total area of glacier cover in the Southern Alps in 1978 was 1158 km^2 (Chinn, 2001) and glacier ice spans an extraordinary elevation range for its latitude (42–44°S) from 280 m above sea level (a.s.l.) at the terminus of Fox Glacier to the highest peak (Aoraki/Mt Cook, 3754 m a.s.l.), with ELAs ranging from 2490 m at the northern end of the range to 1380 m in the south. Of the ~3100 glaciers in the Southern Alps, Fox and Franz Josef are two of the best known and are the third and fourth largest glaciers by volume respectively (Chinn, 2001). The glaciers in the Southern Alps experience a cool temperate climate with precipitation totals ranging from 12 m a^{-1} a few kilometres north-west of the main drainage divide to ~1.5 m a^{-1} at the eastern-most glaciers (Chinn, 1979; Griffiths and McSaveney, 1983; Kees, 2011; Stuart, 2011). The difference between the warmest and coldest mean monthly temperatures varies between 9 K in the west and 13 K in the east (Anderson and Mackintosh, 2012).

Franz Josef Glacier is presently (2014) just under 10.5 km long and covers ~35 km^2 on the western flanks of the Southern Alps of New Zealand at 43°29′ S, 170°11′ E (Fig. 1). The maximum elevation of the glacier is 2900 m a.s.l., although the bulk of the glacier consists of the upper névé area of broad gently-sloping snowfields at elevations ~1900 to 2400 m a.s.l. The glacier tongue descends steeply down a narrow valley terminating within a temperate rainforest at only ~300 m a.s.l. The adjoining Fox Glacier is slightly larger, at ~12.5 km long with an area of ~36 km^2. It also has a larger elevation range, with ice feeding from the western face of Mt Tasman at 3497 m a.s.l. Like Franz Josef, Fox Glacier has a broad high-elevation névé that funnels ice down a similar steep narrow tongue, and terminates below 300 m a.s.l. (Fig. 1).

3. Methods

3.1. Determining length change

Most of the data available on fluctuations of these glaciers are length changes, and these data come from several sources, with varying degrees of accuracy. Where possible, historic maps have been scanned and geo-referenced to a modern map projection (NZTM); the accuracy of this process is limited by the quality of the cartography, and the number of points on the map that can be used as ground control points. At Franz Josef Glacier a number of survey points used in early maps (e.g. Bell, 1910) were used in subsequent maps; these survey points have been located on the ground and their positions recorded using a global positioning system (GPS). At Fox Glacier spot heights from the topographical plan produced by C. Douglas and W. Wilson (Wilson, 1896) were used to geo-reference this first map, and subsequent maps and sketches were aligned based on prominent topography, and river channels. In addition to historic maps, photographs from a range of sources have been used to ‘fill gaps’ during times when no formal surveying

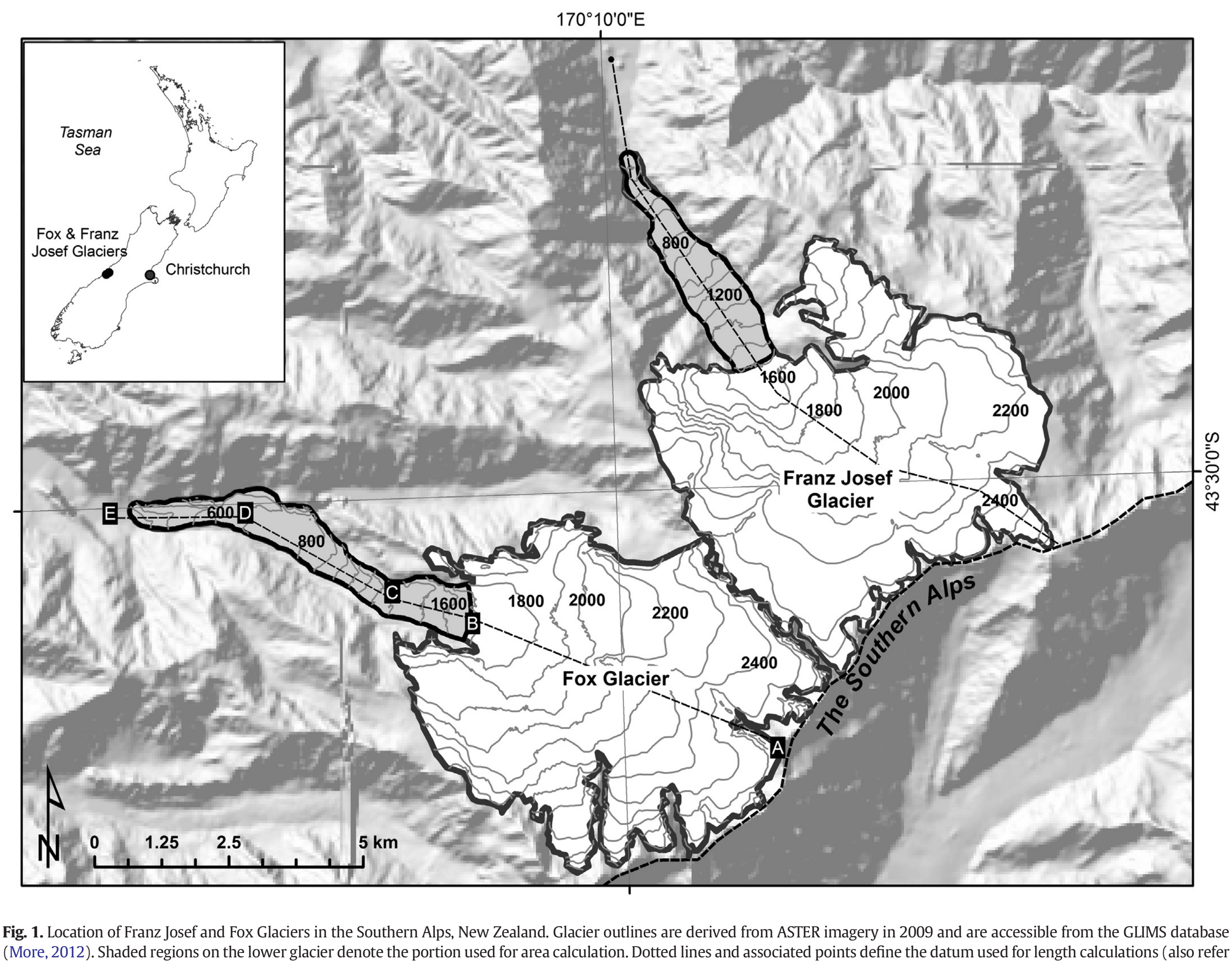

Fig. 1. Location of Franz Josef and Fox Glaciers in the Southern Alps, New Zealand. Glacier outlines are derived from ASTER imagery in 2009 and are accessible from the GLIMS database (More, 2012). Shaded regions on the lower glacier denote the portion used for area calculation. Dotted lines and associated points define the datum used for length calculations (also refer to Tables 1 and 2).