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Glacier Retreat and Tourism: Insights from New Zealand

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Glacier tourism, a multimillion-dollar industry in New Zealand, is potentially under threat by ongoing glacial retreat. Surface morphology changes associated with retreat and thinning result in increasingly difficult access for guided walks on the Franz Josef Glacier, but simultaneously, an enlarging proglacial lake is increasing tourism opportunities at Tasman Glacier. Steepening ice slopes, increased debris cover, and an increase in the rockfall hazard are just some of the challenges glacier tourism operators face as glaciers around the world retreat. To date in New Zealand, glacier tourism has kept pace with ongoing glaciological change, often by increasing mechanized access. Focusing scientific research on short-term process studies—for example, determining thinning rates and assessing hazards—will help tour operators and policy-makers make decisions about future glacier utilization and accessibility.

Keywords: *Glacier tourism; climate change; glacier retreat; hazards; New Zealand.*

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Introduction

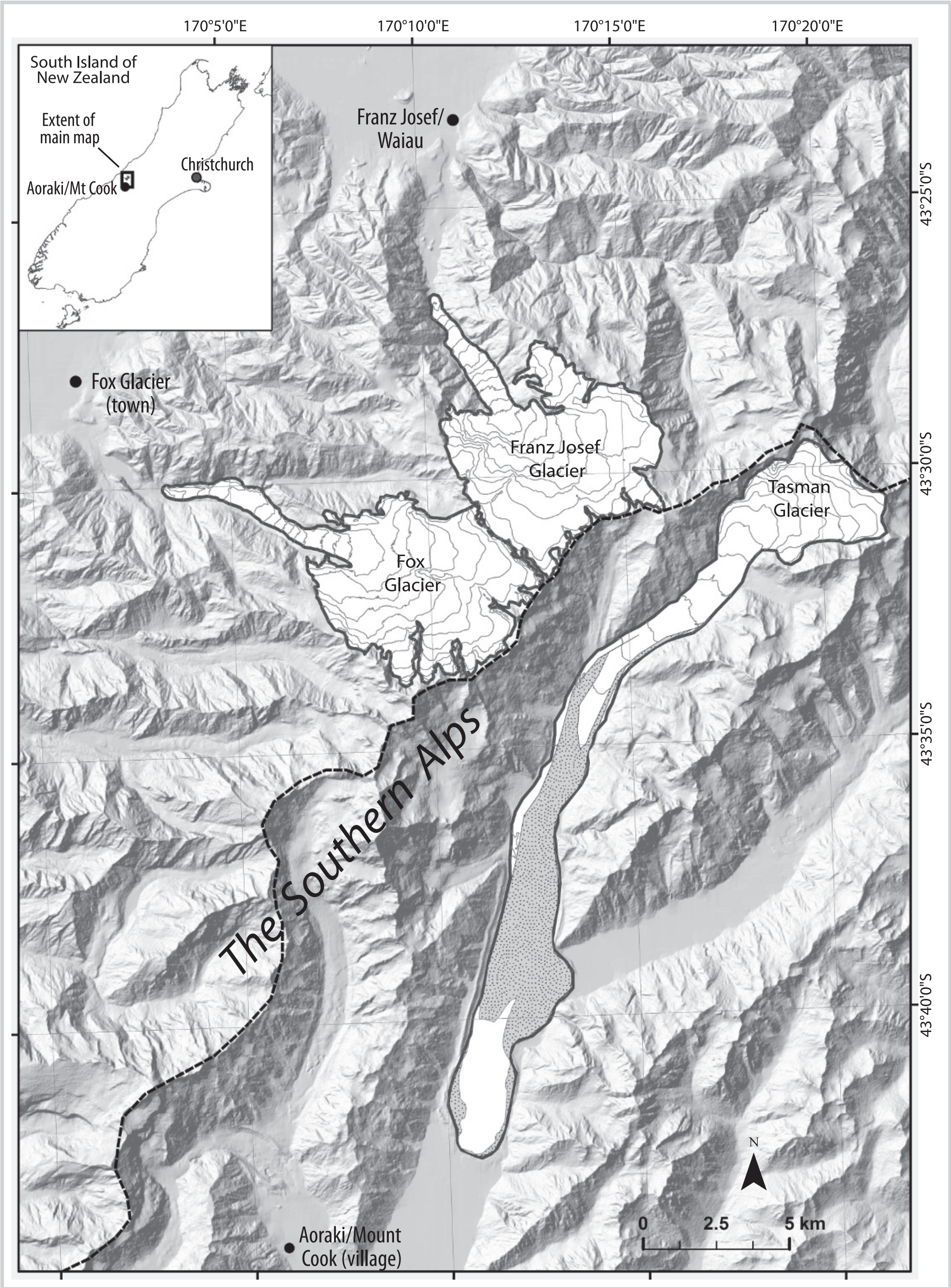
Glaciers are well-recognized indicators of changing climate (eg Solomon et al 2007; WGMS 2011), and, although glaciers in general have been retreating since the end of the Little Ice Age, from the mid-1980s glaciers worldwide have undergone "drastic" retreat (WGMS 2008: 24). Reference glaciers from 10 different mountain ranges around the world are recording increased melt rates and cumulative loss in ice thickness and length (WGMS 2011). Currently, a major focus of glaciological research is trying to determine the impact that shrinking ice will have on global sea levels (eg Pfeffer et al 2008; Hock et al 2009; Rohling et al 2009; Pritchard et al 2012) and future water resources (eg Nolin et al 2010; Bury et al 2011; Baraer et al 2012; Beniston 2012). In many countries, glaciers are also intimately linked to the tourism industry, yet to date, only a few studies have explored the potential impact that glacier recession will have on this often important economic earner (eg Wang et al 2010; Ritter et al 2012); this research focuses mainly on the ski industry (eg Bürki et al 2005; Fischer et al 2011; Hendrikx et al 2012) and potential changes to visitor numbers and experiences (eg Scott et al 2007).

New Zealand has over 3100 glaciers (Chinn 1999), and although fewer than 1% of these glaciers are utilized for tourism operations, 3 are intensively utilized: the Tasman, Fox, and Franz Josef Glaciers (Figure 1). Glacier-related tourism in New Zealand dates back to the late 1880s. With the establishment of the Hermitage Hotel at Aoraki/Mount Cook, visitors began going for guided glacier walks on the then very accessible Tasman Glacier (Figure 2), and guiding services were first advertised in a local newspaper in February 1884 (Pearce 1980; Tourism New Zealand 2001; Langton 2011). Initially, guiding operations on the western glaciers were less formal. Peter Graham (who would later become lead guide at Mount Cook) started exploring the broken ice of the Franz Josef Glacier with his brother Alex, cutting steps with a prospecting (miner's) pick around 1902. These personal excursions evolved into taking visitors onto the glacier, initially free of charge because "it was such a pleasure to do so" (Graham 1965: 53). It was not until 1929 that commercial glacier guiding began on Fox Glacier when then hotel owner Mick Sullivan set up operations to provide some competition to guiding at Franz Josef (New Zealand Mountain Guides Association 2012).

Today tourism is big business in New Zealand. For the year ending March 2012, total tourism expenditure was NZD 23.4 billion (US$ 18.8 billion), and the tourism industry employed 100,000 people (Statistics New Zealand 2012). In terms of export earnings, international tourism is surpassed only by the dairy industry, bringing in NZD 9.6 billion (US$ 7.7 billion) in revenue, and since the turn of the century, total expenditure in tourism has risen by 60% (Statistics New Zealand 2012). The spectacular alpine scenery around the Southern Alps draws tourists to the South Island's West Coast and McKenzie Country. New Zealand glaciers are reported to have high tourist appeal due to their accessibility and natural beauty, and they convey a sense of adventure (Hay and Elliot 2008). Tourists can not only view but also walk on glaciers.

Of the 2.5 million annual visitors to New Zealand, around 700,000 travel to the glacier region on the West Coast, termed Glacier Country by Development West Coast, and it is estimated that direct economic

FIGURE 1 Location map of the Fox, Franz Josef, and Tasman Glaciers in relation to the Southern Alps and the South Island of New Zealand (insert). (Map by author)



contributions from this glacier-related tourism exceeds NZD 100 million (US$ 81 million) per year (Tourism Resource Consultants 2007). The Fox and Franz Josef Glaciers are central to the ongoing success and development of the west coast region. Likewise, on the eastern side of the Southern Alps in Aoraki/Mount Cook National Park, glacier-related tourism is booming, with a number of companies selling glacier-reliant products.

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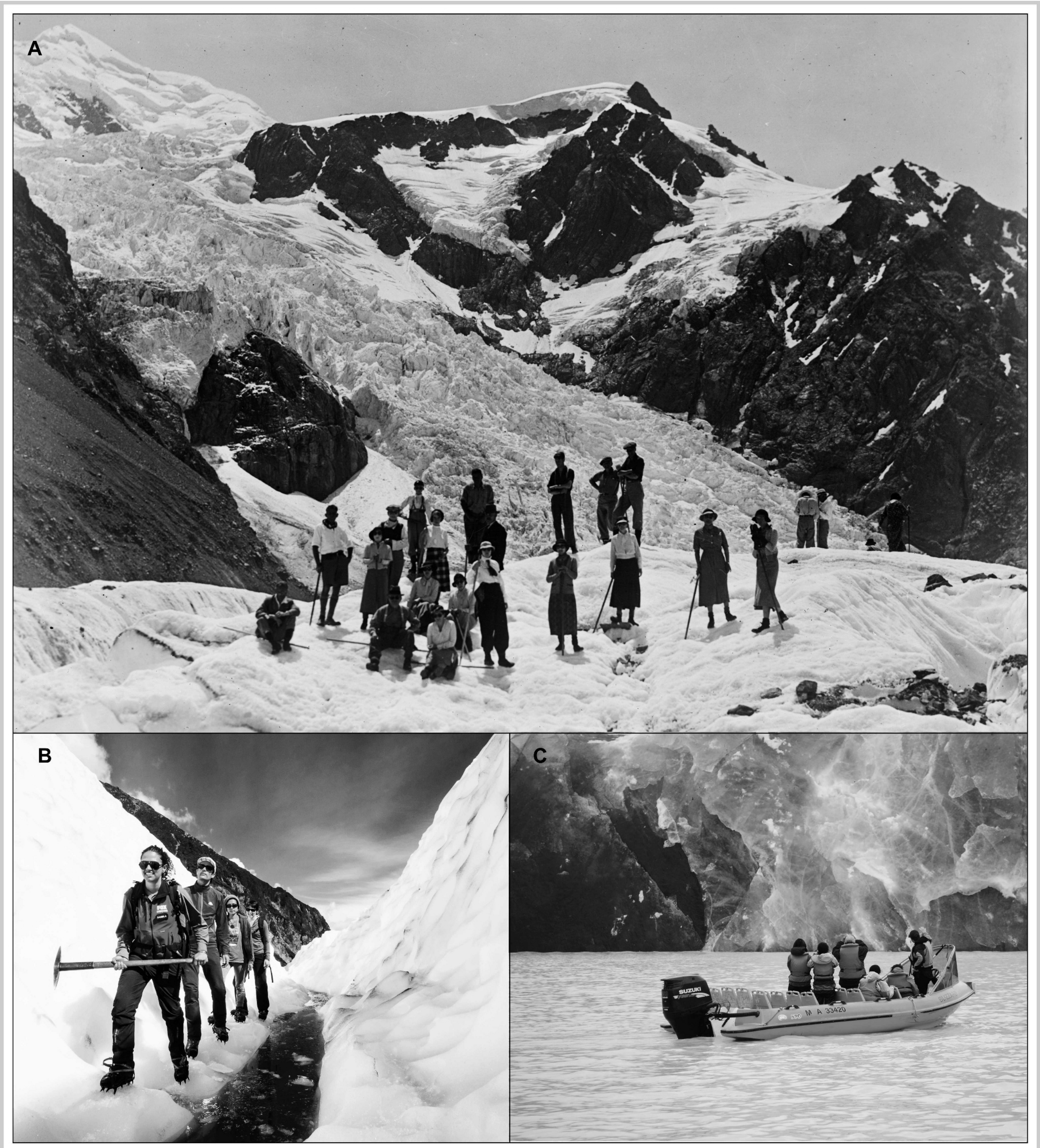
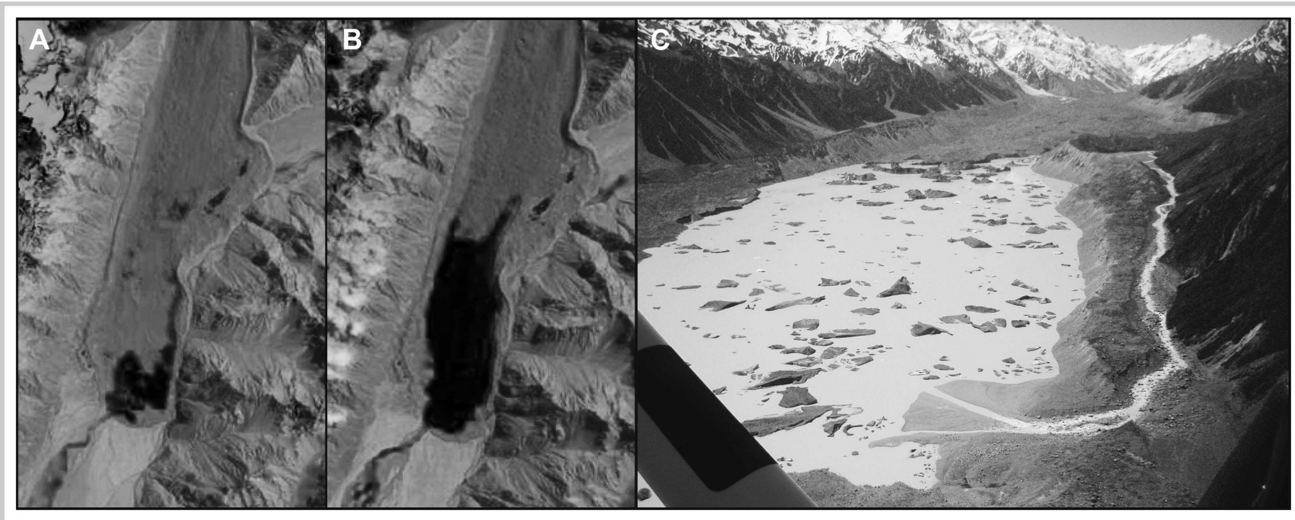
FIGURE 2 Glacier tourism in New Zealand. (A) Guided walk on Tasman Glacier overlooking the Hochstetter icefall ~1920s (photo courtesy of Railways Collection, G-3837-1/1, Alexander Turnbull Library, Wellington, New Zealand); (B) Fox Glacier Guides conducting a day walk on Fox Glacier (photo courtesy of Fox Glacier Guides); (C) Glacier Explorers boat tour on Tasman Glacier Lake (photo courtesy of Glacier Explorers).



This article investigates the impact of climate-driven glacial retreat on glacier-related tourism in New Zealand. It identifies recent glaciological change and considers how such change impacts glacier tourism. It explores past and potential future adaptations in consideration of the sustainability of the glacier-tourism industry. Finally, it calls for glaciological research to focus on short-term process studies, which could assist in future glacier-

FIGURE 3 Growth and dynamics of the Tasman Glacier Lake. (A) 1990 (satellite images from Landsat 4); (B) 2011 (satellite images from Landsat 5; Landsat images are available from the United States Geological Survey at http://earthexplorer.usgs.gov/); (C) icebergs in the lake after an exceptional calving event in December 2008; the Murchison River (seen entering the lake photo right) used to flow parallel to the moraine wall, but broke through into the lake after flooding and a landslide in January 1994; the input of relatively warm water changed lake dynamics and increased down-cutting at the outlet (Röhl 2005; Wakelin 2012). (Photo by Julian Thomson)



tourism management. Although the discussion focuses on New Zealand, it is situated within the broader international experience.

Recent glaciological change

Glaciological investigations on the Tasman, Fox, and Franz Josef Glaciers date back to the late 1800s (Haast 1864; Brodrick 1891; Douglas 1894; Wilson 1896); over the years, monitoring has been sporadic. Since those initial surveys, Tasman Glacier, New Zealand's largest, has been undergoing retreat. Initially, retreat was dominated by surface thinning (down-wasting), but after the development of a proglacial lake in 1990, retreat became more rapid because of a combination of down-wasting and calving (Kirkbride 1993; Kirkbride and Warren 1999; Röhl 2006; Dykes et al 2010). Analysis of Landsat satellite images reveals that the Tasman Lake has increased in area from ~1.65 km^2 in 1990 to ~6.73 km^2 in 2011, equating to a rate of increase of 0.24 km^2 per year (Figure 3). The rate of lake expansion has varied temporally, with a turning point identified by Dykes et al (2011) around 2006, when retreat rates increased, due in part to increasing lake depth and buoyancy-driven calving.

Unlike the continual retreat recorded at Tasman Glacier, the Fox and Franz Josef Glaciers have undergone a number of retreat/advance phases, with the most recent advance culminating in 2008 (Anderson et al 2008; Purdie et al 2008, 2013). During these cycles, the terminus position of the glaciers can vary by as much as 1 km (Figure 4).

As glaciers advance and retreat, there is also a change in ice volume, which can have a profound effect on surface morphology. The surface morphology of a glacier is influenced by the stress regime of the ice, which is in part determined by the underlying bed topography (Paterson 1994). As a glacier thins, underlying structures—for example, a rock step or protuberance—will result in slope steepening, which in turn increases tensile stress and crevassing. Geophysical studies of New Zealand glaciers are few (eg Watson 1995), so little is known about underlying structures on these high-use glaciers. However, observing surface morphology changes between advance/retreat phases can provide an indication of what lies below. On the lower tongue of the Fox Glacier, crevassing increases during advance, when the terminus is steep and glacier velocity increases. During retreat phases the surface mellows, indicating that at least under the lower tongue, the underlying bed topography

FIGURE 4 Length changes at Fox and Franz Josef Glaciers, 1950 to present. Both glaciers are currently rapidly retreating toward their previous minimum extents. (Unpublished Franz Josef Glacier data supplied by Brian Anderson, Ian Owens, and Trevor Chinn; Fox Glacier data supplied by Heather Purdie and Trevor Chinn)

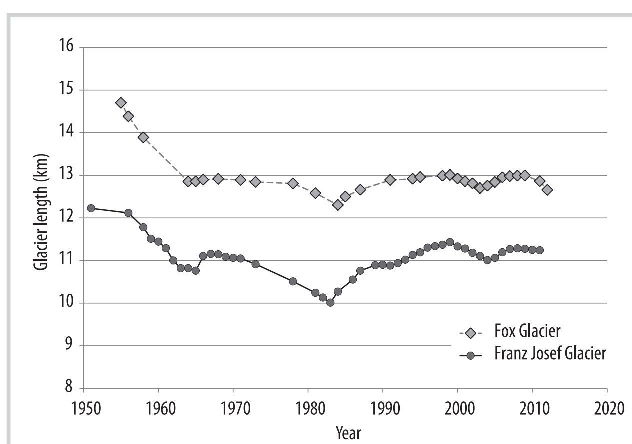


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FIGURE 5 Changes in length, volume, and surface morphology at the Fox and Franz Josef Glaciers between an advance phase in 2008 and a retreat phase in 2012. During retreat, the glaciers thin, debris cover increases, and crevassing generally decreases, but slope angles tend to increase—for example, in the icefall region on the true right side of Fox Glacier (left side of Fox 2012 photo). (Fox Glacier photos by Heather Purdie; Franz Josef Glacier photos by Blair Campbell)

appears relatively smooth. However, there is a noticeable elevation step in the glacier tongue associated with the lower icefall (Figure 5). During retreat, the ice slopes in this region steepen as the glacier thins.

Also during retreat, the overall decrease in surface elevation of the glacier tongue results in increased melt rates due to increased temperatures at lower elevation. Enhanced melting accelerates the delivery of englacial debris to the surface, and the ongoing thinning exposes moraine walls; combined, these trends result in an increase in surface debris (Kirkbride 2002). This increased surface debris is not evacuated as quickly because of the lower velocity. The thicker debris coating in turn reduces melt rates (Nakawo and Young 1981), resulting in differing surface elevation between the "clean" and debris-covered ice. All these changes can be observed by comparing photographs of the lower Fox and Franz Josef Glaciers between advance and retreat phases (Figure 5). Such changes can potentially reduce the aesthetic properties of the glaciers.

Glacier-related tourism in New Zealand

Today around 300,000 people visit the Franz Josef Glacier annually; in 2005, when the glacier was advancing, visitor numbers reached ~346,000. The busiest months are December through March, when on average 36,000 people visit the glacier each month (Department of Conservation 2012a). One of the most popular glacier-related tourism activities is guided glacier walks. The geometry of the Fox and Franz Josef Glaciers means that their ice tongues descend into very accessible low-elevation valleys. Commercial operators at both Fox and Franz Josef Glaciers offer a variety of products, including terminus walks, half- and full-day walks, helicopter-assisted walks (heli-hikes), and ice climbing (Figure 2). This range of products caters to tourists with a variety of budgets, fitness levels, and time commitments; importantly, it can be undertaken without previous experience in technical alpine terrain. In addition to providing the thrill of walking on the ice, interpretation provided during guided trips educates participants about glacier dynamics and how rapid changes can occur.

In Aoraki/Mount Cook National Park, the dominance of down-wasting retreat on the large debris-covered glaciers (Chinn et al 2012) has destabilized moraine walls (Blair 1994), making access to the glacier surface increasingly difficult and dangerous. By 1956 the traditional guided glacier walks (Figure 2A) were abandoned (Bowie 1969). However, the development of proglacial lakes at the termini of these debris-covered glaciers provided new opportunities for glacier tourism—in particular, the development of the Glacier Explorers boat tours on Tasman Glacier Lake in the summer of 1992–1993 (Wakelin 2012). These trips give tourists the opportunity to view the impressive terminal face of the Tasman Glacier and get close to large icebergs that have calved off the glacier into the lake (Figure 2). Originally a small family business, Glacier Explorers is now a major attraction to visitors, but unlike the year-round operations on the west coast glaciers, its boat trips cease during winter when the lake freezes over.

In addition to boat and sea kayak trips on the proglacial lake, Tasman Glacier supports ski-plane landings, heli-skiing, alpine climbing courses, and vehicle/walking tours to view the glacier. Although the Tasman Glacier is the main venue for glacier tourism in Aoraki/Mount Cook National Park, the adjacent Hooker Glacier is popular for guided and self-guided walkers, and the smaller proglacial lake of Mueller Glacier also hosts kayak tours.

In addition to commercial activities, many people choose to visit and view the glaciers independently (Wilson 2012). These visitors also make important economic contributions to local communities by paying for accommodations and other goods and services (Tourism Resource Consultants 2007). The Department of Conservation maintains public-access tracks and regularly modifies glacier-viewing points based on current terminus position and safety considerations; in doing so, it helps to look after the experience of the independent visitor.

Glacial recession and glacier tourism

Glacial recession in the early 1980s saw Fox and Franz Josef Glaciers at their smallest recorded extent (Figure 4). This recession spawned the development of heli-hikes. The lower tongue of the Franz Josef Glacier is very steep. As the glacier thins and shortens, it retracts into a region of complex bed topography, and the lower ice slopes, commonly used for guided walks, become increasingly difficult and dangerous for inexperienced walkers. Air access enables walkers to be flown up to regions of the glacier that are less steep and broken. Current (2012) rapid retreat has meant that yet again the terminus area of Franz Josef Glacier has become treacherous for guided walks. This presents a significant challenge for the local guiding company, Franz Josef Glacier Guides (Buckland 2012). Heli-hikes are more expensive, so they attract fewer customers, and restricted guiding terrain could potentially lead to crowding issues. To adapt to this, Franz Josef Glacier Guides launched a new product, a heli-hike that lands lower on the glacier, avoiding problems associated with walking access up the unstable terminal face. This trip has a shorter flight time and is therefore less expensive than their normal 3-hour heli-hike, but still more expensive than previous foot-access tours. In addition, it required negotiation with the Department of Conservation for an extension to the existing landing permit in order to land helicopters at lower elevations on the glacier. Both excitement and safety are emphasized in the marketing of this new tour (Franz Josef Glacier Guides 2012).

In contrast, for the Fox Glacier (left side of Figure 5), because of morphological differences between the Fox and Franz Josef glacier valleys, recession tends to ease access. When the glacier is advanced, the increased ice volume and crevassing force guided groups to climb high on tracks through forest on the northern side of the valley to safely access the ice. As the glacier shrinks, access can swiftly be gained from the valley floor by traversing moraine exposed between the valley side and the glacier, resulting in a quicker, less strenuous walk for tourists. In addition, the mellowing of the ice surface means that Fox Glacier Guides can safely take groups further up the glacier, so although the glacier tongue is shorter, more of it is passable (Bron 2012). The flip side to increasingly mellow terrain is that there is less topography to hide groups from one another. To avoid clients' feeling crowded, guides need to adapt by creatively utilizing smaller surface features and moving into more technical terrain at glacier margins, all of which requires them to have a higher level of skill and experience (Bron 2012).

Unlike at Fox and Franz Josef Glaciers, where tourism operators are faced with a generally shrinking resource, the expanding Tasman proglacial lake is increasing tourism opportunities. Kylie Wakelin, cofounder of Glacier Explorers, said, "As the lake grew so did public interest . . . the calvings got larger and created more publicity" (Wakelin 2012). With the ongoing increase in lake size, the new owners of Glacier Explorers (Aoraki Mount Cook Alpine Village Ltd) have moved to larger, faster boats, to ensure that tourists still get close to the glacier terminus during a 3-hour tour. Their operational season has also increased, because of delays in winter freezing of the larger lake; the lake now remains frozen for only a few weeks each year, usually late June to early August. Increasingly large calving events, coupled with more aggressive marketing (eg Daly 2012), have seen visitor numbers on the Glacier Explorers boat trip increase by ~730%, and visitor numbers exceeded 25,000 in the 2011–2012 season (Knights 2012).

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Hazards and glacier tourism

Not only can glacier access be a challenge during recession, but certain hazards also increase. Of particular importance at valley glaciers is the increased risk of rockfall. Erosional processes at the ice–valley interface result in oversteepening of valley walls (Bennett and Glasser 2009). Debuttressing of these slopes when the ice retreats makes glacially eroded valleys prone to rockfall (Ballantyne 2002). The threat of rockfall increases after heavy rainfall (Purdie et al 2008), and at higher elevations, melting ice and permafrost are also increasing the frequency of rockfall in many mountain regions, including the New Zealand Southern Alps (eg Allen et al 2009, 2011), the Swiss Alps (eg Bürki et al 2005), and the Austrian Alps (eg Ritter et al 2012). In addition, rocks previously caught in gullies between the glacier and valley wall can, as a glacier thins, cascade out onto the ice, further reducing safe guiding corridors (Nolan 2011; Buckland 2012).

Iceberg calving into proglacial lakes at shrinking glacier termini has become a significant tourist attraction. At Miage Glacier Lake in Italy, tourist numbers peak in summer during the early afternoons when calving activity peaks (Smiraglia et al 2008). Tourists crowd the lake shore and try and get as close as possible to the calving face, putting themselves at risk from waves triggered by large calving events (Smiraglia et al 2008). Tourist accounts from Alaska and Greenland report close calls when large waves initiated by calving events destabilize tour boats (eg Downey and Klint 2011; Peddie 2012). The hazards of operating vessels in iceberg-infested waters have been well illustrated by a number of high-profile incidents in the Antarctic region (Jaincill 2009). At Tasman Glacier, prolific iceberg calving, when coupled with down-valley winds, can result in icebergs physically blocking the boat jetty. Trips have to be postponed until winds from the opposite quarter move the icebergs back up the lake (Wakelin 2012).

In society today, there appear to be increased expectations of safety, diminished tolerance of risk, and yet an increased desire by tourists to experience controlled risk or thrills (eg Espiner 2001; Carter 2006). At Fox and Franz Josef Glaciers, the rockfall hazard is actively managed in the glacial valleys by the guiding companies and by the Department of Conservation. This management includes ground and aerial surveys to identify and map areas that are prone to rockfall; using this information, the guiding companies can then plan routes that minimize client exposure (Bron 2012; Buckland 2012). Carter (2006) highlights how tourist operators need to undertake a balancing act, managing risk while maintaining the thrill. As glaciers continue to retreat, this balancing act between safe access and client satisfaction will be a constant challenge.

The future of glacier-related tourism

Estimated changes to glacier volume from projected climate warming vary greatly around the world. A recent modeling study found that in terms of percentage loss of volume, greatest loss is likely to be experienced in New Zealand (72%) and the European Alps (75%), even though the contribution from glaciers in these regions to sea level rise would be relatively small (Radic and Hock 2011). The Intergovernmental Panel on Climate Change noted that predicted glacier shrinkage and retreat would reduce visitor numbers in tourism-dependent towns like Fox Glacier and Franz Josef/Waiau (Hennessy et al 2007).

However, despite the challenges of maintaining glacier-related tourism, as glaciers worldwide retreat, the interest in glacier tourism is increasing. At Jostedalsbreen in Norway, information and discussion about climate change is seen as a catalyst for increasing visitor numbers (Aall and Høyer 2005). This response to glacier retreat can be understood in terms of last-chance tourism, a phenomenon defined in part as "tourists explicitly seeking vanishing landscapes" (Lemelin et al 2010: 478). Increasingly, tourists appear drawn to locations where particular landscapes, species, or social heritages are disappearing (eg Lemelin et al 2012). Indeed, such motivations may be contributing to increasing visitor numbers on the Tasman Glacier boat tours.

However, such a response to glacial retreat will put increased pressure on the few remaining accessible glaciers (Hay and Elliot 2008). At Baishui Glacier No. 1 in China, there are calls to restrict glacier access to keep the diminishing resource as pristine as possible, and to develop other tourism opportunities like telescope tours and a glacier museum (Wang et al 2010). Conversely, increasing infrastructure to maintain glacier access—for example, extending roads up valleys as glacier termini retreat—has already occurred at Athabasca Glacier, Canada (Luckman and Kavanagh 2000), and such adaptation measures are currently under debate in New Zealand.

As Fox and Franz Josef Glaciers retreat, the Department of Conservation (2012b) is reviewing its management plan that governs activities on and around the west coast glaciers, seeking feedback on issues like increasing aircraft access, extending road access, and increasing the number of people on guided walks. A proposal to construct new private roads for the use of tour operators has sparked an outcry from recreational and environmental groups (eg Federated Mountain Clubs of New Zealand 2012; Mussen 2013). Interestingly, a survey on the impacts of climate change on tourism in the Canadian Rocky Mountains found that although tourist numbers are expected to increase with warmer temperatures extending the summer tourist season, they are then expected to diminish as natural assets like glaciers diminish (Scott et al 2007). In addition, perceptions of

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crowding at the few remaining glaciers could cause tourists to go elsewhere (eg Kearsley and Coughlan 1999; Hall 2006).

While adaptation measures addressing glacier retreat and tourism are gaining momentum, internationally, the ski industry has already been proactive (eg Bürki et al 2005; Price 2010; Fischer et al 2011). This is not surprising given the economic value of the industry; in New Zealand, skier days can exceed 1.4 million per year (Price 2010). It has even been postulated that climate change may positively impact the New Zealand ski industry, as skiing options diminish in neighboring Australia (Craig-Smith and Ruhanen 2005; Carroll 2010). Climate change adaptation in the ski industry focuses strongly on snowmaking technology and the development of higher-elevation terrain (Scott et al 2003; Bürki et al 2005; Hendrikx and Hreinsson 2012). Although advances in snowmaking technology will help offset reductions in winter snow cover, such interventions come at a cost in both monetary and environmental terms (Steiger and Mayer 2008; Pickering and Buckley 2010).

More extreme adaptation measures have been trialed in the Austrian Alps, where textile covers have been applied to the snow surface, reducing summer melting by up to 60% (Olefs and Fischer 2008; Olefs and Lehning 2010). Deteriorating glacier access, which threatens the summer ski industry at Vedretta Piana in the Italian Alps, has prompted the removal of snow from the accumulation area of the glacier to be used to fill crevasses and make trails in the ablation area (Smiraglia et al 2008). These last two examples clearly disrupt natural glacier mass balance processes, and in the case of Vedretta Piana, the transported snow will likely melt in the ablation area, further reducing mass balance on a glacier already in retreat.

Clearly, in order to make sound decisions about the future of glacier tourism, there needs to be more collaboration between the scientific community and those involved with the management and delivery of glacier tourism. Inherent glacier–climate relationships mean that glacier length can be modeled based on future estimates of temperature and precipitation under various warming scenarios (Anderson et al 2008). However, because of large interannual climate variability and a lag between climate change and glacier response (Johannesson et al 1989), studies of this nature usually consider change on multidecadal timescales, for example, estimated sea level rise. Yet tour operators and those responsible for policy and management of tourism ideally want to know where a glacier terminus will be in 1–5 years, how access may change, and how hazards and risks may change.

This current mismatch between science and industry could in part be addressed by focusing on short-term process studies—for example, geophysical surveys to determine bed topography and possible surface morphology changes, calculations of thinning/retreat rates from field measurement and remote sensing, analysis of feedbacks associated with surface melting and increased debris cover (eg Brook and Winkler 2013; Purdie et al 2013), and, perhaps most pressingly, hazard analysis. Studies such as these will improve our understanding of how glaciers retreat, providing estimation of where a terminus might be, what the glacier surface may be like, and how safely the glacier can be accessed.

The termini of the Fox and Franz Josef Glaciers are drawing increasingly close to their previous minimum, which, coupled with observed thinning, indicates that retreat will continue into the near future. Adaptation to changes associated with retreat, like steepening ice slopes and increased rockfall, includes the increased use of helicopters to access flatter parts of the glacier, and shortening glacier length can be compensated by extending access roads up valleys. But such solutions come at a cost, not only in monetary terms, but also in terms of increased environmental disturbance, and negotiation to establish acceptable degrees of adaptation will be ongoing.

Despite dramatic changes in glacier length and thickness, glacier tourism has been maintained in New Zealand. The introduction of boat tours instead of walking tours on Tasman Glacier means that a century on, tourists can still visit the glacier. Likewise, mechanized access will ensure tourism on the Fox and Franz Josef Glaciers. If tourist demand increases with trends like last-chance tourism, this could be managed through policy changes and price adjustment. However, it is likely that the greatest impact will be felt by self-guided tourists, with access and viewing points becoming increasingly unsatisfactory as glaciers retreat into steeper, more inaccessible terrain. Scientists, policy makers, and tour operators need to work together, sharing knowledge, ideas, and experience, to find a balance between utilization, safety, and conservation.

Conclusion

Glacier-related tourism, an important part of the New Zealand economy, is experiencing increasing challenge from ongoing glacial retreat. However, while some glacial resources are shrinking, others are increasing. As glaciers worldwide retreat beyond previous minima, tourism operators and tourists will need to adapt. Utilizing expanding proglacial lakes and helicopter access are options that tourism providers have already embraced in order to maintain glacier access. Scientists can assist adaptation by focusing glaciological research on shorter temporal scales and contributing knowledge to the development and review of environmental policy.

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REFERENCES

Aall C, Høyer KG. 2005. Tourism and climate change adaptation: The Norwegian case. *In:* Hall M, Higham J, editors. *Tourism, Recreation and Climate Change*. Clevedon, United Kingdom: Channel View Publications, pp 209–221.
Allen S, Cox S, Owens I. 2011. Rock avalanches and other landslides in the central Southern Alps of New Zealand: A regional study considering possible climate change impacts. *Landslides* 8:33–48.
Allen S, Gruber S, Owens I. 2009. Exploring steep bedrock permafrost and its relationship with recent slope failures in the Southern Alps of New Zealand. *Permafrost and Periglacial Processes* 20:345–356.
Anderson B, Lawson W, Owens I. 2008. Response of Franz Josef Glacier *Ka Roimata o Hine Hukatere* to climate change. *Global and Planetary Change* 63: 23–30.
Ballantyne C. 2002. Paraglacial geomorphology. *Quaternary Science Reviews* 21:1935–2017.
Baraer M, Mark B, McKenzie J, Condom T, Bury J, Huh K-I, Portocarrero C, Gómez J, Rathay S. 2012. Glacier recession and water resources in Peru's Cordillera Blanca. *Journal of Glaciology* 58(207):134–150.
Beniston M. 2012. Impacts of climate change on water and associated economic activities in the Swiss Alps. *Journal of Hydrology* 412–413:291–296.
Bennett M, Glasser N. 2009. *Glacial Geology: Ice Sheets and Landforms*. Chichester, United Kingdom: Wiley-Blackwell.
Blair R. 1994. Moraine and valley wall collapse due to rapid deglaciation in Mount Cook National Park, New Zealand. *Mountain Research and Development* 14(4):347–358.
Bowie N. 1969. *Mick Bowie: The Hermitage Years*. Wellington, New Zealand: AH & AW Reed.
Brodrick TN. 1891. Report on the Tasman Glacier. *Appendix to the Journal of the House of Representatives of New Zealand* 1, C-1A(4):39–43.
Bron M. 2012. Transcript from interview. Available from author of this article.
Brook M, Winkler S. 2013. Debris cover and surface melt at a temperate maritime alpine glacier: Franz Josef, New Zealand. *New Zealand Journal of Geology and Geophysics* 56(1):27–38.
Buckland C. 2012. Transcript of interview held on 12 July 2012. Available from author of this article.
Bürki R, Elsasser H, Abegg B, Koenig U. 2005. Climate change and tourism in the Swiss Alps. *In:* Hall M, Higham J, editors. *Tourism, Recreation and Climate Change*. Clevedon, United Kingdom: Channel View Publications, pp 155–163.
Bury J, Mark B, McKenzie J, French A, Baraer M, In Huh K, Luyo M, Lopez R. 2011. Glacier recession and human vulnerability in the Yanamarey watershed of the Cordillera Blanca, Peru. *Climate Change* 105:179–206.
Carroll J. 2010. Climate change may favour resort. *Otago Daily Times,* online edition, 15 February 2010. www.odt.co.nz/on-campus/university-otago/93434/climate-change-may-favour-resort; accessed on 4 July 2012.
Carter C. 2006. Playing with risk? Participant perceptions of risk and management implications in adventure tourism. *Tourism Management* 27:317–325.
Chinn TJ. 1999. New Zealand glacier response to climate change of the past 2 decades. *Global and Planetary Change* 22:155–168.
Chinn TJ, Salinger J, Fitzharris B, Willsman A. 2012. Annual ice volume changes 1976–2008 for the New Zealand Southern Alps. *Global and Planetary Change* 92–93:105–118.
Craig-Smith S, Ruhanen L. 2005. Implications of climate change on tourism in Oceania. *In:* Hall M, Higham J, editors. *Tourism, Recreation and Climate Change*. Clevedon, United Kingdom: Channel View Publications, pp 181–191.
Daly M. 2012. Tasman glacier shed 30 million tonnes. *Fairfax News*. 1 February 2012. www.stuff.co.nz/environment/6350277/Tasman-glacier-sheds-30-million-tonnes; accessed on 28 June 2012.
Department of Conservation. 2012a. Transcript of email communication on 27 June 2012. Available from author of this article.
Department of Conservation. 2012b. *Westland Tai Poutini National Park Management Plan—Partial Review*. www.doc.govt.nz/upload/documents/getting-involved/consultations/current-consultations/west-coast/public-notice-westland-national-park-glacier.pdf; accessed on 17 October 2012.
Douglas CE. 1894. On the Westland Alps. *Appendix to the Journal of the House of Representatives of New Zealand* C-1(appendix 6):71–75.
Downey M, Klint C. 2011. Woman injured after wave from calving glacier hits boat. *Channel 2 News*. 8 August 2011. www.ktuu.com/news/ktuu-woman-injured-after-wave-from-calving-glacier-hits-boat-20110808,0,3882373.htmlstory; accessed on 13 July 2012
Dykes R, Brook M, Robertson C, Fuller I. 2011. Twenty-first century calving retreat of Tasman Glacier, Southern Alps, New Zealand. *Arctic, Antarctic and Alpine Research* 43(1):1–10.
Dykes R, Brook M, Winkler S. 2010. The contemporary retreat of Tasman Glacier, Southern Alps, New Zealand, and the evolution of Tasman proglacial lake since AD 2000. *Erdkunde* 64(2):141–154.
Espiner S. 2001. *The Phenomenon of Risk and Its Management in Natural Resource Recreation and Tourism Settings: A Case Study of Fox and Franz Josef Glacier, Westland National Park, New Zealand* [PhD thesis]. Lincoln, Canterbury, New Zealand: Lincoln University.
Federated Mountain Clubs of New Zealand. 2012. Re Westland Tai Poutini National Park Management Plan Partial Review. Letter to the New Zealand Department of Conservation, 9 September 2012. www.fmc.org.nz/wp-content/uploads/2009/07/Westland-Plan-Review-FMC-Submission.pdf; accessed 7 August 2013.
Fischer A, Olefs M, Abermann J. 2011. Glaciers, snow and ski tourism in Austria's changing climate. *Annals of Glaciology* 52(58):89–96.
Franz Josef Glacier Guides. 2012. *New Glacier Experience Launch*. www.franzjosefglacier.com/social/blog/new-glacier-experience-launch-our-press-release/; accessed on 4 July 2012.
Graham P. 1965. *Peter Graham Mountain Guide: An Autobiography*. Wellington, New Zealand: AH & AW Reed.
Haast J. 1864. Notes on the mountains and glaciers of the Canterbury Province, New Zealand. *Journal of the Royal Geographical Society of London* 34:87–96.
Hall M. 2006. *The Geography of Tourism and Recreation: Environment, Place and Space*. Oxon, United Kingdom: Routledge.
Hay J, Elliot T. 2008. New Zealand's glaciers: Key national and global assets for science and society. *In:* Orlove B, Wiegandt E, Luckman B, editors. *Darkening Peaks: Glacier Retreat, Science, and Society*. Berkeley, CA: University of California Press, pp 185–195.
Hendrikx J, Hreinsson E. 2012. The potential impact of climate change on seasonal snow in New Zealand: Part 2—Industry vulnerability and future snowmaking potential. *Theoretical and Applied Climatology* 110(4):619–630. http://dx.doi.org/10.1007/s00704-012-00713-z.
Hendrikx J, Hreinsson E, Clark M, Mullan AB. 2012. The potential impact of climate change on seasonal snow in New Zealand: Part 1—An analysis using 12 GCMs. *Theoretical and Applied Climatology* 110(4):607–618. http://dx.doi.org/10.1007/s00704-012-0711-1.
Hennessy K, Fitzharris B, Bates BC, Harvey N, Howden SM, Hughes L, Salinger J, Warrick R. 2007. Australia and New Zealand. Climate change 2007: Impacts, adaptation and vulnerability. *In:* Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE, editors. *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom: Cambridge University Press, pp 507–540.
Hock R, De Woul M, Radic V, Dyurgerov M. 2009. Mountain glaciers and ice caps around Antarctica make a large sea-level rise contribution. *Geophysical Research Letters* 36(L07501). http://dx.doi.org/10.1029/2008GL037020.
Jaincill J. 2009. Ship accidents in Antarctica raise ecological and safety concerns. *Travel Weekly*. 28 April 2009. www.travelweekly.com/Cruise-Travel/Ship-accidents-in-Antarctica-raise-ecological-and-safety-concerns/; accessed on 17 July 2012.
Johannesson T, Raymond C, Waddington E. 1989. Time-scale for adjustment of glaciers to changes in mass balance. *Journal of Glaciology* 35(121):355–369.
Kearsley G, Coughlan D. 1999. Coping with crowding: Tourist displacement in the New Zealand backcountry. *Current Issues in Tourism* 2(2–3):197–210.
Kirkbride M. 1993. The temporal significance of transitions from melting to calving termini at glaciers in the central Southern Alps of New Zealand. *Holocene* 3(3):232–240.

Kirkbride M. 2002. Processes of glacial transportation. *In:* Menzies J, editor. *Modern and Past Glacial Environments*. Oxford, United Kingdom: Butterworth-Heinmann, pp 147–169.
Kirkbride M, Warren C. 1999. Tasman Glacier, New Zealand: 20th-century thinning and predicted retreat. *Global and Planetary Change* 22:11–28.
Knights C. 2012. Transcript of interview held on 2 May 2012. Available from author of this article.
Langton G. 2011. *Summits and Shadows, Jack Clarke and New Zealand Mountaineering*. Palmerston North, New Zealand: Steele Roberts Aotearoa.
Lemelin H, Dawson J, Stewart E. 2012. *Last Chance Tourism: Adapting Tourism Opportunities in a Changing World*. London, United Kingdom: Routledge.
Lemelin H, Dawson J, Stewart E, Maher P, Jueck M. 2010. Last-chance tourism: The boom, doom, and gloom of visiting vanishing destinations. *Current Issues in Tourism* 13(5):477–493.
Luckman B, Kavanagh T. 2000. Impact of climate fluctuations on mountain environments in the Canadian Rockies. *Ambio* 29(7):371–380.
Mussen D. 2013. Views clash over glacier roads. *Press*, 16 April 2013. www.stuff.co.nz/the-press/news/8553667/Views-clash-over-glacier-roads; accessed on 7 August 2013.
Nakawo M, Young GJ. 1981. Field experiments to determine the effect of a debris layer on ablation of glacial ice. *Annals of Glaciology* 2:85–91.
New Zealand Mountain Guides Association. 2012. *History of NZ Guiding*. www.nzmga.org.nz/pages/8/history-of0nz0guiding.htm; accessed on 26 June 2012.
Nolan D. 2011. *Franz Josef Glacier, New Zealand 13/10/11*. www.youtube.com/watch?v=Vq8Hwsjf2XM; accessed on 12 July 2012.
Nolin A, Phillippe J, Jefferson A, Lewis S. 2010. Present-day and future contribution of glacier runoff to summertime flows in a Northwest watershed: Implications for water resources. *Water Resources Research* 46(W12509):1–14.
Olefs M, Fischer A. 2008. Comparative study of technical measures to reduce snow and ice ablation in Alpine glacier ski resorts. *Cold Regions Science and Technology* 52:371–384.
Olefs M, Lehning M. 2010. Textile protection of snow and ice: Measured and simulated effects on the energy and mass balance. *Cold Regions Science and Technology* 62:126–141.
Paterson WSB. 1994. *The Physics of Glaciers*. Oxford, United Kingdom: Butterworth-Heinemann.
Pearce D. 1980. Tourist Development at Mount Cook since 1884. *New Zealand Geographer* 36(2):79–84.
Peddie C. 2012. Adelaide woman Sarah Williams survives Greenland iceberg 'tsunami'. *News.com.au*. 26 July 2012. www.news.com.au/travel/news/adelaide-woman-sarah-williams-survives-greenland-iceberg-tsunami/story-e6frfq80-1226436116246; accessed on 1 August 2012.
Pfeffer WT, Harper JT, O'Neel S. 2008. Kinematic constraints on glacier contributions to 21st-century sea-level rise. *Science* 321(5894):1340–1343.
Pickering C, Buckley R. 2010. Climate response by the ski industry: The shortcomings of snowmaking for Australian resorts. *Ambio* 39:430–438.
Price BW. 2010. *Climate Change Adaptation and Mitigation in New Zealand Snow Tourism*. Industry Report, Ministry of Economic Development, The Tourism Strategy Group, School of Geography, Environment and Earth Sciences, Victoria University of Wellington, Wellington, New Zealand. www.med.govt.nz/sectors-industries/tourism/pdf-docs-library/tourism-research-and-data/other-research-and-reports/research-projects-and-reports/tourism-research-scholarship-reports/Tour.0143%20-%20Climate%20change%20adaptation%20and%20mitigation%20in%20New%20Zealand%20snow%20tourism.pdf; accessed on 4 July 2012.
Pritchard HD, Ligtenberg SRM, Fricker HA, Vaughan DG, van den Broeke MR, Padman L. 2012. Antarctic ice-sheet loss driven by basal melting of ice shelves. *Nature* 484:502–505.
Purdie H, Anderson B, Chinn TJ, Owens I, Mackintosh A. 2013. A century of length change at Fox and Franz Josef Glaciers, New Zealand. *Davos Atmosphere and Cryosphere Assembly DACA-13*, Davos, Switzerland. http://www.daca-13.org/wsl/daca13/program/DACA-13_Abstract_Proceedings.pdf; accessed on 13 October 2013.
Purdie H, Brook M, Fuller I, Appleby J. 2008. Seasonal variability in velocity and ablation of Te Moeka o Tuawe/Fox Glacier, South Westland, New Zealand. *New Zealand Geographer* 64(1):5–19.
Radic V, Hock R. 2011. Regionally differentiated contribution of mountain glaciers and ice caps to future sea-level rise. *Nature Geoscience* 4:91–94. http://dx.doi.org/10.1038/ngeo1052.
Ritter F, Fiebig M, Muhar A. 2012. Impacts of global warming on mountaineering: A classification of phenomena affecting the alpine trail network. *Mountain Research and Development* 32(1):4–15.
Röhl K. 2005. *Terminus Disintegration of Debris-Covered, Lake-Calving Glaciers* [PhD thesis]. Dunedin, New Zealand: Department of Geography, University of Otago.
Röhl K. 2006. Thermo-erosional notch development at fresh-water-calving Tasman Glacier, New Zealand. *Journal of Glaciology* 52(177):203–213.
Rohling EJ, Grant K, Bolshaw M, Roberts AP, Siddall M, Hemleben C, Kucera M. 2009. Antarctic temperature and global sea level closely coupled over the past five glacial cycles. *Nature Geoscience* 2:500–504. http://dx.doi.org/10.1038/ngeo557.
Scott D, Jones B, Konopek J. 2007. Implications of climate and environmental change for nature-based tourism in the Canadian Rocky Mountains: A case study of Waterton Lakes National Park. *Tourism Management* 28(2):570–579.
Scott D, McBoyle G, Mills B. 2003. Climate change and the skiing industry in southern Ontario (Canada): Exploring the importance of snowmaking as a technical adaptation. *Climate Research* 23:171–181.
Smiraglia C, Diolaiuti G, Pelfini M, Belò M, Citterio M, Carnielli T, D'Agata C. 2008. Glacier changes and their impacts on mountain tourism. *In:* Orlove B, Wiegandt E, Luckman B, editors. *Darkening Peaks: Glacier Retreat, Science, and Society*. Berkeley, CA: University of California Press, pp 206–215.
Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt K, Tignor M, Miller H, editors. 2007. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom: Cambridge University Press.
Statistics New Zealand. 2012. *Tourism Satellite Account: 2012*. Wellington: Statistics New Zealand. www.med.govt.nz/sectors-industries/tourism/tourism-research-data/tourism-satellite-account/tourism-satellite-accounts/tsa-full-report-oct-2012.pdf; accessed on 15 August 2013.
Steiger R, Mayer M. 2008. Snowmaking and climate change. *Mountain Research and Development* 28(3/4):292–298.
Tourism New Zealand. 2001. *100 Years Pure Progress*. Wellington, New Zealand: Tourism New Zealand. www.tourismnewzealand.com/media/127126/tourism%20centenary.pdf; accessed on 26 June 2012.
Tourism Resource Consultants. 2007. Glacier country: Issues and options for product development and growth. Report prepared for Development West Coast by Tourism Resource Consultants in association with Boffa Miskell. www.westcoastnz.com/content/library/glacier_country_issues_and_options_report_091107_.pdf; accessed on 17 May 2012.
Wakelin K. 2012. Transcript of email communication on 21 May 2012. Available from author of this article.
Wang S, He Y, Song X. 2010. Impacts of climate warming on alpine glacier tourism and adaptive measures: A case study of Baishui Glacier No. 1 in Yulong Snow Mountain. Southwestern China. *Journal of Earth Science* 21(2):166–178.
Watson M. 1995. *Geophysical and Glaciological Studies of the Tasman and Mueller Glaciers* [MSc thesis]. Auckland, New Zealand: University of Auckland.
WGMS [World Glacier Monitoring Service], editor. 2008. *Global glacier changes: Facts and figures*. Zurich, Switzerland: United Nations Environment Programme, World Glacier Monitoring Service.
WGMS [World Glacier Monitoring Service], editor. 2011. *Glacier Mass Balance Bulletin, Bulletin No. 11 (2008–2009)*. Zurich, Switzerland: World Glacier Monitoring Service.
Wilson J. 2012. *The Impact of Climate Variability on Tourism Business and Tourism Infrastructure Providers in Glacier Country*. Research paper No. 4, Land Environment and People, Lincoln University, Canterbury, New Zealand. http://researcharchive.lincoln.ac.nz/dspace/bitstream/10182/4185/1/LEaP_rp_4.pdf.
Wilson W. 1896. The Fox Glacier. *Appendix to the Journal of the House of Representatives of New Zealand* 1(C-1):108–109.