Glacier science and environmental change
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Glacier variations in central Chile (32°S–41°S)

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Glaciers in the Chilean central Andes (Fig. 49.1, 32°S–41°S) have shown significant frontal retreat, area shrinkage and ice thinning in an accelerating trend during recent decades, presumably in response to atmospheric warming and reduction of precipitation.

Nearly 1600 glaciers with a total ice area of ca. 1300 km^2 have been inventoried in the Chilean central Andes, which have experienced a total volume loss due to thinning and retreat of 46 ± 17 km^3 of water equivalent between 1945 and 1996 (Rivera *et al.*, 2002), affecting water resources availability for agriculture, mining and human consumption.

This region includes the most populated part of the country (33°S–36°S) and its glaciers have been recognized as a key factor in contributing to late summer runoff in many of the main river basins, especially during summers with severe drought when up to 67% of the water flow is generated by glacier meltwater (Peña & Nazarala, 1987). In spite of the importance of the regional glaciers, very limited glaciological research has been carried out since the pioneering work of Lliboutry (1956). There are still some basins without glacier inventories, especially regarding debris-covered ice, very few ice-thickness data exist (Rivera *et al.*, 2001) and very little is known about the energy and mass balance of the glaciers (Corripio, 2002).

The only systematic mass balance programme is taking place at Glaciar Echaurren Norte (33°35′S, 70°08′W) where results have shown that during warm (cold) phases of ENSO events, high (low) winter precipitation has generated more positive (negative) annual balances (Escobar *et al.*, 1995). As a result, the water resources of central Chile have been under pressure during recent decades owing to increased competition for water allocation as a result of rapid economic growth, and also because the availability of these resources has been stressed by higher interannual variability of the weather system and reduction of the glacier areas.

One of the most dramatic glacier responses has taken place on Glaciar Juncal Sur (33°05′S, 70°06′W), which has experienced an average frontal change of −50 m yr^{-1} between 1955 and 1997, with a total area loss of ca. 10% since 1955.

The glacier with the longest historical record of frontal variations is Glaciar Cipreses (34°33′S, 70°22′W), which has been systematically retreating and shrinking since 1860; in an accelerated

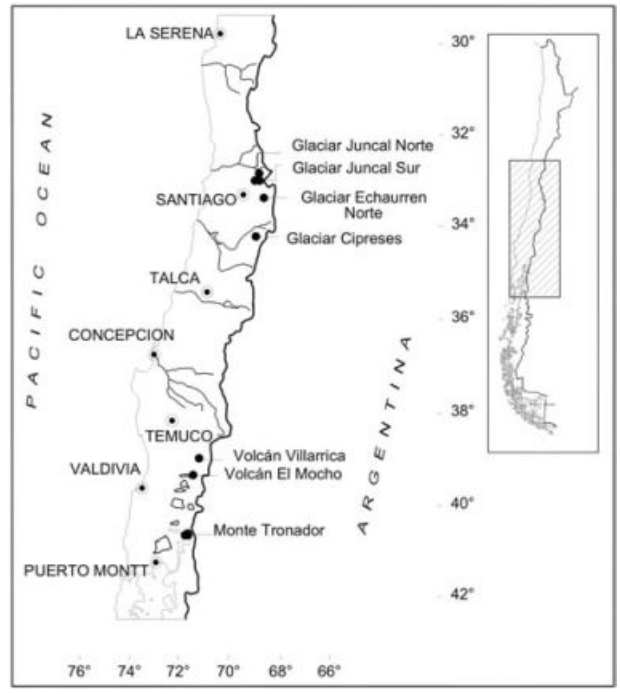

Figure 49.1 Index map showing the location of the glaciers discussed in the text.

trend during recent decades when the retreat rates tripled (Fig. 49.2A). Ice-elevation changes have been measured in this glacier by comparing digital elevation models based upon regular cartography generated from aerial photographs acquired in 1955 and Shuttle Radar Topography Mission (SRTM) data acquired in 2000, yielding an average thinning rate of 1.06 ± 0.45 m yr^{-1} for the ablation area (Fig. 49.2B).

Between 36°S and 41°S, most of the glaciers are located on active volcanoes where eruptions have generated damaging lahars owing to sudden melting of snow and ice by ash deposition and lava flows. One of the most active volcanoes in this region is

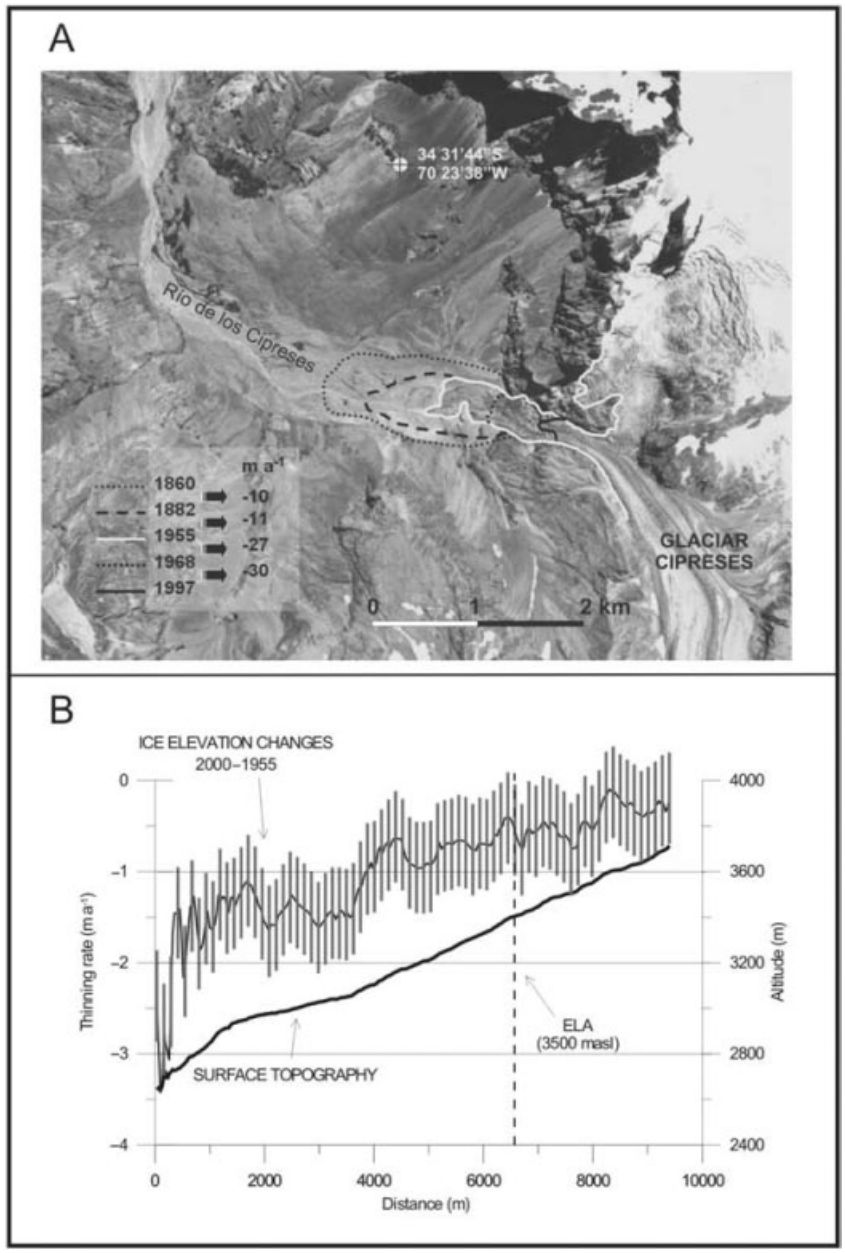

Figure 49.2 Glaciar Cipreses frontal variations between 1860 and 1997 (A) and ice elevation changes between 1955 and 2000 (B).

Volcán Villarrica (39°25′S, 71°55′W), which is ice capped by partially debris-covered glaciers that have been shrinking between 1961 and 2003 at an average rate of $-0.4\,km^2\,yr^{-1}$, with an areal loss of ca. 25% of the 1961 glacier area. Most of these glacier changes have taken place after large eruptions and they are not necessarily related to climate changes.

In spite of having experienced surface atmospheric cooling between the 1950s and the 1980s (Rosenblüth *et al.*, 1997), the region between 38°S and 41°S shows extensive glacier retreat during the second half of the 20th century, presumably in response to both an atmospheric warming at the approximate altitude of the equilibrium line altitude (ELA) of the glaciers (ca. 2000 m a.s.l.) and a significant reduction of precipitation between 1960 and 2000 (Bown & Rivera, in press).

Considering the current glacier behaviour it is possible to presume that the glaciers are out of balance with present climate and further retreat will probably take place.