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Chironomid-based reconstructions of summer air temperature from lake deposits in Lyndon Stream, New Zealand spanning the MIS 3/2 transition

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Abstract

We present chironomid-based temperature reconstructions from lake sediments deposited between ca 26,600 cal yr BP and 24,500 cal yr BP from Lyndon Stream, South Island, New Zealand. Summer (February mean) temperatures averaged 1 °C cooler, with a maximum inferred cooling of 3.7 °C. These estimates corroborate macrofossil and beetle-based temperature inferences from the same site and suggest climate amelioration (an interstadial) at this time. Other records from the New Zealand region also show a large degree of variability during the late Otiran glacial sequence (34,000–18,000 cal yr BP) including a phase of warming at the MIS 2/3 transition and a maximum cooling that did not occur until the global LGM (ca 20,000 cal yr BP).

The very moderate cooling identified here at the MIS 2/3 transition confirms and enhances the long-standing discrepancy in New Zealand records between pollen and other proxies. Low abundances (<20%) of canopy tree pollen in records from late MIS 3 to the end of MIS 2 cannot be explained by the minor (<5 °C) cooling inferred from this and other studies unless other environmental parameters are considered. Further work is required to address this critical issue.

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1. Introduction

The ability to accurately reconstruct past climates is a reflection of our capability to predict major climate change in the future. Since the initiation of Climate Long-range Investigation, Mapping, And Prediction (CLIMAP) almost 30 years ago (CLIMAP project members, 1976) the Last Glacial Maximum (LGM) (23,000–19,000 cal yr BP (Mix et al., 2001) has remained an important benchmark for the testing of global climate models. The LGM represents the most recent, well recorded, example of major natural climate change that lies within the limits of a large number of dating techniques. Therefore it is possible to obtain a large amount of paleoclimatological data which not only serves to validate climate models but direct their construction.

Recent studies (Crowley and Baum, 1997; Crowley, 2000; Kohfeld and Harrison, 2000; Moreno et al., 2005) have emphasised the importance of an 'earth-system' approach to model development; climate models should account for possible effects of ocean–atmosphere–cryosphere–biosphere interactions. Global climate models have, until recently been based largely on reconstructions of sea surface temperatures (SSTs) (e.g. CLIMAP, 1981) because SST reconstructions are based on a globally extensive dataset of modern analogues (e.g. Barrows and Juggins, 2005). However, observations based on an ever increasing terrestrial dataset (e.g. dust records, lake-levels, faunal and floral-based reconstructions, and paleo snow-line elevations) have revealed inconsistencies between terrestrial conditions inferred from SST-based global climate models and inferences based on local proxy data (Pinot et al., 1999).

Terrestrial paleoclimate data from the Northern Hemisphere far exceeds the quantity of data from the southern latitudes. The few quantitative estimates for land-based LGM temperature anomalies in the Southern Hemisphere

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have been based on snow-line depressions (Hilton et al., 1994; Bacon et al., 2001), TEX_{86} lake surface temperatures (LSL) (Powers et al., 2005), and pollen-based estimates (e.g. Bush et al., 2004). Increasing this dataset is essential for the purposes of global climate model development and validation.

Despite being identified as a key site for future investigation into LGM climate variability (Broecker, 1997), quantitative paleoclimate data generated for the LGM period in New Zealand is also limited. These data are especially important, as recent studies (Suggate and Almond, 2005; Vandergoes et al., 2005) indicate that so-called 'LGM' cooling in New Zealand may have begun as early as 34,000 cal yr BP; predating the real LGM by 11,000 years. The last glacial cycle (ca 74,000–ca 11,500 cal yr BP) is locally known as the Otira Glaciation (Suggate, 1990). In this paper, we refer to the period between 34,000 and 18,000 cal yr BP in New Zealand which corresponds to a series of major ice advances (Suggate and Almond, 2005) as the late Otiran glacial sequence (LOGS).

We avoid the use of the term LGM as the term 'LGM' as it is officially defined denotes the last period of maximum global ice volume (Mix et al., 2001). The use of this term to label local ice advances (even though there are Southern Hemisphere correlatives (Denton et al., 1999b)) has already caused confusion. We use the term 'sequence' because there were several major ice volume fluctuations in New Zealand during this time (Suggate and Almond, 2005) and a great deal of climate variability (Sandiford et al., 2001, 2003; Hägg and Augustinus, 2003; Hormes et al., 2003; Vandergoes et al., 2005). Although some large ice advances occurred early in the LOGS (Suggate and Almond, 2005) it appears that the greatest amount of cooling did not occur until the time of the global LGM (Barrows and Juggins, 2005).

Pollen-based estimates imply mean annual temperature (MAT) depressions for the LOGS ranging from 4 to 7 °C (Soons, 1979; McGlone et al., 1993; Shulmeister et al., 2001). Beetle-based mutual climate range (MCR) reconstructions from middle (ca 27,000–22,000 cal yr BP) of the LOGS suggest a maximum cooling of between 1.9 and 5 °C in summer (February mean) and 2.2 and 6 °C for winter (July mean daily minimum) (Marra et al., 2004, 2006).

Previous studies elsewhere in the world (Seppa et al., 2004) have used pollen-based transfer functions to infer past climate conditions. Despite the fact that pollen has been the most widely used proxy for climate change in New Zealand, only one study (Norton et al., 1986) has explored the possibility for the development of pollen-based transfer functions. The resulting transfer functions were not robust enough to be confidently applied to the fossil pollen record. Therefore generalisations about climate have continued to be inferred from the modern species distribution of taxa found in the fossil record. A major climate deterioration spanning the entire LOGS has been inferred from the low abundance of pollen belonging to canopy trees (Podocarpaceae and *Nothofagus*) and the abundance of herb and grass pollen in records spanning approximately 34,000–18,000 years ago (Moar, 1980; Moar and Suggate, 1996; Vandergoes et al., 2005, Fig. 4).

Very little cooling has been inferred from some of the beetle-based reconstructions (Marra et al., 2004, 2006) and from recent climate model-based air temperature inferences (Weaver et al., 1998; Bush and Philander, 1999). A slight increase in canopy tree pollen abundance is recorded in some LOGS pollen records at the MIS 3/2 transition (Vandergoes et al., 2005). However, if the inferences of mild cooling from other proxies are correct, most of the North Island and the northern half of the South Island below 600–700 m above sea level (asl) should have been forested (McGlone et al., 1993). Therefore a number of other environmental factors including altered CO_2 regimes, fire, drought, invasion of cold maritime polar air masses, and strong winds have been cited as possible causes for the lack of forest cover during the LOGS (McGlone and Bathgate, 1983; McGlone, 1985, 1988).

Given the problems with pollen-based reconstructions and the paucity of other quantitative proxies for climate in New Zealand, there is an obvious need to develop new proxies. This paper presents results of the first chironomid-based summer temperature reconstructions from lake deposits in New Zealand. The site reported comes from the banks of Lyndon Stream in the high country of Canterbury, on the eastern side of South Island of New Zealand (Fig. 1) and lies in the middle (~26,500–24,500 cal yr BP) of the LOGS. Studies elsewhere in the world have validated the ability for chironomid-based transfer functions to predict air temperatures (Walker et al., 1991; Olander et al., 1997). The locality was chosen because there are existing qualitative temperature estimates based on macrofossils (Soons and Burrows, 1978) and quantitative temperature estimates from beetles (Marra et al., 2006) for this site. Here, we provide temperature estimates for the complete section of lake silts preserved at this site. The results from this study serve not only to provide a more complete picture of climate conditions in New Zealand during the LOGS at this locality, but also enable comparison of the chironomid-based temperature estimates with independent proxies.

2. Site description

2.1. Physiography and site context

Lyndon Stream is located in the Acheron Valley, in the eastern foothills of the Southern Alps, South Island, New Zealand (Fig. 1). The study site is at an altitude of 700 m asl. Locally, the eastern foothills reach elevations of up to 2300 m and are composed largely of moderately indurated Triassic–Jurassic metasediments belonging to the Torlesse Supergroup (Bradshaw, 1972). The local geomorphology has been profoundly influenced by a series of Late Pleistocene glacial advances (Soons, 1963; Suggate, 1990).

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