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Analysing Mid-Holocene climate in the NZ region from PMIP2 data

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Abstract
The Paleoclimate Modeling Intercomparison Project (PMIP) was undertaken to represent past climates as a test for state of the art climate models and to understand the physical atmospheric processes of those climates. The work undertaken here focuses on the mid-Holocene simulations of 6000 years before present where the orbital parameters of the Earth were different from today. This work shows the analysis of some of the PMIP2 models in the Austro-New Zealand region to show how the climate there responded to the orbital changes (relative to today). The aim of doing this work is to help provide a background to running a nested Regional Climate Model (RCM) over the New Zealand region for the mid-Holocene in order to get high resolution model data and identify how the climate varied from today's. We also aim to compare the model output with proxy data for the same time period.

Developing a mass balance model to evaluate climate sensitivity and the effects of landslide debris on Franz Josef Glacier, South Island, New Zealand

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Abstract

The purpose of this project was to develop a simple two-dimensional steady-state mass balance model of Franz Josef Glacier to investigate climate sensitivity and also the effects of debris cover on glacial length. Initially this model required the collation of information on the profile, precipitation and temperature variations in the Franz Josef/Waiho Valley including a rain to snow conversion equation from Rother and Shulmeister (2006). Instead of incorporating an ice flow rule, a simple basal shear stress rule was calibrated to yield glacier surface slope.

The mass balance model was calibrated to place the glacier terminus in its current-day position – which it has occupied with little variation for the last decade. The model was applied to vegetation trimlines in the Waiho Valley attributed to the Little Ice Age (LIA) 1 and LIA 3 glacial advances. Model results demonstrate that the Franz Josef Glacier is highly sensitive to small changes in temperature. The glacier required minimum cooling of (1) 0.5 °C to reach the LIA 3 terminal moraines, and (2) 0.8 °C to reach the LIA 1 terminal moraines.

Tovar et al. (2008) recently reported that the Early Holocene Waiho Loop terminal moraine, 11 km beyond the present-day terminus, contains much rock avalanche debris. They suggested that the moraine was a product of a large rock avalanche deposit triggering an advance from near Canavans Knob to the Waiho Loop. This will be tested by reducing the ablation over varying lengths of the glacier to account for glacial surface debris. Anderson and Mackintosh (2006) estimated that 4.2 °C to 4.7 °C cooling is required to advance the glacier from its current position to the Waiho Loop. This is incompatible with the proxy data results for the 13-10 ka period. Either the glacier was well advanced of the modern position prior to the Waiho Loop advance (which is quite likely) or less than 4.2-4.7 °C cooling can drive the glacier to the position of the loop, with surface ablation reduced by landslide debris. The results from this model should help resolve this issue.

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AutoStage: a low-cost automated trainable classifier system for use in the pollen lab

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Abstract
Palaeovegetation reconstructions, by way of palynology, are a tool now widely employed in understanding past climates in both New Zealand, and around the world. However, pollen extraction and particularly analysis (slide reading) has traditionally been a very time-consuming process, and now the increasing need for high-resolution palaeoenvironmental records potentially requires vast numbers of samples be processed and analysed in order to generate these records. Here, we present an ongoing project aimed at the realisation of a low-cost, automatic trainable system for recognition and counting of pollen on standard glass microscope slides, known as AutoStage. This system is ultimately aimed at dramatically reducing the amount of hours the palynologist must spend on the microscope, and thus considerably increasing productivity in the pollen lab.

The system employs robotics, image processing and neural network technology to locate, photograph and classify pollen on a slide. It locates pollen grains on a microscope slide, captures images of them and then classifies them into types using comparison with a predetermined set of pollen types. To date, the performance of the system including pollen location and image capture has been assessed by comparing counts of classified pollen grains on microscope slides obtained automatically by AutoStage with counts obtained manually by experienced palynologists. This whole-of-system test resulted in similar inter-group proportions between the system and the palynologist. Variation between counts was less with AutoStage than the variation between human counts, thus confirming the systems's potential as a valuable tool within the pollen lab.

Present-day fluctuations of glaciers in the Southern Alps, New Zealand, and their climatic drivers

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Abstract
As in many glacierised parts of the world, glaciers in the Southern Alps have lost significant mass in recent decades. Much of this loss is due to ongoing dynamic changes to glaciers, including the formation of pro-glacial lakes, generally attributed to warming since the 1860s and particularly since the 1930s. However the cause of recent changes in mass, and in particular the advance of some of the more responsive glaciers such as Franz Josef Glacier/Ka Roimata o Hine Hukatere, has been variously attributed to temperature, precipitation, and/or atmospheric circulation changes. In order to better quantify these mass changes and understand the factors that drive them, an energy balance model, tuned to mass balance measurements on one glacier and verified against mass balance and snowline measurements on other glaciers, is used to link climatic changes to mass balance, and hence ice volume, changes over the mountain range.

The results indicate that, removing the dynamic response to earlier warming, the volume of the Southern Alps ice mass has changed significantly in the period 1972 to 2008, with a substantial volume loss (0.7 km^3 or ~3%) between 1972 and 1983, followed by an equal mass gain between 1983 and the present. The terminus position of the Franz Josef Glacier tracks with the total ice volume very closely, with a lag of 2-3 years. Sensitivity analyses indicate that ice volume is rather sensitive to temperature changes, with a 40% increase in precipitation required to offset a 1 ^{o}C warming. However modelling experiments where the temperature and precipitation are in turn held at their mean values indicate that the changes evident in recent decades cannot be attributed to either temperature or precipitation in isolation.

The recent mass gain of some New Zealand glaciers has occurred during an overall period of Earth warming, widely agreed to be due to anthropogenic influence, whereas the majority of 20th Century ice loss resulted from warming that predated this influence. Thus, New Zealand glaciers highlight the under-appreciated role of Southern Hemisphere decadal-scale climate variability.

Records of rapid Late Quaternary environmental change from Auckland maar lakes

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Abstract

High-resolution Late Quaternary paleoclimate archives are preserved in the sedimentary records contained in Auckland maar lakes. Their northern New Zealand location is ideal for the examination of the interplay between subtropical and polar forcings on regional climate. The presence of well-dated rhyolitic tephras, combined with radiocarbon ages, allows a reliable chronostratigraphy to be developed, with Hopua, Orakei, Onepoto, Pukaki and Pupuke maar lakes containing high-resolution, laminated sediment records with excellent chronological control for the period from ca 50 ka BP to the present day. Furthermore, two of the maar lakes contain records that extend beyond the last glacial cycle with the oldest dated to ca 250 ka. A range of proxies for environmental change have been measured from several of the maar crater records including: pollen and diatom paleoecology, environmental magnetism, sediment grain size, major oxide and trace element geochemistry, total organic carbon, nitrogen and sulphur, plus bulk organic matter stable isotopes. Pollen analysis has been carried out on Onepoto and Pukaki cores spanning the last ca. 120-140 ka in which marked vegetation changes reflect orbital forcing. However, the multi-proxy analyses of these records indicate the presence of marked and rapid changes in limnological conditions and environment that may be at least partially forced by climate.

Reduction of forest cover and expansion of grass and shrublands coeval with deposition of the Okaia tephra (ca 29 ka BP) is interpreted as the start of the Last Glacial Coldest Period (LGCP), after which cool, dry and windy conditions dominated, although our multi-proxy approach indicates that the situation is complex with warmer/wetter phases punctuating the LGCP. Warming commenced ca. 17.7 ka BP and is apparent in several proxies from the maar lake records, especially the expansion of podocarp forest at the expense of beech forest, shrub and grassland. However, the pollen record does not reflect the marked changes displayed in many of the other proxies during the Lat Glacial-Interglacial Transition. Furthermore, the Holocene pollen record from Pupuke maar lake indicates environmental stability and shows little change throughout the pre-human Holocene though a sustained phase of drier conditions is apparent in other proxies between ca 7.9 and 8.2 kyr BP. The multi-proxy approach used here allows us to reliably infer environmental changes in the maar lakes and their catchments, some of which display remarkable similarity to the nature and timing of events in late glacial records from the North Atlantic region. We are undertaking compound-specific $\delta^{13}C$ and δD analysis of lipid biomarkers extracted from the sediment organic matter, and $\delta^{18}O$ analysis of diatom silica, sponge spicules and organic matter cellulose to better understand the controls on the complex isotopic signals extracted from the lake sediment sequences and allow the reconstruction of more reliable paleotemperature and paleohydrological records.

Glacier fluctuations recorded in landforms: a glacial geomorphologic map of the central South Island, New Zealand, and its utility for paleoclimate research

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http://www.gns.cri.nz/who/staff/1641.html

Abstract
Glaciers leave distinctive imprints in a landscape. The outer limits of a glacier are commonly marked by a belt of moraines constructed from rock debris deposited at the glacier margins. In more stable parts of landscapes where landforms are easily preserved, morainal landforms may provide a rich and intricate record of past ice-margin limits. The size of a glacier reflects prevailing climatic conditions; atmospheric temperatures and amounts of precipitation determine the position of the annual snowline, and this in turn controls how far a glacier may extend down-valley. Glaciers respond rapidly to changes in snowline position and thus changes in glacier extents are sensitive indicators of climatic changes.

The only locations in the Southern Hemisphere mid-latitudes that have been occupied persistently by glaciers are New Zealand and Patagonia. We have compiled a 1:100,000-scale map of glacial geomorphology encompassing about 35,000 km^2 of the central South Island of New Zealand. This map shows modern glaciers as well differing types of glacier-related landforms (moraines, moraine ridges, outwash plains and terraces). The map also shows the natures of boundaries between the landforms and indicates the ages of the landforms. Other landforms on the map include alluvial fans, coastal terraces, river floodplains and terraces, beach ridges and landslides.

A very broad interpretation of landform ages is shown using colour. Factors such as the degrees of landform preservation, relative positions of landforms in the landscape and available radiometric dates have guided the grouping of landforms according to age. The map separates morainal landforms into five (calendar) age groups; Historic (< ~250 years), Holocene (< ~11,500 years), Late-Glacial (~11,500 to ~16,000 years), Late Otiran (~16,000 to ~45,000 years; including the Last Glacial Maximum – LGM) and Early Otiran and older (> ~45,000 years).

The map is based on the interpretation of aerial photographs and field inspection of landforms and associated deposits. It has been compiled in digital form using a Geographic Information System (GIS). In addition to the ability to generate printed maps, the GIS format allows access to the map data via the internet, or other electronic delivery means. The map provides a foundation for paleoclimate research, such as dating of moraines, estimation of paleosnowlines and paleobiologic investigations. The map information will provide a valuable input for numerical modelling of glaciers and climate.

Records of past climate changes obtained from glacier landforms, central South Island, New Zealand – an overview

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Abstract

New Zealand is an ideal location for evaluating the global significance of climate changes defined from Northern Hemisphere locations, such as the North Atlantic and its adjacent land masses. A multi-disciplinary research project examining the glacial history of New Zealand began in the late 1990s; its major goal is quantifying the chronology and magnitudes of New Zealand climate variations, as expressed by former glacier extents preserved in morainal landforms of the central South Island.

Early work focused on Last Glaciation moraines on the western side of the Southern Alps, where wet climates have favoured the preservation of ^{14}C-datable organic deposits within glacial and fluvio-glacial sediments; organic deposits are less common on the drier eastern side of the Southern Alps. As part of the work, we have compiled a regional glacial geomorphologic map, encompassing about 35,000 km^2 of the central South Island, including both sides of the Southern Alps. Major advances in the precision of ^{10}Be Surface-Exposure Dating (SED) of morainal landforms led to a shift in focus to the spectacularly preserved moraines on the eastern side of the Southern Alps, particularly in the Lake Ohau and Lake Pukaki basins, and their catchments near Mt Cook. SED results indicate great complexity of glacier fluctuations during the Last Glaciation, and throughout the Late-Glacial and Holocene. Systematic disparities between ^{14}C ages and ^{10}Be SED ages imply that ^{10}Be production-rates derived from Northern Hemisphere data are not applicable in New Zealand. To overcome this, we are establishing a local ^{14}C/^{10}Be calibration site that is showing promising results.

Moraines of cirque and small valley glaciers have been used, via glaciological parameters, to estimate the altitudes of former snowlines that existed at the time each moraine was formed. In conjunction with high-precision chronologies for moraines and paleobiologic stratigraphic studies (e.g. pollen, chironomids), we are developing a detailed quantitative picture of climate fluctuations over at least the past 40,000 years, revealed by New Zealand landforms and near-surface deposits. The results are looking set to provide robust ground-truth for the testing and modelling of hypotheses of global climate processes and dynamics.

Neoglacial activity on Mt Taranaki, New Zealand

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Abstract

Evidence of glaciation on New Zealand's North Island is limited compared with the wider New Zealand region, with a detailed late Quaternary glacial extent and chronology of the South Island emerging. While the North Island's central volcanoes such as Mt Ruapehu are thought to have been permanently glaciated during the late Quaternary, there is a lack of published direct evidence of glaciation. This is partly due to several cone-building and collapse episodes, with the slopes of the volcanoes forming an apron of coalesced fans of laharic, pyroclastic and alluvial volcanoclastics, some of which have been mistaken for glacial moraines in the past. Knowledge of neoglacial activity on the North Island is absent, though ^{14}C dates from the central Southern Alps indicate several periods of ice expansion during the latter half of the Holocene (Gellatly *et al.*, 1985). Mt Taranaki, at 2518 m high, is the highest andesitic stratovolcano in New Zealand and the second highest mountain on the North Island. Volcanic activity probably began around 130,000 yrs BP, with the most recent volcanic activity around A.D. 1755. The upper section of Mt Taranaki has formed over the last 10,000 yrs, and breaking the perfect form of the southern flank of the upper section of Mt Taranaki summit is the 1962 m high parasitic cone, Fanthams Peak, 1.5 km to the south. Between the main Mt Taranaki summit and Fanthams Peak is a south-facing basin, Rangitoto Flat, on which two linear ridges are formed. On the basis of their size, sedimentology, linear planform and topographic and spatial positioning, we interpret these unconsolidated ridge deposits as lateral moraines, formed along the margins of a small cirque glacier. As the final construction phase of Fanthams Peak commenced around 3,300 yrs BP, and the upper part of the Rangitoto Flat basin is partly in-filled by the Skeet Ridge lava flow from *c*. 1,300 yrs BP, this indicates the moraines formed during the 3,300-1,300 yrs BP interval. The elevation of the two ridges suggests an equilibrium line altitude (ELA) of 1900-1940 m calculated using the maximum elevation of lateral moraine (MELM) and cirque floor altitude (CF) methods. However, this elevation is likely to represent the lowest elevation of glacial activity, as the Skeet Ridge lava flow appears to have destroyed the upper 40-50% of the two ridges. At present, on the summit of Mt Taranaki, a small nevé field exists, indicating a present-day ELA of *c*. 2500 m. Based on temperature depression alone, using a simple environmental lapse rate of 6°C/1000 m, *c*. 2°C of cooling would have been required to initiate glaciation of the Rangitoto Flat area. This apparent high temperature depression suggests precipitation changes may also have contributed to neoglacial activity on Mt Taranaki.

Reference

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Changes in ocean circulation and water masses since the Last Glacial Maximum – the New Zealand record

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Abstract

New Zealand occupies a special place in the world ocean. It forms the gateway for the Pacific deep western boundary current (DWBC), it constricts the Antarctic Circumpolar Current (ACC) and it sits across the Subtropical Front (STF). Thus northern NZ is bathed by subtropical surface water and the southern reaches by subantarctic to circumpolar waters. Given that the NZ landmass contributes ~1% of sediment entering the world ocean, local sediment deposits yield detailed palaeoceanographic records of these major ocean features.

Holocene and Last Glacial Maximum (LGM) water mass structures have been identified from benthic stable isotope profiles determined for the shallow to deep ocean. Results suggest a persistent structure (from shallow to deep) of Antarctic Intermediate Water – Upper Circumpolar Deep Water/North Pacific Deep Water – Lower Circumpolar Deep Water, with no major change in the depths of water mass boundaries between the LGM and Holocene. Furthermore, there was no major change in the strength of the local DWBC that carries Circumpolar Deep Water into the Pacific.

The response of the surface ocean following the LGM varied with latitude depending upon the respective influences of the subtropical and subantarctic inflows. In the case of the Antarctic Cold Reversal (ACR; 14.2 – 12.5 ka), the seas off southern NZ cooled in phase. In contrast, cooling off northern NZ was delayed ~700 years after onset of the ACR reflecting an amelioration of its impact by the subtropical inflow. It was not until the ACR was coldest (~13.5 ka to 11.5 ka) that the northern ocean responded. It became less warm and fertile, and its surface structure changed as shown by the merging of three $\delta^{18}O$ planktic profiles. These conditions ended part way through the Younger Dryas (YD; 13-11.5 ka) when NZ climate warmed, out of phase with YD cooling.

Evidence for change in the ACC is limited. Sea surface temperatures suggest a northward migration of the Subantarctic and Polar frontal jets of the ACC. It is assumed that this displacement and resultant compression of the fronts against Campbell Plateau, together with stronger glacial winds, intensified the ACC. As a result, cold subantarctic waters jetted westward to NZ via Pukaki Saddle and northward of the STF via the eastern and western ends of Chatham Rise. Again, it is assumed that the ACC weakened during the last deglaciation as winds lessened and ACC fronts migrated to their present positions. However, the present warming and southward migration of westerly winds appear to have invigorated the ACC.

Landslide-triggered glacial advances and terminal moraines; paleoclimatic implications

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Abstract
We review published information on the formation of moraines as a result of large-scale landsliding onto glaciers causing non-climatic advances, using data from the Southern Alps and the Karakoram Himalaya. A simple analysis of the effect of reduced ablation due to debris-cover matches these data. We present evidence that the Waiho Loop terminal moraine of the Franz Josef glacier is composed predominantly of monolithologic (greywacke) landslide-derived debris; and our analysis indicates that a landslide of the volume of the Loop from the greywacke source zone in the Waiho valley could cause sufficiently extensive and thick debris cover to trigger an advance of the terminus from the vicinity of Canavan's Knob to the Loop position. This calls into question the use of this moraine for paleoclimatic inference; and sends a serious message about the importance of identifying landslide-derived terminal moraines.

Lead isotope evidence for dust transport from Australia to Antarctica. A call for coring in the Pacific sector of the Southern Ocean to determine the effects of aeolian dust on oceanic ecosystems through time

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Abstract
Systematic analysis of Pb, Sr and Nd isotopes of 32 fluvial clay samples (<2µm fraction) from many of the major tributaries of the vast (1.10^6 km^2) Murray Darling Basin (MDB) located in southeastern Australia displays similar isotopic values between some MDB clays and those of dust from several ice core samples from the EPICA Dome C in Antarctica. Close scrutiny of several ratios of the four Pb isotopes, and in particular $^{208}Pb/^{207}Pb$ versus $^{206}Pb/^{207}Pb$, shows that several samples from the Darling-sub-basin (that is today located in semi-arid Australia and also under the influence of sporadic summer rains) display similar values for the same isotopes for Dome C samples from different ages, and more particularly during wet phases in Australia [Marine Isotopic Stages 5e, 3 and 1]. The combination of Nd and Sr isotopic ratios from the same MDB fluvial clays clearly eliminates the Murray-sub-basin as a potential source of aeolian material to Antarctica. Overall, the Australian dust supply to Antarctica predominantly occurred during interglacial periods.
The work to be presented shows that aerosols generated in southeastern Australia can travel to parts of Antarctica and this is supported by atmospheric observations and models. In addition, evidence of Australian dust in Antarctic ice cores further implies dust deposition in the Southern Ocean would have occurred in the past. Current meteorological observations also imply that the east Antarctic sector of the Southern Ocean would frequently receive aeolian dust components originating from southeastern Australia.

This presentation will suggest locations where to take deep-sea cores that would be located below the path of dust plumes in the Pacific sector of the Southern Ocean to help determine the effects of aeolian dust on oceanic ecosystems through time.

Decadal to centennial-scale climate variability associated with coastal processes around the Southwest Pacific Ocean

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Abstract

Coastal processes, particularly those associated with coastal inundation and erosion/accretion, vary in magnitude and annual frequency at decadal and centennial time-scales. At shorter time-scales, the role of the El Niño-Southern Oscillation (ENSO) in forcing coastal change is relatively well understood. It is now apparent that longer-term climatic oscillations and cycles also play an important role. The Pacific Decadal Oscillation (PDO) reinforces and attenuates ENSO impacts at decadal scales, affecting sea level, storm surges, and coastal storms. Coastal features, such as cheniers and shore-parallel beach ridges on sandy and coral coasts, provide a record of these longer-term variations. These indicate there are cycles present that operate at periods between those of the Bond Cycle and the PDO. The behaviour and impact of various cycles are illustrated with examples from north-eastern New Zealand, Queensland and Pacific Islands.

Holocene ^{10}Be surface-exposure chronology of moraines deposited by the Cameron Glacier, Arrowsmith Range, Southern Alps, New Zealand

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Abstract
Most northern hemisphere glaciers achieved their maximum Holocene extent during the ‘classic Little Ice Age’ with advances culminating in the middle-to-late AD1800’s. Here we examine the New Zealand glacial record to see if the classic Little Ice Age signature is present in the south. This comparison allows a critical evaluation of proposed forcing mechanisms of Holocene climate. At least twelve glacier expansions produced moraines at progressively less extensive positions throughout the Holocene in the Cameron River Valley, New Zealand Southern Alps. More than forty ^{10}Be surface-exposure ages from these moraines constrain the history of Cameron Glacier activity during this time. Results show that the Cameron Glacier was most extensive in the early Holocene, corresponding to a snowline depression of ~300 m from the present value. The glacier snout subsequently migrated up-valley by the middle Holocene, corresponding to a snowline rise of ~150 m during that time. The last major readvance culminated by ~600 yrs ago, equivalent to a snowline lowering of ~150 m below present, and since then the Cameron Glacier snout withdrew 2 km up-valley to the present position. The historical Cameron Glacier ice margin documented in 1863 by Julius Haast was between the 600-yr moraine and the present glacier position. Thus, unlike the pattern documented in the north, the ‘classic Little Ice Age’ encompasses of withdrawn ice extent in New Zealand.

^{10}Be surface-exposure chronology of the Birch Hill moraines, Pukaki Region, Southern Alps, New Zealand

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Abstract

The Birch Hill moraine is a conspicuous feature at the margins of the Tasman valley, on the eastern side of the Southern Alps in the central South Island of New Zealand. The Birch Hill morainal landforms include a succession of ice-contact lateral moraine ridges. Collectively, they represent a major episode of moraine formation by the Pukaki Glacier well up-valley from its Last Glacial Maximum moraines. The Birch Hill moraine has not previously been dated directly. Whether it may correlate with the Younger Dryas cooling episode known from the North Atlantic region ('YD'; ~12,900 – 11,500 yrs ago), or with the Antarctic Cold Reversal ('ACR'; ~14,500 – 13,000 yrs ago), or with neither, has been a matter of uncertainty and a source of debate. To address this problem, we obtained 22 ^{10}Be surface-exposure ages from boulders embedded in Birch Hill moraine ridge crests in the right-lateral sector of the moraine. Two samples collected from a small moraine remnant just outboard of the main moraine belt returned an age of approximately 14,200 years for this remnant. The remaining 20 samples, collected from a prominent ridge that is semi-continuous along the outer margin of the main moraine belt, as well as from inboard recessional ridges, all overlap at the 68% confidence interval, and afford an arithmetic mean age of 13,100 ± 300 years. The similarity and consistency of ages across the breadth of the main moraine belt implies that withdrawal from the outer ridge, and formation of inner ridges, occurred over no more than a few hundred years. The ages indicate that the Birch Hill moraines formed during the 'ACR'. Birch Hill moraine formation overlaps in time with glacier advances represented by buried organic deposits at Canavans Knob on the western side of the Southern Alps, and in association with the Puerto Bandera moraines of southern South America. The withdrawal of the Pukaki Glacier from the Birch Hill moraines is interpreted to reflect climatic warming; the ^{10}Be ages indicate that this occurred close in time to the end of the 'ACR', and prior to the onset of the 'YD' cold interval in the Northern Hemisphere.

^{10}Be Cosmogenic Exposure-Ages from Late Pleistocene Moraines near Mary Burn, Lake Pukaki, central South Island, New Zealand

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Abstract

Milankovitch Theory explains the basic link between variations in Earth's orbital parameters and the occurrence of ice ages. By this hypothesis, glaciers at different latitudes respond to different insolation signals, which are out of phase between the Northern and Southern Hemispheres because they are precession-dominated. However, existing moraine chronologies indicate that glaciers in the middle-latitude Southern Hemisphere may be in-sync with those in the Northern Hemisphere (Mercer, 1984). To provide a basis for understanding what drives glaciations in southern middle latitudes I developed a ^{10}Be exposure-age chronology for Last Glacial Maximum (LGM) moraines in the Pukaki Basin, New Zealand. Results show that the regional glacial maxima were achieved at ~35,000, 27,000, 25,000, 20,000, 19,000 and 18,200 years ago. Moraines distal to the LGM sequence yield an age range of 60,300 ± 1,400 to 69,300 ± 1,600 years ago. The precision of these exposure ages allows for detailed comparisons with climate records from Northern Hemisphere and Southern Hemisphere middle latitudes as well as with insolation curves. The maxima occur during both local summer intensity insolation maxima and minima, suggesting that insolation is not the most important factor controlling glacier mass balance, at least during times of maximum glaciation.

Timing and duration of the Last Glacial Maximum inferred from a ^{10}Be surface-exposure chronology of the Lake Pukaki moraine complex, Mackenzie District, Southern Alps, New Zealand

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Abstract

During the last glacial maximum (LGM), over fifty individual moraine crests were deposited by a glacier occupying the Lake Pukaki basin, located east of the Main Divide, central Southern Alps, New Zealand. More than 100 ^{10}Be surface-exposure ages determined from boulders embedded in the terminal and left-lateral moraines demonstrate that the LGM was achieved during Marine Isotope Stage (MIS) 3, and that the Pukaki Glacier maintained its maximum extent for several thousands of years before retreating at the onset of Termination I. These results complement and augment the ^{10}Be chronology developed from moraines of the nearby Ohau Basin (see companion poster). Comparison to other Southern Hemisphere glacial, marine, and ice core data shows that the LGM climate pattern was hemispheric in nature. Together, this suite of records indicates a long Southern Hemisphere LGM in which cold temperatures were maintained over the course of a full precession cycle. Thus the chronology presented here implies that local insolation intensity cannot sufficiently account for the whole of the New Zealand ice age pattern.

Late-glacial re-advance during the Last Glacial-Interglacial Transition; revisiting the Misery moraines in the Southern Alps of New Zealand

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Abstract
Locating evidence for or against a glacial readvance commensurate with Northern Hemisphere YD-time (~11-13 ka) in Southern Hemisphere glacial systems is a key aspect in addressing millennial-scale hemispheric climate linkages during the late Quaternary. Paleo-environmental evidence from New Zealand pollen records suggest a minor cooling or hiatus in warming during the period from ~14.5 – 12.0 ka that pre-dates the onset but overlaps with the YD chron, and is more commonly associated with the Antarctic Cold Reversal (ACR). Evidence for a glacial re-advance during the YD chron has been proposed previously (Waiho Loop moraine, Denton and Hendy, 1994) and more recently based on a limited exposure age sample set (n=4, 11.7 ± 0.3 ka) from the Misery moraine sequence at Arthur's Pass (~950 masl), Southern Alps, NZ (Ivy-Ochs et al 1999). The full group of moraines comprises a set of discontinuous latero-terminal moraines and elevated kame terraces (McGrath moraines) positioned on the eastern flanks of the Pass up to 3 kilometres down valley from the proximal Misery moraines within the Otira Gorge. However, a recalculation of the original data set (Ivy-Ochs et al 1999), based on revised 10-Be production rates, updated production rate scaling schemes and a remeasure of horizon site shielding, shifts the mean age from 11.7 ± 0.3 ka to 14.0-14.5 ka – a result more in line with other deglaciation ages (~14-16 ka) from proximal and cirque moraine sequences in NZ, Tasmania and southern South America. To further investigate this issue, we have determined paired 10-Be and 26-Al exposure ages from 38 greywacke samples taken from all major moraines throughout the Arthur's Pass area and including repeat sampling from the Otira Gorge (Misery) moraine complex. The new exposure ages show that the Arthur's Pass moraine system represents a glacial chronology for the last deglaciation spanning a period of 18.8 ka (at distal sites) to 10.4 ka (at proximal sites) (maximum to minimum sample age) with mean moraine ages following in chrono-stratigraphic sequence with ice flow direction. Although our new age for the proximal Misery moraine complex does not revise the conclusion reached by Ivy Ochs et al (1999) (though it does challenge the validity of the measurement) our more comprehensive sampling regime and extensive data set provides a different interpretation. The timing of deglaciation at Arthur's Pass is similar to that observed at more distal down-valley terminal positions of the Rakaia and Rangitata Valleys and suggests that the scale of any late glacial readvance, as evidenced at the Misery moraine site, was insignificant in comparison to the magnitude of ice volume at the end of the LGM in New Zealand. Details regarding age interpretation, the importance of production-rate corrections necessary to provide a robust and reliable glacial chronology at the required sub-millennial resolution will be presented.

Southern Hemisphere millennial glaciations during the past 30 ka driven by Antarctic ice sheet variability

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Abstract

Recent exposure dating of last-glacial cycle deposits in Tasmania, New Zealand and Patagonia reveal a temporal and spatial variability of glacial advances different to that apparent in the Northern Hemisphere. Interhemispheric correlation of millennial-scale glaciations is presently the centre of much debate (e.g., Younger Dryas (YD) versus Antarctic Cold Reversal (ACR) cooling, timing of 'global' Last Glacial Maximum (LGM), relative strength of MIS-2 to MIS-6 glaciations). However, the role of Antarctica in Southern Hemisphere glaciations during the late Pleistocene is difficult to assess. Exposure ages from six alpine valley systems in Tasmania and three in New Zealand reveal similar trends: (1) MIS-3 (~30-40 ka) advances are of limited extent in Tasmania and less extensive than New Zealand MIS-2 advances; (2) peak glacial cold conditions ('LGM') occur between ~24-29 ka; (3) amelioration of LGM conditions and glacial retreat commenced ~19-22 ka; (4) deglaciation inferred from recessional moraine sequences continued to 14-15 ka; (5) there is little evidence for a major late glacial readvance younger than 14-15 ka with lower valley regions devoid of ice. This moraine chronology suggests that following a 'weak' MIS 3 cool phase, the Southern Hemisphere, or 'local' LGM, peaked and was followed by warming a few thousand years prior to that apparent in the Northern Hemisphere. These moraine ages from New Zealand and Tasmania for the LGM–LGIT (ca 30 to 11 ka) show a remarkable similarity to the glacial chronology emerging from Lagos Buenos Aires in Patagonia.

A near-complete record of glacial expansion phases over the last glacial cycle is preserved in the series of 10 glacial moraine benches (8 of which have been exposure dated) that flank the slopes of Mt Murchison above Lake Te Anau, Fiordland, New Zealand. The ages span from 15-80 ka with the highest bench dated to MIS 4 (ca 65-75 ka) and suggests that MIS 4 may have generated by far the largest glacial expansion of the last glacial cycle. Five other glacial advance phases are recorded as distinct benches with ages decreasing with altitude from LGM peak (27.2 ka, 830masl), recessional phases (24.4, 19.9, 20.7 and 17.2 ka) with the youngest terrace just above the lake (15.8 ka, 220 masl). This deglaciation chronology correlates well with $\delta^{18}O$ variability apparent in the ice core records from Byrd and Law Dome in Antarctica, each of which display most depleted $\delta^{18}O$ values from 30 to 20 ka, followed by general warming to 10 ka. Over this period, Byrd displays $\delta^{18}O$ inferred cooling at 29, 27 and 22 ka, with hiatuses in warming at 18.9, 17.8, 16.8 and 15.9 ka. The latter phases can be matched to the Te Anau exposure dated moraine benches with an ca 1-3 ka delay between the polar warming phases and response of the Fiordland glaciers. Hence, the general character of Antarctic climate variability as observed in $\delta^{18}O$ trends from the ice cores appear to be reflected in the Southern Hemisphere mid-latitude terrestrial deglaciation chronologies determined by cosmogenic exposure dating.

Surface exposure dating in the Holocene – precise ^{10}Be techniques for very young surfaces

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Abstract

Recent advances in sample preparation and in instrumental techniques have improved AMS sensitivity to the point that ^{10}Be concentrations can be determined with good accuracy in Holocene samples, even those young enough to be dated on the basis of historical records. We present the requisite geochemical and analytical techniques for dating samples with concentrations as low as one thousand ^{10}Be atoms/g quartz. Our new ^{10}Be data sets include the youngest samples ever dated by cosmogenic nuclide techniques and achieved a high reproducibility of ages, with very few outliers. These results indicate that disturbance caused by geomorphic processes such as inheritance, erosion and snow cover are much less important than previously thought in certain settings, and, in turn, that in some applications ^{10}Be surface exposure dating can rival radiocarbon dating in accuracy. We elaborate the scientific impacts of this geochronological progress with examples from well-preserved moraine sequences from both the Southern and the Northern Hemispheres focusing on the key climate question of the extent to which Holocene glacial advances were inter-hemispheric events.

Equilibrium Line Altitude Depression of Mountain Glaciers at the Last Glacial Maximum: Greenhouse Gas and Orbital Controls

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Abstract
Although Earth's orbital parameters are well established as drivers of ice sheets, the controls on mountain glaciers are far less certain, and theories range from the local to global scales. This study compares model generations with observations to analyze the relative contributions of orbital factors and greenhouse gases to the equilibrium line altitude (ELA) depression observed in mountain glaciers worldwide at the Last Glacial Maximum. We use a two-dimensional, asynchronous, coupled ice-flow and energy-balance model with an insolation component to conduct sensitivity tests. Earth's orbital configuration induces ELA change in our model on the order of 100 m with regional patterns following those of the anomalies in the intensity of summer insolation. In contrast, the observed changes in greenhouse gases induce a nearly uniform global ELA change on the order of 1000 m. Comparison of the observed changes in ELA with our model predictions suggests that greenhouse gases are the dominant driver of changes in glacier ELA on the basis of both magnitude and spatial distribution.

Seasonality and glacier mass balance: implications for palaeoclimate reconstructions of northern and southern hemispheres

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Abstract
Ocean – atmosphere heat exchange during glacial periods is significantly influenced by the extent of sea ice. Thus times of widespread sea ice expansion are associated with seasonally enhanced air temperature deviations, primarily evident in lowering of winter values. Glacial / interglacial transitions in maritime areas normally dependent on oceanic heat may therefore have been characterised by significant changes in climatic seasonality. Yet palaeoclimate inferences based on reconstructed glacier geometries rarely allow for this possibility, leading to discrepancies between glacier-based palaeoclimates and those predicted by General Circulation Models (GCMs) and by regional modelling of palaeoecological data. Since the ability of GCMs to predict future climate scenarios depends on their accurate calibration against former climates, it is important to discover whether accounting for seasonality-induced mass balance differences can resolve mismatches between these various palaeoclimate proxies. Focussing on climate transitions in the North-east Atlantic during the Lateglacial, we find that by allowing for increased (winter-dominated) temperature deviations, our predicted glacial climate is significantly drier than previous glacier-based interpretations, and consequently much more in line with climate scenarios predicted by GCMs. Whether these considerations are equally applicable to southern hemisphere palaeoclimate reconstructions, where sea ice expansion played a lesser role in suppressing ocean-atmosphere heat transfer, is uncertain, and remains the focus of future research.

New Zealand studies into rising and acidifying seas

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Abstract
Some of our foraminiferal research of late has been focussing on the following climate related questions:
1. What are the present and historic rates, and variability around NZ, of relative sea-level rise, and does the recorded accelerated rise parallel increases in greenhouse gases?
2. Is the greenhouse-gas-related acidification of the oceans starting to impact on shelled marine organisms in pH-sensitive environments, such as NZ's more pristine estuaries?

Modern sea level:
A study of the NZ record of sea-level rise in the last 500 yrs in tectonically stable regions (east Southland and NW Nelson) is well underway using salt marsh foraminifera to provide estimates of pre-tide-gauge sea levels. Aims include extending the NZ tide gauge record (post 1900), characterise sea-level variability, improving predictions of future sea-level change, and investigating a northern Hemisphere-based hypothesis that the present period of rapid rise coincides with increases in greenhouse gases. Work at Pounawea in the Catlins indicates sea level was rising slowly (0.3±0.3 mm yr^{-1}) before 1900, but during the 20^{th} century increased to 2.8±0.5 mm yr^{-1}. Age models have been constructed using ^{14}C, $^{206}Pb/^{207}Pb$, Pb/Sc, ^{137}Cs, charcoal and palynology. A similar story is emerging further south with studies at Waikawa Harbour (20^{th} century rate c. 3.5 mm yr^{-1}) and Mokomoko Inlet (4-5 cm in last 10-15 yrs; ~0.3+/-0.1mm yr^{-1}), and in NW Nelson at Whanganui Inlet.

Ocean acidification:
One way to assess future impacts of ocean acidification is to measure what dissolution, if any, the recorded increased acidification over the last 150 yrs has already caused in environments that are highly sensitive to pH changes. In most brackish NZ estuaries there is a zonation from calcareous benthic foraminiferal faunas in the lower parts, where salinity and pH are higher, to agglutinated faunas in the upper estuary, where salinity and pH decrease. Our research targets "pristine" estuaries that have had little or no impact from forest clearance and increased freshwater runoff to see if ocean acidification has caused an increase in dissolution. Areas currently being investigated are NW Nelson and east Southland with Great Barrier and Stewart Islands proposed for future study. At Whanganui Inlet, NW Nelson we do not have an adequate age model yet but preliminary results from a short core (50 cm) shows selective loss of some higher magnesium calcite benthic foraminifera (miliolids) and ostracods upcore that could be attributed to decreasing pH.

Post-glacial coupling of the Australasian monsoon and teleconnections to the North Atlantic: New insights from Indonesian speleothems

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Abstract

The Australasian monsoon system orchestrates rainfall variability and terrestrial productivity in the densely populated region of the tropical Indo-Pacific. A clear understanding of the dominant mechanisms governing its variability has been difficult to resolve, partly because we currently lack high-resolution proxy records of past monsoon behaviour, particularly for the southern tropics. Here we provide a radiometrically dated reconstruction of Australian-Indonesian summer monsoon (AISM) rainfall based on oxygen isotopes and trace element data in stalagmites from southern Indonesia. The multi-proxy records are tied to age-depth models constructed from 62 TIMS and MC-ICP-MS U-series ages, covering the period 0 to 12.6 ka B.P.

The record shows that the AISM was anti-phased with the East Asian summer monsoon (EASM) on orbital to millennial-centennial timescales over the past 12.6 ka. At the orbital-scale, local summer insolation was an important driver of opposing changes in AISM and EASM rainfall. However, a slight mismatch between the AISM and insolation from 9 to 11 ka B.P. is concurrent with the sharp rise in eustatic sea-level, which apparently increased the supply of northwesterly summer monsoon moisture to the Indonesian maritime continents.

At millennial-centennial timescales, the oxygen isotope and trace element records show that periods of weakened North Atlantic meridional overturning circulation and cooling, including the Younger Dryas cold stage, are in phase with sharp increases in AISM rainfall. The connection between the AISM and a cooler North Atlantic is probably due to enhanced outflow from the Asian winter monsoon and associated southward migration of the intertropical convergence zone. These interhemispheric connections were dominant until ~6.5 ka, when the El Niño-Southern Oscillation became the governing influence on AISM variability.

Glacial chronology from the McMurdo Sound Region, Antarctica: Implications for the history of the Ross Sea ice sheet

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Abstract

The behavior of the marine-based West Antarctic Ice Sheet (WAIS) in the Ross Embayment is important for understanding Antarctica's contribution to global sea-level changes, both past and future. Here, we review pertinent data from the McMurdo Sound region of southern Victoria Land that bear on last glacial maximum (LGM) ice extent and thickness, as well as on the timing of grounding-line recession.

During the LGM, the WAIS advanced across the sea floor, merged with expanded East Antarctic outlet glaciers, and terminated near the continental shelf edge, forming what is known as the Ross Sea ice sheet. However, in the McMurdo Sound region, East Antarctic outlet glaciers did not reach the sea. Instead, a widespread drift sheet with prominent moraines and diagnostic kenyte erratics indicates that a lobe of the Ross Sea ice sheet flowed across parts of Ross Island and westward into McMurdo Sound and the mouths of the Dry Valleys. The valleys themselves were occupied by large, ice-dammed lakes, the existence of which required the presence of grounded ice in McMurdo Sound. This ice reached 350-400 m elevation at the mouth of Taylor Valley and ~700 m elevation up flowline on Ross Island. We suggest that such ice elevations and flow patterns could not have existed in the absence of a larger grounded ice sheet in the Ross Embayment.

Calibrated radiocarbon dates from the LGM moraine on the headland near Taylor Valley indicate that this position was maintained between at least 15,000-17,700 cal yr B.P. Moreover, dates of high-elevation deltas and shorelines from the ice-dammed lakes, as well as the distribution of kenyte erratics, show that thick grounded ice with a flowline extending back across parts of Ross Island must have been present between at least 9370-28,500 cal yr B.P. Gradual ice-sheet thinning was initiated as early as about 15,000 cal yr B.P., with ice levels remaining near the maximum until after 12,800 cal yr B.P. Grounding-line retreat lagged thinning. Relative sea-level data, along with dates of marine organisms from the sea floor, show grounding-line recession along the northern Victoria Land coast at ~8000 cal yr B.P. with recession to the McMurdo Sound region by 7500 cal yr B.P.

History of the grounded ice sheet in the Ross Sea sector, Antarctica: New data from Scott and Reedy Glaciers

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Abstract

The behavior of the West Antarctic Ice Sheet (WAIS) remains an unresolved problem for predicting future sea-level change. In addressing this issue, the history of the ice sheet is an important guide to its stability and likely evolution. Here, we focus on the Ross Embayment, one of the areas of greatest ice-volume change during the last glacial maximum (LGM) and subsequent deglaciation. During the LGM, the WAIS advanced across the sea floor, merged with expanded East Antarctic outlet glaciers, and terminated near the continental shelf edge. The expanded WAIS buttressed outlet glaciers draining through the Transantarctic Mountains, causing significant changes in both ice surface elevations and profiles.

Our present work focuses on two East Antarctic outlet glaciers in the interior embayment. Reedy Glacier currently flows into the WAIS, whereas Scott Glacier enters the Ross Ice Shelf. At the LGM, both glaciers were substantially thicker than at present (450-800 m at Reedy, as much as 1000 m at Scott) near the coast, while remaining virtually unchanged at the East Antarctic ice plateau. At Reedy Glacier, ^{10}Be exposure ages of erratics indicate the LGM position occurred at ~14.3-17.3 ka in the Quartz Hills and was reached at progressively younger times up-glacier. We are awaiting ages for the LGM at Scott Glacier. However, dates of erratics perched on bedrock at Mt. Rigby, near the glacier mouth, indicate that the summit (~950 m elevation), which was overrun at the LGM, emerged at ~11.5 ka. Twenty-two exposure ages, none of which shows evidence of prior exposure, show that ice thinned throughout the Holocene. Moreover, the data obtained so far, from both glaciers, suggest that the thinning rate may have decreased over the past 2000-4000 years. If true, then it is possible that retreat may have slowed and the present WAIS grounding line may be approaching relative stability.

Antarctica has been suggested as a source for deglacial sea-level pulses, such as meltwater pulse 1A. Our data indicate that most of the thinning and nearly all of the grounding-line retreat in the Ross Sea sector occurred after meltwater pulse 1A. Thus, ice from the Ross Sea sector could not have contributed substantially to this event.

A southern hemisphere lead at the last two glacial terminations, indicated by montane speleothem records from New Zealand and Italy

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Abstract
Determination of precise lead/lag relationships between hemispheres at glacial terminations is of paramount importance in the understanding of the processes that trigger these abrupt climatic events, and has proved elusive for all but the latest event (Termination I). Stable isotope records from nine overlapping speleothems from Corchia Cave, Italy are collectively anchored by over five hundred U–Th, U–U and U–Pb radiometric age determinations and now give continuous coverage of the last 1.05 million years. $\delta^{18}O$ has been closely controlled by variation in North Atlantic sea surface temperature over this time, allowing nearby marine cores to be tuned onto an absolute radiometric timescale. In all cases $\delta^{13}C$ of these montane speleothems lags the SST-driven $\delta^{18}O$ deglacial signal and is confirmed as a reliable, lagging indicator of post-glacial warming. At Nettlebed Cave, New Zealand, a prominent post-glacial fall in $\delta^{13}C$ centred on 15.2 ± 0.4 ka has been previously interpreted as reflecting a soil and vegetation response to rapid regional warming, now supported by this site's close similarity to Corchia Cave. Whilst the $\delta^{13}C$–temperature lag at Nettlebed is presumed to be less than at Corchia due to better persistence of soil during glaciations, this is nonetheless a minimum age for the deglacial temperature signal. New data from Nettlebed place the deglacial $\delta^{13}C$ signal of Termination II at 135 ± 2 ka, pre-dating the corresponding Corchia (North Atlantic SST) $\delta^{18}O$ signal by ~3 ka. Taken together these leads argue against classical 65°N summer insolation forcing of global glaciations and require the consideration of alternative orbitally driven models.

Assessment of the integrity of the Southern Hemisphere ^{14}C calibration curve and its extension from AD 785 to 195 BC, with a new preliminary calendar age for the Taupo Tephra

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Abstract

Numerous studies show a measurable difference in $\Delta^{14}C$ in wood from trees growing in the same year in opposite hemispheres. Although this inter-hemispheric offset was assumed to be constant in time, duplicate high precision $\Delta^{14}C$ measurements on contemporaneous Southern Hemisphere (SH) and Northern Hemisphere (NH) sample pairs from AD 955-1845 demonstrate that it is variable, with SH wood 8-80 ^{14}C years older during this interval. The SH atmospheric ^{14}C calibration curve, SHCal04, consists of a measured phase (AD 955-1955) and a modelled phase (the remainder of the Holocene), with the latter based upon the NH curve, IntCal04, with an applied variable offset (based upon that observed from AD 955-1845) generated by a random effects model.

We present >100 high precision ^{14}C measurements on decadal samples of dendrochronologically-dated New Zealand kauri to extend the measured phase of SHCal04 and to test the integrity of the modelled phase between AD 785-195 BC. The inter-hemispheric offset is investigated in this interval with 15 high precision ^{14}C measurements on selected paired decadal samples of dendrochronologically-dated Irish oak (*Quercus petraea*). Five decadal samples (AD 955-995) overlap with the measured phase of SHCal04 for QA purposes. We also introduce a new method for assessing published SH Holocene data sets to determine their usefulness in estimating the offset for these earlier time periods. A new calendar age for the Taupo Tephra is established by wiggle-matching 25 decadal high precision samples from the Pureora *Phyllocladus trichomanoides* chronology.

Our kauri measurements are in very close agreement where they overlap with the measured phase of SHCal04 and with the modelled phase of SHCal04 from AD 785-195 BC and confirm the integrity of SHCal04 for this period. The kauri-oak decadal sample pairs indicate a continuance of the inter-hemispheric offset, which averages 27-58 years for the measured intervals. We show that many of the published SH Holocene data sets are too imprecise to detect an offset of this magnitude. We also present a new preliminary calendar age for the Taupo Tephra of AD 236 ± 4.

Variations in tree-ring ^{14}C for the Younger Dryas

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Abstract
Of all millennial-scale paleoclimate reversals during the Last Glacial Cycle, the Younger Dryas (YD), from ~13 to 11.6 cal kyr BP, has attracted the most attention and controversy. The debate centres on understanding the physical mechanisms for such an abrupt change in climate and radiocarbon, which are associated with small changes in solar output and/or major changes in earth-system interactions dealing with oceanic circulation and exchanges between the carbon reservoirs. The leads and lags between climatic proxy records of the YD event are at the heart of such research. Unfortunately, one of the problems is that there is no reliable, direct atmospheric ^{14}C record based on tree-ring chronology for the whole YD period, thus negating any possibility of locking in the critical time marker of its initiation.

Here we present new high-precision, high-resolution radiocarbon measurements for the early YD chronozone derived from 4 sub-fossil logs of Huon pine with clearly defined annual tree rings. These logs were excavated from alluvial sediments along Stanley River in north-western Tasmania, Australia. A floating 617-ring Huon pine chronology has been constructed based on ring width and AMS radiocarbon measurements. Our ^{14}C record, covering an age range from 10,350 to 10,760 ^{14}C years BP, has been linked to the European absolute tree-ring and floating Late Glacial Pine chronologies, bridging the current gap in the European tree-ring ^{14}C chronologies during the early YD. A continuous and reliable atmospheric ^{14}C record for the past 14 cal kyr BP is now available. This allows a more precise determination of the timing in observed climatic and environmental parameters and allows for a critical evaluation of mechanisms of atmospheric ^{14}C variations for the YD.

Re-evaluating the deglacial sequence in New Zealand – Part 1 - Processes of moraine formation

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Abstract
What do end moraines represent in New Zealand glacial systems? New work on New Zealand east coast glacial systems highlights the nature of moraine formation. At the modern Tasman glacier, the terminal moraine system is associated with an outwash fan head. At the modern terminus the terminal moraine formed only after an extended period of ice thinning with a stable terminal margin. The moraine is preserved when the outlet stream(s) incise into permanent channel(s). The lateral moraines in this system have remained *in situ* during the ice thinning and have become volumetrically enlarged as a result. Both morphologies are indicative, not of a major ice re-advance, but of a prolonged stasis during a period of ice loss. Maximum ice volume occurs prior to terminus retreat and moraine preservation and there can be a considerable time lag between these events. By comparing the Tasman terminus with Pleistocene moraines from the Rakaia and Ashburton Lakes areas, we argue that most Pleistocene ice margins on the eastern side of New Zealand reflect this situation. The climatic significance of ages from such features need to be carefully considered.

Glacial Geomorphology and its links to Ice Sheet thicknesses, Diamond Hill, Transantarctic Mountains

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Abstract
An understanding of how the Antarctic continent has reacted to past climates is necessary to accurately predict the response of its ice sheets to current and future climate changes. The thickness and proximity of the peripheral ice to the continental margin are key to the discussion and relate directly to the volume of ice within the East and West Antarctica ice sheets and their melt water contribution to sea level rise since the LGM.

The Darwin / Hatherton is a outlet glacial system that drains the East Antarctic Ice Sheet into the Ross Sea through the Transantarctic Mountains. At the confluence of the Darwin Glacier and Ross Ice Shelf, Diamond Hill a relatively ice free area, contains evidence of glacial advances at altitudes up to 1000 m above the current ice surface.

Here both ice sheets have created landforms that will allow a reconstruction of ice thickness. Cosmogenic dating will be used to create a timeline of post-LGM glacial retreat in which the influence of cold based ice must also be evaluated.

This work will contribute fundamental data to an important international debate on the scale of the glaciation in the last ice age. It will help validate ice thickness reconstructions for the ice sheets and it may give insight into the timing and nature of Antarctic contributions to global sea-levels.

^{10}Be surface-exposure chronology of Lateglacial moraines in the Ben Ohau Range, South Island, New Zealand

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Abstract

Whether climatic variations during the transition from the last glacial to the Holocene interglacial were of world-wide extent is of great importance to understanding climatic processes and dynamics, but is subject to ongoing debate. Several valleys within the Ben Ohau Range, which separates lakes Pukaki and Ohau in the central South Island, contain well-preserved sequences of moraines. Previous mapping and relative-age dating using methods such as lichenometry and rock weathering rinds (e.g. Birkeland 1982) identified several sets of moraines, the farthest down-valley of which was inferred to be Lateglacial (Birch Hill) while mid- to late Holocene ages were inferred for moraines closer to the heads of the catchments.

To gain a better knowledge of Lateglacial glacier activity in the Southern Hemisphere, we mapped and dated the landforms in the valley of Irishman Stream, Ben Ohau Range, utilizing recent developments in the ^{10}Be dating method, and calculated paleo-snowlines for key moraines. The glacial landforms lie between 1800 and 2060 m altitude. The valley is steep, relatively broad, and the major stream flows within a narrow single-thread channel; the moraines show minimal modification due to fluvial erosion or sedimentation. Valley steepness has precluded the formation of glacier-retreat lakes, thus the Ben Ohau glaciers in general have been free of the dynamic effects of floating or calving ice that characterize some larger, low-gradient valley glaciers.

Twenty nine ^{10}Be exposure ages of boulders from the crest tops range from 13,700 ± 330 to 11,100 ± 270 yr; these Lateglacial ages cluster at three time periods, 13.0 ± 0.4, 12.1 ± 0.3, and 11.5 ± 0.3 (average ± 1σ). The outermost moraine corresponds to a paleo-snowline of ~1900 m, ~ 260 m lower than the estimated late-20th century snowline at this location. Moraines previously assigned middle to late Holocene ages were deposited actually during Lateglacial time. Our findings add to the growing detailed picture of Lateglacial climate variations recorded in New Zealand moraines. The data indicate that a glacial event occurred before the Northern Hemisphere Younger Dryas chron and is of a similar timing to the Antarctic Cold Reversal, as these terms are defined in the literature.

^{10}Be surface-exposure chronology of moraines deposited in upper Whale Stream, Ben Ohau Range, South Island, New Zealand

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Abstract

A lack of quantitative chronologic data, even where paleoclimate records do exist, limits knowledge of climate variability and the forcing mechanisms in the Southern Hemisphere during the Holocene. In the Northern Hemisphere, most glaciers reached their maximum Holocene extent during the European Little Ice Age (LIA). Furthermore, the expanded LIA glacial position was at the end of the Neoglacial period, which followed a warm early Holocene interval. Here we investigate the glacial record in the New Zealand Southern Alps to determine whether northern Neoglacial and LIA signatures are evident in the Southern middle latitudes. Previous mapping and relative-age dating using methods such as lichenometry and rock weathering rinds (e.g. Birkeland 1982) identified several sets of well-preserved moraines, which were inferred to be Lateglacial and mid- to late Holocene in age. Using recent analytic advances, we employ ^{10}Be measurements on the moraines to obtain numerical ages.

Glacier expansions produced moraines at progressively less extensive positions since the end of the last glacial maximum in the Whale Stream basin, Ben Ohau Range. Prominent moraine loops at ~1200-1400 m altitude provide ^{10}Be exposure ages ranging from 15.6±0.4 to 11.4±0.3 ka; lateglacial moraines in the upper basin correspond to a paleo-snowline of ~1750 m, ~350 m lower than late-20th century snowline. Closer to the head of the catchment, a succession of at least five moraines (1600-1900 m) ranges in age from ~11 ka (outer) to <2000 yrs (inner). The three outermost are early Holocene and the innermost moraines are late Holocene in age. They correspond to paleo-snowlines ranging from ~300 to ~150 m lower than present. The new data add to the growing detailed picture of Lateglacial to Holocene climate variations recorded in New Zealand moraines. The overall pattern of glacial activity during the Holocene differs markedly between the hemispheres. In the south, the early Holocene was a period of relatively expanded glacier margins. In comparison, during the time of the European LIA, Ben Ohau glaciers were withdrawn relative to their early Holocene limits. Interestingly, the pattern broadly mirrors changing summer insolation intensity at this latitude.

A mid-to-late Holocene regional climate regime reconstruction for New Zealand

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Abstract

Assimilation of the diverse array of environmental proxy archives in New Zealand that cover all or part of the Holocene is attempted here using regional climate regime classification (RCRC). This technique attempts to exploit contrasting or in-phase precipitation signals located on opposite sides of the country's main axial ranges in order to reconstruct past regional-scale atmospheric circulation anomalies. RCRC ascribes an overall precipitation anomaly for six regional climate districts across New Zealand based on available proxy evidence during discrete time slices. A comparison of the palaeo-precipitation signals for the six major New Zealand regional climate districts with modern national-scale climate regime reference patterns permits identification of past climate regimes, and also an interpretation of circulation anomalies that arose as a result of increased synoptic type frequencies in the past. The New Zealand palaeoclimate regime interpretations that are based on the palaeo-precipitation archives are corroborated using palaeo-temperature proxy records. All of the available terrestrial proxy archives in New Zealand have susceptibility to 'distortion' by geophysical, analytical, and/or anthropogenic impacts. Primary distortion effects for many of the Holocene records relate to archive resolution, sampling schemes and dating methods employed, and during much of last 1000 years are due to the impact of human activities on the landscape. We therefore provide an objective weighting toward the palaeoclimate archives with the least susceptibility to distortion for this reconstruction. This creates two uneven divisions for the mid-to-late Holocene; Present - 1000 ybp (based primarily on tree rings, speleothems, & glacial deposits), and 1000ybp – 8000 ybp (based primarily on speleothems, lacustrine records, glacial deposits, and pollen). Examples of Zonal, Blocking, and Trough climate regimes, as well as hybrid circulation types are observed in this study. Multi-centennial to millennial-scale circulation regimes revealed here indicates that zonal and meridional circulation anomalies during the Holocene have significantly influenced New Zealand's regional-scale climate patterns. Additional data from key New Zealand climate districts that are sensitive to westerly circulation changes will help to improve the resolution of this reconstruction.

Advances on the construction, palaeoenviromental associations, and palaeoclimatic significance of ancient kauri (*Agathis australis*) tree ring chronologies, Northland, New Zealand

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Abstract

To date, nine ancient kauri tree ring chronologies (some multi-millennial length) with varying replication have been developed from northern New Zealand. They are discontinuously scattered across OIS3 and earlier, collectively covering ~15,000 years of the pre-LGM. These archives have potential to be used for investigating past Southern Hemisphere mid-latitude climate variability during a time when notable millennial scale oscillations and abrupt changes occurred. Historically though, there have been few palaeoenvironmental details or metadata associated with excavated bog kauri samples (eg. *in situ* prone tree bole orientations, spatial distribution of sub-fossil kauri). These limitations mean ascribing ancient kauri ring width variations solely to climatic forcing factors is problematic. Palaeoenvironmental, dendrochronology, tephrostratigraphy, and radiocarbon data have been assembled from three sites on the east coast of Northland (Omaha, Mangawhai, and Ruakaka) to assist in understanding the environments in which ancient kauri grew, and therefore what conditions might have influenced the ring width and biogeochemistry tree ring archives in the trees. The sub-fossil kauri extracted from these sites is associated with relict penultimate interglacial coastal barrier systems that established when sea level was higher. Subsequently these barrier systems prograded, and superposed bogs developed on them prior to and during OIS3. It is likely that modification of the underlying dunes and superposed bogs by aeolian activity, sub-aerial weathering, and/or geophysical activity through time may have occurred. Dune swale bog deposits viewed along strike in excavations at Ruakaka show peat development was enhanced by antecedent topography and geomorphic controls. Multiple layers of chaotically orientated woody debris indicate disturbance also played a contributing role in organic accumulation at ancient kauri sites. *In situ* sub-fossil kauri root plates indicate some trees grew directly on peat, and freshly exposed relict dune surfaces show kauri peg root wood fibres penetrating the old dune surfaces. In this situation, it is probable that kauri were still susceptible to aperiodic windthrow, particularly when the underlying substrates were saturated. Alignment of the OIS3 kauri chronologies to proxy data suggests a tenable link between chronology replication and past periods of mild climate. Peat sections recently collected from these sites may be able to provide complementary information about the bogs that would valuably contribute to a better understanding of ancient kauri tree ring records.

Introducing SUPRAnet and some implications for age modelling in the Australasian INTIMATE project

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Abstract
Australasian INTIMATE II should be interesting. A provisional climate event stratigraphy developed for the New Zealand region, but not yet published, is to be examined closely and revised in the coming months. Assuming that we are interested in understanding the timing and rate of past climate change events as well as the nature of the changes themselves, attempting to reconstruct palaeoclimates without concomitantly developing a robust chronology is pointless. High-precision chronologies, and hence reliable age estimates, enable palaeoenvironmental signals or events at different sites to be compared using a common time scale so that synchronous past changes, or leads or lags, can be evaluated at local, regional, or global extents (1). By 'age estimate' here we mean not just a single number representing the best currently available assessment of the date on which a particular layer was deposited, but an associated (and equally reliable) assessment of the nature and quantity of the uncertainty on that assessment. As will be illustrated in the talk, such uncertainty assessments are critical to our ability to interpret and reliably use age estimates. SUPRAnet, "Studying uncertainty in palaeoclimate reconstruction – a network", is an innovative international collaborative research project led by Caitlin Buck and sponsored mainly by the Leverhulme Trust (UK) (http://caitlin-buck.staff.shef.ac.uk/SUPRAnet/). The first meeting in Sheffield in June, 2008, with 48 participants, involved a range of short summary presentations by groups of people who effectively inhabit different worlds and in many cases would never cross paths: climate modellers, Bayesian statisticians, geochronologists, and palaeoenvironmental 'reconstructionists' (experts in various proxies). These presentations were followed by quite taxing discussions. Two papers are in preparation as a result, one on quantifying and modelling uncertainty in understanding past climates and the other on improving chronologies for palaeoenvironmental reconstructions by recognising and reducing uncertainties. Bayesian statistical modelling offers a formal framework in which to represent uncertainty across a range of types of dating evidence, take account of stratigraphic superposition (and thus relate depth to age), and consider possible outliers in a systematic fashion. It also offers opportunity to construct millions of plausible reconstructions of chronologies for palaeoenviromental records through which uncertainties both within and between archives can be quantified. This paper presents case studies relevant to SUPRAnet with important implications for INTIMATE II, including dating the Waiho Loop moraine, dating the late-glacial reversal recorded at Kaipo bog, and refining and testing age models for key marker tephras. (1) Parnell, A.C. et al. 2008. *Quaternary Science Reviews* 27, 1872-1885.

Defining and dating the base of the Holocene for Australasia at Lake Maratoto (New Zealand), an auxiliary stratotype for the Holocene Global Stratotype Section and Point (GSSP)

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Abstract
Holocene (meaning 'entirely recent') is the most recent interval of Earth history, and includes the present day. Alternative terms 'Recent' and 'Post-glacial' have no formal status. Even though the Holocene has been recognised as a stratigraphic unit of series status since 1885, a proposal for the definition of its base (the Pleistocene-Holocene boundary) was not formally ratified until May 2008 by IUGS. The Holocene GSSP is located at 1492.45 m depth within the NorthGRIP ice core, reflecting the first signs of warming at the end of the YD/Greenland Stadial 1 cold phase and dated at 11,700 ± 99 cal. yr before AD 2000 (~2σ) (1). Five auxiliary stratotypes have been recognised including one for Australasia at Lake Maratoto (LM). LM near Hamilton is one of >30 small riverine lakes in the Waikato lowlands formed c. 20 cal. ka by aggradation of the ancestral Waikato River. It preserves a continuous sedimentary sequence since the LGM (or soon thereafter) from which detailed pollen and tephrochronological records have been obtained, as well as chironomid, Cladocera, sedimentary pigments, geochemical and stable isotope ($\delta^{13}C$) data. An extensive stratigraphic survey, including 33 lake cores and use of ground radar, and 34 ^{14}C dates, enabled the development of the lake and adjacent bog to be reconstructed (2). The base of the Holocene can be pinpointed using tephrostratigraphy with palynostratigraphy. Full Holocene warmth, as reflected in the pollen sequence, is attained at close to the time of deposition of the Egmont-derived andesitic Konini Tephra (KT), dated at 11,720 ± 220 cal. yr BP (2σ) at Kaipo bog (LM sediment containing KT was dated at 11,305–12,049 cal. yr BP (2σ), calibrated from Wk-519, 10,100 ± 100 ^{14}C yr BP). KT, known originally as tephra Eg-11, has been correlated via its ferromagnesian mineralogical assemblage and by electron microprobe analysis of glass shards (3). In a 3-m long core from LM (known variously as core X79/1, MoA/1, and 4,1a), KT is preserved as a pale grey fine-ash layer 2-3 mm in thickness at a depth of 1.50 m below Taupo Tephra. Its stratigraphic position is constrained by two easily recognised tephras: a greyish-black coarse andesitic ash (Mangamate) lies above it at 1.40-1.45 m depth, and a white and cream, fine and medium-bedded rhyolitic ash (Waiohau) lies below it at 1.67-1.70 m depth. Attainment of full climatic warmth associated with the onset of the Holocene at around the time of deposition of KT has been reported from other North Island pollen sites. LM is located 3 km SW of Hamilton Airport and 1.5 km due west of SH 3. Although on private land, the lake is protected from any development in perpetuity by a covenant under the QE II National Trust Act of 1977. There is easy access by vehicle to the northern shore of the lake on a well-surfaced farm road.

(1) Green, JD, Lowe, DJ (1985). *NZ Journal of Geology & Geophysics* 28: 675–699.
(2) Walker, M et al. (2009). *Journal of Quaternary Science* 29: 3-17.
(3) Lowe, DJ (1988). *NZ Journal of Geology & Geophysics* 31: 125–165.

Climate-change driven slope failures in New Zealand

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Abstract

This research investigates the responses that New Zealand alpine slopes have had to the change from glacial to non-glacial climates and attempts to understand what drives these responses. One of the 'classic' landscape modifications recognised to be caused by climate change is the change from the steep sided 'U' shape valley to that of a 'V' shape valley. The gentling of the steep 'U' valley-wall profile is largely the result of slope failures. In alpine regions throughout the world there has been a recognised increase in the incidence of slope failures following deglaciation. These responses have not always been immediate, linear in nature, or spatially uniform. The response to deglaciation is complicated by tectonics, structure, lithology, and other geomorphic processes. There is uncertainty over the relative importance of each of these variables and there are problems with attributing slope failures entirely to deglaciation. The study proposed here takes a holistic approach by investigating: slope response patterns on a regional landscape scale, mechanics of individual slope failures, and the individual controls on slope stability. This approach will give an understanding of the relative importance of these mechanisms and allow the development of a model for landscape evolution. This in turn will allow a better understanding of the potential increases in (post-glacial) landslide hazards and downstream effects such as increased sediment production. This presentation provides an introduction and the methodology for this study.

Drivers of Southern Hemisphere climate variability: a view from modelling of New Zealand glaciers

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Abstract

We report on the use of glacier models for ranking of climate variables that cause glacier fluctuations, and for quantifying late Quaternary climate changes in New Zealand. Our models are tuned to match empirical mass balance measurements from glaciers of the Southern Alps, and are validated against an independent 30-year ‘end of summer snowline’ dataset. The validated models are used to calculate glacier ‘mass balance sensitivity’ and quantify past climate for late Quaternary glacier extents known from the Central South Island Glacial Geomorphology (CSIGG) project. Four different modelling studies show that glacier mass balance is more sensitive to temperature changes than precipitation variability. Incoming short wave radiation is an important term in the present-day energy balance of New Zealand glaciers, but local insolation values in New Zealand have not varied enough to cause large glacier fluctuations (beyond a few kilometres) during the late Quaternary.

Model experiments indicate that mean annual temperatures during the last glacial maximum (~35-18 ka) and late glacial (~13 ka) in New Zealand were up to ~7ºC and ~4ºC colder than present, respectively (relative to a 30-year mean modern climatology). Concurrent precipitation increases of ~30% during these periods could lessen estimated temperature depression by ~1ºC but precipitation change alone cannot be used to explain the overall late Quaternary glacier fluctuations. Warming of 0.8-1.2 ºC was responsible for causing retreat of ~3 km at Franz Josef Glacier during the historic period, and small-scale readvances during this time resulted mostly from regional cooling and not precipitation increase. In future work we plan to assess 1) the potential influence of changes in NZ palaeoclimate seasonality on former glacier mass balance and 2) the relationship between Antarctic temperatures and southern mid-latitude glacier fluctuations.

In-phase or out-of-phase? The synchroniety of NZ Holocene river activity with global and regional climate based on meta-analysis of alluvial histories

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Abstract
One of the major questions in Holocene palaeoclimate research is whether climate change is synchronous or out-of-phase between the northern and southern hemispheres. Recent meta-data analysis of large ^{14}C datasets in northern hemisphere river systems has demonstrated the utility of fluvial sedimentary archives for reconstructing centennial scale hydro-climate change. Rapid river responses to hydro-climatic forcing overcome lags inherent in other climate proxies. This paper presents preliminary research which provides the first meta-data analysis on available ^{14}C ages from New Zealand Holocene fluvial sedimentary archives, producing a high resolution record of national-scale and regional Holocene river activity. This analysis of ~400 Holocene ^{14}C ages indicates that periods of increased river activity in the UK and NZ are generally out of phase. However the NZ curve combines distinct climate regions, known to have responded differently to Holocene climate change. Results show eastern North Island (NI) river activity is out-of-phase with that in western and southern South Island (SI) suggesting El Niño Southern Oscillation forcing. There are, however, a number of factors that complicate reconstructing the climate record from the NZ fluvial archive. Most notably in NI some river catchments are strongly influenced by volcanic activity, which is evident in increased river activity in north-western NI coinciding with the Taupo eruption ca.1800 cal BP. Furthermore, in both NI and SI earthquake triggered disturbance can also affect sediment delivery and fluvial sedimentation patterns. The challenge of future research within this area will be the unravelling of the climate signal from seismic and volcanic 'noise'.

Late Quaternary climate change in central Australia: mega-lake phases and the climate that drove them

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Abstract

The quest for freshwater in inland Australia became a preoccupation when Europeans first arrived. The explorer John Oxley devoted much of his career to searching for the *Inland Sea* and in 1844 Charles Sturt's expedition, with a view to sailing upon it, optimistically dragged a whaleboat deep into the arid interior! Although ultimately shown to be just a 'sea of sand', there is growing evidence that a large area of inland Australia was indeed home to extensive lakes and freshwater rivers. Our preliminary data from the Lake Eyre basin show that what is now salt-crusted Lake Frome had as much as 41km^3 of water at times between 90 and 50ka, 16km^3 during the mid to late Holocene (~5-2ka), and 12.5km^3 at least once within the medieval period. In 1974, the largest flood in ~150 years of European settlement provided just 0.5 km^3 to Frome. Indeed, at about the time humans first arrived, all these lakes including Mega-Eyre were periodically full and formed a near continuous body of fresh water some ~35,000km^2 in area, ~400 km^3 in volume and in the form of a vast 600km long crescent around the now-barren Flinders Ranges. When and why did so much water characterise what is presently such an arid part of the continent? What does it tell us of moisture conditions here in the cooler wetter periods when remnants of a remarkable megafauna roamed? In contrast, how wet was Australia when temperatures were relatively high, such as during the last interglacial maximum, mid Holocene and even as recently as medieval times? Did humans help to change the climate by altering the biota or did they struggle to adjust to conditions they had little chance of influencing? The Lake Eyre basin is now the most arid region on the world's driest inhabited continent, yet it provides a vast repository of evidence for truly major wet periods within the last full glacial cycle. It could well offer a credible bellwether of future change. The pressing issue for today, should global temperatures continue rise, is what does past evidence tell us will happen to climate in the temperate south compared with the tropical north on landmass where, due largely to aridity, more than 80% of the population presently live within 50 km of the coast.

Reconstructing late Quaternary climates and environments of subtropical eastern Australia: A high resolution, continuous, multi-proxy record

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Abstract

A continuous 40 cal kyr BP record of palaeoclimatic and palaeoenvironmental variability has been developed from multiple proxies in lake sediment from Tortoise Lagoon, North Stradbroke Island. A core sampling frequency of ca. 2 – 5 mm has provided a record of aeolian sedimentation with a high temporal resolution of ca. 10 – 40 years (average 22 years). In addition to aeolian sediment content, grain size, pollen and charcoal analyses were used to provide insight into past climatic and environmental variability in subtropical eastern Australia. Identification of the bioclimatic envelopes associated with pollen taxa present in the Tortoise Lagoon record has allowed quantification of past climate variables (viz. temperature and precipitation). Vegetation assemblages from Tortoise Lagoon correlate well with those from other sites in southeastern Australia e.g. Caledonia Fen, Victoria (Kershaw et al. 2007), Redhead Lagoon, New South Wales (Williams et al. 2006) and Barrington Tops, New South Wales (Sweller and Martin 2001) suggesting that the record reflects regional temperate conditions. The presence of *Nothofagus*, *Asteraceae tubilifloreae* and spineless *Asteraceae* indicate significantly cooler temperatures during the Last Glacial Maximum (LGM). The LGM appears to be an extended period of cool, dry climate, characterised by two peaks, which corresponds well with the record from nearby Native Companion Lagoon (McGowan et al. 2008; Petherick et al. 2008; Petherick et al. 2009), along with records from Chile (Denton et al. 1999), New Zealand (Suggate and Almond 2003; Alloway et al. 2007; Newnham et al. 2007) and Antarctica (Rothlisberger et al. 2002; EPICA 2006). Results indicate that climate reversals during the deglaciation saw the return to conditions of possible increased aridity. The Holocene is generally characterised by decreased aridity. A peak in ferns and rainforest suggests the presence of an early-Holocene climatic optimum. The presence of *Pinus* in the late Holocene signifies the arrival and occupation of the region by Europeans around 180 years ago.

Timing and duration of the Last Glacial Maximum inferred from a ^{10}Be surface-exposure chronology of the Lake Ohau terminal moraine complex, Southern Alps, New Zealand

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Abstract

Determining robust chronologies of glacier fluctuations in both hemispheres is fundamental to assessing the underlying causes of ice ages. Much work has focused on resolving the glacial history of the north, but fewer data are available in the south. Here we present 64 10Be surface-exposure ages determined from boulders embedded in Last Glacial Maximum (LGM) terminal moraines surrounding Lake Ohau, located east of the Main Divide of the central Southern Alps, New Zealand. Results show that the LGM in New Zealand was achieved as early as ~31,000 years ago and ended ~18,000 years ago, at which time the Ohau glacier retreated into the mountains and uncovered the present Lake Ohau basin. The general chronology of moraine-building determined from the Ohau moraine system has been replicated in the Pukaki basin, reflecting regionally consistent glacier activity during the last ice age (see companion posters). The timing of Mackenzie Basin moraine formation is consistent with nearby fossil pollen records, regional SST reconstructions, Antarctic ice-core isotopic and carbon dioxide signatures, and the radiocarbon-based chronology of LGM glacial advances in the Chilean Lake District. Together, these collective records point to a coherent pattern across a large tract of the southern hemisphere, showing little or no direct influence of insolation.

Rate of *in situ* ^{10}Be production over the last ~10,000 years at Macaulay valley, New Zealand

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Abstract

^{10}Be surface-exposure dating has revolutionized the field of Quaternary geomorphology, and affords a tool for directly measuring the ages of some types of climatically significant landforms. However, age calculations rely on knowing the rate at which ^{10}Be accumulates in a rock surface, known as the 'production rate'. Production rates vary significantly according to latitude and altitude, and estimates of production rates are determined empirically by measuring ^{10}Be concentrations from rock surfaces of independently constrained age (calibration sites). All ^{10}Be calibration sites are in the Northern Hemisphere, which reduces the certainty of ^{10}Be ages obtained in the Southern Hemisphere. Here we present a ^{10}Be production rate determined from a radiocarbon-dated early Holocene boulder field, interpreted as a debris-flow deposit, from the Macaulay valley, Southern Alps, New Zealand. Nine radiocarbon ages show tight consistency, and afford an age of ~9,700 calendar years for the Macaulay valley boulder field deposit. Seven ^{10}Be concentrations measured from the surfaces of boulders protruding from the deposit yield high internal consistency. The average production rate is 12-14% lower than the global calibration data set reported in the literature, but agrees well with a production-rate value obtained from radiocarbon-constrained moraine landforms in northeastern North America. We tested the New Zealand production rate by comparison between minimum-limiting radiocarbon ages and ^{10}Be data from LGM moraines near Lake Pukaki, ~40 km southwest of the Macaulay valley, and found close agreement. These results indicate that the commonly used global calibration ^{10}Be production rate underestimates ^{10}Be ages in New Zealand by as much as 14% for the last ~10,000 years and probably for at least the last ~20,000 years. This is likely to be true of other Southern Hemisphere locations, and perhaps farther afield, if the problem reflects deficiencies in the global calibration data set.

Holocene climate variability in arid Australia from speleothem and alluvial records

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Abstract
New high-resolution MC-ICPMS U/Th ages and C and O isotopic analyses from a fossil speleothem in the arid Australian interior provide evidence for increased effective moisture at ca. 11.5 ka and 8.0-5.2 ka, peak moisture at 7-6 ka, and the onset of modern arid conditions by ca. 5 ka. Mid-Holocene $\delta^{18}O$ and $\delta^{13}C$ time-series data exhibit marked (>+1‰) contemporaneous excursions over base-line values of -5.3‰ and -11.0‰, respectively, suggesting increased moisture variability between 7-6 ka. Optically stimulated luminescence and ^{14}C ages from alluvial fan deposits in the region indicate an increase in large flood recurrence interval after 5 ka, from ca. 7 kyr recurrence intervals between 29-5 ka to ca. 0.9 kyr recurrence intervals from 4 ka to present. We interpret the speleothem and alluvial records to record significant changes in rainfall frequency-magnitude distributions through the Holocene. The mid-Holocene 'wet period' is characterised by increased rainfall and wetting/drying episodes and an apparent absence of large magnitude floods, interpreted to indicate increased southward penetration of the Australian summer monsoon into the arid continental interior. This coincides with an interval of globally decreased ENSO intensity, suggesting ENSO weakening may have allowed other weather systems to exert a greater influence on precipitation regimes over the Australian continent. The onset of aridity and coeval increase in large flood frequency at ca. 4-5 ka is interpreted to indicate the re-establishment of an ENSO-like climate in the late Holocene. The origin of episodic late Holocene floods remains a focus of future research.

Paleotemperature reconstructions from Mount Field National Park, Tasmania

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Abstract
We applied a chironomid-based inference model (Rees et al. 2008) for reconstructing the mean temperature of the warmest quarter (Dec., Jan., and Feb.) to samples from two well-dated cores obtained from lakes in subalpine woodland in Mount Field National Park, Tasmania; Eagle Tarn (1040m asl) and Platypus Tarn (954m asl). Our temperature reconstructions are quite different from previous inferences drawn largely from pollen data. Pollen data (Markgraf et. al. 1986) have been interpreted as indicating low initial temperatures and a broad maximum in summer temperature from 11 500 to 8900 cal yr BP (10 000 – 6000 ^{14}C yr). Our results indicate that summer temperature reached modern temperatures by 15 000 cal yr BP and remained about 0.5 to 1.0 above modern until 13 000 cal yr BP when they began a persistent decline, with both sites reaching a minimum at about 9000 cal yr BP – a time of maximum temperatures according to the pollen data. Our temperature reconstructions are broadly consistent with the summer insolation curve for 40^{o} S latitude. Our results are similar to the foraminiferan-based SST reconstruction for core GC07 taken south of Tasmania (Sikes et al. 2009) in showing warm initial temperatures, but differ in lacking both a peak in temperature between about 12 500 and 11 000 cal yr BP and a sharp drop in temperature at 11 000 cal yr BP. There is no convincing evidence for either the Antarctic Cold Reversal or Younger Dryas in the temperature records, but the ACR is evident in the loss-on-ignition (organic content) records of both Eagle and Platypus Tarns.

Changing environments of the Coorong, South Australia: a more suitable baseline for management

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Abstract

The Coorong, a narrow lagoon complex, extends for over 100 km along the coast of South Australia. Formed following the mid-Holocene optimum, the Coorong is located between a Holocene barrier dune, the Younghusband Peninsula, and a calcrete cemented shoreline relict from the last interglacial marine highstand. Connection to the sea occurs via the Murray River mouth and freshwater inputs are from a series of minor tributaries and groundwater. The lagoon was separated from Lake Alexandrina by a series of five barrages constructed in the early part of the 20th Century, to reduce the intrusion of tidal marine water.

In 1985 the region was listed as a wetland of international significance under the Ramsar protocol. Since this time, with extended drought conditions and increased upstream water abstraction resulting in closure of the Murray mouth via siltation, the southern lagoon of the Coorong has become hypersaline, causing lower fish stocks and significant decreases in the number of migratory birds. Under the Ramsar Convention, there is a requirement for the State Government to maintain the ecological character of the Coorong. However, there is not a clear understanding of what the "natural condition" of the system is. This study looks to provide an understanding of the pre-European conditions within the Coorong to inform the management debate.

Ostracod faunal assemblages from 6 cores, which span the length of the Coorong system, have been established. The longest of the cores (27(2)) spans 6.8 m, and basal dates are consistent with the inferred mid-Holocene age of the system. The fauna therein inform on the contributions of marine and freshwater to the lagoon, energy levels of the environment and the dissolved oxygen levels and salinity of the water. Complimentary sedimentary, diatom assemblage and geochemical analyses of the material are have also been undertaken.

The ostracod faunal assemblages retrieved from the cores clearly show that:

- prior to European settlement, the Coorong was essentially an estuarine system with tidal input of marine water to the northern lagoon and periodically closed conditions in the southern lagoon,
- since European settlement, the southern lagoon has increased in salinity, becoming hypersaline (since ~1980 AD),
- absence of freshwater taxa in all but core 3 indicate that River Murray input was minimal, even prior to regulation.

The closure of the Murray mouth, causing decreased inflow of marine waters, appears to have created the greatest impact on the Coorong system. These results are in agreement with previously published ostracod (De Deckker, 1994, 1995) and diatom records (Gell and Haynes, 2005).

The effects of debris cover on glacier ablation: experiments and implications

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Abstract

Glacial systems are indicators of modern and past climates but not all changes in behaviour correlate directly with climatic fluctuations. In tectonically active areas, the mass balance of a glacier can be modified by the emplacement of rock avalanche debris onto its surface and the consequent effect on ablation rates, morphology and moraine formation. These effects are only partially understood. Most existing studies concentrate on the thickness of the debris mantle as the controlling factor on ablation rates and estimate ablation from conduction rates. These estimates result from field observations on individual glaciers with specific local conditions that are used to explain variations in the ablation rates. Here we present an experimental approach to the problem and directly measure the effect of debris cover of known physical properties on ice melt rates under controlled conditions. To examine the influence of debris on the ice-surface ablation rates we compare bare ice ablation rates with those under debris-cover thicknesses of 1, 5, 9 and 13 cm. We examine in particular the effects of diurnal temperature and radiation cycles in comparison with steady-state conditions. Heat transportation by rainfall percolation was considered as a source of advected heat. Ice surface lowering, temperature profiles and heat flux were recorded.

Initial results indicate that the strength of the diurnal cycle exerts a strong control on the rate of melting. In the absence of diurnal variability the primary role of debris cover is to delay the onset of melting; once melting is initiated it has no further effect. These findings suggest insights into the differences between areas with strong diurnal cycles (e.g. Bualtar Glacier in the Karakoram Himalaya) and those with low diurnal variability (e.g. Sherman Glacier in Alaska). The results of the ground-penetrating radar (GPR) studies of the (1991) Mt. Cook rock-avalanche deposit will be presented.

A methylsulphonate snow pit record controlled by Ross Sea Polynya size and productivity

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Abstract

The Ross Sea Polynya (RSP) accounts for half the annual primary production on the Antarctic continental shelf and is a major zone of sea-ice formation. As a result, variability in RSP conditions has implications for carbon dioxide uptake and bottom water formation.

We present snow pit chemistry data, which provide a quantitative proxy to reconstruct both the size of the RSP and the level of primary production. The methylsulphonate (MS) record from Mt Erebus Saddle is strongly correlated with polynya area (r^2 = 0.929, $p < 0.01$) and annual primary production (r^2 = 0.916, $p < 0.05$).

In addition, inter-annual variability observable in the MS record is linked to the presence of large icebergs B-15 and C-19, which calved from the Ross Ice Shelf in 2000 and 2002. The resultant sea-ice damming effect restricted the area of open water available for primary production.

We explore the potential of the 180 m deep Mt Erebus Saddle ice core to trace the variability of the Ross Sea polynya conditions beyond the observational record. In conjunction with other proxies, this could allow the identification of previous major iceberg-rafting events, as well as providing information on bottom water export and carbon dioxide uptake.

Detailed surface exposure age chronology for last glacial sequences in the Rangitata and Waimakariri Valleys, South Island, New Zealand

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Abstract

The response of mid-latitude Southern Hemisphere glaciers to Quaternary climate forcing has become a prime research focus in the debate on the dynamics of global climate teleconnections. Of key importance in this research is the investigation of the timings of late Quaternary mountain glacier fluctuations in New Zealand relating both to last glacial ice maxima and ice decay signals. To address these questions we collected 62 rock samples from glacial moraine sequences in two major valley systems of the central Southern Alps for surface exposure dating (SED). Here we present geomagnetically corrected ages derived from cosmogenic ^{10}Be isotope concentrations that provide absolute age control for glacial events in these valleys from 23.0 ka to 13.7 ka. Results show that recession from extended LGM positions commenced close to 22 ka followed by a slow ice retreat and ice margin stabilization at 19-18 ka. This sequence is similar to other New Zealand sites but commences several ka earlier than in the Northern Hemisphere. Our data also show that the largest of the LGM advances in the Waimakariri Valley extended much further than previously recognized and overran the so-called Avoca surface (previously OIS 8). Further slow ice retreat re-commenced at around 16.5 ka resulting in multiple closely spaced retreat positions over a ~10 km distance in both valleys that date to 14.5 - 16.0 ka (Blackwater III in Waimakariri; Spider Lake / Lake Emma in Rangitata). The youngest late glacial moraines date to 14.0 ka (Poulter, Waimakiriri) and 13.7 ka (Lake Clearwater, Rangitata). In summary our findings document that:

(1) the period 23.0 – 13.7 ka is characterized by a slow and gradual ice retreat interrupted by stabilization phases but no major ice re-advances

(2) very extensive valley glaciers of 30 – 50 km length survived in New Zealand until at least 14 ka

(3) as a consequence of (2), either an accelerated retreat rate or a short-lived ice collapse would necessarily have occurred after 13.7 ka in order to restrict ice limits to upper valley positions prior to the onset of the Holocene.

A preliminary 210 ka terrestrial palynomorph record from a marine sediment core, West Coast, South Island

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Abstract

Fossil pollen assemblages provide an important record of vegetation, and by inference environmental change, over time. Terrestrial sites containing long continuous pollen records are rare and are often difficult to date beyond the range of ^{14}C (~40 ka). Therefore we are extracting pollen from marine cores proximal to Okarito swamp, which yielded a detailed record of vegetation change over the last glacial cycle (Vandergoes et al., 2005).

Three cores collected by the *RV Tangaroa* (Tan 0513) from overbank deposits of the Hokitika and Cook submarine canyon systems have been dated by $\delta^{18}O$ stratigraphy. The resulting age models give a basal age of 70 ka for core TAN0513-47 with an average sedimentation rate of 2.84 cm/ky, 130 ka for TAN0513-27 (2.49 cm/ky) and 210 ka (1.58 cm/ky) for TAN0513-14 suggesting we can extend the paleo-vegetation for Westland by at least 60Ky.

Pollen analysis has focussed on; (a) comparing the terrestrial pollen assemblage from Okarito with the marine record from TAN0513-14 over the period of time they have in common to assess differences in environmental sensitivity due to differences in catchment area and transport history; (b) to examine in more detail the factors driving vegetation change at Southern Hemisphere mid-latitudes during the Late Quaternary including sea level, sea surface temperature, local insolation and atmospheric CO_2 concentrations.

In particular, a recently published Antarctic ice volume model suggests that marine isotope stage 5c and 7a were characterised by greatly enhanced ice sheet melting. The model is driven by high latitude Southern Hemisphere insolation and global ice volume. The significance of this proposed melting event on the New Zealand climate is presently unknown, as it is poorly represented in terrestrial pollen records.

Stable Carbon isotope constraints on CO_2 fluxes during the last glacial period: a case study

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Abstract
The Southern Ocean exerts strong control over global climate by varying carbon dioxide exchange between ocean and atmosphere, which determines the atmospheric mixing ratio of carbon dioxide [CO2]. The underlying mechanisms, relative timing and connections between climate events, oceanographic changes and [CO2] levels with their attendant radiative forcing must be studied to understand natural climate variability and possible future developments. Our work presents a record of stable carbon isotope ratios of CO2 (δ13CO2) archived in an ice core from Berkner Island, Antarctica. The data cover Antarctic Isotope Maximum 12, ~45 000 years ago, a time of Antarctic warming and elevated [CO2]. The record provides constraints on the role of the Southern Ocean and other carbon reservoirs in the observed [CO2] variations.

High-frequency fluctuations of Mueller, Tasman and Hooker Glacier, New Zealand's Southern Alps, during the last 7,000 years

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Abstract
Understanding the timings of inter-hemispheric climate changes during the Holocene, along with their causes, remains a major problem of climate science. The moraine sequences of New Zealand's Southern Alps hold unique potential for transformational progress in our understanding of Holocene climate variations, but reliable dating of the glacier events has remained challenging. Here we present a high-resolution ^{10}Be chronology of three large mountain glaciers, Mueller-, Hooker, and Tasman Glacier, over the last 7,000 years, including at least five events during the last millennium. The extents of the glacier advances decreased from the middle to late Holocene, in contrast with the Northern Hemisphere pattern. Several glacier advances occurred in New Zealand during classic northern warm periods. These findings point to the importance of regional driving and/or amplifying mechanisms. We suggest that atmospheric circulation changes in the southwest Pacific were one important factor in forcing high-frequency Holocene glacier fluctuations in New Zealand.

Precise ^{10}Be dating of glacier fluctuations in the Southern Alps, New Zealand, over the last 70,000 years

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Abstract
Mountain valley glaciers respond very rapidly to climate changes; climatic amelioration causes near-instantaneous retreat of glaciers from their terminal and lateral moraines. Each moraine thus pinpoints a climatic event; the ages of moraines provide sensitive climate event chronologies. World-wide, there has been long-standing difficulty in obtaining reliable ages for moraines. Recent advances in ^{10}Be surface exposure dating techniques are now affording high-resolution chronologies of glacier events with unprecedented internal consistency. We present a comprehensive chronology of glacier fluctuation events on the eastern side of the Southern Alps spanning the last 70,000 years. Our data show that in the Southern Alps: (i) the Marine-Isotope (MIS)-Stage 4 glaciers in New Zealand were slightly more extensive than the MIS-Stage 2 glaciers; (ii) that over a more than 15,000 year period including the latter half of MIS-Stage 3 and all of MIS-Stage 2, glaciers repeatedly fluctuated about an advanced full-glacial extent; (iii) that a rapid retreat (deglaciation) began about 18,400 years ago, approximately coincident with the global Termination 1; (iii) that the deglaciation was interrupted by prominent late glacial advance(s), the most recent of which ended about 13,000 years ago, approximately coincident with the end of the Antarctic Cold Reversal; (iv) that many glacier fluctuations occurred throughout the Holocene, with progressively decreasing extents, differing in important ways from the Northern Hemisphere patterns of Holocene glacier variability. These robust results provide a substantive quantitative basis for advancing our understanding of the driving mechanisms of regional, intra-hemispheric and global climate change.

Can pedogenic carbonate provide a paleotemperature record from ice-free areas of Antarctica?

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Abstract
Antarctic climate conditions have a significant influence on Southern Hemisphere and global climate. Long-term paleotemperature records have been obtained from ice cores, but, as yet, there are no proxy records from ice-free areas. This study investigates whether pedogenic (soil) carbonate can be used to develop a new terrestrial paleotemperature proxy for ice-free areas of Antarctica.

In temperate environments, pedogenic carbonate has been shown to form in isotopic equilibrium with soil CO_2. Temperature-dependent fractionation of carbon isotopes during the formation of pedogenic carbonate enables calculation of the temperature at which the carbonate formed. However, little is known about the mechanism of pedogenic carbonate formation in cold climates. The validity of the proxy relies on pedogenic carbonate forming in isotopic equilibrium with soil CO_2.

Soil CO_2 and pedogenic carbonate were sampled to test this assumption, and soil respiration rate was measured to assess biological influences on carbonate formation. This paper presents preliminary results of CO_2 surface fluxes and soil profile CO_2 concentrations. Soil CO_2 data show diurnal variability in CO_2 fluxes, profile concentrations and isotopic composition. $\delta^{13}C$ values vary with depth and proximity to surface water, and $\delta^{18}O$ values vary according to depth and surface age. Dating and isotopic analyses of pedogenic carbonate are to follow.

Re-evaluating the deglacial sequence in New Zealand – Part 2 - sudden ice collapse or gradual retreat?

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Abstract
New data on moraine formation and glacial valley chronology challenges the existing understanding of the nature of deglaciation in New Zealand. When the glaciers retreat from glacial maximum limits they drop behind their fan heads and this creates accommodation space. This almost invariably leads to the formation of a pro-glacial lake system during retreat. Where the glacier trough is well developed deep lakes are formed. This results in an apparent collapse of the ice margin as floating ice leaves no terminal moraines. In contrast, if an over-deepened trough is not present, the glacier retreats in a stepwise fashion up valley with many terminal positions created (though not always preserved).

At Rakaia Valley ice retreated less than 10 km in 10,000 years from its glacial maximum position. In dated east coast systems, the subsequent timing of 'ice collapse' differs from valley to valley. The chronology of deglaciation in New Zealand indicates that apparent ice collapse occurred at different times in different valleys during the deglaciation but this is largely an artifact of the timing of pro-glacial lake formation. Instead of ice collapse during the early part of the deglaciation followed by a significant very late glacial (ACR/YD) re-advance, we propose that extended ice remained in valleys with high elevation catchments until after ~15 ka. There is no major ice collapse prior to this time. Subsequently a minor ice re-advance occurred in these systems, which might relate in timing to either the ACR or YD. It may alternatively reflect a change from a calving terminus into a proglacial lake back to an outwash fan head system. In either case this event is of minor significance.

Northern New Zealand Deglacial Climate and the Antarctic Cold Reversal, Cooler, Drier, or Both?

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Abstract

We compare sea surface temperature (SST) reconstructions from marine cores in the Bay of Plenty and the eastern coast of the North Island based on foraminiferal assemblages and alkenones to a multi-proxy terrestrial climatic record that includes pollen, biomarker, and compound specific isotopes from Onepoto Crater, a maar lake from the Auckland region of New Zealand. Records in both cores have robust age control based on well know and well-dated chemically distinguishable late Quaternary tephra. These document ecological and climatological changes from the Last Glacial Maximum (LGM) to the early Holocene in northern New Zealand.

All proxies indicate a drier and/or cooler climate in the glaciation followed by a shift to warmer and/or wetter conditions beginning around ~18 ka. Terrestrial compound-specific ^{13}C on fatty acids from Onepoto Crater suggest conditions became wetter around 20 ka preceding warming associated with the glacial to interglacial climate shift by as much as 2 ka. The marine record shows a smoother, more gradual transition than the terrestrial record based on pollen and charcoal. After an initial warming of 3-5°C, SST in the Bay of Plenty dropped by nearly 3°C during the Antarctic Cold Reversal (ACR) suggesting high latitiude conditions influenced subtropical water temperatures in this region of the southwest Pacific. Geobiomarkers for conifer burning (vanillic acid and dehydroabietic acid) in our terrestrial record indicate a return to somewhat dryer conditions during the ACR. The biomarker and isotopic data suggest these drier conditions in the ACR were associated with cooling evident in the foraminiferal SST but moderated in the alkenone record. Seasonality offsets between the SST proxies would suggest that this cooling was concentrated in winter and spring rather than summer. Cooling seen in these Northern New Zealand records is synchronous with Southern Ocean ACR records of cooler temperatures. Cooling and decreased upwelling at the ACR is believed to have been caused by an equatorward shift in southern Westerlies relative to deglacial conditions before and after. These results indicate that climate in Northern New Zealand was driven by high latitude conditions throughout the deglaciation.

Can seasonal snowpacks help inform ice core analyses?

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Abstract

The variability of synoptic circulation and associated shifts in vapour transport pathways exert a major influence on stable isotopes in paleoclimatic records. For this reason, understanding the interaction between precipitation isotopes and vapour trajectories on a seasonal timescale can lend insight into the interpretation of long-term climate archives.

Snow pit isotope data and snow accumulation records were obtained over the 2004-05, 2005-06 and 2006-07 winter accumulation seasons at two alpine field sites in the Canadian Rocky Mountains. Isotope stratigraphies in these supraglacial snowpacks exhibited little postdepositional change on a seasonal timescale. This enabled the identification of an isotope signature from each major storm system in the record. Temperature is found to control 47% of the variability in $\delta^{18}O$ and it is hypothesized that vapour pathways, and the consequent terrain that storms encounter as they move across western Canada, are an important second order control on stable isotopes in this region.

To investigate this further, 10 major storm events that occurred in the 2006-07 season are modelled with a coupled orographic-Rayleigh distillation model, constrained with water isotope data from Vancouver. The orographic model explicitly represents the effects of topography on the distribution and intensity of precipitation along each storm trajectory. On average, this results in a 39% improvement in the prediction of $\delta^{18}O$ compared to results obtained without accounting for orography.

These trajectory modelling techniques will be applied to the analysis of a ~100 m ice core from the Whitehall Glacier, Antarctica. This site is only 12 km from the coast and is expected to contain a high-resolution record of temperature, greenhouse gas concentrations and trace elements for the past 300 years.

Late glacial ice advance in South America?

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Abstract
To come

New Zealand cave records show distinctive Southern Hemisphere paleoclimatic signatures: LGM at Stage 4, no Younger Dryas, and a Polynesian Warm Period

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Abstract
Results from a huge amount of paleoclimatic research in the Northern Hemisphere dominate the world view of paleoclimatic history. But research from the Southern Hemisphere is increasingly showing a different story, partly attributable to the see-saw effect demonstrated by evidence from ice cores and deep sea cores. Terrestrial evidence provided by speleothems complements ice core records because it is available from virtually all ice-free continental areas, can be accurately dated by uranium series and can often be resolved to annual level. This paper presents the results of speleothem-based research from New Zealand, strategically located in a mid-latitude oceanic environment between Antarctic and tropical influences.

The stable isotope record from New Zealand speleothems is presented from the last interglacial to the present. Broad similarities are found between New Zealand and comparable records from the Northern Hemisphere, but there are also some marked differences. Three in particular are of interest, because they show that the climatic systems of the Northern and Southern Hemispheres do not work entirely in unison: (1) the Last Glacial Maximum in New Zealand was not at isotope stage 2 but at stage 4; (2) a Late Glacial cold reversal occurred that in timing and form resembles the Antarctic Cold Reversal rather than the Younger Dryas; (3) a late Holocene warm interval occurred, termed the Polynesian Warm Period, because its start and end dates are different to the Medieval Warm Period experienced in Europe; and (4) the recent phase of global warming only became evident from the beginning of the 20th century. However, the Little Ice Age occurred at about the same time in both hemispheres and many D/O events have the same timing.

It is concluded that at a time scale of 10^5 years or more the hemispheres are broadly in step, but at the millennial and centennial scales there are often – but not always-significant differences. In comparing last glacial cycle events in New Zealand with those in the Northern Hemisphere, one must also remember that one is comparing climatic responses in an alpine glacial environment to those in a continental glacial system. The alpine system is much more responsive to short-term change. The intensity of climate change recorded in New Zealand, and perhaps also in much of the rest of the oceanic Southern Hemisphere, may also be less than in the Northern Hemisphere, because the moderating effect of the ocean dampens extreme changes.

New Zealand paleoclimate over the last 2000 years: high resolution speleothem records

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Abstract
There is no evidence for a Northern Hemisphere style 'hockey-stick' in New Zealand. This conclusion is drawn from a high resolution 2000 year stable isotope record from Waitomo in western central North Island. The record is at decadal or better resolution, and is supported by a lower average resolution record from NW Nelson. From $\delta^{18}O$ values it is evident that palaeo-temperatures have varied significantly in the Late Holocene. The recent upwards trend in temperature commenced about 200 years ago, but was matched by comparable rates and magnitudes of temperature rise in the past. The interval from 500 – 800 years BP was especially warm, although the exact timing of temperature peaks may have varied in North and South Islands. The Little Ice Age is evident as a series of cold troughs between 100-600 years ago, although 2000 years ago was particularly cool as New Zealand climbed out of the Neoglacial.

Water balance information as represented by $\delta^{13}C$ values also shows considerable variability. Central western North Island and NW Nelson were wet as well as cool about 2000 years ago, but since then $\delta^{13}C$ values have become generally less negative (suggesting a generally drying trend with reduced biological activity), although with some marked perturbations. In NW Nelson, by contrast, $\delta^{13}C$ values have tended to become more negative over the same interval probably reflecting regional contrasts in rainfall conditions.

Late Pleistocene onset of monsoonal rain and abrupt strengthening of ENSO 3,900 cal yrs BP recorded by diatomaceous sediments from dry tropical Australia

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Abstract

A continuous diatomaceous sediment record from dry tropical Queensland, Australia, provides new evidence for rapid precipitation variations over the last 14,000 cal years. Lava flows from Toomba Volcano formed a unique runoff-isolated lake system ~13,600 cal yrs BP that contains 5.5 m thick purely diatomaceous debris. High precipitation during shortly after the development of the lake system supports other studies that the monsoonal system developed around 13,000 cal yrs BP. Geochemical data and isotope analysis of the diatoms reveal that primary productivity was high during the onset of the deposit with little changes until the mid Holocene, when abrupt moisture regime changes occurred ~6,000 years ago. Prior to that, precipitation across this present-day dry tropical site must have been plenty to sustain a perennial lake system. Furthermore, oxygen isotope data of the diatoms indicates that changes in moisture source took place progressively shortly after 9,000 years ago and lasted until about 6,500 years when abrupt shifts in source occurred until 6,000 years ago. Since then, isotopic values remained similar with to periods of rapid changes between 3,000-1,800 and ~400-200 cal yrs BP (Little Ice Age).

Trace elemental composition of the record provides further evidence for marked changes of the atmospheric composition ~3,900 yrs BP and may represent the timing of the drying of the Australian continent (enhanced erosion of top soils), which most likely signifies the intensification of the El Niño Southern Oscillation (ENSO) in this region. The interpretation is supported by previous studies from corals from tropical Pacific and marine sediments from, for example, the Cariaco Basin off the Venezuelan coast. At Cariaco, the changes were interpreted to be due to the onset and intensification of ENSO. These studies suggested that over the last 4000 years, strong ENSO with increasing variability dominated the monsoonal regions.

In summary, our record shows that the dry tropics received more precipitation during the late Pleistocene and early Holocene than during the late Holocene. These findings are similar to findings from the wet tropical NE-Australia. However, our record shows a marked collapse of the ocean/atmospheric system in the low latitudes and an intensification of ENSO during the latter part of the Holocene round 3,900 cal yrs Bp with several marked climatic shifts since then, with the last one occurring during the Little Ice Age.