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# The Anatomy of Last Glacial Maximum (LGM) Climate Change in the Southern Hemisphere Mid- Latitudes: Paleoecological Temperature Reconstructions from Terrestrial Archives

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## Preview of Award 0902386 - Final Project Report

[Cover](#) |  
[Accomplishments](#) |  
[Products](#) |  
[Participants/Organizations](#) |  
[Impacts](#) |  
[Changes/Problems](#)

### Cover

Federal Agency and Organization Element to Which Report is Submitted:	4900
Federal Grant or Other Identifying Number Assigned by Agency:	0902386
Project Title:	The Anatomy of Last Glacial Maximum (LGM) Climate Change in the Southern Hemisphere Mid-Latitudes: Paleocological Temperature Reconstructions from Terrestrial Archives
PD/PI Name:	Marcus J Vandergoes, Principal Investigator A. C Dieffenbacher-Krall, Co-Principal Investigator
Recipient Organization:	University of Maine
Project/Grant Period:	01/01/2010 - 03/31/2013
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Submitting Official (if other than PD\PI):	A. C Dieffenbacher-Krall Co-Principal Investigator
Submission Date:	06/28/2013
Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	A. C Dieffenbacher-Krall

### Accomplishments

#### \* What are the major goals of the project?

The objective of the research is to test if leading hypotheses about drivers of global ice ages explain glacial climate change in the Southern Hemisphere mid-latitudes. The research is driven by the goals of understanding and documenting past temporal and spatial variability of Earth's climate system, evaluating rates of change associated with variability of the climate system, and determining the sensitivity of the climate system to variations in forcing factors.

The research is focused on Last Glacial Maximum (LGM) climate change in the Southern Hemisphere mid-latitudes, encompassing ~32-18 ka (thousand cal yrs before present). For many of the existing paleoclimate records from this region, ascertaining the exact timing and duration of the LGM or onset of the termination is difficult due to insufficient chronology or sampling resolution. Many of these records have yet to produce continuous, quantitative estimates of the magnitude of LGM temperature change. A focussed effort to define the timing of LGM climate events and temperature change, as undertaken in this study, is needed to evaluate which events were interhemispherically

symmetric and which were not.

The major goal of the project is to provide a comprehensive paleoclimate data set that is directly applicable to testing hypotheses about forcing mechanisms responsible for major climate changes. The research will establish the timing, magnitude, and structure of southern mid-latitude Last Glacial Maximum climate from three sites bordering the Southern Alps, New Zealand, by reconstructing temperature changes from continuous, isotopically dated, paleo-chironomid and pollen records.

The project has two primary goals: 1) to develop paleotemperature reconstructions for the western and eastern margins of the Southern Alps from three lakes located outside LGM moraine belts using pollen and chironomid temperature inference models, and 2) to determine the precise timing and duration of LGM climate changes for this location using detailed AMS radiocarbon dating.

Study began in January 2010. Persons responsible for each task abbreviated as MJV = Vandergoes, ADK = Dieffenbacher-Krall, UGS = undergraduate students, JW = Janet Wilmhurst (subcontract).

March 2010
Remove and prepare additional chironomid samples from Galway Tarn cores (MJV). Planning for core collection from new sites Alpine Lake and Forks Lagoon in austral summer (Jan 2011). <b>Completed 100 %</b>
January 2011
Collection of cores from Alpine Lake and Forks Lagoon during the height of the austral summer (MJV, ADK, UG). Cores shipped to the University of Maine. <b>Completed 100%</b>
Spring and Summer 2011
Log, describe and sample Alpine Lake and Forks Lagoon cores for loss-on-ignition, pollen, and chironomid analyses (ADK, UG). Remove additional chironomid samples from Galway Tarn cores (MJV). Preparation of chironomid samples (4-10 hours per sample) continuing through the three years of the project (ADK, UGS). <b>Completed 100%</b>
Fall 2011
Preparation of pollen concentrates (MJV). Submission of initial radiocarbon dates at strong lithological changes (MJV). Preparation of chironomid slides (ADK, UGS). Counting of chironomid slides (ADK). <b>Completed 100%</b>
Spring and Summer 2012
Continued preparation of chironomid slides (ADK, UGS). Continued counting of chironomid slides (ADK, MJV). Counting of pollen slides from Alpine Lake (MJV). Application of inference model to Galway Tarn pollen data (MJV, JW, ADK). <b>Completed 100%</b>
Fall 2012
Preparation of additional radiocarbon dates at points of chironomid or pollen assemblage change (MJV, ADK). Continued preparation of chironomid slides (ADK, UGS). Continued counting of chironomid slides (ADK). Application of inference model to Alpine Lake pollen data (MJV, JW, ADK).

<b>Completed 100%</b>
Spring and Summer 2013
Preparation of additional radiocarbon dates at points of chironomid or pollen assemblage change (MJV, ADK). Continued preparation of chironomid slides (ADK, UGS). Complete counting of chironomid slides (ADK). Counting of pollen slides from Forks Lagoon (MJV). Application of inference model to Forks Lagoon pollen data (MJV, JW, ADK). <b>Completed 100%</b>
Fall 2013
Application of chironomid inference model to data from all sites (ADK, MJV). Data analysis and manuscript preparation (ADK, JW, MJV). <b>Completed 85%</b>

**\* What was accomplished under these goals (you must provide information for at least one of the 4 categories below)?**

Major Activities:

Three lake sites bordering the western and eastern margins of the Southern Alps, New Zealand were target to produce detailed, continuous, quantitative reconstructions of LGM temperature change. New lake sediment cores were collected from Alpine Lake and along with previously collected cores from Galway Tarn and Forks Lagoon were analyzed to produce pollen and chironomid stratigraphies.

Cores from Alpine Lake and Forks Lagoon were initially subsampled at 5 cm intervals through the LGM-age sediment. Closer interval sampling at 1-0.5 cm intervals was performed where significant changes in pollen or chironomid assemblages are found. This sampling achieved a resolution of sub 200 years per sample depending on sedimentation rate. The pre-existing preliminary chironomid record from Galway Tarn was boosted with additional analysis to refine the analytical resolution and the detail of the chironomid stratigraphy. The pollen inference model of Wilmshurst et al., (2007) was applied to obtain pollen based temperature estimates while the application of the chironomid temperature transfer function of Dieffenbacher-Krall et al., (2007) was used to develop chironomid based temperature reconstructions.

AMS radiocarbon dates were obtained for Alpine Lake and Forks Lagoon to provide robust high-resolution chronologies for the LGM. Sediment samples were collected at 2-3 cm spacing for the LGM section of the cores and at sediment levels showing significant paleoecological and lithologic changes. Macrofossil remains, primarily from sedge grasses were selected for dating when possible. For less organic sections of the Forks Lagoon core, where macrofossil remains were not abundant, no dates were obtained. To constrain these and other critical horizons in each core multiple ages (3-5) from were obtained to determine the age error spread associated with each horizon and allow for robust age modelling. From both Alpine Lake and Forks Lagoon, up to 50 AMS dates were obtained from each site, thus providing on average a 220 year dating resolution through the LGM, similar to that achieved for Galway tarn. The radiocarbon dates from these lake cores were calibrated using IntCal09 and modelled in a Bayesian framework using the age modelling programme 'Bacon' (Blaauw & Christen 2011). We used this approach to enhance the coherence of the chronological models and provide a comprehensive chronology for each site. Accumulation rates of the sequences were calculated to determine sedimentation rates through time.

Results from the three sites were collated compared in preparation for publication. A manuscript outlining the LGM temperature reconstructions from pollen and chironomids at Galway Tarn is in preparation for publication in Quaternary Science Reviews with the results from Alpine Lake and Forks Lagoon marked for a subsequent publication.

Sixteen undergraduate students assisted with this research project. A graduate student and a community volunteer also provided assistance.

Graduate and undergraduate students were fully trained in the preparation of chironomid (midge fly) fossil samples and completed samples from Galway Tarn, Alpine Lake, and Forks Lagoon. Three students became competent chironomid analysts, one completed an independent, "capstone" project. Another has transferred her expertise to analyze late-Holocene-age samples from northwest Iceland in a separate NSF-funded project. The project also provide research experience for one volunteer which included laboratory analysis, field work in southern New Zealand and project management.

#### References cited

Blaauw, M., Christen, J.A., 2011. Flexible paleoclimate age-depth models using an autoregressive gamma process. *Bayesian Analysis* 6, 457-474.

Dieffenbacher-Krall, A.C., M.J. Vandergoes, and G.H. Denton. 2007. An inference model for mean summer air temperature in the Southern Alps, New Zealand, using subfossil chironomids. *Quaternary Science Reviews* 26: [2487-2504](#).

Wilmshurst, J.M., M.S. McGlone, J.R. Leathwick, and R.M. Newnham. 2007. A pre-deforestation pollen-climate calibration model for New Zealand and quantitative temperature reconstructions for the past 18,000 years BP. *Journal of Quaternary Science* 22: 535-547.

#### Specific Objectives:

The project has two primary goals:

- 1) to develop paleotemperature reconstructions for the western and eastern margins of the Southern Alps New Zealand from three lakes located outside LGM moraine belts using pollen and chironomid temperature inference models.
- 2) to determine the precise timing and duration of LGM climate changes for this location using detailed AMS radiocarbon dating.

#### Significant Results:

A comprehensively AMS dated, pollen and chironomid stratigraphy from Galway Tarn provides the first chironomid-derived temperature reconstruction to quantify temperature change encompassing the LGM (Last Glacial Maximum, 30,000-11,000 cal yr BP) in the Southern Alps, New Zealand, in conjunction with pollen analysis. The onset of cooling, marked by expansion of alpine grassland, occurred at this site ~29 ka (thousand cal yrs before present). Cool conditions were maintained until about 17.6 ka. Milder interstadials occurred from ~25.8 to 24.4 and 22.6 to 21.9 ka. Pollen- and chironomid-based temperature reconstructions for the LGM imply a ca. 3.0 to 5.0

o

C temperature depression (relative to present) during the coldest parts of the LGM, ameliorating to between 2 to 3

o

C cooler than present during LGM

interstadials. These results demonstrate that high resolution, precisely dated, multi-proxy records can make a significant contribution to: 1) understanding the complex timing and pattern of local LGM change emerging from terrestrial climate proxies in this region, and 2) determining the relative role of temperature in these changes. The results further highlight close associations between Antarctica and mid-latitude terrestrial climate systems, and enable comparisons with other Southern Hemisphere records to clarify climate relationships and evaluate climate coupling mechanisms.

Radiocarbon dating, pollen and chironomid analysis from Forks Lagoon and Alpine Lake provide broad support for the changes identified at Galway Tarn. Pollen based temperature reconstructions from Alpine Lake compare well with those identified at Galway Tarn for the LGM between ~29 to 17.6 ka indicating that these proxy records

represent a regional response to climate change. Chironomid based temperature reconstructions from Alpine Lake have proven to more complicated with chironomid assemblages indicating low faunal diversity with the abundant species exhibiting little correlation to temperature change. From assessment of our modern lake and chironomid training set it seems likely that the Alpine Lake chironomid assemblage is primarily responding to a tannin rich, deep lake environment that persisted during the LGM and may be less representative or changing climate in the region.

The intra-LGM detail preserved by the pollen and aquatic spores at the drier, more eastern site Forks Lagoon seems to be indicative of periods of precipitation variability. At this site, episodes of deeper water seem to occur during to the milder interstadial episodes identified in Galway tarn and Alpine Lake. This significant result provides some of the first proxy data indicative of precipitation change in the drier eastern regions of southern New Zealand during the LGM and is important for determining the regional variability of climate over Southern New Zealand in association with fluctuations in intensity and possible latitudinal shifts of the southern westerly wind belt during this time.

A similar general pattern of stadials and interstadials is seen, to varying degrees of resolution but generally with lesser chronological control, in many other paleoclimate proxy records from the New Zealand region. The timing of colder (and drier?) periods corresponds with evidence of glacial advance derived from results of intensive  $^{10}\text{Be}$  dating programmes on the eastern side of the New Zealand Southern Alps (e.g. Putnam et al., 2013). These results place culminations of glacier advances at ca 32,500 cal. yr BP, tentatively at ca 27,400 cal. yr BP but definitely at ca 22,500 cal. yr BP and ca 18,200 cal. yr BP, with glacier withdrawal underway by ca 17,700 cal. yr BP. These results reinforce other regional evidence that full-glacial climatic conditions were attained in the southern mid-latitudes during Marine Isotope Stage 3. Prominent culminations of terminal moraine formation at ca 22,500 and ca 18,200 cal. yr BP fit well with the culminations of the middle and last stadials of the LGM identified in the pollen and chironomid records. Combined, these pollen, chironomid and glacial chronology results provide quantitative data input for numerical modeling of LGM glaciers and climates.

A major development associated with this project has been the refinement of a key South-West Pacific LGM chronostratigraphic tephra marker. Radiocarbon dating associated with the sites used in this project have been utilised to refine the age of the Kawakawa/Oruanui tephra (KOT). A revised age for the KOT of  $25,360 \pm 160$  cal yr BP ( $\pm 2$  sd) is ca. 1700 cal years younger previously used estimates of  $27,097 \pm 957$  cal yr BP. The results have significant implications for developing robust chronologies of LGM climate and environmental change in the South West Pacific region, the inter-

regional alignment of proxy records and comparison with well-dated records

elsewhere as well as refining marine reservoir ages for the LGM in the South-West

Pacific.

As a direct spin-off result of this project, sediment samples from Alpine Lake formed the basis of a new study to develop a bacterial "geo-thermometer" to reconstruct paleotemperatures from bacterial lipid glycerol dialkyl glycerol tetraethers (GDGTs) preserved in lake sediment. Pollen and chironomid based temperature reconstructions from the currently funded NSF project are used to confirm the validity of lipid-derived temperature estimates. Preliminary results show strong relationship between lipids and temperature and comparable temperature estimates with pollen and chironomid reconstructions. Preliminary lipid-inferred temperature estimates range from 5

o

C during the LGM cold periods to 3

o

C during the LGM interstadials.

Key outcomes or  
Other achievements:

The development of continuous multi proxy records of LGM temperature change has confirmed that the ~29 ka onset to LGM temperature depression is reproduced spatially in the west and east of the New Zealand Southern Alps, and is therefore a regional event. The structure of LGM climate changes as seen in pollen and chironomid records from the region and identified elsewhere in New Zealand marine and terrestrial records is likely to be driven at the first order by regional temperature depression with the influence of local variations in temperature and precipitation responsible for inter LGM variations.

The differences highlighted between LGM paleoclimate records from the Southern Hemisphere and the commonly defined global LGM of Mix et al., (2001), have been at the heart of debate about LGM climate change and climate drivers in New Zealand. Recent re-evaluations of Northern Hemisphere ice sheet extent are more in accord with the New Zealand record, with evidence that ice sheet expansion began in some regions as early as 33,000 cal. yr BP, with the maximum extent of most Northern Hemisphere ice sheets (i.e., LGM) achieved by ca 26,500 cal. yr BP and persisting to ca 19,000 cal. yr BP (Clark et al., 2009).

The timing of stadials and interstadials in these records from southern New Zealand matches closely with those recorded in Antarctic ice cores and Southern Ocean marine records, and aligns with an emerging realisation that full-glacial climatic conditions globally were attained earlier than previously thought. The similarity of patterns of LGM variability represented in New Zealand terrestrial proxy records and in marine proxy records derived from offshore New Zealand and the Southern Ocean, and in temperature indicators from Antarctica, highlights the linkage between oceanic and atmospheric conditions though that time. This data supports recent assertions that the driver of the observed southern LGM pattern may be best explained by southern winter duration modulating Southern Ocean sea ice, which in turn influenced Southern Ocean stratification and made the surface ocean cooler; and that orbitally induced cooling of the Southern Ocean provides an explanation for the LGM in the Southern Alps having been coincident with the northern LGM (Putnam et al., 2013). Nevertheless, it is important to note that some differences between proxies are apparent and these demonstrate our incomplete understanding of their basic climate controls.

The pollen and chironomid based paleotemperature reconstructions will provide quantitative temperature data, which can be used to drive and test glacier flow-climate models currently being developed for the region (e.g. Anderson and Mackintosh 2006, Golledge et al., 2012). This work allows a link between past and present climate and glacier response. The modeling experiments

provide quantitative explanations of glacial history, inversely translating the moraine record into temperature and precipitation ranges (Anderson and Mackintosh 2006). The pollen and chironomid based paleotemperature reconstructions of LGM temperature change will be used to independently drive the glacier flow models in order to compare and evaluate temperature estimates derived from moraine evidence. Examples of this approach have been recently published (Doughty et al., 2012) and allows testing of hypothesized forcings that ultimately could have driven the snowline lowering and glacial advance, such as various insolation factors and their changes (e.g., summer energy or degree days), precipitation, and temperature. Driving these models for the LGM with an independent local temperature signal can now be undertaken will help determine the relative contributions of different forcing mechanisms.

The age revision of the KOT has been a critical step in developing robust chronologies for LGM climate change from marine and terrestrial sedimentary archives in the New Zealand region. Publication of the KOT age revision was essential before any other publication of pollen and chironomid data from associated records could proceed. This unexpected outcome is responsible for the stated outcome of “publication of final manuscripts” not being met.

**Stated goals not met :** Publication of final manuscripts:

Publication of the revised age for the Kawakawa/Oruanui tephra, used as a key LGM South West Pacific chronostratigraphic time marker, has delayed subsequent publication of records that contain this tephra. The revised age of this horizon is now incorporated into the age models of each site. The stated goal of submitting manuscripts relating to pollen and chironomid temperature reconstructions, before culmination of the current grant has therefore not been met. A manuscript outlining the LGM temperature reconstructions from pollen and chironomids at Galway Tarn is in preparation for publication in *Quaternary Science Reviews* with the results from Alpine Lake and Forks Lagoon marked for a subsequent publication. Both are now planned for submission later this year.

**References cited**

Anderson, B. and Mackintosh, A., 2006. Temperature change is the major driver of lateglacial and Holocene glacier fluctuations in New Zealand. *Geology* 34(2), 121- 124.

Clark, P.U., Dyke, A.S., Shakun, J.D., Carlson, A.E., Clark, J., Wohlfarth, B., Mitrovica, J.X., Hostetler, S.W., McCabe, A.M., 2009. The Last Glacial Maximum. *Science* 325, 710-714.

Doughty, A.M.; Anderson, B.M.; Mackintosh, A.N.; Kaplan, M.R.; Vandergoes, M.J.; Barrell, D.J.A.; Denton, G.H.; Schaefer, J.M.; Chinn, T.J.H.; Putnam, A.E. 2012. Evaluation of Lateglacial temperatures in the Southern Alps of New Zealand based on glacier modelling at Irishman Stream, Ben Ohau Range. *Quaternary science reviews*, *Online first*: doi: [10.1016/j.quascirev.2012.09.013](https://doi.org/10.1016/j.quascirev.2012.09.013) (10 p.)

Golledge, N.R.; Mackintosh, A.N.; Anderson, B.M.; Buckley, K.M.; Doughty, A.M.; Barrell, D.J.A.; Denton, G.H.; Vandergoes, M.J.; Andersen, B.G.; Schaefer, J.M. 2012. Last Glacial Maximum climate in New Zealand inferred from a modelled Southern Alps icefield. *Quaternary Science Reviews*, 46: 30-45; doi: [10.1016/j.quascirev.2012.05.004](https://doi.org/10.1016/j.quascirev.2012.05.004)

Mix, A.C., Bard, E., Schneider, R., 2001. Environmental processes of the ice age: land, oceans, glaciers (EPILOG). *Quaternary Science Reviews* 20: 627-657.



Putnam, A.E., Schaefer, J.M., Denton, G.H., Barrell, D.J.A., Birkel, S.D., Andersen, B.G., Kaplan, M.R., Finkel, R.C., Schwartz, R., Doughty, A.M., 2013. The Last Glacial Maximum at 44oS documented by a 10Be moraine chronology at Lake Ohau, Southern Alps of New Zealand. *Quaternary Science Reviews* 62, 114-141.

**\* What opportunities for training and professional development has the project provided?**

The Co-PI Dieffenbacher-Krall attended an intensive workshop in June 2010, University College London, about statistical analysis of ecological data, which improves our skills base and will enhance final analyses of data generated by this project.

A total of one graduate and sixteen undergraduate students assisted with laboratory work, gaining research skills and valuable experience. One student assisted with field work in New Zealand and completed an independent, senior 'capstone' research project, a requirement for graduation, from sediment collected during this trip. This experience, particularly the involvement in field work in a foreign country has greatly enhanced her understanding of the processes involved in undertaking paleoclimate research, logistics planning for field campaigns, analytical research, and scientific research. A second student developed her chironomid analysis skills and applied them to a separate NSF-funded project focusing on North Atlantic Oscillation cycles in northwest Iceland lake sediment. An additional student is transferring his new skills to Holocene-age lake sediment from Maine.

Three undergraduate students participated in an "ethics in science" program co-hosted by the co-PI in June 2012.

The project also provided research experience for one volunteer (Karen Marysdaughter), which included laboratory analysis and project management.

**\* How have the results been disseminated to communities of interest?**

Results of pollen, chironomid and lipid analysis associated with this study were presented at the Southern Connections Congress, Dunedin, New Zealand, January 21-25, 2013.

Initial results of the Kawakawa/Oruanui tephra age revision were presented at the New Zealand Geoscientific Society of New Zealand (GSNZ) Conference, Nelson NZ November 28-Dec 2011.

The results of this study to date were presented at the (XXVIII) INQUA Congress, Bern, Switzerland 20th July - 27th July, 2011.

Objectives and methods of this research project were presented through lecture, tour, and a hands-on experience to an undergraduate archaeology class and a group of grade 4-7 students from a local school, 2010-2012.

Objectives and preliminary results were presented at the Southern Connections Meeting in Bariloche, Argentina in March 2010.

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## Products

## Books

### Book Chapters

#### Conference Papers and Presentations

Vandergoes, M.J., Zink, K.G., Newnham, R., Wilmshurst, J., Dieffenbacher-Krall, A.C., Schwark, L., Li, X. (2013). *Lipid-based paleotemperature reconstructions for the late Quaternary in southern New Zealand, part 2: preliminary applications*. VII Southern Connections Congress. Dunedin, New Zealand. Status = OTHER; Acknowledgement of Federal Support = Yes

Vandergoes, M.J., Newnham, R.M., Dieffenbacher-Krall, A., Denton, G.H., Zink, K. G., Schwark, L., Wilmshurst, J. (2011). *Multiproxy paleotemperature reconstructions for the Last Glacial Maximum in Southern New Zealand*. XVIII INQUA-Congress. Bern, Switzerland. Status = OTHER; Acknowledgement of Federal Support = Yes

Callard, S.L., Newnham, R., Vandergoes, M., Marra, M., 2011. (2011). *Pollen-climate reconstructions spanning the last glacial maximum and deglaciation in southern New Zealand*. XVIII INQUA-Congress. Bern, Switzerland. Status = OTHER; Acknowledgement of Federal Support = No

Vandergoes, M.J., Hogg, A., Lowe, D. J., Newnham, R.M., Denton, G.H., Barrell, D, Almond, P.C., Allan, A., Wilson C.J. (2011). *Refining the age of the Kawakawa/Oruanui tephra in New Zealand*. XVIII INQUA-Congress. Bern, Switzerland. Status = OTHER; Acknowledgement of Federal Support = Yes

Callard, S.L., Newnham R.M., Vandergoes, M.J. (2010). *The last glacial maximum and deglaciation in southern New Zealand: new pollen-climate reconstructions*. Australasian Quaternary Association biennial meeting. North Stradbroke Island, Australia. Status = OTHER; Acknowledgement of Federal Support = Yes

Newnham, R.M., McGlone, M.S., Moar, N.T., Vandergoes, M.J., Wilmshurst, J.M. (2011). *The vegetation cover of New Zealand at the last glacial maximum*. XVIII INQUA-Congress. Bern, Switzerland. Status = OTHER; Acknowledgement of Federal Support = Yes

#### Inventions

Nothing to report.

#### Journals

Vandergoes, M.J., Newnham, R.M., Denton, G.H., Blaauw, M., Barrell, D.J.A. (2013). The anatomy of Last Glacial Maximum climate variations in south Westland, New Zealand, derived from pollen records. *Quaternary Science Reviews*. xxx 1-15. Status = AWAITING\_PUBLICATION; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: [10.1016/j.quascirev.2013.04.015](https://doi.org/10.1016/j.quascirev.2013.04.015)

Vandergoes, M.J.; Hogg, A.G.; Lowe, D.J.; Newnham, R.M.; Denton, G.H.; Southon, J.; Barrell, D.J.A.; Wilson, C.J.N.; McGlone, M.S.; Allan, A.S.R.; Almond, P.C.; Petchey, F.; Dabell, K.; Dieffenbacher-Krall, A.C.; Blaauw, M. (2013). A revised age for the Kawakawa/Oruanui tephra, a key marker for the Last Glacial Maximum in New Zealand. *Quaternary Science Reviews*. xxx 1-7. Status = AWAITING\_PUBLICATION; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: [10.1016/j.quascirev.2012.11.006](https://doi.org/10.1016/j.quascirev.2012.11.006)

Zink, K.-G., M.J. Vandergoes, K. Mangelsdorf, A.C. Dieffenbacher-Krall, and L. Schwark. (2010). Application of bacterial glycerol dialkyl glycerol tetraethers (GDGTs) to develop modern and past temperature estimates from New Zealand lakes.. *Organic Geochemistry*. 41 (9), 1060-1066. Status = PUBLISHED; Acknowledgment of Federal Support = No ; Peer Reviewed = Yes

#### Licenses

Nothing to report.

#### Other Products

*Databases.*

Site location metadata and scientific data associated with the radiocarbon dating and temperature reconstructions from each site will be lodged in the publicly accessible database Pangaea (<http://www.pangaea.de/>). Chironomid and pollen data will be deposited in the publicly accessible NOAA National Climatic Data Center.

#### Other Publications

#### Patents

Nothing to report.

#### Technologies or Techniques

Nothing to report.

#### Thesis/Dissertations

#### Websites

Nothing to report.

## Participants/Organizations

### What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Vandergoes, Marcus	PD/PI	1
Dieffenbacher-Krall, A.	Co PD/PI	4
Bavaro, Dawn	Technician	1
Chase, Brenda	Graduate Student (research assistant)	1
Anderson, Neal	Undergraduate Student	0
Cloutier, Elizabeth	Undergraduate Student	0
Dixon, Daniel	Undergraduate Student	0
Duke, Jonathan	Undergraduate Student	1
Edes, Sorel	Undergraduate Student	0
Hannington, Thomas	Undergraduate Student	0
Hewett, Nathan	Undergraduate Student	0
Ibekilo, August	Undergraduate Student	0
Introne, Alexander	Undergraduate Student	1
Kubicke, Emily	Undergraduate Student	1
McCann, Erin	Undergraduate Student	1
Suitter, Ashley	Undergraduate Student	0
Traceski, Matthew	Undergraduate Student	1
Twitchell, Emmaline	Undergraduate Student	0
Winski, Gabriel	Undergraduate Student	0
Marysdaughter, Karen	Other	1

### Full details of individuals who have worked on the project:

#### Marcus J Vandergoes

**Email:** vandergoes@maine.edu

**Most Senior Project Role:** PD/PI

**Nearest Person Month Worked:** 1

**Contribution to the Project:** Vandergoes processed material for the radiocarbon dating from all sites and analyzed pollen samples from Alpine Lake and Forks Lagoon. Vandergoes led a field expedition in January 2011 to retrieve lake sediment cores for this process. Vandergoes and Dieffenbacher-Krall were responsible for project oversight, data collection and analyses, and writing of final manuscripts.

**Funding Support:** none

**International Collaboration:** Yes, Germany, New Zealand, United Kingdom

**International Travel:** Yes, New Zealand - 0 years, 1 months, 0 days; New Zealand - 0 years, 0 months, 22 days; New Zealand - 0 years, 0 months, 14 days

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**A. C Dieffenbacher-Krall**

**Email:** ann.dieffenbacher@umit.maine.edu

**Most Senior Project Role:** Co PD/PI

**Nearest Person Month Worked:** 4

**Contribution to the Project:** Dieffenbacher-Krall supervised lab operations and student workers, led preparation and analysis of chironomid samples, participated in field collection of lake sediment, and, with Vandergoes, data analyses and writing of articles.

**Funding Support:** University of Maine

**International Collaboration:** Yes, Germany, New Zealand, United Kingdom

**International Travel:** Yes, New Zealand - 0 years, 1 months, 0 days; United Kingdom - 0 years, 0 months, 16 days

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**Dawn Bavaro**

**Email:** dawn.bavaro@umit.maine.edu

**Most Senior Project Role:** Technician

**Nearest Person Month Worked:** 1

**Contribution to the Project:** Dawn prepared chironomid samples for analysis and helped train other students. Upon completion of her degree, Dawn served as a temporary technician, assisting with chironomid analyses, lab management, student supervision, and student training.

**Funding Support:** none

**International Collaboration:** No

**International Travel:** No

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**Brenda Chase**

**Email:** brenda.chase@umit.maine.edu

**Most Senior Project Role:** Graduate Student (research assistant)

**Nearest Person Month Worked:** 1

**Contribution to the Project:** Preparation of chironomid samples.

**Funding Support:** none

**International Collaboration:** No

**International Travel:** No

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**Neal Anderson**

**Email:** neal.anderson@umit.maine.edu

**Most Senior Project Role:** Undergraduate Student

**Nearest Person Month Worked:** 0

**Contribution to the Project:** Anderson prepared chironomid samples for analysis.

**Funding Support:** federal work-study

**International Collaboration:** No

**International Travel:** No

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**Elizabeth Cloutier**

**Email:** elizabeth.cloutier@umit.maine.edu

**Most Senior Project Role:** Undergraduate Student

**Nearest Person Month Worked:** 0

**Contribution to the Project:** Cloutier prepared chironomid samples for analysis.

**Funding Support:** none

**International Collaboration:** No

**International Travel:** No

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**Daniel Dixon**

**Email:** daniel.c.dixon@umit.maine.edu

**Most Senior Project Role:** Undergraduate Student

**Nearest Person Month Worked:** 0

**Contribution to the Project:** Dixon prepared chironomid samples for analysis.

**Funding Support:** none

**International Collaboration:** No

**International Travel:** No

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**Jonathan Duke**

**Email:** jonathan.duke@umit.maine.edu

**Most Senior Project Role:** Undergraduate Student

**Nearest Person Month Worked:** 1

**Contribution to the Project:** Duke prepared chironomid samples and assisted with chironomid analysis.

**Funding Support:** federal work-study

**International Collaboration:** No

**International Travel:** No

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**Sorel Edes**

**Email:** sorel.edes@umit.maine.edu

**Most Senior Project Role:** Undergraduate Student

**Nearest Person Month Worked:** 0

**Contribution to the Project:** Edes prepared chironomid samples for analysis..

**Funding Support:** none

**International Collaboration:** No

**International Travel:** No

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**Thomas Hannington**

**Email:** thomas.hannington@umit.maine.edu

**Most Senior Project Role:** Undergraduate Student

**Nearest Person Month Worked:** 0

**Contribution to the Project:** Hannington prepared chironomid samples for analysis.

**Funding Support:** federal work-study

**International Collaboration:** No

**International Travel:** No

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**Nathan Hewett**

**Email:** nathan.hewett@umit.maine.edu

**Most Senior Project Role:** Undergraduate Student

**Nearest Person Month Worked:** 0

**Contribution to the Project:** Hewett prepared chironomid samples for analysis.

**Funding Support:** federal work-study

**International Collaboration:** No

**International Travel:** No

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**August Ibekilo**

**Email:** august.ibekilo@umit.maine.edu

**Most Senior Project Role:** Undergraduate Student

**Nearest Person Month Worked:** 0

**Contribution to the Project:** Ibekilo prepared chironomid samples for analysis.

**Funding Support:** federal work-study

**International Collaboration:** No

**International Travel:** No

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**Alexander Introne**

**Email:** alexander.introne@umit.maine.edu

**Most Senior Project Role:** Undergraduate Student

**Nearest Person Month Worked:** 1

**Contribution to the Project:** Introne prepared chironomid samples for analysis..

**Funding Support:** federal work-study

**International Collaboration:** No

**International Travel:** No

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**Emily Kubicke**

**Email:** emily.kubicke@umit.maine.edu

**Most Senior Project Role:** Undergraduate Student

**Nearest Person Month Worked:** 1

**Contribution to the Project:** Kubicke prepared chironomid samples for analysis and assisted with chironomid identification.

**Funding Support:** none

**International Collaboration:** No

**International Travel:** No

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**Erin McCann**

**Email:** erin.mccann@umit.maine.edu

**Most Senior Project Role:** Undergraduate Student

**Nearest Person Month Worked:** 1

**Contribution to the Project:** McCann prepared chironomid samples, assisted with chironomid analyses, and participated in field collection of lake sediment in New Zealand.

**Funding Support:** none

**International Collaboration:** No

**International Travel:** Yes, New Zealand - 0 years, 0 months, 21 days

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**Ashley Switter**

**Email:** ashley.switter@umit.maine.edu

**Most Senior Project Role:** Undergraduate Student

**Nearest Person Month Worked:** 0

**Contribution to the Project:** Suitter prepared chironomid samples for analysis.

**Funding Support:** none

**International Collaboration:** No

**International Travel:** No

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**Matthew Traceski**

**Email:** matthew.traceski@umit.maine.edu

**Most Senior Project Role:** Undergraduate Student

**Nearest Person Month Worked:** 1

**Contribution to the Project:** Traceski prepared chironomid samples for analysis and learned chironomid analysis.

**Funding Support:** federal work-study

**International Collaboration:** No

**International Travel:** No

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**Emmaline Twitchell**

**Email:** emmaline.twitchell@umit.maine.edu

**Most Senior Project Role:** Undergraduate Student

**Nearest Person Month Worked:** 0

**Contribution to the Project:** Twitchell prepared chironomid samples for analysis.

**Funding Support:** federal work-study

**International Collaboration:** No

**International Travel:** No

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**Gabriel Winski**

**Email:** gabriel.winski@umit.maine.edu

**Most Senior Project Role:** Undergraduate Student

**Nearest Person Month Worked:** 0

**Contribution to the Project:** Winski prepared chironomid samples for analysis.

**Funding Support:** federal work-study

**International Collaboration:** No

**International Travel:** No

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**Karen Marysdaughter**

**Email:** karenmd@myfairpoint.net

**Most Senior Project Role:** Other

**Nearest Person Month Worked:** 1

**Contribution to the Project:** Marysdaughter was a volunteer on the project. She assisted with chironomid sample preparation and data entry.

**Funding Support:** none

**International Collaboration:** No

**International Travel:** No

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**What other organizations have been involved as partners?**

Name	Type of Partner Organization	Location
GNS Science	Other Organizations (foreign or domestic)	New Zealand

Landcare Research	Other Organizations (foreign or domestic)	Lincoln, New Zealand
Victoria University	Academic Institution	Wellington, New Zealand

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**Full details of organizations that have been involved as partners:**
**GNS Science**

**Organization Type:** Other Organizations (foreign or domestic)

**Organization Location:** New Zealand

**Partner's Contribution to the Project:**

In-Kind Support

Facilities

**More Detail on Partner and Contribution:** We cooperated through Dr. Vandergoes with GNS Science throughout the entire course of this project. GNS has provided support for obtaining samples for radiocarbon dates on lake cores located in New Zealand, and provided support (field equipment and logistics support i.e. vehicles) for field work in January 2011. GNS provided support for all palynological analysis, core logging and core characterisation through researcher lead and student projects. Vandergoes, Callard (student) and Li (GNS Science palynological technician) have been responsible for developing all pollen records. GNS Science Rafter radiocarbon laboratory provided additional support for radiocarbon analysis and methodological expertise to identify and resolve site specific problems with radiocarbon dating.

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**Landcare Research**

**Organization Type:** Other Organizations (foreign or domestic)

**Organization Location:** Lincoln, New Zealand

**Partner's Contribution to the Project:**

Collaborative Research

Personnel Exchanges

**More Detail on Partner and Contribution:** Dr. Janet Wilmshurst, Landcare Research, Lincoln, New Zealand (subcontract current grant), collaborated on producing pollen based temperature reconstructions for the LGM from the three sites Galway Tam, Alpine Lake and Forks Lagoon.

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**Victoria University**

**Organization Type:** Academic Institution

**Organization Location:** Wellington, New Zealand

**Partner's Contribution to the Project:**

Collaborative Research

**More Detail on Partner and Contribution:** Prof. Rewi Newnham, School of Geography, Environment and Earth Sciences, Victoria University of Wellington, New Zealand, collaborated on producing pollen based temperature reconstructions for the LGM from the three sites Galway Tam, Alpine Lake and Forks Lagoon.

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**What other collaborators or contacts have been involved?**

YES

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**Impacts**
**What is the impact on the development of the principal discipline(s) of the project?**

The project has produced the first chironomid-based paleotemperature reconstruction for New Zealand covering the Last Glacial Maximum. It is providing new insights into maximum (terrestrial) summer temperature depression for southern New Zealand and the Southern Hemisphere mid-latitudes, as well as extent of climate variability for this time period.



The results of the project has highlighted that the detailed timing of LGM climate change in southern New Zealand, precedes that of classic LGM and is more in tune with recent estimates of Northern Hemisphere LGM ice sheet growth. The results of the project aids in refining our understanding about what drives ice age climate change and provides support for mechanisms that drive or modulate Southern Ocean sea ice, Southern Ocean stratification and surface ocean cooling, such as the extended duration of the Southern Hemisphere winter.

The revised KOT age will have a significant impact on South-West Pacific Quaternary geochronology and paleoclimate reconstructions as it will enable a more definitive alignment and comparison with paleoclimate records that are dated independently of  $^{14}\text{C}$  (e.g., via U/Th,  $^{10}\text{Be}$ , or ice-core layer counting). The timing of key events and the spatial patterning of leads or lags in climate proxies can be critical for distinguishing between postulated climate forcings, and so it is important that this revised age for the KOT be used in future investigations of LGM climate variability that involve this key chronostratigraphic marker.

### **What is the impact on other disciplines?**

We have continued to collect modern chironomid (midge fly) data to improve performance of our chironomid-temperature transfer function as well as qualitative analysis of subfossil chironomid remains. The information generated by both modern and subfossil chironomid study will be of use to the fields of biology, entomology, aquatic ecology, and geography. Data from pollen studies will be of use to plant ecology and geography.

The revised KOT age has implications for estimating surface marine reservoir ages for the LGM. Using an error weighted mean age of  $21,299 \pm 123$   $^{14}\text{C}$  yr BP ( $n=8$ ; eruption ages;  $df=7$ ,  $T=7.2$  (5%  $^{14}\text{C}$ .1) the surface marine reservoir age now increases to  $3280 \pm 190$   $^{14}\text{C}$  yr BP based on age data reported on planktonic foraminifera for KOT by Sikes et al. (2000). Similarly, the apparent ventilation age for this period in the LGM is now  $4760 \pm 190$   $^{14}\text{C}$  yr BP on the basis of age data for benthic foraminifera reported by Sikes et al. (2000).

### **References cited**

Sikes, E.L., Samson, C.R., Guilderson, T.P., Howard, W.R., 2000. Old radiocarbon ages in the southwest Pacific Ocean during the last glacial period and deglaciation. *Nature* 405, 555–559.

### **What is the impact on the development of human resources?**

Sixteen undergraduate students and one graduate student have obtained experience in laboratory research in geology and paleoecology. Three students became competent chironomid analysts. One obtained a position as a research assistant in paleoclimatological research after graduation.

### **What is the impact on physical resources that form infrastructure?**

The production capacity of the Paleocology Research Laboratory, University of Maine, was increased by the addition of two dissecting microscopes, a high-resolution microscope camera, and a surface sediment coring device.

### **What is the impact on institutional resources that form infrastructure?**

Nothing to report.

### **What is the impact on information resources that form infrastructure?**

Nothing to report.

### **What is the impact on technology transfer?**

Nothing to report.

### **What is the impact on society beyond science and technology?**

The research documents temporal and spatial extent and magnitude of climatological phenomenon. Better understanding of Last Glacial Maximum climate of the southern mid-latitudes directly tests the viability of several hypotheses about ice age mechanisms and contributes to numerical models predicting future climate and sea level changes.

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## **Changes/Problems**

### **Changes in approach and reason for change**

Nothing to report.

**Actual or Anticipated problems or delays and actions or plans to resolve them**

Nothing to report.

**Changes that have a significant impact on expenditures**

Nothing to report.

**Significant changes in use or care of human subjects**

Nothing to report.

**Significant changes in use or care of vertebrate animals**

Nothing to report.

**Significant changes in use or care of biohazards**

Nothing to report.