VICTORIA UNIVERSITY OF WELLINGTON
TE HERENGA WAKA

ANTARCTIC RESEARCH CENTRE
TE PUNA PĀTIOTIO

Annual Review 2019

CAPITAL THINKING. GLOBALLY MINDED.
MAI I TE IHO KI TE PAE

IMPROVING UNDERSTANDING OF ANTARCTIC CLIMATE AND ICE SHEET PROCESSES, AND THEIR IMPACT ON NEW ZEALAND AND THE EARTH SYSTEM

CONTENTS

VICTORIA UNIVERSITY OF WELLINGTON
TE HERENGA WAKA

Antarctic Research Centre
Te Puna Pātiotio

The Antarctic Research Centre's new reo Māori name is Te Puna Pātiotio. Te Puna means 'the spring', and refers to something that wells up or flows, and Pātiotio means 'to be frozen over'. The name captures both the energy and output of the Centre with the concept of 'flowing ice' relating to the glaciers and ice sheets studied at the Centre and in the context of how research conducted in the frozen environment of Antarctica and New Zealand springs forth into the world.

IMPACTS BY NUMBERS

4th
ARC Director
Rob McKay, appointed to the position following the resignation of Andrew Mackintosh.

$324 thousand
subcontract to PI Rob McKay from NIWA for Antarctic Science Platform Project 2: Ocean Mechanics.

10 theses
submitted in 2019 by ARC supervised students; five PhD and five MSc.

6 *Nature & Science*
publications by ARC staff in 2019.

6 new staff
welcomed to the ARC: Alexandra Gossart, Liz Keller, Jamey Stutz, Lauren Vargo, Oliver Wigmore, and Holly Winton.

$1.6 million
of Capex funding from ARC and GNS Science to build an Antarctic Intermediate Depth Drill as part of the Antarctic Science Platform.

17 staff & students
deployed to Antarctica for the 2019/20 field season, making it one of the largest Victoria University of Wellington Antarctic Expeditions ever!

37 publications
in 2019 with ARC staff and student authorship.

36 ocean voyages
taken by Lionel Carter during his career. Lionel retired in June, but continues working with the ARC as an Emeritus Professor.

$3 million marsden fund
awarded to Bella Duncan as co-PI on one of the first two Marsden Fund Council Awards.

19 researchers
from the ARC are involved in research within the Antarctic Science Platform.

40 interviews
given by ARC staff and students on Antarctic and climate related issues.

42 year legacy
of Antarctic science and drilling support celebrated at Alex Pyne's retirement function in June.

$4.4m subcontract
awarded to co-PI Huw Horgan for Antarctic Science Platform Project 1: Antarctic Ice Dynamics – Past, Present, and Future.

584 metre
hole drilled through the Ross Ice Shelf for Project 1 of the Antarctic Science Platform.

41 presentations
given to politicians, stakeholders, schools and community groups by ARC staff and students.

TE PUNA PĀTIOTIO-ANTARCTIC RESEARCH CENTRE IS A CENTRE OF RESEARCH EXCELLENCE WITHIN THE WELLINGTON FACULTY OF SCIENCE AT TE HERENGA WAKA-VICTORIA UNIVERSITY OF WELLINGTON

DIRECTOR'S SUMMARY

The Antarctic Research Centre (ARC) has undergone a period of significant growth over the past year, and several long-term strategic investments are now setting us up to lead key aspects of New Zealand's Antarctic research direction for the next decade and more. The past year was also a period of significant change, with the departure of our previous director, Professor Andrew Mackintosh in April. The leadership skills Andrew demonstrated with our group will be well valued in his new position as Head of the School of Earth, Atmosphere and Environment at Monash University, Australia. Over his 17 years at Victoria University of Wellington, Andrew's strategic vision was fundamental in helping expand our Centre into the avenues of numerical modelling and glaciology, and we will miss his unique and diverse perspectives. However, he remains a part of the global ARC family and his move is a fantastic opportunity for us to help foster and broaden New Zealand's Antarctic research links with Australia.

We also saw the retirement of two other staff members who have been fundamental in our Centre's success of achieving its vision of becoming a world-class Antarctic scientific leader. Alex Pyne retired after 42 years of service to the University, and without his contributions the ARC would not exist in the form it does today. New Zealand's international recognition as innovators in Antarctic science are the direct result of Alex's creativity and vision. His unique contributions to Antarctic geological drilling with the CIROS and Cape Roberts Projects were revolutionary, where he figured out how to overcome countless logistical and technical issues to obtain geological drill-cores from floating sea ice drilling platforms. He then topped these achievements with the design of the even more logistically demanding ANDRILL project, providing sedimentary drill cores from the sea floor beneath the Ross Ice Shelf – the world's largest ice shelf. This technological breakthrough cemented our international reputation as global innovators in Antarctic scientific research, and provided the first direct evidence that the West Antarctic Ice Sheet melted during climates similar to those projected by the end of the century, providing guidance for models used to determine Antarctic contributions to future sea level scenarios.

The second retirement was that of Lionel Carter who was employed as Professor of Marine Geology in 2006. While Lionel only spent the latter part of his illustrious career at the ARC, he was instrumental in the diversification of our research into the oceanographic realm. His broad and insightful perspectives encouraged us all in the ARC to consider the environmental and oceanic consequences of Antarctic ice sheet change to regions beyond that of the icy continent. In particular, he emphasized that New Zealand was a maritime island located at the boundary of the warm Pacific Ocean and cold Southern Ocean, and consequently New Zealand's climate was at the centre of a constant tug of war of competing influences from the polar and tropical regions.

Personally, I have found that taking on the role as Director of the Antarctic Research Centre since April 2019, to be a highly rewarding job. It has been a privilege to work with the ARC team, who are an incredibly driven and ambitious group but work together for a common purpose. It is this collective mindset that has been fundamental for our scientific successes this year, but it is most notable for the building of the solid foundations that will allow major expansion of our field-based research campaigns over the next decade. In this context, the strong emphasis that the ARC has made in investment in early career researchers over recent years is now paying significant dividends. We currently have a critical mass of mid-career researchers who are taking major leadership roles in both national and international science projects. In recognition of this capability, we have seen a large increase in revenue and infrastructure investment within the ARC this year, and this will fuel the future of our research priorities for many years to come.

The year also saw the last field season of the NZARI-funded Aotearoa New Zealand Ross Ice Shelf Project. The science in this project has clearly seen significant success, but it will also leave a lasting legacy in developing New Zealand capability for traverse-based logistics. In particular, it allowed us to more readily conduct remote deep-field campaigns at critically sensitive regions of the West Antarctic Ice Sheet. Over the past four years, the University and the ARC have been instrumental in the success of this project, through the financing and building of a ~$1M Hot Water Drill (HWD) system. The successful deployment of the ARC's HWD through 584 metres of the Ross Ice Shelf in the 2019/20 season is an outstanding achievement from our Science Drilling Office. This achievement has now laid the foundations for a new phase of ambitious NZ-led science within the $49 million MBIE-funded Antarctic Science Platform (ASP) that was launched in 2019.

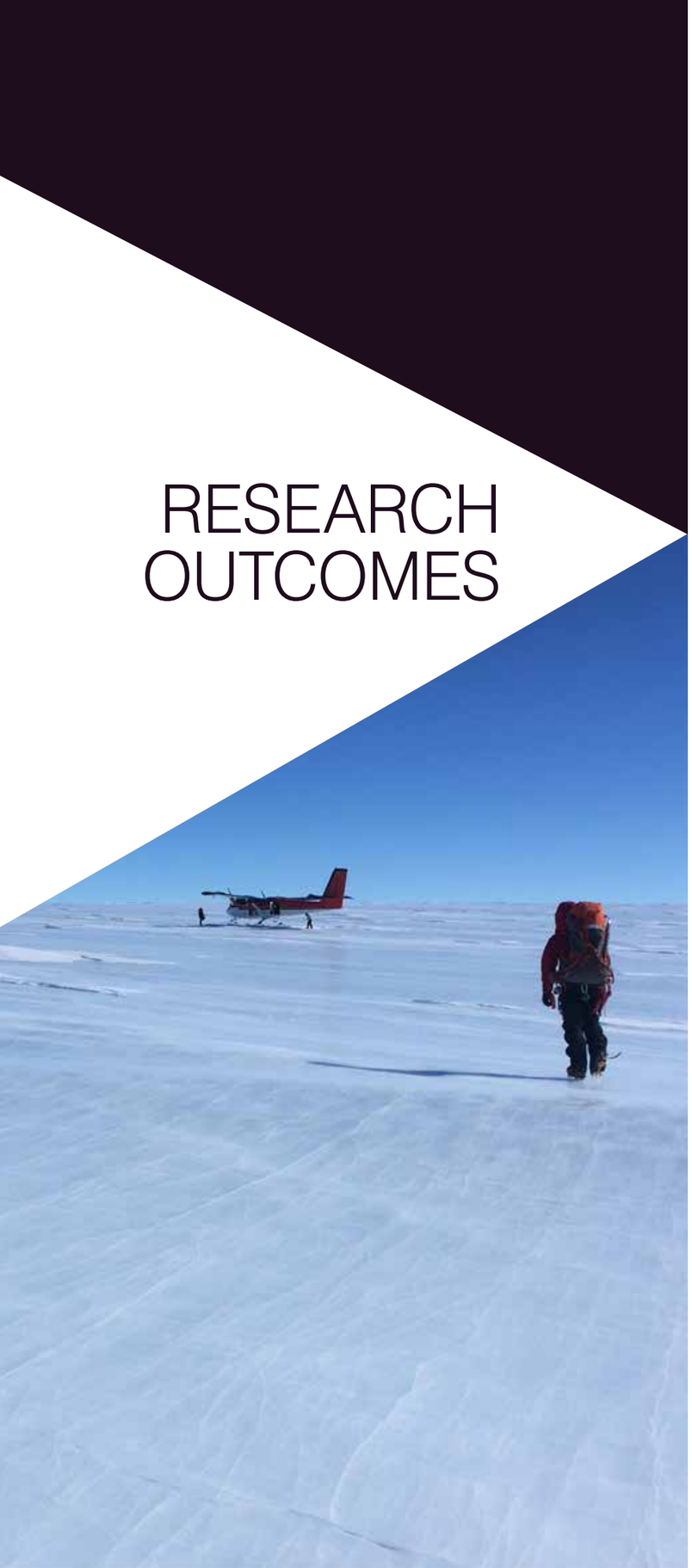
The ASP represents a fundamental shift in the way New Zealand research in Antarctica will be funded in the future. Nancy Bertler has developed a long list of international leadership experience in her career at the ARC, and this was recognised by her appointment as the Director of the ASP. However, our successes in hot water drilling, and the scientific leadership of the entire ARC team was recognised by a total of 19 ARC staff and students being involved in contracts with the ASP. Several of our staff are appointed in key leadership roles, with Tim Naish employed to oversee the strategic direction of the Physical Science aspects of the platform, while Huw Horgan and Richard Levy are co-leading the flagship "Antarctic Ice Dynamics – Past, Present and Future" project. This project is particularly important for the ARC, as it requires major new technological innovations by our Science Drilling Office, led by Darcy Mandeno and Alex Pyne. In 2019, the ARC entered into a partnership with GNS Science and the ASP to co-fund the $1.6m Antarctic Intermediate Depth Drill system. We anticipate this new technology will maintain our place as global leaders and innovators in sub-ice shelf exploration and has great potential to stimulate international partnerships to further broaden the scope, ambition and relevance of the science that New Zealand is are able to conduct in the Ross Sea.

One of the most exciting developments for us this year has been the planning of the Antarctic Science Platform's National Modelling Hub, a joint Victoria University of Wellington, GNS Science, and NIWA facility, with a physical space hosted by the ARC that is due to formally open in 2020. This facility will be managed by Nick Golledge and Liz Keller as part of their roles as chairs of an Expert Group on 'Future Projections' for the ASP. Nick and Liz worked tirelessly in 2019 to get this initiative up and running, and they have successfully led the international search for four new research fellows employed across the three institutes. These new positions and shared facilities will promote a vibrate, cross-discipline research dynamic, and strengthens the ARC's already strong collaborations with NIWA and GNS Science. It is initiatives such as this that underpins our core strategic aim to translate our Antarctic research programme into society relevant outcomes, an aspect of our work that is becoming increasingly more measurable. This is emphasized by Richard Levy and Tim Naish's leadership of the MBIE-funded NZ SeaRise programme, another GNS Science and NIWA collaboration led by the ARC, that is now resulting in more accurate projections of regional sea-level rise in New Zealand. We are also excited to continue to provide key capability to NIWA-led efforts to monitor New Zealand's shrinking glaciers, an area of research that is critical not only for tourism, but also future energy and water resources. It is exciting that the ARC is taking a key role in these initiatives with our Crown Research Institute partners in Wellington, and we hope the successes of these projects will act to seed many more collaborative opportunities with them into the future.

Finally, despite the departure of three senior staff this year, we have also seen an expansion of staff numbers. Oliver Wigmore and Holly Winton were employed in 2019, with Liz Keller, Alexandra Gossart, Lauren Vargo and Jamey Stutz joining in early 2020. It is most satisfying that these appointments are in the form of early career research fellows, as we have long considered a significant part of the ARC's long-term success over the past two decades has resulted from the investment and support of early career researchers. Many of the new positions have been made possible through the above collaborations with NIWA and GNS Science, but we have also been disproportionally successful in obtaining nationally competitive, investigator-led grants. In my mind, this has resulted from the development of an international reputation for the ARC of fostering early career researchers, and a place where the world's best young talent want to come and work. As I write this, the spectre of Covid-19 has brought much of the world to a halt, and it is clear 2020 will bring challenges across all sectors of our society. However, the hard work of the entire ARC team throughout 2019, along with the inherent adaptability that is required to work in hostile environments such as the Antarctic, gives me assurance the ARC is well placed to weather this storm.

Associate Professor Rob McKay
Director, Antarctic Research Centre

RESEARCH OUTCOMES



OUR RESEARCH APPROACH

Rationale

We are rapidly heading towards a climate that is 2-4ºC warmer than present. Ice sheets and oceans take centuries to millennia to fully adjust to climate forcing, and the fundamental changes that we are observing today may be irreversible on human timescales. In order to provide reliable, policy-relevant projections of future climate and sea level, scientists are increasingly relying on computer models. Our Centre has undergone a numerical revolution, and around half of our staff now routinely carry out physics-based computer simulations of past, present and future climate.

We develop confidence in future climate projections if models show skill at simulating present and past climate. Because direct climate and ice sheet observations span the last century at best, reconstructions of past climate conditions provide the only means to assess climate and ice sheet models on their relevant timescales. Furthermore, past climate observations provide insight into the long term "endgame" (equilibrium response), that we will commit our planet to this century based on current warming scenarios. Past climate records also provide insight into the rates and magnitudes of climate and ice sheet changes that may be possible in the near future, and allow the fingerprint of human influences to be identified in the context of natural variability in the climate system.

Outcome-based research

Our research approach is policy-relevant and outcome focused. We aim to improve forecasts of future climate change including their global and New Zealand impacts, for the benefit of humanity. By reducing the uncertainties around future climate and sea-level rise predictions, our cutting-edge research is informing the International Panel on Climate Change (IPCC). Improved understanding of climate change impacts including sea-level rise impacts in the southwest Pacific region provide tangible benefits to all New Zealanders. Our research is leveraged by very strong national and international collaborations and partnerships, and world-leading in-house polar drilling technology provided by the Science Drilling Office. We are funded and supported through a range of MBIE, Marsden, and Rutherford programmes, Antarctica New Zealand and private donations.

In summary, our approach involves:

a. Improving our physical understanding and observation of modern climate, ocean, glacier and ice sheet systems.

b. Acquiring past observations of surface temperature, precipitation, atmospheric composition (greenhouse gases and aerosols), ice sheet, glacier, and sea-ice variability, and oceanic conditions from terrestrial, marine, lacustrine and ice core archives.

c. Developing and improving numerical models of climate-ocean-glacier and ice sheet systems, by advancing the physics, and then carrying out sound evaluation of models against modern observations and past climate reconstructions.

d. Using our models to improve future climate simulations, and projections of glacier and ice sheet contribution to sea-level rise, river flows and other changes in the Earth System.

e. We disseminate our research findings through publications in the world's leading scientific journals, and through education, communication and engagement with the public, practitioners and policy makers.

OUR RESEARCH PROVIDES EXCITING OPPORTUNITIES AND CHALLENGES FOR YOUNG RESEARCHERS, A SOUND BASIS FOR INTERNATIONAL CLIMATE CHANGE ASSESSMENT, AND WILL HELP BUILD A MORE RESILIENT NEW ZEALAND

Nansen Ice Shelf, Antarctica - Photo: Gavin Dunbar

EARTH'S TILT MAY INTENSIFY ANTARCTIC MELTING

New research published in *Nature Geoscience*, confirms a connection between astronomical changes, variations in the amount of carbon dioxide in the atmosphere, and changes in the size and extent of the Antarctic ice sheet.

We've long known that the way the Earth moves in space influences climate – both the shape of our passage around the sun and variations in the Earth's rotational axis affect the distribution and intensity of incoming energy from the sun.

The research led by Richard Levy (ARC and GNS Science), with contributions from ARC's Tim Naish, Nick Golledge and Rob McKay, synthesized scientific drilling results in the Ross Sea and placed these into a global context through integration with long-term deep sea records. This paper represents a culmination of decades of ARC-led drilling research, beginning with Emeritus Peter Barrett's leadership within the Deep Sea Drill Project, CIROS, and Cape Roberts Projects in the 1970s to 1990s, through to the subsequent successes by Richard and Tim with the ANDRILL programme in the 2000s. Combined, these geological records suggest significant variability in the size of the Antarctic ice sheet driven by the predictable changes in Earth's astronomical parameters and threshold changes in atmospheric carbon dioxide levels. Prior to this new research, it remained a mystery as to why the ice sheet responded differently to the same astronomical cycles at different times in the geological past.

To recreate the history of the ice sheet over the past 34 million years, we used geologic records from around Antarctica and linked them to more distant deep-sea marine sediment cores containing the fossil shells of ocean dwelling microscopic organisms known as foraminifera. The oxygen chemistry of foram shells contains a signature that documents the ebb and flow of Antarctic ice. Forams living in the deep ocean accumulate oxygen isotopes in their shells, and different isotopes of oxygen can yield a detailed chemical record of the changing volumes of the Antarctic ice sheet.

The study found a relationship between the sensitivity of the ocean oxygen isotope record and changes in the tilt of Earth's rotational axis relative to its orbit around the sun. These changes coincided with evidence from Antarctic drill cores of large variations in ice sheet expansion and retreat across Antarctica's continental shelves. The results indicate that ice sheets were most sensitive to change driven by Earth's tilt during the early to mid Miocene, a geological epoch between 23 and 14 million years ago when the Earth and its polar regions were temperate. Atmospheric carbon dioxide was higher-than-present during this time and global temperatures, on average, were warmer by 3-4ºC. We also found that sensitivity to Earth's tilt generally decreased after 14 million years when carbon dioxide dropped below 400 parts per million and sea ice became a more persistent feature in the Southern Ocean. These results suggest that ocean dynamics at the Antarctic margin are influenced by changes in the tilt of the Earth's axis, and that ice sheet response to these changes are amplified when it is most exposed to the ocean.

Today, sea ice creates a barrier between the ocean and Antarctica's ice shelves and marine ice sheets and reduces the influence of Earth's tilt on ice sheet sensitivity. Elevated carbon dioxide in the atmosphere and the resulting loss of sea ice around the Antarctic previously played a big role in amplifying the effects of changes in the Earth's astronomical motions on the Antarctic ice sheet. If we fail to achieve carbon dioxide emissions targets and Earth's average temperature warms more than 2ºC, sea ice will likely diminish. We will then jump into a world that is more like that last experienced during the early to mid Miocene, one in which Antarctica's ice sheets were highly variable, driving sea-level changes of 40 metres across glacial cycles.

CONTACT: Richard.Levy@vuw.ac.nz

PAST SEA LEVELS REVEAL POTENTIAL FOR WIDESPREAD ANTARCTIC MELTING

Antarctic ice sheets are capable of widespread melting, raising sea-levels up to 20 metres under current atmospheric carbon dioxide levels, according to an ARC-led study published in *Nature*.

The research shows up to one third of Antarctica's ice sheets melted during the Pliocene epoch around three million years ago, causing sea levels to rise as much as 25 metres above present levels. Carbon dioxide in the Earth's atmosphere was similar to today's levels and in response, temperature was 2-3ºC warmer.

Led by Georgia Grant, a recent ARC PhD graduate now at GNS Science, the study developed a new method as part of her PhD research on geological cores from Whanganui Basin on the west coast of North Island, New Zealand. Georgia analysed marine geological sediments to determine the magnitude of past sea-level change through analysing the size of particles moved by waves. Georgia was able to show that during the past warm period of the Pliocene about three million years ago, global sea levels regularly fluctuated between 5 and 25 metres.

The study, which was funded by the Royal Society Te Apārangi's Marsden Fund, also involved the ARC's Tim Naish, Gavin Dunbar, Rob McKay and Richard Levy, as well as other scientists from GNS Science, Waikato University, the Netherlands, the United States and Chile. Georgia says of critical concern is that over 90% of the heat from global warming to date has gone into the ocean, and much of it into the Southern Ocean which surrounds the Antarctic ice sheet. One third of the Antarctic ice sheet—equivalent to up to 20 metres sea-level rise—sits below sea level and is vulnerable to widespread and catastrophic collapse from ocean heating. The Antarctic ice sheet melted in the past when atmospheric carbon dioxide levels were in excess of 400 parts per million, as they are today.

This supports the idea that a tipping point may be crossed, if global temperatures are allowed to rise more than two degrees, which could result in large parts of the Antarctic ice sheet being committed to melt-down over the coming centuries. It reinforces the importance of the Paris Agreement target.

The study also has implications for computer-based ice sheet modelling. The new sea-level estimates provide a target for testing the results from computer models and improving their ability to make accurate projections of the Antarctic contribution to global sea-level rise.

This new research is consistent with model results by the ARC's Nick Golledge that show long-term ice sheet retreat under current carbon dioxide levels. The rate of sea-level change estimated from this study is also in line with our understanding of climate sensitivity and supports future predictions of one metre of sea-level rise by 2100.

CONTACT: Timothy.Naish@vuw.ac.nz

Georgia Grant (front) and former MSc student Juliet Sefton at Siberia Station drill site, Whanganui - Photo: Darcy Mandeno

Icicles, Antarctica - Photo: Nick Golledge

MELTING ICE MELTS MORE ICE

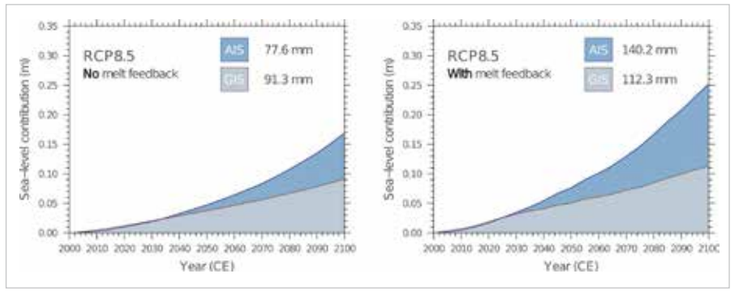
Research published in *Nature* shows even with immediate stabilization of emissions, parts of West Antarctica will still most likely collapse.

In February 2019, Nick Golledge and his collaborators published two new papers in the journal *Nature*. The first of these, led by Nick and bringing together a team of climate and ice sheet modellers from New Zealand, the UK, Canada, the USA and Germany, presented results from simulations of the Greenland and Antarctic ice sheets under low and high greenhouse gas emissions scenarios forecast for the 21st century.

The culmination of nearly three years of effort, the model experiments were the first in the world to use observational datasets to constrain all parts of the mass budget of the two ice sheets. That is, the models correctly simulate the balance between accumulation through snowfall, calving of icebergs, and melting beneath floating ice. Furthermore, by also running climate model experiments in which ice sheet melt was allowed to influence oceanic conditions, Nick and his team explored the significance of a positive feedback effect that previous work had suggested could lead to accelerated ice sheet retreat. Nick's results showed that this feedback could almost double the amount of ice loss, under certain conditions, and also that this meltwater could substantially affect ocean circulation and disrupt global climate. The results also showed lower contributions to global mean sea level by the year 2100 than some previous studies had suggested, which came as something of a surprise.

A thorough statistical reassessment of one such previous study, led by Tamsin Edwards (King's College London, UK) and published jointly with Nick's other paper in *Nature*, showed that the mechanisms invoked to produce previously high sea-level contributions were not necessary for explaining past, or present, ice loss. And without those mechanisms, the predicted sea-level contribution from Antarctica is much lower. Despite this 'good news', however, the models also predicted something much more worrying. Under all scenarios, even with immediate stabilization of emissions, parts of West Antarctica will still most likely collapse. Geological evidence and model simulations suggest that this last happened around 125,000 years ago, at a time when global mean air temperatures were only a degree or two warmer than pre-industrial times - essentially the same as the aspirational 'safe limit' of global warming agreed to in the 2015 Paris Agreement. Global sea level during that past warm period was more than five metres higher than today, suggesting that even relatively modest warming can trigger significant changes to the world's coastlines. Since the process of self-sustaining retreat seems to have already been initiated in parts of West Antarctica, our best hope to limit the scale and speed of future sea-level rise is to implement rapid and widespread emissions reductions across the world.

CONTACT: Nicholas.Golledge@vuw.ac.nz



The consequence of the ice-ocean melt feedback is greater for Antarctica (blue) than Greenland (grey), due to the much larger volume of ocean-terminating ice - Image: Nick Golledge

ACCURATELY PREDICTING ANTARCTICA'S ICE SHEET RESPONSE

A new model could help accurately predict how Antarctica's ice sheets will respond to a warming world and impact global sea-level rise.

Recently completed ARC PhD student Dan Lowry, developed the model and published the results in the open-access *Science* journal *Science Advances*. The purpose of this research was to determine how stable the West Antarctic Ice Sheet is in a warming world to help project future sea-level rise.

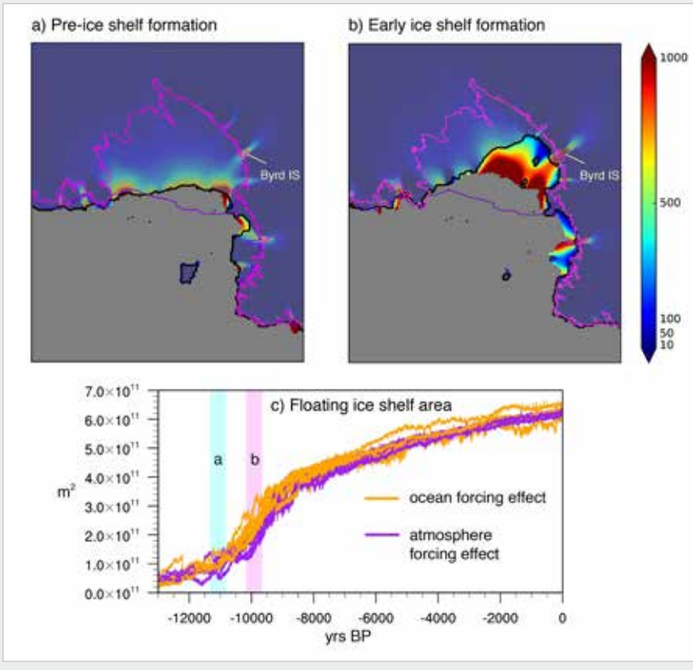
The main findings are that ocean and atmosphere warming are the primary controls on the major glacial retreat that took place in the Ross Embayment since the last ice age. But significantly, the modelling showed that the dominance of these two controls in influencing the ice sheet was different at different times, with melting from underneath the Ross Ice Shelf due to ocean warming becoming the main driver of ice sheet retreat over time.

The model works by simulating the physics of the ice sheet and its response to changes in ocean and atmosphere temperatures. The simulations are then compared to geological records, many of which were developed by ARC researchers, and tested against past scenarios to check its accuracy. This all goes back to the question of sea-level rise and how the processes, that have affected the Antarctic ice sheet through its history, will continue to affect global sea level. The past really is the key to the future.

Dan's supervisor and co-author Nick Golledge says this modelling work is critical to help policy makers and communities develop adaptation and mitigation strategies for sea-level rise. It fundamentally supports sea-level projections for cities and infrastructure in New Zealand and elsewhere.

Dan's research was funded by the Royal Society Te Apārangi's Marsden Fund and in 2017, Dan also received an Antarctica New Zealand Sir Robin Irvine Postgraduate Scholarship to support his research. Dan is now employed at GNS Science to support the ARC's MBIE- funded NZ SeaRise programme.

CONTACT: Nicholas.Golledge@vuw.ac.nz



Simulated formation of the Ross Ice Shelf. As the ice sheet retreats toward Byrd Glacier, ice velocity increases (indicated by panel a and b), and the ice sheet begins to float. The black line represents the grounding line (the transition between grounded and floating ice). With the development of the ice shelf, simulations that use different ocean forcings (orange lines in panel c) show greater variation than model simulations that use different atmosphere forcings (purple lines in panel c), highlighting the importance of sub-ice shelf melting in past ice sheet retreat over the past 10,000 years
Image: Dan Lowry

Measuring a transect along the boundary between the tidal flat and the low salt marsh at Aramoana, Dunedin - Photo: Dan King

ANOTHER PRODUCTIVE YEAR FOR THE NZ SEARISE PROGRAMME - TE TAI PARI O AOTEAROA

Considerable progress has been made in the NZ SeaRise programme to improve simulations of Antarctic ice sheet response to climate warming.

These simulations reduce the uncertainty in estimates of future sea-level change at both the global and regional scale. Stefan Jendersie was appointed as a Research Fellow in Ocean Modelling at the ARC to develop high-resolution ocean modelling capability that will be coupled to ice sheet models to improve understanding of the role of ocean warming on ice shelf melting. Paolo Stocchi (Netherlands Oceanographic Institute), visited New Zealand in 2019, and developed a plan on how to conduct the Glacial Isostatic Modelling component of the project. The research on local relative sea-level projections, to include vertical land movement, is progressing well and will help make better decisions about how to manage the consequences of rising seas in New Zealand.

NZ SeaRise funded PhD student, Dan King, is also making excellent progress on his detailed reconstructions of past sea-level change in Dunedin, Auckland, and Porirua. Colleagues at GNS Science have established a refined reference frame for GPS measurements and have produced a closely spaced grid (100 metre resolution) of vertical land movement for the entire New Zealand coastline using GPS calibrated InSAR satellite data. These data are being integrated with regional estimates of sea-level change to provide the first location-specific probabilistic projections of sea level for New Zealand for the range of IPCC climate scenarios. To achieve this, the team are using the methodology of project collaborator Professor Bob Kopp (Rutgers University, USA). Bob's methodology is the international standard and is being used for global sea-level projections for the IPCC's 6th assessment report.

Public engagement efforts and activities continue. The NZ SeaRise website (www.searise.nz) is online. Rebecca Priestley, Director of the Science in Society research centre at Victoria University of Wellington, conducted a survey to acquire information on public understanding of future sea-level change. Stakeholder activities included targeted meetings with regional councils and iwi. A highly successful science and stakeholder workshop held at the University in December, led to a new case study on impacts of sea-level rise for the vulnerable Southern Firth of Thames and Hauraki Plains, involving Waikato Regional Council and local district councils. A drilling programme in South Dunedin, was completed, to characterise the sub-surface geology and provide information for the groundwater model that will be used to access future flooding hazard in this vulnerable region. The team also conducted a case study for Antarctica New Zealand providing sea-level projections for the Scott Base redevelopment. Finally, a broad range of media interactions and outreach events have helped to raise the profile of the NZ SeaRise programme and sea level research in New Zealand.

CONTACT: Richard.Levy@vuw.ac.nz or
Timothy.Naish@vuw.ac.nz

ICE SHELF-OCEAN MODELS HELPING TO UNDERSTAND SEA-LEVEL RISE

Fringing ice shelves play a key role in stabilizing Antarctica's ice sheets and understanding their future behaviour is critical for predicting global sea-level rise.

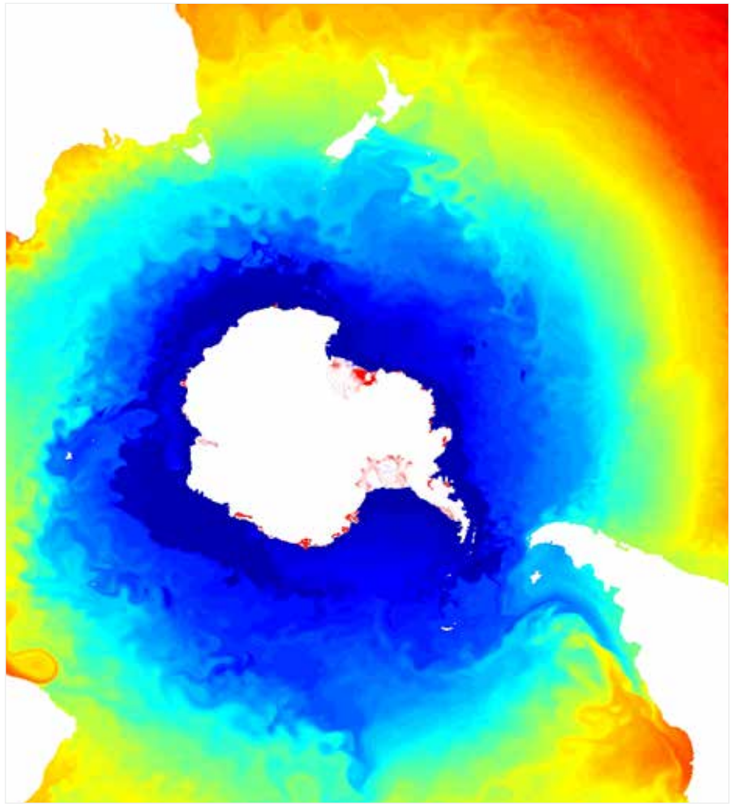
It is widely recognized that basal melting, driven by oceanic heat is the main threat to their structural integrity. A multitude of processes on a wide range of spatial and temporal scales are responsible for delivering heat to the base of ice shelves.

Three modes of ice shelf melting are being distinguished; one induced by sea ice formation over Antarctica's continental shelf seas, the second by heat that is entrained in the global deep oceans at intermediate depths between 1000 and 3000 metres, and the third from summer warming of surface waters near ice shelves.

The mechanisms that are responsible for the three modes are still not well understood, including the elevation of warm water from the deep Southern Ocean to the continental shelf seas, the subduction of warm surface water under the front of ice shelf cliffs, deep ice shelf melting near grounding lines, and the evolution of the boundary layer between the ice shelf base and the ocean beneath.

Numerical ice shelf-ocean models, constrained by observations are an effective method to investigate these different mechanisms, and explore the underlying physical processes and their interactions to predict the evolution of the system in the context of warming oceans.

This work, conducted by the ARC's Stefan Jendersie, is linked into the NZ SeaRise programme that aims to project sea levels along New Zealand's coasts and expected impacts under the different warming scenarios as projected by global climate models (GCM). Stefan developed an ensemble of currently five nested ice shelf-ocean models that encompasses different geographic domains at a range of resolutions, with the largest being the Southern Ocean Cirumpolar Simulation and the smallest, the Terra Nova Bay Model (8 kilometre and 180 metre resolution, respectively). By using GCM outputs as boundary conditions, the ensemble is designed to bridge a crucial gap whereby current GCM neither simulate ocean cavities under ice shelves nor have sufficient spatial resolution to explicitly capture some of the very important meso-scale oceanographic processes that lead to ice shelf melting.



Simulated ocean surface temperature and ice shelf melt rates in the year 2080. Red ocean is about 23°C and dark blue is -1°CDark; red ice shelf is where melt rates are greater than 5 metres per year, blue is where the ocean water freezes to the ice base - Image: Stefan Jendersie

Coupling these new ocean-ice shelf models to existing ice sheet models operated at the ARC will fundamentally improve understanding of where, when and how much ice shelf melting impacts the mass loss of Antarctica's ice sheets and contribution to global sea-level rise.

CONTACT: Stefan.Jendersie@vuw.ac.nz

Loading the Twin Otter at KIS1 Camp, Antarctica - Photo: Theo Calkin

ANTARCTIC SCIENCE PLATFORM TAKES FLIGHT

Inaugural Platform Director, Nancy Bertler, and her leadership team have had a very busy and successful first year working with the Steering Group chaired by ex-Antarctica New Zealand Chief Executive, Gillian Wratt, to get the Antarctic Science Platform up and running.

The purpose of the Antarctic Science Platform (ASP), funded at $49m by the New Zealand Ministry of Business Innovation and Employment (MBIE) and hosted by Antarctica New Zealand, is to conduct excellent, world-leading science to understand Antarctica's impact on the global earth system, and how this might change in a warmer world of +2ºC (the Paris Agreement target). Nancy oversaw that project proposals were rigorously reviewed by an independent science advisory panel comprising the world's leading Antarctic scientists and chaired by Rob Dunbar (Stanford University, USA), thus allowing $38m of research investments to be approved. This process has ensured the Platform's science plan is well-integrated, both nationally and internationally, and is addressing the highest priority questions for both New Zealand and the world concerning the response of Antarctica's physical and biological systems to climate change.

The funds support four strategic research projects, two expert groups, four research fellowships in modelling, and a contestable funding round including support for early career researchers.

The world-leading scientific capability of the ARC has resulted in numerous staff playing roles in the platform. Tim Naish is providing strategic science leadership of the Physical Sciences Programme, which contains two of the core research projects, by coordinating the national and international science community to improve our understanding of Antarctica's contribution to future sea-level rise. This programme highlights our strong collaborative links to our GNS Science partners, with Richard Levy and Huw Horgan co-leading one of the flagship research projects - 'Antarctic Ice Dynamics – Past, Present, and Future'. Projections of Antarctic ice sheet melt being produced in this project will feed into IPCC reports and the MBIE-funded NZ SeaRise programme, co-led by Richard and Tim, which is providing improved location-specific sea-level predictions for anticipating and managing the impacts of sea-level rise in New Zealand.

Nick Golledge and Liz Keller are chairing the Expert Group on 'Future Projections' which aims to prioritise and coordinate modelling experiments and to provide policy-ready projections for stakeholders and decision-makers. Building on longstanding partnerships, a collaboration between Victoria University of Wellington, NIWA and GNS Science, has created the ASP National Modelling Hub, hosted in new facilities within the ARC, due to be formally opened in 2020. The Hub, managed under the Expert Group 'Future Projections', will co-host four leading research fellows and facilitates interactions between diverse modelling experts, bringing perspectives and skills to the wider science community. The fellows have a background in ice-ocean, regional climate, biogeochemical modelling and large data analysis. The Hub supports the four core projects and is addressing key questions around better predicting the future contribution Antarctic meltwater contribution to sea-level rise, changes in ocean uptake of heat and carbon dioxide, changes in ocean currents, sea ice extent, nutrient fluxes, and ecosystem dynamics and impacts. Overall, a total of 14 ARC staff and five students contribute significantly to strategic research priorities of the ASP.

Of equal importance, the ASP is also driving technical innovation. The ARC's Science Drilling Office team Darcy Mandeno and Alex Pyne supported a hugely successful field season, drilling 584 metres through the Ross Ice Shelf near the grounding line at the Kamb Ice Stream on the Siple Coast of West Antarctica, providing critical access to the Ross Ice Shelf ocean cavity near the grounding line. This allowed the team to collect short sediment cores, conduct in situ measurements in the ocean cavity, and provided access for NIWA and NASA colleagues to deploy a long-term mooring, and an underwater remotely operated vehicle, called Icefin. At the same time, the team is pushing ahead with the development of a new, lightweight sediment drilling system to recover the longer sediment records below the ice shelf that may hold a precious archive of West Antarctic Ice Sheet behaviour from the geological past when the world was known to be 1-3ºC warmer.

For more information please visit: www.AntarcticSciencePlatform.org.nz

THE FIRST ANTARCTIC SCIENCE PLATFORM FIELD SEASON COMPLETED

The 2019/20 season saw the Antarctic Ice Dynamics Project team working alongside the NZARI Ross Ice Shelf Project to directly access the ocean cavity beneath the Ross Ice Shelf near the grounding zone of Kamb Ice Stream on the Siple Coast.

The Antarctic Ice Dynamics Project is a collaborative study led by GNS Science as part of the Antarctic Science Platform's Project-1, and will be a major focus for the ARC over the coming years. The interest in the Siple Coast region is motivated by the knowledge that the West Antarctic Ice Sheet (WAIS) has an important role to play in future sea-level rise. A key control on whether the WAIS grows or shrinks are the large ice streams by which most ice leaves the ice sheet and enters into the floating ice shelves and ocean. These ice streams are capable of speeding up and slowing down (or even stopping) on geologically short (years to centuries) timescales, and our limited understanding of the processes governing these behaviours introduces significant uncertainties to models used to conduct future projections.

The 2019/20 field location, approximately 850 kilometres from Scott Base, was supported primarily by a traversing train of sleds towed by large snow tractors that took 14 days to reach the site. A 584 metre access hole was melted through the ice using Victoria University of Wellington's Hot Water Drilling (HWD) system. The HWD system melted approximately 150 tonnes of ice. The hole was kept open for nine days before the deployment of a long-term oceanographic mooring. Numerous experiments were run throughout the season, examining the ice shelf, ocean cavity, and underlying sediment properties. Robots swam, probes probed, and corers cored. Highlights included retrieving shallow cores that record past ice sheet and ice shelf behaviour, seeing the underside of the ice shelf through the eyes of our US collaborators tethered ROV (Icefin), and NIWA recording the previously unknown temperature and salinity structure of the water column at this remote and important location.

Science experiments were also conducted in the region near the borehole site, with glaciological surveys and sub-ice geophysical survey work characterising the broader ice stream behaviour, and laid the groundwork for identifying the exact locations for the next two seasons of direct access drilling on the Siple Coast. This work is anticipated to culminate in the intermediate depth coring scheduled for the 2021/22 season. Beyond the Siple Coast, separate teams sampled the rock outcrops surrounding Byrd Glacier in a study of long-term ice thickness changes and deployed permanently recording GPS stations on the front of the Ross Ice Shelf to investigate its velocity variability. ASP Project-1 is off to flying start, and we are grateful to everyone who pitched in to help make it happen - in particular, Antarctica New Zealand to get us to this remote, but critically important region.

CONTACT: Huw.Horgan@vuw.ac.nz

MSc student, Theo Calkin, with the gravity corer - Photo: Theo Calkin

RECONSTRUCTING PAST ICE THICKNESS CHANGES

Building on successful cosmogenic surface exposure dating campaigns in Victoria Land, the 2019/20 field season saw the ARC's Jamey Stutz and Shaun Eaves move south to Byrd Glacier, one of the largest glaciers in East Antarctica.

Supported by Project 1 of the Antarctic Science Platform, this project aimed to provide terrestrial constraints on past changes in ice sheet geometry using cosmogenic surface exposure dating. The priority this year was Byrd Glacier - a major outlet glacier draining approximately 10% of the East Antarctic Ice Sheet to the Ross Ice Shelf– the gatekeeper of the marine-based West Antarctic Ice Sheet.

They targeted Lonewolf Nunataks, a remote site situated upstream of the Byrd Glacier fjord, on the edge of the polar plateau. This lonely group of rocky peaks have a long history in NZ-led polar exploration after a four-man New Zealand geological and surveying expedition made the first sighting of these outcrops in 1960, and several of the nunataks are now named after sled-dogs that pulled that team.

The site was accessed via more comfortable means - a scenic Twin Otter flight along the Transantarctic Mountains south from Scott Base. At each of the three nunataks visited, they found the dolerite bedrock to be littered with cobbles of exotic lithologies – a clear sign that ice had previously covered these outcrops and a window into geological diversity of the East Antarctic continent. We collected samples of these glacial erratics in systematic vertical transects, which extended up to 300 metres above the present-day ice surface.

The samples have recently arrived in Wellington, where work will soon begin in the Victoria University Cosmogenic Laboratory to unveil when and how fast the Byrd Glacier changed in the centuries and millennia prior to human observations.

CONTACT: Shaun.Eaves@vuw.ac.nz
Jamey.Stutz@vuw.ac.nz

Joides Resolution, IODP leg 374 - Photo: William Crawford, IODP

OCEAN DRILLING LEGACY CONTINUES

ARC continues to contribute to the success of the IODP Program with new drilling expeditions and frameworks for future ocean drilling.

A flagship accomplishment for International Ocean Discovery Program (IODP) Expedition 374, which investigates West Antarctic Ice Sheet history over the past 20 million years in the Ross Sea, was the publication of the *Scientific Proceedings* volume. This volume is the cornerstone document of the expedition and was led by the ARC's co-chief scientist Rob McKay, alongside Italian co-chief Laura De Santis (Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Italy). It is the culmination of over five years of planning and implementation bringing together a large international collaboration of 33 scientists. This 871 page volume synthesizes all of the initial results of this expedition, and like all previous IODP proceedings volumes, will guide analysis on the cores over many decades. The detailed scientific results are now widely being communicated to the scientific community, with 62 conference presentations already presented from this expedition so far, including plenary and invited presentations at the International Symposium of Antarctic Earth Science and the American Geophysical Union Fall Meeting during 2019.

Looking to the future, Rob and Laura submitted a brand new IODP drilling proposal in April 2019, which also included ARC proponents Richard Levy, Huw Horgan and Tim Naish. The aim of this proposed expedition is to drill an East to West transect on the Ross Sea continental shelf that seeks to obtain unprecedented insights into the earliest ice sheets in both East and West Antarctica. The targets also seek to obtain the first detailed geological long-term reconstructions of "pre-icehouse" climates at high latitudes in Antarctica during the Late Cretaceous to Eocene (100 to 34 million years ago); while another novel aspect of this new proposal is the aim to constrain timing of Ross Sea tectonic rifting, and how these tectonic processes may have influenced ice sheet evolution over the past 100 million years. The scientific rationale for this new proposal was well-received by the IODP Science Evaluation Panel, and after some suggested revisions, a resubmission of this proposal is anticipated for late 2020.

Rob was also one of 16 scientists internationally to be selected to write the scientific framework for the next 25 years of scientific ocean drilling, after the current phase of IODP comes to an end in 2023. This document is a major stepping-stone towards ensuring that the 50-year legacy of scientific ocean drilling continues to provide innovative new science into the future. Rob was a lead author on the Flagship initiative chapter "Groundtruthing Future Climate Change" that sets out a strategy on how scientific drilling can directly inform on climate change at policy relevant timescales, through integration with modelling communities and instrumental timescale data scientists.

CONTACT: Robert.McKay@vuw.ac.nz

ARC PARTICIPATES IN THE LARGEST POLAR EXPEDITION EVER

Ruzica Dadic will take part in MOSAiC, the first year-round expedition into the central Arctic exploring the Arctic climate system and the role it plays in climate change.

Spearheaded by Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI), MOSAiC (Multidisciplinary drifting Observatory for the Study of Arctic Climate) will focus on direct in-situ observations of the climate processes that couple atmosphere, ocean, sea ice, biogeochemistry, and ecosystems. Ruzica is the sole New Zealand participant, and one of hundreds of researchers from 20 countries who will take part in the operation. Scientists rotate in roughly 2-month shifts on board the icebreaker *RV Polarstern*, drifting with the sea ice across the central Arctic during the years 2019-2020. The expedition set sail in September 2019.

Ruzica is participating as part of the project "Direct imaging of 3D snow and sea ice microstructure by micro-CT", which is led by the WSL Institute for Snow and Avalanche Research SLF, Switzerland.

In February 2019, Ruzica participated in a training camp to prepare scientists for the expedition. The weeklong training took place in Hailuoto, Finland, and was designed so that all participating scientists, who have a special interest in sea ice, were trained in handling each others instruments. Considering the logistical scale and the integrated nature of MOSAiC, the scientists need to not only operate their own instruments, but contribute to daily operations to ensure the success of the project while onboard the icebreaker.

CONTACT: Ruzica.Dadic@vuw.ac.nz

RV Polarstern in sea ice - Photo: AWI

FROM THE POLES TO THE TROPICS

Indonesia is as far from the polar regions as one can get. Nonetheless the link between them is profound.

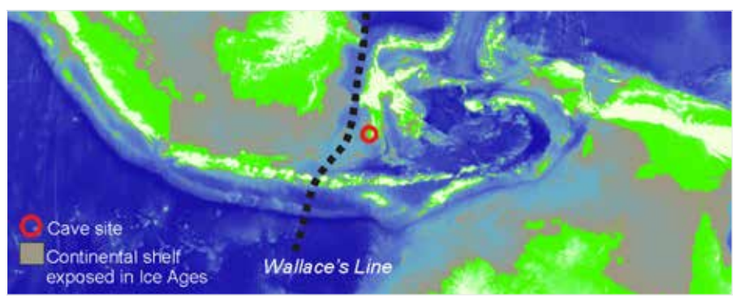
On the scale of ice ages, this link comes about through the impact of changing ice volume on sea level, which dramatically changes the land area in what is now the 'Indonesia maritime continent' – but it was much less maritime in the last ice age. Exposure of the continental shelves results in a dramatic decrease in the strength of deep atmospheric convection and thus rainfall in the Indo-Australian region.

A biogeographic consequence of this sea level fall was pointed out by evolution pioneer and contemporary of Charles Darwin, Alfred Russell Wallace; the channel (Wallace's Line) between the islands of Bali and Lombok is so deep it was a barrier to the migration of Asian animals into Australasia across the otherwise widely exposed continental shelves. So, tigers are (were) found in mainland Asia, Sumatra, Java, Bali (the last Balinese tiger was killed in the 1920s), but nowhere east of there.

A new study, by PhD student Claire Krause (The Australian National University) and including ARC co-author Gavin Dunbar, published in *Earth and Planetary Science Letters* investigates stalagmites collected in Sulawesi, Indonesia in 2009 by Dan Zwartz (previously with the ARC), and colleagues from Indonesia and Australia. Oxygen isotopes in the calcium carbonate that form the stalagmites, combined with radiometric ages from the abundance of uranium and thorium allow for reconstruction of monsoon rainfall patterns. These revealed that the exposure of the continental shelves in ice ages resulted in a dramatic decrease in the strength of deep atmospheric convection and thus rainfall across the Indo-Australian region.

CONTACT: Gavin.Dunbar@vuw.ac.nz

Flooding and exposure of the continental shelf - Image: Gavin Dunbar



Shaun Eaves showing a boulder with glacier striae, Mt Ruapehu - Photo: Emily Warren-Smith

GLACIER DETECTIVES PIECE TOGETHER PAST CLIMATE CHANGE

ARC researchers have been piecing together evidence left by glaciers, combining state-of-the-art geological dating techniques and computer modelling to provide quantitative constraints on past natural climate variability in New Zealand.

Glaciers drag themselves over Earth's surface, eroding and transporting rocks and sediment, creating characteristic glacial landscapes that can persist for tens or hundreds of millennia. These ice age clues left behind after glacier retreat provide windows into past climates.

In the journal *Quaternary Science Reviews*, ARC researcher Shaun Eaves and co-authors presented a new chronology of length changes from New Zealand's northernmost glaciers, situated on Mt Ruapehu. Applying a technique known as cosmogenic surface exposure dating to ancient glacial landforms, Shaun and his colleagues showed that deglaciation of the volcano after the last ice age was punctuated by a significant re-advance that occurred 12,000-14,000 years ago. This advance coincides with a cold interval seen in geological records from elsewhere in the southern mid-latitudes, as well as in Antarctic ice cores. More recently, during the Holocene interglacial (the last ~11,000 years), glaciers on Mt Ruapehu have undergone overall retreat, punctuated by several advances, including during the Little Ice Age (around 150-400 years ago). Shaun and others, reconstructed the former snowlines associated with the Little Ice Age glacier extent and found that retreat over the last century is consistent with that expected from the observed 1°C temperature increase detected by long-term weather station data.

Well-dated former glacier limits, such as those described above, afford useful targets from which we may quantify past climatic changes using physics-based computer models. Published in *Geology* this year, Shaun, and fellow ARC researchers, Brian Anderson and Andrew Mackintosh (now Monash University), used such numerical modelling to explain why a former glacier situated in Cobb Valley (northwest Nelson region), retreated many kilometres during the last ice age. Between 25,000 and 20,000 years ago the former 25 kilometre long Cobb Valley glacier reduced in length by more than half. This retreat is curious as most glaciers in New Zealand, and around the world, remained at their maximum extent during this interval. Shaun's model experiments showed the low elevation and low surface-slope of this former glacier enhanced its sensitivity to climate change, such that warming of just 0.5°C was enough to drive the retreat recorded in the geological record. In contrast, steeper glaciers, with higher-altitude accumulation areas, were more resilient to this small climatic change. These results highlight the importance of glacier geometry in dictating glacier response to climate change and further demonstrate the utility of numerical modelling to quantify the climatic significance of past glacial change.

CONTACT: Shaun.Eaves@vuw.ac.nz

NEW ZEALAND'S LITTLE ICE AGE REALLY WAS QUITE LITTLE

Master's research provided quantitative constraint on the magnitude and timing of past glacier length changes in New Zealand.

The Little Ice Age is commonly cited as one of the greatest glacier advance events of the Holocene, but its global influence is debated. Master's student Lisa Dowling examined this debate in her MSc thesis, completed in 2019, in which she provided quantitative constraint on the magnitude and timing of past glacier length changes at Dart Glacier in the Mt Aspiring region of New Zealand's Southern Alps. Previous research undertaken in the 1980s used the size of lichens on boulders atop a well-defined moraine to estimate that the glacier was 4.5 kilometres longer than present in the year 1850, during the Little Ice Age. However, the speed of lichen growth is poorly constrained, making this age highly uncertain. Supported by a Marsden Fast Start grant led by ARC researcher Shaun Eaves, Lisa applied cosmogenic beryllium-10 dating, which uses the well-constrained rate of beryllium-10 production by cosmic radiation in the boulder surfaces, to estimate the time since deposition by the glacier.

Lisa showed that this landform actually formed in the year 1696 (± 44 years), also during the Little Ice Age, but 150 years earlier than the lichen-based estimate. Furthermore, Lisa found an older glacial landform situated further down valley which formed 7,800 ± 300 years ago, indicating the Little Ice Age advance was a relatively small event in the wider context of the present Holocene interglacial. This result contrasts evidence of a longer and larger event in the Northern Hemisphere. Lisa received First Class Honours for her thesis and a highly competitive Masters Publication Scholarship to support the publication of her results.

CONTACT: Shaun.Eaves@vuw.ac.nz

IS CLIMATE CHANGE MAKING GLACIERS RETREAT?

This seems like a simple question with an obvious answer. But, as in many areas of science, reality is far more complex and the answer requires careful work.

Until now there have been just a handful of studies that have formally attributed glacier retreat to climate change; Gerard Roe and others (*Nature Geoscience,* 2017) showed that the current rate of glacier retreat is far outside natural variability; and Ben Marzeion and others (*Science,* 2014) showed that the difference between glaciers in a 'natural' climate and a human-modified climate could only be robustly detected after 1990. These studies were difficult to interpret in a New Zealand context as many glaciers here were advancing after 1990. The reasons behind that advance are now clear as Andrew Mackintosh and others (*Nature Communications,* 2017) showed, a regional cooling in the 1990s supplied enough additional mass to the glaciers to make them advance.

The large year-to-year variability in glacier mass changes makes attribution studies difficult, so Lauren Vargo, who completed her PhD in the ARC in 2019, took a new approach. Rather than relying on long records of glacier mass balance (which are very rare), she looked at a few extreme years of glacier mass loss and asked the question – could these extreme negative mass balances happen in a 'natural' climate? Lauren did this by driving a glacier mass balance model with climate data downscaled from a series of Global Circulation Models (GCMs), both as a set of different GCMs (to get the spread from a range of different models) and as a number of different realisations of the same GCM (the CESM large ensemble). By comparing the model output between a 'natural historic' and anthropogenically-altered climate, she was able to calculate whether human-induced climate changes caused these extreme melt years, and if so, by how much?

The results showed that for the two glaciers which have mass balance records in New Zealand, the extreme melt years (2011 and 2018) were at least 10 times more likely to have happened in the human-modified climate. The end-of-summer snowline records provide an easier to measure but less direct indication of glacier mass change. However, these records can determine melt by measuring how far stakes drilled into the glacier in spring have melted out from the glacier at the end of each summer. For the additional nine glaciers measured, each one was more likely to have experienced these very high snowlines in the human-modified climate.

As a result of this work, we now have much more certainty about the role of anthropogenic climate change – and yes, climate change is making glaciers retreat! Critically, this work has developed a new toolkit that can be applied much more widely to understand glacier loss, and which does not depend on sparsely distributed long-term records of mass balance.

CONTACT: Brian.Anderson@vuw.ac.nz
Lauren.Vargo@vuw.ac.nz

Lauren Vargo measuring the total melt over the summer of Brewster Glacier; in this case the melt was over five metres of water equivalent - Photo: Lauren Vargo

SCIENCE DRILLING OFFICE

The Science Drilling Office is hosted within the Antarctic Research Centre, comprising Darcy Mandeno as Operations and Field Engineer, and Alex Pyne - now as Antarctic Drilling Advisor, following his retirement.

With an eventful year culminating in a successful hot water drilling (HWD) season at Kamb Ice Stream in Antarctica, the Science Drilling Office (SDO) took time in June to take stock and celebrate the legacy of Alex Pyne upon his retirement. Attended by many of Alex's past and current colleagues alongside industry partners from Webster Drilling and Exploration, we celebrated the highs and lows of a prolific and distinguished career in Antarctic drilling and science support. Alex continues with the ARC in a part-time capacity to provide critical technical support to our current projects.

Over the last few years the SDO has continued its focus with HWD for ice shelf and ocean cavity access after the construction of the VUW HWD1000 facsimile of a British Antarctic Survey's 1000 metre HWD in 2016. This system has now been successfully utilised during the summers of 2016/17 at Windless Bight, 2017/18 for the Ross Ice Shelf Project (HWD2), and continuing this year's 2019/20 season for the Kamb Ice Stream Project (KIS1/HWD1). A further four drill sites are planned under the Antarctic Science Platform (ASP) for the next five to six years.

A rare Antarctic field work hiatus for Darcy over the 2018/19 season, allowed him to work with long-time SDO collaborator Jeff Rawson to reassess the power requirements from our current generators for the HWD - as drilling operations in 2017/18 had persisted in throwing up a few technical issues with the engine fuel system. Alex continued with the scoping and conceptual design work for the Antarctic Intermediate Depth Drill (AIDD) core system, a major contribution to future seafloor and potential sub-glacial bed coring capability.

With the additional works in retrofitting three new engines, and the resulting electrical and mechanical reconfiguration with the existing chassis and genset systems required the focussed expertise of diesel mechanic Jeff and engineer Darcy. Together, they spent six weeks in the workshop after three new Deutz diesel engines arrived in April 2019, supplied by Shaw's Diesel Ltd of Auckland.

Testing and running on Diesel, and then AN8 (Kerosene), was completed at Webster Drilling and Exploration's Porirua workshops. Swapping to AN8 with oversight of Peter Shaw from Shaw's Diesel ensured that the generators were in the best state they could be for the 2019/20 drilling season at Kamb Ice Stream. All gensets were ready for their southbound journey to Christchurch in August in time for a winter flight ensuring enough time to make the 1200 kilometre traverse from Scott Base to the Kamb Ice Stream drill location.

A large part of the remainder of 2019 involved effort from Darcy with Alex and external independent liquid fuel heater expert David Howell of Gaslabs Ltd, to get the existing hot water drill kerosene heaters certified to the required Worksafe NZ legislative standards. This required justified engineering exemptions where the legislation could not be applied in a safe way to the system within an Antarctic context. David was able to evaluate additional risk mitigation systems to the operation and observed a test rig setup by Darcy. This involved using the heater in an environment closely mimicking Antarctic ambient conditions and provided supporting data submitted for the Worksafe NZ report.

In late September and early October, Alex, Darcy and Rebecca Pyne (GNS Science Ice Core Lab Manager) attended the Copenhagen Eighth Ice Drill Symposium. This meeting, held every four to six years, provided a rare opportunity to meet and discuss with the rest of the Arctic and Antarctic drilling community the latest drilling and field support technologies supporting science in the polar regions.

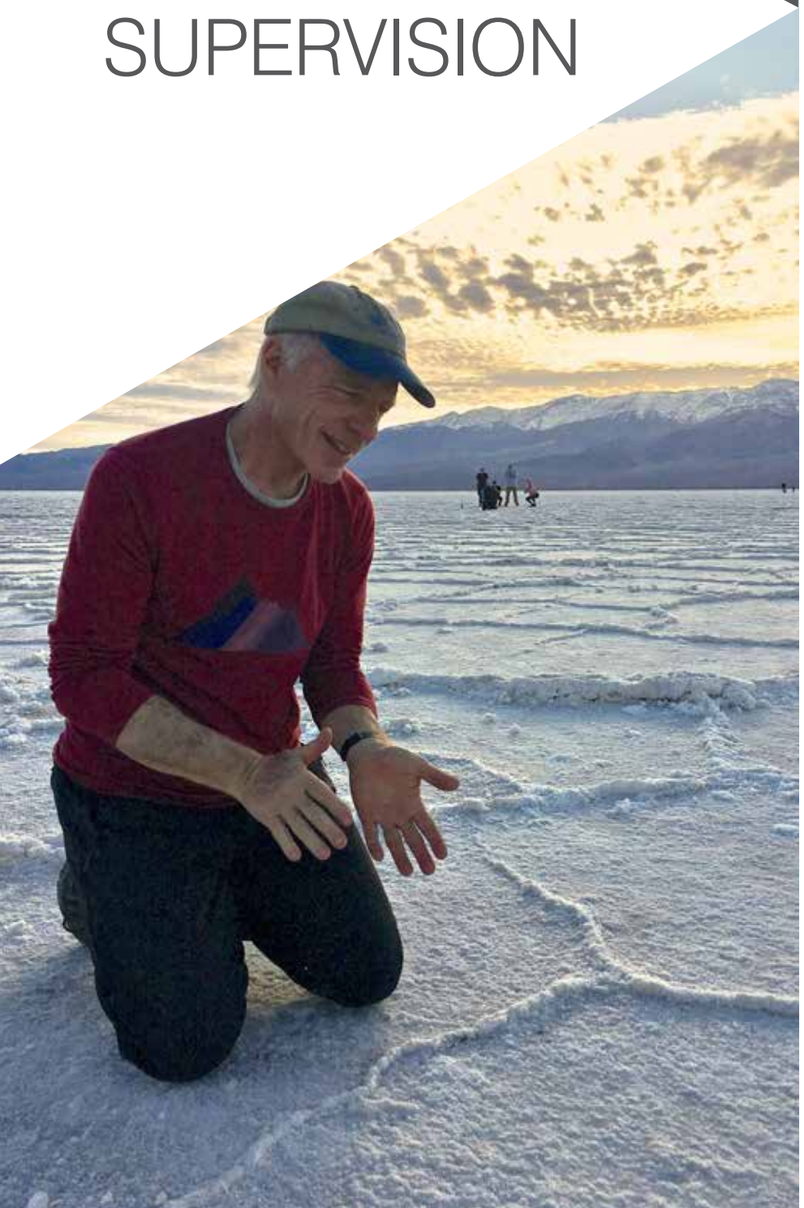
The close of the year saw hot water drilling operations at Kamb Ice Stream, Ross Ice Shelf approximately 850 km from Scott Base. The science was led by ARC researcher Huw Horgan (co-PI) with Darcy as the Drill Systems Field Leader along with drill team members, Jane Chewings (seconded to ARC from the School of Geography, Environment and Earth Sciences), Hedley Berge (contracted Senior Electrician), Sean Heaphy (contracted Mechanic), Tim McPhee (contracted Electrician) and Da Gong (Jiling University, China). The team drilled and maintained a 350 millimetre diameter, 584 metre deep hole through the Ross Ice Shelf for nine days allowing various scientific observations, data collection and instruments to be installed. Despite challenges from logistical constraints and HWD technical issues the system proved once again to be a capable asset for gaining access to one of the least known bodies of water in the world.

The success of this season's scientific objectives was once again built on the ARC's reputation for innovative world-class technical, drilling and scientific capabilities in Antarctica, a satisfactory conclusion to another busy year.

CONTACT: Darcy.Mandeno@vuw.ac.nz

The drill team, KIS1 (L-R) Darcy Mandeno, Hedley Berge, Jane Chewings (sitting), Tim McPhee, Da Gong, and Sean Heaphy (in front)
Photo: Jane Chewings

TEACHING & SUPERVISION



Our staff support a wide range of teaching being carried out in courses within the School of Geography Environment and Earth Sciences.

The ARC supports a significant proportion of the research being carried out in the paleoclimatology theme through teaching and graduate supervision. There is also a close interaction between ARC staff and projects with other research programmes in geophysics, geology, physical geography, and the environmental studies programme.

Our teaching contribution includes lectures in both undergraduate and graduate courses as well as supervision of graduate students enrolled with the School of Geography, Environment and Earth Sciences (SGEES). In 2019, our staff supervised 19 PhD and five MSc students, with ten students completing their thesis.

COURSES ARC STAFF TAUGHT IN

ESCI 111	The Earth System: An Introduction to Physical Geography and Earth Sciences
ESCI 132	Antarctica: Unfreezing the Continent
ESCI 201	Climate Change and New Zealand's Future
ESCI 204	Petrology and Microscopy
GEOG 220	Hydrology and Climate
ESCI 241	Introductory Field Geology
ESCI 301*	Global Change: Earth Processes and History
GEOG 318	Quaternary Environmental Change
ESCI 349/449*	Earth Sciences - International Field Course
ESCI 403*	Stratigraphy and Paleoenvironments
ESCI 412*	Paleoclimatology
GISC 424*	Introduction to Remote Sensing
ENVI 520	Environmental Management

* An ARC staff member was the course co-ordinator

GRADUATE COMPLETIONS

Lisa Dowling (MSc)
The Holocene glacial history of Dart Glacier, Southern Alps, New Zealand.
Supervised by - Shaun Eaves (ARC/SGEES) and Andrew Mackintosh (then ARC).

Clarrie Macklin (MSc)
Finite-element modelling of Haupapa/Tasman Glacier's basal sliding events.
Supervised by - Huw Horgan (ARC/SGEES) and Brian Anderson (ARC).

Rebecca Pretty (MSc)
Ice dynamics and ocean productivity during the Late Miocene, offshore Wilkes Land, East Antarctica.
Supervised by - Rob McKay (ARC) and Tim Naish (ARC).

Simon Reeve (MSc)
Development of an improved ramped pyrolysis method for radiocarbon dating and application to Antarctic sediments.
Supervised by - Rob McKay (ARC) and Tim Naish (ARC).

Nikita Turton (MSc)
East Antarctic Ice Sheet and Southern Ocean response to orbital forcing from Late Miocene to Early Pliocene, Wilkes Land, East Antarctica.
Supervised by - Rob McKay (ARC) and Tim Naish (ARC).

Lukas Eling (PhD)
Early Holocene Antarctic climate variability - drivers and consequences as captured by major ions in the Roosevelt Island Climate Evolution (RICE) ice core.
Supervised by - Nancy Bertler (ARC) and Rob McKay (ARC).

Dan Lowry (PhD)
Deglacial climate and ice sheet evolution of the Ross Embayment, Antarctica.
Supervised by - Nick Golledge (ARC) and Nancy Bertler (ARC).

Abhijith Ulayottil Venugopal (PhD)
Glacial Antarctic warm events as captured by the RICE ice core.
Supervised by - Nancy Bertler (ARC) and Guiseppe Cortese (GNS Science).

Lauren Vargo (PhD)
Drivers of modern New Zealand glacier change.
Supervised by - Huw Horgan (ARC/SGEES) and Brian Anderson (ARC).

Ross Whitmore (PhD)
Outlet glacier and landscape evolution of Victoria Land, Antarctica.
Supervised by - Andrew Mackintosh (then ARC) and Kevin Norton (SGEES).

INTERNATIONAL FIELD COURSE TO THE USA

In November 2019, Warren Dickinson (ARC course co-ordinator) and Nikita Turton (ARC MSc graduate) along with Christine Siddoway and Solomon Seyum (Colorado College, USA) ran a four-week geology field trip in the southwestern USA, as part of the ESCI 349/449 course. Nine students from Victoria University of Wellington and five from Colorado College took part in the trip. The first two days were spent studying the San Andreas Fault, which is similar to the Alpine Fault, and threatens about 20 million people in Southern California. The next 10 days were spent at Borrego Springs Research Station where exposures at Split Mt Gorge record the opening and closing of the Gulf of California over the past six million years.

The American tradition of Thanksgiving dinner took place in a snowstorm at an old homestead in the Mojave Desert. The feast, not unlike those at McMurdo Station in Antarctica, included mashed potatoes, sweet potatoes, various kinds of salads, cheese cakes, pavlovas, and fruit pies, all centred around a deep-fried "Turducken" - a turkey stuffed with a chicken, stuffed with a duck.

The group then spent the next eight days at the SHEAR Centre just outside Death Valley owned by the University of Washington. One could spend three months studying the geology of Death Valley, but some of our highlights included; un-metamorphosed Snowball Earth sediments (750 million years old), enormous alluvial fans, ancient lake sediments (1-14 million years old) representing wetter periods in Death Valley, and lots of recent faults and folds. The Tecopa hot pools in the centre of ancient Lake Tecopa featured as a good wash-up before dinner.

The final week was spent around the Grand Canyon. Unfortunately, early snow prevented hiking to the bottom of the canyon to observe the Great Unconformity, which recent papers suggest results from glacial erosion during Snowball Earth time.

Our Kiwi students gained some remarkable insight into continental geology in desert environments with 100% outcrop exposures. In addition, they bonded with their American peers, getting a good dose of American culture and southwestern US cuisine.

SIGNIFICANT EVENTS

2019 HILL TINSLEY MEDAL AWARDED TO NICK GOLLEDGE

Nick Golledge was awarded the 2019 Hill Tinsley Medal from the New Zealand Association of Scientists.

The Hill Tinsley Medal is awarded to an early career scientist for outstanding fundamental or applied research in the physical, natural, or social sciences. In 2016, the New Zealand Association of Scientists (NZAS) awarded the first Beatrice Hill Tinsley Medal, which replaced the Association's Research Medal for early career researchers.

Nick received the award for his work in modelling ice sheet and individual glacier behaviour over a range of time periods. His work has provided valuable insight into past ice sheet behaviour. Nick joined the ARC in 2009, soon after completing his PhD. While at the Centre, he has focused on modelling Antarctic ice sheets and their contribution to sea-level rise. He has published many high-impact scientific articles, including a recent *Nature* paper which explores the global consequences of 21st century ice-sheet melting, and his findings have made media headlines across the world.

The Hill Tinsley Medal - Photo: NZAS

The SCAR Team at the Antarctic Parliamentarians Assembly Tim Naish (2nd from right) and SCAR President Steven Chown (far right) - Photo: SCAR

THE FIRST ANTARCTIC PARLIAMENTARIANS ASSEMBLY

The very first 'Antarctic Parliamentarians Assembly' involving Parliamentarians from 13 countries took place in London on 2-3 December 2019.

The Assembly, hosted by the House of Commons and held at Whitehall, highlighted the importance of Antarctica in the understanding of our planet and featured presentations from SCAR President Steven Chown and the ARC's Tim Naish. It provided an opportunity for parliamentarians, rather than governments, to learn more about Antarctica and be able to press their legislatures to support and prioritise the work of the Treaty. Andrew Bayly (Member of Parliament for Hunua), was invited as the New Zealand delegate. He worked closely with Tim and Jana Newman (Ministry of Foreign Affairs and Trade, NZ) to emphasise the important contribution New Zealand has played in the scientific understanding and governance of Antarctica.

Tim's presentation on "How is climate change affecting Antarctica and what does it mean for us?" focussed on the global consequences of future sea-level rise from loss of Antarctic ice. Tim highlighted the vulnerability of West Antarctica, which lies below sea level and could contribute several metres of global sea-level rise. And stressed that even with global efforts to curb emissions, a certain amount of sea-level rise was unavoidable, resulting in the potential displacement of millions of people this century. However, Tim also reminded the parliamentarians that with swift co-ordinated global action the target of the Paris Agreement of stabilising Earth's temperature below +2°C could still be achieved, and that would greatly reduce the risks associated with sea-level rise from Antarctic melting.

Parliamentary delegations were invited from the 54 signatory countries of the Antarctic Treaty to take part in discussions and debates about subjects ranging from climate change and loss of ice from Antarctic ice sheets, to the increase in polar tourism and protecting Antarctic biodiversity. A consensus statement signed by all 19 parliamentary delegates present declares that, as a group of parliamentarians from Antarctic Treaty Parties, they:

'Note with concern the recent Intergovernmental Panel on Climate Change's Special Report on the Ocean and Cryosphere in a Changing Climate, which highlights the profound effects of climate change on Antarctica's ecosystems and the potentially catastrophic effects of Antarctic ice loss on global sea level.'

AWARDS AND APPOINTMENTS

In 2019 ARC staff and students were awarded the following:

Awards

Bella Duncan — Co-PI on a Marsden Council Award.

Nick Golledge — Hill Tinsley Medal.

Jamey Stutz — New Zealand Antarctic Science Conference Early Career Researcher award winner.

Promotions

Brian Anderson — Promoted to Associate Professor scale in the 2019 Academic Promotion Round.

Huw Horgan — Promoted within the Senior Lecturer scale in the 2019 Academic Promotion Round.

Rob McKay — Promoted within the Associate Professor scale in the 2019 Academic Promotion Round.

Appointments

Tim Naish — Appointed as the Antarctic Science Platform Programme Leader: Physical Sciences.

Levan Tielidze — International Association of Cryospheric Sciences National Correspondent for Georgia.

Lauren Vargo — Board member for the International Glaciological Society (IGS) Early Career Glaciologist Group (EGG).

Lauren Vargo — Member of the International Glaciological Society (IGS) committee on governance changes.

FAREWELL TO ANDREW MACKINTOSH

We farewelled Andrew Mackintosh, on 4 April, after 17 years at Victoria University of Wellington, to take up a position as Head of the School of Earth, Atmosphere and Environment at Monash University, Melbourne.

When Andrew was employed as a lecturer in the School of Earth Sciences (now SGEES) in 2002, he came with an excellent pedigree in glacial geomorphology, mentored by David Sugden; and in glaciology, mentored by Hans Oerlemans. These two strands of research intertwined throughout Andrew's time at SGEES and the ARC. Andrew joined the ARC for 50% of his time as a Senior Lecturer in 2009 and became Associate Professor and Deputy Director of the Centre in 2013, and Director and then Professor in 2017.

Highlights of Andrew's time here include the start of the Brewster Glacier mass balance programme in 2004; publication of one of the first examples of using glacier models and geomorphology in examining the climatic significance of the Waiho Loop glacial moraine (*Geology*, 2006); and a long association with George Denton, Aaron Putnam (University of Maine, USA) and others mapping and modelling the glacial geomorphology of the central Southern Alps - now one of the best dated regions in the world. In the Antarctic space, Andrew pioneered the use of 'mountain dipsticks' - using boulders left at the margins of ice sheets to date their thinning - and thence gain insights into the origin of meltwater pulses, and the stability of marine ice sheets. However, for Andrew, the most rewarding aspects of his time here were working with students on their projects in the Southern Alps and Antarctica, and close collaborations over many years with Brian Anderson (ARC), Kevin Norton (SGEES), and others at the University.

Andrew Mackintosh at his farewell function
Photo: Michelle Dow

Alex Pyne at Mt Bastion, Antarctica in 1978 - Photo: Peter Barrett

THIS IS YOUR LIFE – ALEX PYNE: THE VUW YEARS

On 13 June, the ARC celebrated the career of Science Drilling Office Director and ARC Projects Manager, Alex Pyne at his retirement function based on the TV series; *This is Your Life*.

Alex began as a geological assistant in 1977, but quickly took a broader interest in all aspects of Antarctic field operations, including sea ice traverses, site surveys and offshore drilling, and in recent years, deep ice coring on land. In 1983, he obtained a permanent position with the ARC.

Alex's first trip to Antarctica was as a third year BSc student with Victoria University of Wellington Antarctic Expedition (VUWAE) 22 in 1977/78 to assist Barrie McKelvey. Among other things, Barrie and Alex measured and sampled the overlying coal measures near the head of Taylor glacier for Alex's Honours project. As Antarctic research interests broadened at the University to study glacial history through offshore drilling, the expeditions required a part-time Expedition Manager with practical and organisational skills, but not too expensive, Alex was the obvious choice.

During the NZ-led McMurdo Sound Sediment & Tectonic Studies (MSSTS-1) drill hole in 1979/80, Alex was completing his MSc field work that season but showed a keen interest in the discussions and planning, so as Expedition Manager and Core Logger he oversaw the whole operation. Sadly, drilling ended with the drill string jammed at 230 metres below the sea floor. Fortunately though, Alex figured out why and encouraged us to try again.

CIROS-1 was the big one - to be drilled 15 kilometres offshore in 200 metres of water. By this time, Alex had acquired several years of sea ice growth data, along with tidal and current data for drill system design. Drilling terminated at a depth of 702 metres below the sea floor with a remarkable 98% core recovery.

Following this success, the Cape Roberts Project (1997-1999) was designed to core thicker, more complete and older sequences than CIROS-1. It also attracted wider international interest, with Italy partnering with New Zealand and the United States to form the big three, and with German, UK and Australian scientists also involved. A lot of operational decision-making came down to Alex with his 20 years of experience. The result was the successful coring of 1500 metres of strata from 34 to 17 million years ago, paving the way for the ANDRILL Project a decade later to capture the younger story.

The scientific discoveries based on the ANDRILL McMurdo Ice Shelf Project have been truly significant. This is in no small part due to the commitment and ingenuity of Alex's work – in understanding the scientific priorities (and uncertainties), and in leading the drilling to produce 1285 metres of high-quality continuous core. The record-breaking drilling revolutionised our understanding of the vulnerability of the West Antarctic Ice Sheet during past warmer-than-present climates.

In between sediment coring, Alex also began working on developing ice coring capabilities. After several successful smaller projects, the next goal needed a big investment – a New Zealand built intermediate depth ice core drill. The drill – Te Wāmua Hukapapa (Ice Cores that Discover the Past) was developed on the much-proven Danish Hans Tausen drill, but Alex and engineer, Darcy Mandeno, added a good portion of ingenius inhouse design. In 2011/12 and 2012/13, after spending almost eight months in the field, they drilled the 784 metre deep RICE ice core, the backbone of a nine-nation collaboration.

Since that first trip to Antarctica 42 years ago, Alex has spent 36 seasons on the Ice. He has played a unique role in organising field operations and adapting drilling technology for high quality sampling of Earth and ice history in the Antarctic and beyond. We thankfully will continue to work with Alex on upcoming projects on a more casual basis allowing him time for fishing in the Marlborough Sounds.

ARC STALWART LIONEL CARTER RETIRES

On the 28 June, the ARC celebrated the career of Professor Lionel Carter at his retirement function held at Victoria University of Wellington.

Prior to joining the ARC as Professor of Marine Geology in 2006, Lionel spent 32 years at NIWA and its predecessor the New Zealand Oceanographic Institute of the DSIR.

Lionel's research career has centred on investigating basic geological and oceanic processes and applying these discoveries to assess ocean environmental change, natural hazards and resources. Some of his major research achievements include determining the abyssal circulation and its interaction with the ocean floor in the SW Pacific Gateway off eastern New Zealand. This system of currents forms the local component of the Ocean Conveyor, which is one of the major transporters of heat around the planet as well as a regulator of climate change. He discovered the long distance transport (>2000 kilometres) of sediment and its accumulation as extensive sediment drifts under abyssal currents. Lionel also identified the Eastern New Zealand Oceanic Sedimentary System (ENZOSS), whereby sediment generated at the southern sector of the New Zealand plate boundary is transferred to the deep ocean, transported up to 4500 kilometres by abyssal currents and returned to the northern sector of the plate boundary via the Kermadec subduction zone.

A firm believer in applying research to real-world problems, Lionel applied his expertise to a wide range of marine engineering projects. For 15 years, he worked with the International Cable Protection Committee – an international forum for the submarine telecommunication cable industry – to better protect the global fibre-optic cable network from marine hazards. This work was significanct as this cable network carries over 95% of all international internet and communications traffic.

During his career, he has participated on 36 oceanographic voyages of which 28 were as voyage leader. Lionel has also been the recipient of numerous awards. In 1998, Lionel received the Geological Society of New Zealand's McKay Hammer for the most meritorious research papers between 1996-1998. He was named a Fellow of the Royal Society of New Zealand in 2003, received the Marsden Medal for outstanding services to science in 2012, and in 2015 the Hutton Medal for outstanding scientific research in Earth sciences.

While at the ARC, he led the ~$2M ANZICE (Antarctica-New Zealand Interglacial Climate Extremes) Programme funded by the then New Zealand Foundation for Research Science and Technology. ANZICE was closely aligned with the Global Change Through Time programme at GNS Science and linked with the ice core group at NIWA and aimed to understand the likely response of the New Zealand-Antarctic region to a warmer world. Lionel also embraced teaching whole-heartedly and is a highly popular and respected lecturer at undergraduate level – and has been a dedicated thesis supervisor. His scientific advice is always sensible and his sense of humour absurdly brilliant, something everyone in the ARC has appreciated. The ARC is pleased to continue working with Lionel as an Emeritus Professor.

Lionel Carter on board NIWA's *Tangaroa* research vessel - Photo: Lionel Carter

WE REMEMBER BARRIE MCKELVEY 1937-2019

The ARC pays tribute to Barrie McKelvey, the first of two Victoria University of Wellington students who went to Antarctica and a supporter and patron of the ARC Endowed Development Fund.

Barrie left us after a short illness, on 7 March 2019, at Armidale, NSW, Australia, and is remembered with great affection by all of us who knew him, in part because he and his fellow student Peter Webb laid the foundation for the Victoria University Antarctic Expeditions (VUWAE), which have continued annually to this day.

Barrie was a third-year geology student here at Victoria University of Wellington when he and fellow student Peter Webb, decided to present themselves at the New Zealand Trans-Antarctic Expedition offices in Wellington as potential polar explorers for the International Geophysical Year (IGY 1956-58). The offer was initially turned down, but later accepted, albeit reluctantly, after it became known that the pair had approached the US Embassy to go south as part of the US Antarctic Program.

Barrie and Peter's arrival at Scott Base was grudgingly accepted, in the words of the IGY NZ Science Leader, Dr Trevor Hatherton, "uninvited, unheralded, and unwanted". However, their first presence, which included the first geological foray into the McMurdo Valleys, and astute observations and publications that followed, led to Hatherton concluding with the words "to the pioneers Webb and McKelvey, to the succeeding teams and to the general, Professor Clark, I offer my congratulations on a remarkably long-sustained endeavour in exploration and research".

Barrie completed his MSc thesis on his work with Peter in the McMurdo Dry Valleys in 1960, and immediately took up a junior position on the lecturing staff at the University of New England, Armidale, New South Wales. Aside from teaching, his geological focus was the Devonian and Carboniferous sedimentary strata in northern New South Wales, completing his PhD thesis in 1967. After this his interests in working with others to interpret Gondwana sedimentary strata took him back four times to Antarctica with VUWAE between 1968 and 1982. In total, Barrie was a member of six

Barrie McKelvey

VUWAE to Antarctica (VUWAE 1 1957/58; VUWAE 2 1958/59; VUWAE 13, 1968/69; VUWAE 22, 1977/78; VUWAE 24, 1979/80; VUWAE 26, 1981/82). However, his interests then led to pioneering studies of the Neogene glacial history of the Prince Charles Mountains through the Australian Antarctic Programme between 1982 and 1998, interleaved with several Ohio State University expeditions with Peter to the glacial sediments of similar age in the central Transantarctic Mountains.

Barrie's diversity of geological interests and his enthusiasm for team work also took him offshore to participate in two ocean drilling legs (DSDP 26 to the Indian Ocean and ODP 145 in the North Pacific) and two oceanographic cruises with CCOP/SOPAC in 1984 and 1986 studying the seafloor around Samoa, Fiji, Vanuatu and Tonga. It's no surprise that for two decades after retiring in 1996 he returned annually to the Antarctic margin as a very popular tour guide on Antarctic cruises, with a memorable circum-navigation of the continent.

Barrie's breadth of knowledge and experience, and unfailing good humour in all situations, will be missed by us all.

Peter Webb and Barrie McKelvey before they boarded *HMNZS Endeavour* to head south on the first Victoria University of Wellington Antarctic Expedition (VUWAE 1) in 1957 - Photo: Mervyn King

MARIE CURIE FELLOW VISITS

Visiting researcher, Lara Perez, is a Marie Curie postdoctoral fellow based at the British Antarctic Survey in the United Kingdom.

Lara will spend 18 months at the ARC working in close collaboration with ARC staff members, including Rob McKay and Tim Naish, on data obtained during International Ocean Discovery Program Expedition 374.

Lara's scientific career has been focussed on the analysis of oceanic basins and continental margins, including sedimentary processes and seismic stratigraphic records from polar regions. Lara works on the understanding of the interaction of tectonic, oceanographic, cryospheric and climatic processes and their evolution through time. Her important scientific contributions have included the reconstruction of the evolutionary history of the Drake Passage and the Scotia Sea, and the implications that this major gateway development has had on the Global Thermohaline Circulation. Lara has also studied the cryospheric and oceanographic evolution of the Greenland margins, and the geological recent glacial history of the Arctic Ocean. Working in both Antarctic and Arctic polar margins gives her a unique global perspective of the Cenozoic evolution of Earth.

Currently, Lara is focussed on the project 'West Antarctic Margin Signatures of Ice Sheet Evolution (WAMSISE)' in the framework of a highly prestigious Marie Skłodowska-Curie Individual-Global Fellowship (MSCA) grant. The overall objective of WAMSISE is to decipher the history of interactions between tectonic, oceanographic, climatic and cryospheric processes along the West Antarctic Margin from Miocene times (https://www.bas.ac.uk/project/wamsise/).

A key part of WAMSISE is working with ARC researchers to decode the ice sheet oscillation over the Ross Sea continental shelf during the Middle Miocene Climatic Optimum (MMCO ~17-14.5 million years ago). During the MMCO global temperatures were about 3°C higher than present, and therefore it is hypothesized that the Antarctic ice sheet was constrained to an inland position. However, this research is pointing to a more complex history and highly dynamic ice sheet over the Ross Sea during certain periods of middle Miocene.

Lara Perez

Lauren Vargo

S.T. LEE YOUNG SCIENTIST EXCHANGE

Lauren Vargo was the 2019 recipient of the S.T. Lee Young Scientist Exchange with the University of Alaska-Fairbanks.

The last chapter of Lauren's PhD thesis involved finding the influence of humans on the highest melt years of New Zealand glaciers. Her research showed that the highest melt years were more likely to have occurred with humans, compared to a world without anthropogenic climate change. But this method requires measurements of glacier melt, which we only have for two glaciers in New Zealand. So, Lauren put in an application for the S.T. Lee Young Scientist Exchange with University of Alaska-Fairbanks with the lofty goal of applying the same analysis used for the New Zealand glaciers, to over 100 glaciers around the world.

Lauren worked with Regine Hock, a leading scientist on simulating global glacier mass balance, developing a plan for applying Lauren's local New Zealand study to glaciers around the world.

Her time in Fairbanks also allowed Lauren a chance to meet and talk with other students and scientists including ice sheet modellers about how this method of calculating the human influence on glacier melt might be applied to ice sheets, which was especially relevant as the Greenland ice sheet was setting melt records at the time.

FINANCIAL SUMMARY

The ARC generated a significant surplus in 2019, and continues to increase revenue, with 83% of funding coming from external sources.

The ARC finances include both a Centre budget and 46 grants held by the Research Trust of Victoria University of Wellington (RTV). Our consolidated revenue sources and expenditure areas as well as five year summaries are summarized in the following charts (all figures are exclusive of GST). These charts combine the Centre and all grant budgets together.

In 2019, the ARC received a total of $5.42m in revenue, with a corresponding expenditure of $4.39m. The Centre contributed $415k of overheads to the University, and generated a $190k surplus.

NEW FUNDING

The ARC was awarded several new grants in 2019. In particular, the MBIE-funded Antarctic Science Platform (ASP) resulted in a number of new grants: Tim Naish was appointed as Programme Leader at 0.3FTE; Huw Horgan is co-PI on Project 1 Antarctic Ice Dynamics subcontract from GNS Science worth $4.4m; Nick Golledge received $956k to lead the expert group on modelling future projections; and $160k to support the National Modelling Hub established in early 2020; Rob McKay is PI on the $324k Project 2 subcontract from NIWA looking at ocean mechanics; and Abhijith Ulayottil Venugopal received $20k from the ASP Data Analysis Fund.

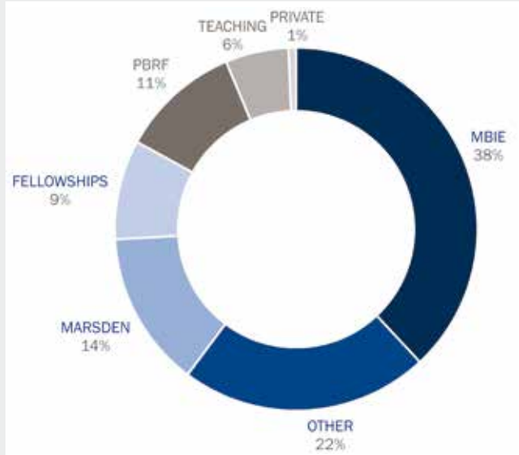
As well as these ASP grants, Bella Duncan is co-PI on a new $3m Marsden Fund Council Award to begin in 2020, and Brian Anderson received a $210k subcontract from NIWA to continue work on the climate observations and processes programme looking into New Zealand's glaciers.

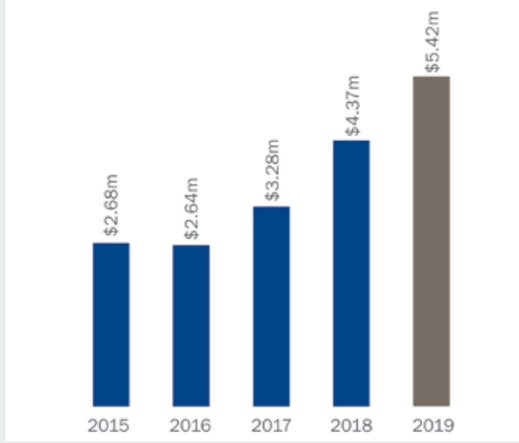
REVENUE

MBIE funding held through contracts to VUW and via subcontracts with our research partners accounts for 38% ($2m) of revenue. 'Other' funding sources includes $800k from GNS Science to support the build of a new Antarctic Intermediate Depth Drill as well as revenue from international organisations such as: The International Cables Protection Committee ($50k); Intergovernmental Panel on Climate Change ($20k); an Antarctic Science Bursary from the UK based charitable company Antarctic Science Ltd ($12k); and the BBC ($2.5k).

The ARC had six active Marsden grants in 2019, contributing $752k (14%) of revenue, and six Rutherford Fellowships ($481k).

The remaining 17% of our revenue comes from internal sources. PBRF (Performance-Based Research Fund) accounts for 11% ($580k) and is calculated by the University for funding it receives from the Tertiary Education Commission based on the quality rating of our staff. We received 6% from Teaching by way of a transfer of $305k from the School of Geography, Environment and Earth Sciences for teaching in their courses and a proportion of the supervision hours and PBRF graduate completion income. Private revenue was $37k of interest earned from private donations, held by the Victoria University of Wellington Foundation, and transferred as ARC Endowed Development Fund awards.





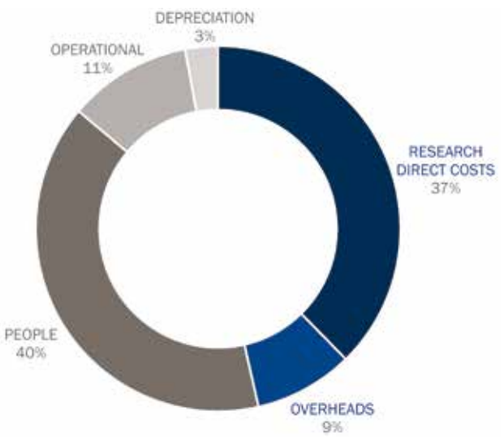
EXPENDITURE

Our expenditure is largely related to people costs (40%) and Research Direct Costs (37%). Of the $1.76m spent on Research Direct Costs, $621k went towards paying subcontracts to our research partners and $245k to support student fees and stipends. The remaining $909k went towards supporting costs such as fieldwork, analyses and travel.

The ARC contributed $415k of overheads from our research grants to the Research Office and the University.

The $1.9m of people related costs was associated with salaries, promotions, annual leave and superannuation. In 2019, the ARC welcomed three new Rutherford Postdoctoral Fellows, but also farewelled three senior permanent staff, resulting in significant savings for the Centre. The Centre's 11% operational budget of $517k, included expenditure that was reimbursed from external organisations or transferred to research grants as well as $165k for office/storage space and $21k for IT related costs.

The final 3% ($137k) of expenditure is for depreciation of CAPEX equipment.



MARSDEN SUCCESS FOR ARC RESEARCHERS

One of the first two Marsden Fund Council Awards was awarded to a team led by Professor Vic Arcus (University of Waikato), that includes ARC's Bella Duncan as a Principal Investigator.

These new $3 million "super marsden" grants are designed to support innovative trans-disciplinary research. This study aims to define a theory - in fact a single equation - that explains the temperature dependence of all terrestrial biology from the enzyme to biosphere scale, and has fundamental implications for microbial growth rates, plant and soil respiration, photosynthesis and, landscape carbon sequestration. Titled *Macromolecular Rate Theory (MMRT) and the temperature-dependence of the terrestrial biosphere over time and space*, the team of researchers will work across scales and disciplines including chemical physicists, molecular biologists, plant physiologists, soil scientists, climate modellers and paleoclimate experts.

The paleoclimate team from the ARC, which also includes Nancy Bertler and Tim Naish, will use geological reconstructions of the evolution of temperature, carbon dioxide, and photosynthetic pathways over the last 40 million years to ground truth models during past warm climates. More specifically, Bella will analyse molecular biomarkers to reconstruct aspects of vegetation evolution and the carbon cycle. The ARC is very excited to see this broadening of our climate research expertise into collaborative, multidisciplinary Earth system science that supports and promotes early career researchers.

A second, $960k standard, Marsden grant was awarded to Nancy Bertler through GNS Science. Titled *Did the West Antarctic Ice Sheet Collapse during the Last Interglacial Warm Period?*, the study aims to develop the first West Antarctic ice core account of the last interglacial, some 115,000 to 130,000 years ago. Then, temperatures were 1-2°C warmer and global sea levels were 6-9 metres higher than today. This makes the last interglacial an important record to test and improve models that assess climate change consequences in a Paris Agreement or warmer world. The ARC's Nick Golledge, Ruzica Dadic and Rob McKay are key partners for this project along with leading international ice core and modelling experts from the United States and Europe.

Bella Duncan in Antarctica - Photo: Bella Duncan

ARC ENDOWED DEVELOPMENT FUND

Through the generosity of past and present staff, alumni, colleagues and collaborators the ARC Endowment Fund has reached over $556,000.

The ARC Endowed Development Fund enables the ARC to give small grants of up to $4,000 to postgraduate students with research links to Antarctica. This provides students with some amazing opportunities that would not have otherwise been possible. Examples include; participation in international summer schools, the opportunity to work with collaborators in world-class analytical facilities, and the ability to travel to international conferences and workshops to present their scientific discoveries on a world-stage.

The 2019 recipients were:

Rachel Corran — to attend the Greenhouse Gases and Measurement Techniques Conference 2019 (GGMT-2019) in Jeju, Korea in September.

Lukas Eling, Dan Lowry, Clarrie Macklin, and Abhijith Ulayottil Venugopal — to write-up papers on their repective research for submission to journals.

Florence Isaacs — to present at the American Geophysical Union (AGU) Fall Meeting in San Francisco, USA in December.

Katelyn Johnson and Jamey Stutz — to attend the XIII International Symposium on Antarctic Earth Sciences in Incheon, South Korea in July.

Marjolaine Verret — to present at the Southern Hemisphere Conference on Permafrost in Queenstown, New Zealand in December.

Ray Dibble looking at seimic readings from Mt Erebus, Antarctica
Photo: Ray Dibble

GENEROUS BEQUEST BY RAY DIBBLE

Ray Dibble (1928-2018), the geophysicist who pioneered "listening to volcanoes", gave $20,000 through his will to the ARC Endowed Development Fund.

Ray Dibble was employed straight from school in 1946 as a cadet in the Public Works Department, pursuing studies at Victoria University College part time. He completed a BSc in geology in 1952 and an MSc in 1956, based on a gravity survey of the northern South Island. His first visit to Antarctica in 1962 was to try out a slow speed tape recording seismograph that he had designed for measuring ice quakes.

In 1965, he joined the Geology Department as the inaugural Lecturer in Applied Geophysics and began a PhD project on "The seismometric study of volcanic activity" - to increase the knowledge and understanding of volcanic mechanism and behaviour, and to search for warning indications of potentially disastrous eruptions." His thesis was based on monitoring the volcanos of Ruapehu, White Island, Kilauea and Stromboli, refining his recording seismograph in the process. In 1974, Ray returned to Antarctica to the more substantial physical challenge of understanding the eruptive behaviour of Erebus volcano (77°S; 3794 metres above sea level), leading to a further 14 visits to the Ice. In 1981, he set up an array of seismographs and other sensors with the help of Phil Kyle and the US Antarctic Program. As part of the New Zealand Antarctic Programme, he installed a video monitoring system of the volcano's lava lake. This almost year-round data was telemetered to Scott Base, giving critical insights into characteristics of the frequent eruptions from the Erebus lava lake. His insights into the plumbing of the volcano and his ability to set up electronic equipment around Erebus summit in sub-zero conditions were legendary.

Ray was a much-respected colleague at the University for many decades. He was innovative, versatile and at times very humorous. He continued to visit the ARC prior to his death. Ray's generous bequest to the ARC's Endowed Development Fund will provide support for future ARC students as they pursue their research.

ARNOLD HEINE ANTARCTIC RESEARCH AWARD

The first recipient of Arnold Heine Antarctic Research Award went to recent PhD graduate Lauren Vargo.

The award supported Lauren to publish the findings of her PhD thesis. Lauren's thesis investigated how New Zealand glaciers have been changing over the past few decades, and the drivers of those changes using the End-of-Summer-Snowline record — photographs of over 50 glaciers along the Southern Alps, taken in March each year since 1977. The record was started by the late Trevor Chinn when he was working at DSIR. Lauren used the photographs to measure changes in snowline elevations (how much snow is left on the glacier every March), which helps our understanding of how the mass of the glaciers change from year to year. Lauren also used mass balance measurements from Brewster Glacier, which involved field work twice each year measuring the accumulation in winter and melt in summer. As well as using glacier modelling to show that some of the highest melt years for the glaciers would not have occurred without human forcing. The final chapter of her thesis showed that high glacier melt years are caused largely by high temperatures, and these high temperatures are caused by anthropogenic climate change.

Lauren Vargo prior to a glacier flight - Photo: Rebekah Parsons-King

OUR ENGAGEMENT

The ARC is committed to presenting our research and knowledge to the wider community. Here are a selection of our contributions.

TV INTERVIEWS

AM Show — 7 February, Nick Golledge, *"Expert says reversing climate change would be 'almost impossible'."* https://www.newshub.co.nz/home/world/2019/02/expert-says-reversing-climate-change-would-be-almost-impossible.html

Newsroom — 18 February, Tim Naish, *"Alarming projections for polar ice sheets."* https://www.newsroom.co.nz/@future-learning/2018/02/27/92887/alarming-projections-for-polar-ice-sheets.

Newshub — 30 April, Tim Naish, *"Parts of ice shelf in Antarctica melting at 'unprecedented levels."* https://www.newshub.co.nz/home/world/2019/04/parts-of-ice-shelf-in-antarctica-melting-at-unprecedented-levels.html

TVNZ Breakfast — 2 July, Tim Naish, talks about climate change, Paris Agreement, sea-level rise and climate emergencies.

Newshub — 16 September, Lauren Vargo, *"Fears as New Zealand's largest glacier continues to shrink." https://www.newshub.co.nz/home/new-zealand/2019/09/fears-as-new-zealand-s-largest-glacier-continues-to-shrink.html*

Newsroom — 16 September, Richard Levy and Nick Golledge, *"Ups and downs of rising seas in a shaky nation."* https://www.newsroom.co.nz/2019/09/16/800304/ups-and-downs-of-rising-seas-in-a-shaky-nation

Newsroom — 17 September, Nick Golledge, Huw Horgan and Gavin Dunbar, *"Drilling into the past to predict the future."* https://www.newsroom.co.nz/2019/09/17/800954/drilling-into-the-past-to-predict-the-future

Newsroom — 3 October, Tim Naish and Nick Golledge, *"Whanganui's ancient rock yields worrying clues about Antarctic melting."* https://www.newsroom.co.nz/2019/10/03/841143/whanganuis-ancient-rock-yields-worrying-clues-about-antarctic-melting

RADIO INTERVIEWS

Radio NZ 'Morning Report' – 7 February, Nick Golledge, *"Extreme weather could worsen, NZ-led climate study says."* https://www.rnz.co.nz/national/programmes/morningreport/audio/2018681371/extreme-weather-could-worsen-nz-led-climate-study-says

Radio NZ 'Environment' – 7 February, Nick Golledge, *"NZ-led research shows extreme weather could worsen."* https://www.rnz.co.nz/news/national/381902/nz-led-research-shows-extreme-weather-could-worsen

Radio NZ 'Pacific' – 8 February, Nick Golledge, *"Tropical Pacific could experience enhanced sea-level rise."* https://www.rnz.co.nz/international/pacific-news/382058/tropical-pacific-could-experience-enhanced-sea-level-rise

The Green Desk Podcast & 95bfm Radio — 8 October, Lauren Vargo, *"Declining glaciers in New Zealand."* https://95bfm.com/bcast/the-green-desk-october-8-2019

Neo1 Mein Radio, Switzerland — 12 December, Ruzica Dadic, *"MOSAiC: Arctic Expeditions with Swiss Participation."* https://www.neo1.ch/news/news/newsansicht/datum/2019/12/12/mosaic-arktische-expedition-mit-schweizer-beteiligung.html

NEWSPAPER/MAGAZINE ARTICLES

NZ Herald — 13 January, Nancy Bertler, *"Big Science - Can we stop Antarctica's collapse?"* http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=12296448

NZ Herald — 22 January, Rob McKay, *"Million-dollar study: When will Antarctica's marine ice sheets melt?"* https://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=12194292

McGill Newsroom — 6 February, Nick Golledge, *"Melting ice sheets may cause 'climate chaos' according to new modelling."* https://www.mcgill.ca/newsroom/channels/news/melting-ice-sheets-may-cause-climate-chaos-according-new-modelling-294392

USA Today — 6 February, Nick Golledge, *"Melting ice from Greenland and Antarctica could cause more extreme weather." https://www.usatoday.com/story/news/world/2019/02/06/global-warming-antarctica-greenland-ice-melting-could-spur-extremes/2791180002/*

NZ Herald — 14 March, Tim Naish, *"Show us how it's done' - 22 leading NZ academics who back the School Strike 4 Climate."* https://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=12212794

NZ Herald — 15 March, Tim Naish and Henry Naish, *"Class action: Thousands of students to march over climate change."* https://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=12212703

NZ Herald — 24 March, Brian Anderson, *"NZ glaciers 'sad and dirty' after third-hottest summer." https://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=12215803*

Otago Daily Times — 8 April, Tim Naish, *"Q & A on NZ SeaRise research."* https://www.odt.co.nz/lifestyle/resilient/q-tim-naish

Greymouth Evening Star — 24 May, Brian Anderson, *"Glaciers 'shorter than ever'."*

The Circle — 13 June, Nick Golledge, *"Fast-forward to the past."* https://arcticwwf.org/newsroom/the-circle/arctic-check-up/fast-forward-to-the-past/

Dominion Post — 28 June, Tim Naish and James Renwick (SGEES), *"Councils declare climate emergencies, but will it result in any real change?"* https://www.stuff.co.nz/environment/climate-news/113747732/councils-declare-climate-emergencies-but-will-it-result-in-any-real-change

NZ Herald — 13 July, Lauren Vargo *"Glaciers melt in NZ's third warmest summer."* https://www.pressreader.com/new-zealand/weekend-herald/20190713/281681141449493

NZ Herald — 19 July, Nick Golledge *"Climate Voices: 15 Kiwis' hopes and fears in a warming world."* https://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=12247279

Stuff — 20 August, Lauren Vargo, *"New Zealand glaciers won't survive this century, scientists say."* www.stuff.co.nz/environment/115135746/new-zealand-glaciers-wont-survive-this-century-scientists-say

The Listener — 16 September, Lauren Vargo, *"Melting moments."* https://www.pressreader.com/new-zealand/new-zealand-listener/20190916/281530817720248

The Spinoff — 16 September, Shaun Eaves, *"Our climate story: Life in Auckland and Southland in 2050."* https://thespinoff.co.nz/science/16-09-2019/our-climate-story-life-in-auckland-and-southland-in-2050/

The Conversation — 2 October, Nick Golledge, *"Climate explained: What each of us can do to reduce our carbon footprint."* https://theconversation.com/climate-explained-what-each-of-us-can-do-to-reduce-our-carbon-footprint-123851

Stuff — 1 October, Brian Anderson, *"New Zealand's incredible shrinking glaciers." https://www.stuff.co.nz/environment/116233362/new-zealands-incredible-shrinking-glaciers*

Stuff — 2 October, Nick Golledge, "*Climate explained: What each of us can do to reduce our carbon footprint."* https://www.stuff.co.nz/environment/climate-news/116231127/climate-explained-what-each-of-us-can-do-to-reduce-our-carbon-footprint

Dominion Post — 3 October, Georgia Grant and Tim Naish, *"Widespread ice sheet melting in Antarctica could raise sea level by 20 m, NZ-led study finds."* https://www.stuff.co.nz/environment/climate-news/116262223/widespread-ice-sheet-melting-in-antarctica-could-raise-sea-level-by-20m-nzled-study-finds

NZ Herald — 3 October, Georgia Grant and Tim Naish, *"Paris Agreement's failure could mean 20 m of sea level rise."* https://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=12159189

The Conversation — 3 October, Georgia Grant and Tim Naish, *"If warming exceeds 2°C, Antarctica's melting ice sheets could raise seas 20 metres in coming centuries."* https://theconversation.com/if-warming-exceeds-2-c-antarcticas-melting-ice-sheets-could-raise-seas-20-metres-in-coming-centuries-124484

Nature Outlook — 14 November, Nick Golledge, *"Beneath the ice."* https://media.nature.com/original/magazine-assets/d41586-019-03464-w/d41586-019-03464-w.pdf

Glacier Hub — 15 November, Levan Tielidze, "*Photo Friday: GIF shows dramatic reduction of Gergeti Glacier."* https://glacierhub.org/2019/11/15/photo-friday-gif-shows-dramatic-reduction-of-gergeti-glacier-georgia/

NZ Herald — 1 December, Tim Naish, *"Scientists to address London Summit."* https://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=12289898.

NZ Herald — 20 December, Nancy Bertler, *"Thousands of kilometres of Antarctic ice housed in Wellington."* https://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=12295732

Marsden Fund 25 Series — Nick Golledge, https://royalsociety.org.nz/what-we-do/funds-and-opportunities/marsden/celebrating-marsden-research/marsden25/professor-nick-golledge

TALKS TO POLICYMAKERS

Waikato Regional Council — 2-3 April, Tim Naish and Richard Levy, discuss Hauraki, Firth of Thames Case study for NZ SeaRise programme.

World Climate Research Programme, 40th Joint Scientific Committee Meeting, World Meteorological Organisation, Geneva — 6-10 May, Tim Naish.

Wellington Harbour Assets group — 27 June, Tim Naish, *"Climate change science, impacts and NZ SeaRise programme."*

Thames Mayor Sandra Goudie — 30 June, Tim Naish, *"Local sea-level rise issues and NZ SeaRise programme."*

Executive Committee of the Scientific Committee on Antarctic Research Meeting — 18-30 July, Tim Naish.

New Zealand Climate Change Business Conference — 8 October, Tim Naish, *"The 10 things every company needs to know: Physical, economic, and operational implications of climate change."*

Task Force on Climate-Related Financial Disclosures (TFCD) Workshop — 17 October, Tim Naish.

Department of Conservation — 1 November, Tim Naish and Richard Levy, *"Food for thought: Melting ice sheets, dynamic coastlines, and consequences for future sea level change."*

Ministry of Foreign Affairs and Trade Environment Team — 15 November, Tim Naish, *"Antarctic climate change and global sea-level rise."*

Antarctic Parliamentarians Assembly, Whitehall, London — 2-3 December, Tim Naish, *"How is climate change affecting Antarctica and what does it mean for us?"*

SCHOOL & COMMUNITY GROUPS

Explorers Club Polar Film Festival, New York City — 23-25 January, Jamey Stutz, selected entry, *"Past Ice/Future Ice."*

Global R&E Network CEO Forum — 14 February, Nancy Bertler, *"Antarctic change and global consequences - Scientific breakthroughs and future opportunities."*

Goethe-Institute — 20 February, Tim Naish, *"Climate change and sea-level rise."*

NZ Antarctic Society (Auckland Branch) — 21 February, Peter Barrett, *"Secrets of the Antarctic."*

Taranaki Geological Society Lecture Series — 1 April, Jamey Stutz, *"Thinning history of David Glacier."*

Hutt City Library — 8 April, Tim Naish, James Renwick, Judy Lawrence (SGEES), *"Climate Change: Its Effects on Aotearoa and the South Pacific."*

Women in Science Photography Project — 9 May, Katelyn Johnson.

Eastern Harbour Environmental Group — 28 May, Tim Naish and Judy Lawrence (SGEES), *"Impacts of sea-level rise."*

Karori West Normal School — 30 May, Ruzica Dadic, *"Polar expeditions, climate change and polar bears."*

Taranaki Geological Society — 3 June, Nick Golledge, *"Causes and consequences of 21st century ice sheet melt."*

VUW Spotlight Lecture Series — 5 June, Tim Naish, *"Sea level rise: How much, when and what can we do?"*

Antarctica After Dark — 17 June, Nick Golledge, *"Ice, dice and Oscar Wilde"*

St Andrews-on-the-Terrace Social Justice Education Group — 23 June, Peter Barrett, *"Saving Antarctica."*

Miramar Central School Antarctic Family Day — 10 August, Peter Barrett, Darcy Mandeno, and Jamey Stutz.

A Memory of Ice – the Voyage of the Glomar Challenger Book Launch (Sydney) — 6 September, Peter Barrett and Rob McKay.

St Michaels and All Angels (Christchurch) — 17 September, Peter Barrett, *"Saving Antarctica."*

U3A Island Bay — 19 September, Peter Barrett, *"Saving Antarctica."*

Miramar North School Antarctic Outreach Day — 24 September, Hannah Chorley, Gavin Dunbar, Stefan Jendersie, Dao Polsiri, Nikita Turton, and Jamey Stutz.

Queen Margaret College — 24 September, Katelyn Johnson.

Explorers Club Polar Film Festival, Auckland, Christchurch, Wellington — September, Jamey Stutz.

Earthsong Eco-village (Auckland) — 13 October, Peter Barrett, THIN ICE screening and Q & A.

Monash University — 2 October, Florence Isaac, *"Climate variability and sea ice in East Antarctica."*

Te Wāhipounamu 'TED' Talk — 24 October, Brian Anderson, *"The glaciers: Why they are remarkable, and why they are retreating."*

Marsden Fund 25 Series — 13 November, Nancy Bertler, *"Stability of Antarctic ice sheets - Implications for sea-level rise."*

Geosciences Public Lecture — 25 November, Tim Naish, *"Science of sea-level change, impacts and management."*

Monash University — 27 November, Levan Tielidze, "*On the trail of the glaciers: Mission to the Caucasus (Georgia)."*

Hudson Middle School, New York — 9 December, Jamey Stutz.

Catawba Springs Elementary, North Carolina — 10 December, Jamey Stutz.

Gros Gap Elementary, Michigan — 11 December, Jamey Stutz.

New Zealand Antarctic Society National Speaker (Auckland, Wellington, Dunedin, Christchurch, Wanaka) — Tim Naish, *"How is climate change affecting Antarctica and what does it mean for us?"*

Track Zero Arts and Climate Science Road Show (Nelson, Dunedin, Hamilton and Christchurch) — Tim Naish.

Jamey Stutz at Miramar North School
Photo: Dao Polsiri

PUBLICATIONS & CONFERENCES

PEER-REVIEWED PUBLICATIONS

Bostock, H., Jenkins, C., Mackay, K., **Carter**, L., Nodder, S., Orpin, A., Pallentin, A., Wysoczanski, R. (2019). Distribution of surficial sediments in the ocean around New Zealand/Aotearoa. Part A: Continental slope and deep ocean. *New Zealand Journal of Geology and Geophysics* 62(1): 1-23. doi: 10.1080/00288306.2018.1523198

Bostock, H., Jenkins, C., Mackay, K., **Carter**, L., Nodder, S., Orpin, A., Pallentin, A., Wysoczanski, R. (2019). Distribution of surficial sediments in the ocean around New Zealand/Aotearoa. Part B: Continental shelf. *New Zealand Journal of Geology and Geophysics* 62(1): 24-45. doi: 10.1080/00288306.2018.1523199

Bracegirdle, T.J., Colleoni, F., Abram, N.J., **Bertler**, N.A.N., Dixon, D.A., England, M., Favier, V., Fogwill, C.J., Fyfe, J.C., Goodwin, I., Goosse, H., Hobbs, W., Jones, J.M., Keller, E.D., Khan, A.L., Phipps, S.J., Raphael, M.N., Russell, J., Sime, L., Thomas, E.R., van den Broeke, M.R., Wainer, I. (2019). Back to the future: Using long-term observational and paleo-proxy reconstructions to improve model projections of antarctic climate. *Geosciences* (Switzerland) 9(6): 255. doi: 10.3390/geosciences9060255

Bradwell, T., Small, D., Fabel, D., Clark, C.D., Chiverrell, R.C., Saher, M.H., Dove, D., Callard, S.L., Burke, M.J., Moreton, S.G., Medialdea, A., Bateman, M.D., Roberts, D.H., **Golledge**, N.R., Finlayson, A., Morgan, S., Ó Cofaigh, C. (2019). Pattern, style and timing of British–Irish Ice Sheet retreat: Shetland and northern North Sea sector. *Journal of Quaternary Science* 1: 1-42. doi:10.1002/jqs.3163

Dadic, R., Schneebeli, M., Wiese, M., **Bertler**, N.A.N., Salamatin, A.N., Theile, T.C., Alley, R.B., Lipenkov, V.Y. (2019). Temperature-driven bubble migration as proxy for internal bubble pressures and bubble trapping function in ice cores. *Journal of Geophysical Research: Atmospheres* 124(17-18): 10264-10282.

Duncan, B., **McKay**, R., Bendle, J., **Naish**, T., Inglis, G.N., Moossen, H., **Levy**, R., Ventura, G.T., Lewis, A., Chamberlain, B., Walker, C. (2019). Lipid biomarker distributions in Oligocene and Miocene sediments from the Ross Sea region, Antarctica: Implications for use of biomarker proxies in glacially-influenced settings. *Palaeogeography, Palaeoclimatology, Palaeoecology* 516: 71-89. doi.org/10.1016/j.palaeo.2018.11.028

Eaves, S.R., Mackintosh, A.N., and **Anderson**, B.M. (2019). Climate amelioration during the Last Glacial Maximum recorded by a sensitive mountain glacier in New Zealand. *Geology* 47(4): 299-302. doi.org/10.1130/G45543.1

Eaves, S.R., Winckler, G., Mackintosh, A.N., Schaefer, J.M., Townsend, D.B., Doughty, A.M., Jones, R.S., Leonard, G.S. (2019). Late-glacial and Holocene glacier fluctuations in North Island, New Zealand. *Quaternary Science Reviews* 223: 105914. doi.org/10.1016/j.quascirev.2019.105914

Edwards, T.L., Brandon, M.A., Durand, G., Edwards, N.R., **Golledge**, N.R., Holden, P.B., Nias, I.J., Payne, A.J., Ritz, C., Wernecke, A. (2019). Revisiting Antarctic ice loss due to marine ice-cliff instability. *Nature* 566: 58-64. doi:10.1038/s41586-019-0901-4

Escutia, C., Deconto, R.M., Dunbar, R., De Santis, L., Shevenell, A., **Naish**, T. (2019). Keeping an eye on Antarctic ice sheet stability. *Oceanography* 32(1): 32-46.

Golledge, N.R., Keller, E.D., Gomez, N., Naughten, K.A., Bernales, J., Trusel, L.D., Edwards, T.L. (2019). Global environmental consequences of twenty-first-century ice-sheet melt. *Nature* 566: 65-72. doi:10.1038.s41586-019-0889-9

Grant, G.R., **Naish**, T.R., **Dunbar**, G.B., Stocchi, P., Kominz, M.A., Kamp, P.J.J., Tapia, C.A., **McKay**, R.M., **Levy**, R.H., Patterson, M.O. (2019). The amplitude and origin of sea-level variability during the Pliocene epoch. *Nature* 574: 237-241. doi:10.1038/s41586-019-1619-z

Jovane, L., Florindo, F., Acton, G., Ohneiser, C., Sagnotti, L., Strada, E., Verosub, K.L., Wilson, G.S., Lacoviello, F., **Levy**, R.H. Passchier, S. (2019). Miocene glacial dynamics recorded by variations in magnetic properties in the ANDRILL-2A drill core. *Journal of Geophysical Research: Solid Earth* 124(3): 2297-2312. doi:10.1029/2018JB016865

Kennicutt II, M.C., Bromwich, D., Liggett, D., Njåstad, B., Peck, L., Rintoul, S.R., Ritz, C., Siegert, M.J., Aitken, A., Brooks, C.M., Cassano, J., Chaturvedi, S., Chen, D., Dodds, K., **Golledge**, N.R., Le Bohec, C., Leppe, M., Murray, A., Nath, P., Raphael, M.N., Rogan-Finnemore, L., M., Schroeder, D.M, Talley, Travouillon, T., Vaughan, D.G., Wang, L., Weatherwax, A.T., Yang, H., Chown, S.L. (2019). Sustained Antarctic research: A 21st century imperative. *One Earth* 1: 95-113. doi:10.1016/j.oneear.2019.08.014

Kirkham, J., Hogan, K., Larter, R., Arnold, N., Nitsche, F., **Golledge**, N., Dowdeswell, J. (2019). Past water flow beneath Pine Island and Thwaites glaciers, West Antarctica. *Cryosphere* 13(7): 1959-1981. doi:10.5194/tc-13-1959-2019

Krause, C.E., Gagan, M.K., **Dunbar**, G.B., Hantoro, W.S., Hellstrom, J.C., Cheng, H., Edwards, R.L., Suwargadi, B.W., Abram, N.J., Rifai, H. (2019). Spatio-temporal evolution of Australasian monsoon hydroclimate over the last 40,000 years. *Earth and Planetary Science Letters* 513: 103-112. doi: 10.1016/j.epsl.2019.01.045

Kulhanek, D.K., **Levy**, R.H., Clowes, C.D., Prebble, J.G., Rodelli, D., Jovane, L., Morgans, H.E.G., Kraus, C., Zwingmann, H., Griffith, E.M., Scher, H.D., **McKay**, R.M., **Naish**, T.R. (2019). Revised chronostratigraphy of DSDP Site 270 and late Oligocene to early Miocene paleoecology of the Ross Sea sector of Antarctica. *Global and Planetary Change* 178: 46-64. doi.org/10.1016/j.gloplacha.2019.04.002

Levy, R.H., Meyers, S.R., **Naish**, T.R., **Golledge**, N.R., **McKay**, R.M., Crampton, J.S., DeConto, R.M., De Santis, L., Florindo, F., Gasson, E.G.W., Harwood, D.M., Luyendyk, B.P., Powell, R.D., Clowes, C., Kulhanek, D.K. (2019). Antarctic ice-sheet sensitivity to obliquity forcing enhanced through ocean connections. *Nature Geoscience* 12: 132-137. doi:10.1038/s41561-018-0284-4

Li, D., **Wigmore**, O., Durand, M., Vander Jagt, B., Margulis, S., Molotch, N., Bales, R. (2019). Potential of balloon photogrammetry for spatially continuous snow depth measurements, IEEE *Geoscience and Remote Sensing Letters*. doi: 10.1109/LGRS.2019.2953481 (available online)

Lipscomb, W.H., Price, S.F., Hoffman, M.J., Leguy, G.R., Bennett, A.R., Bradley, S.L., Evans, K.J., Fyke, J.G., Kenedy, J.H., Perego, M., Ranken, D.M., Sacks, W.J., Salinger, A.G., **Vargo**, L.J., Worley, P.H. (2019). Description and evaluation of the Community Ice Sheet Model (CISM) v. 2.1. *Geoscientific Model Development* 12: 387-424. doi:10.5194/gmd-2018-151

Lowry, D.P., **Golledge**, N.R., **Bertler**, N.A.N., Jones, R.S., **McKay**, R.M., (2019). Deglacial grounding-line retreat in the Ross Embayment, Antarctica, controlled by ocean and atmosphere forcing. *Science Advances* 5(8): 8754. doi:10.1126/sciadv.aav8754

Lowry, D.P., **Golledge**, N.R., Menviel, L., **Bertler**, N.A.N. (2019). Deglacial evolution of regional Antarctic climate and Southern Ocean conditions in transient climate simulations. *Climate of the Past* 15: 189-215. doi: 10.5194/cp-15-189-2019

Lowry, D.P., and Morrill, C. (2019). Is the Last Glacial Maximum a reverse analog for future hydroclimate changes in the Americas? *Climate Dynamics* 52(7-8): 4407-4427. doi: 10.1007/s00382-018-4385-y

McKay, R.M., De Santis, L., Kulhanek, D.K., and the Expedition 374 Scientists. (2019). Ross Sea West Antarctic Ice Sheet history. *Proceedings of the International Ocean Discovery Program* Volume 374. doi.org/10.14379/iodp.proc.374.2019

Muto, A., Anandakrishnan, S., Alley, R.B., **Horgan**, H.J., Parizek, B.R., Koellner, S., Christianson, K., Holschuh, N. (2019). Relating bed character and subglacial morphology using seismic data from Thwaites Glacier, West Antarctica. *Earth and Planetary Science Letters* 507: 199-206. doi: 10.1016/j.epsl.2018.12.008

Ohneiser, C., Yoo, K.C., Albot, O.B., Cortese, G., Riesselman, C., Lee, J.I., **McKay**, R., Bollen, M., Lee, M.K., Moon, H.S., Kim, S., Beltran, C., **Levy**, R., Wilson, G.S. (2019). Magneto-biostratigraphic age models for Pleistocene sedimentary records from the Ross Sea. *Global and Planetary Change* 176: 36-49. doi:10.1016/j.gloplacha.2019.02.013

Rainsley, E., Turney, C.S., **Golledge**, N.R., Wilmshurst, J.M., McGlone, M.S., Hogg, A.G., Li, B., Thomas, Z.A., Roberts, R., Jones, R.T., Palmer, J.G. (2019). Pleistocene glacial history of the New Zealand subantarctic islands. *Climate of the Past* 15: 423-448. doi.org/10.5194/cp-15-423-2019

Schiller, M., **Dickinson**, W.W., Iverson, N.A., Baker, J.A. (2019). A re-evaluation of the Hart Ash, an important stratigraphic marker: Wright Valley, Antarctica. *Antarctic Science* 31(3): 139-149. doi: 10.1017/S0954102019000129

Seroussi, H., Nowicki, S., Simon, E., Abe-Ouchi, A., Albrecht, T., Brondex, J., Cornford, S., Dumas, C., Gillet-Chaulet, F., Goelzer, H., **Golledge**, N.R., Gregory, J.M., Greve, R.,

Hoffman, M.J., Humbert, A., Huybrechts, P., Kleiner, T., Larour, E., Leguy, G., Lipscomb, W.H., **Lowry**, D., Mengel, M., Morlighem, M., Pattyn, F., Payne, A.J., Pollard, D., Price, S.F., Quiquet, A., Reerink, T.J., Reese, R., Rodehacke, C.B., Schlegel, N.-J., Shepherd, A., Sun, S., Sutter, J., Van Breedam, J., van de Wal, R.S.W., Winkelmann, R., Zhang, T. (2019). initMIP-Antarctica: An ice sheet model initialization experiment of ISMIP6. *Cryosphere* 13: 1441-1471. doi. org/10.5194/tc-13-1441-2019

Tapia, C.A., Grant, G.R., Turner, G.M., Sefton, J.P., **Naish**, T.R., **Dunbar**, G.B., Ohneiser, C. (2019). High-resolution magnetostratigraphy of mid-Pliocene (3.3-3.0 Ma) shallow-marine sediments, Whanganui Basin, New Zealand. *Geophysical Journal International* 217(1): 41-57. doi: 10.1093/gji/ggz004

Taylor-Offord, S., **Horgan**, H., Townend, J., Winberry, J.P. (2019). Seismic observations of crevasse growth following rain-induced glacier acceleration, Haupapa/Tasman Glacier, New Zealand. *Annals of Glaciology* 60(79): 14-22. doi: 10.1017/aog.2019.20

Tielidze, L.G., Kumladze, R.M., Wheate, R.D., Gamkrelidze, M. (2019). The Devdoraki Glacier catastrophes, Georgian Caucasus. *Hungarian Geographical Bulletin* 68(1): 21-35. doi.org/10.15201/hungeobull.68.1.2

Vargo, L.J., Galewsky, J., Rupper, S., Ward, D.J. (2019). Reply to "Comment on Sensitivity of glaciation in the arid subtropical Andes to changes in temperature, precipitation, and solar radiation by Vargo *et al.* (2018)" by Martini and Astini (2018). *Global and Planetary Change* 172: 479-481. doi:10.1016/j.gloplacha.2018.10.003

Webb R.W., **Wigmore**, O., Jennings, K., Fend, M., Molotch, N.P. (2019). Hydrologic connectivity at the hillslope scale through intra-snowpack flow paths during snowmelt, *Hydrological Processes* 34: 1616-1629. doi: 10.1002/hyp.13686 (available online)

Wigmore, O., Mark, B.G., McKenzie, J., Baraer, M., Lautz, L. (2019). Sub-metre mapping of surface soil moisture in proglacial valleys of the tropical Andes using a multispectral unmanned aerial vehicle. *Remote Sensing of Environment* 222, 104-118. doi:10.1016/j.rse.2018.12.024

Winstrup, M., Vallelonga, P., Kjær, H.A., Fudge, T.J., Lee, J.E., Riis, M.H., Edwards, R., **Bertler**, N.A.N., Blunier, T., Brook, E.J., Buizert, C., Ciobanu, G., Conway, H., Dahl-Jensen, D., Ellis, A., Emanuelsson, B.D.f., Hindmarsh, R.C.A., Keller, E.D., Kurbatov, A.V., Mayewski, P.A., Neff, P.D., Pyne, R.L., Simonsen, M.F., Svensson, A., Tuohy, A., Waddington, E.D., Wheatley, S. (2019). A 2700-year annual timescale and accumulation history for an ice core from Roosevelt Island, West Antarctica. *Climate of the Past* 15(2): 751-779. doi: 10.5194/cp-15-751-2019

Zemp, M., Sajood, A.A., Pitte, P., van Ommen, T., Fischer, A., Soruco, A., Thomson, L., Schaefer, M., Li, Z., Ceballos Lievano, J.L., Cáceres Correa, B.E., Vincent, C., **Tielidze**, L., Braun, L.N., Ahlstrøm, A.P., Hannesdóttir, H., Dobhal, D.P., Karimi, N., Baroni, C., Fujita, K., Severskiy, I., Prinz, R., Usubaliev, R., Delgado-Granados, H., Demberel, O., Joshi, S.P., **Anderson**, B., Ove Hagen, J., Dávila Roller, L.R., Gadek, B., Popovnin, V.V., Cobos, G., Holmlund, P., Huss, M., Kayumov, A., Lea, J.M., Pelto, M., Yakovlev, A. (2019). Glacier monitoring tracks progress in limiting climate change. *Nature* 576: 39. doi: 10.1038/d41586-019-03700-3

INVITED PRESENTATIONS

Carter, L., Collins, K., Creese, C., Waterworth, G. (2019). Chemical and physical stability of submarine fibre-optic cables in the area beyond national jurisdiction (ABNJ). *SubOptic 2019,* New Orleans, USA, 8-11 April 2019.

Carter, L. (2019). UNCLOS BBNJ The United Nations Convention on the Law of the Sea/ Biodiversity Beyond National Jurisdiction Keynote Panel Session. *SubOptic 2019 and the International Cable Protection Committee*, New Orleans, USA, 11 April 2019.

Golledge, N. (2019). Ice sheets, climate, and sea-level, from the past to the future. *Caltech*, Pasadena, USA, 4 March 2019.

Golledge, N. (2019). Ice sheets, climate, and sea-level, from the past to the future. *University of California*, Irvine, USA, 5 March 2019.

Golledge, N., **Lowry**, D., **van Haastrecht,** L., **Keller**, L., **Jendersie**, S., **Alevropoulos-Borrill**, A., **Levy**, R., **Bertler**, N. (2019). The Antarctic ice sheet in our rapidly warming world. *Antarctic Science Conference*, Christchurch, New Zealand, 19 June 2019.

Golledge, N., **Lowry**, D., **van Haastrecht,** L., **Keller**, L., **Jendersie**, S., **Alevropoulos-Borrill**, A., **Levy**, R., **Bertler**, N. (2019). The Antarctic ice sheet in our rapidly warming world. *Risk Conference*, Wellington, New Zealand, 13 November 2019.

McKay, R.M. (2019). Reflections of a past winner. *Prime Minister's Science Prize*, Wellington, New Zealand, March 2019.

McKay, R.M. (2019). Plenary - Antarctic ice sheet history in the Ross Sea during the Late Cenozoic from geological drill core studies. *SCAR International Symopsium on Earth Science*, Korea, 22 July 2019.

Naish, T. (2019). Opening address. *Malaysian International Symposium on Antarctica*, Kuala Lumpur, Malaysia, 18 June 2019.

Naish, T. (2019). Keynote. *International Symposium on Antarctic Earth Sciences*, Incheon, Korea, 25 July 2019.

Naish, T. (2019). Mid-Late Pliocene global sea-level and polar ice sheet variability. *13th International Conference on Paleoceanography*. Sydney, Australia, 2 September 2019.

Stutz, J., and Wilson, T. (2019). Co-location of geophysical and geodetic instrumentation with long-term ice load histories. *KOPRI LIONESS Workshop*, Incheon, South Korea, 2 May 2019.

CHAIRED WORKSHOPS

Bertler, N. (2019). 21st Century climate projections and predictions. *AntClim21 Workshop,* Cambridge, UK, 26-28 July 2019.

Bertler, N. and Isern, A. (2019). International Ross Sea Region Collaboration and Coordination Workshop, *International Symposium on Antarctic Earth Sciences (ISAES),* Incheon, Korea, 21 July 2019.

Vargo, L. and **Wigmore**, O. (2019). Technological and computational innovations in the geosciences. *Geosciences*, Hamilton, New Zealand, 24-27 November 2019.

STUDENT ORAL PRESENTATIONS

Dowling, L., **Eaves**, S., Mackintosh, A., Norton, K., **Anderson**, B., Hidy, A., Lorrey, A., Ryan, M., **Vargo**, L., Tims, S. (2019). Current glacier extent in the Southern Alps may be unprecedented in the Holocene. *Geosciences*, Hamilton, New Zealand, 24-27 November 2019.

Elliot, D., **Barrett**, P., and **Stutz**, J. (2019). Pre-middle Miocene landslide deposits in the central Transantarctic Mountains. *XIII International Symposium of Antarctic Earth Sciences*, Incheon, Republic of Korea, 22-26 July 2019.

Isaac, F.E., Renwick, J.A., and Mackintosh, A.N. (2019). Influence of Southern Hemisphere atmospheric variability on recent sea ice concentration in East Antarctica. *Snow and Ice Research Group (SIRG) Meeting*, Kurow, New Zealand, 20-22 February 2019.

Johnson, K.M., **McKay**, R., **Bertler**, N.A., Etourneau, J., Jiménez-Espejo, F.J., Albot, A., Riesselman, C., **Horgan**, H., *et al.* (2019). Holocene drivers of biogenic bloom events linked to tropical teleconnections, offshore Adélie Land, East Antarctica. *XIII International Symposium on Antarctic Earth Sciences*, Incheon, Republic of Korea, 22-26 July 2019.

Leong, W-J., and **Horgan**, H. (2019). DeepBedMap: A super-resolution deep neural network for resolving the bed topography of Antarctica. *International Glaciological Society (IGS) Symposium,* Stanford, California, USA, 8-12 July 2019.

Lowry, D. (2019). Developments and challenges in Paleo-ice sheet modelling to constrain past sea level. *Geosciences*, Hamilton, New Zealand, 24-27 November 2019.

Stutz, J., Mackintosh, A., Norton, K., **Whitmore**, R. (2019). Rapid, dynamic Holocene thinning of David Glacier. *New Zealand Antarctic Science Conference*, Christchurch, New Zealand, 17-20 June 2019.

Stutz, J., Mackintosh, A., Norton, K., **Whitmore**, R. (2019). Rapid, dynamic Holocene thinning of David Glacier. *International Symposium of Antarctic Earth Sciences*, Incheon, South Korea, 22-26 July 2019.

Tielidze, L. (2019). Current state, progress, and challenges of glacier monitoring in Georgia. *World Glacier Monitoring Service General Assembly*, Almaty, Kazakhstan, 10-14 September 2019.

Tielidze, L. and Gadrani, L. (2019). Change in glacier area and number in Georgia from repeat inventories. *Second Caucasus Mountain Forum*, Ankara, Turkey, 30 October-1 November 2019.

Vargo, L., **Anderson**, B., **Horgan**, H., Mackintosh, A., **Dadic**, R., King, A., Lorrey, A. (2019). Attribution of glacier mass loss to natural and anthropogenic forcings. *Snow and Ice Research Group Meeting*, Kurow, New Zealand, 20-22 February 2019.

Vargo, L., **Anderson**, B., **Horgan**, H., Mackintosh, A., **Dadic**, R., King, A., Lorrey, A. (2019). Attribution of glacier mass loss to natural and anthropogenic forcings. *27th International Union of Geodesy and Geophysics General Assembly,* Montreal, Canada, 8-18 July 2019.

Verret, M., **Dickinson**, W., Lacelle, D., Norton, K., **Levy**, R., **Naish**, T. (2019). Origin of ground-ice in Miocene sediments, Friis Hills, Antarctica. *1st Southern Hemisphere Conference on Permafrost (SouthCOP),* Queenstown, New Zealand, 4-14 December 2019.

STUDENT POSTER PRESENTATIONS

Barrett, P., Elliot, D., and **Stutz**, J. (2019). Erosional history from landslide deposits in the Central Transantarctic Mountains. *New Zealand Antarctic Science Conference*, Christchurch, New Zealand, 17-20 June 2019.

Eaves, S.,and **Dowling**, L., (2019). Glacial overdeepenings in the Southern Alps: A review. *Geosciences*, Hamilton, New Zealand, 24-27 November 2019.

Isaac, F.E., Renwick, J.A., **Dadic**, R., Mackintosh, A.N. (2019). Influence of Southern Hemisphere atmospheric variability on recent sea ice variability in East Antarctica. *AGU Fall Meeting*, San Francisco, USA, 9-13 December 2019

Johnson, K.M., **McKay**, R., **Bertler**, N.A., Etourneau, J., Jiménez-Espejo, F.J., Albot, A., Riesselman, C., **Horgan**, H., Crosta, X., Dunbar, R., Escutia, C., Bendle, J. (2019). Holocene ice-ocean interactions in the Ross Sea and Adélie Land regions. *13th International Conference on Paleoceanography*, Sydney, Australia, 2-6 September 2019.

Leong, W-J., and **Horgan**, H. (2019). DeepBedMap: Using a deep neural network to better resolve the bed topography of Antarctica. *European Geosciences Union (EGU) General Assembly*, Vienna, Austria, 7-12 April 2019.

Stutz, J. Baroni, C., and Lee, J. (2019). Terrestrial-Marine glacial reconstruction within Terra Nova Bay/western Ross Sea. *XIII International Symposium of Antarctic Earth Sciences, side meeting*, Incheon, Republic of Korea, 22-26 July 2019.

Stutz, J., **Eaves**, S., Norton, K., Balco, G., Spector, P., Goehring, B., Licht, K. (2019). Constrain long-term thickness changes of southern TAM outlet glaciers using cosmogenic surface exposure dating. *2019 NSF Antarctic Deep Field Camp Planning Workshop*, Cedar Glen, California, USA, 15-16 October 2019.

OUR PEOPLE

Rob McKay
Associate Professor & Director
Stratigraphy & sedimentology

Michelle Dow
Centre Manager

Dao Polsiri
Administrator & NZ SeaRise
Project Manager

Darcy Mandeno
Science Drilling Office
Operations & Field Engineer

Alex Pyne
Antarctic Drilling Advisor

Brian Anderson
Associate Professor
Glacial modelling

Peter Barrett
Emeritus Professor
Antarctic climate history

Nancy Bertler
Associate Professor
Ice core climatology

Lionel Carter
Emeritus Professor
Ocean history & processes

Ruzica Dadic
Senior Research Fellow
Snow & ice processes

Warren Dickinson
Senior Research Fellow
Sedimentary petrology

Gavin Dunbar
Senior Lecturer
Sedimentary geology & geochemistry

Bella Duncan
Postdoctoral Fellow
Paleoceanography

Shaun Eaves
Lecturer
Glaciology & paleoclimatology

Nick Golledge
Associate Professor
Ice sheet modelling

Alexandra Gossart
Postdoctoral Fellow
Regional climate modelling

Huw Horgan
Senior Lecturer
Glacial geophysics

Stefan Jendersie
Research Fellow
Ocean modelling

Liz Keller
Research Fellow
Modelling Hub Co-Leader

Richard Levy
Associate Professor
Stratigraphy

Tim Naish
Professor
Sedimentology & paleoclimatology

Jamey Stutz
Postdoctoral Fellow
Antarctic geology

Lauren Vargo
Postdoctoral Fellow
NZ glacier monitoring & modelling

Oliver Wigmore
Postdoctoral Fellow
Glacial processes

Holly Winton
Postdoctoral Fellow
Ice core biomarkers

ARC ADVISORY BOARD

Dave Harper (Convenor), Dean of Science, Victoria University,
TBC, Antarctica New Zealand
Craig Cary, New Zealand Antarctic Research Institute
Jana Newman, Ministry of Foreign Affairs & Trade
Ian McIntosh, Research Office, Victoria University
Rob Murdoch, NIWA
Ian Simpson, GNS Science
James Renwick, SGEES, Victoria University
Prue Williams, Ministry of Business, Innovation & Employment

ARC ADJUNCTS

Helen Bostock
Robert DeConto
Robert Dunbar
Mario Krapp
Dave Lowe
Dan Lowry
Alena Malyarenko
Peter Webb
Mike Williams
Terry Wilson
Dan Zwartz

POSTGRADUATE STUDENTS

Alanna Alevropoulos-Borrill	PhD	Modelling
Francesca Baldacchino	PhD	Remote sensing
Hannah Chorley	PhD	Antarctic climatology
Lukas Eling*	PhD	Paleoclimatology
William Gonzalez	PhD	Palynology
Florence Isaacs	PhD	Antarctic climatology
Katelyn Johnson	PhD	Ice core climatology
Wei Ji Leong	PhD	Machine learning
Dan Lowry*	PhD	Modelling
Jamey Stutz	PhD	Glaciology
Matthew Tankersley	PhD	Geopotential modelling
Levan Tielidze	PhD	Glaciology
Abhijith Ulayottil Venugopal*	PhD	Paleoclimatology
Laurine van Haastrecht	PhD	Antarctic glaciology
Lauren Vargo*	PhD	Climate dynamics
Marjolaine Verret	PhD	Permafrost geochemistry
Arran Whiteford	PhD	Subglacial hydrology
Ross Whitmore*	PhD	Glaciology
Theo Calkin	MSc	Glaciomarine geology
Lisa Dowling*	MSc	Glaciology
Clarrie Macklin*	MSc	Subglacial hydrology
Emily Moore	MSc	Glacial history
Rebecca Pretty*	MSc	Sedimentology
Simon Reeve*	MSc	Paleoclimatology
Nikita Turton*	MSc	Sedimentology

*thesis submitted for examination in 2019

ASSOCIATED RESEARCHERS

Cliff Atkins	Senior Lecturer in Earth Sciences	Sedimentary processes and environments
Michael Hannah	Associate Professor in Earth Sciences	Marine palynology
Kevin Norton	Associate Professor in Geography	Geomorphology and geochemistry
Rebecca Priestley	Associate Professor - Science in Context	Antarctic science history
James Renwick	Professor in Physical Geography	Atmospheric circulation
Tim Stern	Professor in Geophysics	Solid earth geophysics and Transantarctic Mountains

OTHER VUW ACADEMICS WITH ANTARCTIC INTERESTS

David Frame	Professor of Climate Change	Climate policy and future climate change
Margaret Harper	Adjunct Research Associate in Geology	Freshwater algae
Malcolm Ingham	Senior Lecturer in Physics	Properties of sea ice
Mark McGuinness	Professor in Mathematics	Modelling
Joanna Mossop	Associate Professor in Law	International law
Nigel Roberts	Emeritus Professor of Political Science	Antarctic politics and history
Ken Ryan	Professor in Antarctic Biology	Marine algae
Rhian Salmon	Deputy Director - Science in Society	Science communication
Ross Stevens	Programme Director in Industrial Design	Design of remote field camps
Joe Trodahl	Emeritus Professor in Physics	Temperature conduction in ice and rock

LIST OF COLLABORATORS

NATIONAL COLLABORATORS

Antarctica New Zealand
Aqualinc Research Ltd.
Bodeker Scientific Ltd.
GNS Science
HPFS Solutions
Massey University
Max Tarr Electrical Ltd.
Meridian Energy - Twizel
NIWA
University of Auckland
University of Canterbury
University of Otago
University of Waikato
Webster Drilling and Exploration Ltd.

INTERNATIONAL COLLABORATORS

Alfred Wegener Institute (Germany)
Berkeley Geochronology Centre (USA)
Binghamton University - State University of New York (USA)
British Antarctic Survey (UK)
Australian Maritime College
Cambridge University (UK)
Centre for Remote Sensing of Ice Sheets (USA)
Imperial College London (UK)
Chinese Academy of Meteorological Sciences
Chinese Academy of Sciences
Curtin University (Australia)
Dartmouth College (USA)
Durham University (UK)
ETH (Switzerland)
Hokkaido University (Japan)
Indiana State University (USA)
International Cable Protection Committee (UK)
Instituto Andaluz de Ciencias de la Tierra (Spain)
Istituto Nazionale di Geofisica e Vulcanologia (Italy)
Imperial College London (UK)
Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (Italy)
Japan National Institute for Polar Research (Japan)
Jilin University (China)
Korea University (South Korea)
Korean Polar Research Institute (Republic of Korea)
Laboratoire de glaciologie et géophysique de l'environnement (France)
Lamont-Doherty Earth Observatory (USA)
Lawrence Livermore National Laboratory (USA)
Los Alamos National Laboratory (USA)
Ludwig-Maximilians-University of Munich (Germany)
Macquarie University (Australia)
NIOZ Royal Netherlands Institute for Sea Research (The Netherlands)
NOAA (USA)
National Oceanography Centre (UK)
National Research Council (Italy)
National Sun Yat-sen University (Taiwan)
Niels Bohr Institute (Denmark)
North Dakota State University (USA)
Northern Arizona University (USA)
Northern Illinois University (USA)
Oregon State University (USA)
Scripps Institution of Oceanography (USA)
Southampton University (UK)
St. Olaf College (USA)
State University of New York (USA)
Swiss Federal Research Institute WSL (Switzerland)
Royal Holloway, University of London (UK)
The Australian National University
The Ohio State University (USA)
The Pennsylvania State University (USA)
Tulane University (USA)
University of Alaska, Fairbanks (USA)
University of Birmingham (UK)
University of California, Irvine (USA)
University of California, Davis (USA)
University of Colorado (USA)
University of Copenhagen (Denmark)
University of Delaware (USA)
University of Delhi (India)
University of Granada (Spain)
University of Lausanne (Switzerland)
University of Maine (USA)
University of Massachusetts (USA)
University of Milano-Bicocca (Italy)
University of Nebraska-Lincoln (USA)
University of New South Wales (Australia)
University of Pisa (Italy)
University of Stockholm (Sweden)
University of Tasmania (Australia)
University of Urbino (Italy)
University of Washington (USA)
University of Wisconsin-Madison (USA)
University of Waterloo (Canada)
U.S. Geological Survey
Utrecht University (The Netherlands)
Virginia Institute of Marine Sciences (USA)
Worcester State University (USA)
Yale University (USA)

Antarctic Research Centre Annual Review 2019
Designed and edited by: Michelle Dow

Contributions from: Brian Anderson, Peter Barrett, Nancy Bertler, Ruzica Dadic, Michelle Dow, Gavin Dunbar, Shaun Eaves, Nick Golledge, Huw Horgan, Richard Levy, Darcy Mandeno, Rob McKay, Lara Perez, Tim Naish, Lauren Vargo, and Peter Webb.

VICTORIA UNIVERSITY OF
WELLINGTON
TE HERENGA WAKA

Antarctic Research Centre

Te Puna Pātiotio

www.wgtn.ac.nz/antarctic

Antarctic-Research@vuw.ac.nz

+64-4-463 6587