TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI
VICTORIA
UNIVERSITY OF WELLINGTON

ANTARCTIC RESEARCH CENTRE

annual review 2016

Contents

Antarctic Research Centre Annual Review 2016
Designed and edited by Michelle Dow
Contributions from Nancy Bertler, Lionel Carter, Warren Dickinson, Michelle Dow, Gavin Dunbar, Nick Golledge, Huw Horgan, Andrew Mackintosh, Rob McKay, Alex Pyne, and Tim Naish.

Photo: Icebergs near Adelaide Island, Antarctica Peninsula - Nick Golledge
Cover photo: Mawson Glacier, Antarctica - Andrew Mackintosh

2016 IMPACTS BY NUMBERS

2 PRESTIGIOUS AWARDS

presented to Nancy Bertler for her ice core science leadership excellence. The Blake Leadership Award and Wellingtonian of the Year - Science and Technology.

4 Rutherford Discovery Fellows

at the ARC with Huw Horgan joining Nancy Bertler, Rob McKay, and Nick Golledge.

28 *Nature*, *Science* and *Proceedings of the National Academy of Sciences* papers

have been authored by ARC staff. Two *Nature*, one *Science* and two *PNAS* papers in 2016.

9 theses

submitted in 2016 by ARC supervised students. Four PhD and five MSc students.

3 lead-authored papers

by ARC's Shaun Eaves are improving our understanding of New Zealands past, present and future alpine glaciers.

14 MARSDEN GRANTS

awarded to ARC staff since 2001, of these eight were Marsden Fast-Starts. Shaun Eaves is the latest recipient of a Marsden Fast-Start in the 2016 round.

43 presentations, briefings and panel discussions

given to the public, stakeholders and decision makers by ARC staff.

27+ radio, TV and newspaper interviews

given by ARC staff on Antarctic and climate related issues.

17,000 year climate archive

recovered in a continuous record of annual sediment layers in cores from Lake Ohau, will provide an unparalleled understanding of high-frequency climate variability in the mid-latitude Southern Hemisphere.

704 DAYS

of research leave for Tim Naish, while on his prestigious RSNZ James Cook Fellowhip awarded in 2016.

600 parts per million

atmospheric carbon dioxide, maybe the threshold for major loss of the East Antarctic Ice Sheet according to a *Science* paper by ARC co-authors Tim Naish and Peter Barrett.

2ºC global warming

above preindustrial is the potential threshold for loss of the Ross Ice Shelf, says ARC's Gavin Dunbar to US Secretary of State, John Kerry, at Scott Base.

$25 million NZD

is the amount the International Ocean Discovery Program will spend to drill six sites in the central Ross Sea in January and March 2018. ARC's Rob McKay is the lead proponent and co-chief scientist of Expedition 374 which was approved in June 2016.

Sea ice meets ice shelf, Antarctica - Photo: Michelle Dow

DIRECTOR'S SUMMARY

From April 1st, 2017 I am taking a two-year hiatus from the Director role, while I focus on my RSNZ James Cook Fellowship and develop some new research directions in sea-level change reconstructions and predictions. While I anticipate several short 1-2 month periods of overseas research and study leave during my fellowship, I will be substantively based in Wellington splitting my time between VUW and GNS Science. The Antarctic Research Centre (ARC) Directorship will be in the very capable hands of Andrew Mackintosh, Deputy Director for the last three years. Andrew is a passionate member of our leadership team, and I know he will get as much satisfaction from the Director role as I have had. I expect he will inject his own leadership style, and while Andrew will have the day to day responsibility, we will continue to work as a team on long-term strategic decisions and issues.

Looking back over the last decade, as recorded in our annual reviews, I'm reminded of just how far we have come. Our staff and income have doubled. We have moved from revenue that was mainly underpinned by a couple of large MBIE grants to a much more diversified revenue stream with almost 40% of our income from highly competitive Rutherford Discovery Fellowships and Marsden Fund grants. This reflects the talent of our present research staff, many of whom joined the ARC with Marsden Fast-Start funding. Our latest superstar, Huw Horgan, received a Rutherford Discovery Fellowship in 2016, ARC's fourth RDF in as many years. Shaun Eaves, the latest early career researcher to join our staff, received a Marsden Fast-Start grant in 2016. Most of our once young academic and research staff received promotions this year and are now at Senior Lecturer and Associate Professor levels. Nick Golledge was the latest to be promoted to Associate Professor.

Yet again, it has been another stellar year for the ARC team in terms of research innovation, impact, awards and recognition. Of special note is the recognition of Nancy Bertler's excellence in research leadership through a 2016 Blake Leadership Award, and winning the 2016 Wellingtonian of the Year for Science and Technology. Like last year we have identified research impacts "by the numbers" up front in this review and have highlighted four major research outcomes, that distinguish themselves in terms of major international climate change research collaborations and policy relevance.

We had 29 PhD and MSc students on the books, with four PhD and five MSc thesis completions. A new cohort of mostly international postgraduate students have settled in well and contribute to a vibrant, fun and stimulating research environment. Our commitment to world-leading Antarctic and climate change research that makes a difference both internationally and in New Zealand is grounded in scholarly research published in leading scientific journals.

Ironsides Glacier with Mt Herschel in the background, Antarctica
Photo: Jamey Stutz

Staff and students were involved in 31 publications in top international peer reviewed journals, and we highlight research published in two *Nature*, one *Science*, and two *Proceedings of the National Academies of Sciences*, as well as a range of other prestigious international journals.

Our commitment to communicating the relevance of our research to the public and stakeholders continues. Our staff and students regularly engage with public, local government, central government, Members of Parliament, schools, youth and the private sector. I had the privilege of delivering the Royal Society of New Zealand "10 by 10" national lecture series this year with James Renwick (SGEES). We visited 13 cities and towns (rather than 10) talking on "Ten Things You Didn't Know About Climate Change" to very engaged and large audiences.

Just over 12 months since the UN Paris Climate Agreement was signed, it really does seem like the urgency to act, in New Zealand at least, is being recognized on a number of levels. The scene in NZ has changed. The OECD released its review of NZ's environmental performance over the last decade, arguing strongly for the transition towards a low-carbon, greener economy. A cross-party group of 35 members of our Parliament representing all parties released a report "Net Zero in NZ" commissioned from VIVID Economics. This is the first report ever to provide credible pathways for New Zealand to reduce its greenhouse gas emissions to zero before 2100. This was followed with Generation Zero, launching their Carbon Zero Act campaign to spur the next Parliament to commit to a legally binding framework for reaching zero carbon emissions by 2050! The Climate Change Minister has set up an adaptation expert working group, and the Ministry for the Environment is soon to release its updated coastal hazards guidelines for local authorities, which includes a high sea-level rise scenario that takes into account rapid Antarctic ice sheet loss. Regional councils and territorial authorities are increasingly aware and concerned that local factors such as vertical land movements matter in New Zealand, and influence the amount of sea-level rise, we will have to adapt to. The ARC has decided to take up the challenge of integrating our knowledge on polar ice sheet and mountain glacier contributions to sea-level rise, with local factors such as vertical tectonics, subsidence and changes in sea-surface height, in order to provide improved location-specific estimates of sea-level rise for New Zealand.

The backbone of our research approach has been in pioneering large data acquisition projects in order to provide constraints and "test-beds" for numerical ice sheet, glacier and climate models. Our niche, and in many cases globally-unique capability in ice and sediment drill coring is provided through the expertise of our in-house Science Drilling Office led by Alex Pyne. This year saw the team of drilling innovators, together with Webster Drilling and Exploration, successfully recover a continuous annual sediment record from the bottom of Lake Ohau going back 17,000 years. Furthermore, they developed and commissioned, in Antarctica, a new ~$1 million dollar Hot Water Drill system for accessing the ocean and sea-bed under the Ross Ice Shelf as part of an NZARI-funded collaborative research programme. Last, but not least, a new compressed air permafrost drill successively recovered 200 m of frozen Miocene (20-14 million years old) glacial, river and lake sediments from the Friis Hills in the Transantarctic Mountains.

Staying with the large scale geological drilling theme, it doesn't get much bigger than this. Rob McKay after years of perseverance, was rewarded by having his proposal approved to take the International Ocean Discovery Program (IODP) drill ship to the Ross Sea in the summer of 2018. The $25M expedition will be co-led by Rob and long-term ARC collaborator, Laura De Santis, from OGS (Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Italy). This will be the first time that a scientific drill ship has been back to the Ross Sea since 1973, when Peter Barrett was on board as a young scientist! The research should provide critical insights into how changes in ocean heat flux have affected the stability of the marine-based sectors of the Antarctic ice sheet.

Professor Tim Naish
2016 Director, Antarctic Research Centre

Funding for Antarctic research in New Zealand remains a challenge. While ARC staff continue to perform well in highly competitive contestable funds (e.g. Rutherford, Marsden), and a new modest-sized philanthropic fund provided by NZARI is a welcome addition, the lack of medium to long-term funding security remains a considerable risk as New Zealand attempts to sustain its world-leading Antarctic research reputation. That may be about to change as the government considers "ring-fencing" a strategic pot of funding for Antarctic research. I look forward to seeing how this evolves in 2017, and continuing to work with our national and international partners, and stakeholders, whose collaboration allows our talented staff and students to continue to produce high-quality, world-class research that matters and makes a difference.

OUR MISSION AND RESEARCH APPROACH

Improve understanding of Antarctic ice sheet and climate processes and their influence on New Zealand and the global climate system

We believe our field of research provides exciting opportunities and challenges attractive to young researchers, and is needed to provide a sound basis for international climate change assessment and predicting local impacts to enhance policy development for a more resilient New Zealand.

The Antarctic Research Centre (ARC) is one of a number of centres of research excellence within the Faculty of Science at Victoria University of Wellington and reports directly to the Dean of Science. It is co-located with the School of Geography, Environment and Earth Sciences, with which it shares academic staff and facilities. It also contributes to both undergraduate and graduate teaching and supervision in the fields of sedimentology, glaciology, paleoclimatology and Antarctic affairs.

Rationale

The warming trend observed over the past century and models of its future trajectory suggest that we are rapidly heading towards a climate last experienced more than 3 million years ago - a time before our species had evolved. In order to assess model-based climate projections, scientists are increasingly looking back to the future to gain insights into the likely response of Earth's climate in a world with high levels of greenhouse gases. Ice sheets and oceans are some of the slowest responding elements of the climate system to an atmospheric carbon dioxide perturbation - taking centuries to millennia to play out, and are therefore potentially irreversible on human timescales. Reconstructing past climate conditions provides the only possible way to assess the long term "endgame" (equilibrium response), that we will commit our planet to this century based on the current warming scenarios - which virtually guarantee +2-3°C increase in global surface temperature. Past climate records also allow the role of anthropogenic influences to be determined in the context of natural variability of the climate system on human timescales.

Outcome-based research

Our research approach is policy-relevant and outcome focused. We reconstruct the response of the Antarctic and Southern Ocean to past climate change, that is similar to that projected for the coming centuries by the Intergovernmental Panel on Climate Change (IPCC). We do this to improve the performance of the models assessed in the IPCC reports in order to reduce the uncertainties around future climate and sea-level rise predictions. We improve understanding of the influence and impact of Antarctic and Southern Ocean change on the global climate system, especially the Southwest Pacific region and New Zealand. 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, and is funded and supported through a range of MBIE, Marsden, and Rutherford programmes, Antarctica New Zealand and private donations.

In summary our approach involves:

a. The acquisition of past (paleo) observations of surface temperature, atmospheric circulation and composition (greenhouse gases and aerosols), ice sheet, glacier, and sea-ice variability, and oceanic conditions from geological and ice core archives.

b. Undertaking process studies of modern glaciers and glacial and marine systems.

c. Integrating the observations and processes with numerical modelling to understand sensitivity and response of the Antarctic ice sheet and climate system to the type of forcings and feedbacks projected for the future.

d. Then use those same models to improve future projections of ice sheet contribution to sea-level rise and other changes in the Earth System.

e. Comparison and correlation with equivalent "far-field" observations and reconstructions, of global extent, and within the SW Pacific and New Zealand (e.g. records of global sea level and local New Zealand ocean and climate change).

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

Tucker Glacier, Antarctica - Photo: Jamey Stutz

MAJOR RESEARCH OUTCOMES

Significant research enhancing our knowledge of the consequences of climate change

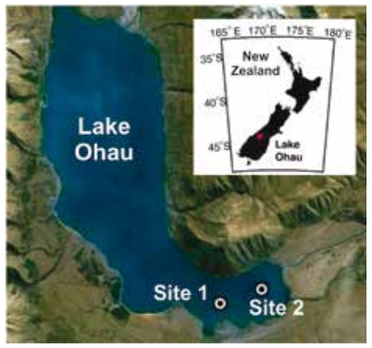
Lake Ohau coring, New Zealand - Photo: Chris Moy (University of Otago)

A 17,000-YEAR SEDIMENTARY CALENDAR OF CHANGE

Using a bespoke barge and drilling system the ARC has been involved with the first deep lake coring project in New Zealand and only the second in the Southern Hemisphere.

Lake Ohau sits in a stunning glacier-sculpted landscape in South Island's Mackenzie country. Ice age glaciers departed the basin occupied today by Lake Ohau ~17,000 years ago. Since then the bottom of the lake has been slowly accumulating layer-upon-layer of silt and clay, forming deposits >100 m thick.

In early 2016 the LOCH (Lake Ohau Climate History) project, a Marsden-funded collaboration between GNS Science, Victoria University, University of Otago, Northern Arizona University, Istituto Nazionale di Geofisica e Vulcanologia, University of New South Wales, Indiana State University and NIWA, used a purpose-built barge and drill rig system designed by the ARC's Science Drilling Office and built by Webster Drilling and Exploration to core two sites in the southern end of the lake – the first time such a setup has been used in New Zealand and only the second deep lake coring project in the Southern Hemisphere. Much time was spent awaiting-on-weather with Ohau living up to its Māori name of 'windy place', but once underway the coring process itself was fast with 2.5 tonnes of sediment piling up in just a few days, representing an 80 m thick record from Site 1 and 42 m thick record from Site 2. Once the cores were safely back in Dunedin, we decided to apply a relatively new technique (for geology at least) by CT (computed tomography) scanning, or 3D x-raying, all our cores to image the many thousands of mm-thick layers they contained. Using an instrument usually tasked to scan



Location of the LOCH project core sites

X-ray images of sediment cores showing 30 mm of annual layers and drop stones (left: near the surface, right: just above the ice age gravels)

animals it generated over 200 Gb of data (a one hour HD TV show is about 1.5 Gb). The results were stunning, with annual sedimentary layers present throughout the entire 17,000 year-long record. Climatic variations are clearly evident in changes in the nature of the layering over time. In the oldest parts of the record fine-grained layers are interrupted by pulses of gravel carried down the lake and dropped by small icebergs, showing that glaciers that now occupy a tiny part of the river valleys above Ohau still terminated in the lake much as Tasman Glacier does today in Tasman Lake. Progressive warming caused the glaciers to retreat from the lake spelling the end of icebergs and gravel deposits. Instead we see an increasingly complex layering as weather events start to impart their signature on top of the winter/summer annual cycle. Large floods in particular leave a characteristic thick deposit of mud behind and their frequency comes and goes over time.

We have now split the cores and started pulling out leaf fragments and twigs for radiocarbon dating. So far we have dated 14 layers ranging from 2600 years old at 14 m below the lake floor (blf) to nearly 12,000 years old at 60 mblf at our high resolution Site 1, but expect more to come. We have also examined the fossil pollen content in samples spaced every thousand years or so, which provides a picture of the vegetation surrounding the lake at that time. Coming out of the last ice age the landscape was dominated by grasses and shrubs which gave way to native conifer trees around 10,000 years ago, followed by migration and rapid expansion of beech forest in the region from ~7000 years ago.

We hope to combine our drill core reconstructions of past climate with regional and global climate model simulations to construct a greatly improved understanding of the past causes, timing, and magnitudes of high-frequency climate variability in the Southern Hemisphere mid-latitudes. With a firmer knowledge of how, and why, changes occurred in the past, we can better anticipate potential changes in New Zealand's future climate.

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OCEAN DRILLING RETURNING TO THE ROSS SEA

Forty-five years after the last ship-based drilling project, a successful proposal led by Rob McKay will see the International Ocean Discovery Program back in the Ross Sea in January 2018.

The modern thinning of Antarctic ice shelves and marine terminating ice sheets is thought to be linked to increased heat delivery to the Antarctic continental margin by oceanic waters adjacent to the ice sheets. Previous geologic drilling on Antarctica's continental margin by the ANDRILL program indicates marine-based ice sheet variability has been significant over the past 20 million years. The IODP has scheduled a new drilling project in the Central Ross Sea to better document ocean-ice sheet interactions through the same period of geological time.

Rob McKay is co-chief scientist for this ambitious new drilling project to document past variability of Antarctica's ice sheets and oceans. In particular, it is hypothesised that variations in oceanic heat flux moving southwards towards the ice sheets are critical in triggering marine ice sheet instabilities. However, the influence of ice sheet meltwater discharge into the oceans during past ice sheet retreat events will also have large-scale implications for the global oceanic circulation. Not only would such melt events raise global sea levels, but would also influence sea ice extent, global oceanic heat transport, and biological productivity in the Southern Ocean. Indeed, observations from the past several decades indicate that the Southern Ocean is warming and freshening significantly, due in part to modern ice sheet melt, with long-term implications for global oceanic circulation.

To assess how such ice-ocean interactions have varied through time, IODP Expedition 374 will drill a latitudinal and depth transect of six drill sites (up to a kilometre deep) from the outer continental shelf and deeper waters on the continental rise in the central Ross Sea. This location was selected because numerical ice sheet models indicate that it is highly sensitive to changes in ocean heat flux. This location is thus optimally located for data-model integration to enable an improved understanding of the sensitivity of Antarctic ice sheet mass balance during warmer-than-present climates since the middle Miocene ~20 million years ago. Additionally, the transect directly links to previous drill records studied by ARC researchers over the last few decades, including ice proximal records from the inner Ross Sea continental shelf (e.g. ANDRILL sites) and deep southwest Pacific drilling sites offshore of New Zealand. This will allow us to complete an ice proximal to far-field view of climate and Antarctic cryosphere evolution over this critical period in Earth's geological past.

The expedition is set to sail to the Ross Sea between 4 January and 8 March 2018. This will be 45 years after geological drill cores were first taken from the Ross Sea in 1973 by the Deep Sea Drilling Project. Peter Barrett was a scientist on that expedition which proved the antiquity of the Antarctic ice sheets. Rob McKay will co-chief the cruise alongside long-time ARC collaborator Laura De Santis (Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Italy). The JOIDES Resolution drilling vessel will be supported by an icebreaker during part of the drilling season - but ice and weather may still decide for us what exact records will be obtained. Accordingly, this consideration has required us to develop extensive contingency plans and back-up drilling sites, particularly given the increasing unpredictability of sea ice conditions in this region over recent years.

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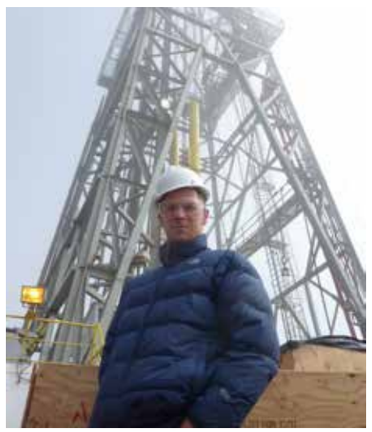

Rob McKay on the *Joides Resolution*
Photo: Rob McKay

WHY 2 DEGREES MATTERS

The future fate of the Antarctic ice sheet is the gorilla in the room for improving estimates of global sea-level rise.

Vulnerable low-lying island and coastal nations were so concerned about sea-level rise, they would not sign the 2015 Paris Climate Agreement unless the Intergovernmental Panel on Climate Change (IPCC) took a closer look at limiting global warming to 1.5°C. Tim Naish together with University of Canterbury social scientist, Bronwyn Hayward and IPCC Vice Chair Andy Reisinger, attended the IPCC's meeting held in Geneva last September to scope the content of the 1.5°C report, and returned with the sad realisation that at our current rate of carbon dioxide emissions, we could pass 1.5°C within the next five years. The report will not be completed for two more years!

The future fate of the Antarctic ice sheet is the gorilla in the room. NASA scientist, Eric Rignot, who gave the 2016 S.T. Lee Lecture, suggests that it is now too late for a large part of the West Antarctic Ice Sheet, which could raise sea level by 3 m. James Hansen, former Director of NASA's Goddard Space Centre, and a highly respected atmospheric scientist, has argued, based on the current acceleration in the rate of the polar ice sheets melting, global sea levels could rise more than 2 m above by the end of the century.

However, the IPCC do not base their predictions on extrapolations of relatively short-trends. Rather, they use computer simulations of the physical processes that occur in an ice sheet in response to climate warming. Since the IPCC report in 2013, significant progress has been made using computational ice sheet models to better capture the key processes that lead to rapid loss of the Antarctic ice. Results from a study published last year in *Nature*, led by Nick Golledge, and highlighted in our 2015 Annual Review, show higher sea-level contributions from Antarctic ice melting for the range of future IPCC climate scenarios above 2°C. The bottom line is that the current sea-level projections may significantly underestimate the Antarctic contribution to future sea level by 2100 by as much as 80 cm for the business as usual scenario without emissions reductions. A recent report by the National Ocean and Atmosphere Administration (NOAA) produced a new set of regional sea-level rise predictions for the US, and by including the new Antarctic estimates predicts a worst case scenario sea-level rise of +2.5 m by 2100 for cities on the eastern seaboard such as Boston.

So whilst the 2015 paper went some way towards identifying thresholds in Antarctic ice sheet behaviour, the time periods and levels of climate change considered only told part of the story. Looking at a much longer timeframe, during periods of the geological past when global temperatures were very much higher than today, a paper published in *Nature* and led by Alan Aitken (University of Western Australia), and co-authored by Nick, explored more extreme threshold responses of the East Antarctic Ice Sheet, some 10 times bigger than its western counterpart. What this study confirmed was that both modelling and geological evidence consistently show that under warmer climates the ice sheet doesn't just retreat gradually, but rather it 'jumps' from one stable configuration to another. Transitions are therefore rapid, and unpredictable.

There is also a good news story in this new research. The results of the Golledge 2015 study, and a second study published in *Nature* in 2016 by our American collaborators, Rob DeConto (University of Massachusetts) and David Pollard (Pennsylvania State University), show that stabilisation of earth's temperature at 2°C above pre-industrial levels, the target signed up to by 197 countries in the Paris agreement, saves the Antarctic ice sheet from significant melting and dramatically improves the prospects for island nations. In other words, there appears to be a threshold in the Antarctic ice sheet at around 2°C of global warming.

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Massive icebergs calving off the Antarctic ice sheet
Photo: Nick Golledge

ARC TACKLES SEA-LEVEL RISE PREDICTIONS FOR NEW ZEALAND

So what does sea-level rise mean for New Zealand and how prepared are we?

The first hurdle is that we do not have an adequate set of location specific sea-level predictions for anticipating and managing the impacts of sea-level rise. Parliamentary Commissioner for the Environment, Dr Jan Wright, said in her recent report - "local factors matter", and in New Zealand vertical land movements caused by tectonic processes must be taken into account.

While our biggest city Auckland is more or less tectonically stable, the lower North Island is subsiding by up to 3 mm per year, which means Wellington could experience 30 cm of additional sea-level rise above the global average predicted over the next 100 years – a worst case scenario might see, sea-level rise nearer 2 m if new Antarctic melt estimates are also included. In South Island, changes in sediment deposition and ongoing subsidence associated with the Christchurch earthquakes has significantly increased the risk of coastal flooding for large parts of Christchurch. In Dunedin, subsidence of south Dunedin, combined with sea-level rise, will result in the 100 year flooding event occurring several times a year by mid-century, and the region will largely be below sea-level by 2100, even if global warming is stabilized at the Paris target of 2°C.

The New Zealand Coastal Policy Statement (NZCPS) requires local authorities to plan for rising seas when regulating green field developments, zoning existing communities (brownfields) and future proofing infrastructure. Spatially variable land subsidence provides an additional challenge for councils who are trying to build resilience to sea-level rise into their district and city plans. In the case of some councils (Kāpiti and Christchurch) opposition to attempts at coastal-hazard management has seen the underpinning science and practitioner approaches questioned in court. The Ministry for the Environment, will shortly be releasing an updated version of "Coastal hazards and climate change: A guidance manual for local government in New Zealand". It provides sea-level rise scenarios, based on a published probabilistic assessment of the IPCC's most recent climate change assessment report, but does not include an assessment of local factors in those projections. The local authorities we have consulted desperately need better predictions specific to their territories for adapting to, and managing the impacts of sea-level rise, but they say they do not have the available expertise or resources.

After extensive consultation with end-users and stakeholders, the ARC has made a strategic decision to broaden its focus. To begin this, Tim Naish's Royal Society of New Zealand James Cook Fellowship will allow him to spend time with international colleagues upskilling in probabilistic sea-level rise prediction science. Then by leveraging off our reputation in ice sheet and sea-level research, ARC have led a collaborative research programme proposal, submitted to the MBIE Endeavour Fund in early 2017.

Our proposed research will provide a set of probabilistic sea-level rise scenarios for New Zealand's coastline, with spatially-resolved estimates of coastal inundation and increasing frequency of flooding and associated risks for the main coastal cities. The estimates will take into account new knowledge of vertical land movements, latest estimates of polar ice sheet melt, global glacier inputs, ocean thermal expansion and sea-surface height changes and the regional dynamical expression of melt water on our oceans.

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OTHER RESEARCH OUTCOMES

Further highlights of our world-leading research

Mawson Glacier, Antarctica - Photo: Andrew Mackintosh

PAST CLIMATE WINDOWS PROVIDE IMPROVED VIEW OF THE FUTURE

RICE: Looking close — looking deep

A major milestone for the international RICE (Roosevelt Island Climate Evolution project) team was the development of two high-resolution, high-precision age scales. One used an annual layer count focusing on the past 2,800 years led by Mai Winstrup (University of Copenhagen, Denmark), and the second, age scale for the past 80,000 years is based on matching the high resolution methane records between RICE, WAIS Divide, and the NGRIP ice cores, led by James Lee (Oregon State University, USA). These age scales now support a flurry of activities interpreting the records and were accompanied by over 4,000 new geochemical measurements from our laboratories focusing on the last few thousand years, deglaciation since the last ice age, and a period of rapid sea-level rise known as Meltwater Pulse 1A.

PhD student Lukas Eling processing RICE samples for ultra low concentration geochemical analysis
Photo: Nancy Bertler

We were excited to liaise with the city councils in the Wellington Region on the implications of our research results on projections of sea-level rise and were happy to see the New Zealand Parliament using question time to debate some of our statements with respect to policy strategies.

We also saw a big change of guard with respect to our early career researchers. Our team welcomed four new students, Lukas Eling from Germany, Abhijith Ulayottil Venugopal from India, and Katelyn Johnson and Daniel Lowry from the USA, who joined us to commence their PhD projects on the RICE record. Their projects range from high resolution geochemical analysis (with GNS Science), to the integration of ice core and marine sediment records (with Rob McKay), to the assessment of the RICE data using ice sheet models (with Nick Golledge). At the same time, Daniel Emanuelsson, successfully defended his PhD thesis which focused on the atmospheric drivers dominating the RICE isotope record in modern times.

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The response of Southern Ocean marine plankton to climate change events

Analysis of microfossils in dozens of drill core records collected over the last 30 years from the Southern Ocean reveal that single-celled marine algae (Antarctic diatoms) are more prone to extinction during major climatic changes and large-scale cooling on Earth. Photosynthesising algae, in the surface of the Southern Ocean form the base of the marine food web, are a crucial element mediating the global cycle of carbon dioxide, and account for about fifty percent of the world's total biological productivity. In a paper published in the *Proceedings of the National Academy of Sciences*, Victoria University paleontologist James Crampton (SGEES) utilised a dataset and approach developed by co-author Rosie Cody during her PhD studies at the ARC. The work also involved ARC researchers Rob McKay and Tim Naish and presented new quantitative analyses of large fossil data sets that allowed for the accurate timing of origination and extinction of diatom species in the Southern Ocean to be determined.

Although climate is known to naturally vary, the research indicated diatom communities can generally tolerate this variability. However, once a certain threshold of environmental and cryosphere change is reached, diatoms are vulnerable and some species become extinct while others evolve. Over the past fifteen million years diatoms in the Southern Ocean experienced five major pulses of extinction that are linked with particularly large and sharp temperature swings from warm to cold. The study showed that diatoms were affected by relatively rapid cooling in the past and appear to be sensitive to major changes in the climate system, and that a similar response may occur during intervals of relatively rapid warming.

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Antarctic ice sheet variability and sensitivity to atmospheric carbon dioxide levels across the Eocene-Oligocene boundary, ~34 million years ago

It's often said that good things take time. Fifteen years after the Cape Roberts Drilling Project was completed, the cores are still providing critical insights into the evolution of the Antarctica's ice sheets. At the time of drilling Tim Naish and colleagues interpreted high-frequency, cyclic marine sedimentation in the CRP 3 drill core as the result of regular oscillations in the marine margin of the first continental-scale ice sheet along the Victoria Land Coast of the Ross Sea. While they had assumed that the regularity of the cycles most likely resulted from known variations in the Earth's orbit on 100,000, 40,000 and 20,000 year time scales, the independent age model for the core was insufficient to confirm this. In 2003, Rob DeConto (University of Massachusetts) and David Pollard (Pennsylvania State University) published in *Nature* an ice sheet simulation showing that the Antarctic ice sheet developed about 34 million years ago in response to Earth's climate cooling as atmospheric carbon dioxide (CO_2) fell below ~750 parts per million (ppm).

Subsequently, a new paleomagnetic chronology for the CRP-3 core and frequency analysis of the cycles, showed that they were indeed paced by orbital glacial cycles between 34 million and 31 million years ago. Further analysis of the glacial cycles published in *Science* by Galeoti *et al*. (2016), including co-authors, Rob DeConto, Tim Naish and Peter Barrett, shows that initially under atmospheric CO_2 levels of ≥600 ppm, the first Antarctic ice sheet was smaller and restricted to the terrestrial continent, and was highly responsive to local insolation forcing. A more stable, continental-scale ice sheet calving ice bergs at the coastline did not form until ~32.8 million years ago, coincident with the earliest time that atmospheric CO_2 levels fell below ~600 ppm. The results provide insight into the potential of the Antarctic ice sheet for threshold behaviour and have implications for its sensitivity to atmospheric CO_2 concentrations above present-day levels.

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Permafrost cores reveal a past warmer and highly dynamic ice sheet when trees last grew on Antarctica

A remarkable sequence of ancient glacial drifts, lake and river deposits bearing fossil evidence of small beech trees, beetles and moss, preserved in the Transantarctic Mountains at Friis Hills, is believed to represent the last time Antarctica supported trees, 15 million years ago. It has been argued that widespread cooling and expansion of the East Antarctic Ice Sheet about 14 million years ago terminated higher plants, and has kept the landscape frozen and arid to this day. Previous work by Adam Lewis and Alan Ashworth (University of South Dakota), has documented numerous cycles of advance and retreat of an alpine glacier system in the Friis Hills. While their stratigraphy was based on careful mapping of the surface geology, they believed that the deposits were preserved as continuous layers in a basin up to 50 m deep. In November 2013, Adam joined our team Richard Levy (GNS Science), Tim Naish, Warren Dickinson, Nicholas Golledge (ARC) and Andrew Gorman (University of Otago) to conduct a seismic survey to evaluate the extent and thickness of the Friis Hills deposits.

Tim Naish collecting samples at Friis Hills while the drilling takes place behind him.
Photo: Tim Naish

In October 2016, Tim and Richard returned to Friis Hills with Alex Pyne, his daughter Rebecca Pyne (GNS Science), ARC PhD student Hannah Chorley and Webster Drilling and Exploration drillers Tony Kingan and Adam Rutten. Over six weeks we recovered 200 m of permafrosted geological cores from three sites with the longest drill hole reaching a depth of over 50 m. The drill system, people and camp gear was flown in by 16 helicopter flights by Antarctica New Zealand's contractor Southern Lakes Helicopters, and the US National Science Foundation. The system utilised an innovative compressed air system to flush cuttings from the hole. The compressor unit alone was 600 kilograms!

The cores are simply spectacular and revealed 10 cycles of advance and retreat of a temperate alpine glacier system across a vegetated landscape dominated by small glacial lakes and glacier-fed rivers and streams, between 19-14 million years ago when Earth's average temperature was 3-4°C warmer and atmospheric CO_2 was 400-600 ppm. Preliminary results suggest a number of datable volcanic ashes have been recovered within the cores and may allow age and timing of the glacial oscillations to be established.

Hannah will spend the next three years analysing the cores and reconstructing the climate and glacial history for her PhD thesis. She will also work with Nick Golledge to develop a model to simulate the glacial history and to provide insights into East Antarctic Ice Sheet behaviour in a warmer world.

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ASSESSING THE STATE OF GLACIERS AND ICE SHEETS

Brewster Glacier mass balance programme now the longest direct, continuous record of glacier health in New Zealand

Mountain glaciers are currently one of the largest contributors to sea-level rise. However, calculating the current rate of ice loss from glaciers is not trivial because so few glaciers are measured. New Zealand is no exception and for many years, no glaciers were monitored regularly. In 2002, Andrew Mackintosh and Sean Fitzsimons (University of Otago) started annual glacier mass balance measurements on Brewster Glacier near Haast Pass. Since then, Brian Anderson and Nicolas Cullen (University of Otago) have largely been responsible for maintaining this effort, along with contributors from the wider New Zealand snow and ice community including ARC's Ruzica Dadic and Huw Horgan. Over the last few years, Andrew Lorrey (NIWA) has partially supported the cost of running this programme.

Since the inception of monitoring, Brewster Glacier has been an important training ground for students. It is now the longest continuously-measured glacier in New Zealand, and one of the most important monitored glaciers in the Southern Hemisphere. Although we have published many process and modelling studies of Brewster Glacier, and report data annually to the World Glacier Monitoring Service, this is the first time that the 11-year record itself has been published (Cullen *et al.*, 2017). We hope that it remains a useful benchmark of glacier health for decades.

CONTACT: Brian.Anderson@vuw.ac.nz

Climate warming leading to degradation of mountain permafrost

Climate warming is leading to greater melting of permafrost leading to the activation of previously stable mountain slopes, and an increase in associated hazards. Debris flows are dangerous combinations of loose debris and water that travel down a slope under the influence of gravity. They are particularly hazardous to infrastructure, and have resulted in recent loss of life in New Zealand. The Southern Alps contain both mountain permafrost and debris flow activity; however, the relationship between these two phenomena has not been studied.

In a paper (Sattler *et al.*, 2016) stemming from her PhD research supervised by Andrew Mackintosh, Brian Anderson, Kevin Norton and Mairead de Roiste, Katrin Sattler developed a comprehensive rock glacier inventory for New Zealand and uses it to create a first regional estimate of the spatial distribution of mountain permafrost. This permafrost distribution surface is a valuable benchmark in today's rapidly changing environment, and also helps to demonstrate that melting permafrost in New Zealand might not be as dangerous as it is, for example, in Europe. Katrin discovered that her mapped permafrost distribution in the Southern Alps is located above the zone where debris flows activate. In the Southern Alps, the availability of readily mobilised sediment, promoted in high-alpine areas by intense frost-weathering activity, and the spatial distribution of heavy rainfall events are more important preconditions and triggers of debris flow activity than permafrost.

CONTACT: Brian.Anderson@vuw.ac.nz

Using air bubbles to understand rapid climate change

Ice cores have revolutionised our understanding of the relationship between greenhouse gases and global temperatures by providing unique archives of past atmospheric conditions. Gases trapped within bubbles provide high-fidelity records of past greenhouse gas levels (especially carbon dioxide and methane), which are vital for understanding the implications of past and present changes in atmospheric composition. Due to the gradual close-off of gas bubbles and the relatively fast diffusion of gases within the firn column, any fast increase in greenhouse gas concentration is spread out, thus smearing the measured gas record in each sample, and affecting the resolution of gas measurements.

Ruzica Dadic, Martin Schneebeli (SLF Switzerland), and Nancy Bertler developed a new method (using Micro computer tomography and laboratory experiments) that can simultaneously estimate pressure distribution in all bubbles in a sample, not only for present conditions, but back through time under varying atmospheric conditions, while also providing accurate measurements of morphological bubble properties, such as size, clustering and shape. Our method can be used to deconvolve the greenhouse gas signal in the ice core record and to accurately estimate the magnitude and timing of rapid climate change.

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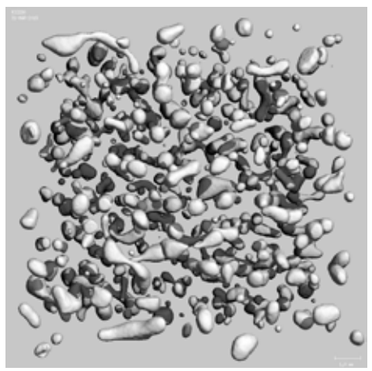

A computer tomograph of bubbles at 80 m in the RICE ice core
Photo: Ruzica Dadic

Slip Sliding Away: The role of water beneath glaciers and ice sheets

Liquid water beneath glaciers, ice sheets, and ice shelves controls much of the form and flow of the overriding ice. The past year has seen continued study of Tasman Glacier, South Island, with a deployment of GPS and seismometers recording the spectacular accelerations of the glacier in response to heavy rainfall. A recently submitted MSc thesis by Sam Taylor-Offord documents a remarkable sequence of crevassing that occurs in response to the pulse of accelerating ice. Rain leads to water pooling beneath the glacier, smoothing the glacier bed and ratcheting the glacier forwards, generating a pulse of crevassing that propagates to the glacier terminus. These findings, along with evidence for rain-induced hydrofracture of the glacier, have implications for glacier and ice sheet decay in a world where liquid water is more prevalent.

On the ice sheet front, work on geophysical data from the grounding zones of the West Antarctic Ice Sheet continues (Christianson, *et al.*, 2016). These data document stabilising sedimentary features beneath the ice sheet – ice shelf transition, and again address the role of water beneath ice. A major drainage feature beneath Kamb Ice Stream shows evidence of amplification through ocean melt, and the ocean cavity in front of Kamb Ice Stream is suprisingly thin, challenging the current paradigm of grounding line melt. These topics, and the wider role of water beneath ice, are now the focus of intense ongoing study, with a new Rutherford Discovery Fellowship awarded to Huw Horgan addressing water beneath ice beginning in March 2017.

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The lake at the terminus of Tasman Glacier, New Zealand
Photo: Huw Horgan

Extending Antarctic ice sheet observations beyond the satellite era

Satellite observations show that Antarctic outlet glaciers respond to climate variability on a decadal timescale. However, the satellite era spans only ~ 40 years, and the longer-term behaviour of outlet glaciers is essentially unknown. For the past two years, we have conducted NZARI and the MBIE Past Antarctic Climates Programme projects to extend the period of observation of outlet glaciers from decades to millennia. This will improve our understanding of outlet glacier processes and their natural variability, making it possible to detect and attribute present and future anthropogenic influences on the Antarctic ice sheet.

In January 2016 we carried out field work at Mawson Glacier, Antarctica located ~ 250 km north of Scott Base, building on the approach that we successfully applied at Mackay Glacier in 2014. A team of four (Andrew Mackintosh, Richard Jones, Shaun Eaves and PhD student Ross Whitmore) collected ~70 glacially-transported cobbles for Beryllium-10 (^{10}Be) cosmogenic exposure dating, sampling from the present-day glacier surface to several hundred metres above. Currently 47 of the samples are being processed from two locations, one near the Nordenskjöld ice tongue (Bruce Point) and one midway up the outlet (Mount Murray). These data will provide a terrestrial cosmogenic record of ice-surface-lowering over the last several thousand years.

In November 2016, a team of four comprising Kevin Norton and Cliff Atkins (SGEES) and ARC PhD students Ross Whitmore and Jamey Stutz, headed to Northern Victoria Land, around 600 km north of Scott Base, to collect ~100 samples of glacial erratics and bedrock from the Tucker Glacier and surrounding area. The aim of this study is two-fold 1) to understand the local retreat history of Tucker Glacier and 2) to constrain the hypothesised extent of grounded ice in the western Ross Sea during the Last Glacial Maximum. Currently samples from two vertical transects are being evaluated prior to physical and chemical processing for ^{10}Be cosmogenic exposure dating. Each of these sample transects should allow us to constrain any changes in glacier thickness for Tucker and Ironsides glaciers over the last several thousand years.

Our team is in the process of planning field work to be conducted in December of 2017 at David Glacier. This field campaign will involve PhD students Jamey Stutz and Ross Whitmore, and Andrew Mackintosh and aims to collect glacially-transported cobbles from areas adjacent to David Glacier. This location is significant because it is the largest outlet glacier along the Victoria Land Coast and changes in this glacier are large enough to affect the mass balance of the whole ice sheet.

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GLOBAL AND INTERPLANETARY CONNECTIONS

The answer lies in the tropics

Progress continues in unravelling the response of the New Zealand ocean to modern climate change. A previous study of satellite-based ocean temperatures suggests a warming of the surface ocean east of central New Zealand by about 1ºC between 1993 and 2012. Critically, all the heat has come from the subtropics. While that ocean record is too short to confidently define a long-term trend, it is consistent with 70 years of observations starting around 1944, from offshore Tasmania. There, the subtropical East Australian Current has extended 350 km south resulting in the replacement of a subantarctic ecosystem by one of subtropical affinity. Further south in the subantarctic islands, a 140 year-old tree ring record, coupled with meteorologic records and model simulations, indicate that those subtropical incursions coincided with a highly variable climate that began in the 1940s and was superimposed on a long-term, albeit irregular warming trend. This raises a key question as to the source of the warmth.

Past reconstructions of the last natural warm period 125,000 years ago, together with modern observations mentioned earlier, indicate the warmth came from subtropical currents associated with (i) the Tasman Front off northernmost New Zealand and (ii) the Subtropical Front off southernmost New Zealand. This latter entry point is presently dominated by subantarctic water, but as the subtropics expand the Subtropical Front will become, warmer. In addition, model simulations suggest the southern entry point may be further enhanced with subtropical water introduced by the Agulhas Current located east of Africa. Like the East Australian Current, the Agulhas has also strengthened southwards to warm flows that move east across the Indian Ocean to intercept New Zealand.

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The Agulhas Current (white arrow) off eastern Africa appears to have strengthened with the potential to transport warm subtropical water, probably mixed with sub-Antarctic water, towards New Zealand
Photo: NASA Visualization Explorer

Antarctic Dry Valleys an analogue to the surface of Mars

Cassandra Trinh-Le recently completed a first-class MSc project studying dry sedimentation processes in University Valley, Antarctica. She came to the ARC with the aim of studying geologic processes in the Dry Valleys as an analogue for Mars. Cassandra obtained a series of dry permafrost samples and permafrost cores, which were collected by NASA scientists from the floor of University Valley. Using a variety of techniques, including Optically Stimulated Luminescence dating, geochemical analyses, and meteoric Beryllium-10 measurements, she determined ages of the subsurface soils and described the complex processes involved in dry cryotic sedimentation.

Highlighted findings from her project include the following: Sediments in University Valley have accumulated at a rate of approximately 2.1 mm/ka for the last 200 ka from erosion of the valley walls and deposition of windblown dust. Accumulation of these sediments is influenced by topography of the valley floor, depth of the ice table (permafrost), aspect of the valley walls, wind direction, and mechanical breakdown of rocks due to solar heating. Chemical processes that occur in this environment are facilitated by exposure to the atmosphere at the ground surface and rely on water vapour in the absence of liquid water.

Together, these results indicate that surfaces in University Valley are remarkably young and sedimentologically active. Because University Valley represents one of the closest terrestrial analogues to the surface of Mars, findings from this thesis may be applicable to understanding the timescales and the processes that control anhydrous sedimentation on the surface of Mars.

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INNOVATIVE DRILLING TECHNOLOGIES

The Science Drilling Office is providing critical support to a range of new projects.

The Science Drilling Office (SDO) is hosted in the Antarctic Research Centre and led by Alex Pyne, SDO Director and ARC Projects Manager, and Darcy Mandeno, Operations and Field Engineer. Alex and Darcy have had another busy year supporting three field projects in preparation and execution.

Bespoke barge provides the base for a successful coring season

Last year started with Darcy still stuck at the Siple Coast through January leaving Alex to work with Webster Drilling and Exploration (WD&E) on finalising the coring barge and drilling systems developed for the Lake Ohau project. Darcy had previously done the detailed drawings for the barge build that was then completed in late 2015. Based in Twizel for three weeks we waited for good weather windows with low winds and completed the planned drilling programme of double coring at two sites. A QDTech hydraulic piston corer borrowed from ANDRILL was used and produced continuous high quality core in all four holes (see page 8 for more information on the research).

Coring through frozen sediments

The first Antarctic project was coring frozen sediments in the Transantarctic Mountains at Friis Hills in October 2016. Alex has been working with WD&E on developing coring techniques in frozen sediments since our first attempts in Antarctica in the 2000 season by using chilled air as the flushing medium for coring. We have developed systems that are now sufficiently mature to have enabled WD&E to receive commercial geotech contracts in Antarctica as well as drilling for the science projects this season. There remains technical improvements to make but we had a successful season that produced good frozen core from three sites (6+ holes) which included our deepest hole yet to 53 m (see page 15 for more information on the research).

Building a Hot Water Drill for the New Zealand science community

The biggest effort for the SDO in 2016 was the development of a Hot Water Drill system, initially for the Ross Ice Shelf project. The Drill is based on a British Antarctic Survey modular design and we purchased similar major components from the UK and Italy to the latest BAS systems that arrived in New Zealand in April. A lot of development was still required in New Zealand and we employed mechanic, Jeff Rawson, for six months who has several season's Antarctic experience to help with the design and development of the system, especially the power generation and fuel components of the system. During August and September we also hosted Jiwoong Chung from the Korean Antarctic Program (KOPRI) who helped with preparation the Hot Water Drill. KOPRI are also considering acquiring a hot water drill and Jiwoong has been tasked to scope out suitable systems.

The Hot Water Drill development has been especially challenging, even though we were able to order some major equipment in late 2015, with a short time line to get equipment ready for commissioning in Antarctica in November and December 2016. Electrician, Hedley Berge, joined the team of Alex, Darcy, Jeff and Jiwoong to commission the drill at a site in Windless Bight and a hole drilled through 224 m of ice shelf was finally achieved in mid-December, only a few days before the team was due to return to New Zealand. The commissioning was a success and has not only shown us which parts of the system work well but allowed us to identify components that require more work to make them reliable in Antarctica. This will be our major focus for the coming year and the team will head back to Antarctica in October 2017 where they will drill holes through the Ross Ice Shelf for the first leg of the Ross Ice Shelf Project.

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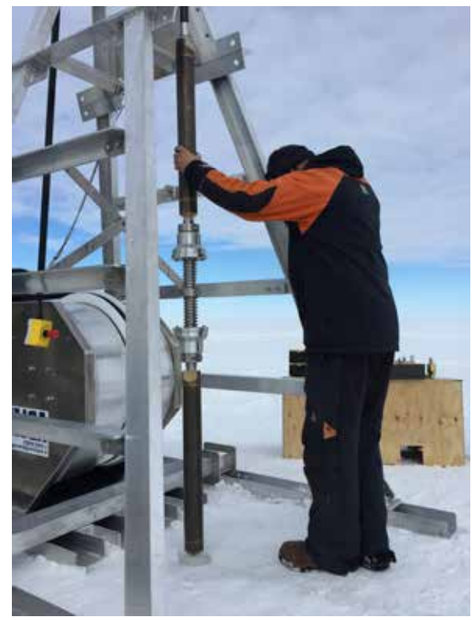


Melting a hole through the ice during the Hot Water Drill commissioning field season, Windless Bight, Antarctica
Photo: Jiwoong Chung (KOPRI)

TEACHING AND SUPERVISION

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

Tim Naish and MSc student, Libby Galbraith, Mt Discovery, Antarctica - Photo: Michelle Dow

TEACHING AND SUPERVISION

There is a close interaction between ARC staff and projects with other research programmes in geophysics, geology, physical geography, and the environmental studies programme. ARC staff contributed to the following courses in 2016:

Undergraduate Courses	
ESCI 111	Earth Systems and Global Change
ESCI 132	Antarctica: Unfreezing the Continent
ESCI 204	Petrology and Microscopy
GEOG 220	Hydrology and Climate
ESCI 241	Introductory Field Geology
ENSC 301	Topics in Environmental Science
ESCI 301*	Global Change: Earth Processes and History
GEOG 318	Quaternary Environmental Change

Graduate Courses	
ESCI 403*	Stratigraphy and Palaeontology
ESCI 404*	Special Topics
ESCI 412*	Quaternary Geology
PHYG414	Climate Change: Lessons from the Past
ESCI 580	Research Preparation

* An ARC staff member is the course co-ordinator

Our teaching contribution also includes supervision of graduate students from the School of Geography, Environment and Earth Sciences. In 2016 our staff supervised 17 PhD and 12 MSc students. The ARC congratulates the following students who completed their theses in 2016:

PhD completions

Jesse-Lee Dimech (PhD)
"Seismic investigations of the lithosphere in an amagmatic back-arc region: North Island, New Zealand."
Supervised by Tim Stern (SGEES), Simon Lamb (SGEES), and Huw Horgan (ARC/SGEES).

Pablo Iribarren Anacona (PhD)
"Hazardous geomorphic processes in the extratropical Andes with a focus on glacial lake outburst floods."
Supervised by Andrew Mackintosh (ARC/SGEES) and Kevin Norton (SGEES).

Kristina Pascher (PhD)
"Paleobiogeography of Eocene radiolarians in the Southwest Pacific."
Supervised by Rob McKay (ARC), Chris Hollis and Giuseppe Cortese (GNS Science).

Matt Ryan (PhD)
"Mid-Late Quaternary vegetation and climate change reconstructed from palynology of marine cores off southwestern New Zealand."
Supervised by Rewi Newnham (SGEES) and Gavin Dunbar (ARC).

MSc completions

Anya Albot (MSc)
"Holocene sediment transport and climate variability offshore Adélie Land, East Antarctica."
Supervised by Rob McKay (ARC) and Lionel Carter (ARC).

Harry Greenfield (MSc)
"Seismic attributes to constrain the distribution of Rakopi Formation coaly facies in the southwest offshore Taranaki Basin, New Zealand."
Supervised by Huw Horgan (ARC/SGEES) and Suzanne Bull (GNS Science).

Christoph Kraus (MSc)
"Oligocene to early Miocene glacimarine sedimentation of the central Ross Sea, and implications for the evolution of the West Antarctic Ice Sheet."
Supervised by Rob McKay (ARC) and Tim Naish (ARC).

Edmond Lui (MSc)
"Ice dynamics of the Haupapa/Tasman Glacier measured at high spatial and temporal resolution, Aoraki/Mt Cook, New Zealand."
Supervised by Brian Anderson (ARC) and Huw Horgan (ARC/SGEES).

Bryn Taiapa (MSc)
"Millennial scale events from marine sediment
cores in the SW Pacific during Marine Isotope Stage 3."
Supervised by Lionel Carter (ARC) and Helen Bostock (NIWA).

TAE Hut, Scott Base, Antarctica
Photo: Michelle Dow

SIGNIFICANT EVENTS

There has been some outstanding achievements by ARC staff and students

Memorial Cross, Observation Hill, Antarctica - Photo: Michelle Dow

ARC'S FOURTH PRESTIGIOUS RUTHERFORD FELLOW

Huw Horgan was awarded a Rutherford Discovery Fellowship to continue his leading-edge research in ice sheet dynamics.

Huw Horgan
Photo: Ruzica Dadic

Huw Horgan, a senior lecturer in the ARC and School of Geography, Environment and Earth Sciences was among a small group of emerging New Zealand scientists to receive a highly sought-after Rutherford Discovery Fellowship from the Royal Society of New Zealand in 2016. Huw is now the fourth recipient of a Rutherford Fellowship within the ARC, joining Nancy Bertler, Rob McKay, and Nick Golledge who were awarded their fellowships in 2011, 2013, and 2015 respectively.

Huw was one of three Victoria researchers from the Faculty of Science who have each been awarded funding of $800,000 over five years. All ten fellowships were announced by Science and Innovation Minister Steven Joyce, which are designed to support future leaders in the New Zealand science and innovation system by encouraging their career development and enabling them to establish a solid track record in their field of expertise.

Huw's research will investigate how the conditions beneath the West Antarctic Ice Sheet affect its contribution to sea level over the coming centuries. Using a combination of remote sensing, oversnow geophysics, and direct access, he will examine the properties and processes beneath the west Antarctic that enable the fast flow of ice streams. Of specific interest to this project is the distribution and role of water beneath the ice sheets. At the centre of the project is an initiative to directly access the base of the ice sheet using VUW's newly acquired Hot Water Drill. Such direct access promises to provide the critical observations most needed to constrain the future of the ice sheets.

"I feel immensely privileged to receive this fellowship, and excited about the opportunity to undertake the research." said Huw.

Professor Mike Wilson, Pro-Vice-Chancellor of Victoria's Faculty of Science, said the awards are a significant achievement.

"It is immensely satisfying to see these researchers being supported to reach their potential, and make a contribution to New Zealand. It's also fantastic national recognition of the calibre of scientific research capability at Victoria."

BLAKE LEADER AND WELLINGTONIAN OF THE YEAR AWARDS

Nancy Bertler received a Blake Leader Award in recognition of her major contribution to exploring climate change in Antarctica and being a role model for young researchers, especially women.

Blake Leader Awards are given to six New Zealanders in the middle of their careers who have demonstrated outstanding leadership and the determination to achieve extraordinary things. The 2016 Blake Medal and Blake Leader awards were presented by the then Governor-General, Lieutenant General the Rt. Hon Sir Jerry Mateparae at Auckland Museum on 1 July.

Nancy is an internationally respected ice core scientist and is jointly appointed by the ARC and GNS Science. She is a pioneer of Antarctic ice core climate science in New Zealand, developed and manages the New Zealand Ice Core Research Laboratory at GNS Science, has led 13 expeditions to Antarctica, and is chief scientist for the Roosevelt Island Climate Evolution (RICE) project, which involves the collaboration of nine nations. In 2011 she received a prestigious Rutherford Discovery Fellowship.

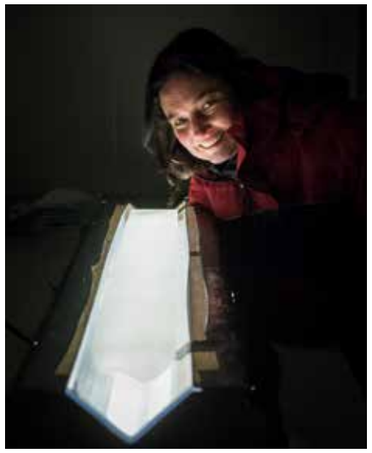
"The award is a huge honour," said Nancy. "It's extremely humbling considering the calibre of previous awardees, their awe inspiring achievements and their dedication. I'm excited to have the opportunity to get to know many of them and to be challenged to stretch further in the spirit of the award."

Pro-Vice-Chancellor, Professor Mike Wilson, said Associate Professor Bertler's award is an outstanding achievement.

"Nancy is a driving figure within the University as well as in the community, establishing a climate change course at Victoria and helping New Zealanders understand the consequences of a warming world. She's a fantastic mentor for students and her colleagues."

Then in November, Nancy won the Science and Technology category in the 2016 Wellingtonian of the Year awards presented at a ceremony at Te Papa. The "Wellys" honour and celebrate the work of outstanding Wellingtonians in nine categories.

Nancy credits her success to support from former directors of the ARC Peter Barrett and Tim Naish, former GNS Science chief executive Alex Malahoff, as well as colleagues and collaborators nationally and internationally.



Nancy Bertler
Photo: ©Gerry Keating, Image Services, VUW

FURTHER RECOGNITION FOR LEADING ANTARCTIC RESEARCHER

Tim Naish was awarded a James Cook Fellowship for his research excellence.

Tim Naish, is one of three leading New Zealand scientists to be recognised for research excellence with an esteemed James Cook Research Fellowship. Two of the three fellowships for 2016 were awarded to Victoria researchers.

Administered by the Royal Society of New Zealand on behalf of the Government, James Cook Research Fellowships are awarded to researchers who demonstrate that they have achieved national and international recognition in their area of scientific research. The fellowships allow researchers to concentrate on their chosen research for two years, and are worth $110,000 annually.

In this project, Tim will work toward reducing the uncertainty of future sea-level rise on two levels. Firstly, he will work closely with international collaborators to drill a geological record on the West Antarctic Ice Sheet that will help researchers to determine how the ice sheet has reacted to temperature changes in the past and hence provide more accurate predictions of future changes. Secondly, with collaborators he will develop a research programme to improve region-specific projections of sea-level rise in New Zealand by taking into account local influences such as vertical land movements and changes in sea-surface height. Ultimately, better predictions of future sea-level rise are critically needed for anticipating and managing the socio-economic impacts of sea-level rise in New Zealand.

Tim Naish
Photo: Image Services, VUW

PRESENTING ‘NAISH PEAKS’

Antarctic feature named ‘Naish Peaks’ in honour of Tim Naish’s outstanding Antarctic career.

Tim Naish holds the plaque presented to him
Photo: Veronika Meduna

Staff and students announced the newly named ‘Naish Peaks’ to a surprised Tim Naish, during the annual send-off for members of the ARC travelling to Antarctica for the 2016-17 season.

The Antarctic feature name was approved by the New Zealand Geographic Board Ngā Pou Taunaha o Aotearoa in September 2016, recognising Tim’s highly successful Antarctic scientific career, particularly in the area of paleoclimatology.

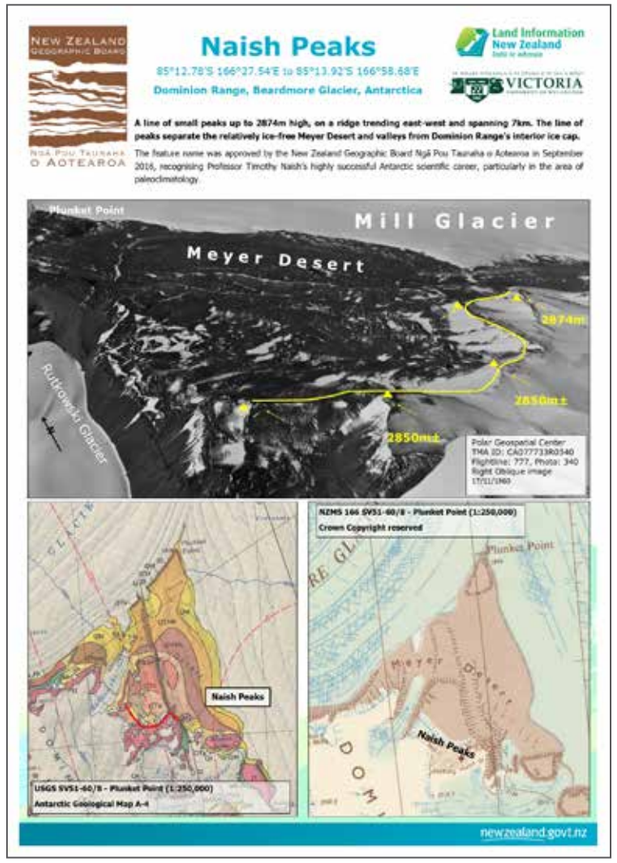
Tim said it was a real honour. “I’m humbled and have to say I was a little lost for words—it isn’t just one mountain, but a whole range. My children seem to think they will get one peak each!”

“I have been very fortunate to have had the opportunity to work with such a talented team of researchers in the ‘coolest’ place on the planet, doing science that matters for our future.”

“In 2010 our group camped in the Beardmore Glacier, which is only 700 kilometres from the South Pole under the then unnamed Naish Peaks, finding fossil evidence of where beech trees once grew under a warmer climate. It is also near where Captain Scott’s team took time to relax on their ill-fated return from the South Pole in January 1912.”

Pro-Vice-Chancellor, Professor Mike Wilson, said “the naming of Naish Peaks is a fitting recognition of Tim’s outstanding contribution to Antarctic science.”

Tim joins fellow ARC colleagues Peter Barrett and Alex Pyne who both have Antarctic glaciers named after them. Naish Peaks, is a line of small peaks that sit between Antarctica’s Meyer Desert and Dominion Range valleys, reach up to 2,874 metres high, on a ridge trending east-west and spanning seven kilometres.



The location and geographical information for Naish Peaks written on the plaque

NEW RESEACH MADE POSSIBLE BY MARSDEN AWARD

New Marsden Fast-Start awarded to Shaun Eaves to determine New Zealand glacier response to previous warming climates.

Ongoing retreat of mountain glaciers worldwide is considered to represent a clear signal of anthropogenic global warming. In the Northern Hemisphere this attribution is strengthened by long (>100 yr) records of glacier and climate observations. However, Southern Hemisphere glaciers are less well studied, thus we must turn to the geological record to provide long-term context for understanding present and future change.
In New Zealand, existing geological records suggest that glaciers may have been larger than present for the majority of the Holocene Epoch (the last ~12,000 years). However, these records only represent snapshots of past glacier advance, thus little is currently known about glacier response to previous periods of warming. Recent advances in geological dating techniques now provide the opportunity to address this knowledge gap, by directly quantifying the duration of past glacier retreat periods.

Funded by a Marsden Fast-Start research grant starting in November 2017, Shaun Eaves and colleagues will utilise state-of-the-art geological dating techniques to determine how long New Zealand glaciers were smaller than today during the Holocene. Integrating these new geological constraints with computer model simulations of past glacier fluctuations, we aim to answer the question: Is the current retreat of New Zealand glaciers unprecedented for the last 12,000 years?

Shaun Eaves in front of the retreating Fox Glacier in 2012 (left) and again in 2016 (right)
Photo: Shaun Eaves

S.T. LEE LECTURE IN ANTARCTIC STUDIES

Professor Eric Rignot presented the 2016 S.T. Lee Lecture looking at the current knowledge on and magnitude of sea-level rise.

The 14th annual S.T. Lee Lecture in Antarctic Studies presented by Professor Eric Rignot had to be rescheduled from its original date in October 2016 to 14 February 2017. The lecture, *Future sea-level rise from warming of polar ice sheets,* focussed on sea-level rise.

The ice sheets in Greenland and Antarctica are contributing faster, sooner and more significantly than expected to global sea-level rise. Predicting the future rates of ice sheet mass loss with deterministic models is a formidable challenge. Observations and physics principles suggest a sea-level rise of more than 1 metre by 2100, and geological information from the Last Interglacial period (125,000 years ago) suggests a potential 6-9 metre sea-level rise with 1-2°C warming above pre-industrial levels. Eric reviewed the current knowledge of ice sheet mass balance and its potential to raise global sea level by many metres. He addressed the question, "Have some of the marine-based sectors already passed a point of no return, and if so, what is the magnitude of sea-level rise we are committed to?" He also explored the emission mitigation pathways that can limit the amount of sea-level rise by the end of the century and beyond.

During his visit, Eric was also involved in a round table meeting discussing the latest science around sea-level rise, he had a meeting with the Green Party Co-Leader, James Shaw, as well as media interviews including one with Radio NZ presenter Kim Hill.

Eric is the Donald Bren Professor of Earth System Science, School of Physical Sciences at the University of California, Irvine, and a senior research scientist/ joint faculty appointee at NASA's Jet Propulsion Laboratory. Eric's primary research interests lie in glaciology, climate change, radar remote sensing, ice sheet numerical modelling, radar interferometry, radio-echo sounding and ice-ocean interaction. His research group focuses on understanding the interactions of ice and climate, ice-sheet mass balance, ice sheet–ocean interaction in Greenland and Antarctica and current and future contributions of ice sheets to sea-level change. He has received NASA Exceptional Scientific Achievement Medals, NASA Outstanding Leadership and was a member of the IPCC team awarded the Nobel Peace Prize in 2007. He is a fellow of the American Geophysical Union and a lead author of the IPCC 5th Assessment Report. His research has been covered by the Los Angeles Times, Washington Post, BBC, CNN, National Geographic, Rolling Stone and the New York Times Magazine and has been featured in Naked Science (2004), Chasing Ice (2012) and HBO series VICE (2015).

Radio NZ Interview: http://www.radionz.co.nz/national/programmes/saturday/audio/201834606/professor-eric-rignot-the-tale-told-by-polar-ice-sheets

Eric Rignot presenting his lecture at Rutherford House, Victoria University
Photos: ©Gerry Keating, Image Services, VUW

S.T. LEE YOUNG SCIENTIST EXCHANGE

The S.T. Lee Young Scientist Exchange Programme offered a researcher the opportunity to travel between the University of Alaska Fairbanks and Victoria University.

On a cold Alaska morning late in March 2016, I boarded a plane to make the long trip from Fairbanks, Alaska to South Island, New Zealand. Through the S.T. Lee Travel Award, I was able to spend an amazing three full weeks split between doing field work on South Island, meeting researchers at the Antarctic Research Centre, and figuring out how to get scientific grade data while flying a small hobby-level drone.

My research focus is on finding better ways to incorporate drones into science, and better ways to handle, process, and manage the data they produce. This award was a brilliant opportunity for me to try those processes in the field while working with researchers Brian Anderson and Huw Horgan to collect drone imagery over different geological sites in New Zealand. I spent my first week meeting Brian and his team, and doing test flights with my drone, collecting and processing the imagery. My second week was at the ARC talking to researchers, learning about what they do, and having some interesting conversations about how we could incorporate drones into that work. I was also able to give a presentation on some of the work that we are doing in Alaska – for which there was a lot of enthusiasm and helpful feedback. For my third week I hit the road with Huw and his graduate student, Lauren Vargo. We placed seismometers on Tasman Glacier, flying from site to site in a helicopter. In between our helicopter flights, I conducted flights of my own with my drone, collecting as much imagery as I could of the enormous glacier.

The entire trip was an incredible whirlwind. I learned a lot – both about scientific needs in New Zealand, and about the strengths and limitations of my own research. I also very much enjoyed getting to brainstorm with Brian about possible new uses for drones in science. I could not be more grateful to Dr Lee for having given me the opportunity to meet with the researchers at the ARC. It was a wonderfully motivating experience to get to work with such a talented and dynamic group and I would love to visit again someday.

Sean Barberie flying his drone at Castle Hill, South Island
Photo: Sean Barberie

AN AUDIENCE WITH THE GOVERNOR-GENERAL

The ARC was honoured to be involved with a visit from the then Governor-General, Sir Jerry Mateparae.

On the 16 February, the then Governor-General, Lieutenant General the Rt. Hon Sir Jerry Mateparae visited Victoria University. Accompanied by Victoria University Vice Chancellor, Professor Grant Guilford, his visit involved three 'stops'. The first was a cinematic performance in commemoration of the First World War. He then headed to the S.T. Lee Antarctic Reading Room for a round table discussion focusing on insights into the impact of CO_2 levels and climate change on the state of Antarctica's ice sheets and their potential contribution to rising sea levels. The discussion was led by Tim Naish, and included Nancy Bertler, Andrew Mackintosh and James Renwick (SGEES). His tour ended with an interactive demonstration on 4D led by the School of Engineering.

Andrew Mackintosh presenting his research to the Governor-General, Sir Jerry Mateparae

ITALY AND NZ IN ANTARCTICA

An event to celebrate the links between Italy and New Zealand in Antarctic research.

The ARC and the Embassy of Italy held a series of short presentations "Italy and New Zealand in Antarctica. Latest achievements and challenges in a common endeavour" on 25 February, to celebrate the long history of collaboration between Italy and New Zealand in Antarctica.

The event was the first formal celebration of this relationship, and was attended by a wide range of interested public, Victoria faculty, government officials, and a number of dignitaries including the Italian Ambassador His Excellency Carmelo Barbarello. The talks were presented by three Italians who had just arrived in New Zealand from Antarctic fieldwork, and five New Zealanders, of which three were also in Antarctica this season, as well as a panel discussion moderated by Tim Naish.

"Antarctica has significant scientific value and is very unique, but it is also a challenging environment to work in. The collaboration with Italy lets us carry out more scientific research because we can work together to share resources and expertise," said Tim.

Left to right: Dr Steve Parker (NIWA), Dr Neil Gilbert (Constantia Consulting), Dr Riccardo Bono (Unita' tecnica Antartide), Assoc. Prof. Laura Crispini (Università di Genova), Italian Ambassador HE Carmelo Barbarello, Pro Vice-Chancellor Prof. Mike Wilson (VUW), Prof. Tim Naish (ARC), Assoc.Prof. Paola Rivaro (Università di Genova), Prof. Peter Barrett (ARC), Dr Richard Levy (GNS Science), Prof. Gary Wilson (New Zealand Antarctic Research Institute)
Photo: Image Services, VUW

OTHER VISITORS TO THE ARC

The ARC also hosted a researcher looking into updating the New Zealand Glacier Inventory.

From February until May 2016, I visited the ARC and was hosted by Andrew Mackintosh. Normally based in Germany at the Technical University of Munich, my research in New Zealand focused on a new project to update the New Zealand Glacier Inventory (NZGI). The existing inventory is based on manually mapped glacier outlines obtained from aerial photographs mainly from 1978. The new NZGI will be based on satellite images mapped (semi-) automatically and will include both clean-ice and debris-covered ice from the most recent imagery. To familiarise myself with New Zealand glaciers, I was involved in two field trips to Tasman and Brewster glaciers and also in a student excursion to Franz Josef and Fox glaciers. A very special event for me was a flight in a small plane over the South Island glaciers as part of the NIWA led mapping of end of summer snow lines.

Initial results were obtained using Landsat-8 satellite imagery from mid-February 2016. Clean-ice regions were detected using an established method that takes a ratio of energy at different wavelengths. These results are combined with information from a digital elevation model, which provides the extent of debris-covered ice. Glacier outlines were then generated automatically, and validation showed the results were promising. To refine the technique, a second satellite platform is being tested. This satellite provides higher spatial-resolution data for the same time period, however a methodology for this platform has not yet been established so its use will need some refinement. Discussions with Andrew, Brian Anderson, and Andrew Lorrey (NIWA) have been very helpful for determining the correct detection parameters suitable for obtaining true glacier outlines. I hope to come back to New Zealand in 2017 to continue more of this work.

Sabine Baumann

ARC ENDOWED DEVELOPMENT FUND

The ARC Endowed Development Fund has awarded 74 grants to postgraduate students since its inception in 2004.

This substantial fund enables the ARC to give small grants of up to $4000 to postgraduate students with research links to Antarctica and enables some amazing opportunities to be taken up, that would not have otherwise been possible. Examples include; participation in international summer schools in glaciology, modelling and paleoclimatology, 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 2016 recipients were:

Lauren Vargo (ARC) — to attend the Ice and Climate Karthaus Glaciology Summer School in Italy, 13-24 September, 2016.

Kyle Clem (SGEES) — to attend the Polar Meteorology and Oceanography Conf in Seattle, USA, 22-27 January, 2017.

Kristina Pascher (ARC) — received salary support to write a paper on her recently completed PhD research on Eocene radiolarians in the southwest Pacific.

Lauren Vargo on the via delle Bocchette, in the Brenta Dolomites, Italy
Photo: Lauren Vargo

Siple Coast camp, Antarctica
Photo: Matt Vaughan
(University of Otago)

AWARDS AND APPOINTMENTS

In 2016 ARC staff and students were awarded the following:

Awards

Nancy Bertler — Sir Peter Blake Leaders Award.

Nancy Bertler — Wellingtonian of the Year – Science and Technology award.

Shaun Eaves — Marsden Fast-Start grant "Establishing natural baselines of glacier variability in a warm world".

Huw Horgan — Rutherford Discovery Fellowship "Accelerating ice – The role of water in the flow of ice sheets".

Tim Naish — James Cook Fellowship "The contribution of the Antarctic ice sheet to past and future sea-level rise and implications for New Zealand".

Promotions

Nancy Bertler — Promoted within the Associate Professor scale in the 2016 Academic Promotion Round.

Ruzica Dadic — Promoted to Senior Research Fellow in the 2016 Academic Promotion Round.

Nick Golledge — Promoted to Associate Professor in the 2016 Academic Promotion Round.

Huw Horgan — Promoted within the Senior Lecturer scale in the 2016 Academic Promotion Round.

Andrew Mackintosh — Promoted within the Associate Professor scale in the 2016 Academic Promotion Round.

Rob McKay — Promoted within the Senior Lecturer scale in the 2016 Academic Promotion Round.

Tim Naish — Promoted within the Professorial scale in the 2016 Academic Promotion Round.

Appointments

Huw Horgan — Appointed President of the Wellington Branch of the Geoscience Society of New Zealand.

Rob McKay — Appointed co-chief scientist on IODP Expedition 374 – Ross Sea West Antarctic Ice Sheet History

Rob McKay — Appointed Lead International Conveyor for IODP workshop: Antarctica's Cenozoic Ice and Climate History, New Science and New Challenges of Drilling in Antarctic Waters, Texas, USA (May 2016)

Tim Naish — Selected for the 1.5 degrees scoping report for the Intergovernmental Panel on Climate Change (IPCC) scoping meeting and Sixth Assessment report.

Tim Naish — Appointed by the Australian Government to the National Advisory Committee for Climate Change Science.

FINANCIAL SUMMARY

In 2016, the ARC contributed $319K of revenue to the University

Sea ice, Antarctica - Photo: Matt Vaughan (University of Otago)

FINANCIAL SUMMARY

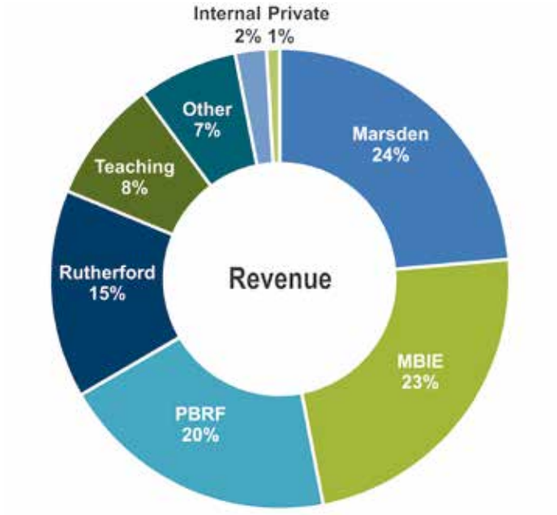
In 2016, the ARC received a total of $2.64M in revenue and contributed $319K profit to the University.

The ARC finances include both a Centre budget and grant funds held by the Research Trust of Victoria University of Wellington. The total ARC revenue and expenditure for 2016 are summarized in the charts below (all figures are exclusive of GST).

These figures combine the Centre budget that operates over the Victoria University financial year (January-December) and Research Trust budgets which operate over the life of the projects. As such, the year-end balances for revenue versus expenditure are often out-of-phase.

In 2016, the ARC received a total of $2.64M in revenue and a corresponding expenditure of $2.99M. The cost centre budget had a $30K deficit, however, the ARC's research funding contribution to the University via overheads from grants was $349K, thus overall the ARC contributed $319K of revenue to the University.

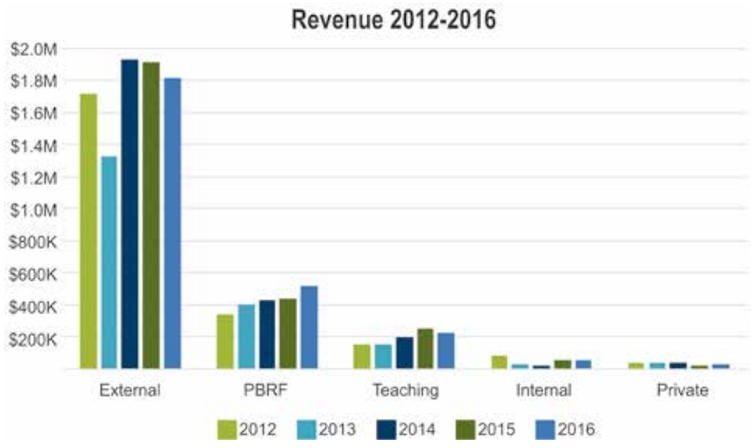
2016 Finances



Around $1.81M (69%) of our funding was from external sources. Our six Marsden grants contributed $625K, Ministry of Business, Innovation and Employment (MBIE) funding via five sub-contracts from GNS Science and NIWA generated revenue of $616K, $387K came from three Rutherford Fellowships and 'Other' funding includes $60K of NZARI funding, $52K from the International Cables Protection Committee, and $24K from other national and international organisations.

The remaining 31% of revenue is made up of PBRF, Teaching, Internal and Private grants. PBRF (Performance-Based Research Fund) contributed $520K and is calculated by Victoria University based on external research funding that meets 'PBRF' criteria and the quality rating of staff. The Teaching portion is the $228K from SGEES for teaching and supervision, based on hours, by ARC staff, as well as a proportion of PBRF graduate completion income. Internal funding is the $58K of University funded grants for staff and students. Finally, Private revenue are donations held by the Victoria University Foundation that have been transferred to the Research Trust.

Five year summary



External combines the revenue from from MBIE, Marsden, Rutherford and Other sources. In 2013, external revenue dropped significantly due to the loss of one of our major research programmes (ANZICE), but peaked the following year due to four new Marsdens grants. Since then the level of funding has declined each year. PBRF however has continued to increase each year. Revenue from 'Teaching' also increased by almost $58K in 2015 due to more graduate completion funding coming through. Internal funding increased in 2015 due to two new University grants awarded. For 'Private' funding, the chart reflects how existing donations are transferred from the Victoria University Foundation to the Research Trust as income to be spent, as currently there have been no new major donations.

New funding success

The ARC successfully secured the following new funding in 2016:

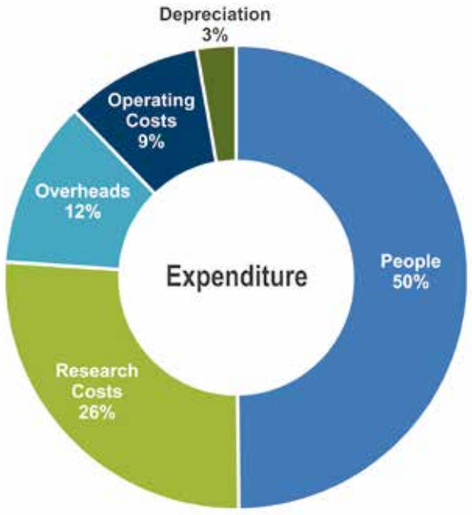
James Cook Fellowship - "The contribution of the Antarctic ice sheet to past and future sea-level rise and implications for New Zealand". $110 for two years for Tim Naish.

Rutherford Discovery Fellowship - "Accelerating ice – The role of water in the flow of ice sheets". $800k over five years for Huw Horgan.

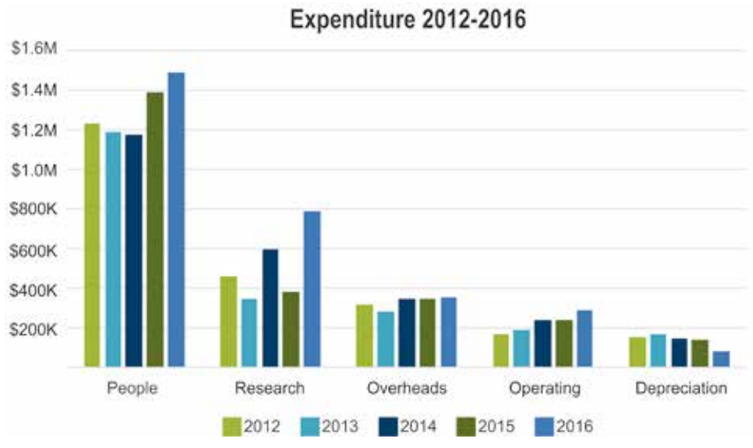
Marsden Fund - "Establishing natural baselines of glacier variability in a warm world" $300K over three years for Shaun Eaves.

National Geographic - "A high precision chronology of glacier fluctuations in southern New Zealand over the last millenium ". $22.5K for Shaun Eaves.

Research Development Fund - "Support for Marsden 2017" $10K for Andrew Mackintosh.



Half of the ARC's expenditure ($1.49M), is related to staff costs associated with salaries, annual leave, ACC and superannuation. Just over $784K of Research Costs are those directly associated with research projects such as fieldwork expenses, sub-contractors, conference attendance, analyses, and student scholarships. $349K of Overheads were transferred directly from grants to cover services provided by the Research Office and central University. General 'Operating' costs of the Centre was $284K and included $179K of office/ storage space charges to the University and $105K associated with running the Centre, including leasing computers, phones, printing, and stationary. Depreciation of CAPEX equipment came to $82K.



People related costs are by far our greatest expenditure. These costs have continued to rise since 2013 primarily due to promotions and pay rises. Research costs reflect the cycle of research projects with higher costs in the fieldwork and analyses years as occurred in 2014 and 2016. 2016 also reflects the three years of PhD scholarship funding deducted. Overheads paid to the University have remained similar over the last three years reflecting the amounts paid for our Marsdens and the reduced overheads for Rutherfords. The basic operational costs for the Centre increased in 2016 due to a refinement in accounting practices where some expenditure (eg flights) is offset by additional revenue through reimbursements by other organisations. Depreciation costs have been decreasing since their peak in 2012 due to equipment either being written-off or reaching the end of its depreciation period.

OUTREACH

The ARC is committed to presenting our research and knowledge to the wider community

Tim Naish talks to then Ministers Simon Bridges and Bill English, Brown Peninsula, Antarctica - Photo: Mike Rowe

OUTREACH

Media interviews

Victorious: Issue 1, 2016, Lionel Carter "Understanding What's Under the Ocean"

NZ Herald: 19 January, Richard Levy (GNS) and Tim Naish "Searching for evidence of past warm climate in McMurdo Sound".

NZ Herald: 13 February, Tim Naish "His views on critical research priorities in Antarctica".

Radio NZ (Our Changing World): 3 March, Gavin Dunbar, Richard Levy and Marcus Vandergoes (GNS Science) "Lake Ohau reveals climate history". http://www.radionz.co.nz/national/programmes/ourchangingworld/audio/201791380/lake-ohau-reveals-climate-history

Timaru Herald: 4 March, Richard Levy and Gavin Dunbar "Lake Ohau sediment could predict future weather ". http://www.stuff.co.nz/environment/climate-news/77508710/Lake-Ohau-sediment-could-predict-future-weather

NZ Listener: 14 March, Tim Naish and James Renwick (SGEES) "Melted ice age". Antarctic ice sheet and sea-level rise at the Pacific Climate Change conference. http://www.noted.co.nz/currently/environment/melted-ice-age/

The Washington Post: 18 May, Aitken *Nature* paper (co-authored by Nick Golledge) "Fundamentally unstable: Scientists confirm their worries about East Antarctica's biggest glacier". https://www.washingtonpost.com/news/energy-environment/wp/2016/05/18/fundamentally-unstable-scientists-confirm-their-worries-about-east-antarcticas-biggest-glacier/?utm_term=.6459271e66f5

ABC: 18 May, Aitken *Nature* paper (co-authored by Nick Golledge) "Melting East Antarctic glacier 'could lift sea levels by 2 metres'" http://www.abc.net.au/news/science/2016-05-19/warning-on-tipping-point-for-east-antarctic-glacier/7425362

BBC News: 19 May, Aitken *Nature* paper (co-authored by Nick Golledge) "Rocks record Totten Glacier's rapid retreat history" http://www.bbc.com/news/science-environment-36327250

Plus 45 other citations of this paper

Timaru Herald: 26 May, Gavin Dunbar "First results from Lake Ohau project to be presented". http://www.stuff.co.nz/timaru-herald/news/80336820/first-results-from-lake-ohau-project-to-be-presented

VUW Brand Campaign: 1 June, Tim Naish "Using Antarctic and climate science to promote research". Worked with VUW and advertising agencies to develop ads, video and billboards.

Timaru Herald: 2 June, Gavin Dunbar "Scientists return to Lake Ohau to collect more data for climate project". http://www.stuff.co.nz/science/80679787/Scientists-return-to-Lake-Ohau-to-collect-more-data-for-climate-project

NZ Herald: 5 June, Tim Naish "Tim Naish: If emission talks focus only on short-term costs, we will pay dearly". http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=11459987

The Dominion Post: 22 June, Nancy Bertler, Rob McKay and Nick Golledge "Big success for Antarctic Research team".

Radio NZ (Nine to Noon): 29 June, Lionel Carter "Oceanography". http://www.radionz.co.nz/national/programmes/ninetonoon/audio/201806321/lionel-carter-oceanography

NZ Herald: 27 July, Brian Anderson "Why our glaciers are disappearing". http://m.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=11682238

Education Today: 1 August, Nancy Bertler "Breaking the ice".

Stuff: 8 August, Brian Anderson "New Zealand's large, fragile mountains face twin threats". http://www.stuff.co.nz/environment/82934497/new-zealands-large-fragile-mountains-face-twin-threats

The Press (front page): 9 August, Brian Anderson "Quick retreat of New Zealand's glaciers an issue for tourism". http://www.stuff.co.nz/business/industries/82972910/quick-retreat-of-new-zealands-glaciers-an-issue-for-tourism

Radio NZ (Nine to Noon): 12 August, Brian Anderson "NZ Glacial shrinkage". http://www.radionz.co.nz/national/programmes/ninetonoon/audio/201811893/nz-glacial-shrinkage

NZ Listener: 23 September, Tim Naish and Nick Golledge "Time and Tide". https://www.pressreader.com/new-zealand/new-zealand-listener/20160923/281547995367834

The Dominion Post: 26 September, Tim Naish "Welcome to the age of the Anthropocene". http://www.stuff.co.nz/science/84522636/Welcome-to-the-age-of-the-Anthropocene

New Zealand Herald: 18 October, Bella Duncan, Gavin Dunbar, Lionel Carter "Plankton blooms in New Zealand suggest the ocean is responding to climate change". http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=11730975

Science Media Centre: 26 October, Andrew Mackintosh "Antarctic glaciers in hot water". http://www.sciencemediacentre.co.nz/2016/10/26/antarctic-glaciers-in-hot-water-expert-reaction/

News Hub: 26 October, Andrew Mackintosh "Antarctic glaciers lose an astonishing amount of ice". http://www.newshub.co.nz/home/world/2016/10/antarctic-glaciers-lose-astonishing-amount-of-ice.html

The Washington Post: 12 December, Andrew Mackintosh "Shrinking mountain glaciers are 'categorical evidence' of climate change, scientists say". https://www.washingtonpost.com/news/energy-environment/wp/2016/12/12/shrinking-mountain-glaciers-are-categorical-evidence-of-climate-change-scientists-say/?utm_term=.ced61a8211bc

North & South Magazine: 20 December, Tim Naish "Prince of tides". http://www.noted.co.nz/currently/environment/prince-of-tides-new-zealands-shrinking-coastline

Talks to stakeholders and policymakers

RSNZ 10 by 10 National Lecture Series: Tim Naish and James Renwick (SGEES) "10 things you didn't know about climate change". 13 lectures in 13 cities and towns around NZ.

Finance Minister Bill English and Associate Minister of Climate Change Simon Bridges: 28-30 January, Tim Naish and Richard Levy (GNS) brief on latest Antarctic climate science, Scott Base, Antarctica.

Governor General visit: 16 February, Tim Naish, Andrew Mackintosh, Nancy Bertler and James Renwick (SGEES) "Impact of CO_2 and climate change" presentation.

Joint Italian-NZ Symposium on Antarctic Science: 28 February, Peter Barrett "*Thin Ice* DVD presentation to Italian Ambassador HE Carmello Barbarolli.

Greater Wellington Regional Council: 20 March, Nancy Bertler.

New Zealand Antarctic Climate and Conservation Stakeholders Meeting: 12 April, Tim Naish hosted at VUW.

Environment Canterbury: 22 June, Gavin Dunbar, "Lake Ohau drilling: 17,000 years of climate history".

Labour Party Caucus: 29 June, Andrew Mackintosh, Tim Naish, James Renwick and Ralph Chapman (SGEES) on climate change issues for developing their policy with the Labour Party.

New Zealand Defence Force Antarctic Stakeholders Workshop: 27 July, Tim Naish and James Renwick (SGEES) "To identify future challenges and opportunities for New Zealand's role in Antarctica and the Southern Ocean".

RSNZ workshop: 12 August, Tim Naish workshop to evaluate the Governments new Environment and Conservation Roadmap.

IPCC Scoping Meeting: 15-18 August, Tim Naish for Special Report on the impacts of climate stabilisation at 1.5 degrees C, Geneva, Switzerland.

Climate Change Minister, Hon. Paula Bennett: 7 September, Tim Naish and James Renwick (SGEES) briefed on latest science and discussed NZ commitments to the Paris climate change agreement.

West Coast Conservation Board: 15 September, Brian Anderson, "The 243 glaciers of Westland Tai Poutini National Park - changes from 1880-2100".

Hutt City Council: 23 September, Nancy Bertler on sea-level rise.

Briefing for US Secretary of State John Kerry: 12 November, Gavin Dunbar "Antarctic ice sheet stability" – cited in Marrakesh Conference of the Parties (COP22) speech. https://www.state.gov/secretary/remarks/2016/11/264366.htm

Forest and Bird Climate Change Meeting: 15 November, Nancy Bertler "Sea level rise potential from Antarctica – Implications for New Zealand", Wellington Zoo.

School & community groups

Kelburn School "Coding Club": ongoing, Lauren Vargo support with teaching coding to primary school children.

NZ Antarctic Society (Wellington): March, Andrew Mackintosh "Antarctic outlet glaciers and climate change - Mawson Glacier".

NZ Writers Festival Climate Science Event: 27 March, Te Radar, Tim Naish, Rhian Salmon, Rebecca Priestley.

Book Launch: 27 March, Tim Naish launches Rebecca Priestley's new book, *Chronicles from Continent seven: An Anthology of Antarctic Science* for AWA Press.

U3A (Kapiti): 4 April, Gavin Dunbar "The stability of West Antarctica".

School Career Advisers: 7 April, Peter Barrett "Presentation on *Thin Ice*".

Te Papa: 20 April, Peter Barrett *Ice and the Sky* screening and panel discussion.

NZ Centre for Literary Translation: 26 May, Peter Barrett presentation on *Thin Ice*.

Ohau Conservation Trust Dinner: 5 June, Gavin Dunbar "Lake Ohau drilling: 17,000 years of climate history".

Uniwersytet Marii Curie-Skłodowskiej (Poland): 8 June, Peter Barrett "Antarctica is a part of your world".

RSNZ Film screening event: 30 June, Tim Naish, participated as panel member for Q&A after showing of the climate change Film *30 Million.*

Wellington High School: 4 July, Nancy Bertler addressed 200 students during the Y10 school assembly and then met with a group of ~40 students to discuss climate change issues and career options.

Wellington Explorers - New Zealand Association for Gifted Children (Wellington Branch): 7 July, Nancy Bertler, Rebecca Pyne (GNS Science), Hannah Brightley, Lukas Eling, and Abhijtih Ulayottil Venugopa. 50 parents and students visited the ice core facility.

SCICON Lower Hutt: 13 July, Peter Barrett *Thin Ice* field trip/discussion for teachers.

McGuinness Institute and Antarctic Youth Council: 14 July, Tim Naish, panelist for Q&A on future of the Antarctic Treaty.

Victoria University of Wellington (LAWS 391): 26 July, Peter Barrett "Climate Change and the Law".

SCAR 2016: 20 August, Peter Barrett *Thin Ice* screening and Q&A.

'Hands on Geo': 24 and 31 August, visit by Wellington schools to SGEES, "Google earth" presentation by Shaun Eaves.

International Antarctic Centre: 1 October, Peter Barrett *Ice and the Sky* – special screening.

Generation Zero: 4 October, Peter Barrett *Thin Ice* screening and Q&A.

Hutt Valley and Wellington Mineral Club: 28 October, Peter Barrett "Antarctica and Climate Change".

Marine Technology Journal: Gavin Dunbar and students from Omarama School.

Public Talk: 7 December, Brian Anderson, "Why did the glaciers advance? Why are they retreating now?"

Catalyst: 7 December, Peter Barrett "Half a century of studying Antarctica and climate change".

Antarctic Treaty System Workshop: 14 December, Peter Barrett "Antarctica in a global context".

Gros Cap School, St. Ignace, Michigan: 15 December, Jamey Stutz, Video chat from the Ice.

PUBLICATIONS, CONFERENCES AND COLLABORATORS

ARC researchers have been involved in a number of high profile publications in *Nature, Science* and *PNAS*

Football moraines, Edisto Inlet, Antarctica - Photo: Cliff Atkins

PUBLICATIONS AND INVITED PRESENTATIONS

Peer-reviewed publications (31)

Aitken, A.R.A., Roberts, J.L., van Ommen, T.D., Young, D.A., **Golledge**, N.R., Greenbaum, J.S., Blankenship, D.D., Siegert, M.J., (2016). Repeated large-scale retreat and advance of Totten Glacier indicated by inland bed erosion. *Nature*, 533: 385-389. doi:10.1038/nature17447

Bakker, P., Clark, P.U., **Golledge**, N.R., Schmittner A., Weber, M.E., (2016). Centennial-scale Holocene climate variations amplified by Antarctic Ice Sheet discharge. *Nature*, 541: 72-76. doi:10.1038/nature20582

Bart, P.J., Mullally, D., and **Golledge**, N.R., (2016). The influence of continental shelf bathymetry on Antarctic Ice Sheet response to climate forcing. *Global and Planetary Change*, 142: 87-95.

Bracegirdle, T.J., **Bertler**, N., Carleton, A.M., Ding, Q., Fogwill, C.J., Fyfe, J.C., Hellmer, H., Karpechko, K. Kusahara, Larour, E., Mayewski, P.A., Meier, W.N., Polvani, L.M., Russell, J.L., Stevenson, S.L., Turner, J., van Wessem, J.M., Wainer, I., (2016). A multi-disciplinary perspective on climate model evaluation for Antarctica. *Bulletin of American Meteorological Society*, ES23–ES26. doi: 10.1175/BAMS-D-15-00108.1

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Huw Horgan and MSc student Merijn Thornton working in Tasman Glacier area, New Zealand
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