

THE DEEP
SOUTH

Te Kōmata o
Te Tonga



RESEARCH BOOK 2018
CHANGING WITH OUR CLIMATE



KEI UTA KI TAI

Our cover photography reflects on the concept “Kei uta ki tai”, which can refer to the marginal space between the land and the sea. Coastal areas are particularly vulnerable to climate change and are also the focus for several research projects of the Deep South National Science Challenge. In these photos, a father and son gaze either shoreward or seaward. They look to the past or to the future from their unique perspectives and with their differing dreams.

*“Though our climate is changing, in the projects
of the Deep South Challenge I see a pathway
forward for our children and grandchildren.”*

**TĀ MARK SOLOMON,
DEEP SOUTH CHALLENGE BOARD MEMBER**

INTRODUCTION

Tēnā koutou katoa. Welcome to our Research Book 2018: Changing with our Climate. After four years of the Deep South National Science Challenge, it’s exciting to see the breadth and depth of research we’re supporting. Together, our projects all help achieve the mission of the challenge: to enable New Zealanders to adapt, manage risk and thrive in a changing climate.

Our challenge is unique among climate research programmes in New Zealand for the way it joins together physical science, predictive modelling and social science. We’re engaging closely with central and regional government, whānau, hapū and iwi, business, infrastructure and industry. We’re finding out about their concerns and priorities and focussing our research to ensure it addresses New Zealand’s needs. We’re collaborating with decision makers to share our research about the kinds of climate change impacts we can expect in the coming decades and centuries, and to develop the kinds of tools required to help people make decisions in the face of complex changes in the future.

Climate science can be complex and challenging, and it isn’t always effectively incorporated in planning and decision making. The Deep South Challenge aims to join up the research we’re doing in the Southern Ocean, for example, to communities of the Far North whose drinking water supply is at risk. We aim to communicate the climate simulations

made by our ground-breaking New Zealand Earth System Model, for example, with decision makers weighing up the future of an airport, or a water storage scheme.

The Deep South Challenge is hosted at NIWA and operated primarily by our Science Leadership Team, who are based at a range of institutions around New Zealand. We report to an independent governance board and garner strategic science input and advice from our advisory groups: the Independent Science Panel, the Kāhui Māori, the Representative User Group and the Technical Advisory Committee on Engagement. We currently fund interdisciplinary researchers at most New Zealand Universities, three Crown Research Institutes and over 20 other organisations.

This broad structure supports the challenge’s best teams approach for research. At the same time, we’re strengthening our internal engagement to unite the research of such a diverse team.

We know that scientists, industry and communities must work together if society is to adapt to our changing climate. The first of our shorter-term projects are now coming to a close and their findings suggest we’re doing well to close the loop and support communities to begin to make the decisions that will enable them to adapt, manage risk and thrive in our changing climate.

We will continue to be deeply strategic in our approach, and to try and ensure our future is a safe and familiar place.

Mike Williams

DIRECTOR, DEEP SOUTH NATIONAL SCIENCE CHALLENGE



*"There was time for fish, there was time for oysters, time for mussels.
And it never altered until recently. Things are changing.
Things are blooming out of season. Right to the flowers, we're different now."*

The quotes that ebb and flow throughout this research book come from interviews conducted with kaumātua in Te Hiku o Te Ika, and have been reprinted here with permission. They illustrate a deep relationship with the environment, with the weather and with our climate. They highlight what has been lost and what might be gained – if we listen closely to our communities and take the question of climate adaptation seriously.



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"Well, for me in those days, the weather up here was very tropical. The summer was hot, the winter was not really that cold. At one time, you could say, okay, winter starts in June and finishes in September.

*Nowadays it's totally different.
You can have wintery days in November."*



“Mā te mahi nga tahi i tēnei rā, ka piki te oranga mō āpōpō”

FOR THOSE WHO WILL BENEFIT FROM OUR UNIFIED EFFORT TODAY

**E ngā mana, e ngā reo, e ngā mātawaka,
e ngā pātaka iringa kōrero o ngā mātua
tūpuna, tēnei te mihi matakuikui ki a
koutou, kua tautī mai i runga i te kaupapa
nei o Te Kōmata-o-te-rangi. Nō reira
tēnā koutou, tēnā koutou, ā, tēnā hoki
tātou katoa.**

Seven Māori-led science projects are currently funded through the Vision Mātauranga science programme of the Deep South Challenge. These projects are investigating climate change impacts and opportunities for iwi, hapū, whānau and Māori business. Together they represent the largest ever Māori-led research effort into the implications of changing climate conditions for Māori society.

Vision Mātauranga underpins the Deep South Challenge's governance and management structure, as well as the entire spectrum of our research and engagement work. It's also a standalone science programme, supported by a committed Kāhui of prominent Māori researchers. Our whakapapa helps us respond to voices from across the Māori world. We know that climate research must be focussed on finding practical and sustainable options for Māori and for the country in general.

The projects within the Vision Mātauranga science programme investigate climate change links, pressure points and adaptation strategies for Māori communities and business. They're also considering new products, services and systems derived from mātauranga Māori. Each project draws on distinct research methods – mātauranga Māori, science, art, design and even games – to unlock collective knowledge and shape conversations about our future climate. These projects all help to strengthen connections and knowledge exchange among Māori and the wider science community.

Given the intergenerational responsibilities Māori have to our own communities and to the living world, questions surrounding how we will deal with climate change are critically important. Tremendous advances in research and learning have been made, but much more remains to be done. We hope these highly collaborative projects will contribute new research capacity, capability and leadership to identify opportunities and pursue actions to manage future climate risks.

Heoi anō rā e aku mareikura, e aku whatukura puta noa i te motu, mei kore ake o koutou tautoko i tēnei kaupapa nui whakaharahara, ka kore rawa atu tēnei mahi rangahau e ea ai, e whakatutuki ai kia tika. Nō reira tēnā koutou, tēnā koutou, ā, tēnā tātou katoa.

Darren Ngaru King

VISION MĀTAURANGA SCIENCE LEAD

“Uenuku”

Photo by Huhana Smith



TE TAI UKA A PIA

Iwi relationships with the Southern and Antarctic Oceans

Project contact

Sandra Lee Morrison, University of Waikato | Ngāti Maniapoto, Ngāti Rārua, Te Arawa

Project budget

\$150,000

Project duration

July 2016 – June 2018

According to the tribal narratives of Ngāti Rārua and Te Āti Awa, the first human to travel to the Antarctic was the Polynesian explorer Hui Te Rangiora.

Te Rangiora sits aloft the meeting house Tūrangapeke, at Te Awhina marae in Motueka. He gazes out in his continual search for new lands, and in this way his journey is remembered and honoured. Te Rangiora also adorns the Pou at the entrance to the Riuwaka Resurgence in Kahurangi National Park. At this place, he took rest and prepared himself spiritually and physically for his journey into the Southern Ocean.

This is one recorded version of Māori journeying into the Southern Ocean. But what other stories are held by hapū and iwi – especially those from Te Waipounamu (the South Island) and Rekohu (the Chatham Islands)? How might these stories frame our ongoing relationship with the Antarctic and our responses to climate change?

In this project, we're working with hapū and iwi from Te Waipounamu and Rekohu to better understand the extent and nature of the relationships Māori had with the Antarctic and Southern Oceans, and to identify local challenges associated with climate change through both tribal stories and contemporary living arrangements.

Māori are historically underrepresented in research conducted in the Antarctic and the Southern Oceans. It's therefore important to identify ways to connect mātauranga Māori with climate change science and to bring Māori perspectives into wider discussions about adaptation to climate change. The learning from this work will be used to carry future messages on climate change to a Māori public. Synergising tribal narratives with scientific explanations can only enhance community interest in the crucial challenges posed by climate change.

"Iceberg"

Photo by Dave Allen



DRINKING WATER IN TE HIKU O TE IKA

Project contact

Wendy Henwood, Massey
University | Te Rārawa

Project budget

\$250,000

Project duration

January 2016 – December 2017

How might three isolated communities of the Far North – Te Kao, Pawarenga and Motukaraka – prepare for the impact of climate change on household drinking water?

In this project, we're exploring the quality and sustainability of water supply in Te Hiku o te Ika (Northland), to contribute to the well-being and viability of these communities into the future.

Rainfall is the main source of drinking water in these rural Māori settlements, and most people collect water from roofs and in tanks. Drinkable mains water is almost non-existent, household infrastructure is generally poor and whānau struggle to keep up with maintenance. Floods and drought will create more serious issues – predictions suggest that water quality could be compromised and that water shortages are likely.

Climate variations within Te Hiku and differences in water supply mean it's important to gather local data. Our communities are recording daily rainfall and temperature, testing for E.Coli and providing data for national climate and rainfall models. We're surveying households about existing infrastructure and interviewing kaumātua to uncover important historical perspectives. The knowledge built collaboratively during this research will be shared through iwi networks such as rūnanga, trust boards, marae, schools and kura.

One important early research learning is that older people have always been resourceful and have treasured water, so strategising about climate change doesn't feel like something new. Kaumātua are used to working with the elements and have the experience to adapt, conserve and innovate, including tapping old water sources.

Our learnings will be useful for remote communities outside of Te Hiku and for indigenous and other communities internationally, and to have far-reaching implications for kaitiakitanga of indigenous flora and fauna, sustainability practices and policy.

"Rising sea level, Taiao Marae Ātea"
Photo by Wendy Henwood

“We need to keep designing opportunities for iwi and hapū to see the potential of what adaptive change can look like.”

HUHANA SMITH



CLIMATE CHANGE & COASTAL MĀORI COMMUNITIES

*Nature, culture, design,
contemporary art and science*

Project contact

Huhana Smith, Te Rangitāwhia
Whakatupu Mātauranga Ltd

Project budget

\$250,000

Project duration

October 2015 – March 2017

Using the knowledge systems of whakapapa (genealogy), hīkoi (walking) and kōrero tuku iho (ancestral knowledge) to activate community understandings of and responses to climate change.

Based around two coastal Māori farms and a whānau trust in the Horowhenua–Kāpiti region, this project collaborated with iwi and hapū to identify culturally-informed climate change adaptation strategies. We also tested the economic, environmental and cultural implications of each strategy through a series of designed, whole-of-farm scenarios.

All participants, including Māori land- and farm-owners, scientists and senior architecture students, co-designed solutions around land and water use that brought together understandings of kaitiakitanga as well as of climate change risks. We identified many possibilities for rejuvenation and transformation, including moving from dairying to other types of farming (such as algae farming, green-lipped mussels or fish hatcheries), or to growing sustainable cash crops such as flax or mānuka honey from bees.

We shared our collective learning through hui and ongoing exhibitions – including one in an old dairy shed next to the Kuku Stream. The project created real opportunities for hapū and iwi to consider how they might adapt their land management and community planning in line with future sea level rise, coastal erosion, salinification and extreme weather. In this way, the project offers a model of participation and engagement that might assist other communities to come together and move forward in a changing climate.

“Kuku exhibition and hui”
Photo by Aroha Spinks



Coastal Māori assets require a broader approach that recognises iwi values, rapid land development and enduring Māori support for sustainable ecosystems:

Whanaungatanga ki te whenua

Bringing whānau back to the whenua

Puawaitanga o te whenua

Ensuring Māori farms are ecologically and economically viable

Whakahokia ngā kai o te awa

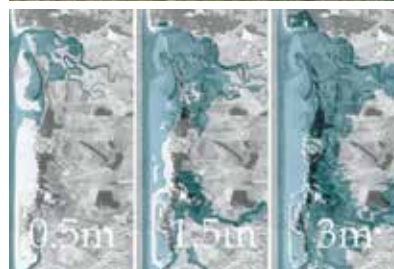
Returning to traditional resource management where possible (kai moana, eels, etc.)

Kaitiakitanga mō āpopo

Protecting Māori farms for future generations

Tiakitanga o ngā wahi tapu

Acknowledging and protecting cultural and ancestral sites and burial areas



Design and installation elements from various exhibitions related to this project.
Images courtesy of Huhana Smith



RISK MANAGEMENT FOR MĀORI COASTAL ASSETS

Project contact

Huhana Smith, Te Rangitāwhia
Whakatupu Mātauranga Ltd

Project budget

\$300,000

Project duration

August 2017 – January 2019

Coastal Māori farming communities are already affected by sea level rise. Erosion of the beach and even the collapse of some coastal infrastructure during storms is happening in several parts of the country. Effects such as flooding due to rising groundwater are subtler and more widespread.

This project builds on the significant collective knowledge about climate change risks and opportunities built throughout 2015–17 in the rohe of Horowhenua–Kāpiti (see page 8). This second phase of our project aims to take another step towards change: co-developing Transition Action Plans that, given local conditions, will enable Māori communities throughout Aotearoa New Zealand to assess the risks and benefits of alternative coastal land use.

In the first phase of our project, we combined data about soil, floods, topography, river sedimentation and sea level rise to identify the most vulnerable areas of our coastal farms. We also used an interdisciplinary approach to identify indicators of change and staged strategies for adaptation. This second phase will examine physical processes such as future change in groundwater levels, and identify a wider range of options for managing wetlands and landscapes.

Although multiple reports have been produced about coastal erosion risks – including by local and regional councils – none have highlighted social engagement processes that could lead to effective community action. Our Māori-led interdisciplinary action research approach prioritises social engagement when considering how to respond to sea level rise and other climate change impacts.



MARAE-OPOLY

*Indigenous games to help
climate adaptation decisions*

Project contact

Jackie Colliar, NIWA |
Ngāti Mahuta

Project budget

\$200,000

Project duration

January 2016 – June 2017

Marae-Opoly helps players identify marae priorities; share information about current and future flood risks; test adaptation options; and trade off different priorities and aspirations.

Deeper engagement and interdisciplinary approaches are needed if Māori communities are to move forward with climate adaptation. We need to make sure that the knowledge held by scientists, environmental managers and Māori is properly shared, to develop plans that respond to climate change while also meeting community aspirations.

To this end, our project facilitated a decision-making process with coastal hapū from Tangoio Marae in the northern Hawke's Bay. We co-created a flood adaptation game, Marae-Opoly, to help the hapū of Maungaharuru-Tangitū assess how sea level rise and extreme floods might impact marae assets. To support the hapū's decision-making process, our project also carried out hydrological and hydrodynamic modelling, to identify how the marae might mitigate flood impacts in the future.

Marae-Opoly is a significant development in indigenous participatory decision making. It helps players (and communities) work through uncertain and complex climate change impacts – making trade-offs and developing strategies for the future, and assessing how well these strategies have served them. Participants have had a lot of fun playing the game, while working through a very serious issue.

This decision-making model is of value for other Māori, indigenous and coastal communities who are grappling with climate change and integrating its impacts into their development plans.

"Playing Marae-Opoly at Tangoio Marae"
Photo courtesy of Jackie Colliar



"The seasons were in order, if you like. Now, your summers have gone into spring and all sorts of things. It's a huge change, weather wise, from what it used to be."





FORECASTING WEATHER & CLIMATE EXTREMES

Project contact

Apanui Skipper, NIWA |
Te Whānau-a-Apanui,
Ngāti Tamaterā, Ngāti Raukawa

Project budget

\$100,000

Project duration

January 2016 – June 2017

Over the centuries, Māori have developed extensive knowledge about local weather and climate conditions. These learnings have formed the bases of traditional and modern practices of agriculture, fishing, medicine, education and kaitiakitanga (guardianship).

Our project has worked closely with Ngāi Tahu knowledge holders to identify and revitalise the use of environmental indicators to forecast weather and climate extremes. We conducted 40 interviews with a diverse range of Ngāi Tahu elders and cultural practitioners, gaining unique insights into how Ngāi Tahu used and continue to use these indicators to forecast, monitor and plan for activities that are sensitive to changes in weather and climate.

One example of a well-known Ōtautahi weather indicator is Te Māuru, or the Nor'west Arch. Initially, a mass of billowing, dark clouds arch over Kā Tiritiri-o-te-moana (the Southern Alps). When seen, local Māori know that the dry nor'wester will start to blow. But when blue sky is seen above and below the arching clouds, it's known as Te Māuru. A southerly is expected, and its strength depends on the height of the arch. The higher Te Māuru rises, the stronger the southerly the next day. It's more than likely that snow will fall on the Southern Alps. This special indicator has been encapsulated within a whakataukī, "Ka taki mai Te Māuru, ka hara mai te toka" (When the nor'wester howls, the southerly advances).

This project makes Māori forecasting knowledge available through video vignettes and new educational resources to promote stronger and closer relationships between people and their local environment. We hope to help make the most of all available expertise to anticipate and manage the risks from weather and climate extremes.

"Murihiku Marae"

Photo by Darren Ngaru King



CLIMATE-RESILIENT FORESTRY & HORTICULTURE

Project contact

Shaun Awatere, Landcare
Research | Ngāti Porou

Project budget

\$250,000

Project duration

October 2015 – September 2017

Māori within the Waiapu catchment on the East Coast have long-term interests in the land they own and manage. Māori are also heavily invested in primary industries. Projected climate change impacts put these interests at risk.

The East Coast is already suffering high rates of erosion and sedimentation – the repercussions of previous land management decisions. More extreme rainfall will likely cause erosion to get worse, and degraded soils mean the effects of drought may become more severe.

To help landowners reduce these risks and to maximise their revenue, this project models the economics of different land-use decisions within a range of potential climate change scenarios.

Alongside landowners, we identified multiple land-use opportunities with a range of social, economic, environmental and cultural benefits. These included alternative forestry options (mānuka, kānuka, tōtara, mataī, puriri, harakeke and kawakawa), horticultural options (honey, olives and olive oil, lemons and hemp) and other medicinal and cosmetic business options derived from mātauranga Māori.

A significant early finding is that for all future climate change scenarios, re-foresting the land – particularly with indigenous species – results in a significant reduction of soil erosion for the Waiapu catchment. The implications of this finding are complex and raise, for example, issues about inter-generational equity. Nevertheless, this finding also provides a strong case that ecosystem services such as erosion control and carbon sequestration should be paid for – potentially leading to an additional revenue source for landowners.

The strong and diverse relationships built throughout this project ensure our research will be properly shared with landowners and that pathways will continue to be developed for landowners wanting to implement change.

PROCESSES & OBSERVATIONS

EARTH SYSTEM MODELLING & PREDICTION

Two interlinked programmes

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"I think last year we had the strongest winds we've ever seen here.
Yes, the tide came right up over

the flats and washed driftwood, all sorts.
Took a hell of a while cleaning it up."

Predictions of our future climate made by international climate models (almost all based in the northern hemisphere), while useful, don't simulate our historical climate perfectly. Gaps in our understanding about Southern Ocean and Antarctic processes limit the reliability of global climate prediction.

These gaps exist partly because measurements in the deep south region are notoriously difficult and expensive to make, and because some aspects of the deep south climate are unique. For example, large ice shelves only exist in Antarctica, there are many more super-cooled liquid clouds over the Southern Ocean than elsewhere and the ozone hole is, predominantly, an Antarctic phenomenon.

Two programmes of the Deep South National Science Challenge are working to fill these gaps in our understanding of the Southern Ocean and Antarctic region. These are the “Processes and Observations” and “Earth System Modelling and Prediction” programmes.

These programmes are deeply interlinked. Both the physical science projects and the climate modelling projects can be understood as contributing to one or more of the following themes:

Establishing the NZ Earth System Model (NZESM):

The NZESM is a complex computer code that represents a variety of physical, chemical and biological processes. Developing the NZESM means that we can complement internationally produced climate projections with our own. We'll also have the resource and expertise to contribute to global climate-modelling efforts, and will be in a better position to appreciate the limitations inherent in climate simulations.

Developing new knowledge: The earth's climate is so complex that individual components of the climate system, and their interactions, need to be well understood if future predictions are to be reliable. These projects focus on improving our knowledge about poorly understood aspects of the ocean, sea ice and atmosphere in the deep south.

Contributing to the model: These projects contribute data and new methods of observation with which to constrain the NZESM. They improve the model's accuracy, while also expanding our understanding of the natural world – the Southern Ocean and Antarctic region in particular.

Evaluating the model: These projects focus on evaluating the NZESM itself – by checking whether the model's simulations mirror our real-world observations. We need to know if our model is reliable, and to pinpoint and address issues. These projects increasingly

draw on new observations made by projects of the challenge.

Making near-term predictions: These projects use the NZESM to improve our predictions for New Zealand's climate over the next 10 to 100 years, and also seek to learn more about the future likelihood of extreme weather. They give the public the chance to be involved, through Weather@Home.

The order in which these projects are presented here shifts between the two programmes. We believe it's more helpful to group together all the projects relating to the Southern Ocean, for example – even

if some of them are about observing the Southern Ocean, and others are about refining how the Southern Ocean is represented in the NZESM.

Work underway in these programmes means that New Zealand is making a distinctive contribution to global climate modelling, and that we can ensure such information is tailored for Aotearoa New Zealand. The ultimate aim of these projects is to provide reliable and detailed local climate predictions (roughly spanning the 10- to 100-year time frame) for those who need them: from kiwifruit growers to policymakers in central government.

Adrian McDonald

SCIENCE LEAD, PROCESSES AND OBSERVATIONS

Olaf Morgenstern

SCIENCE LEAD, EARTH SYSTEM MODELLING AND PREDICTION



"RV Tangaroa"

Photo by Dave Allen



SIMULATING NEW ZEALAND'S CHANGING CLIMATE

*Establishing a New Zealand
earth system modelling
capability*

Project contact

Olaf Morgenstern, NIWA

Project budget

\$1.9 million

Project duration

2015–2019

A project which sits at the heart of the Deep South Challenge is the construction of the NZ Earth System Model (NZESM). The NZESM is a kind of crystal ball – a mathematical model of the earth's natural systems so intricate it can predict the effects of emissions from our atmosphere, land and seas, and the terrestrial and marine biosphere, far into the future.

The two main aims of this major endeavour are to advance our fundamental understanding of important climate processes, and to predict New Zealand's future climate out to the year 2100.

Almost all of the world's climate modelling capacity is based in the northern hemisphere. Yet gaps in international observations and understandings of the deep south region (of great importance to global climate change) are reflected in projections of climate produced by these models. Our proximity means this particularly impacts the quality of climate projections for New Zealand.

In this significant endeavour – an international partnership led by the UK Meteorological Office – we're helping to develop a powerful climate model and are augmenting it with improved formulations of Southern Ocean and Antarctic processes, informed by Deep South Challenge observations, to develop a comprehensive tool for simulating climate – the NZESM. We're awaiting a new supercomputer – arriving in stages between late 2017 and early 2018 – which will greatly enhance our capacity to contribute to global understandings of climate change and make more accurate predictions of future climate in New Zealand and the Pacific.

By strengthening our ability to understand and anticipate our future climate, we're giving New Zealanders the best possible chance to adapt and manage risk in the years to come.

"Climate scientist Olaf Morgenstern"
Photo by Dave Allen



Photo by Dave Allen

THE SOUTHERN OCEAN IN A WARMING WORLD

Assessing the Southern Ocean in a warming world and its influence on New Zealand's climate

Project contact

Melissa Bowen,
University of Auckland

Project budget

\$1 million

Project duration

2015–2019

The ocean stores and transports heat and can release that heat into the atmosphere. Changes in ocean heat dominate the global energy budget, accounting for 93 percent of global energy change since the 1970s.

Changes in Southern Ocean temperatures also influence weather systems reaching New Zealand, by altering the position of the southern hemisphere storm track and cyclone development. With so much energy involved, understanding how the Southern Ocean stores and transports heat is integral to understanding climate change in New Zealand.

Unfortunately, scientists don't have enough measurements from the Southern Ocean to accurately predict how it is changing. In our project, we're using existing oceanographic data to identify the physical processes that will have the most impact on the NZ Earth System Model (NZESM). We're developing modelling of ocean processes, including heat storage and transport, for inclusion in the NZESM, and test the model to make sure it replicates ocean behaviour accurately.

In this way, we're contributing to ensuring the accuracy and reliability of the NZESM, both for our region as well as globally.



CARBON DIOXIDE & THE SOUTHERN OCEAN

*Seasonality of Southern Ocean
dynamics from Antarctic
radiocarbon observations*

Project contact

Jocelyn Turnbull, GNS Science

Project budget

\$197,000

Project duration

3 years – over two
Antarctic winters

It's common knowledge that burning fossil fuels releases carbon dioxide into the atmosphere and contributes to climate change. It's less well-known that only about half of it stays there. Plants, soil and oceans all act as “carbon sinks” absorbing and storing carbon dioxide from the atmosphere.

The Southern Ocean is one of the largest and most important carbon sinks in the world, taking in roughly 15 percent of global carbon dioxide emissions. By measuring a unique isotope called radiocarbon, this fact can be used to our advantage. We'll collect air samples from Arrival Heights in Antarctica, Baring Head in Wellington, and on ships travelling between New Zealand and Antarctica (much easier than collecting samples during the Antarctic winter). Together with information gathered from tree rings in New Zealand's Sub-Antarctic islands, we'll use these samples to determine information about circulation in the Southern Ocean that we can't obtain any other way.

This will result in a better understanding of the Southern Ocean's processes, improved simulations by the NZ Earth System Model and more accurate predictions of New Zealand's climate. Because the Southern Ocean is the biggest carbon sink in the world, and ocean circulation plays a big role in this climate system, this research will also have a substantial impact on international research and global climate modelling.



TAKING THE PULSE OF THE ROSS SEA OUTFLOW

Project contact

Melissa Bowen,
University of Auckland

Project budget

\$300,000

Project duration

July 2017 – June 2019

Melt water produced by ice shelves around Antarctica influences ocean currents, temperature and salinity around the Southern Ocean and globally. The Ross Ice Shelf to the south of New Zealand is amongst the largest Antarctic ice shelves. Currently, our capacity to model its outflow and impact on our climate system is limited.

This project will take new measurements, both from ships and from robotic gliders programmed to fly up and down through the ocean, to understand how water moves between the shallow shelf and the deeper ocean. We'll compare our findings to historical data and document the ways in which the Ross Sea outflow has changed over the past decade.

In doing so, we'll improve how these processes are simulated in the NZ Earth System Model and contribute to more accurate predictions of New Zealand's future climate.



Photo by Joseph Michael



"I know the times for the fish is all up the chute."

Everything has its time. It doesn't happen anymore."

See, we should be eating the mullet from April through to about August."



Photo by Craig Stevens

ANTARCTIC SEA ICE

*Targeted observation and
process-informed modelling of
Antarctic sea ice*

Project contact

Pat Langhorne,
University of Otago

Project budget

\$1.9 million

Project duration

2015–2019

Antarctic sea ice plays a major role in the global climate system. Its presence maintains cold conditions that help sustain Antarctica's ice sheets, and it affects the rate of global warming by changing heat uptake in the Southern Ocean. Antarctic sea ice has a significant influence on both the ocean and atmospheric components of the climate system, and sea ice extent is closely linked with weather systems over New Zealand.

While the rapid retreat of Arctic sea ice is alarming researchers worldwide, satellite observations show that sea ice extent has actually been increasing in the Antarctic over the past 37 years. This behaviour is seemingly at odds with global warming. The truth is that current earth system models can't faithfully reproduce the trends in sea ice coverage, and a lack of observations has meant that the drivers of these trends are poorly understood.

(In late 2016–early 2017, total Antarctic sea ice extent actually reduced. We still don't know if this is a reversal of the pattern or just natural variability. Regardless, it's important we understand what is going on.)

Antarctic sea ice grows and recedes fastest at the margins. The movement of the ocean surface waves break up ice on the outer edges, while extremely cold water causes sea ice to grow closer to the continent. This project involves field experiments on sea ice around Antarctica, and modelling work, to better understand the drivers of sea ice growth and decay. Our goal is to understand these processes well enough to ensure the NZ Earth System Model (NZESM) accurately reproduces the behaviour we're seeing in Antarctic sea ice.

This project is linked with Far from Frozen, a project funded through Curious Minds and supported by our Engagement programme (see page 64).



MELTING ICE IN THE NZESM

Freshwater from icebergs and ice shelf melt in the NZESM

Project contact

Inga Smith, University of Otago

Project budget

\$300,000

Project duration

July 2017 – June 2019

While the reduction of Arctic sea ice is alarming researchers worldwide, Antarctic sea ice extent has actually been increasing over the past 30 years.

Changes in Antarctic sea ice can have a huge effect on weather patterns over New Zealand, causing varying wind patterns that lead to cyclones, increased rainfall and abnormal temperatures. In addition, the amount of Antarctic sea ice affects the global climate, by influencing the heat uptake of the Southern Ocean – one of the world's largest carbon sinks.

Current climate models have been unable to replicate the increase in Antarctic sea ice. Through model development and improvements, this project will investigate if the recent increase in Antarctic sea ice is being influenced by freshwater from melting icebergs or from the bases of Antarctic ice shelves. Our research will inform the development of the NZ Earth System Model.

“RV Tangaroa”

Photo by Dave Allen



4D DRONES TO MEASURE ANTARCTIC CLOUDS, SNOW & ICE

Versatile 4D drones for observations of key deep south earth system processes

Project contact

Wolfgang Rack, University of Canterbury, Gateway Antarctica

Project budget

\$300,000

Project duration

July 2017 – June 2019

We have large gaps in our observational data about sea ice, clouds and snow in the Southern Ocean and Antarctica, which effects the quality of our climate models.

The challenging polar environment restricts our ability to gather data effectively, particularly about the thickness of sea ice and the distribution of aerosols, which are critical to cloud formation. We need better tools for observing these systems that function well in a tough environment.

In this project, we're developing and testing the use of drones to gather and validate data, including satellite data. Drones can be deployed from sea ice or ships and can cover a large area quickly – a big advantage. The application of smart technologies means we can contribute to data gathering by other Deep South Challenge projects.



Photo by Dave Allen

CLOUDS & AEROSOLS OVER THE SOUTHERN OCEAN

Reducing biases in the representation of clouds and aerosols in the NZESM

Project contact

Adrian McDonald,
University of Canterbury

Project budget

\$1.8 million

Project duration

2015–2019

Clouds have a massive effect on climate. Cloud cover reflects radiation from the sun that would otherwise be absorbed by oceans, raising their temperatures. Cloud cover can also act as a blanket, keeping warmth near the surface.

Despite their significant influence on climate, clouds represent one of the largest sources of uncertainty in modern climate models. For example, the frequency of clouds over the Southern Ocean is often underestimated, causing models to predict storm tracks incorrectly and warmer sea temperatures than actually observed. These biases also affect the sensitivity of the model to human-induced climate drivers, such as increasing greenhouse gases.

This project will improve our understanding of the chemistry and physics of clouds and aerosols in the Southern Ocean, by combining detailed measurements made during voyages with satellite observations and modelling studies. We recently completed our first measurement voyage on the RV Tangaroa, which saw researchers travel to the Campbell Plateau, while making measurements from the ship and launching instrumented balloons.

Improving our understanding of clouds and incorporating this understanding into the NZ Earth System Model is critical, as these processes significantly affect New Zealand's climate and have influences as far away as the tropics.



NEW METHODS TO SIMULATE SOUTHERN OCEAN CLOUDS

*Climate model evaluation
using satellite simulators:
A like for like methodology*

Project contact

Adrian McDonald,
University of Canterbury

Project budget

\$149,800

Project duration

July 2016 to June 2018

Modelling clouds and their influence is a significant challenge. Most cloud processes happen at scales far smaller than can be simulated by a climate model such as the NZ Earth System Model (NZESM).

This project will expand on two existing Deep South Challenge projects, focussing on the evaluation and improvement of the NZESM with specific reference to clouds in the Southern Ocean.

This project will couple a satellite simulator (which replicates what a satellite would “see” of a given cloud distribution) to the NZESM and will apply advanced data analysis to the results, to assess satellite measurements of different kinds of clouds. The information produced will help us understand how the NZESM may be misrepresenting clouds, and will help improve the representation of clouds in the model.



SULFATE AEROSOLS OVER THE SOUTHERN OCEAN

*Improving the representation
of sulfate aerosols over the
Southern Ocean in the NZESM*

Project contact

Laura Revell, Bodeker Scientific

Project budget

\$255,710

Project duration

July 2017 – June 2019

Have you ever looked at the ocean and noticed that the sky above it appeared hazy? This is caused by the presence of tiny particles or droplets in the air.

In remote, unpolluted regions such as the Southern Ocean, such “aerosols” form from natural sources, such as ocean waves breaking and releasing sea salt into the air. A particularly important type of aerosol, sulfate aerosol, forms when sea ice melts. Algae growing on the underside of sea ice produce dimethyl sulphide, which – when the ice melts – is released into the atmosphere. Dimethyl sulfide then undergoes a series of chemical reactions to form sulfate aerosol.

Aerosols over the Southern Ocean are important because they influence cloud formation and play a role in the energy budget. However, the way aerosols behave in the atmosphere is complex, and it’s currently difficult to model them accurately. This may be one reason why the NZ Earth System Model (NZESM) has difficulty simulating the energy budget over the Southern Ocean, which has flow-on implications for simulating New Zealand’s climate. In this project, we’ll upgrade and fine-tune the way the NZESM simulates sulfate aerosols, with the aim of improving climate simulations of the southern hemisphere.

Discovery See Answer

DATE.		Latitude.		Longitude.		Current when determined at short intervals.	Course and Distance.		Wind at the time of observation.		Barometer*		True Atmospheric Pressure at Sea Level. The barometer reading corrected for Temperature, Height, Gravity. See pages 15-20 Marine Observer's Handbook, 4th Edition.	Thermometer.
Year	Month	Observed.	Dead Reckoning.	Observed.	Dead Reckoning.		Each four hours.		Direction.	Force 0 to 12.	Height of Cistern above Sea level, feet.			
							True Course.	Distance by Log.			Uncorrected Reading.	Atm. Therm. Absolute Scale.		
1929	11													
The D.R. position is needed daily, in addition to that by Observation, but it should be the result of careful calculation, in order to give any value to the estimation of the current.														
Day	Hour.													
12	4						165	19	NE x N	5	992.7	276	995.0	33.0
	8						Var	21	NN E	4	990.7	277	992.3	34.0
M.T.	NOON	49 27 1/2	49 27 1/2	70 23	70 23		Var	22	NNE	4	989.2	278	991.2	36.2
	4	Current in last hrs. mls.					Var	23	NW x W	1	988.4	278	990.3	41.8
	8	alongside quarry jetty					Var	4	NNW	2	989.0	278	990.0	38.9
	MIDT.	Port Jean d'arc.					observations missed							
13	4	Royal Sound												
	8	Rupert's Bay							NNW	2	991.8	280	993.6	34.8
M.T.	NOON	49 33 1/2	49 33 1/2	69 49	69 49 E				NW x N	3	992.2	281	993.9	41.9
	4	Current in last hrs. mls.							SW	3	993.4	280	995.1	39.5
	8								West	3	995.0	280	996.8	37.2
	MIDT.								NW x W	3	996.2	279	996.1	37.5
14	4								NW x N	2	992.4	278	994.4	35.0
	8								SW	5	992.7	278	994.7	32.8
M.T.	NOON								WSW	5-6	994.6	278	996.5	39.0
	4	Current in last hrs. mls.							W	3	995.8	278	997.8	34.8
	8								West	4	996.4	278	998.5	34.9
	MIDT.								West	3	997.2	278	999.3	34.8
15	4								WSW	4	996.9	277	999.1	33.5
	8								WSW	5	997.9	278	1000.0	37.7
M.T.	NOON								WSW	6	998.5	278	1000.6	39.3
	4	Current in last hrs. mls.							SW	5	1000.1	278	1002.1	37.4
	8								SW	5	1001.6	277	1003.8	34.0

EVALUATING THE NZESM AGAINST MODERN & HISTORICAL OBSERVATIONS

*Assessing and validating the
NZESM using modern and
historic observations*

Project contact

Stefanie Kremser,
Bodeker Scientific

Project budget

\$1.1 million

Project duration

2015–2019

The NZ Earth System Model (NZESM) is designed to simulate how our climate will change over the coming decades. It's highly complex, modelling everything from weather systems to changes in Antarctic sea ice, ocean temperatures to stratospheric chemistry.

The complexity of the NZESM means that any shortcomings in one component of the model can compromise the fidelity of the entire model. We're testing the ability of the model to simulate reality by comparing its results against modern and historical observations. If, in comparison with past climate and atmospheric chemical composition data, the model accurately replicates the past, we can have increased confidence that the model includes the appropriate processes needed to simulate future changes in climate.

To gather comprehensive historical climate data about Antarctica and the Southern Ocean, our project sees scientists and historians working together to recover meteorological observations over the southern hemisphere made as far back as 1850. We're also constructing global records on ozone and other gases that absorb or emit radiation. Ozone changes have had a major impact on New Zealand's climate in the past, and it's likely this will be the case in the future.

With these datasets, we can thoroughly test the NZESM and, in doing so, contribute to more accurate simulations of our future climate.



STRATOSPHERIC CHEMISTRY IN THE NZESM

*Improving the simulation
of stratospheric chemistry in
the NZESM*

Project contact

Olaf Morgenstern, NIWA

Project budget

\$300,000

Project duration

October 2016 – June 2018

The aim of this project is mainly to improve the simulation of stratospheric chemistry in the NZ Earth Systems Model (NZESM). Stratospheric ozone is particularly relevant to climate change in the southern hemisphere because of the emergence, in every spring, of the ozone hole above Antarctica.

Ozone depletion is a major (and, seasonally, the dominant) driver of southern hemisphere climate change. However, problems with simulating ozone means it's difficult to have confidence that the extent of its influence is properly represented in the model. This work improves the simulation of stratospheric ozone depletion, and in particular Antarctic ozone depletion, to contribute to a more realistic simulation of southern hemisphere climate and its response to human activity.

This project builds on a strong heritage in stratospheric model development in New Zealand and complements the work of our international partners in earth system modelling. We're collaborating closely with another Deep South Challenge project ("Testing the NZESM against modern and historical observations", see page 37) that will produce observational datasets to help us validate the NZESM. We're also strengthening a long-standing relationship with Australian colleagues interested in climate–ozone links.



TESTING THE NZESM THROUGH A SINGLE VERTICAL COLUMN

Developing capacity in process assessment and improvement in NZESM through the use of the single column version of the model

Project contact

Jono Conway, Bodeker Scientific

Project budget

\$91,300

Project duration

October 2017 – September 2018

Imagine that you're standing at Scott Base in Antarctica. Look straight up into the atmosphere. Our project tests the accuracy of the NZ Earth System Model (NZESM) along this vertical column.

The NZESM is a powerful tool for simulating climate – but it's very complex. Its mathematical formulae simulate many physical systems and all the ways they might interact with each other. Its scale and complexity makes it difficult to assess how accurately the NZESM represents the individual physical processes that comprise it. By running the NZESM on a single column with no horizontal dimension – instead of running it across the entire globe – we greatly reduce its complexity.

By focussing on this single column we can bring to bear all the complex physics of the NZESM on a small area, and more easily evaluate the reliability of the model. Running the model at this scale is much faster and far cheaper than the full NZESM, so we can do tests that would otherwise take years. We can iterate quickly, tweaking and testing the model to make it more accurate.

Our project benefits from a rich suite of atmospheric measurements recently collected at sites around Scott Base – measurements of solar and thermal radiation at the earth's surface, measurements of the temperature and concentration of gases through the vertical column, and measurements of clouds.

If the model can accurately replicate our observations, then we'll have confidence in its accuracy on a wider scale. If not, we can hone in on the problem and try to fix it. In this way, we're developing an independent and cost-effective means to assess and validate physical processes against the NZESM.

A wide-angle photograph of a calm ocean under a vast blue sky. The horizon is visible in the distance, with a dark, silhouetted coastline on the right. The water is a deep blue with gentle ripples. The sky transitions from a deep blue at the top to a lighter, hazy blue near the horizon. A small, dark object, possibly a boat, is visible on the horizon line.

*"Now, we can have floods anytime and big floods... They tell me it should be a 100-year event or 140-year event...
But it's now an anytime event. So, that must be, that must have some effect [from] climate change."*



“Te Mana o Kupe ki Aotearoa”
Photo by Dean Zillwood



NEAR-TERM CLIMATE PREDICTIONS FOR NEW ZEALAND

Improving predictions and understanding deep south drivers of New Zealand's climate

Project contact

Dave Frame, NZ Climate Change
Research Institute, Victoria
University of Wellington

Project budget

\$1.4 million

Project duration

2015–2019

Climate change is already here. Living in a changing climate means playing catch-up: trying to work out what has changed, what is changing and what changes are just around the corner. Although the dramatic transformations expected later this century get the most attention, the impact of current change is already significant, and is affecting societies now.

This project uses a range of climate modelling tools – simple models, existing climate model ensembles and the NZ Earth System Model – to improve our understanding of the emergence of climate change and its drivers. Our project involves three closely related areas of research:

Detection and attribution

Events like floods and droughts can cause life-altering shocks to families and communities. We need to look at changes in the recent past to work out if extreme weather events are more frequent, and the extent to which human-induced climate change is responsible.

Extreme weather events are inherently rare. We need to run the models until we have enough data to draw reliable conclusions about how aspects of the climate system interact to cause such dangerous weather. This takes a huge amount of processing power. For this reason, we are part of Weather@Home, a citizen science project that harnesses the power of thousands of personal computers around the world to run a climate model.

The emergence of climate change

This part of our research examines how climate models expect weather and climate to change, relative to “normal” or “expected” climate and weather variability. Our Pacific and Southeast Asian neighbours – and trading partners – are experiencing the effects of climate change most intensely.



Deep South Challenge researchers are at the global forefront of research in this area. Recent work includes using climate models to simulate the link between cumulative carbon dioxide emissions and human exposure to more frequent hot days; and research into how reducing carbon emissions can slow climate change and ensure the climate of the coming decades is familiar to humanity (this will not be the case if emissions continue unabated).

Decadal predictability in the New Zealand region

We're trying to understand predictability on timescales between a few years and a few decades. We use climate observation datasets (from a range of instruments and, most importantly, satellites) to examine the sources of New Zealand's climate variations. By learning which features of the climate system most strongly influence changes in New Zealand's climate, we then examine these more closely to see how they might evolve in future years.

WEATHER@HOME

Modelling climate events on home PCs

Project contact: Suzanne Rosier, NIWA

One of the most innovative ways of understanding weather extremes involves running models of the same year many thousands of times.

This requires vast amounts of computing power – more than is feasible even on the best supercomputers currently available to scientists. The problem can be overcome through distributed computing, which combines the power of thousands of ordinary home and work computers.

Using ordinary PCs limits the size of the models that can be run, so in this project we use a relatively simple climate model. We run both global simulations and regional simulations that cover the Australasia region.

Weather@Home in New Zealand is run at NIWA by the Deep South Challenge, working closely with the project's headquarters at the University of Oxford, England.

IMPACTS & IMPLICATIONS

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"[Our crops] don't last. You can't store them like how we [used to],

I'm certain of that. It is most definitely the weather [that] has affected it.

Those natural things that we took for granted, all our lives, aren't there anymore."



By improving our understanding of the likely impacts of climate change, and how people are adapting and might adapt in the future, this programme aims to support decision-making about and adaptation to climate change.

Impacts: Climate change is having, and will have, a range of impacts, including physical impacts (for example, sea level rise or changing temperatures), socioeconomic impacts (for example, risks to infrastructure, housing, communities and health), and environmental impacts (for example, risks to native flora and fauna).

If we can understand how climate change will impact New Zealand, we can plan for it more effectively. This involves taking a ‘big picture’ view. We need to explore how the many and varied impacts of climate change will interact with each other. Our research into the impacts of climate change will also feed into and be informed by the emerging NZ Earth System Model.

Implications: We’re also aiming to make sure individuals, communities, the private sector and government consider climate change in multiple contexts and make robust decisions about adaptation. Further, we need to better understand the institutions that facilitate climate change adaptation. Our research is looking into historical responses to environmental

threats, and at the way climate-sensitive decisions are currently being made, and trying out some new approaches.

The Dialogues: The Deep South Challenge aims to produce knowledge that New Zealand communities, including Māori, industry and government groups can use to plan for, and adapt to, climate change. It’s therefore crucial that these groups are involved in framing the research itself – we need to learn which issues relating to the impacts of climate change are most important to them.

Our programme is running a series of innovative stakeholder dialogues that enable the co-creation of research questions by researchers and end users, to make sure our research directly meets people’s needs. The Dialogues bring together researchers, community leaders, government agencies and NGOs to formulate research questions around key climate-related questions.

Building on existing work: The Impacts and Implications programme builds on a four-year project that finished in 2016: Climate Changes, Impacts & Implications for New Zealand. This MBIE-funded project modelled the impacts of climate change on human and natural systems and produced a series of case studies about different ecological areas in New Zealand as well as a valuable dataset on possible future climates around New Zealand.

Suzi Kerr

IMPACTS AND IMPLICATIONS SCIENCE LEAD



SNOW, ICE AND GLACIERS IN OUR CHANGING CLIMATE

Impact of climate change on New Zealand's frozen water resources

Project contact

Andrew Mackintosh,
Victoria University of Wellington

Project budget

\$390,000

Project duration

March 2017 – June 2019

New Zealand is projected to warm by 1-4°C during the 21st century. This warming will melt our frozen water resources – our snow, ice and glaciers. However, the scale, area and timing of changes to our meltwater are unclear.

Mountain rivers in both the North and South Islands of New Zealand feed our largest hydro-electric power schemes, and provide critical water for irrigation, especially during drought. Melting snow and ice may also cause increased flooding.

Our aim is to make projections about how runoff from New Zealand's glaciers and seasonal snow will change into the future. We'll also be engaging with iwi and with local authorities to determine the specific needs of communities that utilise water flows. This data is crucial for decision makers in government, communities and industry – all of whom rely on this climate-sensitive resource.

This project brings together, for the first time, New Zealand's leading snow and glacier scientists. We'll be developing computer models to simulate how snow and ice respond to climate change scenarios. We'll make projections of future snow and ice cover, and the resultant runoff from alpine catchments. We'll investigate the future availability of spring and summer meltwater from snow, and probable changes in summer flow as glaciers are lost. We'll look at extreme weather events, providing some insight into the frequency and likelihood of large snowfall events, for example, or 'rain on snow' events which can cause exceptional floods. We'll also help to identify the extent to which snow and ice melt can ease the effects of drought, and whether this protective effect will continue in the future.

Improved water projections are essential for the development of climate change adaptation policies that can balance both the financial and intrinsic value of water.

"Pouakai Plateau"

Photo by Rakairoa Hori



CLIMATE IMPACTS ON THE NATIONAL WATER CYCLE

*National hydrological and
water resource impacts of
climate change*

Project contact

Christian Zammit, NIWA

Project budget

\$400,000

Project duration

July 2017 – June 2019

This century, climate change will alter New Zealand’s natural water cycle significantly. It will change how much rain and snow we receive, and at what time of year. It will change how much water is stored in the soil, snow, glaciers and aquifers. It will change how much water evaporates back to the atmosphere and how much flows through streams and rivers to the coast. And it will change the severity of droughts, floods and power shortages.

In New Zealand, fresh water is central to our natural environment, economy and way of life. It has shaped our landscapes and wildlife, supports farming, tourism and other industries, supplies over 50 percent of our electricity through hydropower, and is integral to our heritage and sense of place.

This research project will conduct a comprehensive national assessment of the impact of climate change on New Zealand’s hydrological cycle this century. Using NIWA’s hydrological modelling tool, TopNet, we’ll examine the potential effects of climate change on the movement of our freshwater, from the mountains to the coast, with a focus on agriculture, hydropower and flood hazards.

As part of this project we’ll identify where New Zealand’s water cycle is most vulnerable to change and develop a new approach to calculating the likelihood and severity of future floods. The data and results we generate will also help other research projects study the implications for flood management and irrigation supply.



NATIONAL FLOOD RISKS & CLIMATE CHANGE

Emergent exposure of flood inundation hazards under future climate change in New Zealand

Project contact:

Ryan Paulik, NIWA

Project budget

\$205,000

Project duration

July 2017 – June 2019

Floods are some of New Zealand's most frequent, most damaging and most disruptive natural hazards. As our climate changes, flooding caused by both increased rainfall and rising sea levels – in coastal areas and on floodplains – is expected to increase.

As floods worsen, so will the social, cultural, economic and environmental consequences. Pinpointing exactly which areas are most at risk can be difficult, especially as extreme weather events become more frequent and less predictable.

There's not a lot of information currently available to central and local government about exactly what infrastructure is at risk. Information is urgently needed to help identify high-risk areas and prioritise mitigation and adaptation efforts.

This project will produce scientific models that allow practitioners and researchers to identify how flood risk may evolve in their area. These models will determine which assets – like buildings, roads, bridges and railway lines – are at risk, on both a regional and national level.

The models produced by this research will be available in open access software called RiskScape, developed by NIWA and GNS Science, to directly help those people whose job it is to manage flood risk. If we can accurately predict the areas of highest risk, we can adapt, minimising harm to New Zealand's population and economy.



CLIMATE CHANGE: THE CASCADE EFFECT

*Cascading impacts
and implications for
Aotearoa New Zealand*

Project contact

Judy Lawrence, NZ Climate
Change Research Institute,
Victoria University of Wellington

Project budget

\$291,800

Project duration

July 2016 – June 2018

The impacts of increases in temperature, rainfall, sea levels and extreme events will cascade across all sectors of society. Our assets, communities and social and economic interactions will all be affected.

As the effects of these changes, become more frequent through flooding, coastal inundation and drought, we'll have less time to recover and there will be cumulative consequences. In addition, as different sectors respond to the changes, there is potential for impacts to compound through the economy.

The Deep South Challenge focusses on four major climate-related impacts: extreme weather events, drought, changes in average weather patterns and sea level rise. The flow-on effects of these changes and their interactions raise many interrelated questions for decision makers and planners at all levels of decision making and across all sectors, such as:

- » How will sea level rise affect transport links regionally, coastal communities and the infrastructure on which they depend?
- » How will changes in seasonal temperatures affect fruit growers, their business, their access to ports and airports, and how will this in turn impact local and national economies?

The interconnected – or cascading – social and economic impacts are the focus of this research, which builds on the Climate Change Impacts and Implications (CCII) work completed in 2016. Working with local government, infrastructure and financial sectors, our researchers will use climate modelling information and socio-economic scenarios, alongside the realities of representative regional communities, to better understand the scale of climate change implications for Aotearoa New Zealand.

By understanding the cascading nature of the impacts of climate change, decision makers will be better able to plan, adapt and manage risks.

“Tamaki Drive flood”



CLIMATE CHANGE & ITS EFFECT ON OUR AGRICULTURAL LAND

*Land-use suitability:
Incorporating climate
change impacts*

Project contact

Anne-Gaelle Ausseil,
Landcare Research

Project budget

\$450,000

Project duration

March 2017 – June 2019

The primary sector has been a key part of New Zealand's growth for a long time. Agriculture, forestry and fishing are all central to our modern economy.

In the past, a piece of land's suitability for agriculture was measured by its capacity for sustained production. That's no longer enough – climate change has the potential to drastically affect the viability of land for use in agriculture and other primary industries. Land once suitable for farming may be rendered unusable by the effects of climate change or extreme weather events. There's also an increasing need to account for more than productivity when deciding whether land is appropriate for agricultural use. Economic, environmental, social and cultural values are all affected by the choice to use a piece of land for agriculture.

The aim of this research is firstly to better understand the impact climate change will have on the land's suitability. Will previously productive pieces of agricultural land become unsuitable? Why? Secondly, we seek to understand the flow-on effects of these changes to land use. What will the economic impact be if lots of land becomes unsuitable for agriculture? How will we adapt?

In studying the causes and effects of changing land use, we can enable those who work in the primary industries to make informed decisions. By incorporating the effects of climate change into their decision making, our primary sector can make effective choices while still meeting soil, water quality and economic objectives.



STORMWATER, WASTEWATER & CLIMATE CHANGE

*Impacts on our economy,
environment, culture and
society*

Project contact

James Hughes, Tonkin + Taylor

Project budget

\$134,670

Project duration

January 2018 - February 2019

We don't yet know how climate change will impact our critical stormwater and wastewater infrastructure. We also don't know the extent to which climate change-induced damage to this infrastructure might directly, or indirectly, impact our economy, environment, culture and society.

This project aims to explore these potential impacts and to develop a detailed theory of change. Only once we have determined the impacts, and the performance required of our storm and wastewater network in a changed climate, can we design an efficient and effective solutions pathway.

This project will involve a comprehensive review of New Zealand and international literature, including local and regional case studies, as well as a detailed process to gather end user needs and requirements, via a panel of a key experts, including iwi representatives.

Although the project is not focussed on adaptation strategies, the research does aim to show which types of economic, social, cultural and environmental impacts are likely to be the most serious, and where they might emerge. The resulting information will provide useful guidance for key local government and water sector decision-makers.

The research team combines excellence in engineering, economics and physical science – and comprises experts from Tonkin + Taylor, NIWA and Infometrics. The project emerged from our October 2017 Climate Change and Stormwater and Wastewater Systems report.



EXTREME WEATHER, CLIMATE CHANGE & THE EQC

Project contact

David Fleming, Motu Economic and Public Policy Research

Project budget

\$154,000

Project duration

May 2017 – March 2019

Earthquakes might not yet be predictable, but increasingly, climate change is. Because of climate change, extreme weather events in New Zealand may be getting worse and happening more often. What does this mean for our state-owned provider of natural hazard insurance – the Earthquake Commission (EQC) – and for the communities and regions directly affected by extreme weather?

Although the EQC mainly helps households suffering earthquake damage, homeowners impacted by extreme weather like storms, floods or landslips can also make EQC claims for some damages. (For floods and storms, for example, the EQC will only cover the cleanup of debris and mud from the land below a house; it won't cover damage to the house or its contents.) More frequent and more intense weather can therefore affect the EQC's long-term sustainability.

Over the last 20 years, the EQC has paid out over \$240 million, on more than 17,000 claims, to households affected by non-earthquake disasters. Our project will study these claims, along with data from Statistics NZ, GNS and NIWA, to better understand how the EQC has covered households over time and across regions after extreme weather events; whether insurance pay-outs have supported households and communities to recover economically; and what the EQC's financial liabilities might be into the future, given climate change projections about extreme weather.

In doing so, we hope to enable local economies and the government to better understand and prepare for the financial challenges of climate change.



CLIMATE CHANGE & THE WITHDRAWAL OF INSURANCE

*Slow and sudden onset
thresholds for private
insurance retreat under
climate change in New Zealand*

Project contact

Belinda Storey, Climate Sigma

Project budget

\$110,000

Project duration

December 2017 - June 2019

Coastal hazards are escalating with climate change. In particular, coastal homeowners can expect both sea level rise and more frequent and intense coastal storms.

However, we see continue to see demand for housing through new coastal residential development and intensification of existing urban areas on the coast. This suggests that climate change related escalating coastal hazards are not yet fully reflected in home-owners decisions to purchase and renovate coastal property.

Consequently, climate risk may not currently be incorporated into the price of residential coastal property.

Evidence from overseas suggests that high insurance premiums and the unavailability of insurance has a stronger impact on private decision making than the uncertain risk of extreme events. Drawing on this, this project will explore how coastal housing markets impacted by climate change may respond to “insurance retreat” – if insurance becomes unavailable.

The project will identify those locations most likely to lose access to insurance within the next few decades (as the probability of extreme events increases).

The project will also estimate the direct economic losses on residential property of an extreme coastal storm making landfall in Tauranga City, to determine whether this size event could trigger reinsurance retreat (the withdrawal of the international insurers, who insure our local insurance companies) from other coastal locations in New Zealand.

Water

New Zealand receives about

550,000 MILLION
METRES³
of water each year



the volume
of Lake Taupō



of our rain and
snowfall eventually
flow to the coast,
the rest evaporates
along the way



OVER
50%

of New Zealand's electricity
comes from hydropower



of our freshwater
resource is used
for hydropower
generation,
irrigation and
drinking water
collectively

BY THE NUMBERS



MAKING ROBUST DECISIONS ABOUT NEW ZEALAND'S WATER

Robust adaptation decision-making under uncertainty: an application of real options analysis to decision making in the water sector

Project contact

Anita Wreford, Scion (NZ)

Project budget

\$267,200

Project duration

March 2017 – March 2019

We all need water, but climate change is putting the availability, supply and distribution of water under increasing pressure. Through drought, erratic rainfall, an expanding population and a growing economy, our access to water is at risk and we need to adapt.

One possible solution to the problem is water storage. If water could be collected and stored in times of plenty, we'd have reliable access to the water we need in times of need. But it's an expensive solution – water storage facilities are a significant investment, and it's difficult to justify the immediate costs when the benefits may not be seen for several years. Given the inherent uncertainty in predicting climate change impacts, there's significant scope for over- or under-investment. Too little, and we may run into significant water shortages. Too much, and we waste valuable resources that could be invested elsewhere.

At present, few large investment decisions in New Zealand consider the uncertainty of climate change in their decision-making process. This project will introduce a tool – Real Options Analysis (ROA) – to decisions being made about water storage in New Zealand. ROA incorporates ongoing learnings into a cost-benefit analysis, placing explicit value on flexibility – making investment as efficient as possible and adaptable to a range of climate futures.

We'll test the effectiveness of this decision-making process at a site in Canterbury, which is already experiencing extreme pressure on its water resources. The primary aim of this project, however, is to apply ROA in a way that can be replicated all over the country. In this way, our research is of direct relevance to local authorities, farmers, investors and any decision makers considering large, irreversible investment that may be affected by a changing climate. It will allow us to make informed decisions, and to adapt – in cost-effective ways – to an uncertain future.

"Light at Benmore"

Photo by Chris Sisarich

TOOLS FOR DECISION MAKERS

*Supporting decision making in
a changing climate*

Project contact

Judy Lawrence, NZ Climate
Change Research Institute,
Victoria University of Wellington

Project budget

\$339,600

Project duration

March 2017 – June 2019

As an island nation with high rainfall, flooding and sea level rise pose threats to economic and social activities on floodplains and at the coast. Decisions in such locations need to be adaptive, to recognise when thresholds may be crossed and to deal with changes before they happen. In this way, decision makers can avoid or reduce the consequent damage and costs.

The mission of the Deep South Challenge is to “enable New Zealanders to adapt, manage risk and thrive in a changing climate”. New and practical tools are needed to enable decision makers to respond appropriately to climate-related impacts, to limit damage and costs to the nation and its communities. With uncertainty about the timing and magnitude of climate change impacts, local government and infrastructure providers in particular need new and adaptive decision-making tools that take into account changing risk profiles. The Dynamic Adaptive Pathways Planning (DAPP) approach is an assessment tool for developing adaptation options. It helps decision makers consider the conditions under which policies will fail to reduce risks, and provides stress-test options using plausible socioeconomic scenarios of the future.

The project is focussing on flood and sea level rise management, enabling decision makers to move, over time, towards sustainable pathways that are more climate resilient. This approach was first developed in the Netherlands, and follows on from the successful development and application of the DAPP approach with local and regional councils in New Zealand, led by Victoria University of Wellington with support from Ministry for the Environment.



Photo by Aaron Smale



SEA LEVEL RISE, HOUSING & INSURANCE

Liability and compensation

Project contact

Catherine Iorns Magallanes,
Victoria University of Wellington

Project budget

\$100,000

Project duration

July 2017 - June 2019

This project looks at the question of sea level rise and insurance. It investigates the “tipping points” at which insurance companies might decide to refuse insurance to coastal property owners, and asks, what happens next?

To what extent can or should homeowners rely on the EQC, or on local or central government, to compensate them if their homes become uninsurable, or uninhabitable, due to sea level rise, or because of associated climate risks like storm surges or coastal erosion?

One of the key trends in international climate litigation is in trying to establish who is liable for taking (or not taking) adaptation measures. For example, in a recent Australian case, residents sought damages from their local council, both to pay for shoreline protection and to compensate them for the loss of property value from rising seas. They argued that the loss was in part the fault of the council and its earlier inaction.

The project will also investigate the Crown’s Treaty of Waitangi obligations in relation to sea level rise. Māori communities are likely to be disproportionately affected by sea level rise, with many rural Maori communities situated along the coast. Where communities have limited economic power and access to finance, and little or no insurance cover, effective policy options for uninsurable Māori housing are critical.



HOW SHOULD THE RISKS OF SEA LEVEL RISE BE SHARED?

Project contact

Elisabeth Ellis, University of Otago

Project budget

\$17,500

Project duration

October 2017 - June 2018

On a principled level, how should the risks of sea level rise be distributed between individuals, insurance, local and central government?

Should we choose to view responsibility as individual or collective? Either way, which approach delivers the best and fairest outcomes?

This project will look international literature on the ethics and policies of risk distribution while highlighting New Zealand's unique history and institutions.



CLIMATE ADAPTATION, VULNERABILITY & COMMUNITY WELL-BEING

Project contact

Judy Lawrence, NZ Climate
Change Research Institute,
Victoria University of Wellington

Project budget

\$196,511

Project duration

January - June 2019

In the coming decades, many New Zealand families and businesses will be exposed to climate change impacts such as flooding and coastal erosion. Some will be resilient but others may find the physical, social, financial or emotional aftermath difficult to recover from.

To ensure communities successfully adapt in the face of climate change, local authorities need both new tools and ways of engaging with affected communities, and to support adaptation initiatives already being driven by iwi and communities.

Using case studies in Te Awa Kairangi (the Hutt Valley) and Ōtepoti (Dunedin), this project investigates how councils already engage with exposed communities, the extent to which this is informing and influencing adaptation planning and practice, and options for improvement.

We explore how community groups, iwi, businesses and NGOs are involved in self-motivated adaptation actions, and the intersection with councils' mandated roles and responsibilities.

Our project focusses on more vulnerable community members to consider whether additional actions – not just engagement – are needed to ensure they are not further marginalised by adaptation processes.



FLOOD MITIGATION SCHEMES: ARE THEY WORKING IN FLOOD-PRONE AREAS?

Project contact

Patrick Walsh, Manaaki Whenua |
Landcare Research

Project budget

\$88,895

Project duration

November 2017 - June 2019

Floods are the most frequent economically damaging natural hazard in New Zealand, and climate change and sea level rise are projected to increase their intensity and frequency. People are increasingly moving into populated places with elevated flood risk, where floods damage both dwellings and primary income sources.

Economic losses from flooding are substantial in New Zealand and are projected to increase. Floods have caused almost \$300 million in damages since only 2014 (not including the New Year floods of 2017/18), with particularly disruptive impacts on homes and farming.

The most common method of managing flood risk in New Zealand is through flood mitigation schemes, in which flood-related infrastructure is funded via targeted property rates and government budget. However, many of these schemes were implemented last century, with mounting evidence that land use and population changes render them insufficient for future risk. There is also a surprising lack of research on these schemes.

This research explores several important and new research questions related to flood mitigation schemes. We will explore whether or not all flood-prone settlements have schemes in place – and will catalogue and map flood mitigation scheme locations using regional council data. We'll investigate whether flood mitigation scheme funding is adequate, by analysing data on flood damage claims and property rates data. This information will be used to identify possible improvements in the system.

We will also try to understand whether flood mitigation schemes are sufficient to protect exposed communities from increased flooding due to climate change. We'll do this by investigating the costs and benefits of flood mitigation schemes, comparing flood risk management in areas with mitigation schemes to areas without such schemes.



Photo by David Straight

THE DEEP SOUTH DIALOGUES

According to the insurance industry, the total 2017 bill for weather-related disasters in New Zealand was \$242 million.

The Whakatāne District Council has applied to purchase 34 properties in Matatā, because it says they are at risk of debris flows in heavy downpours. When it comes to communities exposed to climate change, where do risk and responsibility lie? How can we be better prepared?

Led by Motu Economic and Public Policy Research, the Deep South Dialogues aim to develop a shared understanding of key issues, to map current knowledge about them, to identify creative ideas to address them, and to pose well-formulated research questions. In this way, the dialogue process creates a more informed policy and research environment.



“Community Engagement”
Victoria University of Wellington

1 Insurance, coastal housing and climate adaptation

This dialogue was held in February-March 2017, and a report was published in June: Insurance, Coastal Housing and Climate Adaptation, led by Ilan Noy and Belinda Storey from Victoria University of Wellington. The report highlights how climate change may challenge our existing insurance arrangements and was covered widely by the media.

Three research proposals to emerge from the dialogue have been funded.

2 Storm and wastewater infrastructure

Water infrastructure is designed to last 50-100 years, so current decisions have ramifications for a future New Zealand, which will experience substantial sea-level rise. End users have explained that even relatively little sea level rise could seriously handicap water infrastructure.

Two research proposals to emerge from the dialogue have been funded.

3 Flood-prone communities and sea level rise

This dialogue focused on the impacts of climate change on vulnerable, especially flood-prone, communities. It brought together researchers from Victoria and Otago Universities, Landcare Research, GNS, NIWA, a former Environment Court Judge and the Parliamentary Commissioner for the Environment, with representatives from Te Rūnanga o Ngāi Tahu, Age Concern and migrant communities, and finally with government voices including Dunedin City Council and Ministry for the Environment.

4 Drought management

Drought is the chief climate impact raised by agricultural stakeholders. We’re currently planning this dialogue, and we’re looking at posing these kinds of questions:

- » How can we better manage more frequent and more severe droughts?
- » Could drought insurance be improved?

- » What is the role of storage and irrigation?
- » Can we develop more drought resistant cultivars and land uses?

This dialogue was held in early 2018.

5 Urban and freight transport

Like water, our transport infrastructure is developed over long timeframes. We aim to hold this dialogue before the end of 2018.

Future dialogues

- » Climate change and biosecurity risks (pest management, food safety)
- » Climate change and health (heat waves, tropical diseases)
- » Drinking water (security and quality of supply in Auckland and in smaller communities)
- » Opportunities (new land uses and economic activities)

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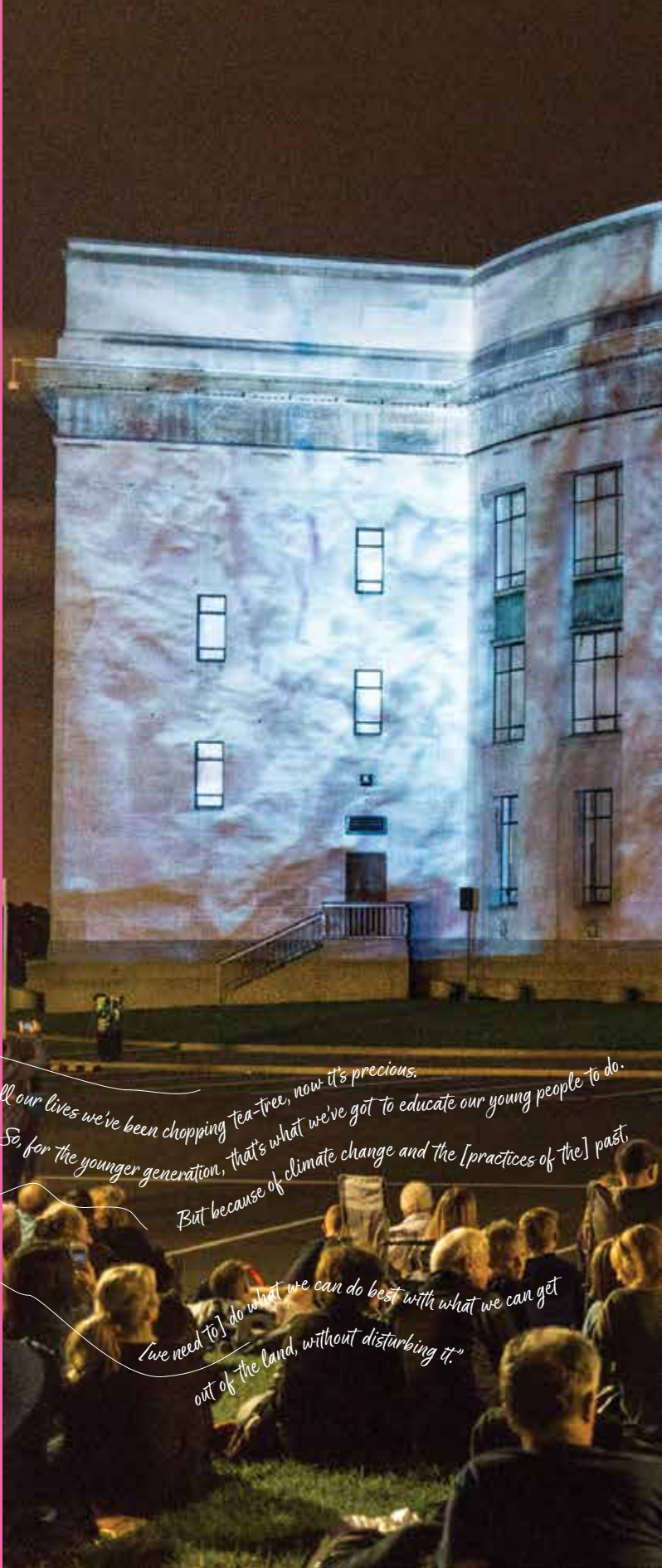
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*You look after the land and live within your means... All our lives we've been chopping tea-tree, now it's precious.
So, for the younger generation, that's what we've got to educate our young people to do.
But because of climate change and the [practices of the] past,
[we need to] do what we can do best with what we can get
out of the land, without disturbing it."*

The Engagement programme is helping New Zealanders make decisions that are informed by climate science.

Successful engagement in science is not only about communicating information. It also involves exploring what decision makers, end users and the public already know, need to know and want to know. The Engagement programme is creating new opportunities for two-way dialogue and for partnerships with our key end users and the public. Understanding the values and attitudes that shape society's engagement with climate change is also core to our work.

Our programme is innovative and ambitious: where traditional science communication uses one-way "push" tools, we explicitly set out to identify and respond to the needs and priorities of future users and beneficiaries of Deep South Challenge research. We feed this information back into the scientific process, to ensure our research is relevant and useful – helping

New Zealanders to adapt to a changing climate.

We work with communities, Māori, industry sectors and local and central government. We also work across and alongside all other programmes of the Deep South Challenge, to facilitate collaboration between our society and our researchers.

We also invest in building capacity for climate change engagement. We support our researchers to develop more engagement skills and experience, and we offer our end users the opportunity to upskill key members of their communities and sectors to become "climate ambassadors".

We prioritise rigorous evaluation to ensure (and continually question) the wise and informed investment of Engagement funds, and to make our engagement more effective. And recently, we've funded a public engagement research project – a first for New Zealand – that explores the role that culture plays in engagement about climate change.

Rhian Salmon

ENGAGEMENT SCIENCE LEAD



DEEP SECTOR ENGAGEMENT

The Engagement programme is concentrating substantial resource on building relationships with key sectors, to help support planning and decision making. It's all about connecting the science to decision making – and helping to ensure our science is focussed on what decision makers need to know.

Alongside our day-to-day engagement with end users, we gather strategic advice from our Representative User Group, an advisory body set up to ensure key decision-making groups are informing, and informed by, Deep South Challenge research.

We're always looking for new opportunities and partnerships on projects that enable informed decision making about climate change.

We're also participating in and supporting key end-user forums such as conferences, workshops and working groups, including:

- » **Climate and Business Conference**
- » **Climate Change Adaptation Technical Working Group**
- » **Local Government New Zealand Conference and Policy Advisory Group**
- » **Ministry of Primary Industries science seminar**
- » **Regional Councils' Resource Managers' Group**
- » **Water NZ Modelling Symposium**

Through briefings, meetings, webinars and workshops, and our Representative User Group, we're engaging with key end users, including:



Primary Industries

- » Beef + Lamb
- » Crown Irrigation Investments
- » Dairy NZ
- » Meat Industry Association
- » Horticulture NZ



Māori & Civil Society

- » Iwi Chairs Forum
- » New Zealand Council of Trade Unions
- » Community Networks Aotearoa
- » Hui Ē



Business & Finance

- » Business NZ
- » Insurance Council
- » New Zealand Bankers' Association
- » Tourism Industry Association



Local, Regional & Central Government

- » Local Government New Zealand
- » Ministry for the Environment
- » Ministry of Primary Industries
- » New Zealand Treasury
- » Productivity Commission
- » Regional Councils
- » Regional Councils' Science Advisory Group
- » Society of Local Government Managers



Infrastructure & Planning

- » Infrastructure New Zealand
- » Institute of Professional Engineers NZ
- » Institute of Public Works Engineers
- » New Zealand Planning Institute
- » Resource Management Law Association
- » Water New Zealand
- » Watercare

CULTURE & CLIMATE CHANGE

*Centring culture in public
engagement on climate change*

Project contact

Debashish Munshi,
University of Waikato

Project budget

\$270,600

Project duration

July 2017 – June 2019

How do people's cultural values shape and influence the way they might adapt to the new realities of climate change?

People need reliable, up-to-date information to be able to make important decisions about their future. Yet many vulnerable businesses and communities in New Zealand are struggling to understand how they should respond to the significant threats that climate change poses to our economy, our social fabric, our cultural traditions and our way of life.

Māori, for example, have a strong interest in debates about climate action and environmental issues, as well as concern about the impact on traditional cultural practices such as weaving and food gathering.

The project will use methodologies such as actor-system mapping, scenario building and citizen panels to construct a framework for engaging with people about climate adaptation that puts culture at its centre. It will engage with a wide range of New Zealanders – including farmers, small-to-medium business owners, tourism operators, iwi and hapū, and residents living in coastal or low-lying areas – to find out what people already know about climate change, and to work on a range of strategies to prepare for climate change events, such as extreme weather, flooding rivers and rising sea levels.



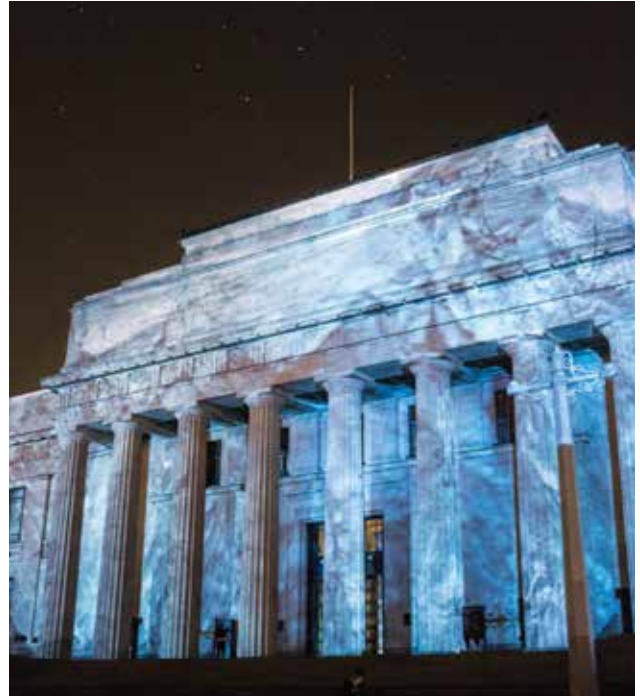
Photo by Aaron Smale

And here's a glimpse into just some of the public activities we've been a part of to date.

ANTARCTICA: WHILE YOU WERE SLEEPING

We helped bring “ANTARCTICA – while you were sleeping” to the 2017 Auckland Arts Festival. In the show, Auckland Museum became the canvas for a 360-degree projection of a majestic Antarctic iceberg. Artist Joseph Michael collaborated with composer Rhian Sheehan to create an immersive installation, translating the awesome scale and sounds of Antarctica.

New Zealanders had the chance to meet one of Antarctica's icebergs, and in doing so, to learn more about processes occurring around the ice, ocean and clouds that are critical to our climate. Visitors could listen to the ice crack, drip, creak and groan as colossal sections of the ice carved off.



GABBY O'CONNOR: STUDIO ANTARCTICA

We supported artist and community educator Gabby O'Connor to mount an installation at Porirua's Pātaka Gallery. Studio Antarctica, which also involved a community event and panel discussion, is the result of a creative collaboration between contemporary fine art and cutting-edge scientific research.

In 2015, O'Connor spent several weeks in Antarctica working in a shipping container laboratory on four-metre-thick sea ice, over McMurdo Sound. While making and researching her art, O'Connor helped the scientific research team K131 document the ice platelet structures found in these sub-zero oceans.



JAMIE'S WORLD ON ICE

In November 2016, our friends at Antarctica New Zealand took Kiwi YouTube and social media star Jamie Curry to Antarctica.

We supported the 20-year-old Jamie to make four YouTube episodes about her once-in-a-lifetime adventure. The series features Jamie and her interactions with some of the researchers studying atmospheric chemistry and ocean physics, and of course the local wildlife. She also talks candidly about discovering the reality of climate change and its significance for her generation.

Jamie Curry's social media footprint:



FOLLOWERS
10 million



EPISODE VIEWS
2.5 million



FOLLOWERS
357^K



SUBSCRIBERS
1.3 million



CLIMATHON NZ

We provided seed funding for the first two years of Wellington's Climathon in 2015 and 2016, and in 2017, we're proud to be supporting the national roll-out of Climathon, which will now be hosted in three New Zealand cities.

Climathon is a 24-hour fast-paced global event occurring simultaneously in over 200 cities around the world. Students, entrepreneurs, big thinkers, technical experts and app developers around the world come up with innovative solutions to city-specific climate challenges in 24-hour marathon sessions. At these events, the Deep South Challenge contributes expertise about the impacts and implications of climate change and fosters the development of projects that consider city-specific adaptation pathways.



FAR FROM FROZEN

This science showcase was held first at Otago Museum and more recently at Space Place, Wellington's Carter Observatory.

These exhibitions created the chance to explore Antarctica and learn about the local and national impact of climate change through state-of-the-art immersive media, hands-on interactives, a planetarium show, TEDxScottBase talks, film screenings, panel discussions, a live magic and science show, and more.



NEW ZEALAND GEOGRAPHIC

New Zealand Geographic, together with the Deep South Challenge, have brought together a range of high-quality climate change journalism and collected it into the New Zealand Geographic Climate Hub.

From the New Zealand Earth System Model to rising sea levels, this is a great place to find a story worth reading about climate change and its impacts on Aotearoa New Zealand.

New Zealand Geographic Climate Hub

www.nzgeo.com/climate

AOTEAROA NZ SCIENCE JOURNALISM FUND

The Aotearoa New Zealand Science Journalism Fund is the first independent fund to support science journalism projects that tackle issues in the public interest that are too costly for mainstream media outlets to undertake alone.

The Deep South Challenge is providing support to encourage journalists to delve into stories about climate change impacts and implications for New Zealand.

The fund is open to all professional journalists working for mainstream media outlets (newspapers and magazines, TV, radio and news websites) as well as freelancers who collaborate with mainstream news outlets.

Aotearoa NZ Science Journalism Fund

www.sciencejournalismfund.nz

"If there was any development, [we] should actually determine that..."

That's how I feel and I promote that... I think that would be a priority for me, having control.

We know where all our pūnua are. We know where all our water supply is... If we can control our own destiny in terms of how slow we move or how fast we move, we're okay."

KEEP IN TOUCH

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YOUTUBE
Deep South National
Science Challenge

APPLY FOR FUNDING

Got a project that will help your community think about how we might adapt to our changing climate? Apply for funding by completing our Expression of Interest form: www.deepsouthchallenge.co.nz/programmes/engagement

