National SCIENCE Challenges

THE DEEP SOUTH

Te Kōmata o Te Tonga

Future Strategy for the

Deep South National Science Challenge

Phase 2 (2019-2024)

Contents

1 Executive Summary

The Deep South National Science Challenge is four years into a 10-year research programme, with the primary aim to improve understanding of New Zealand's changing climate to support timely decision making for adaptation. Two-way engagement in our first phase has confirmed that we should continue our research focus on five key Climate Impacts: climate extremes, floods, droughts, changes in typical temperature and rainfall, and sea-level rise.

Our improved projections of New Zealand's changing climate will come from the seamless interlinking of the New Zealand Earth System Model (a global climate model); the New Zealand Regional Climate Model; the New Zealand Water Model (a national-scale hydrological model); and Riskscape (a risk and impacts model). In parallel, the ensemble climate model Weather@Home will provide information on extremes.

These projections will underpin focussed research on how key Climate Impacts will likely play out across four broad Domains to support New Zealand adaptations to climate change. These Domains are:

- Māori (whānau, hapū, iwi and Māori business) — Māori-led research will draw from mātauranga Māori, kaupapa Māori research methodology, and climate modelling, to understand climate risks and appropriate adaptation strategies;
- Communities: in this Domain, we aim to identify those sectors of our society and economy (e.g. primary industry, geographic communities and local governments) that are most exposed and susceptible to harm from direct climate impacts and understand the patterns of impact upon them.
- Infrastructure — we will work alongside New Zealand's water, transport and energy sectors, to integrate technical knowledge with scientific understanding of climate impacts; and
- National Economy — we will build on our understanding of macroeconomic risks to New Zealand from climate change, with a focus on extreme events.

We will continue to strengthen engagement pathways with end-users and decision makers to ensure our research is useful, useable and used. Researchers, supported by engagement professionals, will participate in the two-way exchange that is at the heart of our already successful engagement strategy.

The five key Climate Impacts will be assessed collectively within each Domain, rather than in isolation. Lessons from cross-programme engagement and Vision Mātauranga research will continue to be shared internally and with end-users across all Domains. This integrated systems approach will contribute to a step change in the production of accessible, up-to-date and integrated climate impact information, analysis of the implications of climate change, and support for New Zealanders facing decisions required to adapt to climate change.

2 Long-term View

Climate change is a significant issue for New Zealand, more so given that most of New Zealand's population resides near the coast and our economy is dependent upon primary industry exports. Government policy and climate change related initiatives are evolving rapidly, creating a dynamic landscape with a range of emerging opportunities. The Zero Carbon Bill has been opened for consultation on how New Zealand will make its contribution to mitigating climate change; and how it "ensures the country has a plan for how we adapt to the effects of climate change"[1]. A Climate Commission is to be established, which is expected to: undertake a national climate change risk assessment, develop a national adaptation plan, undertake regular review of progress, and have adaptation reporting power. The recent report by the Government's Climate Change Adaptation Technical Working Group (CCATWG) concluded New Zealand is in the early stages of planning for adaptation to the impacts of climate change, and has identified three characteristics that need to be in place for effective adaptation: being informed, being organised, and taking dynamic action.

The Deep South National Science Challenge is strategically positioned to provide underpinning research that can contribute to the CCATWG framework, to the proposed national climate change risk assessment, and address needs identified through the Challenge's own two-way engagement.

By 2024 the Challenge expects to have enabled New Zealand to better adapt to climate change, manage its associated risks and identify opportunities for New Zealanders to thrive, by:

- Enhancing capability to make projections of future climate and its impacts relevant to New Zealand, through interconnecting models across a range of scales and greenhouse gas emission scenarios;
- Increasing decision makers' understanding of future climate impacts on, and their implications for, New Zealand;
- Enhancing the capacity of iwi, hapū, whanau and Māori business to adapt to future climate;
- Collaborating across communities, Māori, infrastructure and key economic sectors of the New Zealand Economy to support the assessment of New Zealand's climate adaptation needs and opportunities; and
- Increasing capability and capacity for climate change research to support decision making.

The Challenge also will aim to eliminate knowledge gaps identified by the CCATWG. Specifically, the Challenge will build on its research to address: how the hydrological cycle in New Zealand may respond to changes in climate, and contribute to understanding how land and water uses may be impacted, and analyse the costs of inaction over the medium and long term.

Effective adaptation to climate change will continue to be dependent on access to the best available knowledge on our future climate. The Challenge is connecting together global and regional climate models to drive impact and risk models for climate change in New Zealand. This model infrastructure will underpin our understanding of New Zealand's future climate and support decision making during the life of the Challenge and beyond. This is more than "business as usual" research for New Zealand and will help create a research legacy that blends and integrates insights from cutting edge climate modelling with mātauranga Māori and an assessment of New Zealand's climate impacts. New Zealand will need this capability not just for the next five years, but for decades to come.

[1]Hon James Shaw, Zero Carbon Bill Consultation Launch, 7 June 2018. www.beehive.govt.nz/speech/zero-carbon-bill-consultation-launch

3 Five-year Strategy

3.1 Overview

The mission of the Deep South National Science Challenge is to *enable New Zealanders to anticipate, adapt, manage risk, and thrive in a changing climate* and requires the development of better understanding of New Zealand's future climate, and the methods, tools and values that will allow New Zealanders to respond to the challenges and opportunities that climate change presents.

Achieving this mission requires continued attention to our Challenge objective of *understanding the role of the Antarctic and Southern Ocean in determining our climate and future environment*. The Challenge recognises that the complex impacts of global warming on Antarctica and the Southern Ocean are important to our long term understanding of how climate change will impact upon New Zealand's climate. Examples are, the recent increased variability in sea ice around Antarctica that will affect the location of the storm tracks over New Zealand, and the potential for increased rates of sea-level rise from faster ocean-driven melting of Antarctica's ice sheets. Our approach of understanding all drivers of New Zealand climate through global climate modelling ensures the influence of Antarctica and the Southern Ocean is incorporated into our understanding of New Zealand's future climate.

We have undertaken a consultative planning process in developing this strategy for Phase 2, including a comprehensive exercise to map climate change research needs to inform adaptation in New Zealand (Section 3.8). We have been explicit in responding to the findings of our work in Phase 1. In particular, we are building on the outcomes of our extensive engagement that has informed us about end-user needs and allowed us to target our research to maximise its impact. In addition, we will address some of the recent findings of the Government's Climate Change Adaptation Technical Working Group (CCATWG). The CCATWG identified the need to both reduce the risks from climate change impacts, and improve the capacity of our social, cultural, environmental, physical and economic systems to adapt. Our strategy seeks to clarify the nature of the climate change risks faced in New Zealand and thereby provide a solid foundation for focusing the national adaptation effort.

By the end of Phase 1 (2014-2019) the Challenge expects to have a fully operational New Zealand Earth System Model (NZESM) able to provide ongoing New Zealand-specific climate projection capability. Projections from the NZESM will be used to underpin our understanding of global changes and the impacts of these changes on New Zealand. We have built a Vision Mātauranga Programme led by Māori researchers and driven by Māori priorities that continues to build on existing New Zealand-specific climate adaptation understanding and capacity. We have developed tailored research underpinned by the concept of co-development with end-users in our Dialogues. New Zealand now has a single research programme to provide physical climate projections and contribute to the delivery of local-scale impacts information tailored to adaptation needs, underpinned by deep and effective two-way engagement.

In Phase 2 (2019-2024) we will both build on what has been achieved in the first five years and hone our focus to achieve maximum impact within our dynamic landscape. We have refined the focus of all aspects of the Challenge to better address the needs of key sectors, based on our new climate projection capability and our increased understanding of end-user and Māori needs. Our research will focus on climate impacts occurring over decades to centuries, for which adaptation responses require decisions in the near or short term. Specifically, we will provide projections of future climate impacts for New Zealand sectors most effected by changing climate. We will collaborate with affected end-users to support their evaluation of options to adapt under the expectation that this will help optimise outcomes for New Zealand. This is consistent with the Challenge's Research and Business Plan (2014), where we stated as part of our original mission that "working with our communities and industry, we

will guide planning and policy to enhance resilience and exploit opportunities associated with those climate drivers that uniquely impact Aotearoa/New Zealand".

Success for the Challenge will be providing a step change in the ability of Māori and end-users from local and central government, the primary sector and industry to access regularly updated information from the five Climate Impacts integrated together, so they can understand their evolving climate change risk and use our research to support their decision making.

Our engagement in Phase 1 has confirmed the relevance of our original focus on hydro-meteorological impacts of climate change and identified flooding as a priority impact. Hence, we will now focus on, floods, droughts, changes in temperature and rainfall, sea-level rise, and other climate extremes. Information on these will come from the physical research that underpins our climate projection capability.

We have categorised as "Domains" broad groupings of end-users with common interests, where Challenge research can support better decisions that manage or mitigate risk, or improve the capacity to adapt. These all have high priority for New Zealand due to their national social or economic significance, and are: Māori, Communities, National Economy, and Infrastructure. The information we provide for each Domain will reflect the needs of end-users and their knowledge of their potential exposure to the key Climate Impacts. The key Climate Impacts will affect all Domains, but the combined effects of these impacts and how they are best addressed will be different in each Domain.

Engagement will be critical to ensuring the information we deliver to support adaptation within Domains is effective, by understanding the climate risks faced by end-users, their values and concerns, and how our research supports increasing resilience. We will take an integrated systems approach to understand the net impact of climate change. This will be facilitated by multidisciplinary research teams and tailored engagement to ensure our research delivers the information most relevant to each Domain.

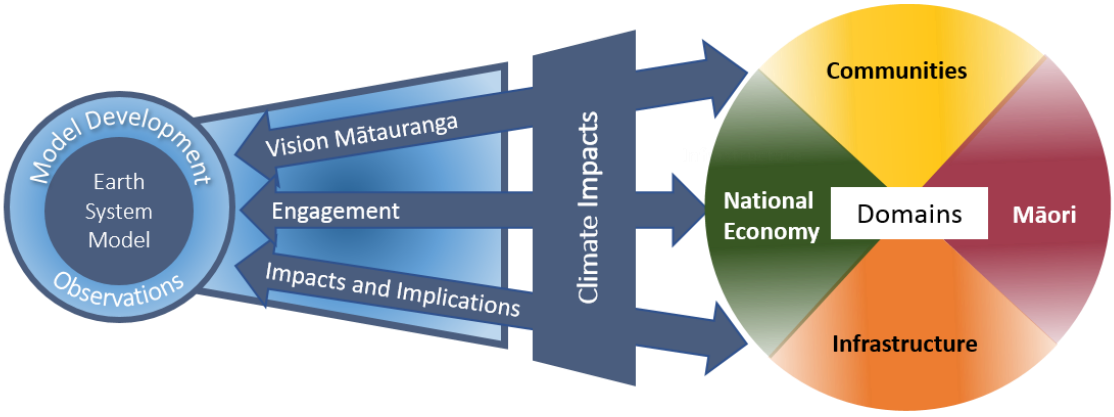

Figure 1: Structure of the Challenge showing the Climate Impacts and Domains, the key research areas for the Challenge.

We have modified the structure of the Challenge to provide better focus on the Climate Impacts for which adaptation is required. This new structure also recognises that the integrated effects of these impacts, and that how they may be addressed will be different in each Domain. We will retain our five existing programmes (as described in the Challenge Research and Business plan 2014). These are: Processes and Observations (P&O), Earth System Modelling and Prediction (ESMP), Impacts and Implications (I&I), Vision Mātauranga (VM), and Engagement. The interactions between the Climate Impacts, Domains and our Programmes are summarised in Figure 1. Working from the left, we will

generate climate projections and improve our modelling capability in the physical research where our P&O and ESMP Programmes are centred. This information will be delivered to the Domains as Climate Impacts by the VM, I&I and Engagement Programmes. However, there will be two-way connection between the physical research and the Domains to ensure information on the Climate Impacts evolves as we increase our understanding of end-user needs. Our research plan also addresses the themes and their associated outcome statements as set out in the eligibility criteria for the Challenge. Namely, we will make "*Predictions/projections of change*", seek to understand "*Processes, uncertainties and tipping points, including detection and attribution*" which will allow us to understand the "*Consequences of change: adaptable, responsive and resilient New Zealand*".

A key end-user for the Challenge will be the Climate Commission once it is established, as it will have a major influence on Government policy for climate adaptation in New Zealand. It is also anticipated it may have a role in encouraging funding for climate adaptation which would expand on the Challenges research findings on Climate Impacts.

We provide more detail regarding our research in the areas of Climate Impacts (Section 3.2) and Domains (Section 3.3), and how we will engage with Challenge end-users in Section 3.4.

3.2 Provision of Information on Key Climate Impacts

The Challenge will deliver accessible information on risks relating to New Zealand's emerging and future climate for five key Climate Impacts, as well as an improved understanding of their implications for the Domains, by building on our research in Phase 1. We will continue to develop our predictive modelling capability across a range of temporal and spatial scales and across all components of the climate system to support projections over a plausible range of future greenhouse gas emission scenarios. This will represent both the processes that are critical determinants of the physical climate system, and those parts of the system that impact upon people. The Challenge seeks to strike a balance between providing information that end-users seek now, and research to improve the quality of information provided in the future.

This information will be created using an integrated suite of New Zealand climate modelling capabilities which the Challenge has brought together (Figure 2). This forms our "model chain" and links across multiple temporal and spatial scales. This is an evolution of the initial model chain which has been developed during Phase 1. Fundamental to this capability is the NZESM, which is based on the UK Earth System Model from the UK MetOffice and has been developed by a range of international partners. The strength of the NZESM for New Zealand and the Challenge is that it allows us to focus on climate processes that are known to be both inadequately represented in most or all climate models and expected to be particularly important for New Zealand.

Research in Phase 1 included heat uptake in the Southern Ocean, effects of sea ice, and the effects of aerosols on cloud formation. Development will continue in Phase 2, with research focusing on improving the accuracy and usefulness of information about the five key Climate Impacts. This will mean both using and investing in research and development to improve the NZESM and other models in the model chain. Enhancements to our predictive capability will be supported by improved observations and understanding of key processes, leading to better information on climate impacts in New Zealand. Confidence in our enhanced predictive capability will be supported by improved observations of key processes most relevant to New Zealand, as part of a cycle which feeds back and supports model evolution and improvements.

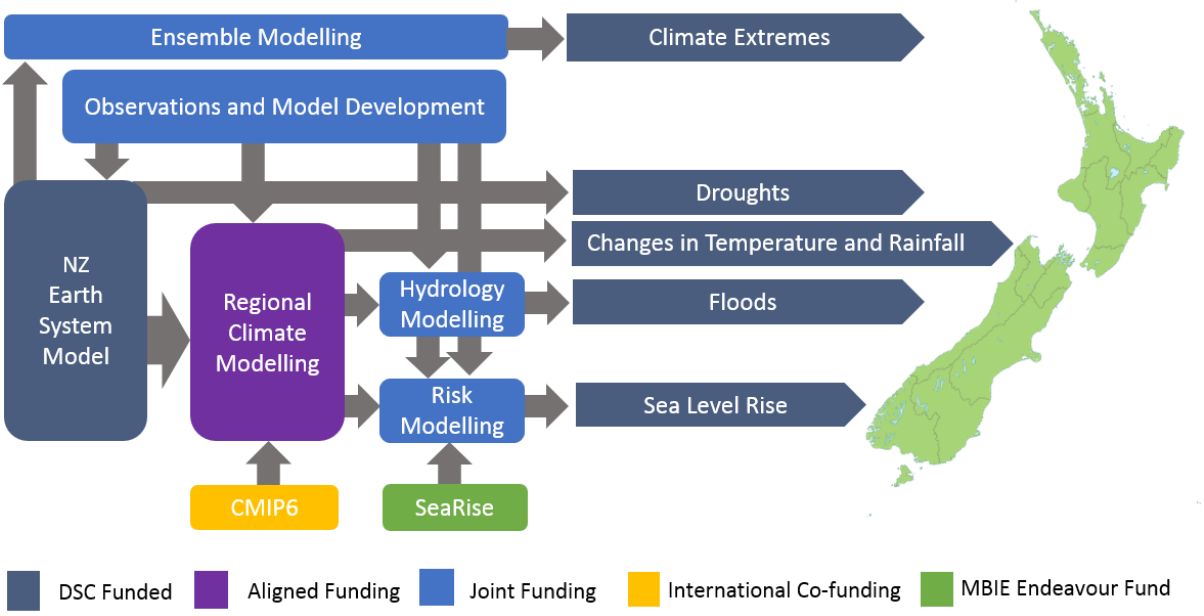

Figure 2: Interconnectivity of Climate Modelling and associated research forming the "model chain" central to the Challenge.

The NZESM will run under selected atmospheric greenhouse gas emission scenarios to provide a range of projections targeted at New Zealand. An example of how the NZESM could be used is to increase ocean model resolution around New Zealand to provide high resolution sea surface temperature to drive downscaling into the New Zealand Regional Climate Model (NZRCM).

The NZESM will provide information directly on regional and national scale *drought* occurrence and persistence. It also will provide outputs to drive other modelling processes, ensuring a consistency across projections. The NZRCM will be used to downscale NZESM outputs to provide higher spatial resolution over New Zealand. The NIWA developed NZRCM is a limited-area implementation of the Unified Model, which has been set up over New Zealand and the Tasman Sea. It will provide information about *changes in temperature and rainfall* and critical input data for the hydrology modelling. The suite of NZRCM projections will be expanded by downscaling outputs from the *Intergovernmental Panel on Climate Change (IPCC) Climate Model Intercomparison Project 6 (CMIP6)* once these become available. The intercomparison with CMIP6 model runs will allow the sensitivity of projections to climate processes that have been incorporated into the NZESM to be tested, and the sensitivity of the New Zealand climate to be understood. The spread of projections from the CMIP6 models will also improve confidence of projections of New Zealand's future climate. This will help give more certainty around the distribution of future change that can be incorporated into end-user adaptation planning and decision making.

Hydrology modelling will provide understanding of climate impacts on water availability in New Zealand, and will provide information about *floods*. This will be supported by the NIWA developed *New Zealand Water Model*. The Water Model is a hydrological model capable of simulating the flow of water through 68,000 river catchments simultaneously across New Zealand and is critical to understanding changes in water resources and flooding under future climates.

Risk modelling, using Riskscape, a software tool developed jointly by GNS Science and NIWA, will help us understand the impacts of *sea-level rise* and flooding on infrastructure. Sea-level rise projections will

be provided by the MBIE Endeavour funded "SeaRise" Programme led by Victoria University of Wellington.

We will gain an understanding of changes in *climate extremes* by running thousands of climate model simulations through the UK-based Weather@Home initiative. A large number of simulations are necessary to derive the needed statistics to understand changes in very rare (extreme) events. The Challenge has played a key role in supporting the development of the technology to achieve this through its collaboration with the UK-based Weather@Home initiative during Phase 1. In Phase 2 we will build on this success by producing projections that are tied closely to those of the NZESM.

Figure 2 also highlights the relationships between the Challenge and other truly aligned funding sources for its climate modelling and associated physical science research. The Challenge would be unable to achieve its objectives without the strong alignment and support of those resources from its participating partners. The Challenge is the primary funder of the NZESM, but most of the other underpinning modelling and observations research is funded jointly with Challenge parties, either through co-funding or complementary resourcing of activities such as climate observations. The NZRCM is completely supported by NIWA through its Climate and Weather Hazards Platform.

Improving New Zealand's modelling climate capability

The first step in providing improved climate projections for decision makers is the production of improved model projections that reduce the uncertainty associated with key model outputs. This model development effort relies on using observations and improved physical understanding, to identify current model deficiencies and ways that key processes can be simulated more accurately.

Research effort in Phase 1 was targeted at better understanding climate processes south of New Zealand that were identified in the Fifth Assessment report of the IPCC as needing research and where New Zealand expertise could improve these processes in the NZESM. We will remove the geographical restriction of our observational campaigns in Phase 2 to target observations that will improve the accuracy and usefulness of the data we provide on the five key Climate Impacts (see Section 4.4 for a description of how we will prioritise research). Observations also will provide benchmarks for model performance, identify opportunities for improvement, and be the basis for making bias-corrections to ensure future projections are fit for purpose.

Efforts to improve the modelling capabilities that are specific to a Climate Impact are described in the relevant section below. Here we indicate how we will change our model development emphasis in ways that are likely to improve projections across multiple climate impacts.

We built core model development capacity for the NZESM during Phase 1 in the areas of aerosols and cloud physics, sea ice, and ocean dynamics, and paired these with observational campaigns to produce improved observational bench marks and model representations of key physical processes. We do not anticipate extensive observational programmes in the Southern Ocean, Antarctica or the overlying atmosphere in Phase 2, but we will continue to improve the NZESM by analysing data collected during Phase 1 and from other New Zealand and international research initiatives (e.g., Argo profiling floats). A particularly valuable source of data will be the new generation of satellite remote sensing capability focussed on the hydrological cycle. The main emphasis of our process studies, however, will move towards data analysis and away from data collection, leading to a new focus on data science. Examples of where data science and analysis can bring additionality are: updating the wave breakup parameterisations for sea ice; identification of the key processes controlling cloud formation over the Southern Ocean; and assessment of wind driven ocean mixing around New Zealand. We will seek to collaborate with the Antarctic Science Platform (see Section 3.7), where appropriate, once their

research strategy is established. We also will take advantage of international collaborative opportunities for observational efforts where it is clear knowledge gaps exist.

Regional climate modelling is a key step in connecting the global scale NZESM outputs to New Zealand scales through dynamic downscaling. Capitalising on the common lineage of the NZESM and NZRCM, we will transfer into the NZRCM improvements in key processes as they are made in the NZESM. We confirmed in Phase 1 that for much of the Southern Hemisphere, atmospheric aerosols levels differ radically from those typical of the Northern Hemisphere. We will examine how the NZESM and NZRCM will form a better representation of the linkages between aerosols, cloud formation, and precipitation, by accounting for the very low-aerosol conditions typical in New Zealand. Any progress in the representation of precipitation in the NZRCM will have flow-on benefits for the hydrological and inundation models that depend on it (e.g., RiskScape). We also will consider supporting new observations in the New Zealand region that could improve processes in any of our models. An example could be the drivers of marine heat waves in the Tasman Sea as occurred in the summer of 2017/18, as these have the potential to drive weather extremes over New Zealand.

Climate Impact 1: Climate extremes

Weather and climate extremes, including rainfall, wind, storms, drought, and extreme temperatures, impact every aspect of our society. There is strong evidence that the frequency and severity of weather and climate extremes are changing. Decision makers and end-users increasingly are highlighting the need for reliable projections of changes in both the magnitude and frequency of extreme weather events over multiple time-scales. We aim to understand better the return period and severity of floods, droughts, heat waves, and other climate extremes and the consequences of these for New Zealand Communities and the National Economy. Initially we will prioritise temperature extremes as these projections are more certain in current models. We will make progress towards addressing end-user demand for strong wind and extreme rainfall projections. This will be a stretch goal for our research as representing these in current climate models remains a key challenge.

It is very difficult to represent extreme events in climate models because they are, by definition, rare. This means large ensembles are needed to provide relevant statistics. Ensembles are groups of model runs starting at different states whose outputs collectively reflect the spread of credible scenarios for future climate. These are prohibitively expensive to produce using the most complex models, including the NZESM. Instead we will take a complementary approach and continue to work with the Weather@Home initiative. This initiative uses a simpler atmosphere only climate model over New Zealand that is small enough to fit onto a regular PC, and then harvests the power of donor computers to run many ensemble members.

We will continue our Weather@Home collaboration from Phase 1 to undertake simulations with an improved version of the model that will be connected with the future climates projections from the NZESM. This approach will provide data on extremes that are more consistent with the NZESM.

In addition, we will undertake new research to improve our understanding of the processes that underlie extreme events via simulations and targeted analysis studies. Historical observations will be used to provide the reference information on extremes studies and to apply bias correction where appropriate. Techniques from data science will be applied to existing climate datasets to provide best estimate climatologies of temperature, wind and precipitation, to support extreme event modelling. The first effort in this respect will be an examination of whether existing observations and climatologies are sufficient to underpin the assessment of extremes. We also will examine the relative roles of large-

scale, regional and local-scale processes in the formation of extremes in existing datasets to guide model development efforts.

Climate Impact 2: Changes in typical temperature and rainfall

The response of the earth system to increasing atmospheric concentrations of greenhouse gases is leading to changes in climate that impact the temperature and rainfall patterns we consider typical. These changes manifest as trends in the frequency, timing, and persistence of weather patterns and are driven largely by the location of storm tracks and weather systems passing over New Zealand. These changes affect all New Zealanders and all sectors. For example, changes in rainfall affect water availability for the primary industry sector, urban water supplies, stormwater infrastructure, and hydroelectricty inflows. Changes in temperature are important for agriculture, both directly, for example, affecting the viability and quality of kiwifruit and through their indirect effects on runoff and evapotranspiration rates.

Projections of change to typical temperature and rainfall will be identified from NZESM and NZRCM outputs. We will characterise "typical weather" using the Kidson-type weather classification for end-users seeking wider analysis. This widely used New Zealand classification scheme is based on 12 characteristic weather patterns, against which actual or simulated weather is compared, e.g. blocking weather patterns. It provides a framework for describing large scale changes in atmospheric circulation. This approach will be complemented with other diagnoses that examine the depth of low pressure systems, and precipitation intensity and its distribution. The use of cyclone tracking schemes to understand changes in the occurrence of low pressure systems in NZESM projections relative to current values from reanalyses also will be an important diagnostic.

Climate Impact 3: Droughts

Droughts can have significant economic, environmental, and social impact upon New Zealand. From our endeavours to date, including our Drought Dialogue, we know these are varied and felt widely across our society, for example, through reductions in productivity in the primary industry sector, or reduction in hydroelectricity generation capacity. The integrated effect of droughts has a concurrent and cumulative impact on the economy, and understanding the information needs at temporal and spatial scales relevant to end-users is key to us providing information useful for planning.

We will address these needs by improving the modelling of processes that drive droughts in New Zealand. They tend to be relatively large-scale events often triggered by stationary blocking high-pressure systems that remain over the country for extended periods. Such events often coincide with an unusually southerly position for the storm track over New Zealand. The key ingredients of such events need to be represented at the top of our model chain in the NZESM, but there is some uncertainty as to why climate models struggle to maintain these events for the time needed to create a drought. Generating useful drought information may require higher-resolution modelling than we can do presently, so we will complement our own NZESM simulations with data produced by the *IPCC's CMIP6 High Resolution Model Intercomparison Project (HighResMIP),* available in late 2018, to provide a multi-model analysis within which to interpret our own model outputs. This, coupled with a "bias-correction" of drought frequency against observational values, will give us an indication of how droughts are anticipated to change under future scenarios and how they are depicted in different climate models. We will also provide statistical analyses of the processes that lead to droughts and develop ways to characterise the likelihood and nature (duration, intensity, area, etc.) of droughts based on changes in these processes.

Observational efforts will focus on quantifying the skill of the model circulation, notably the storm track and the frequency and magnitude of high pressure situations. This builds upon Challenge research from Phase 1 that focussed on connecting droughts to anomalous synoptic situations.

We will compare new results with previous work supported by the Ministry for Primary Industry's (MPI) Sustainable Land Management Adaptation and Climate Change (SLMACC) programme on projected changes to drought frequency and engage with MPI and the primary sector community, as well as other affected sectors, to evaluate that information.

Climate Impact 4: Floods

Floods are a significant concern in both urban and rural areas. The nature of flood events differs across areas, with urban floods typically triggered by short, very intensive events and rural floods by longer, larger-scale precipitation. We will build on previous Challenge research and respond to the needs of our hydrologists, risk experts, and engineers who require improved projections of precipitation and flooding. We seek to address concerns associated with impacts on land use (including development and urbanisation, and upstream flood control), water availability (e.g., for irrigation or hydro-electricity generation), as well as beginning to support identification of socioeconomic implications.

We propose to produce flooding information from the model chain already outlined (Figure 2). In parallel, we propose to benchmark the model chain against observations (which also are required for bias-correcting the model projections) and to assess opportunities for model improvement. Precipitation errors partly arise from problems in the representation of large-scale circulation in climate models, so we propose to assess model improvements that enhance the representation of key meteorological features in the NZESM, notably cyclones, fronts, and most importantly, the Southern Hemisphere storm track.

We will examine historical data linked to specific events, such as the 2017 Edgecumbe Flood, to aid in model development and bias correction associated with flooding. This effort also will also be of value directly by developing connections between physical parameters and socioeconomic data. A portfolio of historical case studies of flood events, with a focus on potential analogues for future change, could inform communities in a meaningful way about the economic scale of impacts upon their communities.

Climate Impact 5: Sea-level rise

Sea-level rise is a significant issue for all coastal nations, and New Zealand is no exception with our large population centres and key infrastructure close to the sea. Sea-level rise primarily is driven by the global impacts of ocean warming, changes in ocean circulation, and melting of land-based ice in glaciers and ice sheets. There also are local contributions from long term land movements, changes in gravitational fields due to the shift of mass from ice sheets to oceans, and effects of local bathymetry on sea-level extremes. Each driver needs to be studied individually, but the contributors to sea-level rise can be combined and considered effectively as a single process for the purposes of analysing effects on our coasts and communities.

End-users and Māori concerns around sea-level rise focus on coastal inundation and its consequences for coastal infrastructure, erosion of asset values, and the implications for coastal communities. There also is concern around how sea-level rise will compound and increase flood risk in coastal regions. We will incorporate up to date sea-level rise projections into our RiskScape modelling in parallel with river flow and flooding information from our hydrology modelling to understand the combined effects of these processes.

The Challenge is working closely with the SeaRise Programme, whose objective is to provide improved sea-level rise projections for New Zealand to better anticipate and manage impacts. We will contribute NZESM output to the SeaRise Programme, which will allow them to understand how the oceans around New Zealand are warming and if ocean circulation is changing. We also will contribute atmospheric and ocean projections to drive their ice sheet modelling of Antarctica. The SeaRise Programme in return will provide us with updated New Zealand-specific sea-level rise projections that integrate all significant drivers of sea-level rise. We will also continue to build on Phase 1, to understand how sea-level rise will affect New Zealand, particularly within our Domains.

3.3 Domains Work Programme

Effective climate adaptation will reduce the exposure and improve the resilience of our economy, built environment, and social and cultural systems to the impacts of climate change. Providing accessible information on future climate risks is vital to assist decision-makers to focus on areas where there is likely to be the greatest human impact. Our intention is to provide an integrated systems approach that allows the effects of the five key Climate Impacts to be assessed collectively within each Domain, rather than considering each Climate Impact in isolation. Work under the Domains will help steer the research direction and form of the outputs from the Climate Impacts.

We will use our Climate Impact information to build directly on the needs prioritised by our end-users in Phase 1 of the Challenge.

- In the *Māori Domain*, we will work with Māori, including hapū, iwi and Māori business, to understand those climate risks that Māori share with all New Zealanders, and those to which Māori are uniquely exposed. This Domain will also support linkages between mātauranga and our climate modelling.
- In the *Communities Domain*, we aim to identify those sectors of our society and economy (e.g., primary industry, geographic communities and local governments) which are most exposed and susceptible to harm from direct climate impacts and understand the patterns of impact upon them.
- In the *Infrastructure Domain*, we will undertake research into the climate impacts on New Zealand's energy, transport and water networks.
- In the *National Economy Domain*, we will partner with risk scholars, economists, and climate modellers to build on our understanding of macroeconomic risks to New Zealand from climate change, with a focus on extreme events.

Domain 1: Māori

The needs and aspirations of Māori remain central to the Challenge. We will consolidate our successful research in Phase 1, where eight projects which combined mātauranga Māori and climate science were supported, and build on our engagement surrounding this research. We will draw from findings across our projects to create a coherent body of knowledge that will support whānau, hapū, iwi and Māori business to make innovative, appropriate climate adaptation decisions. Further analysis of our research strengths and of gaps in our key messages will motivate future research.

Māori face the same climate challenges as the wider New Zealand population, in addition to their own unique challenges (e.g., responding to coastal inundation of communally-owned, intrinsically important places such as marae or urupā). It is important to work closely with Māori to ensure that science is provided in such a way that it can support communities to find appropriate solutions. Our research is structured so that it can be used by those with the mana to make climate adaptation decisions that have broad value for all New Zealanders. It will have two strands, one which uses mātauranga Māori to

facilitate adaptation and a second which emphasises collaboration for the benefit of the whole Challenge and wider New Zealand.

The Challenge has the wisdom and experience of the Kāhui Māori to drive its Māori-focused and Māori-led research. We will build on our success by focusing on three key principles.

- *Research dissemination and knowledge transfer to Māori communities* by making culturally appropriate tools that are accessible and can be implemented across Māori society. These tools will support Māori to exercise control while upholding whakapapa, the mana of the natural environment, and kaupapa Māori principles.
- *Stronger co-creation of knowledge and increased integration within the Challenge* through co-creation of Challenge research to allow an interdisciplinary approach. We will provide a pathway to transform data, analysis, and modelling into meaningful outcomes for Māori communities, and support research grounded in Tikanga Māori and Te Reo Māori to increase our understanding of New Zealand's climate.
- *Strengthen capacity and capability* of iwi, hapū, whānau and Māori business to deal with climate change impacts and risks and to identify appropriate adaptation pathways, in accordance with kaupapa Māori principles. This will deepen the knowledge-base of both communities and researchers. It also will promote the practical documentation of innovations in ways that reflect the lived realities of our Māori communities.

Domain 2: Communities

Our focus on communities recognises that it is all the people of New Zealand who will bear the impacts of climate change, in different ways and at multiple scales. In this Domain we aim to define better and understand those sectors of our society and economy most exposed, and their level of susceptibility, to direct climate impacts. This will enable decision makers to target adaptation efforts most effectively across communities, and allow end-users to choose and implement their own solutions, drawing on research from the Challenge and on best-practice approaches to adaptation.

Identifying who is most exposed and the reasons for that exposure will come from combining our Climate Impacts modelling with population and economic data, and data on physical assets on which people depend, such as infrastructure. Practically, this will involve the parallel mapping of, for example, population and population characteristics, economic activity (the location of firms, employment and production), and physical asset and property exposure to physical climate impacts. Examples of this approach are:

- For the Primary Industry Sector, building upon current and historical research on land suitability by extending it to focus on the effects of climate extremes on land suitability; and
- For local government, combining climate impact data with infrastructure asset mapping to understand total exposure across New Zealand, and the potential costs and mechanisms of adapting this infrastructure to future conditions.

Understanding susceptibility will then focus on the 'communities', whether geographic or sectoral, who are most exposed. Our existing research has begun to explore the susceptibility of those exposed to flooding and/or coastal inundation by, for example, considering their residual risks from existing protection mechanisms. Methods that aim to understand which groups are at risk from situations driven by or analogous to climate change impacts, and why groups are less able to respond, will include panel data analysis, longitudinal data analysis, and hedonic analysis.

All these studies will be upscaled to ensure national relevant issues are identified, allowing identification of exposure and vulnerability issues for the public as a whole. This is key to enabling New Zealand to adapt effectively to climate change, through a more accurate understanding of the risks to people, and people's activities. Work will build on Phase 1 research from the drought and flood-prone communities Dialogues, and research on public insurance. It will also build on previous MBIE funded Climate Change Impact and Implications (CCII) research (See Section 9). The overlap with our Māori Domain will enable sharing of the lessons around adaptation that we have learned from our Māori-led research, and ensure Māori are included when we look at communities as a whole.

Domain 3: Infrastructure

The risk to infrastructure from climate change is variable in time and space, and has been noted as a key concern by multiple end-users. Community expectations of utilities providers (e.g., water, energy, and transportation) are that they will minimise the impacts of every day and catastrophic events. Determining whether such service provision remains viable in the future will hinge on incorporating climate projections with better understanding of the nature of physical impacts on key infrastructure. Engineers, economists, operations researchers, network analysts, and other impact modellers will work with climate scientists, to assess future infrastructure performance using network and economic models not currently used to assess these issues. This research will involve an iterative series of projects, likely covering the following sectors.

- *Transport*: We will extend the Deep South Dialogue research focusing on climate impacts on land transportation networks and associated infrastructure. We will use this research to identify the Climate Impacts most important to transport, including where those impacts will occur and the scales of their effects.
- *Water*: Work on impacts to water systems will build on our Stormwater and Wastewater Dialogue, and the tailored research it initiated. This will focus on research and engagement to better link climate impact projections with the end-users making decisions on the infrastructure for the three-waters (water supply, storm water, and wastewater). To date little attention has been paid to how the dependencies among them could alter with climate change.
- *Electricity*: Researchers will use stochastic network theory to identify the most critical inter-dependencies and to quantify the potential economic cost when climate change places a stress on generation of resources and use. We will collaborate to look at challenges to network reliability, such as during extreme weather events. This will build on Phase 1 research on climate change effects on frozen water resources and the national water cycle and address concerns raised in our current Drought Dialogue.

Researchers could also explore the impact of cumulative effects on infrastructure from small to medium events, and the potential of these to create cascading effects.

Domain 4: National Economy

The aggregate level of climate change-related vulnerability of New Zealand's economy is highly uncertain. Recent research estimated that climate change-related floods and droughts have cost the New Zealand economy at least $840 million over the last 10 years, but future costs may be much higher. We are beginning to clarify the risks at specific locations and for specific groups, such as the primary sector, but we do not know yet whether these risks are nationally significant. The risk would need to be sufficient to have economic effects that: affect the government's long-term budgeting and risk management; dramatically alter New Zealand's terms of trade; create a threat to the stability of the financial system; or create previously unexperienced systemic threats to key infrastructure that will

require a nationally coordinated response. Alternatively, creeping impacts such as a reduction in primary production or impacts that overwhelm households' and local councils' abilities to adapt could aggregate to create a nationally significant challenge. Research in this Domain will enable New Zealand to better anticipate systemic risks to our economy.

Our extensive engagement and Dialogues suggest that climate extremes are likely to dominate risks to the economy. Research in this Domain will focus on critical areas of risk identified through our Dialogues and subsequent reports on insurance, storm water and waste water, transport, and drought. Future projects will extend and focus on major fiscal and financial risks, to understand better the implications of more extreme weather events for the New Zealand's economy.

3.4 Strategies for Engagement

Experience has shown it is not sufficient to merely produce projections of future climate and climate impacts, risk assessments or adaptation options, and anticipate they will be adopted. Deep engagement using mixed methods with end-users and Māori is required to ensure that Challenge research is useful, useable, and used. Māori and end-users need to see a natural point of connection with the Challenge, and see the Challenge is listening to and understanding their needs. This is needed to underpin a relationship of trust with the Challenge over time.

Challenge researchers need to understand what information will be most useful for end-users and Māori and in what form it needs to be provided to be used. Researchers supported by engagement professionals will deliver the two-way exchange that is at the heart of our engagement strategy (Figure 3). This strategy is dependent on more than the Engagement Programme and it will be implemented across the Challenge, for example, in the Domains where engaging to support end-users' decision making is crucial.

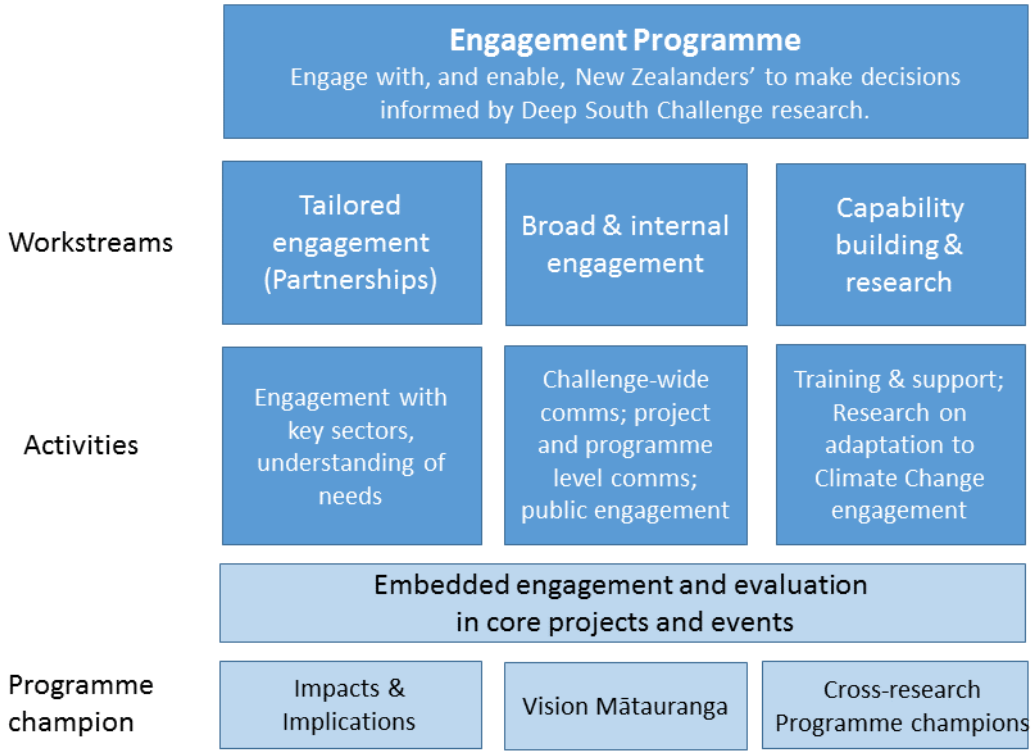

Figure 3: Proposed Engagement Programme structure. The dark blue indicates current workstreams; the light blue indicates proposed workstreams and engagement positions

Engagement will take place through two pathways: within the Challenge (including within research projects); and external to the Challenge. Building on our success in Phase 1 our engagement will be planned and highly integrated. In Phase 2 we will follow the best practice of the International Association of Public Participation (IAP2) to inform the design, methods and intended outcomes of our engagement practise. It is recognised that there is no one-size-fits all approach to engagement: the most appropriate method will depend on the context, the audience and how the information will be used.

The *Tailored Engagement workstream* will engage with key sectors to understand their needs. It will be central to building the partnerships necessary for implementing the work in the Domains. This workstream will ensure integration of end-user needs both internal and external to the Challenge.

The *Broad and Internal Communications workstream* ensures our researchers and end-user communities are well-informed about Challenge research and Challenge activities. We aim for them to understand the relationship of each project to the whole Challenge, and to take up opportunities to become involved with the Challenge. This workstream will enhance integration across the Challenge and present a clear and meaningful climate narrative that researchers and end-users can trust and easily engage with. This theme will work very closely with our Māori-led research to ensure it engages successfully across all of our Domains. Expected outputs from this workstream also include external communications, including through the Challenge website, social media, newsletters, and media releases on Challenge research.

The *Capability workstream* will provide training and support for targeted end-users and Māori to build their capacity to make good decisions on climate change adaptation. Our engagement capability will build upon international best practice for adaptation engagement. We also will contribute to this body of knowledge through the peer reviewed publication of Challenge engagement techniques. This will provide an avenue for show casing the evidence-based engagement the Challenge undertakes.

The Engagement strategy explicitly recognises the importance of having cross-research programme (National Science Challenges, MBIE Endeavour and Research Platforms) champions to: improve the connections in common research areas (e.g., coastal inundation research with *Resilience to Nature's Challenges* and *SeaRise*); ensure Challenge research is provided to other research programmes to inform their research when and where appropriate; gain efficiencies when engaging with specific communities; and to encourage funding leverage when and where appropriate. The expanded programme encourages engagement and evaluation to be embedded in all research across the Challenge.

There will be an increased need for engagement in Phase 2 due to an increased focus on the delivery of tools to support societal needs. Key roles to implement our engagement strategy are:

- A Partnership Director to coordinate the tailored engagement for climate change impacts and implications issues for the Challenge;
- A Communications Advisor to coordinate and prepare communication material to support engagement for the Challenge;
- An Internal Engagement Advisor to focus on internal Challenge engagement (e.g., quarterly researcher updates, presentations, researcher symposiums, researcher liaison); and
- A Māori Communications Specialist to assist in the production of communications products tailored for Māori communities.

Our engagement also will be supported by two external advisory groups:

- The Technical Advisory Committee for Engagement (TACE) will provide strategic input and technical oversight of the engagement programme, and will support the engagement team; and,
- A proposed Consultant Engagement Group (CEG) will focus on engaging with consultants. Consultants often are the knowledge brokers that are commissioned to undertake research and produce reports specific to their context, but typically are not directly engaged on relevant research. We will bridge this gap by forming a group of key national consultant representatives, with the aim of informing them of Challenge research outcomes, understanding their needs, and enabling them to use Challenge outcomes in their consultancies.

3.5 Strategic, Integrated, and Multidisciplinary Research

The Challenge portfolio of research, science, technology, and related activities is strategic, integrated and multidisciplinary.

The plan is *highly strategic*, with a mission that is broad, challenging, and will result in a step change for New Zealand. We have taken a strategic approach to identify where our effort is best spent for maximum contribution. This has resulted in two central strategic thrusts.

- Climate Impact Work Programme: We have refocused the Challenge to address five key Climate Impacts for New Zealand's future climate, but broadened our approach of enhancing New Zealand's climate modelling capability to understand these Climate Impacts. They were chosen because better information on these impacts will be key to improving resilience and adaptation to climate change. The research will focus on providing fit-for-purpose data on these impacts, and their implications, to end-users. We will continue research on the underlying processes and observations influential on all steps in our model chain to improve the quality of the data we generate.
- Domain Work Programme: We will focus on four Domains to understand how to use the information that will equip many New Zealanders to respond to the challenges and opportunities of a changing climate, and will customise our approach for each Domain. They were chosen based on the national economic or social significance of the scale of the adaptation decisions which are needed.

The plan is fully integrated, with its focus on the five key Climate Impacts and four Domains demanding that our research draws on expertise from each of our Programmes. We have a specific workstream to drive integration, recognising that it will be critical for success (see Section 3.7 for more details of our collaboration mechanisms). Understanding each of the Climate Impacts, and how they interact, requires a combination of physical science to project future changes, applied research to provide an understanding of potential impacts and their response options — to understand the implications of those impacts and engagement to ensure both the climate projections and the impacts meaningfully inform adaptation options for Māori and end-users. Research within the Domains will consider the integrated effect of the Climate Impacts and how Challenge research may be best used to increase resilience, realise opportunities, and address risk. There will be two-way flow of information between the Climate Impact and Domain work programmes to ensure that data from models will be useful, useable, and used.

The plan is inherently multidisciplinary to enable us to take physical information about climate, apply it to fundamental environmental and engineering processes, and work with people to understand how they need information to plan their adaptation options. The broad nature of this Challenge, with the underlying physical science and model development, and the need to work closely with end-users and

Māori across a wide variety of sectors, requires an equally broad range of expertise and collaboration (Section 3.7). We recognise this and have designed programmes and projects that are inherently multidisciplinary. For example, the Climate Impacts work programme will require expertise in atmospheric science, meteorology, statistical analysis, physical oceanography, scientific computing, and Mātauranga Māori. The Domains will add economists, risk modellers, planners, science communicators, hydrologists, geographers, engineers, and others to the mix of skills.

3.6 Relevance to Government Strategies

Two Government roadmaps relevant to climate change have been released since the Challenge begun, both of which identify climate change as a major stressor. The Conservation and Environment Science Roadmap articulates the research needs of the Ministry for the Environment and Department of Conservation, and calls for research on "*Projections of how, where, and when New Zealand's climate, including its extremes and variability, will change as a result of a range of plausible emission scenarios*", "*Adapting to and mitigating climate change including reducing its impacts and risks*", and "*Exploring use of scientific tools and approaches to support Māori functions and powers, duties and roles".* The Primary Sector Roadmap articulates the research needs of the Ministry for Primary Industries and calls for science to support "*A primary sector that is adaptive to a changing climate (including ocean acidification) and minimises greenhouse gas emissions*" and also highlights the importance of using mātauranga Māori within research relevant to Māori. The Challenge will continue to fund research that will help achieve these outcomes and will maintain a close working relationship with these agencies to ensure they are aware of our research, we understand their needs, and together we can deliver information aligned to those needs. In addition, the Challenge will support other government priorities, for example, those laid out in He kai kei aku ringa (the Māori Economic Development Strategy and Action Plan) and the Treasury Living Standards Framework, as well as broader initiatives, e.g., the UN Sustainable Development Goals.

The May 2018 Recommendations from the Climate Change Adaptation Technical Working Group (CCATWG) includes a number of principles, recommendations, and actions to support effective climate change adaptation, several relevant directly to the Challenge (Table 1).

Table 1: Climate Change Adaptation Technical Working Group recommendations directly relevant to Deep South, and Deep South responses over 2019–2024.

CCATWG	Deep South Contribution
Prioritise action to the most vulnerable communities and sectors.	Our priority sectors are Māori, Communities, National Economy, and Infrastructure.
Integrate climate change adaptation into decision making.	Our research informs the development of a national framework for assessing climate change risks and vulnerabilities.
Understand risks, vulnerabilities and opportunities.	Our research will provide the best available information about climate change impacts and implications from which risks, vulnerabilities, and opportunities can be identified.
Make decisions based on the best available evidence, including science, data, knowledge, and Mātauranga Māori.	Our research will contribute to enabling decision makers to make informed climate adaptation

	decisions based on state of the art models, data, knowledge, and Mātauranga Māori.
Commission Mātauranga Māori-led measures that reflect cultural impacts and climate change and are developed and managed by iwi/hāpu.	Our research in the Māori Domain and our Vision Mātauranga guided integration will be led by and work closely with Māori, to shape the delivery of culturally relevant information about climate change.
Build capability in adaptation across central government agencies and in key professional bodies and industry groups by developing and implementing training and development programmes.	We will continue to offer opportunities to build capability for adaptation within decision-making bodies through our Engagement programme, particularly through our targeted workshops.

3.7 Collaboration

Collaboration within the Challenge

In Phase 1, our 38 projects have been based on a "best teams" approach and involved collaborations that have included combinations across seven Universities, three Crown Research Institutes (CRI), consultancies, private organisations, Iwi Development Trusts, Communities, Māori and end-users. This has provided a robust basis for developing Phase 2 (see Section 3.8), including identifying strong multidisciplinary teams.

We have developed a number of mechanisms to facilitate effective collaboration including the *Challenge Symposia* and the *Deep South Challenge Virtual Seminar Series*. These have provided a mechanism for synergies around research effort to be realised. Our first symposium in 2017 provided significant opportunities for scientific interaction among our researchers, with Māori and end-users, and provided the opportunity to expand connections and collaborations within and beyond the Challenge. A range of mini symposia enabled in-depth discussion among researchers on areas that are central to the Challenge's success. We plan to follow a similar model for future symposia.

Our seminar series has been a major success, capturing audiences from across a range of Universities, CRIs, research organisations and end-users. We will continue to deliver these seminars in Phase 2 with some fine tuning to ensure that they better meet the needs of both researchers and end-users, and are able to facilitate stronger cross-disciplinary conversations.

Collaboration with other National Science Challenges

Collaborations will be strengthened with other National Science Challenges to build on shared research in Phase 1. Collaboration with some Challenges will be through the provision of climate change data for application by other Challenges. Examples include: *Sustainable Seas*, which considers climate change as one of many stresses within a multi-stressor environment; and *New Zealand's Biological Heritage*, where climate information needs are largely around biosecurity.

Water will be a key area for collaboration with *Our Land and Water* (OLW) and *Better Homes Towns and Cities* (BHTC). OLW is interested in water quality, in particular, how changing patterns of rainfall will impact on nutrient and sediment runoff from agricultural land, and water availability in the rural sector. We will build on the current joint OLW and Deep South Challenge project "*Land-use suitability: incorporating climate change impacts"*. BTHC is interested in urban water supply and urban drainage

issues. OLW's and BTHC's interests overlap strongly with our desire to understand precipitation change over New Zealand, our hydrological modelling, and our interest in climate change impacts on infrastructure.

Coastal inundation and high intensity weather will be key collaboration areas with *Resilience to Nature's Challenges* (RNC). Both RNC and the Deep South Challenge in Phase 1 resourced teams to research the impacts of coastal inundation, but from slightly different perspectives. We aim to fund research teams jointly in Phase 2 where initiatives overlap or can be integrated efficiently. We also will join our engagement efforts and further integrate this with the SeaRise Programme.

Interest from RNC in high intensity weather links with the broad interest in water from other Challenges, but also presents a challenge for our modelling efforts, as high intensity weather typically occurs on scales that are not well resolved in the NZESM or NZRCM. The global coverage of the NZESM and CMIP6 experiments such as HighResMIP, however, may provide scenarios to inform commentary around potential changes in risks associated with ex-tropical weather systems coming to New Zealand.

We also seek wider collaboration with other Challenges in relation to our Vision Mātauranga research. Ideally, we would like to see researchers that work across multiple projects and programmes better supported by initiatives that can contribute greater gains for Māori research, communities, and researchers. For example, we will support shared research hui with other Challenges to present and engage on Vision Mātauranga research from multiple Challenges which will facilitate more connections for the Challenge with Māori.

Collaboration with other New Zealand research

The Climate and Weather Hazards Platform, hosted by NIWA, is the largest climate programme in New Zealand, and spans a wide range of research, from the collection and analysis of climate observations to the assessment of impacts of climate on New Zealanders. Some of this research has been aligned to the Challenge and has actively supported Challenge research efforts. For example, it has seamlessly supported the Challenge's sea ice research. This interaction with the NIWA Platform is fundamental to establishing the legacy of the Challenge, as the Platform is expected to have a lifetime longer than the National Science Challenges and has a long term strategic interest in ensuring New Zealand climate science is useful and useable to end-users.

The two main, non-NSC research programmes we will collaborate with are: the SeaRise Programme, and the Antarctic Science Platform. The MBIE Endeavour funded SeaRise Research Programme focuses on the physical drivers (including global contributions) of sea-level rise around New Zealand. We also will collaborate on engaging about the impacts of sea-level rise with the SeaRise programme in conjunction with *Resilience to Natures Challenges.*

The Antarctic Science Platform is designed to provide stable funding for underpinning, longer-term Antarctic science that will provide essential for scientific and strategic benefits for New Zealand. The Challenge is looking to develop a collaboration with the Platform in the following research areas: sea ice, Southern Ocean processes, and high-latitude atmospheric processes. Research from the Platform will provide insights into processes that can inform the development of the NZESM. In return, we will partner with the Platform by providing climate model output to set the global context for the climate change research that the Platform will support.

The Sustainable Land Management and Climate Change (SLMACC) Research Programme is administered by the Ministry for Primary Industry. It is designed to help the agriculture and forestry sectors with the challenges arising from climate change. It includes both climate mitigation and

adaptation focused, basic, applied and policy research. In Phase 1, Challenge research, for example, on the hydrological cycle has been co-funded by SLMACC, and where feasible this is expected to continue.

International collaboration

All areas of the Challenge have deep international connections with world-leaders in relevant fields. These collaborations are both essential to the delivery of our research programme and provide a measure of quality control of our research, whilst also raising the international profile of Challenge researchers. The following are some examples.

- The IPCC 5th Assessment Report was used to inform research selection to ensure it was timely and internationally relevant. We expect research results from the Challenge to be used in the IPCC's sixth assessment report (AR6). We are pleased that five scientists from the Challenge have been selected to join AR6 authorship teams. This includes the Coordinating Lead Author for the Australasian Chapter. We also have one researcher who is an author on the IPCC Special Report on Cryosphere and Oceans.
- The Weather@Home activity, to produce large ensembles, is a key international collaboration with UK and Australian researchers.
- The UK Met Office and NIWA (the Challenge host) have a strong formal relationship, on which the Challenge depends. The Unified Model, a numerical model of the atmosphere developed by the UK Met Office, is at the heart of the NZESM and the NZRCM. NIWA is a licensed partner in the Unified Model Consortium, a growing group of national weather forecasting and research agencies from around the world that both use and develop the suite of climate modelling software that comprise the Unified Model. NIWA is permitted to sub-license access to the Unified Model to academic and other research institutions in New Zealand. The improvements we make to NZESM are expected to generate improvements to the Unified Model and be available to all Consortium members, including Challenge researchers.
- Observations in the Antarctic and Southern Ocean are dependent on strong international linkages. Our partnership with Antarctica New Zealand has supported connections with international efforts such as the US led SOCRATES Research Programme during Phase 1. These kinds of relationships will continue to be important to the Challenge and will underpin the analysis of data collected during the 2018 and 2019 *RV Tangaroa* voyages and corresponding instrumented aircraft flights. We have strong links to upcoming observational efforts led by NASA, associated with the IceSat2 satellite mission, focussed on sea ice and cloud studies. This and similar collaborations will ensure continued access to the best possible datasets for model improvements and ensure that Challenge researchers continue to be well connected internationally.
- The Challenge has collaborated with the Snowchange Cooperative, an indigenous organisation formed in 2000, to work with local indigenous cultures in the northern hemisphere. This extends the Challenge's network to understand how other indigenous people are adapting to climate change.
- Aroha Mead, a member of the Challenge's Kāhui Māori, has been an elected member of the IUCN where she has served as a Councillor with responsibility for Indigenous Issues. This international link brings a valuable perspective to the Challenge's Kāhui Māori that shapes the strategic direction of the Vision Mātauranga Programme.
- The I&I Programme is enhancing its links to international impact researchers such as the Climate Impact Lab at the University of Chicago.

3.8 Strategy Development

The Challenge has consulted with a wide range of partners, researchers, and end-users as part of the development of this strategy. There has been a total of 17 workshops and meetings between July 2017 and June 2018, during which the strategic direction for Phase 2 has been discussed and refined. The scope, foci, and participants of these types of consultation vary widely, but some of the highlights were:

- *Deep South Strategic Review Day* (July 2017) — Including representatives of the Challenge research organisations and key end-users (e.g., Ministry for the Environment, Ministry of Primary Industries, CCATWG, Victoria University of Wellington, GNS Science, Landcare and Treasury);
- *The Deep South Symposium* (September 2017) — included a series of mini-symposia focusing on key areas central to the Challenge's success, including predicting extremes, decision-making tools for managing uncertainty, data flows/downscaling methods, and improving projections using the NZESM;
- *Building Bridges - how does the Deep South Challenge meet your needs?* (September 2017) — Involved ~180 participants (including 110 researchers and 79 end-users for key sectors);
- *Researcher consultation* (February 2018) — Two facilitated workshops on the research programmes of the Challenge, with a total of 77 participants (internal and external to the Challenge);
- *NIWA Climate and Weather Hazards Platform* (March 2018) — Participated in end-user workshop to understand the breath and scope of New Zealand's largest climate research programme, to ensure the Challenge can effectively integrate with the Platform; and
- *Tailored engagement* (2016-2018) — Over one hundred, one-on-one engagements between the Challenge Partnerships Director and climate sensitive sectors, including primary industry, finance, infrastructure, local government, and central government;

The Challenge's ISP, Kāhui Maori, Representative User Group, and sector representatives have met at various stages and provided comment on the current status of the Challenge and the proposed future direction.

The governance group has played an important role in shaping the future scope of the Challenge. They have worked alongside the SLT, reviewing documentation, attending a full meeting with the SLT, clarifying scope, and providing input to ensure that the Challenge is able to deliver impact and additional benefit to its targeted sectors within the allocated resources and its original brief.

Responding to key messages

Several key themes have emerged from our consultation. These are to: improve integration, strengthen influence in decision-making processes, and enhance national capability development. The Challenge has created Domains for Phase 2 to address integration and proposes a continuation of the two-way engagement with end-users and Māori started in Phase 1. We will allocate resources specifically to ensure our integration initiatives will be effective, and will support specific engagement and integration positions. These include a Data Manager who will work closely with our Partnerships Director to ensure that our data are produced in relevant, accessible formats that are useable by decision-makers, and resources for internal integration to address the need to strengthen influence in decision making processes. Finally, we have considered how to use Challenge resources to develop existing and build new capability in New Zealand. This includes the development of climate impact champions, i.e., researchers who can act as knowledgeable points of contact on the research being done on each

Climate Impact. We also will leverage the strength of the New Zealand modelling community to support the range of models used in the Challenge effectively.

Other messages that we have heard through our consultation, and incorporated where feasible into our Future Strategy, include:

- The Challenge is heading in the right direction in terms of the physical science and modelling;
- The Deep South Dialogues that have been popular amongst end-users and researchers and should be continued;
- Two-way communication between programmes and with Māori and end-users needs to be increased;
- Continue engagement with Local Government, providing an adaptive process that can meet their timelines along with useful tools;
- Identify channels for messaging to Ministers;
- Strengthen coordination and links with other National Science Challenges;
- Target funding to increase cross-disciplinary research;
- Build capacity in social sciences and trans-boundary researchers, and provide opportunities for early career scientists to keep talent in New Zealand;
- Ensure access to Challenge data at a scale relevant for decision-makers;
- Create tools that allow us to scale research findings with limited resources;
- Provide training for researchers/communities/decision-makers to facilitate communication and engagement in adaptation conversations and activities; and
- Showcase Vision Mātauranga research nationally and internationally and share lessons learned among Challenge Programmes.

Mapping climate change adaptation research and needs

We have mapped the climate change adaptation landscape in New Zealand, as part of the strategic review process, to clarify sector needs and to identify what research is being done or has been done to address those needs. We focussed on five sectors (local government, central government, primary industry, urban water & infrastructure, and finance) chosen because they are exposed to elevated risk from one or more of the five key Climate Impacts and because they make or enable long term investments that may be affected by these Climate Impacts. The mapping of these sectors helped inform the selection and development of our Domains, as did the identification of the following research needs where the Challenge could add most value:

- Climate change implications for drinking water supply and quality;
- More detailed analysis of primary industry impacts and implications (including cumulative stressors, biosecurity, and climate related diseases);
- Research into the socioeconomic implications of flooding;
- Research into financial risks from climate change and integration of projections into financial forecasts, including the costs of inaction; and
- Additional work on adaptation strategies to manage and reduce risk.

We have integrated the research needs listed that are within the scope of the Challenge into our plans for Phase 2. We will encourage collaboration with other providers for the research needs which lie outside the scope of the Challenge, but where the Challenge can support the research, e.g., with the provision of climate projections. We are expecting to make the mapping widely available to encourage these issues to be addressed.

4 Science Excellence

4.1 Research Teams

We will actively recruit the best talent and build the skills and expertise of New Zealand researchers to deliver the Challenge mission and enable adaptation within our Domains. We will fund the best New Zealand research teams, and continue to develop stronger collaborations with overseas researchers and research organisations (see Section 3.7). This approach also will raise the profile of Challenge researchers both domestically and internationally. In addition, the Challenge will recruit via collaborating organisations required expertise and build new capability as new areas of research are developed.

Building teams

Achieving the Challenge mission requires cohesive teams, across many disciplines and organisations, conducting an integrated programme of research. Challenge teams need to have the required expertise, technical capability, ability to deliver, leadership, end-user focus, communication skills, and track records for delivery and publication. We will use two approaches to ensure that we have the best teams.

- We will encourage existing research teams with strong track records to contribute to the Challenge's updated work plan, whether from within the Challenge already or as a known team in a new area. This may include bringing new researchers into the team, including early-career researchers, possibly from outside to New Zealand, or researchers with different skills from the current team. These teams then will be reviewed as part of project setup.
- We will invite targeted researchers with required expertise to form a team where there are no existing teams in New Zealand. They will work with the Challenge to develop research proposals to meet our mission. This approach was very successful in Phase 1, as it allowed us to identify high quality leaders for each team, confirm appropriate expertise, and ensure team members would work well together, prior to them submitting research proposals.

One example of how this has worked in Phase 1 is the Challenge project "*The impact of climate change on New Zealand's frozen water resources*" that brought together New Zealand's leading snow and glacier scientists from Victoria University of Wellington, the Universities of Otago and Canterbury, and Aqualinc Ltd. Another is our "*Drinking water in Te Hiku o Te Ika*" project, which involves kaupapa Māori researchers, hydrology and climate modellers, and kaumātua from Te Hiku Iwi Development Trust in collaboration with Massey University, ESR, NIWA and Stormwater 360.

New Zealand has a strong research culture, but as a small country often lacks research capability and capacity in particular areas. We will seek to resource new positions where missing skills are key to achieving the Challenge mission. For example, we funded the recruitment of a sea ice modeller to the University of Otago in Phase 1 and have supported the development of expertise in economic climate impact modelling. We also have recruited existing researchers with relevant skills who have previously not focused on climate impact issues. We encourage our research teams to collaborate internationally when this is more pragmatic than recruiting new positions domestically. We are cognisant of the need to leverage off the strength of the New Zealand climate and modelling communities to help effectively support our wide range of models.

Building capability

There are several areas of the strategy for Phase 2 that will require the Challenge to recruit or include new and additional expertise. For example, the increased focus on the Domains requires capability in areas not strongly involved in the Challenge (e.g., engineers). We will develop "climate impact champions" who will provide points of contact and oversight of the products we create. We will need to resource capability and capacity in data sciences, due to the increased focus of data analysis over data collection. We are seeking a Māori communications specialist to ensure our Māori engagement is effective, and a Data Manager to ensure that our data is produced in relevant, accessible formats that are useable by other researchers and decision-makers. We will need to grow our current pool of model experts as we seek to work with a broader range of climate modelling capability.

We engaged the research community in development of this strategic plan to identify the new research capacity needed in New Zealand, and where possible we have included these researchers in our workshops. We anticipate including these individuals in the Challenge research as we develop projects in more detail.

Our use of Dialogue and workshop processes to develop research, both at the initial strategic level and during proposal development, allows us to continue providing opportunities for researchers to become part of the Challenge. This is expected to continue in Phase 2.

We also intend to build capacity for further engagement by our researchers and for ongoing work with Māori. There is limited expertise in the field of climate change engagement, and developing capacity will provide additional expertise in New Zealand and ensure researchers have knowledge of techniques to assist us in achieving our mission, i.e., more effective ways of engaging to ensure new knowledge, data, and tools are taken up by decision-makers.

The Challenge has been successful in helping train students, either through direct postgraduate scholarship funding for projects which fit the Challenge mission, or through the alignment of research scholarships funded by universities, to Challenge research. We will work to expand aligned scholarships in Phase 2, as they provide immediate benefit to the Challenge, and also address the long-term aim of the Challenge to increase capability and capacity for climate change research in New Zealand.

4.2 Science Quality

Research quality is essential to Challenge success and we have established robust processes to ensure excellence. Our project proposal review and decision processes are managed and overseen by the SLT, who also play a key role in reviewing proposals. Strategic advice on science directions is provided by the ISP, and the Kāhui Māori for Māori focused and Māori relevant research. In addition, the drive toward research excellence comes via our research prioritisation processes (Section 4.4), annual reporting processes, team selection, the ways in which we ensure collaboration (Section 3.7), and integration (Section 3.5), and our expectations of researchers.

All research programme and project proposals will be extensively reviewed by the SLT and where relevant by the Kāhui Māori or the Technical Advisory Committee on Engagement. In addition, the ISP will provide the SLT and governance group with their view of the scientific strategies and directions that are being taken by the Challenge. In some cases, the ISP will review Requests for Proposals and the SLT recommendation papers on proposals to be funded. Their focus in these cases will be mainly on strategic fit to the Challenge scope and mission.

The governance group assesses strategic relevance and fit with the Challenge mission and makes funding decisions based on the SLT's recommendations and advice from the ISP and Kāhui. The primary

criteria for funding are that proposed research is excellent and addresses the Challenge mission. It must be well integrated with other Challenge research, and should build on or use core Challenge science. Secondary criteria are that research uses a best teams approach; provides additionality; includes appropriate engagement, capacity building, and collaboration (including appropriate aligned research and co-funding); and plans risk management processes (including addressing ethical implications of the research). It also must address Vision Mātauranga, and be feasible and cost-effective. This is a long list of criteria against which funding decisions are made. More information about how we prioritise research (in both development and in decision-making) is provided in Section 4.4.

The Independent Science Panel (ISP) provides strategic scientific oversight of the Challenge research, via review of the strategic directions and priorities of the science programmes, and provision of high-level advice. The ISP meet in person approximately every 18 months to formally review the Challenge research, ideally around the Challenge Symposium to enable the ISP to participate and gain an understanding of the current status of Challenge research prior to their in-depth meeting. This means that the Challenge will benefit from their participation in activities such as mini-symposia and panel sessions during the Symposium. The ISP produces a report for the governance group from each meeting that includes a formal set of recommendations for the Challenge, each programme individually, and for the structure and operational role of the ISP. The SLT formally responds to this report providing detail as to how the Challenge will address the recommendations. The membership of our ISP reflects the strategic direction of the Challenge, and membership of the panel has adapted to ensure this. A growing emphasis on the implications of climate change led to Professor Kathy Jacobs joining the panel in 2018. She brings expertise on climate impacts, adaptation, and social science. We plan to host a Challenge Symposium and ISP meeting in May 2019, in order that the ISP can participate in the Symposium and review the core proposals for Phase 2.

The Kāhui Māori also will help to ensure research excellence. The Kāhui will support the Challenge in ensuring that this continues by reviewing proposals that are directed towards the Vision Mātauranga Programme, as well as relevant parts of other research. Integrating Vision Mātauranga throughout the Challenge will continue to be a priority in Phase 2. We will rely on the expert guidance of the Kāhui and the VM Programme Leader to ensure that this is done in an effective and appropriate way, building on the strong foundations established in Phase 1.

The Challenge *expects research outputs to be of high quality* and publishable in internationally recognised peer reviewed journals, where appropriate. Researchers also are expected to present research at international conferences. This ensures that the research is up to international standard and that Challenge researchers are aware of the latest scientific developments. It also facilitates collaboration with experts from other countries. We expect research to produce meaningful, useful and useable outputs for end-users and Māori, in parallel with producing high quality science outputs.

We track progress via formal quarterly and annual project reporting processes. Each principal investigator is required to submit a quarterly report for approval by the Programme Leader(s) before payment is approved to their institution. This report includes progress made against deliverables, research highlights, risks to the research, collaboration, and communication and engagement plan implementation. The quarterly reports are provided to the governance group, using a traffic light reporting system for each project and contribute to an annual report that is provided to the governance group and MBIE. This process enables us to ensure that research stays on track and allows us to identify and address issues early. We receive feedback from the governance group quarterly, and MBIE annually, which also helps us to improve the excellence of our research.

4.3 Portfolio Balance

We will seek a considered balance across the broad portfolio of research required to deliver on the Challenge mission. Achieving this balance will be managed by the SLT with support from the ISP and subject to final review and approval by the governance group. We will shift our focus in Phase 2 from being primarily programme based to being driven by our Climate Impacts and Domains. The range of science needed to support climate modelling, and deliver analyses of climate change impacts and implications, from which adaptation options can be developed, requires a balance of skills from physical scientists to social scientists and engagement specialists. We are proposing greater investment in roles that support integration and bridge gaps between difference disciplines. This is in direct response to feedback received in Phase 1.

We will ensure we have the appropriate mix of research that is longer-term and lower risk (i.e., more underpinning of progress) and high-risk, high-return research. An example of our longer term lower risk research is the work developing climate modelling capability. Our higher risk, higher return research tends to be society-facing because this is a newer area of research, and there can be a risk when end-users are unable or unwilling to engage sufficiently. However, our society-facing research is where there is most potential for gain, as the new insights and novel knowledge could have significant returns for our key end-users. We therefore are placing a greater emphasis on high-risk, high-return research in Phase 2, with the potential to have greater impact for end-users.

We will encourage researchers to "push the boundaries" in Phase 2 and build capability in areas where it is currently lacking. We also will use new researchers to bring fresh perspectives. Much of the research in the Climate Impact work programme will both enhance and deliver understanding of physical processes. Applying this new understanding to solve problems within our Domains, also will produce research that is expected to generate significant new knowledge of great value to end-users.

4.4 Prioritising Research

The demand for research within the scope of the Challenge will exceed the Challenge's resources, requiring prioritisation of our research. We have a hierarchy of priorities regarding both the research to be done and the quality of research proposed (Section 4.2) that we will use to determine the research we will support, and its level of support.

We will look at alignment opportunities for the Challenge when prioritising research, particularly from the Challenge collaborating parties. This will ensure we avoid duplication of research and instead focus on integrating existing research with Challenge research to maximise the opportunities for aligned and co-funding in the Challenge.

Research that is central to the Challenge and fundamental to achieving the Challenge mission — the "backbone" research — is the top priority and must be resourced at an adequate level. Major Projects in these research areas will be identified, designed, and funded through negotiation between the SLT and the research team. These projects will be subject to peer review, review by the ISP, and approval by the governance group. We anticipate around 40% of the Challenge funding will support projects up to 5-years in length to deliver these central research needs. Research in this category includes climate projections from the NZESM, their downscaling, and input into the hydrological and risk models. Māori-led research is a priority for the Challenge and specific funding is set aside to support it.

The second priority will be research that is important to the Challenge, but where there are multiple approaches or multiple areas where advances can be made. Most Challenge research will be in this category. Examples are the use of observations to improve models or to assess model fidelity. We will

issue a Request for Proposals for this research, providing the scope of the research requested. The proposals will be assessed for science quality and fit to mission, with only those meeting both criteria continuing. We then will take one of two approaches, depending on the strategic merit of the proposals and the research space. We will either use a best proposals approach and award funding as appropriate and at the requested level, or we will negotiate with applicants on the project work package and funding levels. The first is the most likely scenario where the Request for Proposals includes caps on funding. The second approach will be important when proposals are strategic, there are several strong competing ideas, or where the proposed research could generate a significant step forward for the Challenge.

Timeframes for this research funding will be for up to five years. Long contracts (> 3 years) will have a mid-contract review, which will be important particularly for research in the Domains, as it will allow us to ensure we retain a focus on end-user needs as they evolve.

In addition, we will maximise the resources available to achieve our mission by seeking support from additional sources. For example, we will work with our research partners to develop compelling proposals for other science funding opportunities (e.g., MBIE Endeavour Fund) where appropriate or aligned to the Challenge mission.

4.5 Research Responsiveness

The context in which the Challenge operates is changing constantly. End-users and Māori in our Domains can be expected to vary in their interest levels and ability to engage over time. Research understanding is continuing to advance and there is a need to stay abreast of the most recent advances and practices. Our research programmes and associated activities will need to be dynamic and responsive to change if they are to deliver on the Challenge mission. We will ensure an appropriate level of dynamism through being alert to external change, and having sufficiently flexible internal project planning and management processes to allow shifts over time or, if required, suddenly.

Our extensive engagement with end-users and Māori will keep us informed as to how their perspectives change and might further change in the future, and also will inform how we should respond to these changes. Challenge researchers will keep abreast of the latest research in their fields, via their domestic and international collaborations, exposure to the scientific literature, and attendance at conferences and symposia in their fields. Our regular review processes also keep us abreast of research issues where the Challenge may have the opportunity to respond.

The SLT will become aware of the need to alter a programme, project or process through the quarterly reporting processes, or direct communication from the research team, ISP, or other source. In Phase 1 we structured two yearly, or halfway reviews of core projects. This allowed projects to respond and adapt to both changes outside their control, e.g., international collaborators losing or not securing funding, and to shifts in research priorities, e.g., parallel research by international researchers requiring a new approach from the Challenge.

Any non-urgent change in direction or emphasis will be managed through our usual annual research planning and reporting processes. Changes that require a fast or immediate response will be managed pragmatically by the SLT, supported by the governance group. The Challenge will remain cognisant of its mission, however, and will avoid widening the Challenge scope.

5 Delivering Impact

5.1 Creating Impacts

Creating impact from excellent science is central to the Challenge. In developing the strategy for Phase 2, we have responded to the question: How can we most effectively enable New Zealanders to anticipate, adapt, manage risk and thrive in a changing climate? The establishment of the NZESM capability and our much greater understanding of end-user needs provides a platform for us to identify where and how the Challenge can have greatest impact. Generating research impact permeates the Challenge projects, programmes, and the Challenge as a whole.

We focus on the five impacts that are likely to have the most effect on New Zealanders (climate extremes, changes in temperature and rainfall, droughts, floods, and sea-level rise). We have chosen specific Domains where Challenge research is most likely to result in significant improvements to how New Zealanders respond to climate change.

Our programmes are designed to identify the most critical end-user needs and to respond to them. Our greatest impact for some end-users will be in producing research that informs policy. For example, we will improve understanding of the financial risks associated with extreme weather events to provide a scientific basis for decisions made by government or the private sector (e.g., insurance companies). Our greatest impact for other end-users will be in supplying critical data to support investment decisions. For example, we will provide information on changing risks to enable local government to make informed decisions on storm water and flood infrastructure. Our greatest impact for yet other end-users will be supporting them to build their capability and capacity to best respond to climate change. For example, we will partner with Māori to develop and support culturally appropriate tools to allow them to manage appropriately the risks of coastal inundation to intrinsically important places such as marae and urupā.

We will use robust methods within projects to understand the needs of end-users and Māori and we will shape our research and tailor our outputs to best meet these needs. We will ensure we provide the right information, to the right people, at the right time, in the right form, and through the most appropriate mechanism. We will achieve this through our Engagement and VM programmes, and the high level of integration across the Challenge (see Section 3.7).

The impact of the Challenge's research is controlled by both the influence and the size of the decisions end-users have to make. We expect that the anticipated Climate Commission will become a key end-user for us, as it is likely to have significant influence over Climate Change adaptation in New Zealand. Its influence will be strongest in central and local government, but it can be expected to have broad influence in other sectors. The Challenge will seek effective ways to assist the Commission in its central role.

Skilled engagement practitioners will be embedded within key research projects and across our Domains. This will ensure both the quality and quantity of successful engagement, and strengthen integration, and collaboration across Challenge projects and programmes, and with our research partners (Universities, CRIs and consultants, see Section 3.4).

A Data Manager will work closely with researchers from projects with dynamic end-user relationships. This role will facilitate conversations about data needs, and enable decision makers to access and use Challenge generated products. This two-way engagement will ensure from the outset that the products developed are valuable to decision-makers and produced in a timely manner so they can be incorporated into decision making.

Our Partnerships Director will work alongside the Data Manager, and will play a key role deepening and strengthening relationships with our targeted end-users, proactively identifying and responding to their needs, testing ideas, and facilitating knowledge exchange between end-users and our research programmes.

Our Māori Communications Specialist will ensure co-creation of products tailored for Māori communities. These outputs, which also will have broader public appeal, will integrate our Vision Mātauranga research and principles throughout the Challenge, and allow them to be shared more widely throughout New Zealand.

5.2 Additionality

This Challenge will deliver significantly more benefit to New Zealand than could be achieved by a series of separate discreet research programmes in the same field. This additionality comes from the collaborative, integrated, cross-disciplinary approach of the Challenge. The following are key components of our additionality.

- We will improve New Zealand's overall climate modelling capability to understand the five key impacts, by filling critical gaps and building synergies within and between the suite of New Zealand's modelling capability, including increasing the New Zealand focus of our models. We aim to increase performance across all models. This will create benefits wider than the five key Climate Impacts, and will support activities beyond the Challenge, and the Challenge's lifetime.
- We will establish ongoing, two-way feedback between the Climate Impacts work programme and the Domain work programme to ensure that the outputs of one are the needed inputs of the other. This high level of integration would be extremely difficult to achieve across separate research programmes, especially given the different disciplines involved.
- We will expand our VM programme to integrate Mātauranga Māori into climate adaptation conversations, taking a globally unique approach. The VM programme ensures Challenge research best meets the needs of iwi, hapū, whanau and Māori business, including addressing capability and capacity issues. This multi-pronged approach within the Challenge realises synergies that help iwi, hapū, whanau and Māori business to make climate-based adaptation decisions, for the benefit for all New Zealanders.
- Our implementation of an engagement programme that includes a range of measures to ensure Challenge research is tailored to meet end-user needs and close the loop between providers and users of Challenge data. The scale of the Challenge, combined with the depth, breadth and specificity of our engagement efforts is unique in the climate change and adaptation research space in New Zealand.

The Challenge also will create additionality by increasing integration of climate change science within New Zealand so the Challenge can maximise its contribution to New Zealand developing policies and making decisions about adaptation in the face of change. For example, we would encourage climate modellers to integrate their research with the NZESM by transferring their focus to analysis of NZESM output, or by providing additional expertise to enhance the NZESM in areas outside the scope of the Challenge, e.g., modelling of the Antarctic Ice Sheet.

6 Decision Making and Accountability

6.1 Challenge Governance and Management

The Challenge does not propose to make any significant changes to the governance and management structure of the Challenge. We retain an independent governance group appointed by the collaborating parties of the Challenge. They represent a range of perspectives and have provided a well-balanced, independent layer of governance that has ensured accountability for the Challenge.

Figure 4: The Challenge's governance and management structure, unchanged from Phase 1.

In general, we have developed excellent processes for managing the Challenge. We have carried out a number of improvements in Phase 1 that have resulted in more effective processes and we feel that, overall, these processes are working well. We therefore plan to keep the original structure (Figure 4) for Phase 2. There are, however, some improvements we will make to our accountability and decision-making processes.

- The governance group have clarified the scope of the research and engagement in the Challenge. This has underpinned the focus of the Challenge's strategic review, and provides on-going clarity around the core purpose of the Challenge and the research it will support.
- There has been an evolution through Phase 1 in how the Challenge works with the ISP to obtain maximum value. Recent changes have been made to the operational role of the ISP, to reduce the demand on them for detailed review of contestable proposals. As a result, they can focus their time on providing strategic advice about the strengths, gaps, and implications of the spread and depth of suites of research projects. The Challenge, in liaison with the ISP, will continue to monitor the effectiveness of this arrangement.
- The Challenge now recognises there is a significant amount of operational time required to implement successfully some of our programmes. We are therefore proposing to increase the support available for our SLT, particularly for roles where significant engagement is needed, or there are a large number of projects to manage. This includes the Engagement, VM, and I&I

Programmes. We are also proposing to increase resources available for internal collaboration, via strategic positions that will facilitate the flow of information within and beyond the Challenge.

- The Challenge needs to leverage better its relationships with the Challenge collaborating parties. Examples are: working closely with NIWA in Phase 1 to integrate effort on earth system and regional climate modelling; with the University of Otago to incorporate sea ice modelling into the NZESM and with Victoria University of Wellington on engagement. We plan to increase engagement with all partners in Phase 2, especially for research that integrates with our Domains. We intend to foster a greater sense of partnership with all the Challenge parties in Phase 2 to the mutual benefit of all.

The programme structure (ESMP, P&O, VM, I&I, and Engagement) will be less prominent in Phase 2, but will remain relevant to administering the Challenge. Retaining the programme structure means we maintain a diverse range of skills and discipline knowledge on the SLT, including Māori research and development, planning, engagement, meteorology, atmospheric physics and physical oceanography. Our foci of Climate Impacts and Domains will intersect with the programmes. Research projects will be assigned to their most natural programme, with research in the Māori Domain assigned to the VM Leader, while the I&I Leader will focus on the other Domains, and some Climate Impacts projects. The Engagement Programme Leader will implement the Engagement strategy and the P&O and the ESMP Leaders will jointly lead the model chain and its associated observations (Figure 2).

The Director, Manager and SLT will have annual performance reviews and the governance Group will undertake a self-review every two years to ensure Challenge management and governance continue to perform at a high standard.

6.2 Giving Effect to Vision Mātauranga Policy

Our highly collaborative, innovative approach has and will continue to follow the best-practice envisioned in MBIE's Vision Mātauranga policy, namely it will encourage: kaupapa Māori research principles; governance Māori; engagement, collaboration and partnerships; research capability, capacity and leadership; and transformative context and future-focused research. We will do this by carefully fostering research that addresses economic growth, sustainability, health and social wellbeing, and indigenous knowledge.

Our Vision Mātauranga Programme has funded eight research projects looking at a range of climate change impacts and adaptation options for Māori communities. Projects have developed tools to facilitate adaptation decisions, including a simple economic analysis tool to assist Māori land-owners with investment decisions; a game to identify adaptation options for a community vulnerable to coastal erosion, flooding and sea-level rise; and the use of science, culture and art to facilitate culturally appropriate and responsive discussion around adaptation options for coastal communities.

This is the first time in the history of climate change research in New Zealand that such a large number of Māori-led, kaupapa-driven research projects have been undertaken concurrently. This already has created a step-change in the quality and quantity of material available to assist iwi, hapū, whanau and Māori business to make climate-based adaptation decisions.

The Challenge in Phase 2 will ensure that lessons from these existing projects, and our new projects, are made more accessible to other communities (both Māori and non-Māori). We will ensure that Vision Mātauranga research is of broad benefit, and its research findings are shared more widely, by translating research findings and outputs into content that is relevant, vital and lay-friendly, and delivered broadly across New Zealand communities.

Aotearoa is and can continue to be a world-leader in the way that it upholds, explores, and even integrates indigenous knowledge into climate adaptation conversations and decision-making processes, for the benefit of the whole of New Zealand society. The Challenge is one vehicle to ensure the centrality of mātauranga Māori in the continuing national conversation on adaptation to climate change (which is also in line with the core principals and recommendations identified in the 2018 CCATWG report).

7 Budget

The following is an indicative budget, as requested for the mid-way review by MBIE, for the distribution of funds across the Challenge in Phase 2. More resolution will be available as project budgets are developed and it is expected that there might be some re-balancing across major budget categories accordingly.

	$'000
Climate Impacts Work Programme	13,650
Earth System Modelling	
Improving Modelling Capability	
Climate Extremes	
Changes in Typical Temperature and Rainfall	
Droughts	
Floods	
Sea-level rise	
Domains Work Programme	5,300
Māori	
Communities	
Infrastructure	
National Economy	
Engagement	2,300
Science Leadership and Management	3,000
Governance, Kāhui, and Science Panel	1,200
Integration	650
Contingency	1,000
Total	**27,100**

8 Extended Scenario Planning

The Challenge has identified three projects that would enhance significantly the benefits that the Challenge can provide for New Zealand. All of these projects would integrate with the Challenge, but the funding to undertake this research is beyond the current resources of the Challenge.

Precipitation: the crucible of climate modelling

Water is a primary concern of end-users in the face of climate change, but our understanding of water in the future is dependent on modelling precipitation (rain and snow). It is an ongoing scientific challenge at all scales in climate models, which requires a step change in resources to lift our projection capability. This new effort will address: large-scale aspects of precipitation biases associated with errors in the positions of storm tracks, fronts, and low-pressure systems; the impact of very high resolution

on the quality of modelled precipitation fields; bias-correction of Regional Climate Model precipitation fields for use in hydrological simulations; water availability; Southern-Hemisphere specific aspects of cloud microphysics influencing cloud formation and evolution; and the use of data analytics to understand the controls on extremes (flooding, drought) and how they can be modelled. It will also consider the economic and societal impacts of changes in water availability and extremes in the past, present, and future. This research will be underpinned by increased collaboration between New Zealand's best teams and global experts.

Evidenced based engagement: from practice to research excellence

The CCATWG report and the consultation around the Zero Carbon Bill highlight the importance of New Zealanders becoming more informed about climate change and what it will mean for them. We propose expanding our engagement, by: extending our research component to enable upscaling of local lessons and experiences to make them nationally relevant; and to enable our lessons and research to contribute to the international body of literature on engagement for climate change impacts and adaptation options. Lessons from local adaptation to climate change engagement initiatives need to be documented, and upscaled so that other communities can be aware of successful engagement activities, including how they were designed to assess their appropriateness. This upscaling requires our Engagement to be extended to appropriately resource this important activity. Further expansion of our programme would support more embedded engagement in key research projects and would contribute to the Challenge's research being used by end-users and Māori beyond our Domains, thereby informing broader audiences.

Comprehensive assessment of climate change in New Zealand

The Government intends to inform New Zealanders about the risks of climate change, through a National Climate Change Risk Assessment. Such assessments are dependent on high quality, timely and accessible climate research to underpin the breath of areas a risk assessment will cover. Here we propose integrating New Zealand climate change research into accessible, authoritative, comprehensive reports of the direct impacts on New Zealanders from physical climate change in New Zealand. It would produce a comprehensive synthesis of knowledge that would be an invaluable resource and entry point for any end-user or researcher seeking climate change information. It would cover information relevant to our key Domains, and other significant areas of human impact. This would create a benchmark document to inform climate change adaptation in New Zealand.

9 Glossary

Common terms

Antarctic Science Platform (ASP): A Strategic Science Investment Fund platform for Antarctic science that will provide stable funding for underpinning, longer-term Antarctic science critical to maximising scientific and strategic benefits for New Zealand.

Climate Change Adaptation Technical Working Group (CCATWG): A Government appointed group of public and private sector technical experts charged with providing advice on how New Zealand could adapt to the effects of climate change.

Climate Change Impacts and Implications (CCII): A precursor MBIE funded research programme that was mapped into the Challenge. Until October 2016 it ran in parallel with the Challenge and undertook research within a similar scope to the Challenge's I&I programme.

Climate Model Intercomparison Project 6 (CMIP6): A global climate model intercomparison experiment organised by the IPCC, which used prescribed emission scenario, or representative concentration pathways to prescribe future greenhouse gas emissions.

Crown Research Institute (CRI): The science research businesses owned by the Crown (i.e., the New Zealand Government) in New Zealand, of which NIWA is one.

Dialogue: A process used by the Challenge to co-create research questions related to a priority topic. These involve two day-long facilitated meetings, held up to a month apart and attended by carefully selected researchers and end-users.

Earth System Modelling and Prediction (ESMP): One of five programmes in the Deep South Challenge.

Impacts and Implications (I&I): One of five programmes in the Deep South Challenge.

Intergovernmental Panel for Climate Change (IPCC): A scientific and intergovernmental body under the auspices of the United Nations, dedicated to providing the world with an objective, scientific view of climate change and its political and economic impacts.

Independent Science Panel (ISP): The ISP provide independent science advice to the Challenge governance group on the research within the Challenge.

Ministry of Business, Innovation and Employment (MBIE): The New Zealand Government department responsible for funding most Government funded research in New Zealand, including the National Science Challenges.

National Science Challenge (NSC): A series of 11 cross-disciplinary, mission-led programmes designed to tackle New Zealand's biggest science-based challenges.

National Institute of Water and Atmospheric Research Ltd (NIWA): A Crown Research Institute, dedicated to conducting leading environmental science to enable the sustainable management of natural resources for New Zealand and the planet. NIWA is the Deep South Challenge host.

New Zealand Earth System Model (NZESM): This is the central global climate modelling effort of the Deep South Challenge.

New Zealand Regional Climate Model (NZRCM): The regional climate model used in the Challenge to downscale output from the NZESM and from CMIP6 models.

Processes and Observations (P&O): One of five programmes in the Deep South Challenge.

Vision Mātauranga (VM): One of five research programmes in the Deep South Challenge. This programme has a focus on Māori-led research.

Riskscape: a software tool developed for assessing hazard risk.

Representative User Group (RUG): A group of key sector representatives selected by the Challenge and appointed by the governance group. The group meets twice yearly, and provides advice on the Challenge's activities, particularly within their sectors.

SeaRise: An MBIE funded research programme whose objective is to provide up to date estimates of sea-level rise around New Zealand that include all sea-level rise contributions.

Science Leadership Team (SLT): The team with management responsibility for the Challenge. It includes the Challenge Director, Challenge Manager, and the Programme Leaders of the five research programmes: VM, I&I, Engagement, P&O and ESMP.

Weather@Home: An initiative that uses a climate model that is small enough to fit onto a regular PC, and uses individual volunteer PC time to run large ensembles of climate models.

Māori terms

Hapū: Subtribe, clan, a collective of related whānau.

Iwi: Tribe.

Kaupapa Māori: A plan of action created by Māori which expresses Māori aspirations, values, and perspectives.

Kāhui Māori: Maori (Advisory) council.

Marae: Traditional community meeting area, with a traditional meeting house as its focal point – often the centre of activity in a Māori community.

Mana: Authority, power, reputation, respected status.

Mātauranga: Knowledge.

Te reo Māori: Māori language.

Tikanga Māori: Customary practices/meaning.

Urupā: Cemetery (Māori burial ground).

Whanau: Family (often extended family).