Australia’s Next Generation of Regional Climate Projections

Final Report to the National Climate Science Advisory Committee

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Summary

Australia and the world are at a turning point in the management of climate risks and opportunities. Decisions made in the next few years will underpin the robustness of Australia’s capacity to manage a dynamic and changing climate and to reduce the most dangerous impacts of climate change.

In July 2019, the National Climate Science Advisory Committee (NCSAC), following its report *Climate Science for Australia’s Future*, requested that the NESP Earth Systems and Climate Change (ESCC) Hub prepare a plan for a program of next-generation climate projections for Australia.

Climate projections are evidence-based statements and information products on plausible future climate at the regional scale under various pathways of human development designed to be useful for decision-making. The purpose of this report is to set out the needs for and an approach to the next generation of climate projections for Australia that strengthens support for our domestic capabilities as well as leveraging international efforts, supplemented by local effort, to produce new regional projections. This report complements the closely related NCSAC study *Informing strategic development of a national climate services capability for Australia*.

This report builds upon analysis and consultation done through the ESCC Hub project on regional climate projections, supplemented by qualitative analysis from a series of consultations with key stakeholders and science partners and a round of consultations on the draft report (listed in Appendix 1). Recent experience from within Australia and internationally, as well as emerging programs and practices are considered. The main conclusions in planning for the next-generation climate projections are:

Meeting user needs

To meet the needs of climate service providers, policy makers and other next-users of climate projection data and information (not necessarily end-users or the wider community), regional climate projections should involve:

- Coordination between new regional climate projections with climate service providers that is compatible with a range of delivery platforms. This is essential to build trust, avoid confusion and duplication of effort as well as to provide ongoing product support.
- Coordination of projections with climate observations, climate reanalysis and process research to link projections to the underpinning knowledge base. This is imperative to ensure credibility.
- Co-design of research and delivery across science agencies and with stakeholder groups to meet existing and emerging uses. Needs from the public sector (e.g. federal, state and local government), primary industries, the private sector (e.g. Taskforce on Climate-related Financial Disclosures (TCFD) activities), emergency management and other sectors must be part of the project design, and an ongoing
consultation and co-production process must be implemented in conjunction with existing structures (e.g. Cross-jurisdictional Community of Practice for Climate Science; Bureau of Meteorology climate services, CSIRO Climate Resilience Enterprise initiative).

- Provision of climate change risk information in an integrated framework – by providing consistent marine and terrestrial projections, and by providing projections of derived climate-impact drivers (CIDs) along with base climate variables such as temperature and rainfall. CIDs include heat waves, drought, floods, fire weather, marine heatwaves, coastal storm surges, tropical cyclones, compound extreme events and agricultural indices (e.g. growing degree days, seasonal timings, frost).

- Projections communicated by ‘global warming level’ (e.g. 2 °C global warming), by emission scenario and by timeframe (e.g. 2050).

- Although there needs to be consistency across spatial scales from national through to state to regional, information needs to be configurable and adaptable for decision-making at different scales (and able to be supplemented with other data and information).

- Projection information for all Australian islands and territories.

- User support and services together with projections as part of a national climate service: ongoing user support, targeted sector support, an online help service, training courses and public communication, and delivery through preferred structures (e.g. Climate Compass for the Federal Government, state-based knowledge brokering).

**Recommended modelling approach to underpin projections**

Following various informal consultations (group meetings, one-on-one discussions) and surveying the national and international landscape, the report suggests an ambitious but practical modelling program:

- Projections in the next few years should be based on simulations from the international database of global climate models under the Coupled Model Intercomparison Project phase 6 (CMIP6) and future scenarios from the Shared Socio-economic Pathways (SSPs) being used in the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6). Judicious use of CMIP6 simulations requires targeted model evaluation, updated ensemble generation methods and careful model selection.

- Regional modelling can yield important insights, and this should be pursued using best practices under a coordinated multi-model program – through the CORDEX-CMIP6 simulation framework for the Australia domain. Suggested technical specifications consistent with CORDEX include: 12-20 km horizontal resolution across Australia, at least 3 different regional models, nested within an ensemble of simulations from a carefully-selected group of CMIP6 models and SSPs, using about 3 simulations from each regional model for each SSP.

- Very-high resolution regional climate simulations can yield important insights near notable features of topography, coasts and urban areas, especially for climate
extremes. Such simulations should be produced also using best practices in a coordinated program of multi-model ensembles nested within national CORDEX-CMIP6 simulations. Recent literature suggests about 4 km resolution (or finer) is useful and can currently be produced covering major population centres and key economic zones.

- Statistical empirical downscaling and advanced statistical post-processing techniques are required to create locally relevant, application-ready outputs for the widest possible range of needs, including on climate hazards.

- Hydrological projections: National projections of runoff, soil moisture and other hydrological characteristics (e.g. streamflow) at 5 km grids for all of Australia, with CMIP6 global climate model simulations, dynamically downscaled regional climate simulations (consistent with the above next generation climate projections), robust bias correction and hydrological modelling (accounting for soils and land use). This will build on hydroclimate projections research and products in the different states, agencies, and the emerging Bureau of Meteorology hydrological projections product.

- Mean and extreme sea-level rise and storm surge projections: For the entire Australian coastline at a minimum of around 5km spatial resolution, using CMIP6 global simulations and downscaled regional climate simulations, with high-resolution wind and ocean wave simulations for projections of storm surges and extreme sea level events.

- Data storage and infrastructure: Web access to key data needs to be provided for all users, including web tools for accessing and extracting data, and very large underpinning data storage infrastructure accessible to expert users. Reliable data access and management is needed to support a robust operational service capability. This also requires critical human resources to support delivery.

- Capacity and awareness needs to be built preparing for future generations of climate change modelling beyond CMIP6 (e.g. the potential for ‘Digital Earths’ simulations outlined in the World Climate Research Program ‘lighthouse’ activity).
1 Introduction

In July 2019, the National Climate Science Advisory Committee (NCSAC) completed its report *Climate Science for Australia’s Future* (NCSAC, 2019) which identified a number of strategic actions that were designed to build on the current strengths and to realise the benefits of Australian climate research.

Some of the conclusions from this report were:

A nationally consistent understanding of projected climate changes and impacts across Australia is needed for business and government to assess and manage their risks. Information needs to be at spatial and temporal scales relevant for decision making and allow for continuous risk assessment for businesses who operate across state borders and jurisdictions (e.g. electricity transmission network companies). Australia has the opportunity to develop a new generation of scientifically robust climate projections based on the synthesis of simulations from multiple global climate models. This is made possible through the international Coupled Model Inter-comparison Project (CMIP). When combined with regional climate models developed and used by CSIRO and universities, high-resolution regional projections can be generated. Extensive end-user engagement and communication of the projections will also be essential for their utilisation. (NCSAC, 2019)

Hence, one of the strategic actions in the report was:

*The NESP Earth Systems and Climate Change (ESCC) Hub and key partners should develop a plan by June 2020, for the program of next generation climate projections for Australia, including:*

- undertaking further market research and stakeholder consultation to inform the work program;
- assessing and utilising data sets and modelling methods to use the inputs more effectively, for example, ensemble generation methods and constraints on projections approaches;
- coordinating new regional scale modelling and integration for use in national projections;
- significantly enhancing links to climate services and knowledge brokering to the diverse range of stakeholder groups. (NCSAC, 2019)

This report complements the closely related NCSAC study *Informing strategic development of a national climate services capability for Australia*, described in Box 1 below. Climate projections are an important component of any national climate services.

Climate projections are model- and evidence-based descriptions of plausible future climates and the pathways leading to them. More specifically, projections are model-derived estimates of future climate scenarios communicated for making decisions. As such, they can be evaluated in four dimensions: scientific credibility, salience to the target audience, legitimacy for use in decision-making and how actionable they are for decision-making (Cash et al. 2003; Kirchoff et al. 2013).
Box 1: Informing strategic development of a national climate services capability for Australia

Climate variability and change pose risks to the Australian economy, environment and society. A properly coordinated and resourced national climate services capability delivering climate data and information to inform decision-making can help mitigate these risks.

The primary purpose of national climate services capability is to help mitigate sovereign risk and thereby create value for all stakeholders in the form of sustainable environmental, economic and social outcomes; in particular through:

- increasing awareness and building capacity to better understand and inform climate action, and
- provision of relevant, usable, legitimate and credible, science-based evidence for decision-making.

Market demand for climate risk guidance is growing in the public and private sectors. This demand is driven by government, business and community awareness of the physical risks and impacts of climate change and variability, including weather and climate-related natural disasters. In the corporate world, regulators, finance providers and insurers increasingly seek disclosure and reporting of companies’ climate risks. It is also the case that investment in climate services can provide tangible, macro-economic benefits at a national scale.

The Australian National Climate Science Advisory Committee (DAWE, 2019) concluded that the value of climate science to Australia could be greatly enhanced by climate services. A national climate services capability would provide decision makers with tailored climate risk information. Broadly, climate services make climate information and analyses useful and useable as an evidence base for decision-making. Through climate information products tailored and differentiated for specific sectors and industries, climate services can provide the insight decision-makers need to manage interactions between climate risk and their sectors’ or industries’ activities.

An enhanced, nationally coordinated climate services capability would provide a more effective and efficient link between providers and users of climate information through public and/or private sector ‘purveyors’ (intermediaries). It would elevate users into the governance arrangements for the national capability and prioritise user needs for decision-making. It would also link core products and services such as climate observations, model-based projections and related assessments with differentiated products and services such as decision support tools and climate risk assessments tailored for specific businesses, industries and sectors.

For more information, see NESP ESCC Hub (2021).

Climate projections are simulations of the future climate under different scenarios of future conditions, including the mean state and its variability and incidence of extreme climate events. Given the dominance of human influence over other ‘forcings’ over recent decades and the foreseeable future multi-decadal changes of climate risks (IPCC 2013), scenarios are specified by the human influence on the climate - mainly the emissions of greenhouse gases and aerosols.
Projections are not predictions of the sequence of weather events in the sense of weather forecasts, but rather a quantification of the shifting statistics of events under a set of given forcing scenarios. Weather and seasonal climate forecasts, on the other hand, aim to predict actual temporal sequences of events based on knowledge of the past and current state of the system, e.g. “Monday sunny and 25; Tuesday rainy and 19”. There are important features of the technical and communication aspects of climate projections that make them different from products such as seasonal climate forecasts.

Climate projections inform a different set of decisions than shorter-term forecasts. Whereas weather and seasonal forecasts are primarily used to make operational decisions and inform tactical responses, projections are used to inform longer-term strategies. These strategies may be aimed at adapting to climate change, increasing climate resilience or mitigating the impacts of climate change through global emissions reductions.

Projections can quantify the scope, timing and scale of likely physical changes under different scenarios of emissions to inform decision-making to the best of our current knowledge. In this context, projections can be used to help with long-term conceptualisations, to raise awareness, inform risk assessments and inform specific, actionable decisions. Given the contested nature of discourse and decision-making at the multi-decadal timescale, projections should be useful for policymakers. Advice based on projections should be neutral to specific policy settings and be policy-relevant but not policy-prescriptive. This includes policy at all levels of government but also in the private sector and communities.

National climate projection statements were produced for Australia in the late 1980s by CSIRO, and then national climate projections products have been produced at regular intervals. National climate projections in 2007 and 2015 were co-produced by CSIRO and the Bureau of Meteorology together with the relevant Federal Government department. There is now a community of multiple organisations involved in the research and delivery of climate projections, including state governments, universities and Cooperative Research Centres (CRCs). Over the last decade, important state and territory-led regional climate projections have been produced by most governments. More information on these climate projections is provided in Section 3.

The following section includes a brief summary of stakeholder consultation in support of this report, together with learnings from some recent relevant user-driven projects. Sections 3 and 4 provide an overview of national and state-led climate projections in Australia and some relevant international experience on national climate projections. Sections 5 and 6 provide an update and assessment of different approaches for regional climate projections and recommended priorities. Sections 7 and 8 provide a synthesis of the recommended program of next generation national and regional climate projections for Australia, together with some recommended technical specifications for this program.
2 User needs for Australian climate projections

2.1 The need to incorporate new knowledge, data and modelling

Australian climate change projections are based on data, models and methods from five to ten years ago or more, so while they are still useful, they are now becoming out of date. There is an urgent need for them to be refined and updated to provide the best and most recent information to users and stakeholders. This is particularly the case as our climate continues to change, our understanding of the climate system advances, climate models are further developed, user needs change and innovations occur in the delivery of products and services.

Projections need to capture and communicate new insights into the processes behind climate variability and change and how they are expressed in Australia, including the potential for exceeding climate tipping points or experiencing abrupt changes. In 2019, the NCSAC commissioned a report from the ARC Centre of Excellence for Climate Extremes for input to its strategic discussions in the area of climate processes research. The report summarises the current state of climate processes research in Australia, identifies gaps, and provides options for moving the area forward into the next decade (Jakob and Singh, 2020).

Projections need to use up-to-date observational datasets to evaluate and contextualise projections, as well as the latest reanalysis products (assimilating data to produce a coherent comprehensive record of past weather and climate changes) from Australia (the ‘BARRA’ reanalysis) and internationally (ERA5 from Europe). Projections also need to use the latest modelling to exploit the latest advances, and to maintain credibility. The current suite of national projections is based on simulations from CMIP5 (Taylor et al. 2012), now 10-15 years old, and new global climate modelling and regional modelling are now available (see Section 5 below).

2.2 Assessing changing stakeholder needs

A short discussion paper from the ESCC Hub with a summary of a proposed approach and timeline for a possible future suite of climate change projections (NESP ESCC Hub, 2019) was provided as background for engagements with stakeholders.

Engagements specifically for this report comprised face-to-face interviews and group discussions with Federal Government departments and agencies (DAWE, DoEE, Emergency Management Australia), state government (NSW, Victoria, Tasmania, Queensland, South Australia) representatives, and scientific organisations (CSIRO, Bureau of Meteorology, Universities). Issues raised in these consultations include:

- Spatial and temporal resolutions of projection data, variables of interest, projections in terms of emission scenarios or global warming levels or both.
- The need for ongoing support of climate information and climate change services.
• Supporting a broader range of users; business and finance sector, agriculture, water resources, local governmental, coastal managers, natural resource managers, etc.

• The need for mutually-beneficial leveraging of effort between state and federal level initiatives.

2.3 Lessons from the Climate Measurement Standards Initiative (CMSI)

Recent experience on initiatives co-produced between research agencies and the private sector has started to clarify their needs. The Taskforce on Climate-related Financial Disclosures (TCFD) guidelines of 2017 has initiated a strong response, particularly from the financial services sector, consisting of banks, insurance, reinsurance, investors, regulators, and ratings agencies. Experience from the science committee in the CMSI, which provided guidance on standards for the analysis of physical climate risk for buildings and infrastructure by the financial services sector, has shown the need for:

• Standardised, fully described climate projections and climate scenarios with narratives to allow sensitivity and stress-testing analyses in a comparable way across multiple sectors. This includes nationally consistent high-resolution projections datasets with clear international context-setting (how regional datasets compare to global ones).

• Data, information and guidance on risks associated with specific hazards (damaging storms including tropical cyclones and east coast lows, fire danger, hail, flood, drought, heat extremes), and particularly on compound climate extremes. This will ideally use a step-change in climate modelling – improved models, higher resolution and many ensemble members to be able to simulate extremes and generate reliable statistics.

• Enhanced documentation and guidance for data and information used in standardised analyses, including observed climate datasets and model projections. This includes more evaluation and confidence setting of global and regional climate model outputs for the hazards of most interest, and standards for non-climate datasets used to assess exposure and vulnerability. Datasets need to be easy to access and available for commercial use.

• Ongoing relationships and co-production of knowledge between research and industry under appropriate governance that ensures independence and prevents conflicts of interest.

The climate science guidelines (NESP ESCC Hub, 2020) and the financial disclosure guidelines (CMSI, 2020) from the CMSI were released in September 2020. The vision for the future from the CMSI climate science guidelines is relevant to planning for regional climate projections for Australia:

In regard to climate projection scenarios, the ideal situation in the future is for climate risk information to be based on a comprehensive, fully evaluated set of high-resolution climate projections. These projections could depict all the relevant hazards and phenomena of interest with high confidence and narrow ranges of spread in future
change, with a full description of natural variability in the hazards. This includes useful projections of averages, moderate extreme events and major extreme events that have the greatest impacts. The full range of required information would be available using appropriate delivery platforms that are accessible, quality-controlled and available for commercial purposes. Spatial and temporal scales relevant to assessing climate risks would be used, extending from present to a century into the future with implementation supported by climate services. (NESP ESCC Hub, 2020)

2.4 Electricity Sector Climate Information (ESCI) project

The ESCI project is designed to improve the reliability and resilience of the National Electricity Market to the risks from climate change and extreme weather. The project was funded through the Department of Environment and Energy for three years from 2018-19 and is being undertaken by CSIRO and the Bureau of Meteorology in collaboration with the Australian Energy Market Operator (AEMO), universities and state projects (e.g. the NARClIM update v1.5 is an important contributor).

The ESCI project is identifying gaps in existing climate information that are critical to understanding climate risk, including information on network vulnerabilities, to support decision-makers in the National Electricity Market. In particular, the project has identified the need for high-resolution depictions of plausible future extreme events under future climate scenarios, including heat, strong winds, fire danger and compound extreme events. The detailed projections of extremes, with supporting datasets, are needed for plausible stress tests and impact analysis of energy infrastructure and systems. Of course, the projection of these extreme events needs to be carefully evaluated and effects quantified using appropriate techniques. The project will start to address these needs, but they remain an ongoing issue for new climate projections.

2.5 National Disaster Risk Information Services Capability (NDRISC) pilot project

In 2019, a pilot project was undertaken by Emergency Management Australia to explore the feasibility and benefits of a national capability for Australia to inform future options for a national climate and disaster risk information services capability, building on the National Disaster Risk Reduction Framework (2019). Such a proposed national disaster risk capability would ensure decision-makers have access to the best information and guidance needed to make risk-informed decisions to improve our future resilience.

The pilot project involved case studies linked to the national Freight and Supply Chain Strategy. It comprised two main activities:

1. Exploration of the use of high-level narrative scenarios to stimulate thinking and frame discussion around climate and disaster risk for freight supply chains; and
2. Modelling of climate and disaster risks for three selected case studies based on the insights from the narrative exploration process.
The project was resourced primarily through in-kind contributions from organisations providing data and modelling capability (Geoscience Australia, CSIRO, the Bureau of Meteorology, the University of Adelaide and the Bushfire and Natural Hazards Cooperative Research Centre).

The case studies demonstrated the value of applying existing knowledge and risk modelling capability to address specific needs and demonstrated the value of modelling to support climate and disaster risk assessments. They highlighted a set of considerations that a national capability would need to address (NDRISC, 2020).

A national disaster risk capability would represent a foundational element for evidence-based systemic climate and disaster risk reduction and decision-making, and climate projections are a key part of that capability.

### 2.6 Hydrological projections projects

Hydrological projections from CSIRO, the Bureau of Meteorology, universities and other agencies have been conducted over many years. There is a wealth of insights from all these projects, across research and delivery.

A relevant major project with a strong national delivery focus led by the Bureau of Meteorology is close to completion and aims to produce hydrological projections that are both consistent across all of Australia, and comparable to hydrological analyses (by using the operational water model). The project draws out several practical and scientific challenges in this space.

The project highlights the importance of using multiple models and methods to quantify the uncertainty space – multiple global models, multiple regional models but also multiple statistical modelling techniques and post-processing methods. The project also highlights the challenges in achieving national consistency using multiple disparate modelling inputs.

Challenges in the science underpinning hydrological projections are significant, as it requires reliable projections of rainfall, evaporation, vegetation change and more. Ongoing effort on the underpinning science and modelling is required.

### 2.7 Royal Commission into National Natural Disaster Arrangements

The Royal Commission into National Natural Disaster Arrangements was established in February 2020 by the Commonwealth Government in response to the extreme bushfire season of 2019-2020. Its terms of reference included examination of Australia’s arrangements for improving resilience and adapting to changing climatic conditions.

A clear national perspective on the importance of climate projections for Australia is provided by recommendation 4.5 of the Report of the Royal Commission, released in October 2020.

**Recommendation 4.5 – National climate projections:**

*Australian, state and territory governments should produce downscaled climate projections:*
1) to inform the assessment of future natural disaster risk by relevant decision-makers, including state and territory government agencies with planning and emergency management responsibilities

2) underpinned by an agreed common core set of climate trajectories and timelines, and

3) subject to regular review

The Commonwealth response to the Royal Commission, *A national approach to national disasters* (Dept. of the Prime Minister and Cabinet, 2020), released in November, in terms of recommendation 4.5, states:

*The Commonwealth Government supports in principle this recommendation. The Commonwealth Government supports the objective of this recommendation and welcomes the opportunity to work with state and territory governments to better understand their information needs and how such projections can inform planning and emergency management decision-making.*
3 Previous Australian efforts and experience in national and regional climate projections


As outlined in Whetton et al. (2016), each release has addressed numerous scientific and communication issues regarding the use of models, future scenario framing and the presentation of data. Projections have faced perennial issues on the quantification and communication of uncertainty; trends towards a wider scope for projections and detail to cater to an expanding range of uses and users; and tensions between scientific complexity and completeness with the ease of use and simplicity for the user (or credibility versus simplicity), including around spatial resolution of information and the use of probabilities.
3.1 National projections

National climate assessments moved from mainly expert judgement in the earliest days to a stronger reliance on climate modelling as a primary tool as those models became available and demonstrated credibility. Since 2001, the release of national projections has become tied to the cycle of Assessment Reports from the IPCC and the release of coordinated global climate model simulations under the international CMIP structure, as part of the World Climate Research Programme (WCRP). There are technical advantages to this timing as it allows the use of the latest global modelling and assessments and also in messaging and communication as there is refreshed relevance and interest in national climate outlooks following global assessments. Not all nations have followed this cycle (see Section 4), however it has made sense for Australia to do so.

The most recent national climate projections used CMIP5 as the main modelling source, (global simulations completed during 2011-15), supplemented by insights from dynamical and statistical downscaling. No national projections product has used regional modelling as the primary source, although the new Electricity Sector Climate Initiative (ESCI) project uses a multi-model ensemble of pre-existing and new regional modelling as a core component.

3.2 State-based projections

Alongside national projections, there have been significant climate change projection projects funded and produced in partnerships between scientific organisations and state and territory governments. This includes projects without a large focus on new regional modelling, including the Southeast Australia Climate Initiative (SEACI), Indian Ocean Climate Initiative (IOCI), Victorian Climate Initiative (VicCI) and Goyder South Australia.

There have also been major projects that have used regional climate models to produce high-resolution simulations for sub-regions of Australia and produced assessment and communication products from those outputs. State governments commissioned downscaling through CSIRO regional models DARLAM and CCAM in 1992 to 2004. More recently there have been major projects such as the Climate Futures for Tasmania (CFT) project initially in 2008-2012 and with follow-on projects, the NSW and ACT Regional Climate Modelling project (NARCliM), Queensland Future Climate projections and the recent Victorian Climate Projections 2019 (VCP19). These projects were commissioned and tailored to meet specific state-level needs for mitigation and adaptation planning, as well as management of critical infrastructure and services, by informing specific institutional and decision-making structures at state and local levels. The projects also support adaptation actions outside government, are a trusted source of climate information for many sectors and have allowed detailed assessments of scientific and climatic questions of relevance at more detailed regional scales than previously available.

The state-based projects to date have typically each used a single regional modelling system to produce 5-12 km resolution simulations, rather than using coordinated multi-model structures. However, recent projects such as VCP19 are able to summarise regional modelling from previous projects and put new simulations into this broader context, provided there are sufficient overlaps in the modelling regions covered, time periods and underlying forcing scenarios.
States have ongoing needs for information relevant to their decision-making and have ongoing plans to use and to produce regional climate modelling outputs and assessment.

**Climate Futures for Tasmania (CFT)**

The CFT project was ground-breaking in Australia in a few ways: through using regional modelling to address the diverse climate of a small region; through forming deep partnerships between research agencies, state government departments and government enterprises (e.g. Hydro Tasmania); through a high level of engagement across many sectors; and through delivery across a range of platforms from scientific papers through to government databases. The project used CSIRO’s CCAM model as a central tool, but brought in specialist expertise and modelling in hydrology, agriculture, extreme events and coastal impacts. The Tasmanian government and agencies have supported ongoing activities in the area of climate projections and impacts analysis at a lower level of resourcing than the original CFT.

**NSW and ACT Regional Climate Modelling (NARClIm)**

NARClIm was co-designed with stakeholders to inform the climate adaptation planning of all NSW and ACT government departments and maintains a high level of visibility and impact. It used multiple models from the Weather Research and Forecasting (WRF) modelling system and an innovative model selection process to create three regional model configurations driven by four CMIP3 global climate models selected for performance and also representativeness (Evans et al., 2014). The projections were analysed to generate region specific summaries and are presented to the public through the user friendly AdaptNSW website. More detailed projection data, including 50km resolution over all of Australia and 10km resolution over southeast Australia, are available through the NSW Climate Data Portal.

NARClIm has been extended with the addition of simulations driven by three CMIP5 models, that run continuously from 1950 to 2100 and use both RCP8.5 and RCP4.5 emission scenarios for future projections. The successor to NARClIm is also being planned. It will be based on downscaling of CMIP6 models. It will use a larger set of GCMs and RCMs as well as downscaling to higher resolution than the original NARClIm.

**Queensland Future Climate**

The Queensland state government supported the production of climate projections for state level purposes and planning. The project had many features that are cutting edge and pushed the field forward. These include high resolution modelling using CCAM delivering national-scale projections at intermediate resolution and a larger number of CMIP5 global climate models selected and used (11), and innovative and user-friendly delivery and support through the Queensland Future Climate portal and dashboard.

**Victorian Climate Projections 2019 (VCP19)**

The Victorian government has supported ongoing climate research and applications, as well as climate projections for the state released in 2019 (VCP19). The VCP19 project assessed and contextualised global climate models and various regional modelling efforts, including a set of new high-resolution CCAM simulations, to produce projections for sub-regions within Victoria.
3.3 Added value of regional projections

The state-based climate projection projects and initiatives have delivered considerable value and benefits for the state decision-makers in terms of co-design, co-production and delivery of knowledge between research and stakeholders. Also, regional modelling has shown cases of key ‘added value’ in understanding regional climate change relevant to decision-making (e.g. regional detail in the projected change signal of rainfall and extremes). There are opportunities for greater cooperation and leverage of effort for mutual benefit as we move to multi-model methods that are now best practice, and to the analysis of those datasets to enable both state and national-scale consistency where required. This opportunity is recognised by the formation of the Interjurisdictional Chief Environmental Scientists (IJCES) group and the Cross-Jurisdictional Community of Practice on Climate Science (XJ CoP). These groups involve DAWE at the federal level and representatives from all the states and territories. This strategic partnership between national and state level effort is critical for future success in this area.

As coordinated regional downscaling programs are established, including the international Coordinated Regional Downscaling Experiment (CORDEX), we can now assess and quantify the ‘added value’ provided by regional simulations in a nationally consistent way, while noting that ‘added value’ in projected change is a complex area to assess (e.g. Ekström et al. 2015). Using CORDEX, DiVirgilio et al. (2020) presents the concept of ‘realised added value’ for average temperature and average rainfall change - where the simulations improve on the global models in the current climate and also project a different and potentially more credible change in the future (see Figure 2 below). The results support the finding that regional modelling gives credible benefits for most of Australia, but especially for areas of notable topography and coastlines. Importantly, we need more work looking at the ‘added value’ from regional modelling for extreme events and climate hazards.
Figure 2: ‘Realised added value’ index of CORDEX modelling over Australia. Positive values (red) indicate where there is both an improved simulation of the current climate and a different projected change in temperature and rainfall (source Di Virgilio et al. 2020).
Recent international experience in regional climate projections, including lessons learned

National climate projections have been produced for many nations. In this section we outline and compare five recent examples: EU, the UK, USA, the Netherlands and New Zealand. Only the overall approach and modelling strategies are compared, there are other lessons from funding, governance, communications and technical support that can be drawn on.

The European Union supports climate projections and delivery through numerous programs; two notable examples are Copernicus and EUCP. Copernicus represents best available practice in some respects, with a high-quality observation, research, modelling and delivery platform across various domains including a climate change service, available at: https://www.copernicus.eu/en/services/climate-change.

EUCP aims to provide improved and high-resolution climate outlooks, transitioning from forecasts and decadal predictions to climate projections for future scenarios, https://www.eucp-project.eu/. The Copernicus and EUCP programs are global leaders and can be used as aspirational targets for Australian efforts.

The UK released national climate projections in 2009 (UKCP09) and 2018 (UKCP18). The timing of the release of UKCP09 and UKCP18 did not align with that of IPCC or CMIP projections. The UKCP projections can be decoupled from the IPCC and CMIP cycles as they use only their own modelling system to cascade from global climate models (GCMs) to regional climate models (RCMs) and secondary models to generate regional projections. The Hadley Centre global and regional modelling system is used, and the various model parameters are systematically changed to sample the range of uncertainty, rather than sampling different models. This has the advantage of being under the central control of the project but has the disadvantages of not fully sampling the structural differences between different models, not having the global relevance and context of CMIP projections work and being expensive to produce.

The US doesn’t have the same system of national climate projections as in Australia and the UK but does have periodic National Climate Assessments that include a future climate component, and also a coordinated regional modelling program through the North America Regional Climate Change Assessment Program (NARCCAP). The NARCCAP program used cutting edge methods and produced useful regional-scale projections for the US, linked to the CORDEX simulations for the North American region. However, the overall effectiveness of projections for decision-making was hampered by not being linked to a national authority or decision-making process.

The Netherlands produced KNMI14, which takes a very different approach to future climate, by providing a set of four internally consistent climate scenarios with attached storylines rather than ranges of change for different climate variables and hazards. The scenario approach is tractable in this case because change in the Netherlands can be representatively sampled quite comprehensively by a matrix with two dimensions with two
levels each: warming level and change in atmospheric circulation over the region (driving changes to rainfall, many types of extremes and so on). This approach does not work well over a country as large and as climatically diverse as Australia. This scenario approach has advantages of standardisation for different applications to ensure that results are comparable between different analyses, as well as a simple and intuitive layout.

New Zealand recognised that the complex topography and varied climate within a small region meant that RCM modelling will offer considerable added value compared to global models. As a result, they have relied on an RCM ensemble as the primary data source for projections (six selected GCMs, four RCPs and a single RCM system). New Zealand has previously developed climate projections using statistical downscaling as well.

4.1 International coordinated downscaling – CORDEX

Coordinated multi-model RCM ensembles have become more tractable and more widely used in the last decade, with regional programs such as NARCCAP mentioned above. In recent years we saw the formation of the international program of Coordinated Regional Downscaling Experiment (CORDEX), similar to the move to the CMIP structure for global modelling 20 years ago.

The first round of CORDEX covered only intermediate resolution (around 50 km) using CMIP5 models as input. CORDEX-CMIP5 is a core component of the assessment of regional climate change in the IPCC AR6 in 2021, assessed alongside the CMIP5 and CMIP6 global models, and viewable in an interactive online Atlas tool. The main goal of the CORDEX CORE framework is to have a core set of RCMs downscaling a core set of GCM projections overall, or most, CORDEX domains, including CORDEX-Australasia.

CORDEX is connected with CMIP6 through its designation as a diagnostic model inter-comparison project (MIP) in CMIP6, with 25 km horizontal resolution a standard for CORDEX-CMIP6 ensembles (Gutowski et al. 2019). While CORDEX-CMIP6 won’t be finished in time and presented in IPCC AR6, it will be a useful resource in due course. CORDEX-CMIP6 can be an essential and leveraged part of national climate projections in Australia.

Like the global CMIP ensembles, CORDEX ensembles remain largely ensembles of convenience, with contributions from multiple international RCM centres. However substantial opportunity exists to improve upon this through coordination of ensemble design for CORDEX-Australasia and implementing innovations that have been introduced through programs like NARCCAP, NARCliM, ESCI and others. Coordination of very high resolution (<5 km) modelling ensembles that are ‘convection permitting’ and have great potential for looking at climate extremes remains largely a focus for individual groups and initiatives, but there is scope for more coordination here as well, as part of Australian national climate projections.
5 An update on different approaches for regional climate projections

As discussed in the previous section, there are advantages and disadvantages to the various approaches that different countries have taken to producing regional climate projections. As climate science has developed, we have seen an increasing variety of climate projection methods used with newer methods, such as the storylines employed by the Netherlands, standing alongside well-established methods, such as climate changes through time under different greenhouse gas emissions scenarios for the coming century. Here we review some current topics related to climate projections and discuss the implications for preparing the next set of Australian climate projections.

5.1 Dynamical and statistical techniques

Global and regional climate models are key tools in climate projections. As covered in Section 3, we can now quantify the potential for ‘added value’ from dynamical downscaling by regional models, and this value must be considered and exploited for projections to remain current. Different regional models can give different results and, just as in global climate modelling, it is best practice to use a multi-model ensemble. While in general the more models the better, there are practical limits to the number of models that can be run. Three is taken here as a minimum number of different models to be used.

However, along with dynamical methods, there is still an important role for statistical techniques, including statistical modelling or downscaling of regional climate – from GCM or RCM inputs. Statistical methods of producing regional climate data can be very powerful, but also need to be assessed and used in a multi-model framework. Also, statistical post-processing of all models is required to produce locally-relevant application-ready data, since the output is typically not calibrated and directly comparable to our observed datasets. Scaling techniques or bias correction using defensible method are critical for the development of useful information on changes in climate risks associated with extreme events, for agricultural applications, such as crop modelling, and for hydrological applications, such as the projection of changes in soil moisture or run-off.

5.2 Framing future change – past change, attribution, emissions pathways, warming levels

To understand the future, we must first understand the past and the present, and put all three in context. High quality observations are essential, along with work on ‘detection and attribution’ – detecting if a change has occurred and what the likely cause or causes were. Assessing and communicating this information is an important motivator for decisions and can also directly inform some decisions.

To address the wide range of user needs, there is still a central need to assess climate change under a range of plausible future emissions pathways, from a plausible very high emissions case through to an ambitious low emissions pathway. The global community still
employs the core of the Representative Concentration Pathway (RCP) framework, but these are now being superseded as they were defined from 2005. The field is now moving to the expanded Shared Socio-economic Pathway (SSP) structure, which present a matrix of different greenhouse gas concentration levels paired with five global socio-economic pathways (covering population, technology, conflict, equity and so forth), defined from 2015 onwards. These global pathways need national and state level interpretation.

Since the Paris Agreement of 2015, there has been an increase of interest in global warming levels, particularly at Paris Agreement targets of 1.5°C and 2°C global warming above pre-industrial levels. This requires additional processing and methods to the usual projection approaches, with regional projections for global warming levels primarily derived by ‘time sampling’ climate models, or else using atmosphere-only model ensembles, or from 'pattern-scaling' approaches (describing the characteristic pattern of change per degree of global warming (Tebaldi and Knutti, 2018)). Such analyses can provide some of the same types of information available to stakeholders as previous projections, but rather than projections for future time periods, the projections are related to a global warming level (e.g. ‘frequency of days above 30°C is X% greater at 2°C global warming than 1.5°C warming’). Given that the world is currently at around +1.1 °C above the pre-industrial baseline, climate change attribution can come together with projections for global warming levels to communicate the impacts at different levels of global warming (including the current level).

5.3 Not just models

In producing projections of the far future, models are a central tool, but they should not be used in isolation to predict future climates. There is still a strong need for assessment of various lines of evidence to form confidence statements and to maintain line-of-sight between the underlying physical science, through modelling, to data and information delivery. Confidence statements draw on process understanding, past trends and their attributions, evaluation of models, agreement between models and other relevant evidence, and are usually made using calibrated language from the IPCC system.

Assessment of multiple lines of evidence, including giving confidence statements, was employed in the 2015 national projections, VCP19 and the CMSI science report, and is being used in ESCI and other projects. This confidence assessment is a critical part of using projections in the appropriate way – from more specific decisions when confidence is high, to more flexible responses when confidence is lower. Practices and methods are always evolving and improving.

The full range of processes driving change need to be assessed and understood – from large-scale changes to ocean and atmosphere circulation, through drivers such as the El Niño Southern Oscillation and its effect on Australia, to local-scale changes such as changes to the land surface. Projections should be tied to underpinning climate science to have confidence in their utility. See also the NCSAC report on climate processes (Jakob and Singh 2020).

This physical understanding can be used to communicate the projections, not just to produce confidence statements. Projections based on models can be supplemented with ‘storylines’ which examine the underlying physical processes driving change and show a range of possible projections due to the diversity of dynamically-based changes.
For example, differing changes between models in the position of the extratropical storm track to the south of Australia is the primary ‘storyline’ behind rainfall change in southern Australia (see Shepherd et al. 2018; Mindlin et al. 2020). This approach may involve selecting representative climate models for each storyline (which builds on the ‘Climate Futures’ framework of Whetton et al. (2012)) to highlight potential dynamically-consistent changes across variables to highlight different possible futures for a region (e.g. warmer and wetter or much warmer and drier). Storyline approaches remain a relatively novel way of presenting climate projections with limited application in regional modelling efforts to date but are rapidly gaining momentum internationally.

Figure 3: The lines of evidence used to assess projected climate change and assign a confidence level. The IPCC system used to assign confidence is shown in the large box: using two dimensions of the amount and agreement between different lines of evidence to assign a semi-quantitative statement on the confidence in the projection statement using expert judgment.
6 Requirements for the development of the next generation of regional climate projections

New and updated regional climate projections are needed to fulfil multiple goals. These include:

- **Enhanced relevance and useability for existing users** – methods of communicating projections, and therefore of connecting to decision-making, are constantly developing, including the international trends mentioned above. Included in this is the need to better integrate climate projections with other sources of data and information. For example, combining projections of changes in climate extreme hazards with databases of infrastructure or natural values.

- **Delivery to new users and for new applications** – since 2015, new uses and users of climate projections have emerged, with new needs. This includes a greater focus from the private sector through mechanisms such as the international TCFD framework.

- **Scientific credibility** – to assess and use the latest research, data and modelling to ensure the projections are as credible as possible.

- **Scientific credibility** - the projections must be evaluated, verified and the data and information must be reproducible to meet modern scientific standards.

- **Relevance** – to use the latest data, information and developments to demonstrate the projections are up-to-date e.g. the new SSPs, the IPCC Sixth Assessment Report due in 2021-22, the latest generation of climate models in CMIP6 and the new generation of regional modelling made under CORDEX.

- **To keep pace with international best-practice** – both in terms of addressing science challenges such as the WCRP grand challenges and ‘lighthouses’ or quantifying the role of atmospheric circulation change on changes to extremes, but also in terms of communication such as the move towards presenting ‘climate impact drivers’ rather than base climate variables, or the move towards presenting physical climate change ‘storylines’ along with ranges of changes.

- **Legitimacy** – to be, and to be seen to be, cognisant of and responsive to the range of stakeholders needs and values, and to be aware of their barriers and enablers

Technical aspects of new projections need to consider the following perspectives:

- **New CMIP6 modelling needs careful and thoughtful handling.** The new model ensemble includes more models than ever, including models that are not ‘independent’ of one another. This can result from, for example, models sharing sections of code (e.g. representing cloud processes), which means they may behave more similarly to each other than we would expect from independently derived models. Climate projections need to take account of the relatedness of
particular models. An ensemble of 20 ‘different’ models, for example, may only have less than half this number of independent models (Knutti et al. 2013).

- Models sample a range of ‘climate sensitivity’. Climate sensitivity is defined as the long-term global mean temperature increase in the model response to a doubling of atmospheric carbon dioxide concentrations. The new generation of models in CMIP6 have on average higher climate sensitivities than in CMIP5, including a notable group with higher climate sensitivity that is considered possible but less likely, as well as two models with very low climate sensitivity that is also considered unlikely. It is important to note that climate models are not the only source of our estimates of climate sensitivity. Other sources are information from past climates (palaeo data), information on the response that has occurred to climate change emissions to date (historical changes) and process understanding of the key factors influencing climate sensitivity. The next set of national climate projections should consider a subset of CMIP6 models spanning the likely range of climate sensitivity.

- Any single model simulation represents just one ‘realisation’ of the climate. To better sample future possibilities, future projections need to consider an ensemble approach. For example, many CMIP6 modelling groups submit multiple projection runs, i.e. multiple simulations of future climate. Some centres also now produce Single Model Initial-condition Large Ensembles (SMILEs) with 30 or even 100 simulations. In addition, very large ensembles of atmosphere-only simulations are possible though projects such as the weather@home project at ClimatePrediction.net, and decadal prediction efforts provide useful large ensembles. Methods need to be devised to include the insights from large multi-member ensembles with CMIP6 and downscaling of CMIP6 in the next set of projections.

- ‘High impact low probability’ extreme climate events such as the Black Summer fires in 2019-20 are now of strong interest. Various techniques are needed to get reliable and quantitative information about these events, such as the application of generalised extreme value statistics to relevant datasets (Min et al., 2013) and the use of high-resolution modelling and large ensembles.

- *Ad hoc* regional modelling using single modelling systems and small domains is not currently supported by CORDEX. Coordinated regional downscaling using multi-model ensembles that representatively ‘sample’ the spread of future climate changes, and whose members demonstrate independence in their model errors, is needed.

- Careful evaluation of GCM and RCM strengths and shortcomings needs to be carried out at both broad and regional scales to assess model skill in representing mean climate, climate variations, weather and climate extremes and climate changes over the last hundred years.

- Projections need to use temporal and spatial resolutions that allow the simulation of a variety of climate hazards that are responsible for much of the risk associated with current climate variations and future climate change. Where the resolution or model evaluation more generally is not sufficient, this must be communicated clearly.

- Statistical modelling and post-processing must use best-practice methods.
• Previous national climate projections have covered all states and major territories in Australia. However, they have not covered the remote island territories of Australia, such as Norfolk Island. There would be value in including information on projected climate changes for these island territories.

• There needs to be links to the NCSAC Climate Services study (NESP ESCC Hub, 2021), with its recommendations for how climate projection data should be made available to end-users.

• The future beyond CMIP6 needs to be kept in focus as we move from 2021 to 2030. The future of CMIP modelling, and possible step changes in modelling (e.g. Digital Earth modelling globally at high resolution, a WCRP Lighthouse activity) needs to be monitored and assessed.
A major new projections release is warranted, as recommended by the Royal Commission, but this should be part of a continuity of information and service, so we propose a staged approach:

**Short term (next one to two years):** maintenance and minor updates of existing projections information, enhancing their usefulness through minor updates on an ongoing basis. Along with this should be ongoing consultation, relationship-building and capacity-building paving the way towards climate services at a series of scales.

**Major update, next four years:** a significantly updated set of national climate change projections based on the imminent IPCC AR6, CMIP6 and CORDEX-CMIP6 climate model outputs and including downscaling to very high resolution (~4 km) for selected regions.

The proposed modelling program would include:

- Support for Australian contributions to CMIP6 (using two configurations of ACCESS).
- Support for regional modelling for CORDEX-CMIP6 at very high resolution from multiple centres and models.
- Regional modelling using multiple models (WRF, BARPA, CCAM and others) in multiple centres including Universities, state agencies, the Bureau of Meteorology and CSIRO.

The program should also facilitate international partners to participate in CORDEX-Australasia and in very high resolution modelling. Along with climate modelling, the program would include extensive model assessment and evaluation, and using new developments of methodologies for combining downscaled model results with that of GCMs, and for optimal development of projections from multiple ensembles. It would produce final projections and confidence levels taking into consideration all available lines of evidence, including past climate, understanding of processes and model evaluation. Enhancements and improvements to products and services will be maintained and scaled up.

All new projections will be put into context of previous projections, so that users can easily understand what is new and what has changed. The program would enable communication across timescales, bringing together decadal forecasts with climate projections to give probabilistic near-term risk estimates, extending out to future scenarios. The program would also deliver locally-relevant, application-ready datasets.

**Ongoing development and delivery:** once the scientific assessment and model datasets are generated, there is a need for ongoing delivery and enhancement of national projections, planning and delivery of further enhancements and mainsteamging of climate change products and services in Australia (See Box 1).
Existing and new web tools on www.climatechangeinaustralia.gov.au and linked websites need to be developed and maintained, and better integrated with other platforms and geospatial datasets, to ensure tools remain relevant, useable and updated. In addition, there is a need to leverage the information obtained to further develop and improve the climate models themselves, ensuring improved projections in subsequent major national climate projections releases.

The goal of climate projections for users (‘customers’) is to support decisions that lessen the impact of climate change, take up opportunities and add to the resilience that underpins our future prosperity. In this context, ongoing monitoring and evaluation will ensure that strengths and weaknesses are identified and managed, and outcomes are achieved. Insights and lessons learned from the projections will be fed back to model development, climate research and climate services communities.

A formal strategy will need to be established to ensure the agreed outputs, outcomes and impacts are delivered. Key elements of the strategy would include governance, a stakeholder engagement plan, a research plan with outputs that target high priority outcomes and impacts, a communication plan, a risk management plan and a monitoring and evaluation plan.

Major features of the staged approach include:

- A new level of cross-institutional collaboration and coordination to improve effectiveness and efficiency.
- Increased collaboration and coordination between state and federal activities on climate projections (both modelling and data platforms), recognising that states will have their own priorities in terms of applications.
- Leveraging of international efforts in climate projections research, products and services.
- Formal partnerships between researchers and stakeholders to facilitate co-production of knowledge that is fit for multiple purposes.
- Formal knowledge brokering services alongside, but intimately linked to, the research stream, based on the national climate service capability plan prepared for NCSAC (See Box 1).
- Formal versioning of releases, as used in software. Each release will have documented technical details, as well as a comprehensive guide about what is new.
- Demonstrator projects at an operational level demonstrating where decision makers have applied projection information (supported by the collaboration team) to assess their climate vulnerability and risks.
8 Options for the next generation of regional climate projections

The national climate change projections and Natural Resource Management adaptation activities released in 2015 were supported by approximately $13 million from the Australian Government from July 2012 to June 2016 ($5m for projections, with $3m co-investment from CSIRO and $0.1m from Bureau of Meteorology). This funding covered stakeholder engagement, analysis of historical data, analysis of projections data from climate models, assessment of peer-reviewed literature, development of a range of products and delivery of a range of services.

Ongoing maintenance of products and services was supported by the NESP Earth Systems and Climate Change (ESCC) Hub until December 2020, however, funding is only $0.2 million. There was also support for the Climate Science Data Enhanced Virtual Laboratory (Climate DEVL) analysis platform, which will be a crucial building block in producing new climate projections. However, support for DEVL ended in 2020.

Options for regional climate projections in Australia prepared or planned during 2020-2030 include:

1. No new coordinated effort, a free market of ideas primarily relying on information products from overseas. Strengths: no investment needed; ideas can be tested elsewhere before being adopted here. Weaknesses: no national or local perspective in information, loss of local capacity.

2. Ongoing competitive market of effort at national, state and local level with no coordination at a national level. Strengths: competition of ideas and effort. Weaknesses: duplication of effort, lack of leveraging, lack of consistency for applications that cross borders, confusion from different messages.

3. No new projections until modelling makes a step change with model biases virtually eliminated and running at global ~1 km scale. Strengths: product will likely be higher quality for small scale processes. Weaknesses: provides no information in the near term and likely limited to one or a very few models with very small number of simulations, so estimates of uncertainties would be severely limited (it is unlikely this vision could be realised within 10 years).

4. Investment in national modelling capacity to produce projections entirely in-house (similar to UKCP18). Strengths: under central control and not vulnerable to international changes, experimental design can be strong. Weaknesses: expensive, doesn’t account for model differences.

5. Leveraging international effort under CMIP and CORDEX programs, supplemented by local effort, to produce new regional projections (the preferred option considered in this report).
Given the balance of efficiency of effort, the expense, and the ability to direct and control the effort, this report has found option 5 to be the most practical and useful.

There is no current funding for the development and delivery of a new major release of national projections. Given past experience, and the additional demands in realising the expanded vision, an approximate estimate of $30-50m of funding is suggested over four years.

8.1 Leveraging international activities

Funding of the next generation of regional climate projections represents immense opportunities to leverage Australia’s established links to internationally coordinated activities to make the best use of a large international investment in climate change projections. International links provide a path for participation and influence in global scientific endeavours and opportunities for Australian leadership where appropriate.

Relevant international activities include:

- The recent CMIP6 database, including new sets of GCM simulations.
- The CORDEX-CMIP6 ensemble of RCM simulations for Australia.
- The IPCC Sixth Assessment Report, Working Group 1 and 2 reports.
- Activities under WCRP and the European Union (e.g. Copernicus).
- Ongoing and future plans from New Zealand’s National Institute of Water and Atmospheric Research (NIWA) regional projections project.

8.2 Plan for next-generation climate projections – meeting information needs

The following points need to be considered when planning for the next generation of climate projections to ensure they meet user information needs:

- Co-design of research and delivery across science agencies and with stakeholder groups to meet existing and emerging uses (e.g. federal and state planning, TCFD activities by the private sector).
- Coordination and links between new regional climate projections with climate service providers, that are compatible with a range of delivery platforms, is essential.
- Coordination with climate observations and process research to link projections to the underpinning knowledge base is important to ensure credibility.
- It is important to emphasise that our climate has changed and revise the present probability of extreme events as context for how they may evolve over the next several decades.
- Marine projections (sea level rise, storm surges, waves, marine heatwaves) need to be used together with land and atmosphere projections in a consistent way for integrated assessments.
• Projections need to provide climate change risk information for chronic (gradual) and acute (extreme) hazards, including derived climate impact drivers (CIDs) such as heat waves, drought, fire weather, floods, marine heatwaves, storm surges, tropical cyclones and compound extreme events, along with base climate variables, in an integrated framework.

• Projections need to report change by ‘global warming level’, by emission scenario and by timeframe at appropriate spatial scales (e.g. regions, gridded data, sites).

• Projections need to ensure consistency across spatial scales from national to state to regional, include projection information for Australian islands and territories and provide information for time periods beyond 2100 (e.g. to 2300) for long-term planning horizons.

• Provide user support and services, including ongoing user support, targeted sector support, online help service, training courses and public communication, as a core component of climate services more widely (See Box 1).

8.3 Detailed plan for next generation regional climate projections

• **Global and intermediate-scale modelling:** New projections should use simulations from the international database of global climate models (CMIP6) being used in the IPCC Sixth Assessment Report to remain current. Judicious use of CMIP6 simulations requires targeted model evaluation, updated ensemble generation methods and careful model selection. Regional modelling can yield important insights. It is now best practice to do this under a coordinated program – through the CORDEX-CMIP6 simulation framework for the Australia domain. Recommended technical specs: 12-20 km horizontal resolution, at least 3 different regional models, nested within existing CMIP6 simulations from 5 or more different global models, historical and 2-3 future scenarios to 2100, 3 simulations from each regional model for each forcing.

• **Regional climate projections for key urban and coastal regions:** Higher resolution simulations (~4 km) yield key insights in areas of significant topography, coastlines and urban areas, especially for climate extremes. As for the national projections, it is best practice to produce these in a coordinated program of multi-model ensembles covering major population centres and key economic zones: NSW, Vic, SE Qld, NE Qld, Tas, SW WA, NW WA, southern SA. Recommended technical specs: 1 to 4 km horizontal resolution, nested within CORDEX-CMIP6 Australia simulations, at least 3 different regional models, 3 simulations from each model for each forcing and region.

• **Empirical statistical downscaling and post-processing:** Statistical modelling should be pursued as well as dynamical modelling. Post-processing techniques and practices need to be stepped up to international good practice standards, including bias-correction methods. Multiple methods need to be systematically tested and documented, then applied in a transparent system.
Hydrological projections: National projections of runoff, soil moisture and hydrological characteristics at 5 km grids for all of Australia, with CMIP6 global climate model simulations, dynamically downscaled regional climate simulations (consistent with the above next generation climate projections), robust bias correction, and hydrological modelling. This will build on hydroclimate projections research and products in the different states and agencies, through a co-ordinated program of development and testing, and translating knowledge and outputs into an operational product delivered by a national agency (like the Bureau of Meteorology).

Mean and extreme sea-level rise and storm surge projections: For all Australian coastline at 5km resolution, using CMIP6 global simulations and downscaled regional climate simulations, with high-resolution wind and ocean wave simulations for projections of storm surges and extreme sea level.

Data storage and infrastructure: There are major needs for web access to key data for all users, web tools for accessing and extracting data and very large underpinning data storage infrastructure accessible to expert users. This should leverage all existing effort, from the National Computing Infrastructure (NCI), and the delivery portal/s for existing regional outputs.
References


<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full meaning</th>
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<tbody>
<tr>
<td>CID</td>
<td>Climate Impact Driver</td>
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<tr>
<td>CMIP5/6</td>
<td>Coupled Model Intercomparison Project Phase 5/6, an international project under the WCRP</td>
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<tr>
<td>CORDEX</td>
<td>Coordinated Regional Downscaling Experiments, an international project under the WCRP</td>
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<tr>
<td>DAWE</td>
<td>Department of Agriculture, Water and the Environment (Commonwealth Government)</td>
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<tr>
<td>DoEE</td>
<td>Department of the Environment and Energy (Commonwealth Government, name change in early 2020)</td>
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<tr>
<td>ESCC Hub</td>
<td>Earth Systems and Climate Change Hub, a research Hub funded as part of the Australian Government’s National Environmental Science Program</td>
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<tr>
<td>EUCP</td>
<td>European Union Climate Prediction system</td>
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<tr>
<td>GCM</td>
<td>Global Climate Model</td>
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<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
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<td>NCSAC</td>
<td>National Climate Science Advisory Committee</td>
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<tr>
<td>NDRISC</td>
<td>National Disaster Risk Information Services Capability</td>
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<tr>
<td>NESP</td>
<td>National Environmental Science Program, funded by the Department of Agriculture, Water and the Environment</td>
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<tr>
<td>RCM</td>
<td>Regional Climate Model</td>
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<td>RCP</td>
<td>Representative Concentration Pathway</td>
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<tr>
<td>TCFD</td>
<td>Taskforce on Climate-related Financial Disclosures</td>
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<tr>
<td>WCRP</td>
<td>World Climate Research Program</td>
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Appendix 1. Stakeholder consultation list

Input for this report was drawn from a set of direct engagements, feedback on the consultation drafts and the experience of authors.

**Direct engagements** – engagements were meetings and panel discussions. Notes were taken, but there are no formal transcripts and formal analyses were not performed.

<table>
<thead>
<tr>
<th>Date</th>
<th>Agency</th>
<th>Person or people</th>
</tr>
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<tbody>
<tr>
<td>18 Jun 2019</td>
<td>NSW Office of Environment and Heritage, Climate and Atmospheric Science</td>
<td>Kathleen Beyer, Matt Riley</td>
</tr>
<tr>
<td>26 Jul 2019</td>
<td>ARC Centre of Excellence on Climate Extremes (CLEX); NCSAC Climate process research priorities study</td>
<td>Christian Jakob</td>
</tr>
<tr>
<td>7 Aug 2019</td>
<td>University of Melbourne School of Earth Sciences</td>
<td>Multiple climate researchers</td>
</tr>
<tr>
<td>22 Aug 2019</td>
<td>CSIRO Land and Water, CSIRO Agriculture and Food</td>
<td>Nicky Grigg, Lilly Lim-Camacho</td>
</tr>
<tr>
<td>7 Oct 2019</td>
<td>Bureau of Meteorology climate services and research sections</td>
<td>~15 participants,</td>
</tr>
<tr>
<td>22 Oct 2019</td>
<td>Australian Department of Energy and Environment</td>
<td>Miriam McMillan</td>
</tr>
<tr>
<td></td>
<td>Electricity Sector Climate Initiative (ESCI)</td>
<td></td>
</tr>
<tr>
<td>18 Nov 2019</td>
<td>Tasmanian Government workshop, Department of Premier and Cabinet (DPAC), water resources, emergency management, Hydro Tasmania, Tas Climate Futures research group</td>
<td>~ 12 participants</td>
</tr>
<tr>
<td>18 Nov 2019</td>
<td>CSIRO Oceans &amp; Atmosphere Hobart, decadal forecasting group, University of Tasmania researchers</td>
<td>~10 participants</td>
</tr>
</tbody>
</table>
## Cross-jurisdictional Community of Practice for Climate Science, online

**Date:** 25 Nov 2019

Cross-jurisdictional Community of Practice for Climate Science, online

~15 participants from almost all states

## BoM Research workshop, climate services,

**Date:** 28 Nov 2019

BoM Research workshop, climate services,

Next Gen climate projections presentation

## Forum on BoM and state government climate change modelling and projection projects, Adelaide

**Date:** 9 Dec 2019

Forum on BoM and state government climate change modelling and projection projects, Adelaide

~30 participants, all states, BoM climate services, hydrological projects, Next Gen study, etc

## Knowledge Exchange: Services and Science Supporting Climate Action KE4CAP workshop, CSIRO Aspendale

**Date:** 3-5 Mar 2020

Knowledge Exchange: Services and Science Supporting Climate Action KE4CAP workshop, CSIRO Aspendale

~40 participants, federal and state govt's, BoM, CSIRO, private sector, EU climate service providers, Copernicus

## Cross-jurisdictional Community of Practice for Climate Science, online meeting, seeking feedback on Consultation Draft, Next Gen projections report

**Date:** 19 Nov 2020

Cross-jurisdictional Community of Practice for Climate Science, online meeting, seeking feedback on Consultation Draft, Next Gen projections report

All states, ~15 participants

### Engagement through responses to the Consultation Draft report:

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<thead>
<tr>
<th>Group</th>
<th>Area of special interest</th>
<th>Response</th>
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<td>NSW Department of Primary Industries</td>
<td>Agriculture and primary industries in NSW</td>
<td>All comments addressed</td>
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<tr>
<td>NSW Department of Environment, Energy and Science</td>
<td>NSW state level planning</td>
<td>Most comments addressed (some beyond scope)</td>
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<tr>
<td>ARC Centre of Excellence for Climate Extremes (CLEX)</td>
<td>Research</td>
<td>All comments addressed at a high level</td>
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<tr>
<td>Bureau of Meteorology (consolidated response from various people)</td>
<td>Weather and climate data, forecasts and services</td>
<td>All comments addressed</td>
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<tr>
<td>CSIRO Decadal Forecasting</td>
<td>Near-term climate forecasts</td>
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<td>CSIRO Regional Climate modelling group</td>
<td>High resolution modelling</td>
<td>All comments addressed</td>
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<tr>
<td>CSIRO Hydrology modelling group</td>
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<tr>
<td>Australian Department of Agriculture, Water and the Environment (DAWE)</td>
<td>Policy and governance</td>
<td>All comments addressed</td>
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<tr>
<td>Cross-jurisdictional Community of Practice on Climate Science (X-J CoP)</td>
<td>State level activities and coordination</td>
<td>Most comments addressed (some beyond scope)</td>
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Direct experience of report authors:

<table>
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<tr>
<th>Author</th>
<th>Project</th>
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<tr>
<td>All</td>
<td>NESP Earth Systems and Climate Change Hub</td>
</tr>
<tr>
<td>David Karoly</td>
<td>Australian Sustainable Financial Initiative (ASFI)</td>
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<tr>
<td>Michael Grose, Jason Evans</td>
<td>Climate Measurement Standards Initiative (CMSI)</td>
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<tr>
<td>Michael Grose, John Clarke</td>
<td>Electricity Sector Climate Initiative (ESCI)</td>
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<tr>
<td>Aurel Moise</td>
<td>Regional Climate Consortium for Asia and the Pacific (RCCAP) and climate projections in Singapore</td>
</tr>
<tr>
<td>Jason Evans</td>
<td>NSW and ACT Regional Climate Project (NARCLIM) version 1</td>
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<tr>
<td>John Clarke, Michael Grose</td>
<td>Victorian Climate Projections 2019 (VCP19)</td>
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<tr>
<td>Michael Grose</td>
<td>World Climate Research Program (WCRP) Variables for Impacts, Adaptation and Climate Services Advisory Board (VIACS-AB)</td>
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<td>Michael Grose</td>
<td>Climate Futures for Tasmania</td>
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<tr>
<td>David Karoly, Rob Colman, Michael Grose, Jason Evans</td>
<td>Intergovernmental Panel on Climate Change (IPCC) assessment reports and special reports</td>
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<tr>
<td>David Karoly</td>
<td>National Disaster Risk Information Services Capability (NDRISC) pilot study</td>
</tr>
<tr>
<td>Most authors</td>
<td>Previous national climate projections for Australia</td>
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