2. Methods

This chapter explains the data sets, models and analysis techniques used to produce the VCP19 climate projections. The chapter outlines the existing set of previous modelling considered in VCP19 and the process to produce the new fine-scale regional climate model (RCM) simulations of the Victorian climate. The chapter also describes the regions considered, and how changes are calculated and presented for the regions.

2.1 Climate data sets

When developing regional climate projections for Victoria, it is important that multiple and reputable lines of information and evidence are examined and considered such as observations, trends, global climate models of future climate and higher resolution regional climate models. This approach ensures that the different possible future climates simulated by climate models are considered and an appropriate level of confidence is assigned to different outcomes of global warming. Without a documented case, no set of outputs should be considered superior to all others and used in isolation, although agreement between different model ensembles can be a source of confidence in the results. It is also important to consider some of the more extreme model simulation results if they are credible, given the significant impacts that could occur if that model projection was realised in our future climate. Developing regional climate projections is a process of collecting all available historical and simulated future climate change information and interpreting that information to understand the probable and possible regional outcomes of global warming.

Global climate models (GCMs) are our best source of information regarding how increasing greenhouse gas concentrations can affect the global climate of the Earth. These GCMs are computer software models that couple various components of the Earth system, including atmospheric processes, land processes, oceans, sea-ice, aerosol feedbacks and carbon cycle feedbacks. By using prescribed scenarios of greenhouse gas emissions, it is possible to estimate how quickly the Earth system can warm and some of the responses to this warming by the different Earth system components (e.g. melting of sea-ice). To aid with the development of climate change projections, the different GCMs all contribute to the Coupled Model Intercomparison Project (CMIP, with the current generation being CMIP5 and the new CMIP6 experiment being underway at the time of writing). For the CMIP5 generation of GCMs, greenhouse gas emission scenarios are described by representative concentration pathways (RCPs). The RCPs comprise RCP2.6, RCP4.5, RCP6 and RCP8.5, where the number after the RCP indicates the increase rate of energy (e.g. stored as heat) trapped in the Earth system by the increased concentrations of greenhouse gases. A higher number associated with an RCP results in a warmer climate and more severe impacts on the environment. RCP2.6 is the greenhouse gas emission scenario used by the GCM development teams that is the closest to that required to meet the Paris Agreement targets discussed in Chapter 6. RCP4.5 and RCP8.5 are often a focus for climate projections as they have been interpreted as medium and high emissions scenarios, respectively.

The GCMs contributing to the CMIP experiments provide the most diverse set of independent model data sources for developing climate projections. However, a limitation of GCM data sets is that the complexity of the modelling combined with limitations on supercomputing hardware results in GCMs typically having a grid-box resolution of 100 to 200 km. This means that mountains and coastlines are not always well resolved, urban areas can be neglected, and certain atmospheric phenomena can be poorly resolved (e.g. storms). Downscaling techniques are often employed to supplement some of the missing information needed for regional projections of climate change that is not directly available from the GCMs.

Downscaling can use a wide variety of techniques, all with various strengths and weaknesses (Ekström et al. 2015). In general, downscaling attempts to interpret regional changes in climate that are poorly resolved in the GCM simulations. Two popular approaches to downscaling climate models are statistical downscaling and dynamical downscaling. Statistical downscaling, as used for the *Victorian Climate Initiative* (VicCI), relies on relationships between large-scale atmospheric behaviour and the local response in weather. Often statistical downscaling is informed by historical observation records, from which the large-scale and local-scale relationships can be derived. In comparison, dynamical downscaling techniques rely on a computer simulation of different atmospheric and land-surface processes, in a similar way to how the GCMs model the atmosphere. However, dynamical downscaling focuses its computing resources to better spatially and temporally resolve a small region, at the expense of resolving the rest of the globe. Dynamical downscaling models also usually focus on the atmospheric and land-surface modelling, neglecting ocean and sea-ice components of the GCMs. Combining the results of statistical (e.g. VicCI) and dynamical methods can often be useful for developing regional climate projections, since the statistical approach relies on historical data to interpret regional changes in climate, whereas the dynamical approach relies on computer simulations of atmospheric processes at finer spatial-scales than is practical for the GCMs to simulate. This leads to different assumptions behind the downscaling technique, which can be best understood by combing multiple sources of downscaling when developing regional projections. The learning from comparing these different downscaling techniques is discussed further in Chapter 5.

An example of an important downscaled data set for Victoria is the statistically downscaled 5 km resolution data sets developed for VicCI. This climate data is already being used within the Victorian Government and water corporations and is important for framing new and future climate modelling. Another source of downscaled climate data for Australia is the *Coordinated Regional Climate Downscaling Experiment* (CORDEX) regional climate model inter-comparison experiment (http://www.cordex.org/). CORDEX provides 50 km resolution climate data for the Australasia region (including Australia, New Zealand and neighbouring islands), using different climate modelling systems within a common experiment framework. The New South Wales Government has previously commissioned a dynamical downscaling of the regional climate for their state at 10 km resolution, which is known as the NSW and ACT Regional Climate Modelling (NARCLiM) project, which overlaps with the Victorian region and therefore contributes towards the Victorian regional projections. Another relevant data set for this study is the *Benefits of Reduced Anthropogenic Climate Change* (BRACE), which is a project looking specifically at the reduced impacts of lower emissions scenarios compared to higher ones (Sanderson et al. 2018). This includes climate change under the Paris Agreement global warming targets of 1.5 and 2°C since pre-industrial times, partly produced to inform the IPCC Special Report on 1.5°C (IPCC 2017). The project included the production of a global climate model medium ensemble of the Community Earth System Model (CESM) where global warming plateaus at each target, titled BRACE1.5. The ensemble features 15 climate simulations meaning that variability is well sampled but is dependent on a single global climate model.

The *Victorian Climate Projections 2019* project draws on a range of available data sets in addition to the new high-resolution modelling undertaken specifically for Victoria using the Conformal Cubic Atmospheric Model (CCAM) described in the following section. The climate data sets used to develop regional projections for Victoria are summarised in Table 1.

Table 1. Climate projection data sources drawn on for the Victorian Climate Projections 2019 (VCP19) development

Data set	Provenance	Resolution	Contribution to VCP19
VCP19 CCAM	Focus on Victoria; based on CMIP5, RCP4.5 and RCP8.5	5 km	Primary high-resolution data source (50 km version also used for national context)
GCMs from the Coupled Model Intercomparison Project phase 5 (CMIP5)	International; up to 42 models; source for IPCC Fifth Assessment Report (2013)	60–200 km	Source of host models for CCAM downscaling; key source of CCIA data sets
Climate Change in Australia (CCIA)[1]	Australia-wide (CMIP5 based); published 2015	Application-ready 5 km; change data: 60–200 km	Key data source; critical context for Victorian projections; includes earlier 50 km CCAM data; source of Australian model evaluation information; guidance material
Bureau of Meteorology Statistical Downscaling Model (BOM-SDM)[1,2]	Contributed to CCIA and VicCI data sets	5 km	Context for VCP19
NSW and ACT Regional Climate (NARCLiM)[3]	Focus on NSW, also covers Victoria; based on CMIP3, SRES A2 only	10 km (some data at higher resolution)	Context for VCP19; comparison of higher emissions scenarios (A2)
Benefits of Reduced Anthropogenic Climate Change (BRACE)[4]	International	Global and Victoria	New application to Australian context; future climate under the Paris Agreement targets of 1.5 & 2.0°C warming

1 https://www.climatechangeinaustralia.gov.au/en/climate-projections/about/modelling-choices-and-methodology/
2 http://www.bom.gov.au/research/projects/vicci/
3 https://climatechange.environment.nsw.gov.au/Climate-projections-for-NSW/About-NARCliM
4 http://www.cgd.ucar.edu/projects/chsp/brace1.5.html

All currently used, or otherwise current generation climate model outputs have been considered, except for the *Climate Futures for Tasmania* data sets that are not included here as:

- they were made using the previous generation (CMIP3) of global climate model inputs
- they were developed using a previous version of the CCAM model
- the winter rainfall projection for southeast mainland Australia is different from host models (the global climate models used as input) due to a model-specific effect that means the results may not be representative of the broader range of projections.

2.2 New modelling

Although there are a number of existing climate data sets described in the previous section, climate change simulations for Victoria at resolutions below 10 km were limited to statistically downscaled data sets that were used for VicCI. Therefore, it was decided that new dynamical downscaling at a resolution of 5 km could be beneficial when developing projections for Victoria, since the dynamical downscaling employs different assumptions and techniques to statistical downscaling, so including them provides a more diverse and independent set of modelling approaches to inform the predicted changes to the regional climate. The new high-resolution dynamical downscaling is not a replacement for the existing VicCI data sets, nor a replacement for the GCM data sets. Rather, the new simulations are intended to provide an additional source of information and data that can help strengthen conclusions drawn from existing data sets, shed new insights into some regional climate phenomena, and help define levels of confidence in the projected regional consequences of global climate change.

There is flexibility in how a dynamical downscaling experiment is undertaken, but in general the regional climate models (RCMs) used for dynamical downscaling adhere to some basic principles:

- The RCM includes information from the GCMs to determine the large-scale changes to the oceans and Earth system as well as the rate of global warming.
- The RCM includes mountains, coastlines, urban areas and other details at the surface that are poorly resolved by the GCMs.
- The RCM improves the representation of atmospheric physical processes that are relevant for the spatial-scales being simulated.

High-resolution dynamical downscaling of global climate simulations can result in improved modelling of regional climate where there is complex orography, such as mountains or coastlines that were poorly resolved by the host global climate model. The higher-resolution dynamical downscaling can also resolve local features such as urban heat islands due to the ability to include urban materials and energy use in the simulation. Regional climate models may also provide better simulation of variability in winds, temperature and rainfall, through better resolution of atmospheric processes (e.g. clouds, boundary layer mixing, etc.). Consequently, certain types of extreme weather such as storms and strong winds are usually better represented by the regional climate models than for the lower resolution global climate models. Dynamical downscaling has been used to produce transient data sets of projected regional climate change (e.g. from 1960–2100) rather than time slices (e.g. 1986–2005, 2041–2060 and 2081–2100) which helps with assessing the progression of change. A possible weakness of standard dynamical downscaling techniques is that errors in the GCM simulation may undermine the performance of the RCM simulation. For this reason, it is common for dynamical downscaling experiments to attempt to address GCM biases and minimise their impact on the RCM simulation (e.g. Katzfey et al. 2016).

For the new VCP19 high-resolution climate simulations, CSIRO's CCAM was used for dynamically downscaling GCM data sets (McGregor 2005; McGregor and Dix 2008). CCAM has been used for numerous regional climate modelling projects in Australia and overseas, including the NRM projections for Australia, *Climate Futures for Tasmania*, *High-resolution Climate Projections for Queensland* and *Climate Projections for the Australian Alps*. CCAM is also contributing to the CORDEX intercomparison experiment and is used in South Africa, New Zealand, South East Asia and the Pacific. The CCAM source code is freely available for scientific researchers (https://confluence.csiro.au/display/CCAM/CCAM).

CCAM has a variable resolution global grid that can be focused over a region of interest (see Figure 2). This means the region of interest can be simulated at high resolution, while still maintaining a lower resolution simulation of the entire globe. This is different to the more traditional approach used by RCMs based on a limited area simulation. Limited area climate models only simulate the climate for a region, often defined by a rectangle, and therefore require atmospheric data to be supplied from a GCM at their lateral boundaries that represent the edges of the limited area simulation. Since CCAM does not have lateral boundaries, it can avoid problems arising from the prescription and interpolation of GCM data at the boundaries of limited area models. Another feature of CCAM is its use of the Community Atmospheric Biosphere Land Exchange (CABLE) land-surface model (Kowalczyk et al. 2013) and the Urban Climate and Energy Model (UCLEM) (Thatcher and Hurley 2012; Lipson et al. 2018). These sub-models were developed to better represent Australian conditions, with the UCLEM model initially developed to represent the climate of Melbourne, including the urban heat island discussed in section 4.2.2. Thirdly, CCAM can operate as a global atmospheric climate model, which allows us to modify the ocean temperatures simulated by GCMs to reduce potential GCM biases that can be introduced into the regional simulation. Although limited area climate simulations also attempt to correct biases in their lateral boundary conditions, these corrections can be complex and non-linear due to the way different atmospheric variables interact with each other such as temperature, moisture, clouds, wind, aerosols, etc. CCAM avoids this problem by using a global simulation where the CCAM physical and dynamical processes can internally resolve the changes arising from correcting GCM biases.

It should be stressed that regional climate simulations do not necessarily improve all aspects of a climate simulation and can feature new biases or errors. Also, different dynamical downscaling models produce different simulations of the future climate, making it more difficult to provide certainty in the production of climate change projections. Regional climate models rely on the same atmospheric physical parameterisations that are used in global climate models and can be prone to the same errors due to the imperfect understanding of the atmosphere. Most regional climate models are atmosphere-only models and do not include feedbacks with the ocean, which can be important for simulating the climate along coastlines. For VCP19, CCAM was configured in an atmosphere-only model, due to the CCAM ocean model being under development. The reduction of GCM ocean temperature biases also weakens the relationship between the downscaled climate and the projections of the host GCM, reducing the diversity in independent sources of climate model data sets.

All climate models and downscaling techniques include different assumptions in their design and hence no single model should be considered a definitive prediction of the future climate. This principle applies to the CCAM dynamically downscaled results provided in VCP19, since CCAM still represents a single modelling system. Therefore, when discussing the projections of future climate, the CCAM results will be presented in the context of existing GCM results, VicCI statistical downscaling and other dynamical

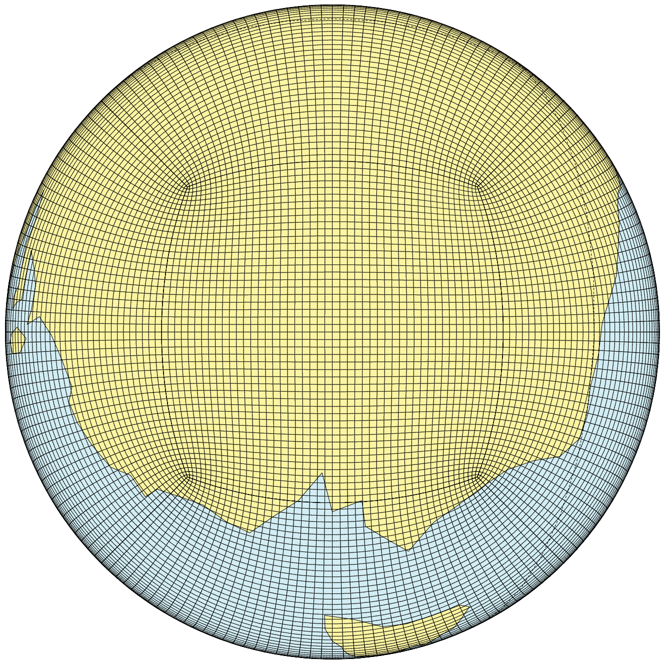


Figure 2. The CCAM variable resolution global grid, focused over Victoria

downscaling experiments such as NARCLiM, where possible. It is then possible to see if the CCAM simulations are an outlier of the existing sources of climate change information and to assign a level of confidence in the CCAM projections. Care is taken to separate the regional changes in climate simulated by CCAM from the larger-scale changes in climate where possible. For example, the simulated change in rainfall by the high-resolution modelling may be modified by the presence of a mountain range that was not resolved in the GCMs, and the simulated change may be supported by a known physical process or mechanism that explains the regional model projection. There may then be more confidence in generalising the simulated regional change in rainfall for regional projections, independently of the larger scale changes found in the individual regional climate simulations.

As well as avoiding using a single source of data for developing regional projections for Victoria, it is also important to downscale multiple GCM simulations of the future global climate to better represent different possible regional changes in climate. This is so that the projected changes in the regional climate as simulated by CCAM are more consistent with the range of different projections of global climate models. This is important when assessing the range of probable and possible future climate scenarios for the regional projections in Chapter 5. Six GCMs were chosen for downscaling by CCAM as listed in Table 2, which were selected from the eight-model subset identified for the CCIA projections. These selected GCMs demonstrated high simulation skill and are representative of the ranges of projected change for Australia. The six models were chosen to represent a range of climate warming that was consistent with the range of projections made by the CMIP5 ensemble of GCMs, including both drier and wetter future climates, as well as having realistic representations of large-scale drivers of the Australian climate (e.g. ENSO, monsoons, etc.). In this way, the six models downscaled can be considered a combination of higher quality global climate models as well as a sufficient cross-section to represent the broad range of global climate model projections for Australia.

In addition to downscaling the six GCM projections of the future climate, CCAM also downscaled the ERA-Interim reanalysis. A reanalysis is produced using data assimilation techniques to incorporate meteorological and ocean observations of the weather into a global atmospheric simulation. The atmospheric variables are then adjusted to ensure that the global simulation is as consistent with the observations as possible, while still following the governing geophysical equations that describe the functioning of the atmosphere. The assimilation of observations in reanalyses that are not available to the climate GCMs (which are designed to simulate a future climate where the observations do not exist) results in reduced simulation errors for the present climate. Hence downscaling of reanalyses is a useful way to evaluate the downscaling performance of CCAM for the present climate. When downscaling climate GCMs for the future climate, CCAM was run from 1960 to 2100, for two representative concentration pathways (van Vuuren et al. 2011): RCP4.5 and RCP8.5.

There are two stages to CCAM downscaling. The first stage is to simulate the global atmosphere at 50 km resolution, with the sea surface temperatures (SSTs) taken from the host GCM after bias correction of the mean and variance (Hoffmann et al. 2016). These simulations run continuously from 1960 to 2100, although the historic period (up to 2005) is common for both RCP4.5 and RCP8.5. The 50 km simulations represent a reconstruction of the atmosphere after removing biases introduced by the GCM SST bias, but to not include any atmospheric information directly from the host GCM. The second stage is to nest a 5 km resolution simulation, focused over Victoria, using CCAM's stretched grid within the 50 km global simulation. The 5 km simulation is guided at large spatial scales by the 50 km simulation using a scale-selective filter (Thatcher and McGregor 2009) but adds considerable detail in surface features (e.g. mountains, coasts, urban heat islands, vegetation, etc.) as well as providing some better-resolved atmospheric processes compared to the GCM (e.g. extreme rainfall). The use of bias-corrected GCM SSTs has significant implications for the downscaling process. Since the GCM SSTs are modified and the global atmosphere is reconstructed, then the downscaled CCAM data sets can differ in their projections from the host GCM. As a result, care is taken to separate the regional-scale projections from the larger-scale projections of the CCAM 50 km simulations. These differences do not necessarily mean that the CCAM projections are incorrect, rather the projections are influenced using a single CCAM-based downscaling process and should be interpreted in the context of the CMIP5 GCM ensemble and other downscaled data sets. A visualisation of the grid spacing and surface height in each stage shows the increasing detail through downscaling (Figure 3).

Table 2. The historical reanalysis model and six global climate models used as host models for downscaling over Victoria using CCAM. The relevance of global climate model is based on Climate Change in Australia.

Model/reanalysis name	Relevance for VCP19 projections
ERA-Interim (reanalysis)	Reanalysis product that is useful when evaluating dynamical downscaling in the present climate.
ACCESS 1-0	A hot, dry model in the south of Victoria. Representative of the consensus of GCM projections in northern Victoria.
CNRM-CM5	Representative of the consensus of GCM projections over Victoria, particularly in the north.
GFDL-ESM2M	Often a hot, dry model for Victoria.
HadGEM2-CC	Often a hot, dry model for Victoria.
MIROC5	Often a low warming, wet model for Australia and Victoria.
NorESM1-M	Often a low warming, wet model for Victoria, especially in the south.

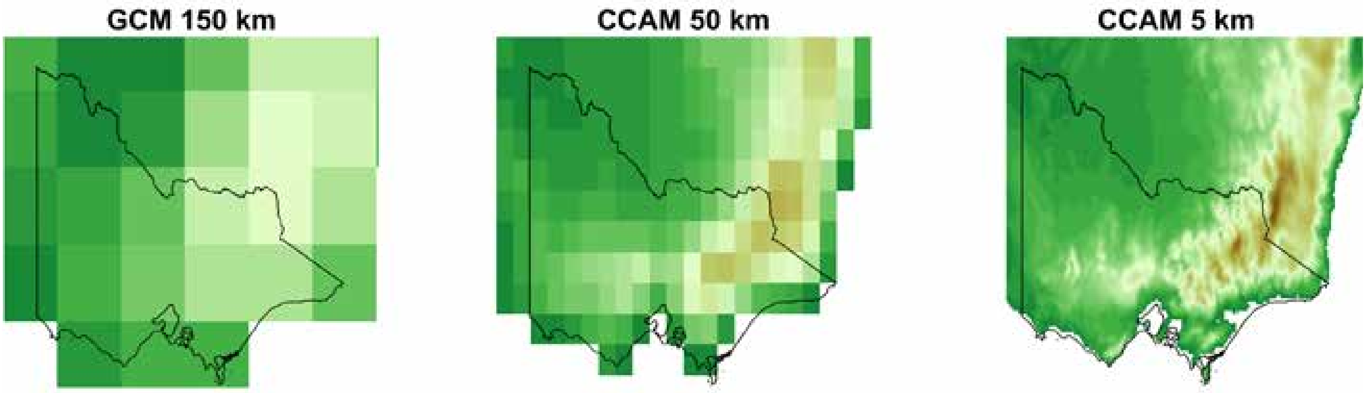


Figure 3. Topography of Southeast Australia in a typical GCM resolution (about 150 km), intermediate downscaling using CCAM (50 km) and high-resolution downscaling using CCAM (5 km), the height scale extends to 2000 m above sea level.

It should be noted that the final report for the VicCI project (Hope et al. 2016) raised some important questions regarding the use of downscaling approaches for developing climate change projections. They observed a marked divergence in the results of the statistically downscaled models compared with the dynamically downscaled models that they examined. This behaviour also occurs for the CCAM dynamical downscaling described in this report. All downscaling models will have broadscale biases and errors in their simulation of the regional climate that are associated with that model. The different biases of downscaling models can be illustrated by comparing the different downscaling data sets, although the model with the smallest biases is usually unknown. Unless there is a physical explanation that can clarify why an individual downscaling approach is incorrect, then no single downscaling modelling system can be preferred over any other downscaling technique. In this way, the CCAM downscaling experiments presented in this report are intended to enhance the amount of climate modelling data that can be used to develop regional projections, rather than be considered a superior data set to other downscaling techniques. There are examples discussed later in this report where CCAM will provide some important insights into future changes in Victoria's climate, but these insights are most effective when their conclusions are reinforced by the other downscaling techniques.

It is important to note that dynamically downscaling to higher resolution does not necessarily eliminate errors from the host GCM's climate simulation. Rather, the dynamically downscaled simulations can supplement and extend projections made by the GCM. For example, the CCAM dynamical downscaling can better represent the mean rainfall near mountains, and better represent extreme rainfall compared to the host GCMs. The CCAM output should not be used independently of the GCM results, which give a much larger ensemble of future climate change for Victoria, but rather be used to better understand the projections of six representative GCMs, such as how regional influences might modify the rainfall compared to the GCM simulation. For this reason, regionally dependent projections of the model are from the large-scale changes that arise from a combination of changes in ocean temperatures simulated by different GCMs but interpreted by a single CCAM atmospheric model. Chapter 5 contains examples of how the CCAM results can modify some regional aspects of the GCM simulations, so that the results can be interpreted in the broader range of GCM projections.

2.3 Area-averaged changes

In line with international practice (IPCC 2013a), a time-slice approach is used to compute future change relative to an historic baseline (see Figure 4). This method involves calculating the difference between a climate model's future and historic values (each averaged over 20 years) for a given emissions scenario and time-period. The historic baseline period used for this calculation was the 20-year period, 1986–2005. This is consistent with the IPCC's Fifth Assessment Report (IPCC 2013a) and the CCIA projections (CSIRO and Bureau of Meteorology 2015).

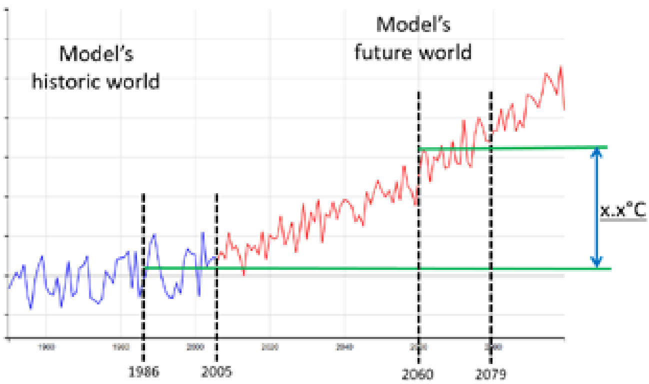


Figure 4. Time-slice method: by computing the difference between the model's future temperature and past values, any inherent bias in the model is removed.

One advantage of this approach is that it corrects for climate model bias (e.g. a model may be consistently slightly too cool or too dry). By comparing the model's simulation of the past with the same model's simulation of the future, the time-slice method removes this bias. Once computed using the time-slice method, the gridded changes were averaged over the regions described in section 2.4. The climate variables that have been computed as regionally-averaged data are described in Table 3.

2.4 Regionalisation

Throughout this report, analyses of past and future climate are presented at both state-wide and regional scales. Regional analyses were undertaken at two spatial scales, as appropriate to the projection data sources used. The lower-resolution pre-existing GCM results were analysed for six regions (see Figure 5), consistent with the *Climate-ready Victoria* work previously commissioned by DELWP (hereafter referred to as 'GCM regions'). For the analysis of the higher-resolution RCM results, the six GCM regions were sub-divided into 10 smaller regions (hereafter referred to as VCP19 regions). These 10 VCP19 regions align with the pre-existing Victorian Government Regional Partnership Regions. The nested nature of the two regionalisation schemes permits meaningful comparison between GCM and RCM results.

The two sets of RCM and GCM regions are described in Table 4 and shown in Figure 5.

Table 4. Description of the regions used for regional analyses of GCM and RCM results, including four larger GCM regions that comprise a pair of smaller RCM regions. Additionally, regional reports were developed for each of the high-resolution regions.

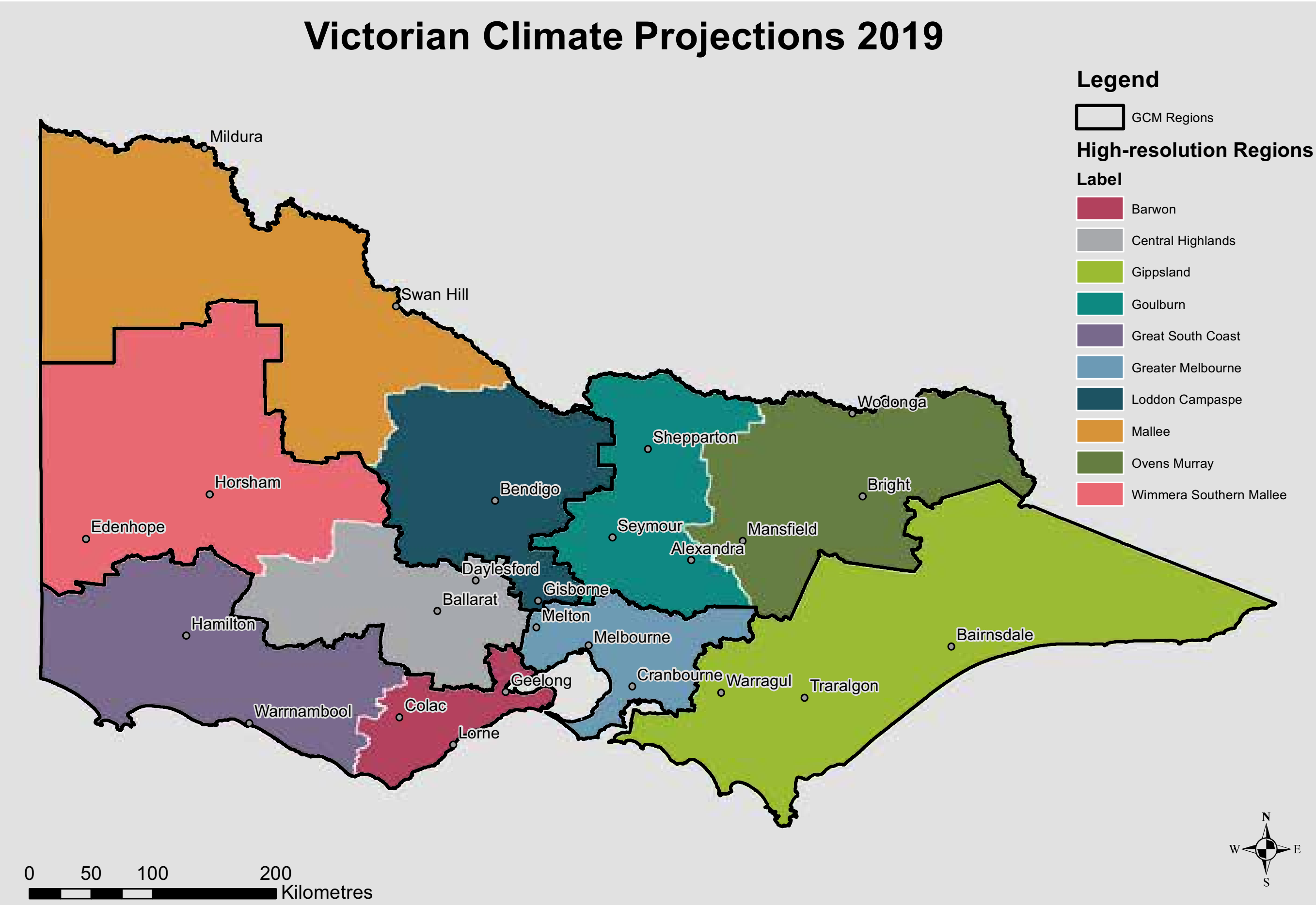
GCM regions	High-resolution regions
Barwon South West (BARSW)	Barwon (BAR)
	Great South Coast (GSC)
Gippsland (GIPPS)	Gippsland (GIP)
Grampians (GRAMP)	Central Highlands (CEH)
	Wimmera Southern Mallee (WSM)
Hume (HUME)	Ovens Murray (OVM)
	Goulburn (GOU)
Loddon Mallee (LODMA)	Loddon Campaspe (LOC)
	Mallee (MAL)
Metropolitan (METRO)	Greater Melbourne (MET)

Regionally-averaged changes were computed from GCM and RCM data for the six GCM regions. Averages were computed from just the high-resolution RCM data for the 10 smaller regions shown in Figure 5. Regional reports have been developed for each of the 10 smaller regions. These can be found at https://www.climatechangeinaustralia.gov.au/vcp19.

Table 3. Climate variables for which area-averaged changes have been computed

Climate variable (change units)	Temporal scale	Availability of gridded data sets
Mean near-surface air temperature (°C)	Annual, seasonal, monthly	Yes
Maximum daily near-surface air temperature (°C)	Annual, seasonal, monthly	Yes
Minimum daily near-surface air temperature (°C)	Annual, seasonal, monthly	Yes
Rainfall (%)	Annual, seasonal, monthly	Yes
Relative humidity (%)	Annual, seasonal, monthly	Yes
Wet areal potential evapotranspiration (%)	Annual, seasonal, monthly	Yes
Mean wind speed (%)	Annual, seasonal, monthly	Yes
Solar radiation (%)	Annual, seasonal, monthly	Yes
Extreme (1-in-20-year) rainfall (%)	Annual, seasonal	No
Extreme (1-in-20-year) daily maximum temperature (°C)	Annual, seasonal	No
Extreme (1-in-20-year) daily minimum temperature (°C)	Annual, seasonal	No
Extreme (1-in-20-year) wind speed (%)	Annual, seasonal	No

Figure 5. Map of the regions used for regionally averaged calculations (GCM and RCM) and for the regional reports (high-resolution regions).



2.5 Application-ready data sets

Application-ready data sets are data in a form that is compatible with an applied model or analysis, including a representation of climate variability compatible with the data used to calibrate the applied model (https://www.climatechangeinaustralia.gov.au/en/support-and-guidance/using-climate-projections/application-ready-data/). Such application-ready data are often used as inputs to sector-specific impacts models (e.g. crop growth models or ecological models) and can provide useful insights into extremes.

For VCP19, application-ready data is derived by using a percentile-percentile scaling approach on a time-slice of observed data (e.g. AWAP for rainfall between 1980 and 2010) to reproduce the changes in the probability distribution predicted by the CCAM simulations relative to the baseline period of 1986–2005. The climate variables for which application-ready data have been developed from CCAM simulations are shown in Table 5. Application-ready data were developed to produce future 30-year time-series data sets for the periods 2016–2045, 2036–2065, 2056–2085 and 2075–2104. Since the percentile-percentile scaling is applied over a 30-year time period, it is possible for the application-ready data to have a different shorter-term trend than was simulated by CCAM. For this reason, the future time-series application ready data can be regarded as representative of the mean state of the relevant future climate, rather than as a transient climate that is changing over time.

Application-ready data are often easier to use as inputs for applied models (e.g. crop models) than the original CCAM data since simulation biases are removed and the probability distribution of the climate variables are consistent with observed data. There can be limitations to using application-ready data, including that the time-series of the observed data determines the time-series of the future climate data (e.g. the hottest day always occurs on the same day in the 30-year future climate). In some cases, the observed data also has lower resolution than the CCAM 5 km results (e.g. solar radiation). Nevertheless, the application-ready data is generally found to be more compatible with applied models and is often an ideal starting point when using climate model data.

Table 5. Climate variables for which application-ready data is available

Climate variable (units)	Temporal scale
Mean near-surface (2 m) air temperature (°C)	Annual, seasonal, monthly, daily
Maximum daily near-surface (2 m) air temperature (°C)	Annual, seasonal, monthly, daily
Minimum daily near-surface (2 m) air temperature (°C)	Annual, seasonal, monthly, daily
Rainfall (mm)	Annual, seasonal, monthly, daily
Relative humidity (%)	Annual, seasonal, monthly, daily
Wet areal potential evapotranspiration (mm)	Annual, seasonal, monthly, daily
Mean surface (10 m) wind speed (ms^{-2})	Annual, seasonal, monthly
Solar radiation (Wm^{-2})	Annual, seasonal, monthly, daily
Days above/below temperature thresholds (count)	Annual, seasonal