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This project used the R programming language and would therefore like to recognise the efforts of the R-core team and those of RStudio in providing the tools and interfaces that made data analysis and visualisation possible and innovative. This project also used the LATEX typesetting system. We would like to recognise the contributors to this system.

A special thanks to Dr Michael Sumner for all his efforts upskilling our team in programming, workflow management, geospatial data and a host of specific programming packages we used within this project.

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Foreword

My interest in viticultural climatology goes back to the late 1970s when Richard Smart and I published a climatic classification of Australian wine regions by means of novel indices of temperature, rainfall, aridity, sunshine hours and relative humidity. This was the first time that this had been done in Australia and our aim was to aid vineyard site selection and to provide guidelines for varietal selection, at a time of major change in the Australian wine industry. In hindsight, our methods were relatively simplistic, but they did provide a good platform for inter-regional comparison and a better basis for the discussion of the impact of climate on wine style and quality.

Therefore, I was delighted to learn that a team of well-credentialed climate scientists from the University of Tasmania had been engaged to produce a climate atlas of Australian wine regions. This method of presentation of climatic information is well overdue and will prove to be a most valuable resource. The graphical presentation of climatic indices in a true atlas format allows for easy interpretation, while the details to describe the methodology and approaches that underpin the climate modelling, scenarios development and data analysis are there for those who are technically inclined.

The first part of the atlas is a comparison of the current period (1997 to 2017) with the base period (1961 to 1990). The authors have utilised well known climatic indices, such as Growing Season Temperature, rainfall and aridity, which clearly demonstrate the significant changes that have taken place in all regions over the past few decades. They have also created some novel indices, designed to better represent the physiological requirements of grapevines over the entire year. By doing so they have been able to capture the influence of heat units, for example, at the beginning of the season on the timing of key phenological events (as we are well aware, we have observed the earlier occurrence of budburst and flowering in many regions over the past 20 years). Also, Non-Growing Season Rainfall change since the base period clearly shows the influence of the drying trend in most regions.

The second part of the atlas presents the projected climate across all Australian wine regions out to 2100. This includes detailed presentations for each individual wine region (or Geographic Indication), grouped for each State (WA, SA, NSW, Vic., Tas. and QLD). The evidence is clear. The industry faces many challenges in the future, not only in terms of diminished productivity and declining wine quality in a warming and drying climate but also in terms of increased likelihood of risk of heat stress of vineyard workers.

Congratulations to the authors and to Wine Australia on the production of this seminal work.

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AGCD  Australian Gridded Climate Data
AI  Aridity Index
AWAP  Australian Water Availability Project
BeM  The Australian Bureau of Meteorology
BARRA  The Australian Bureau of Meteorology Atmospheric high-resolution Regional Reanalysis for Australia
CCAM  CSIRO’s Conformal Cubic Atmospheric Model
CFAP2019  Climate Futures Australasian Projections 2019
CFT  Climate Futures for Tasmania
CMIP  Coupled Model Intercomparison Project
- Has three most common variations CMIP3 and followed by CMIP5 and the current CMIP6, which indicate the experimental configuration of the intercomparisons
CORDEX  Coordinated Regional Downscaling Experiment
CSIRO  Commonwealth Scientific and Industrial Research Organisation
EHF  Excess Heat Factor
Ensemble member  The output from one CCAM simulation driven by one of the six global models
ENSO  El Niño-Southern Oscillation
ERA  European Centre for Medium-Range Weather Forecasts re-analysis
GCM  Global Climate Model
GDD  Growing Degree Days
GI  Geographic Indication
GSR  Growing Season Rainfall
GST  Growing Season Temperature
IOD  Indian Ocean Dipole
IPCC  Intergovernmental Panel on Climate Change
IPCC-AR5  Intergovernmental Panel on Climate Change Fifth Assessment Report
MOST  Monin-Obukhov Similarity Theory
NRM  National Resource Management
PDO  Pacific Decadal Oscillation
RCM  Regional Climate Model
RCP  Representative Concentration Pathway
- Comes in the flavours RCP2.6 (best case), RCP4.5, RCP6.5 and RCP8.5 (worst case; business as usual)
SAM  Southern Annular Mode
SRES  Special Report on Emissions Scenarios
SST  Sea Surface Temperature
UHI  Urban Heat Island
UTas  University of Tasmania
WCRP  World Climate Research Programme
Introduction

Over the last century, Australia’s climate has warmed by 1°C, and few regions have been unaffected (CSIRO and Bureau of Meteorology, 2018). Hotter average temperatures, hotter summers, longer heatwaves, more frequent bushfires and changes to rainfall intensity and seasonality have already had impacts across the country, and these trends are expected to continue. Rapid and ongoing climate change has the potential to affect all aspects of the wine industry, including vineyard performance, pest and disease incidence, wine quality and market competitiveness. In recognition of these challenges, Wine Australia funded a collaborative research project to consider the impact of climate variability and longer-term trends in climate on the wine industry.

Australia’s wine future (2016–2019) was a collaborative research project that brought together researchers from a range of disciplines, including climate scientists, viticulturalists and adaptation specialists. The project was led by the Antarctic Climate Ecosystem Cooperative Research Centre (ACE CRC, University of Tasmania) in partnership with the South Australian Research and Development Institute (SARDI), the Australian Wine Research Institute (AWRI), CSIRO Marine and Atmospheric Research and the Tasmanian Institute of Agriculture (TIA).

The Australian wine sector is likely to face challenges as the climate continues to warm, but, in general, grape growers are experienced in responding to short-term climate surprises. In the short- to medium-term, adaptation approaches may be learnt from the regions that are currently experiencing the climate conditions that Australia is predicted to see in the future. Fine-scaled climate information tailored for particular sector applications is vital for identifying such adaptation needs.

Australia’s wine future generated the finest available climate projections for South-eastern Australia and provided detailed information about how the climate may change in the near, mid and long-term time horizons. In addition to providing climate information, the project focused on how climate information can be used to inform adaptation decisions and identify lessons that might be transferable across regions already managing a range of climate challenges.

The main legacy of the project is this atlas of climate information for all Australian wine regions, providing information to grape growers and wine makers about climate trends for the near, mid- and long-term horizons. The atlas showcases the most up-to-date climate information at the finest resolution available in Australia, based on the CSIRO’s Conformal Cubic Atmospheric Model (CCAM). Viticultural indices are presented that describe temperature, heat accumulation, heatwaves, rainfall, and moisture indices. Future trends in mean climate conditions, variability and extremes are visualised with reference to the current and historical climate. High resolution maps and time series for each region are presented to show the projected change in climate indices over time, highlighting the variability within and across the wine regions of Australia. The new atlas will help to answer the question – What will my region’s climate look like in the future? This is essential knowledge for making good management decisions and supporting strategic decisions over the longer term such as changing varieties or vineyard sites both within and between regions. The atlas is an important resource that will help the wine industry understand how climate change could affect grape yield, profitability and wine styles across Australia into the future.
Part I

Introducing the Atlas
General background information
The difference between weather and climate
Weather describes what is happening in the atmosphere on a day-to-day basis or at a specific time, while climate describes the characteristic patterns of weather at a specific location. This changes with time (typically 30 years). The climate of a location is affected by latitude, topography, altitude and proximity to large bodies of water and their associated currents and can only be assessed over long time periods in order to incorporate the natural variability that occurs over several years.

Climate change

Greenhouse effect
Greenhouse gases such as carbon dioxide and water vapour trap heat from the sun to enter the atmosphere, while trapping a greater portion of outgoing radiation within the atmosphere. Greenhouse gases such as carbon dioxide keep the earth warm by allowing radiation from the sun to pass through, but trapping a greater proportion of outgoing radiation from the earth and the atmosphere back to the surface. This results in a warmer climate. Without greenhouse gases, the average temperature on Earth would be about -18°C, too cold to sustain life as we know it.

What are climate predictions/forecasts?
Climate forecasts aim to accurately and precisely predict the weather that will be experienced at a precise place and time in the future. In order to achieve this, climate forecasts use observations to confine the atmosphere within a climate model. This model represents the configuration of the actual atmosphere as accurately as possible (at a particular time, usually today or now). The more accurately the atmosphere is configured, the more likely it is that the forecast will predict the future. Forecasting has improved such that the accuracy and precision of a 5 day forecast in 2017 is more reliable than a 2 day forecast in the 1970s. Climate models have been developed by advances such as higher resolution observational data archives (due to satellite and surface ocean measurements), increased computing power and improved understanding and representation of atmospheric dynamics within climate models.

What are weather reanalysis products?
Weather reanalysis products (such as the ERA-Hermon mentioned within the methods) use climate model outputs explicitly designed for retrospective variables at locations or times between observations. A climate model is configured using observations and then is run forward in time until the next set of observations can be incorporated. Reanalysis data products provide data archives that are consistent (use the same assumptions and equations), have full spatial coverage across the target domain (no missing data points), are continuous in time and estimate atmospheric variables that were not measured or cannot be measured. Reanalysis products aim to provide a better estimate of the observed atmosphere. They can be more accurate than observations (due to site specific interferences such as shading, or protection from winds).

Regional Climate Models (RCMs)
The complexity of GCM results in them being configured for coarse resolutions (spatial resolution of 50 to 200km, temporal resolutions of 6 hourly timesteps), due to the limitations of current supercomputers. As a result certain features in the regional climate are poorly represented by GCMs including mountains, coastlines, urban areas and other atmospheric phenomena such as storms and rainfall processes. Downscaling methods are sometimes employed to address this limitation of the GCMs, providing higher spatial and temporal resolution climate simulations for a region (typically improved resolutions of between 1 to 5km resolution, and temporal resolutions of 1 minute to 1 hourly timesteps). Two popular downscaling methods are statistical downscaling and dynamical downscaling. Statistical downscaling relies on historical statistical relationships between observations and modelled behaviour of the atmosphere. Dynamical downscaling employs Regional Climate Models (RCMs) that are based on modelling techniques that are like those used by GCMs, but with the computing resources focused over a region and with a focus on the atmosphere and surface components (i.e., a trade-off is made where there is less space covered/predicted, but higher resolution representation of the climate system). In both cases, the downscaling process has key inputs from (i.e., they are informed by) coarse resolution GCM projections, often referred to as a forced or parent climate model.

Climate models replicate the climate at different scales?
Scale is a key component of understanding the climate and fundamental to detecting climate change signals. GCMs are run at low resolution, so do not perform well when compared with observations from specific locations, as the gridpoint is representing the average of a vast area rather than a single point, which is affected by local microclimatic characteristics. This means that the gridbox scale processes such as cumulus clouds, convection, updrafts and downdrafts in storms are not well represented. These phenomena are linked to small-scale processes that can only be represented by the GCMs when the grid resolutions are very fine (e.g., 1 or 2 km). The limitations in computing power or limited scientific understanding of the physical processes they represent a good job at simulating global and continental scale climate and provide a general overview of how the climate is changing. Long timescale averages of parameter values, such as temperature and precipitation, are good represented by the GCMs. They are also adept at simulating aspects of regional climate variability, such as the monsoon systems and seasonal changes in temperature, often driven by those large-scale processes.

Detecting climate change signals at different scales
Detecting climate change signals is about the signal versus the natural variability (or noise) ratio for the area of interest. The larger the area, the more the day-to-day variability is averaged down, as the day-to-day variability is less uniform across that area. This allows better detection of the signal. The longer the timescale, the more variability is averaged out. This is also true over shorter and longer timescales. The more accurately the atmosphere is configured, the more likely it is that this event would have been impossible without climate change and that this event is likely to happen again. Two popular downscaling methods are statistical downscaling and dynamical downscaling. Statistical downscaling relies on historical statistical relationships between observations and modelled behaviour of the atmosphere. Dynamical downscaling employs Regional Climate Models (RCMs) that are based on modelling techniques that are like those used by GCMs, but with the computing resources focused over a region and with a focus on the atmosphere and surface components (i.e., a trade-off is made where there is less space covered/predicted, but higher resolution representation of the climate system). In both cases, the downscaling process has key inputs from (i.e., they are informed by) coarse resolution GCM projections, often referred to as a forced or parent climate model.

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Uncertainty in climate projections
There are three main sources of uncertainty in climate models, which become more important as the models are used to predict future changes. These are internal climate variability, model uncertainty and future emission scenarios. The importance of each of these sources of uncertainty varies across different variables, the size of the area of interest and the length of time period.
Internal variability

Internal variability is due to the year-to-year changes in the weather which are independent of climate change. This timescale is difficult for the climate models to simulate as they are driven by mesoscale processes (that are often at smaller scales than the grid resolution). This uncertainty remains present throughout the model runs but has less weighting as time goes on due to the other sources growing. The smaller the area of interest, the more this internal variability dominates the total uncertainty, however it is still significant at the global scale. This is linked to phenomena such as ENSO and other drivers of natural variability.

Model uncertainties

Model uncertainties are either due to different representations of the same process within different model configurations (i.e., differing equations to solve the same problem); parameterisations due to differing model resolutions; poor understanding and simulation of processes within the model (i.e., the equations or parameterisation schemes are unable to represent the processes correctly). Many of these model uncertainties would be greatly improved with higher model resolution; however, there will always be model uncertainty because mesoscale processes are impossible to fully simulate. These uncertainties will always grow as a model run goes further into the future.

Emission scenarios

Uncertainty regarding emission scenarios are based on Representative Concentration Pathways (RCPs, discussed above). These are storylines of how humans act into the future and are represented by the resulting change in average global radiative forcing by 2100. The four RCPs are numbered according to the change in radiative forcing by 2100: +2.6, +4.5, +6.0 and +8.5 watts per square metre. The spread in these emission scenarios add uncertainty to GCM projections which always increase through time. Until 2050, all scenarios result in similar climate change impacts, as we do not add much uncertainty to the future outcome. However, past 2050, they begin to diverge rapidly, eventually becoming the dominant source of uncertainty when estimating the future climate.

Importance of uncertainties with scales and parameters

When investigating global mean temperatures, at first the internal variability is the main source of spread, with the different models and emission scenarios having less of an impact early on in the projections. From 2009 to 2020 the model uncertainties begin to dominate the overall uncertainty, whereas the emission scenario, still has little influence (although for some variables, such as global mean precipitation, model uncertainty is by far the largest contributor throughout).

Past 2050 it is the uncertainty surrounding the emissions scenario, the socio-economic pathway the global community chooses to take, that drives uncertainty around global (and in turn local) temperatures.

How can uncertainty be dealt with when using projections?

Research into understanding why the uncertainties in the models exist and what can and can’t be relied on is key to dealing with these uncertainties. The models produce plausible communities of scientists to better understand how the climate is represented by simulations; implement changes that improve simulations of the Earth’s climate; and interpret the impact that different plausible futures may have on humanity. This multi-model approach allows the global community to identify the most plausible impacts that will be realised following different socio-political pathways into the future. The range of Global Climate Models included in CMIP5 represent the most diverse range of independent climate models and projections of how the global climate will change.

The CMIP collaboration is now within its 6th phase (CMIP6), due to be completed in 2020. This is based on CMIP5 model output. The CMIP5 series of global climate simulations were designed to test how various climate drivers impact upon the Earth’s climate. Instead of the SRES emissions scenarios (e.g., A2, B1), which were used in previous CMIP archives, CMIP5 presented a series of experiments called the Representative Concentration Pathways (RCPs). These were designed to test the impact of different concentrations of heat-trapping gases (e.g., atmospheric CO2 concentrations) over a range of time periods (see section below on RCPs). To further appreciate the depth and breadth of CMIP5’s experiments scope, as well as develop an understanding of the value and implications realised by this internationally coordinated research effort, we recommend referring to:


Emissions scenarios

One of the main sources of uncertainty around climate change is what choices humans make regarding the amount of greenhouse gases we release in the future. Different emissions scenarios are used to describe a range of socio-economic pathways the global community may follow, and the resulting influence on the Earth’s climate. Some scenarios are based on the business as usual narrative where humans continue to be dependent on fossil fuels. Other scenarios are based on how well humans deal with the problem, with a range from making small, deliberate actions to reduce emissions; to actively removing greenhouse gases from the atmosphere.

The resulting range reflects the uncertainty inherent in quantifying human activities and their influence on climate. Scenarios are essentially a set of storylines based on population projections, demographics, international trade, flow of information and technology, and other social, technological, and economic characteristics of plausible future worlds.

To ensure that the projections of GCMs can be compared in a sensible way, various scenarios of future greenhouse gas emissions are applied consistently to all GCMs. The latest scenarios used by the climate modelling community are called the Representative Concentration Pathways (RCPs). These are not emission scenarios in the traditional sense but encompass all of the changes in the storyline leading to range in average global radiative forcing (change in temperature due to change in atmospheric composition) by 2100.

The RCPs include RCP2.6, RCP4.5, RCP6.0 and RCP8.5. The size of the number indicates more energy (in the form of heat, in units of Wm⁻²) being trapped in the Earth system such that RCP8.5 leads to a significantly warmer future climate than RCP2.6. The highest is RCP8.5 which is the business as usual scenario (though by no means the upper limit), whereas RCP2.6 is ambitious in that it achieves net negative carbon dioxide emissions before the end of the century by including a policy option. The other RCPs have different pathways and represent different future worlds, which result in different levels of overall warming.

- RCP2.6 — following a low emissions, intense mitigation scenario where the heat trapping capacity of the Earth is 4.5 Wm⁻². This is the emission scenario that is closest to a <2°C, warming consistent with the Paris Agreement target. As of 2019, this scenario is only achievable with dramatic and rapid changes to our economic and social systems and arrangements that must be implemented by ~2030.
- RCP4.5 — following a late start to a low emissions, intense mitigation scenario where the heat trapping capacity of the Earth is 4.5 Wm⁻². As of 2019, this scenario is only achievable with dramatic and rapid changes to our economic and social systems and arrangements that must be implemented by ~2040.
- RCP6.0 — following a moderate emissions, less effective mitigation scenario where the heat trapping capacity of the Earth is 6.0 Wm⁻². This is the scenario that current international commitments to emissions reductions (as of 2019) could achieve if targets are met.
within the range of downscaled climate. The future climate, rather than an analysis of the most probable future climate, which lies reductions in rainfall (see Table 1). Note that because we are selectively downscaling GCMs, These were CSIRO-BOM-ACCESS1-0, CNRM-CERFACS-CNRM-CM5, NOAA-GFDL-GFDL-ESM2M, MOHC-HadGEM2-CC, MIROC-MIROCC and NCC-NorESM-M. These models are based on the recommended GCMs for studying Australian climate change from the Climate Change in Australia web portal. The host GCMs for downscaling were selected to show a range of possible climate futures such as changes in the amount of warming and reductions in rainfall (see Table 1). Note that because we are selectively downscaling GCMs that show a range of possible futures, the downscaled simulations provide scenarios to explore the future climate, rather than an analysis of the most probable future climate, which lies within the range of downscaled climate.

Global Climate Models used in the atlas
Six Global Climate Models (GCMs) from the CMIP5 archive were downscaled for the atlas. These were CSIRO-BOM-ACCESS1-0, CNRM-CERFACS-CNRM-CM5, NOAA-GFDL-GFDL-ESM2M, MOHC-HadGEM2-CC, MIROC-MIROCC and NCC-NorESM-M. These models are based on the recommended GCMs for studying Australian climate change from the Climate Change in Australia web portal. The host GCMs for downscaling were selected to show a range of possible climate futures such as changes in the amount of warming and reductions in rainfall (see Table 1). Note that because we are selectively downscaling GCMs that show a range of possible futures, the downscaled simulations provide scenarios to explore the future climate, rather than an analysis of the most probable future climate, which lies within the range of downscaled climate.

Table 1: The six host GCMs used for dynamical downscaling and the reasons for their selection

<table>
<thead>
<tr>
<th>Host GCM for downscaling</th>
<th>Relevance for downscaling regional climate</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSIRO-BOM-ACCESS1-0</td>
<td>A hot, dry model that is representative of the consensus of GCM projections, especially for south-eastern Australia. Warming exceeds 2.7°C across most of Australia, and 3.1°C in central Australia. Drying is projected over most areas. This model has a high skill score with regard to historical climate.</td>
</tr>
<tr>
<td>CNRM-CERFACS-CNRM-CM5</td>
<td>A hot, wet model, consistent with the consensus of GCM projections in Southern Australia. It has a good representation of extreme El Niño in CMIP5 evaluations.</td>
</tr>
<tr>
<td>NOAA-GFDL-GFDL-ESM2M</td>
<td>A hot, very dry model, with warming in central regions exceeding 3.7°C. Drying is projected across most of the continent, with annual precipitation projected to decline more than 30% in many areas.</td>
</tr>
<tr>
<td>MOHC-HadGEM2-CC</td>
<td>A hot, dry model, with warming typically &gt;2.7°C and &gt;3.7°C in central regions. Annual precipitation is projected to increase in central Australia and decline elsewhere, including the horticultural zone. Greatest reduction in wet areas. Maximum consensus for many regions.</td>
</tr>
<tr>
<td>MIROC-MIROCC</td>
<td>A low warming, wet model for Australia, especially the south-eastern region. Warming does not exceed 2°C, and slight changes in annual precipitation are projected with declines in northeast Queensland and south-west Australia.</td>
</tr>
<tr>
<td>NCC-NorESM-M</td>
<td>Low warming, wetter model, representative of the wettest scenarios within the CMIP5 archive. Warming over most of Australia exceeds 2°C. Little change in annual precipitation is projected, particularly in the northwest, although there is drying in south-west WA.</td>
</tr>
</tbody>
</table>

The high-resolution downscaled climate simulations available at the time of publication were only for the RCP8.5 scenario. This can be used as well as at the time of publication the scenario most representative of trajectory the Earth is following based on social, economic and political actions and achievements as of 2019. Moving forward, if action to mitigate the impacts of climate change changes, such as that the Earth follows a scenario more similar to RCP8.5 (or at best B1/C), then the RCP8.5 scenario provides a worst-case scenario for risk managers to test future strategies against, while also being inclusive of the projected impacts of lower emissions scenarios.

Description of the regional climate modelling approach
To develop high-resolution climate simulations for South East Australia, we used the Conformal Cubic Atmospheric Model (CCAM) developed at CSIRO (McGregor 2005 and McGregor and Dix 2008). Unlike most RCMs, CCAM is a global atmospheric model with a variable resolution, which can be focused on an area of interest. In this way, CCAM can generate a higher resolution climate simulation, but is still coupled to the large-scale atmospheric circulation. Formally CCAM is a stretched grid global model, but we will refer to CCAM as an RCM in this atlas. CCAM includes several sub-models that are useful for simulating the Australian climate, including:

- direct and indirect aerosol feedbacks (Boucher et al., 2013)
- gravity wave drag (Chouinard et al., 1986)
- cloud microphysics (Lin et al., 1983; Rotstayn et al., 1997)
- radiative (Schwarzkopf and Ramaswamy, 1999; Feidhscheid and Ramaswamy, 1999)
- aerosols (Rotstayn and Lehmann, 2002; Rotstayn et al., 2011; Horowitz et al. 2017)
- boundary layer turbulent mixing (McGregor, 1993)
- the Australian developed Community Atmospheric Regional Model (CARM) land-surface and carbon cycle model (Kobayashi, 2013)
- the Urban Climate and Energy Model (UCLEM) for Australian cities (Lipsen, et al., 2018)

CCAM has been used for several regional climate simulations in Australia and South East Asia, including the CORDEX multi-model experiment, the National Resource Management (NRM) national projections for Australia, the Climate Futures for Australia, Climate projections for the Australian Alps and High-resolution projections for Queensland.

The downsampling process used by CCAM for the high-resolution climate simulations involves two steps. The first stage involves the projective changes in the Sea-Surface Temperatures (SSTs) from the GCMs, correcting the biases and variance on a month-by-month basis relative to the observed SSTs from 1980–2010 (Hoffman et al. 2010). The CCAM model is then used to rebuild the atmosphere at a uniformly global 50km resolution consistent with the corrected SSTs. This removes the first order errors that are present in the GCM output and helps to simulate a more realistic present day climate. The second stage is to then downscale the 5km CCAM simulations to 5km resolution (centred over Victoria) using CCAM’s stretched grid and scale-selective filters (Thatcher and McGregor 2008). Underlying model resolution is described in Figure 77. This approach ensures that the regional 5km resolution simulation is consistent with the large-scale behaviour of the global 5km resolution simulation, but also allows CCAM to add additional information such as extreme events. It is important to note that the SST bias correction process retains the impact of SSTs but can allow CCAM to modify the projections of the GCMs in other respects (such as changes in mean sea-level pressure or rainfall). When analysing the CCAM projections it can be useful to separate the regional-scale changes, the large-scale changes and the differences between the GCM projections so that the processes that explain the changes can be better understood.

The CFP2019 ensemble was designed to balance competing needs of finer resolution, larger ensembles of downscaled host GCMs and additional emission scenarios. By simulating the downscaled climate that avoids errors that can arise in GCM simulations. For Western Australian regions (and South Burnett in Queensland), we investigated the usefulness of using dynamically downscaled simulations available from other archives, particularly those produced over the north-western Australia. We compared these archives for compatibility with the key archive we have used for the south-eastern Australian regions with regards to spatial resolution, available variables and both spatial and temporal domain (coverage). In order to be consistent with the rest of Australia, these alternative archives required continuous temporal coverage from the 1960s to 2010. Unfortunately alternative archives investigated were not continuous. This introduced confusion when visualising many of the outputs, and thus could not be used. An alternative approach was adopted that made use of the 50km resolution CFP2019 ensemble outputs, as this model domain was global, which had coverage over all other Australian regions. However, this coarse resolution provided limited value when investigating the small wine regions. In order to transform the 50km outputs into more valuable forms, these were statistically downscaled to 5km resolution (using a quantile-quantile bias adjustment method Godinoum et al. 2013), based on the Australian Gridded Climate Data product. This produced far more useful, reasonable representations of the regions of interest to the project, providing the best continuous estimates currently available of climate changes into the future.

Methods and Interpretation
General methods

Figure 1: The domains of the CFP2019 ensemble showing the different resolutions across Australia, ranging from 5km to 50km.
Methods and Interpretation

General methods

Bias adjustment

Model biases introduce systematic errors which vary from place to place, as these errors are heavily dependent on the topography, altitude, latitude and distance from large water bodies. The biases are due to insufficient spatial resolution and the subsequent limited representation of meteorological processes (Rauscher et al. 2010). This is not a problem when investigating climate change as the interest is on the relative changes over time rather than the absolute values. However, when looking at climate impacts, the absolute values are needed, particularly when investigating temperature extremes. Therefore, in order to make the atlas more useful, there was a need to statistically bias adjust the CCAM model outputs prior to climate impact assessment (Christensen et al., 2008).

Bias adjustment is a statistical method that adjusts the climate model output so that it matches the observations over the entire probability distribution. This adjustment is then applied to each quantile of the probability distribution into the future period, preserving any changes to the distribution projected by the climate models. The raw CFAP2019 ensemble outputs were bias-adjusted using the quantile statistical transformation, which has been widely used for adjusting modelled variables, especially temperature and rainfall (Gudmundsson et al., 2013). Temperature and rainfall were bias adjusted using the qmap package (Gudmundsson et al., 2013) within the R programming language. Specific parameter settings were: method = quant; qstep = 0.001 ; wet.day = FALSE for Temperature and TRUE for rainfall. Observation data inputs were from the Australian Gridded Climate Data product (Jones et al., 2009).

An example of the impact bias adjustment can have on the distribution of values is presented in Figure 2. The probability distribution of the model output has been adjusted such that it reflects the distribution of observed values.

Figure 2: Probability distributions of maximum daily temperature at screen height (2m above the surface) for the period 1961-1990, for different data archives, displayed for the example wine regions Hunter and Tasmania South East. Observed data is sourced from AGCD. Only a single example ensemble member from CFAP2019 is displayed (CNRM-CERFACS-CNRM-CM5), similar impacts are observed when bias-adjusting the other ensemble members. The black solid thin lines are the observations. The purple dashed lines are the raw CFAP2019 output. The orange dashed lines are bias-adjusted CFAP2019 output. Note how the bias-adjusted CFAP2019 distributions (orange dashed lines) closely resemble the observed distributions (black thin solid line).

Time periods

Time periods were calculated based on Australian growing years, which are the period from July to June each annual cycle, winter to winter in the Southern Hemisphere. Growing years were labelled as the calendar year in which July fell. Time periods used within this atlas are defined as:

<table>
<thead>
<tr>
<th>Time period</th>
<th>Start and end month</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997–2017</td>
<td>July 1997 to June 2018</td>
</tr>
<tr>
<td>2001–2020</td>
<td>July 2001 to June 2021</td>
</tr>
<tr>
<td>2021–2040</td>
<td>July 2021 to June 2041</td>
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<tr>
<td>2041–2060</td>
<td>July 2041 to June 2061</td>
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<tr>
<td>2061–2080</td>
<td>July 2061 to June 2081</td>
</tr>
<tr>
<td>2081–2100</td>
<td>July 2081 to June 2100</td>
</tr>
</tbody>
</table>

Table 2: Start and end months for each time period

Wine Regions / Geographic Indications (GIs)

The terms Wine Regions and Geographic Indications (or GIs) are used interchangeably throughout this atlas. They are determined, registered, managed and curated by Wine Australia (Wine Australia, 2019). Shapefiles of all wine regions were provided by Wine Australia.

*This period is 19 years (instead of 20 years like the others) due to an absence of available data past December 2010*
Evaluation of the CFAP2019 ensemble

The following section evaluates the CFAP2019 ensemble for the period 1986–2005 by comparing the results to observations. In this section we use the Australian Gridded Climate Data products (AGCD), which were produced by the Australian Water Availability Project (AWAP), a collaborative effort of CSIRO and the Bureau of Meteorology (BoM). These are national gridded data sets at 5km resolution of observed daily rainfall and daily maximum and minimum air temperature at 2m. AGCD data is based on interpolated weather station measurements and hence there are some gaps where the station network is less densely populated (e.g., in the Victorian Alps). We also used ERA-Interim reanalysis for evaluating the large-scale performance of the CFAP2019 ensemble such as mean sea level or winds at 850 hPa. The ERA-Interim reanalysis is a combination of model simulations and observations. As such, it is a reconstruction of the weather through time, providing information about surface conditions (e.g., temperature, precipitation, wind speed and direction, humidity, evaporation and soil moisture), information at pressure and model levels, and information on solar radiation and cloud cover. It provides a reasonably accurate representation of past weather over a number of years, so is valuable to validate the model output over the same time period. The Bureau of Meteorology Australian Regional Reranlsis for Australia (BARRA) was under development at the time of atlas development and publication, so was not yet available.

The region of Victoria was used to assess the capability of the model because it covers a large number of the Australian wine regions and has a range of climate zones (coastal, open plains, low elevation hills through to high elevation alpine mountains).

Methods and interpretation

Temperature

The CFAP2019 ensemble variables average daily maximum and minimum air temperature (at 2m, i.e., screen temperature) between 1986–2005 are compared to the AGCD interpolated observations and the host GCM models in Figures 3 and 4. The ensemble mean for CFAP2019 ensemble and six host GCMs are presented. The results indicate that CFAP2019 ensemble better represents the temperatures for mountain regions and coastlines than the GCMs when compared to AGCD. The CFAP2019 ensemble also shows a significant improvement (compared to the host GCMs) in daily minimum temperature, as well as much better representation of daily maximum temperatures for alpine regions of Victoria. The host GCMs tend to show a warm bias in the daily minimum temperatures over Victoria that is not apparent in the CFAP2019 ensemble. However, for maximum temperatures there is a warm bias apparent in the CFAP2019 ensemble in summer, particularly for eastern Victoria. The spatial pattern of this warm bias is not apparent in the future projected change in daily maximum temperature, suggesting that the issue is related to the diagnoses of the 2m air temperature for tall vegetation (e.g., forest). Some caution is therefore advised in interpreting the projected changes in climate for daily maximum temperatures within or nearby forested regions.

Another example of how the CFAP2019 ensemble has improved the daily minimum temperature can be seen by examining the Urban Heat Island (UHI) for Melbourne. Urban areas are generally poorly resolved in GCMs. However, regional models like CCAM include special parameterisations to account for the building materials, urban vegetation of typically 1°C, 2°C, depending on the density of the urban area and the amount of green space. Urban areas are generally poorly resolved in GCMs. However, regional models like CCAM include special parameterisations to account for the building materials, urban drainage, shadowing effects and changes to air circulation within the urban canyon. Figure 5 compares the difference in daily minimum temperature between an inner-city weather station (BoM Melbourne Regional Office — Red dot) and three outer-city weather stations (Laverton RAAF — Blue dot, Coldstream — Green dot and Cranbourne Botanic Gardens — Yellow dot). Location of the weather stations are shown in the top plot and the observed and simulated difference in temperatures between the inner-city site and the three outer city sites is shown in the bottom plot.
Rainfall
A comparison of the average rainfall simulated for different seasons from 1986–2005 by CCAM with AGCD interpolated observations and the host GCMs can be seen in Figure 6. The CCAM 5km resolution simulations better represent the average rainfall over the Victorian Alps than the GCMs where the mountains are poorly resolved. CCAM also represents increased rainfall along the southern coastline that was not represented by the GCM simulations. The simulated average rainfall from the CCAM 5km resolution simulations is higher than what is measured for the AGCD interpolated observations. However, the AGCD interpolated observations can also underestimate the rainfall in mountain regions due to a more sparse network of observing stations. The larger scale features in the CCAM simulated rainfall resemble some of the larger scale features in the GCM simulations (e.g., a slightly higher average rainfall in the north west of Victoria in summer and autumn), which reflects some similarities in how rainfall is parametrised in global and regional dynamical climate models. Nevertheless, downscaling does improve the distribution of simulated average rainfall, demonstrated in the CCAM 5km simulations.

Mean Sea Level Pressure and 850 hPa winds
Although the use of CCAM simulations is primarily for downscaling the regional climate, it is also important to consider the large-scale behaviour of the CCAM atmospheric simulation. This large-scale behaviour can influence the projections of the climate model simulations and is useful for interpreting the outputs of CCAM in the context of the ensemble of CMIP5 GCM projections. As discussed when describing CCAM, the use of blue corrected SSTs can allow CCAM to differ from the host GCM in some respects.

Figure 8 compares the simulated Mean Sea Level Pressure (MSLP) averaged between 1986–2005 from the six AGCD global simulations with the ERA-Interim reanalyses and the average of the six host GCMs. When compared to ERA-Interim, the CCAM 50km simulations are somewhat biased towards easterly flow in the MSLP compared to the host GCMs, most noticeable in autumn and winter. This can lead to winds too easterly as indicated with the 850 hPa winds shown in Figure 9. Figure 9 compares the average 850 hPa wind speed and direction for different seasons over 1986–2005 between the ERA-Interim reanalyses, the average of six CCAM 50km global simulations and the average of the six host GCMs. The 850 hPa winds represent the winds at approximately 2 to 2.5km above the surface, whereas ERA-Interim is less influenced by smaller scale mountains. Although the CCAM simulations are a reasonably good representation of the 850 hPa winds, the wind speed is too strong and the wind direction is too easterly in autumn and winter. This result is consistent with the easterly bias within MSLP results for the host GCMs which could not be captured in the GCM simulations.

Figure 7: Comparison of the 99th percentile of daily rainfall between 1986 and 2005 from AGCD interpolated observations (left column), the average of six CCAM 5km simulations (middle column) and the average of six GCMs (right column).

Figure 8: Comparison of Mean Sea Level Pressure averaged over 1986–2005 between ERA-Interim reanalyses (left column), the average of six CCAM 50km global simulations (middle column) and the average of six host GCMs (right column).

Figure 9: Comparison of average wind speed and direction at 850 hPa (approximately 2 to 2.5km above the surface) between 1986–2005. The ERA-Interim reanalysis is shown on the left column, the average of six CCAM 50km simulations in the middle column and the average of six GCMs on the right column.

Extremes
Another aspect where downscaling should improve the simulated climate is extreme rainfall. We used the 99th percentile of daily rainfall over the 1986–2005 period as an indicator of CCAM’s ability to represent extreme rainfall. A comparison of the 99th percentile of daily rainfall between 1986–2005 for AGCD, CCAM and the GCMs is shown in Figure 7. The extreme rainfall is underestimated by CCAM when compared to AGCD interpolated observations, although CCAM significantly improves on the extreme rainfall from the GCMs which do not represent the high rainfall for the Alpine regions at all. For average daily rainfall, the AGCD interpolated observations may underestimate the size of the extreme rainfall for mountain regions due to the sparse observing network, which is also suggested by comparing the results to BARRA (not shown). Nevertheless, CCAM is able to represent extreme rainfall that could not be captured in the GCM simulations.
Methods and interpretation of figures

Infographic:

Each regional section of the atlas starts with an infographic page that summarises the future changes in climate in general terms. This section describes the methods used to calculate each index.

Interpretation:

These infographics provide a snapshot of the projected climate across each region at different time periods. Values are summarised across space and time, so they give a good overall indication of change across the region, but may be less useful when interested in exact conditions at specific sites. These summaries enable easy and rapid comparisons between regions, or across time periods, in a broad, general sense.

Data sources

Values for the 1997–2017 (the current period) were calculated using the Australian Guided Climate Data product (Jones et al., 2009).

Mean values

Mean values are the spatial and temporal average of the target variable within a specific time-period, across all grid-cells within each wine industry Australian Geographical Indications (Wine Australia, 2019). For example, the mean GST value for the period 2041–2060 for the Barossa Valley is an average of 260 input values (13 grid-cells x 20 annual timesteps), summarised into a single value.

Interpretation:

Values are presented for selected 20-year periods representing the:
- current period (1997–2017) — reflecting recent memory;
- the mid-term future (2041–2060) — the high-likelihood future expected by 2050 (before which ECP scenarios are similar and after which they begin to diverge), this period is most relevant to strategic decision making; and
- far future (2081–2100) — providing a quantitative estimate of changes by the end of century (following the worst case scenario).

The three time-periods indicate the rate of adaptation that may be required over the next 30 or 40 years while providing context to help guide planning over a longer time-frame.

Temperature

Growing Season Temperature (GST) is defined as the mean atmospheric temperature at screen height (2m above the land surface) over the period from October to April of each annual cycle. This is calculated for every growing season year, for every grid-cell within the region. Annual values from all grid-cells and all annual timesteps are averaged.

Interpretation:

Growing Season Temperature (GST) increases into the future for every region across Australia. The rate of increase accelerates exponentially towards 2100. Values are summarised over space and time, so for regions with high topographic variability, average values are unlikely to reflect conditions at specific sites within the wine region, although they will give a reasonable indication of the direction and rate of change projected into the future.

Extreme Cold

Mean Growing Season Frost Risk Days is the number of days within the period from October to April of each annual cycle where temperature are <2°C. Annual values from all grid-cells and all annual timesteps are averaged.

Interpretation:

Mean Growing Season Frost Risk Days are projected to decrease in all wine regions across Australia as temperatures continue to rise. Values are summarised over space and time. For regions with high elevations within the wine regions, average values will be higher (lower) than those expected in the lowlands (highlands).

Rainfall

Mean Growing Season Rainfall is the average sum of all precipitation that falls within the period from October to April of each annual cycle. Annual values from all grid-cells and all annual timesteps are averaged.

Interpretation:

Rainfall is one of the most uncertain components within the climate system. However, even modest increases in annual rainfall can actually result in decreased moisture availability across a region within a warming climate, as rainfall rates are required to increase in order to offset evaporative (and other) losses (see Aridity Index sections). Confidence in temperature, the warming trend and evaporative demands is high. Thus, although confidence surrounding rainfall projections is low, very few simulations indicate increases in rainfall with sufficient magnitude to offset these projected losses. Rainfall should be viewed in concert with Aridity Index projections.

Heat

We have high confidence in how temperature will change into the future (depending on the emissions scenario). The physical drivers of how it changes within the climate system are well understood, so we can use the large spatial scales and use therefore straightforward to represent within climate models. This allows the models to achieve high levels of skill in the predictions (weather forecasts) and projections (climate projections) they produce.

There is strong agreement across the CFAP2019 ensemble members regarding the rate and magnitude of warming projected into the future. As such, there is high confidence regarding projected variables related to temperature.

Each ensemble member describes a possible future, with different timing and sequencing of broad global drivers (such as the Southern Annular Mode (SAM), the El Niño–Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD)). As such hot or cold years can be out of phase with each other. This is a strength of an ensemble mean as the highs and lows (expressions of the natural variability within the climate system) are smoothed out, revealing the general climate trend. For some regions, variability between the different ensemble members is lower than the variability that occurs spatially across a wine region. This is especially true for those regions with significant hills or mountains (e.g. Barossa Valley, Tasmania East Coast). For regions that are more uniform spatially (e.g. Riverland), the ensemble variability is more noticeable, expressed as clusters of points that escape the point cloud in some years. These high and low years are useful for understanding the likelihood of extremely hot or cold years over time. Often, the extremely hot years are indicative of the conditions to expect in the future. For example, the hot year (along with the associated extreme daily temperature) observed in south east Australia during the 2015/2016 growing year is indicative of typical projected conditions in 2050. Similarly, cooler conditions (relative to the surrounding decades) can occur at any time (although even the coldest year by the end of century would be considered an average year today).

The trend lines highlight how typical conditions are projected to change over time — they are representative of the ensemble mean at warmer and cooler locations within the region. It is most interesting to determine where the cooler location becomes hotter than the warmer location (typically around 2030, depending on the region and the magnitude of spatial variability). It is important to note that interannual and decadal variability is present, but the trend is clearly warming, especially from 2018 onwards.

Aridity Index

The Aridity Index provides an indication of available water by considering the magnitude of annual precipitation compared to the magnitude of evaporation. This is calculated as annual precipitation / annual pan evaporation. The aridity index is independent of site specific characteristics (e.g., soil type, vine varietal) or changes in vineyard management (e.g., shading, row orientation, mulching), but captures evaporation, aspect, humidity and the influence of wind. Annual values from all grid-cells and all annual timesteps are averaged.

The annual cycle was defined as July to June, which is winter to winter in the southern hemisphere. Annual precipitation is the sum of all rainfall that has fallen within a single grid-cell within the period July to June of each annual cycle. Annual pan evaporation is the sum of all evaporation that could occur if water was always present within a grid-cell over the period July to June of each annual cycle. Evaporation is calculated at screen height (2m above the land surface) over the growing season (October to April of each annual cycle). Annual values from all grid-cells and all annual timesteps are averaged.

Interpretation:

Aridity Index is the number of days within the period from October to April of each annual cycle. Annual values from all grid-cells and all annual timesteps are averaged.

Extreme Heat

Extreme Heat Factor (EHF) is an index that describes the severity of short term, acute heat impacts on humans during heat waves. It accounts for how hot any three-day period is in relation to an annual temperature threshold at a particular location, as well as how hot the three-day period is with respect to the recent past (the previous 30 days). This reflects the recent past fact that people acclimatise, to a certain extent, to their local climate but may not be prepared for a sudden rise in temperature above that of the recent past.

The calculation is described in Nairn and Fawcett (2015). Annual values from all grid-cells and all annual timesteps are averaged.

Interpretation:

Extreme Heat Factor (EHF) represents the intensity of heatwaves within a region as experienced by humans, after accounting for any capacity to acclimatise to the typical conditions within a region. Increasing EHF values indicate more intense heatwaves. As heatwaves are large synoptic scale features, regional variability is less influential than longer term climatic changes.
Methods and interpretation of figures

Figure 1: Observed mean Growing Season Temperature

Underlying data source: Australian Gridded Climate Data Product (Jones et al., 2009).

Daily average temperature is calculated as the mean of daily maximum and minimum temperatures each day. Growing Season Temperature (GST) was calculated as the average of all daily average temperature values for each day during the period from October to April of each growing season. Growing Season Temperature is the average of all annual GST values over the current period (1997–2017). Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australian Geographical Indications (Wine Australia, 2019). Values were calculated for each grid cell.

Interpretation:
- Each tile represents the mean Growing Season Temperature during the period 1997–2017, which is the period of recent memory. This map reflects the level of variability across the region as it is currently experienced. Tiles are the resolution of the underlying data. Lower values typically correspond to higher elevation regions. Towns and roads are included to help identify specific sites within the region. Tiles have an average elevation of the area they represent, so they best represent regions that have similar elevations (~200m) across 5–10km². Typically, the highest peaks occur at smaller scales (~1km²) and thus are poorly represented. This can influence the representation of some climatic features and should be considered when interpreting these figures.

Figure 2: Observed change in mean Growing Season Temperature

Underlying data source: Australian Gridded Climate Data Product (Jones et al., 2009).

Growing Season Temperature (GST) was calculated as the average of all minimum and maximum temperature values for each day within the period from October to April of each growing season year. Mean Growing Season Temperature is the average of all annual GST values over the current period (1997–2017), or the baseline period (1961–1990). The baseline period mean GST was then subtracted from the current period mean GST, resulting in the observed change in mean GST. Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australian Geographical Indications (Wine Australia, 2019). Values were calculated for each grid cell.

Interpretation:
- Each tile represents how mean Growing Season Temperature during the current period (1997–2017) has changed when compared to mean Growing Season Temperature during the historical period (1961–1990). Climate change is a large scale feature, so the level of change observed is relatively similar when viewed at local scales. Towns and roads are included to identify specific sites within the region. Tiles have an average elevation of the area they represent, so they best represent regions that have similar elevations (~200m) across 5–10km². Typically, the highest peaks occur at smaller scales (~1km²) and thus are poorly represented. This can influence the representation of some climatic features and should be considered when interpreting these figures.

Figure 3: Projected mean Growing Season Temperature

Underlying data source: Climate Futures Australasian Projections 2019 (CFAP2019).

Growing Season Temperature (GST) was calculated as the average of all minimum and maximum temperature values for each day within the period from October to April of each growing season year for each member within the CCAM ensemble. Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australian Geographical Indications (Wine Australia, 2019). Values were calculated for each grid cell.

Interpretation:
- Each tile represents the mean Growing Season Temperature during the current period (2021–2040, 2041–2060, 2061–2080, 2081–2100) according to the Representative Concentration Pathways (RCPs) scenario. These are the results of the underlying data. Lower values typically correspond to higher elevation regions. Towns and roads are included to help identify specific sites within the region. Tiles have an average elevation of the area they represent, so they best represent regions that have similar elevations (~200m) across 5–10km². Typically, the highest peaks occur at smaller scales (~1km²) and thus are poorly represented. This can influence the representation of some climatic features and should be considered when interpreting these figures.

Figure 4: Projected annual mean Growing Season Temperature

Underlying data source: Climate Futures Australasian Projections 2019 (CFAP2019).

Blue points: Growing Season Temperature (GST) was calculated as the average of all minimum and maximum temperature values for each day within the period from October to April of each growing season year for each member within the CCAM ensemble. Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australian Geographical Indications (Wine Australia, 2019). Values were calculated for each grid cell.

Interpretation:
- Each solid line represents either a warmer location or a cooler location relative to the rest of the region. These locations were selected based on observed mean GST values, calculated from the Australian Gridded Climate Data product (Jones, et al., 2009) for the current period (1997–2017). The warmer location (cooler location) is a grid cell that represents the 80th (20th) percentile of all mean GST values across the region. The 20th and 80th percentile thresholds were selected to identify typical subregions where, highlighted, rather than high elevations, coastlines or particularly warm grid cells (or subregions in the larger wine regions).

Grey Bars: The grey bars represent the observed mean GST for the current period (1997–2017) for each of the wine industry Australian Geographical Indications (Wine Australia, 2019). Values were averaged across space and time, calculated from the Australian Gridded Climate Data product (Jones, et al., 2009).

Coloured zones: The coloured zones indicate the time when average global climate temperature increases by 1°C, 2°C, 4°C or 6°C (following the Representative Concentration Pathways 8.5 scenario (RCP8.5), often referred to as the business as usual scenario). These estimates are the ensemble means as reported by the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5), based on the World Climate Research Programme (WCRP) Coupled Model Intercomparison Project - phase 5 (CMIP5) global model archive (which has ~100 ensemble members).

Interpretation:
- Key elements:
  - There is a strong warming trend, with a rate of change that increases towards the end of the century.
  - All ensemble members agree so there is high confidence in the direction and magnitude of the projected future following the RCP8.5 scenario.
  - Extremely hot years (representative of mean conditions in the future), can occur as much as 30 years earlier than projected by the mean trend.
  - The pathways calculated by different ensemble members (hotter vs warmer, which in turn is cooler vs warmer) across different types of years (e.g., hot, average or cold).
  - Different ensemble members capture different climate configurations (e.g., El Niño, neutral, or La Niña phases of ENSO), thus better estimate the range of possible outcomes.

Figure 5: Probability distribution of Growing Season Temperature

Underlying data source: Climate Futures Australasian Projections 2019 (CFAP2019).

Growing Season Temperature (GST) was calculated as the average of all minimum and maximum temperature values for each day within the period from October to April of each growing season year for each member within the CCAM ensemble. Values were calculated for each cell. Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australian Geographical Indications (Wine Australia, 2019).

The curves represent the distribution of GST values from all grid cells and all ensemble members during each distinct 20-year period. Time periods were: 2001–2020, 2021–2040, 2041–2060, 2061–2080, 2081–2100.

The grey, filled curves represent the distribution of observed GST values for contrasting Australian regions for the current period (1997–2017).

Interpretation:
- Probability distributions reflect the spread and potential likelihood of values within a particular region. High, narrow peaks indicate low variability with a high frequency of particular values occurring within the population. Low, broad peaks indicate high variability, with few values occurring frequently. The probability distribution displayed in the atlas incorporate all spatial grid cell values, across each 20-year time-end of the century.

The different coloured curves indicate how conditions are expected to change across all wine regions (cooler vs warmer subregions) and across different types of years (e.g., hot, average or cold). Different ensemble members capture different climate configurations (e.g., El Niño, neutral, or La Niña phases of ENSO), thus better estimate the range of possible outcomes. Low likelihood years (extreme hot or cold) can be included, indicating what is possible, while simultaneously representing the expected or typical conditions for a particular region. Curves with multiple peaks indicate either strong, stable spatial differences (highland vs lowland conditions), or a strong modal character of the regions climate (e.g., a region is either very warm years, or very cold years but rarely in between). The different coloured curves indicate how conditions are expected to change across the future. As the curves are all distinct and the direction of change across the five time-periods is consistent, this indicates all ensemble members agree on the rate and direction of the change into the future. The future curves are typically lower and broader than their population.
Growing Degree Days

Growing Degree Days calculations are not standardised across Australia. Growers within each GI often have their own adaptation either for their vineyard or across their region. As such, GDD means different things to different people and the values are not interchangeable. For this atlas, we selected a method to calculate GDD that was standardised, relevant and useful across Australia. The two main limitations of existing methods were: 1) limiting the period when heat is accumulated to May—October — this does not account for the effect of warm winter/spring periods, increasingly important under a warming climate. 2) limiting the influence of heat to daily values >10°C — this does not account for physiological responses that clearly occur at far lower temperatures, especially during the winter/spring period.

In response to these limitations, we established a new method to use daily climate values as inputs, take into account the influence of heat across the entire growing season (July to June) and reflect the physiological demands of grape vines as they change throughout the year. The value of this adaptation is the additional information it provides earlier in the season, particularly useful in cooler regions. The value of this adaptation is the additional information it provides earlier in the season, particularly useful in cooler regions. The new method uses the following equation:

\[
GDD = \left( \frac{T_{\text{max}} + T_{\text{base}}}{2} \right) - T_{\text{base}}
\]

Where: 
- GDD = Growing Degree Days
- T\(_{\text{max}}\) = Maximum daily temperature
- T\(_{\text{base}}\) = Minimum daily temperature above which heat is considered to have value to the vines.

The value of T\(_{\text{base}}\) is altered for three different phenological stages: dormancy to budburst, budburst to leaf appearance, leaf appearance to harvest (or end of season), reflecting the physiological requirements of grape vines during these different periods of growth. The value of T\(_{\text{base}}\) is set to the minimum daily temperature above which heat is considered to have value to the vines.

The method is simple enough to implement (and adjust) at the vineyard scale where required (by users external to the atlas) and remains relevant into warmer future conditions. The approach captures the importance of increased heat accumulation prior to October as the climate warms, providing a better representation of the impacts expected to be seen into the future, while also improving the utility of the GDD metric as a measure of heat accumulation within cooler climates (or cooler seasons) as it better reflects the influence of low temperature days relevant to grapevine physiology.

**Methods and interpretation**

Methods and interpretation of figures

**Table 3:** Mean cumulative monthly GDD for example location in Tasmania East Coast for the current period (1997-2017)

<table>
<thead>
<tr>
<th>Month</th>
<th>July–June</th>
<th>October–April</th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
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**Table 4:** Mean cumulative monthly GDD for example location in Coonawarra for the current period (1997-2017)

<table>
<thead>
<tr>
<th>Month</th>
<th>July–June</th>
<th>October–April</th>
<th>Adjusted</th>
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</thead>
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<tr>
<td></td>
<td>10°C</td>
<td>7°C</td>
<td>4°C</td>
</tr>
<tr>
<td>Jul</td>
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<td>273</td>
</tr>
<tr>
<td>Aug</td>
<td>186</td>
<td>372</td>
<td>588</td>
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<tr>
<td>Sep</td>
<td>306</td>
<td>582</td>
<td>858</td>
</tr>
<tr>
<td>Oct</td>
<td>493</td>
<td>862</td>
<td>1231</td>
</tr>
<tr>
<td>Nov</td>
<td>761</td>
<td>1220</td>
<td>1679</td>
</tr>
<tr>
<td>Dec</td>
<td>1165</td>
<td>1607</td>
<td>2290</td>
</tr>
</tbody>
</table>

**Table 5:** Mean cumulative monthly GDD for example location in Geographe for the current period (1997-2017)

<table>
<thead>
<tr>
<th>Month</th>
<th>July–June</th>
<th>October–April</th>
<th>Adjusted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10°C</td>
<td>7°C</td>
<td>4°C</td>
</tr>
<tr>
<td>Jul</td>
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<td>1122</td>
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<tr>
<td>Aug</td>
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<td>Oct</td>
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<tr>
<td>Dec</td>
<td>2257</td>
<td>4079</td>
<td>6011</td>
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</table>

**Table 6:** Mean cumulative monthly GDD for example location in Swan District for the current period (1997-2017)

<table>
<thead>
<tr>
<th>Month</th>
<th>July–June</th>
<th>October–April</th>
<th>Adjusted</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10°C</td>
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<td>4°C</td>
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<tr>
<td>Jul</td>
<td>2823</td>
<td>5194</td>
<td>7503</td>
</tr>
</tbody>
</table>

21
Underlying data source: Climate Futures Australasian Projections 2019 (CFAP2019).

**Annual Maximum Growing Degree Days** is the sum of all daily GDD values (calculated as described above) over the period from July 1st to June 30th for each growing season year for each member within the CCCM ensemble. Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australian Geographical Indications (Wine Australia, 2019). Values were calculated for each grid cell.

The coloured curves represent the probability distribution of Annual Maximum GDD values from all grid cells and all ensemble members during each different 20-year period. Time periods were: 2001–2020; 2021–2040; 2041–2060; 2061–2080; 2081–2100.

The grey, filled curves represent the distribution of observed Annual Maximum GDD values within the period 1997–2017 for contrasting wine industry Australian Geographical Indications (Wine Australia, 2019).

**Interpretation:**

Probability distributions reflect the spread and potential likelihood of values within a particular population of values. High, narrow peaks indicate low variability with a high frequency of particular values occurring within the population. Low, broad peaks indicate high variability, with few values occurring frequently. The probability distributions displayed in the atlas incorporate all spatial grid cell values across each 20-year time period, from six ensemble members (i.e., independent simulations). Variability across spatial, temporal scales and across the CFAP2019 ensemble is represented with each curve. This has the advantage of reflecting the diversity that is found within each wine region (cooler vs warmer subregions) and across different types of years (e.g., hot, average or cold). Different ensemble members capture different climate configurations (e.g., El Niño, neutral, or La Niña phases of ENSO), thus better estimate the range of possible extremes. Low likelihood years (extreme hot or cold) can be included, indicating the possible, while simultaneously representing the expected or typical conditions for a particular region. Curves with multiple peaks indicate either strong, stable spatial differences (highland vs lowlands conditions), or strong modal character of the regions climate (e.g., a region is either has very warm years, or very cold years but rarely is in between). The different coloured curves indicate how conditions are expected to change into the future. As the curves are all distinct and the direction of change across the five time-periods is consistent, this indicates all ensemble members agree on the rate and direction of warming into the future. The future curves are typically lower and broader as different simulations follow different trajectories, increasing the variability within the population of values. For some wine regions, higher Growing Degree Days thresholds are not reached, or are reached irregularly. In these cases the curves have inconsistent, irregular shapes (due to a lack of underlying data, please note, curves with <60 underlying values were excluded). Irregular shapes should not be over-interpreted, they just indicate an emerging trend to reach higher Growing Degree days. As these curves transition towards more normal distributions, there is higher confidence in the information they provide and they become more useful.

**Figure 6: Probability distribution of Growing Degree Days**

Different ensemble members capture different climate configurations (e.g., El Niño, neutral, or La Niña phases of ENSO), thus better estimate the range of possible extremes. Low likelihood years (extreme hot or cold) can be included, indicating the possible, while simultaneously representing the expected or typical conditions for a particular region. Curves with multiple peaks indicate either strong, stable spatial differences (highland vs lowlands conditions), or strong modal character of the regions climate (e.g., a region is either has very warm years, or very cold years but rarely is in between). The different coloured curves indicate how conditions are expected to change into the future. As the curves are all distinct and the direction of change across the five time-periods is consistent, this indicates all ensemble members agree on the rate and direction of warming into the future. The future curves are typically lower and broader as different simulations follow different trajectories, increasing the variability within the population of values.

Underlying data source: Climate Futures Australasian Projections 2019 (CFAP2019).

**Annual Maximum Growing Degree Days** is the sum of all daily GDD values (calculated as described above) over the period from July 1st to June 30th for each growing season year for each member within the CCCM ensemble. Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australian Geographical Indications (Wine Australia, 2019). Values were calculated for each grid cell.

The grey, filled curves represent the distribution of observed Annual Maximum GDD values within the period 1997–2017 for contrasting wine industry Australian Geographical Indications (Wine Australia, 2019).

**Interpretation:**

Probability distributions reflect the spread and potential likelihood of values within a particular population of values. High, narrow peaks indicate low variability with a high frequency of particular values occurring within the population. Low, broad peaks indicate high variability, with few values occurring frequently. The probability distributions displayed in the atlas incorporate all spatial grid cell values across each 20-year time period, from six ensemble members (i.e., independent simulations). Variability across spatial, temporal scales and across the CFAP2019 ensemble is represented with each curve. This has the advantage of reflecting the diversity that is found within each wine region (cooler vs warmer subregions) and across different types of years (e.g., hot, average or cold). Different ensemble members capture different climate configurations (e.g., El Niño, neutral, or La Niña phases of ENSO), thus better estimate the range of possible extremes. Low likelihood years (extreme hot or cold) can be included, indicating the possible, while simultaneously representing the expected or typical conditions for a particular region. Curves with multiple peaks indicate either strong, stable spatial differences (highland vs lowlands conditions), or strong modal character of the regions climate (e.g., a region is either has very warm years, or very cold years but rarely is in between). The different coloured curves indicate how conditions are expected to change into the future. As the curves are all distinct and the direction of change across the five time-periods is consistent, this indicates all ensemble members agree on the rate and direction of warming into the future. The future curves are typically lower and broader as different simulations follow different trajectories, increasing the variability within the population of values. For some wine regions, higher Growing Degree Days thresholds are not reached, or are reached irregularly. In these cases the curves have inconsistent, irregular shapes (due to a lack of underlying data, please note, curves with <60 underlying values were excluded). Irregular shapes should not be over-interpreted, they just indicate an emerging trend to reach higher Growing Degree days. As these curves transition towards more normal distributions, there is higher confidence in the information they provide and they become more useful.

Different ensemble members capture different climate configurations (e.g., El Niño, neutral, or La Niña phases of ENSO), thus better estimate the range of possible extremes. Low likelihood years (extreme hot or cold) can be included, indicating the possible, while simultaneously representing the expected or typical conditions for a particular region. Curves with multiple peaks indicate either strong, stable spatial differences (highland vs lowlands conditions), or strong modal character of the regions climate (e.g., a region is either has very warm years, or very cold years but rarely is in between). The different coloured curves indicate how conditions are expected to change into the future. As the curves are all distinct and the direction of change across the five time-periods is consistent, this indicates all ensemble members agree on the rate and direction of warming into the future. The future curves are typically lower and broader as different simulations follow different trajectories, increasing the variability within the population of values. For some wine regions, higher Growing Degree Days thresholds are not reached, or are reached irregularly. In these cases the curves have inconsistent, irregular shapes (due to a lack of underlying data, please note, curves with <60 underlying values were excluded). Irregular shapes should not be over-interpreted, they just indicate an emerging trend to reach higher Growing Degree days. As these curves transition towards more normal distributions, there is higher confidence in the information they provide and they become more useful.

**Figure 7: Projected annual cumulative Growing Degree Days**

Underlying data source: Climate Futures Australasian Projections 2019 (CFAP2019).

**Annual Cumulative Growing Degree Days** is the cumulative sum of all daily GDD values (calculated as described above) over the period from July 1st to June 30th for each growing season year for each member within the CCCM ensemble. Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australian Geographical Indications (Wine Australia, 2019). Values were calculated for each grid cell.

Each curve represents the annual accumulation of heat for a single grid cell for each ensemble member. Time periods were: 2001-2020; 2021-2040; 2041-2060; 2061-2080; 2081-2100.

**Interpretation:**

Probability distributions reflect the spread and potential likelihood of values within a particular population of values. High, narrow peaks indicate low variability with a high frequency of particular values occurring within the population. Low, broad peaks indicate high variability, with few values occurring frequently. The probability distributions displayed in the atlas incorporate all spatial grid cell values across each 20-year time period, from six ensemble members (i.e., independent simulations). Variability across spatial, temporal scales and across the CFAP2019 ensemble is represented with each curve. This has the advantage of reflecting the diversity that is found within each wine region (cooler vs warmer subregions) and across different types of years (e.g., hot, average or cold). Different ensemble members capture different climate configurations (e.g., El Niño, neutral, or La Niña phases of ENSO), thus better estimate the range of possible extremes. Low likelihood years (extreme hot or cold) can be included, indicating the possible, while simultaneously representing the expected or typical conditions for a particular region. Curves with multiple peaks indicate either strong, stable spatial differences (highland vs lowlands conditions), or strong modal character of the regions climate (e.g., a region is either has very warm years, or very cold years but rarely is in between). The different coloured curves indicate how conditions are expected to change into the future. As the curves are all distinct and the direction of change across the five time-periods is consistent, this indicates all ensemble members agree on the rate and direction of warming into the future. The future curves are typically lower and broader as different simulations follow different trajectories, increasing the variability within the population of values. For some wine regions, higher Growing Degree Days thresholds are not reached, or are reached irregularly. In these cases the curves have inconsistent, irregular shapes (due to a lack of underlying data, please note, curves with <60 underlying values were excluded). Irregular shapes should not be over-interpreted, they just indicate an emerging trend to reach higher Growing Degree days. As these curves transition towards more normal distributions, there is higher confidence in the information they provide and they become more useful.

**Figure 8: Probability distribution of date when Growing Degree Days reaches threshold**

Underlying data source: Climate Futures Australasian Projections 2019 (CFAP2019).

**Date when cumulative Growing Degree Days reaches threshold** was calculated by determining the date within each year (for each member within the CCCM ensemble) when each cumulative Growing Degree Days threshold (1997, 1998, 2000, 2005) was exceeded. Values were calculated for each cell. Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine region’s Geographical Indications (Wine Australia, 2019).

The coloured curves represent the probability distribution of the date when cumulative Growing Degree Days reaches threshold values from all grid cells and all ensemble members during each different 20-year period, displayed separately for each threshold. Time periods were: 2001–2020; 2021–2040; 2041–2060; 2061–2080; 2081–2100. Curves with <60 underlying values were excluded.

**Interpretation:**

Probability distributions reflect the spread and potential likelihood of values within a particular population of values. High, narrow peaks indicate low variability with a high frequency of particular values occurring within the population. Low, broad peaks indicate high variability, with few values occurring frequently. The probability distributions displayed in the atlas incorporate all spatial grid cell values across each 20-year time period, from six ensemble members (i.e., independent simulations). Variability across spatial, temporal scales and across the CFAP2019 ensemble is represented with each curve. This has the advantage of reflecting the diversity that is found within each wine region (cooler vs warmer subregions) and across different types of years (e.g., hot, average or cold).
Rainfall projections from the bias adjusted CFAP2019 ensemble are the highest accuracy, highest precision rainfall projections currently available for Australia. Rainfall is a well understood weather and climate variable, controlled by the ocean, atmosphere and uniform dynamics at large, medium and small scales across space and time. Large and medium scale processes are well resolved within the CFAP2019 ensemble, resulting in reasonable representation of the distribution of rainfall across Australia. This is exemplified within the representation of wet and dry subregions within some wine regions. However, it is those processes that occur at small spatial scales which are sometimes poorly resolved leading to inaccuracies or poor precision. As such, there is greater inaccuracy and precision within the projections of rainfall than there are for temperature. This means there is reduced levels of confidence (i.e. greater uncertainty) surrounding projections of this variable.

There is often greater variability across the ensemble than there is spatially across a region, reflecting the large differences between wet and dry years across most regions. Each ensemble member describes a possible future, with different timing and sequencing of broad global drivers (such as the Southern Annular Mode (SAM), the ENSO Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD)). This results in the timing of wet or dry years being out of phase with each other, resulting in dramatically different projections of any one year (sometimes seen as disconnected clusters of points). Because of this, 10-year or 20-year averages (or distributions) are far more useful for characterising the rainfall trends for a region. Annualised values are useful for identifying the possible extremes, especially the potential timing of their occurrence (for example, it is more likely to have a wet year now, or by 2100).

Figure 1: Observed mean Growing Season Rainfall

Underlying data source: Australian Gridded Climate Data Product (Jones et al., 2009).

Growing Season Rainfall (GSR) was calculated as the sum of all daily rainfall values within the period from October to April of each growing season year. Growing Season Rainfall was the average of all annual GSR values over the current period (1997–2017). Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australian Geographical Indications (Wine Australia, 2019). Values were calculated for each grid cell.

Each tile represents the mean Growing Season Rainfall during the period 1997–2017, which is the period of record (note the boundary). This map reflects the level of variability across the region as it is currently experienced, indicating subregions with higher or lower rainfall. Tiles are the resolution of the underlying data. Towns and roads are included to help identify specific sites within the region. Rain shadows are often visible, although the exact boundaries should be interpreted with caution, especially in small regions where grid cells may be large compared to the controlling topographic features.

Figure 2: Observed change in mean Growing Season Rainfall

Underlying data source: Australian Gridded Climate Data Product (Jones et al., 2009).

Growing Season Rainfall (GSR) was calculated as the sum of all daily rainfall values within the period from October to April of each growing season year. Mean Growing Season Rainfall is the average of all annual GSR values over the current period (1997–2017), or the baseline period (1961–1990). The baseline period mean GSR was then subtracted from the current period mean GSR, resulting in the observed change as mean GSR. Grid cell selections were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australian Geographical Indications (Wine Australia, 2019). Values were calculated for each grid cell.

Each tile represents how mean Growing Season Rainfall during the current period (1997–2017) has changed when compared to mean Growing Season Rainfall during the historical period (1961–1990). Change is presented in millimetres. Towns and roads are included to help identify specific sites within the region. Rain shadows are often visible, although the exact boundaries should be interpreted with caution, especially in small regions where grid cells may be large compared to the controlling topographic features.

Figure 3: Projected mean Growing Season Rainfall

Underlying data source: Climate Futures Australasian Projections 2019 (CFAP2019).

Growing Season Rainfall (GSR) was calculated as the sum of all daily rainfall values within the period from October to April of each growing season year for each member within the CFAP2019. Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australian Geographical Indications (Wine Australia, 2019). Values were calculated for each grid cell. Mean Growing Season Rainfall is the average of all annual GSR values within each time period (2021–2040, 2041–2060, 2061–2080, 2081–2100). These values were calculated for each ensemble member within the CFAP2019. The 6 ensemble member values (for each cell) are averaged generating the ensemble mean for each cell within the region.

Each tile represents the mean Growing Season Rainfall during each 20-year period (2021–2040, 2041–2060, 2061–2080, 2081–2100) following the RCP8.5 scenario. These reflect the level of variability across the region, indicating subregions with higher or lower rainfall and how these are projected to change into the future. Tiles are the resolution of the underlying data. Towns and roads are included to help identify specific sites within the region. Rain shadows are often visible, although the exact boundaries should be interpreted with caution, especially in small regions where grid cells may be large compared to the controlling topographic features.

Figure 4: Projected annual Growing Season Rainfall (October to April)

Underlying data source: Climate Futures Australasian Projections 2019 (CFAP2019).

Blue points: Growing Season Rainfall (GSR) was calculated as the sum of all daily rainfall values within the period from October to April of each growing season year for each member within the CFAP2019. Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australian Geographical Indications (Wine Australia, 2019). Values were calculated for each grid cell.

Grey Bars: The grey bars represent the observed mean Non-Growing Season Rainfall for the current period (1997–2017) from contrasting wine industry Australian Geographical Indications (Wine Australia, 2019). Values were calculated for each grid cell.

Methods and interpretation of figures

Underlying data source: Climate Futures Australasian Projections 2019 (CFAP2019).

Non-Growing Season Rainfall is the sum of all daily rainfall values within the period from May to September of each calendar year (i.e. the May to September prior to the growing season for each year). Mean Non-Growing Season Rainfall was the average of all annual GSR values over the current period (1997–2017) from contrasting wine industry Australian Geographical Indications (Wine Australia, 2019). Values were averaged across space and time, calculated from the Australian Gridded Climate Data product (Jones et al., 2009).

The coloured zones are intended to be used independently of the Growing Year (May to June) axis, allowing decisions to be made based on the expected magnitude of global warming (such as which national governments are committed to within the Paris Agreement), rather than being based on the passage of time. This allows these plots to be useful regardless of the emissions scenario the world eventually follows.

Figure 5: Projected annual Non-Growing Season Rainfall (May to September)

Underlying data source: Climate Futures Australasian Projections 2019 (CFAP2019).

Non-Growing Season Rainfall is the sum of all daily rainfall values within the period from May to September of each calendar year (i.e. the May to September prior to the growing season for each year). Mean Non-Growing Season Rainfall was the average of all annual GSR values over the current period (1997–2017) from contrasting wine industry Australian Geographical Indications (Wine Australia, 2019). Values were averaged across space and time, calculated from the Australian Gridded Climate Data product (Jones et al., 2009).

The coloured zones indicate the ensemble mean time when average global climate temperature increases by 1 °C, 2 °C, 3 °C or 4 °C, following the Representative Concentration Pathway 8.5 scenario (RCP8.5, often referred to as the business as usual scenario). These estimates were taken from the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC-AR5), which are based on the World Climate Research Programme (WCRP) Coupled Model Intercomparison Project — phase 5 (CMIP5) global climate model archive.

Interpretation:

Key elements:

- Natural variability of Non-Growing Season Rainfall is very high over the entire 140 year period for most regions, with dramatic differences between wet and dry years.
- Regional variability in any one year is exhibited by large regions.
- For Non-Growing Season Rainfall the influence of climate change is observable from around the 2000s onwards for most regions, although for some the influence appears to have been since the 1980s and for others there is no obvious climate change signal at all.
- Although ensemble members do not always agree on the magnitude of the projected changes, following the RCP8.5 scenario most regions exhibit a drying trend during the non-growing season into the future. Where this trend is occurring, model agreement in the direction provides improved confidence, however the rate and magnitude is far less certain.
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Figure 7: Probability distribution of seasonal rainfall

Underlying data source: Climate Futures Australasian Projections 2019 (CFAP2019).

Seasonal Rainfall is the sum of all daily rainfall values within each calendar season (Winter, Spring, Summer, Autumn), for each growing season year for each ensemble member within the CFAP2019. Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australian Geographical Indications (Wine Australia, 2019). Values were calculated for each grid cell. All individual spatial and ensemble member values were included, no spatial or ensemble averaging is performed. The coloured curves represent the probability distribution of seasonal rainfall values from all grid cells and all ensemble members during each different 20-year period. Time periods were: 2001–2020; 2021–2040; 2041–2060; 2061–2080; 2081–2100.

The grey, filled curves represent the distribution of observed seasonal rainfall values from the current period (1997–2017) for contrasting wine industry: Australian Geographical Indications (Wine Australia, 2019).

Interpretation:

Probability distributions reflect the spread and potential likelihood of values within a particular population of values. High, narrow peaks indicate low variability with a high frequency of particular values occurring within the population. Low, broad peaks indicate high variability, with few values occurring frequently. The probability distributions displayed in the atlas incorporate all spatial grid cell values, across each 20-year time-period, from six ensemble members (i.e., independent simulations). Variability across spatial and temporal scales as well as across the CFAP2019 ensemble is represented with each curve. This has the advantage of reflecting the diversity that is found within each wine region (wetter vs drier subregions) and across different types of years (e.g., wet, average or dry). Different ensemble members capture different climate configurations (e.g., El Niño, neutral, or La Niña phases of ENSO), thus better estimate the range of possible extremes. Low likelihood years (extreme wet or dry) can be included, indicating what is possible, while simultaneously representing the expected or typical conditions for a particular region. Curves with multiple peaks indicate either strong, stable spatial differences (e.g., desert adjacent to alpine), or a strong modal character of the regions climate (e.g., a region either has wet years, or dry years but hardly average years). The different coloured curves indicate how conditions are expected to change into the future. The future curves are typically lower and broader as different simulations follow different trajectories, increasing the variability within the population of values.

When curves for each time period are all distinct and the direction of change across the five time-periods is consistent, this indicates all ensemble members agree broadly on the rate and direction of warming into the future. In such cases there is increased certainty surrounding the projected future.

When the curves from all time periods are overlapping, natural variability dominates the climate change trend, with the future conditions projected to be much the same as at present. When the direction of change is confused between time periods, or the spread of the curves is significantly broadened (but the average conditions are more or less the same), ensemble variability is high, there is significant uncertainty regarding the projections of the future.

The grey curves are the probability distribution for contrasting Australian wine regions, selected to present the range observed across Australia, and indicate the approximate analogous a region may become similar to into the future. These grey curves are calculated using the Australian Gridded Climate Data product from the period 1997–2017. The coloured curves are calculated using the bias-adjusted CFAP2019 ensemble during the period 2001–2040. As there are differences between these two archives, the 2001–2040 curves for some selected regions are slightly different to the grey expected. These differences are expected.
Figure 1: Observed mean annual aridity index

Underlying data source: Australian Gridded Climate Data Product (Jones et al., 2009).
Annual Aridity Index was calculated as \( \frac{P}{E} \), where \( P \) is the sum of daily rainfall during the period from July to June each annual cycle, and \( E \) is the sum of daily evaporation during the period from July to June each annual cycle. Aridity Index values below 0.25 and above 2 offered limited meaningful information, so values >0.25 were rounded up to 0.25 and values <2 were rounded down to 2. Mean Annual Aridity Index is the average of all Annual Aridity Index values over the current period (1997-2017). Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australian Geographical Indications (Wine Australia, 2019). Values were calculated for each grid cell.

Interpretation:
Each tile represents the mean Annual Aridity Index during the period 1997-2017, which is the period of recent memory. This map reflects the level of variability across the region as it is currently expressed, indicating drying/wetter Index subsquares (if they exist). Tiles are the resolution of the underlying data. Towns and roads are included to help identify specific sites within the region. Rain shadows or regions more exposed to evaporation are often visible, although the exact boundaries should be interpreted with caution, especially in small regions where grid cells may be large compared to the controlling topographic features.

Figure 2: Observed change in mean annual aridity index

Underlying data source: Australian Gridded Climate Data Product (Jones et al., 2009).
Annual Aridity Index was calculated as \( \frac{P}{E} \), where \( P \) is the sum of daily rainfall during the period from July to June each annual cycle, and \( E \) is the sum of daily evaporation during the period from July to June each annual cycle. Mean Annual Aridity Index is the average of all Annual Aridity Index values over the current period (1997-2017), or the baseline period (1961-1990). The baseline period mean Annual Aridity Index was then subtracted from the current period mean Annual Aridity Index, resulting in the observed change in mean Annual Aridity Index (as an absolute value). This was divided by the baseline period mean Annual Aridity Index and multiplied by 100 to produce the observed change in mean Annual Aridity Index as a percentage, which was considered more useful than the logarithmic scale of the aridity index. Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australian Geographical Indications (Wine Australia, 2019). Values were calculated for each grid cell.

Interpretation:
Each tile represents how mean Annual Aridity Index during the current period (1997-2017) has changed compared to mean annual Aridity Index during the historical period (1961-1990). Change is presented as a percentage, to allow regions with high variability to understand the rate of change within their subregion. Towns and roads are included to help identify specific sites within the region. Rain shadows or regions more exposed to evaporation are often visible, although the exact boundaries should be interpreted with caution, especially in small regions where grid cells may be large compared to the controlling topographic features.

Figure 3: Projected mean annual aridity index

Underlying data source: Climate Futures Australasian Projections 2019 (CFAP2019).
Annual Aridity Index was calculated as \( \frac{P}{E} \), where \( P \) is the sum of daily rainfall during the period from July to June each annual cycle, and \( E \) is the sum of daily evaporation during the period from July to June each annual cycle. Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australian Geographical Indications (Wine Australia, 2019). Values were calculated for each grid cell.

Interpretation:
Mean Annual Aridity Index was calculated as \( \frac{P}{E} \), where \( P \) is the sum of daily rainfall during the period from July to June each annual cycle, and \( E \) is the sum of daily evaporation during the period from July to June each annual cycle. Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australian Geographical Indications (Wine Australia, 2019). Values were calculated for each grid cell. Mean Annual Aridity Index is the average of all Annual Aridity Index values within each grid cell during each 20-year period (2021-2040, 2041-2060, 2061-2080, 2081-2100 following the RCP8.5 scenario). These reflect the level of variability across the region, indicating drier/wetter subregions (if they exist) and how these are projected to change into the future. Tiles are the resolution of the underlying data. Towns and roads are included to help identify specific sites within the region. Rain shadows or regions more exposed to evaporation are often visible, although the exact boundaries should be interpreted with caution, especially in small regions where grid cells may be large compared to the controlling topographic features. Further, Australia’s wine regions exhibit Annual Aridity Index values that are decreasing across the country, indicating a drier, moisture constrained future.

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Aridity

Figure 4: Projected annual aridity index

Underlying data source: Climate Futures Australasian Projections 2019 (CFAP2019).
Blue points: Annual Aridity Index was calculated as \( \frac{P}{E} \), where \( P \) is the sum of daily rainfall during the period from July to June each annual cycle, and \( E \) is the sum of daily evaporation during the period from July to June each annual cycle. Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australian Geographical Indications (Wine Australia, 2019). Values were averaged across space and time, calculated from the Australian Gridded Climate Data Product (Jones et al., 2009).

Grey Bars: The grey bars represent the observed mean Annual Aridity Index for the current period (1997-2017) from contrasting wine industry Australian Geographical Indications (Wine Australia, 2019). Values were calculated for each grid cell.

Coloured zones: The coloured curves represent the probability distribution of average global climate temperature increases by PC, ZC, ZPC or FC, following the Representative Concentration Pathways 8.5 scenario (RCP8.5, often referred to as the business as usual scenario). These estimates were taken from the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC-AR5), which are based on the World Climate Research Programme (WCRP) Coupled Model Intercomparison Project - phase 5 (CMIP5) global climate model archive.

Interpretation:
Key elements:
- Ensemble members broadly agree on the magnitude and direction of the projected changes. Following the RCP8.5 scenario most regions exhibit a drying trend.
- Ensemble means for most years become less common in the future.
- For Annual Aridity Index, the influence of climate change is obvious from around 2020 onwards for most regions, although for some regions the influence appears to have been since about the 1980s.
- Values are limited between 0.05 and 2 (outside of this range, values become meaningless). As such, in some cases, values cluster at these boundaries.
- Divergence away from these clusters (say from 2 to 1.5) indicates a significant, strong drying trend.
- Data is presented on a log scale, so the differences across regions (e.g., the difference between the Riverland and the Barossa Valley) are difficult to see on a standard scale. Following the RCP8.5 scenario most regions exhibit a drying trend.
- Due to the log scale, decreasing trends are amplified (so they look steeper than they are).

Figure 5: Projected monthly aridity index

Underlying data source: Climate Futures Australasian Projections 2019 (CFAP2019).
Violin plots represent 20-years of values for each month within each time period (2021-2040, 2041-2060, 2061-2080, 2081-2100). All individual spatial and ensemble member values are included, no spatial or ensemble averaging is performed.

Interpretation:
Violin plots are a combination of box-and-whisker plots and probability distribution curves. Like a box-and-whisker plot, the shape is defined by the values within that population. The violin is created by mirroring the probability distribution of the values, plotted in the vertical direction, describing the frequency and spread of values in the y-axis space. Where there is a concentration of values, the violin is broad. Where there are few values the violin is narrow (possibly only a single line). As the probability distribution is continuous, where extreme outlier values occur, narrow lines can be drawn between the main body and the outlier (typical of high rainfall areas/months that may be particularly dry in some years).

Differences between the months, or time periods is expressed as changes to the shape of the violin. The 2001-2020 violin for each month is shadowed underneath future time periods, so that changes in future periods can be more easily determined.

Figure 6: Probability distribution seasonal aridity index

Underlying data source: Climate Futures Australasian Projections 2019 (CFAP2019).
Seasonal Aridity Index is calculated as \( \frac{P}{E} \), where \( P \) is the sum of rainfall within each calendar season (Winter, Spring, Summer, Autumn), and \( E \) is the sum of evaporation within each calendar season (Winter, Spring, Summer, Autumn). This is calculated for each growing season year and for each ensemble member within the CFAP2019. Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australian Geographical Indications (Wine Australia, 2019). Values were calculated for each grid cell. All individual spatial and ensemble member values are included, no spatial or ensemble averaging is performed.

The coloured curves represent the probability distribution of Seasonal Aridity Index values from all grid cells, all ensemble members and all years during each 20-year time period. Time periods are: 2001-2020, 2021-2040, 2041-2060, 2061-2080, 2081-2100.
METHODS AND INTERPRETATION

Methods and interpretation of figures

Figure 7: Probability distribution of mean aridity index from season start until harvest

Underlying data source: Climate Futures Australasian Projections 2019 (CFAP2019).

Harvest date was determined as the date within each year when each cumulative Growing Degrees Days threshold (1000, 1500, 2000, 2500) was exceeded. Thus, there were 4 potential harvest dates, to account for different regional, varietal or style preferences of different users of the atlas. The aridity index from season start until harvest was calculated as P/E, where: P = the sum of rainfall from July 1st to harvest date, and E = the sum of evaporation from July 1st to harvest date. Values were calculated for each cell and for each ensemble member within CFAP2019. Grid cells selected were those within (or intersecting with the boundary of) the polygons that defined each wine region’s Geographical Indications (Wine Australia, 2019).

The coloured curves represent the probability distribution of aridity index from season start until harvest values for all grid cells and all ensemble members for all years during each different 20-year period, displayed separately for each GDD threshold. Time periods were: 2001–2020, 2021–2040, 2041–2060, 2061–2080, 2081–2100.

Interpretation:
Probability distributions reflect the spread and potential likelihood of values within a particular region. High, narrow peaks indicate low variability with a high frequency of particular values occurring within the population. Short, broad peaks indicate high variability, with low values occurring frequently. The probability distributions displayed in the atlas incorporate all spatial grid cell values, across each 20-year time-period, from six ensemble members (i.e., independent simulations). Variability across spatial and temporal scales as well as across the CFAP2019 ensemble is represented with each curve. This has the advantage of reflecting the diversity that is found within each wine region (wetter vs drier subregions) and across different types of years (e.g., wet, average or dry). Different ensemble members capture different climate configurations (e.g., El Niño, neutral, or La Niña phases of ENSO), thus better estimate the range of possible extremes. Low likelihood years (extreme wet or dry) can be included, indicating what is possible, while simultaneously representing the expected or typical conditions for a particular region. Curves with multiple peaks indicate either strong, stable spatial differences (e.g., desert adjacent to alpine), or a strong modal character of the regions climate (e.g., a region either has wet years, or dry years but rarely average years). The different curves indicate how conditions are expected to change into the future.

When the curves from all time periods are overlapping, natural variability dominates the climate change trend, with the future conditions projected to be much the same as at present.

When the direction of change is confused between time periods, or the spread of the curve is significantly broadened (but the average conditions are more or less the same), ensemble variability is high, there is significant uncertainty regarding the projections of the future.

When curves for each time period are all distinct and the direction of change across the five time-periods is consistent, this indicates all ensemble members agree broadly on the rate and direction of warming into the future. In such cases there is increased certainty surrounding the projected future.

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When the direction of change is confused between time periods, or the spread of the curve is significantly broadened (but the average conditions are more or less the same), ensemble variability is high, there is significant uncertainty regarding the projections of the future.
Extreme Heat

Underlying data source: Australian Gridded Climate Data Product (Jones et al., 2009)

Excess Heat Factor (EHF) is an index that describes the severity of short term, acute heat impacts on humans during heat waves. It accounts for how hot a period of three days or more is in relation to an annual temperature threshold at a particular location, as well as how hot the period is with respect to the recent past (the previous 30 days). This reflects the fact that people acclimatise to a certain extent to their local climate but may not be prepared for a sudden rise in temperature above that of the recent past. This is calculated in Nairn and Fawcett (2015). In order to apply this assessment into the future, the baseline period used to calculate the annual temperature thresholds needed to be applied on a rolling basis, to take into account acclimatisation. The baseline period was always calculated as the previous 30 years (rounded to the nearest 5 years, so for example, the baseline period for the year 1993 was 1963–1992; the baseline period for the year 2020 was 1991–2020). Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australian Geographical Indications (Wine Australia, 2019). Values were calculated for each grid cell. Heatwave days were identified as those when EHF is positive for 3 consecutive days or more. Mean EHF is the average of all observed EHF values during heatwave days within the current period (1997–2017).

Interpretation:

Each tile represents the mean Excess Heat Factor (EHF) during the period 1997–2017, (which is the period of recent memory). Higher (lower) EHF values indicate more (less) intense heatwaves. For more information refer to Nairn and Fawcett (2015). This map reflects the level of variability across the region as it is currently experienced. Lower values tend to appear in regions exposed to large water bodies (typically oceans) which provides higher relief, particularly overnight. Tiles are the resolution of the underlying data. Towns and roads are included to help identify specific sites within the region.

Figure 2: Observed change in excess heat factor

Underlying data source: Australian Gridded Climate Data Product (Jones et al., 2009)

Excess Heat Factor (EHF) is an index that describes the severity of short term, acute heat impacts on humans during heat waves. It accounts for how hot a period of three days or more is in relation to an annual temperature threshold at a particular location, as well as how hot the period is with respect to the recent past (the previous 30 days). This reflects the fact that people acclimatise to a certain extent to their local climate but may not be prepared for a sudden rise in temperature above that of the recent past. This is calculated in Nairn and Fawcett (2015). In order to apply this assessment into the future, the baseline period used to calculate the annual temperature thresholds needed to be applied on a rolling basis, to take into account acclimatisation. The baseline period was always calculated as the previous 30 years (rounded to the nearest 5 years, so for example, the baseline period for the year 1993 was 1963–1992; the baseline period for the year 2020 was 1991–2020). Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australian Geographical Indications (Wine Australia, 2019). Values were calculated for each grid cell. Heatwave days were identified as those when EHF is positive for 3 consecutive days or more. Mean EHF is the average of all observed EHF values during heatwave days within the current period (1997–2017).

Interpretation:

Each tile represents the mean Excess Heat Factor (EHF) during each 20-year period of 2011–2030, 2031–2050. 2051–2070, 2071–2090 (following the RCP8.5 scenarios). These reflect the level of variability across the region and the rate of change projected into the future. In many regions, heatwave intensity is relatively stable: as EHF assumes community will acclimatise to more extreme conditions and this index does not account for hard physiological limits. Higher (lower) EHF values indicate more (less) intense heatwaves. Tiles are the resolution of the underlying data. 

Figure 4: Projected mean number of extreme heat days

Underlying data source: Climate Futures Australasian Projections 2019 (CFAP2019)

The annual number of days where daily maximum temperature exceeded either 35°C, 37°C, 40°C or 45°C was calculated for each cell and ensemble member within CFAP2019. Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australian Geographical Indications (Wine Australia, 2019). Values were calculated for each grid cell. Heatwave days were identified as those (i.e., a summary single value for each year from all inputs).

Interpretation:

Violin plots represent 20-year values of within each time period (2001–2020, 2021–2040, 2041– 2060, 2061–2080, 2081–2090). All individual spatial and ensemble member values are included, no spatial or ensemble averaging is performed.
Interpretation:

The coloured curves represent the probability distribution of daily minimum temperature and daily maximum temperature during a heatwave. Values are for all grid cells, all ensemble members, for all years during each 20-year period. Time periods were: 2001–2020; 2021–2040; 2041–2060; 2061–2080; 2081–2100. All individual spatial and ensemble member values are included, no spatial or ensemble averaging is performed.

Figure 7: Probability distribution of daily minimum and maximum temperature during a heatwave


Excess Heat Factor (EHF) is an index that describes the severity of short-term, acute heat impacts on humans during heat waves. The calculation is described in Nairn and Fawcett (2015). Heatwave days were identified as those days when EHF was positive.

Date of Heatwave Days was determined as the date within each year a heatwave occurred. For multi-day events, all days were included and daily minimum and maximum temperature values of those days were extracted. Values were extracted for each cell and for each ensemble member within CFAP2019. Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine region's Geographical Indications (Wine Australia, 2019).

The coloured curves represent the probability distribution of daily minimum temperature and daily maximum temperature during a heatwave. Values are for all grid cells, all ensemble members, for all years during each 20-year period. Time periods were: 2001–2020; 2021–2040; 2041–2060; 2061–2080; 2081–2100. All individual spatial and ensemble member values are included, no spatial or ensemble averaging is performed.

Figure 8: Probability distribution of date of heatwave days


Excess Heat Factor (EHF) is an index that describes the severity of short-term, acute heat impacts on humans during heat waves. A definition of how it is calculated is described in Nairn and Fawcett (2015). Heatwave days were identified as those days when EHF was positive.

Date of Heatwave Days was determined as the date within each year a heatwave occurred. For multi-day events, all days were included and daily minimum and maximum temperature values of those days were extracted. Values were extracted for each cell and for each ensemble member within CFAP2019. Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine region's Geographical Indications (Wine Australia, 2019).

The coloured curves represent the probability distribution of Date of Heatwave Days values for all grid cells and all ensemble members for all years during each 20-year period. Time periods were: 2001–2020; 2021–2040; 2041–2060; 2061–2080; 2081–2100. All individual spatial and ensemble member values are included, no spatial or ensemble averaging is performed.

Interpretation:

Probability distributions reflect the spread and potential likelihood of values within a particular population of values. High, narrow peaks indicate low variability with a high frequency of particular values occurring within the population. Short, broad peaks indicate high variability, with few values occurring frequently. The probability distribution displayed in the atlas incorporate all spatial grid cell values, across each 20-year time period, from six ensemble members (i.e., independent simulations). Variability across spatial and temporal scales as well as across the CFAP2019 ensemble is represented with each curve. This has the advantage of reflecting the diversity that is found within each wine region (wetter vs drier subregions) and across different types of years (e.g., wet, average or dry). Different ensemble members capture different climate configurations (e.g., El Niño, neutral, or La Niña phases of ENSO), thus better estimate the range of possible outcomes. Low likelihood years (extreme wet or dry) can be included, indicating what is possible, while simultaneously representing the expected or typical conditions for a particular region. Curves with multiple peaks indicate either strong, stable spatial differences (e.g., desert adjacent to alpine), or a strong modal character of the regions climate (e.g., a region either has wet years, or dry years but rarely average years). The different curves indicate low conditions are expected to change into the future. The future curves are typically shorter and broader as different simulations follow different trajectories, increasing the variability within the population of values.

When curves for each time period are all distinct and the direction of change across the five time-periods is consistent, this indicates all ensemble members agree broadly on the rate and direction of warming into the future. In such cases there is increased certainty surrounding the projected future.

When the curves from all time periods are overlapping, natural variability dominates the climate change trend, with the future conditions projected to be much the same as at present.

When the direction of change is consistent between time periods, or the spread of the curves is significantly broadened (but the average conditions are more or less the same), ensemble variability is high, there is significant uncertainty regarding the projections of the future.

Heatwaves are a specifically characterised event. As the date of heatwave days for each region does not change significantly, heatwaves are calculated relative to a 30-year baseline period. Heatwaves are calculated relative to a 30-year baseline period. However, within a climate change context, the 30-year baseline needs follow the target year (to account for acclimatisation of organisms within the region as the climate warms). This rolling 30-year baseline period warms with climate change. This means that the latest days threshold typically occurs at the peak of summer (with a normally distributed spread surrounding this mean). The absolute temperatures of heatwaves are much hotter and in many regions the EHF values increase, indicating an increase in heatwave intensity, however, the chance of a heatwave in any month of the year is projected to remain relatively constant into the future.
**METHODS AND INTERPRETATION**

### Methods of interpretation

- **Frost risk days** are defined as any day when daily minimum temperature was < -2°C.
- **Annual frost risk days** is the number of individual frost risk day events that occur during the period from October to April each annual cycle.
- **Mean frost risk days** is the average of all annual frost risk days within each current period (1997–2017).
- **Extreme Cold**

#### Figure 1: Observed mean frost risk days

- **Underlying data source:** Australian Gridded Climate Data Product (Jones et al., 2009). A frost risk day was defined as any day when daily minimum temperature was < -2°C.
- **Mean frost risk days** is the average of all annual frost risk days within the current period (1997–2017).
- **Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australian Geographical Indications (Wine Australia, 2019).** Values were calculated for each grid cell.

#### Interpretation:

Each tile represents the mean frost risk days during the period 1997–2017, (which is the period of recent memory). Higher (lower) frost risk values indicate more (less) days where minimum temperatures were < -2°C. For many regions, frost risk is very low (often less than 1 day per year). This map reflects the level of variability across the region as it is currently experienced. Tiles are the resolution of the underlying data. Higher values typically correspond to higher elevation regions. Tiles have an average deviation of the area they represent, so they best represent regions that have similar elevations (~1km²) and thus are poorly represented. This can influence the representation of some climatic features and should be considered when interpreting these figures. Towns and roads are included to help identify specific sites within the region.

#### Figure 2: Observed change in mean frost risk days

- **Underlying data source:** Australian Gridded Climate Data Product (Jones et al., 2009). A frost risk day was defined as any day when daily minimum temperature was < -2°C.
- **Mean frost risk days** is the average of all annual frost risk days within the current period (1997–2017), or the baseline period (1961–1990).
- **The baseline period mean frost risk days** was then subtracted from the current period frost risk days, resulting in the observed change in mean frost risk days.
- **Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australian Geographical Indications (Wine Australia, 2019).** Values were calculated for each grid cell.

#### Interpretation:

Each tile represents the mean frost risk days during each 20-year period of 2011–2040, 2041–2060, 2061–2080, 2081–2100 (following the RCP8.5 scenario). Higher (lower) frost risk values indicate more (less) days where minimum temperatures were < -2°C. This map reflects the level of variability across the region as it is currently experienced and for many regions, frost risk is very low, often less than 1 day per year (so these figures have few features). Tiles are the resolution of the underlying data. Higher values typically correspond to higher elevation regions. Tiles have an average deviation of the area they represent, so they best represent regions that have similar elevations (~1km²) and thus are poorly represented. This can influence the representation of some climatic features and should be considered when interpreting these figures. Towns and roads are included to help identify specific sites within the region.

#### Figure 3: Projected mean frost risk days

- **Underlying data source:** Climate Futures Australasian Projections 2019 (CFAP2019). An ensemble mean was generated for each cell within the region, generating the ensemble mean for each cell within the region.
- **Mean frost risk days** is the average of all annual frost risk days within each time period (2001–2030, 2021–2050, 2041–2060, 2061–2080, 2081–2100). These were calculated for each ensemble member within the CFAP2019. The 6 ensemble member values (for each cell) are averaged, generating the ensemble mean for each cell within the region.
- **Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australasian Geographical Indications (Wine Australia, 2019).** Values were calculated for each grid cell.

#### Interpretation:

Each tile represents the mean frost risk days during each 20-year period of 2001–2040, 2041–2060, 2061–2080, 2081–2100 (following the RCP8.5 scenario). Higher (lower) frost risk values indicate more (less) days where minimum temperatures were < -2°C. This map reflects the level of variability across the region as it is currently experienced and for many regions, frost risk is very low (often less than 1 day per year). This can influence the representation of some climatic features and should be considered when interpreting these figures. Towns and roads are included to help identify specific sites within the region.

#### Figure 4: Projected monthly minimum temperature

- **Underlying data source:** Climate Futures Australasian Projections 2019 (CFAP2019). Monthly minimum temperatures were extracted directly from the CFAP2019.
- **Violin plots** represent 20-years of values for each month within each time period (2021–2040; 2041–2060; 2061–2080; 2081–2100). All individual spatial and ensemble member values are included. Spatial or ensemble averaging is performed. Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australasian Geographical Indications (Wine Australia, 2019). Values were calculated for each grid cell.

#### Interpretation:

Violin plots are a combination of box-and-whisker plots and probability distribution curves. The shape is narrow (possibly only a single line). As the probability distribution is continuous, where extreme outlier values occur, narrow lines can be drawn between the main body and the outlier (typical of high rainfall areas/months that may be particularly dry in some years).

Differences between the months, or time periods is expressed as changes to the shape of the violin. Where there is a concentration of values, the violin is broad. Where there are few values the violin is narrow (possibly only a single line). As the probability distribution is continuous, where extreme outlier values occur, narrow lines can be drawn between the main body and the outlier (typical of high rainfall areas/months that may be particularly dry in some years).

In all wine regions across Australia, minimum daily temperatures are projected to increase rapidly from 2030 onwards.

#### Figure 5: Projected monthly frost risk days

- **Underlying data source:** Climate Futures Australasian Projections 2019 (CFAP2019). Frost risk days were defined as days when daily minimum temperature was < -2°C. The monthly count of frost risk days was calculated for each month, within each year for each ensemble member within CFAP2019. Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australasian Geographical Indications (Wine Australia, 2019). Values were calculated for each grid cell and then averaged into a regional mean for each 20-year time period (i.e., a single summary value for each time period from all inners across the region). Time periods were: 2001–2020, 2021–2040, 2041–2060, 2061–2080, 2081–2100.

#### Interpretation:

Average monthly frost risk days for each 20-year period of 2021–2040, 2041–2060, 2061–2080, 2081–2100 (following the RCP8.5 scenario). Differences between the months, or time periods is expressed as changes to the height of each column. The 2011–2030 column for each month is shadowed underneath future time periods, so that changes in future periods can be more easily determined.

#### Figure 6: Projected accumulated frost intensity

- **Underlying data source:** Climate Futures Australasian Projections 2019 (CFAP2019). Frost risk days were defined as days when daily minimum temperature was < -2°C. The daily frost intensity was calculated as the absolute value of temperature less than < -2°C (e.g., a daily minimum temperature of -3°C has a daily frost intensity of 1°C). The annual accumulated frost intensity was calculated as the sum of daily frost intensity over the period from July 1st to June 30th each annual cycle. This was calculated for each ensemble member within CFAP2019. Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australasian Geographical Indications (Wine Australia, 2019). Values were calculated for each grid cell. All individual spatial and ensemble member values are included, no spatial or ensemble averaging is performed.

#### Interpretation:

For all Australian wine regions, accumulated frost intensity is projected to decrease into the future. As temperatures rise, days that are < -2°C are projected to warm, decreasing the shift or frost intensity of these days. In many regions, these days are dominated by high elevation regions, rather than the true growing areas. However, they provide a strong indication of the direction and rate of change projected into the future. The decreasing trend appears to have been occurring since the 1960s (although it is possible it started earlier).

#### Figure 7: Projected mean number of extreme cold days

- **Underlying data source:** Climate Futures Australasian Projections 2019 (CFAP2019). The annual number of days where daily minimum temperature fell below either -2°C, -1°C, or 0°C was calculated for each cell and ensemble member within CFAP2019. Grid cells selected were those within (or intersecting with the boundary of) the polygon that defined each wine industry Australasian Geographical Indications (Wine Australia, 2019). Values were calculated for each grid cell. Those values were then averaged into a regional ensemble mean for each year (i.e., a single summary value for each year from all inners across the region).
Part II

Australia’s Wine Future — A Climate Atlas
Figure 1: Spatial representation of the Australian wine regions used within this atlas. For mainland Australia these are the Wine Australia Geographical Indications (GI).

The Tasmania GI was divided into 8 regions based on Australian Bureau of Meteorology forecast districts, in recognition of the different climatic zones across the state.
Figure 2: Observed mean Growing Season Temperature (Oct–Apr) across Australia’s wine regions

Australia’s Wine Future — A Climate Atlas

OBSERVED CLIMATE ACROSS AUSTRALIA’S WINE REGIONS

National Maps

Figure 3: The change in Growing Season Temperature between the current (1997–2017) and historical (1961–1990) periods. Growing Season Temperature has increased across the region over recent decades.

Figure 3: Observed change in mean Growing Season Temperature across Australia’s wine regions
Figure 4: Observed mean Growing Season Rainfall across Australia’s wine regions
Figure 5: Observed change in mean Growing Season Rainfall across Australia’s wine regions

Western Australia
1. Swan District 6. Blackwood Valley
2. Perth Hills 7. Pemberton
3. Peel 8. Margaret River
5. Margaret River

South Australia
10. Southern Flinders Ranges 19. Southern Pauine
11. Clare Valley 20. Currayn Creek
12. Barossa Valley 21. Langhorne Creek
13. Eden Valley 22. Padthaway
14. Riverland 23. Mount Benson
15. Adelaide Plains 24. Wirrabara
18. Kangaroo Island 27. Mount Gambier

Queensland
28. South Burnett 29. Granite Belt

New South Wales
30. New England 37. Willunga
31. HUNGA 38. Southern Highlands
32. Hunter 39. Gundagai
33. Mudgee 40. Canberra District
34. Orange 41. Shoalhaven District
35. Cowra 42. Tumbarumba
36. Riverina 43. Peninsular

Victoria
44. Murray Darling 51. Alpine Valleys
45. Swan Hill 52. Strathbogie Ranges
46. Goulburn Valley 53. Upper Goulburn
47. Rutherglen 54. Heathcote
48. Goulburn 55. Bedford
49. Beechworth 56. Pyrenees
50. King Valley 57. Macedon Ranges

Tasmania
64. Tasmania King Island 68. Grampians
65. Tasmania Freycinet Island 69. High Land
66. Tasmania North-West Coast 70. Yarra Valley
67. Tasmania Central North 71. Yarra Valley Peninsula
68. Tasmania North East 72. Yarra Valley
69. Tasmania East Coast 73. Yarra Valley

Figure 5: Change in Growing Season Rainfall (Oct–Apr) between the current (1997–2017) and historical (1961–1990) periods. Negative values indicate a trend towards drier conditions. Positive values indicate a trend towards wetter conditions.
Figure 6: Observed mean Non-Growing Season Rainfall across Australia's wine regions
Figure 7: Observed change in mean Non-Growing Season Rainfall across Australia’s wine regions

Figure 7: Change in Non-Growing Season Rainfall (May–Sep) between the current (1997–2017) and historical (1961–1990) periods. Negative values indicate a trend towards drier conditions. Positive values indicate a trend towards wetter conditions.
Figure 8: Observed mean Growing Year Rainfall across Australia's wine regions
Figure 9: Observed change in mean Growing Year Rainfall across Australia’s wine regions

Figure 9: Change in Averaged Rainfall (Jul–Jun) between the current (1997–2017) and historical (1961–1990) periods. Negative values indicate a trend towards drier conditions. Positive values indicate a trend towards wetter conditions.
Figure 10: Observed mean Aridity Index across Australia’s wine regions

The map illustrates the observed mean annual Aridity Index across Australia’s wine regions. Aridity Index is a value that characterises the ratio between the mean annual rainfall and mean annual evaporation. Low values indicate drier conditions, while high values indicate wetter conditions. The map is color-coded to show the range of Aridity Index values across different wine regions, providing a visual representation of the climate conditions for viticulture. The map highlights the diversity of climate across the various wine regions, crucial for understanding the impact of climate on wine production.
Figure 11: Observed percentage change in mean Aridity Index between the current (1997–2017) and historical (1961–1990) periods. This shows the change already experienced across the country. Negative values indicate a trend towards drier conditions. Positive values indicate a trend towards wetter conditions.
OBSERVED CLIMATE ACROSS AUSTRALIA’S WINE REGIONS

Reference Bar Charts

Figure 12: Mean Growing Season Temperature for current period (1997–2017)

Figure 13: Mean maximum growing year Growing Degree Days for current period (1997–2017)
OBSERVED CLIMATE ACROSS AUSTRALIA’S WINE REGIONS

Reference Bar Charts

Figure 14: Wine regions of Australia ranked by total Growing Season Rainfall for the period 1997–2017. The growing season is defined to be October to April; e.g. the first growing season is October 1997 to April 1998, and the last growing season is October 2016 to April 2017.

Figure 15: Wine regions of Australia ranked by total Non-Growing Season Rainfall for the period 1997–2017. The non-growing season is defined to be May to September; e.g. the first non-growing season is May 1997 to September 1997, and the last non-growing season is May 2016 to September 2016.
OBSERVED CLIMATE ACROSS AUSTRALIA’S WINE REGIONS

Reference Bar Charts

Figure 16: Wine regions of Australia ranked by total Annual Rainfall for the period 1997–2017. The annual period is defined to be July to June; e.g. the first annual period is July 1997 to June 1998, and the last annual period is July 2016 to June 2017.

Figure 17: Wine regions of Australia ranked by mean growing year Aridity Index for the period 1997–2017. The growing season is defined to be October to April; e.g. the first growing season is October 1997 to April 1998, and the last growing season is October 2016 to April 2017.
Figure 18: Representation of mean Growing Year Aridity Index vs mean Growing Season Temperature for each Australian Geographic Indication, averaged within the time periods (1961–1990, 1997–2017, 2021–2040, 2041–2060, 2061–2080, and 2081–2100), following the RCP8.5 scenario. Points represent observed conditions during the current period (1997–2017). Lines indicate the general direction of change experienced and projected into the future (based on the CR2540 ensemble mean). Line segments represent the shorter-term direction of change projected between time periods. Values are regional and ensemble averages (i.e., a single value for each region, for each time period). The plot shows a tendency of regions to move towards warmer and drier conditions (i.e., higher mean Growing Season Temperature and lower mean Growing Year Aridity Index). Regions that currently experience quite wet conditions (points on the right-hand side of the plot) are projected to have both drying and warming challenges to address into the future (pathways are diagonal). Regions that are already very arid (points on the left-hand side of the plot) are projected to have challenges driven mostly by warming temperature (pathways are more vertical).
Australia’s Wine Future — A Climate Atlas

SOUTHERN FLINDERS RANGES

Heat

Figure 1: Observed mean Growing Season Temperature (Oct–Apr) across all growing years from 1997–2017.

Figure 2: Observed change in mean Growing Season Temperature 1997–2017 versus 1961–1990 periods. Growing Season Temperature has increased across the region over recent decades.

Figure 3: Projected mean Growing Season Temperature 2021–2040.

Figure 4: Projected Growing Season Temperature (October to April) for 20-year time periods from 2021 to 2100. Growing Season Temperature is expected to increase steadily into the future. Each grid cell is the mean of the 6 ensemble members.

Figure 5: Observed and projected Growing Degree Days (GDD) across the growing year (July–June). Dashed lines show GDD values (1000, 1500, 2000, 2500) for some example phenological thresholds. Each growing year is represented by a colored line. In future time periods, heat accumulates faster, thresholds are reached earlier and maximum GDD reached is higher.

Figure 6: Probability distributions showing the range of dates at which the example phenological thresholds (1000, 1500, 2000, 2500) are reached for each time period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates earlier (later) harvest dates. A wider (thinner) curve indicates a larger (smaller) range of harvest dates. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).

Figure 7: Cumulative Growing Degree Days (GDD) across the growing year (July–June). Dashed lines show GDD values (1000, 1500, 2000, 2500) for some example phenological thresholds. Each growing year is represented by a colored line. In future time periods, heat accumulates faster, thresholds are reached earlier and maximum GDD reached is higher.

Figure 8: Probability distributions showing the range of dates at which the example phenological thresholds (1000, 1500, 2000, 2500) are reached for each time period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates earlier (later) harvest dates. A wider (thinner) curve indicates a larger (smaller) range of harvest dates. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
Australia’s Wine Future — A Climate Atlas

SOUTHERN FLINDERS RANGES

Moisture

Figure 1: Observed mean Growing Season Rainfall (Oct–Apr) across all growing years from 1997–2017.

Figure 2: Observed change in Growing Season Rainfall (Oct–Apr) between the current (1997–2017) and historical (1961–1990) periods. Negative values indicate a trend towards drier conditions. Positive values indicate a trend towards wetter conditions.

Figure 3: Projected mean Growing Season Rainfall for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Time series of Growing Season Rainfall (mm). Blue points are the annual values for each grid cell, for each of the 6 ensemble members. Horizontal grey bars represent the mean Growing Season Rainfall value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions (1997–2017) and future conditions in this region and help identify future analogue regions. Coloured bars represent the projected mean global temperature increase into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time.

Figure 5: As with Figure 4, but for Non-Growing Season Rainfall (mm). These provide a comparison between current conditions (1997–2017) and future conditions in this region and help identify future analogue regions. Coloured bars represent the projected mean global temperature increase into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time.

Figure 6: Violin plots of monthly rainfall (mm) for 20-year time periods from 2001 to 2100. Each violin represents monthly totals for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. In each panel the median value indicates the expected probability distribution of rainfall across the growing year. The current period (2001–2020) is shaded underneath the future time periods to highlight any differences expected into the future. Dots represent the mean monthly rainfall for each violin. If the violin shifts lower (higher) this indicates a change towards drier (wetter) conditions.

Figure 7: Distribution of seasonal rainfall (Winter, Spring, Summer, Autumn) presented as a probability distribution for each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of seasonal rainfall for contrasting regions during 1997–2017. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates an increase in drier (wetter) conditions.

Figure 8: Number of rainy days during harvest for each 20-year period. Harvest refers to the date when Growing Degree Days (GDD) reach example phenological thresholds (1000, 1500, 2000, 2500) which were chosen to reflect development time of different grape styles and varieties. Rainy days during harvest were defined as days with 0.1mm of rain from 7 days before to 7 days after the date each GDD threshold was reached. Variability can occur spatially within the region, across years, or between ensemble members. A shift in the curve to the left (right) indicates fewer (more) rainy days during harvest. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
Figure 1: Observed mean annual Aridity Index across all growing years from 1997–2017. Aridity Index is a value that characterises the ratio between the mean annual rainfall and mean annual evaporation. Low (high) values indicate drier (wetter) conditions.

Figure 2: Observed percentage change in mean annual Aridity Index between the current (1997–2017) and historical (1961–1990) periods. This shows the change already experienced across the region. Negative (positive) values indicate a trend towards drier (wetter) conditions.

Figure 3: Projected mean annual Aridity Index for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Decreasing (increasing) values indicate a trend towards drier (wetter) conditions.

Figure 4: Time series of annual Aridity Index. Points are the annual means for each grid cell in the region, for each of the 6 ensemble members. Aridity Index values >2 all indicate very wet conditions. There is no meaningful difference past this value, so higher values were not presented. Horizontal grey bars represent the mean annual Aridity Index from selected regions across Australia — these provide an example of conditions this region may transition towards in the future. Coloured bars indicate the projected global temperature increase expected in the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than rise (for example, if the rate of warming rapidly increases, where temperature changes are experienced earlier, useful information can still be extracted from these figures by using the coloured boxes instead of the time-scale).

Figure 5: Violin plots of monthly Aridity Index for 20-year time periods from 2001 to 2100. Each violin represents monthly averages for each grid cell, for each of the 6 ensemble members, and for each of the months within the period. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates an increase in drier (wetter) conditions.

Figure 6: Distribution of seasonal Aridity Index.

Figure 7: Mean annual Aridity Index accumulated from start of the growing season (July) to date of harvest, presented as a probability distribution for each 20-year period. Date of harvest refers to the date at which Growing Degree Days reach some example phenological thresholds (1000, 1500, 2000, 2500), chosen to reflect development time of different grape styles and varieties. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates drier (wetter) conditions. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
Australia’s Wine Future — A Climate Atlas

SOUTHERN FLINDERS RANGES

Extremes — Hot

Figure 1: Observed mean Excess Heat Factor (EHF) during heatwaves (as per Nairn and Fawcett (2013)), across all growing years from 1997–2017. EHF is an index that characterises heatwaves, high values indicate more intense heatwaves. The mean EHF is the mean value from all heatwaves that occurred from 1997–2017.

Figure 2: Change in mean EHF during heatwaves between the current (1997–2017) and historical (1961–1990) periods. Positive (negative) values indicate a trend towards more (less) intense heatwaves.

Figure 3: Projected mean EHF during heatwaves for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards more (less) intense heatwaves.

Figure 4: Projected mean number of extreme heat days. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the right (left) indicates higher (lower) temperature heatwaves.

Figure 5: Projected number of days with severe risk to humans working outside temperatures greater than 30°C, 35°C, 40°C and 45°C. Areas indicate the number of days such thresholds are exceeded per growing year. Values are averaged across all grid cells and the 6 ensemble members. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than time.

Figure 6: Violins plots of high temperatures (°C) per growing year for 20-year time periods from 2001 to 2100. Colours indicate extreme threshold values (90th, 95th and 99th percentile) of temperature during each growing year. The 99th percentile value reflects the 4th hottest day each growing year; the 95th percentile is the 18th hottest day each growing year; and the 90th percentile is the 36th hottest day each growing year. Generally increasing values reflect a warming climate.

Figure 7: Probability distributions of daily maximum temperatures and minimum overnight temperatures during heatwaves. Colour of each curve indicates different 20-year periods. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the right (left) indicates higher (lower) temperature heatwaves.

Figure 8: Distribution of date of heatwave days. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the right (left) indicates heatwaves occurring earlier (later).
Australia’s Wine Future — A Climate Atlas

SOUTHERN FLINDERS RANGES
Extremes — Cold

Figure 1: Observed mean number of days at risk of frost during the growing season (October to April) over the period 1997–2017. Days at risk of frost are those with a daily minimum temperature <2°C. High (low) values indicate high (low) frost risk.

Figure 2: Change in the mean number of days at risk of frost during the growing season (October to April) between the current (1997–2017) and historical (1961–1990) periods. Days at risk of frost are those with a minimum temperature <2°C. High (low) values indicate increased (decreased) frost risk.

Figure 3: Projected mean number of days at risk of frost during the growing season (October to April) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards higher (lower) frost risk.

Figure 4: Violin plots of daily minimum temperature (°C) for each month for 20-year periods from 2001 to 2100. Each violin represents daily data for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period; e.g. the top-left most violin represents the daily minimum temperature for every January day in the period 2001–2020, for each grid cell in the region, for each of the 6 ensemble members. The current period (2001–2020) has been shadowed underneath future time periods to highlight any differences expected into the future. Dots represent the means for each violin. If the violin shifts lower (higher) this indicates a change towards colder (warmer) conditions.

Figure 5: Projected monthly frost risk days

Figure 6: Projected accumulated frost intensity

Figure 7: Projected mean number of extreme cold days

Figure 8: Timeseries of accumulated frost intensity, which is the cumulative total of temperatures less than 2°C over a growing season. This index characterizes exposure to cold conditions. High values indicate cold winters/springs. Points are for each grid cell, averaged across the 6 ensemble members.

Figure 9: Time-series of the number of days per growing year when temperatures fall below selected thresholds (< -2°C, < -3°C, < -4°C). Areas indicate the number of days temperatures fall below each threshold. Darker shades indicate a trend towards colder conditions.

Values are averaged across all grid cells and the 6 ensemble members. Fewer instances reflect a warming climate.
CLARE VALLEY

Heat

Figure 1: Observed mean Growing Season Temperature (Oct–Apr) across all growing years from 1997–2017.

Figure 2: Observed change in mean Growing Season Temperature (Oct–Apr) between the current (1997–2017) and historical (1961–1990) periods. Growing Season Temperature has increased across the region over recent decades.

Figure 3: Projected mean Growing Season Temperature (Oct–Apr) for 20-year time periods from 2021 to 2100. Growing Season Temperature is expected to increase steadily into the future. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Projected Growing Season Temperature (October to April) over time. Blue points are the values for each grid cell for each of the 6 ensemble members. Solid lines are timeseries representing grid cells for colder and warmer locations within the region. These provide a comparison between current conditions and future conditions in the region, helping to identify future analogue regions. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time (for example, if the rate of warming rapidly increases, useful information can still be extracted from these figures by using the shade boxes instead of the time-axis).

Figure 5: Distribution of Growing Season Temperature. Grey shapes represent the probability distribution of Growing Season Temperature for contrasting regions during 1997–2017. A shift to the right (left) indicates warmer (cooler) conditions.

Figure 6: Distribution of Growing Year Maximum GDD. Grey shapes represent the probability distribution of Growing Year Maximum GDD for contrasting regions during 1997–2017. A shift to the right (left) indicates warmer (cooler) conditions.

Figure 7: Cumulative Growing Degree Days (GDD) across the growing year (July–June). Dashed lines show GDD values (1000, 1500, 2000, 2500) for some example phenological thresholds. Each growing year is represented by a colored line. In future time periods, heat accumulates faster; thresholds are reached earlier and maximum GDD reached is higher.

Figure 8: Distribution of date when Growing Degree Days reaches threshold. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates earlier (later) harvest dates. A wider (thinner) curve indicates a larger (smaller) range of harvest dates. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
Australia’s Wine Future — A Climate Atlas

CLARE VALLEY

Figure 1: Observed mean Growing Season Rainfall (Oct–Apr) across all growing years from 1997–2017.

Figure 2: Change in Growing Season Rainfall (Oct–Apr) between the current (1997–2017) and historical (1961–1990) periods. Negative values indicate a trend towards drier conditions. Positive values indicate a trend towards wetter conditions.

Figure 3: Projected mean Growing Season Rainfall for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Projected Growing Season Rainfall (October to April). Coloured bars represent the projected mean global temperature increase into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time.

Figure 5: Violin plots of monthly rainfall (mm) for 20-year time periods from 2001 to 2100. Each violin represents monthly totals for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. In each panel the median (middle) of the violin indicates the expected probability distribution of rainfall across the growing year. Horizontal grey bars represent the mean Growing Season Rainfall value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions (1997–2017) elsewhere and future conditions in this region and help identify future analogue regions. Coloured bars represent the projected mean Growing Season Rainfall for 20-year time periods from 2021 to 2100. Each violin represents monthly totals for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. In each panel the median (middle) of the violin indicates the expected probability distribution of rainfall across the growing year. Horizontal grey bars represent the mean Growing Season Rainfall value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions (1997–2017) elsewhere and future conditions in this region and help identify future analogue regions. Coloured bars represent the projected mean Growing Season Rainfall value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions (1997–2017) elsewhere and future conditions in this region and help identify future analogue regions. Coloured bars represent the projected mean Growing Season Rainfall for 20-year time periods from 2021 to 2100. Each violin represents monthly totals for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. In each panel the median (middle) of the violin indicates the expected probability distribution of rainfall across the growing year. Horizontal grey bars represent the mean Growing Season Rainfall value during 1997–2017 in selected regions across Australia.

Figure 6: Number of rainy days during harvest for each 20-year period. Harvest refers to the date when Growing Degree Days (GDD) reach example phenological thresholds (1000, 1500, 2000, 2500) which were chosen to reflect development time of different grape styles and varieties. Rainy days during harvest were defined as days with >10mm of rain from 7 days before to 7 days after the date each GDD threshold was reached. Variability can occur spatially within the region, across years, or between ensemble members. A shift in the curve to the left (right) indicates fewer (more) rainy days during harvest. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
Australia’s Wine Future — A Climate Atlas

Aridity

Figure 1: Observed mean annual Aridity Index across all growing years from 1997-2017. Aridity Index is a value that characterises the ratio between the mean annual rainfall and mean annual evaporation. Low (high) values indicate drier (wetter) conditions.

Figure 2: Observed change in mean annual Aridity Index since 1997-2017 relative to 1961-1990. This shows the change already experienced across the region. Negative (positive) values indicate a trend towards drier (wetter) conditions.

Figure 3: Projected mean annual Aridity Index for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Decreasing (increasing) values indicate a trend towards drier (wetter) conditions.

Figure 4: Time series of annual Aridity Index. Points are the annual means for each grid cell in the region, for each of the 6 ensemble members. Aridity Index values >2 all indicate very wet conditions. There is no meaningful difference past this value, as no higher values were presented. Horizontal grey bars represent the mean annual Aridity Index from selected regions across Australia — these provide an example of conditions the region may transition towards in the future. Coloured bars represent the projected global temperature increase expected in the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than time (for example if the rate of warming rapidly increases, where temperature changes are experienced earlier, useful information can still be extracted from these figures by using the coloured boxes instead of the time-axis).

Figure 5: Violin plots of seasonal Aridity Index for each growing year from 2001 to 2100. Each violin represents monthly averages for each grid cell for each of the 6 ensemble members, and for each growing year within the time period. Each panel in the violin plots indicate the expected probability distribution of Aridity Index for each month across the growing year. The current period (2001-2020) is shadowed underneath the future time periods to highlight any differences expected into the future. Dots represent the mean monthly Aridity Index for each month. If the violin shifts lower (higher) this indicates a change towards drier (wetter) conditions.

Figure 6: Seasonal Aridity Index (Winter, Spring, Summer, Autumn), presented as a probability distribution for each 20-year period. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of seasonal aridity for contrasting regions during 1997–2017. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates drier (wetter) conditions. Aridity Index values >2 all indicate very wet conditions.

Figure 7: Distribution of mean Aridity Index from July until harvest. Date of harvest refers to the date at which Growing Degree Days reach some example phenological thresholds (1000, 1500, 2000, 2500) chosen to reflect development time of different grape styles and varieties. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates drier (wetter) conditions. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
CLARE VALLEY
Extremes — Hot

Figure 1: Observed mean Excess Heat Factor (EHF) during heatwaves (as per Nairn and Fawcett (2013)), across all growing years from 1997–2017. EHF is an index that characterises heatwaves; high values indicate more intense heatwaves. The mean EHF is the mean value from all heatwaves that occurred from 1997–2017.

Figure 2: Change in mean EHF during heatwaves between the current (1997–2017) and historical (1961–1990) periods. Positive (negative) values indicate a trend towards more (less) intense heatwaves.

Figure 3: Projected mean EHF during heatwaves for 20-year time periods from 2021 to 2100. Increasing (decreasing) values indicate a trend towards more (less) intense heatwaves.

Figure 4: Time series of the number of days per growing year with temperatures greater than 30°C, 35°C, 40°C and 45°C. Areas indicate the number of days each threshold is exceeded per growing year. Values are averaged across all grid cells and the 6 ensemble members. Generally increasing frequencies reflect a warming climate.

Figure 5: Time series of the number of days per growing year with high human heat stress. This is defined as days when daily maximum temperatures are >30°C and daily minimum humidity is >60%. These conditions cause severe risk of heat stress to humans (and potentially low productivity) to those working in exposed areas. Humans cannot work in high temperature, high humidity environments without appropriate adaptive behaviours and equipment. Points are for each grid cell from each of the 6 ensemble members. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than time.

Figure 6: Violins plots of high temperatures (°C) per growing year for 20-year time periods from 2001 to 2100. The 99th percentile value reflects the 4th hottest day each growing year; the 95th percentile is the 18th hottest day each growing year; and the 90th percentile is the 36th hottest day each growing year. Generally increasing values reflect a warming climate.

Figure 7: Distribution of daily minimum and maximum temperature during a heatwave. Color of each curve indicates different 20-year periods. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the right (left) indicates higher (lower) temperature heatwaves.

Figure 8: Distribution of the date when heatwaves occur. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the right (left) indicates heatwaves occurring earlier (later).
Figure 1: Observed mean frost risk days

Figure 2: Observed change in mean frost risk days

Figure 3: Projected mean frost risk days

Figure 4: Projected monthly minimum temperature

Figure 5: Projected monthly frost risk days

Figure 6: Projected accumulated frost intensity

Figure 7: Projected mean number of extreme cold days

Figure 8: violin plots of daily minimum temperature (°C) for each month for 20-year periods from 2001 to 2100. Each violin represents daily data for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. High (low) values indicate increased (decreased) frost risk.

Figure 9: Monthly average cumulative frost days for 20-year periods from 2001 to 2100. Values are a summary across all grid cells, for each of the 6 ensemble members.

Figure 10: Timeseries of accumulated frost intensity when temperatures fall below selected thresholds (−2°C, −4°C, −6°C). High values indicate cold winters/springs. Points are for each grid cell, averaged across the 6 ensemble members.

Figure 11: Time-series of the number of days per growing year when temperature falls below selected thresholds (−2°C, −4°C, −6°C). Areas indicate the number of days temperatures fall below each threshold per growing year. Values are averaged across all grid cells and the 6 ensemble members.
Figure 1: Observed mean Growing Season Temperature (Oct–Apr) across all growing years from 1997–2017.

Figure 2: The change in Growing Season Temperature between the current (1997–2017) and historical (1961–1990) periods. Growing Season Temperature has increased across the region over recent decades.

Figure 3: Projected mean Growing Season Temperature (Oct–Apr) for 20-year time periods from 2021 to 2100. Growing Season Temperature is expected to increase steadily into the future. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Growing Season Temperature (GST) over time. Blue points are the values for each grid cell for each of the 6 ensemble members. Solid lines are timeseries representing grid cells for colder and warmer locations within the region based on current conditions (1997–2017). Horizontal grey bars represent the mean GST value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions (current and future conditions in the region, helping to identify future analogue regions. Coloured bars represent the temperature increase expected into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time (for example, if the rate of warming rapidly increases, useful information can still be extracted from these figures by using the shade boxes instead of the time-axis).

Figure 5: Probability distribution of GST for 20-year time periods from 2001 to 2100. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of GST for contrasting regions during 1997–2017. A shift to the right (left) indicates warmer (cooler) conditions.

Figure 6: Probability distribution of growing year maximum GDD for 20-year time periods from 2001 to 2100. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of growing year maximum GDD for contrasting regions during 1997–2017. A shift to the right (left) indicates earlier (later) harvest dates. A wider (thinner) curve indicates a larger (smaller) range of harvest dates. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).

Figure 7: Cumulative Growing Degree Days (GDD) across the growing year (July–June). Dashed lines show GDD values (1000, 1500, 2000, 2500) for some example phenological thresholds. Each growing year is represented by a colored line. In future time periods, heat accumulates faster, thresholds are reached earlier and maximum GDD reached is higher.

Figure 8: Distribution of date when Growing Degree Days reaches threshold.
Figure 1: Observed mean Growing Season Rainfall (Oct–Apr) across all growing years from 1997–2017.

Figure 2: Observed change in Growing Season Rainfall 1997–2017 minus 1961–1990.

Figure 3: Projected mean Growing Season Rainfall (Oct–Apr) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Projected Growing Season Rainfall (October to April) for 20-year periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members.

Figure 5: Projected Non-Growing Season Rainfall (May to September) for 20-year periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members.

Figure 6: Time series of Growing Season Rainfall (mm). Blue points are the annual values for each grid cell, for each of the 6 ensemble members. Horizontal grey bars represent the mean Growing Season Rainfall value during the 1997–2017 period. The current period (1997–2017) is highlighted to indicate the current conditions.

Figure 7: Distribution of seasonal rainfall.

Figure 8: Number of rainy days during harvest for each 20-year period. Harvest refers to the date when Growing Degree Days (GDD) reach example phenological thresholds (1000, 1500, 2000, 2500) which were chosen to reflect development time of different grape styles and varieties. Rainy days during harvest were defined as days with >10 mm of rain from 7 days before to 7 days after the date each GDD threshold was reached. Variability can occur spatially within the region, across years, or between ensemble members. A shift in the curve to the left or right indicates fewer or more rainy days during harvest. A missing time period indicates that the specific phenological threshold was not reached within the growing season (July–June).
Figure 1: Observed mean annual Aridity Index across all growing years from 1997–2017. Aridity Index is a value that characterises the ratio between the mean annual rainfall and mean annual evaporation. Low (high) values indicate drier (wetter) conditions.

Figure 2: Observed percentage change in mean annual Aridity Index between the current (1997–2017) and historical (1961–1990) periods. This shows the change already experienced across the region. Negative (positive) values indicate a trend towards drier (wetter) conditions.

Figure 3: Projected mean annual Aridity Index from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Decreasing (increasing) values indicate a trend towards drier (wetter) conditions.

Figure 4: Time series of annual Aridity Index. Points are the annual means for each grid cell in the region, for each of the 6 ensemble members. Aridity Index values > 2 indicate very wet conditions. There is no meaningful difference past this value, so higher values were not presented. Horizontal grey bars represent the mean annual Aridity Index from selected regions across Australia — these provide an example of conditions the region may transition towards in the future. Coloured bars represent the projected global temperature increase expected in the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than time (for example, if the rate of warming rapidly increases, where temperature change is experienced earlier, useful information can still be extracted from these figures by using the coloured bars instead of the time-axis).

Figure 5: Violin plots of monthly Aridity Index for 20-year time periods from 2001 to 2100. Each violin represents monthly averages for each grid cell of the 6 ensemble members, and for each growing year within the time period. The current period (2001–2020) is shaded underneath the future time periods to highlight any differences expected into the future. Dots represent the mean monthly Aridity Index for each violin. If the violin shifts lower (higher) this indicates a change towards drier (wetter) conditions.

Figure 6: Distribution of seasonal Aridity Index. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of seasonal aridity for contrasting regions during 1997–2017. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates a change towards drier (wetter) conditions. Aridity Index values > 2 all indicate very wet conditions.

Figure 7: Mean annual Aridity Index accumulated from start of the growing season (July) to date of harvest, presented as a probability distribution for each 20-year period. Date of harvest refers to the date at which Growing Degree Days reach some example phenological thresholds (1000, 1500, 2000, 2500) chosen to reflect development time of different grape styles and varieties. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates drier (wetter) conditions. A missing time period indicates that the specific phenological threshold was not reached within the growing season (July–June).
Australia’s Wine Future — A Climate Atlas

BAROSSA VALLEY
Extremes — Hot

Figure 1: Observed mean Excess Heat Factor (EHF) during heatwaves (as per Nairn and Forcelli (2013)), across all growing years from 1997–2017. EHF is an index that characterises heatwaves, high values indicate more intense heatwaves. The mean EHF is the mean value from all heatwaves that occurred from 1997–2017.

Figure 2: Change in mean EHF during heatwaves between the current (1997–2017) and historical (1961–1990) periods. Positive (negative) values indicate a trend towards more (less) intense heatwaves.

Figure 3: Projected mean EHF during heatwaves for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards more (less) intense heatwaves.

Figure 4: Time series of the number of days per growing year with temperatures greater than 30°C, 35°C, and 45°C. Areas indicate the number of days each threshold is exceeded per growing year. Values are averaged across all grid cells and the 6 ensemble members. Colours indicate each of the extreme threshold values. Generally increasing frequencies reflect a warming climate.

Figure 5: Time series of the number of days per growing year of high human heat stress. This is defined as days when daily maximum temperatures are >30°C and daily minimum humidity is >60%. These conditions pose severe risk of heat stress to humans (and potentially low productivity) to those working in exposed areas. Humans cannot work in high temperatures, high humidity environments without appropriate adaptive behaviours and equipment. Points are for each grid cell from each of the 6 ensemble members. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than time.

Figure 6: Violin plots of high temperatures (°C) per growing year for 20-year time periods from 2001 to 2100. Colours indicate extreme threshold values (90th, 95th and 99th percentile) of temperature during each growing year. The 99th percentile value reflects the 4th hottest day each growing year; the 95th percentile is the 18th hottest day each growing year; and the 90th percentile is the 36th hottest day each growing year. Generally increasing values reflect a warming climate.

Figure 7: Probability distributions of daily maximum temperatures during heatwaves. Colour of each curve indicates different 20-year periods. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the right (left) indicates higher (lower) temperature heatwaves.

Figure 8: Probability distribution of the date when heatwaves occur. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the right (left) indicates heatwaves occurring earlier (later).
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BAROSSA VALLEY
Extremes — Cold

Figure 1: Observed mean number of days at risk of frost during the growing season (October to April) over the period 1997–2017. Days at risk of frost are those with a daily minimum temperature < 2°C. High (low) values indicate high (low) frost risk.

Figure 2: Observed change in mean frost risk days. Days at risk of frost are those with a minimum temperature < 2°C. High (low) values indicate increased (decreased) frost risk.

Figure 3: Projected mean number of days at risk of frost during the growing season (October to April) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards higher (lower) frost risk.

Figure 4: Violin plots of daily minimum temperature (°C) for each month for 20-year periods from 2001 to 2100. Each violin represents daily data for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period; e.g. the top-left most violin represents the daily minimum temperature for every January day in the period 2001–2020, for each grid cell in the region, for each of the 6 ensemble members. The current period (2001–2020) has been shadowed underneath future time periods to highlight any differences expected into the future. Dots represent the means for each violin. If the violin shifts lower (higher) this indicates a change towards colder (warmer) conditions.

Figure 5: Monthly average cumulative frost days for 20-year periods from 2001 to 2100. Values are a summary across all grid cells, for all years with each 20-year period, for each of the 6 ensemble members. This reflects how frost risk varies across the year within each 20-year period. The current period (2001–2020) has been shadowed underneath future time periods to highlight any differences expected into the future.

Figure 6: Timeseries of accumulated frost intensity, which is the cumulative total of temperatures less than 2°C over a growing season. This index characterises exposure to cold conditions. High values indicate cold winters/springs. Points are for each grid cell, averaged across the 6 ensemble members.

Figure 7: Timeseries of the number of days per growing year when temperature falls below selected thresholds (<2°C, <0°C, <−2°C). Areas indicate the number of days temperatures fall below each threshold in each growing year. Values are averaged across all grid cells and the 6 ensemble members. Fewer instances reflect a warming climate.
EDEN VALLEY

RAINFALL
Projected Mean Growing Season Rainfall
- 221 mm (1997–2017)
- 255 mm (2041–2060)
- 239 mm (2081–2100)

TEMPERATURE
Projected Mean Growing Season Temperature
- 18.4°C (1997–2017)
- 19.5°C (2041–2060)
- 21.0°C (2081–2100)

EXTREME COLD
Projected Mean Growing Season Frost Risk Days
- 1.5 days (1997–2017)
- 0.4 days (2041–2060)
- 0.1 days (2081–2100)

EXTREME HEAT
Projected Mean Excess Heat Factor
- 21.6 EHF (2041–2060)
- 22.4 EHF (2081–2100)

ARIDITY
Projected Mean Annual Aridity Index
- 0.34 (1997–2017)
- 0.29 (2041–2060)
- 0.23 (2081–2100)
EDEN VALLEY
Heat

Figure 1: Observed mean Growing Season Temperature (Oct–Apr) across all growing years from 1997–2017.

Figure 2: The change in Growing Season Temperature between the current (1997–2017) and historical (1961–1990) periods. Growing Season Temperature has increased across the region over recent decades.

Figure 3: Projected mean Growing Season Temperature (Oct–Apr) for 20-year time periods from 2021 to 2100. Growing Season Temperature is expected to increase steadily into the future. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Growing Season Temperature (GST) over time. Blue points are the values for each grid cell for each of the 6 ensemble members. Solid lines are timeseries representing grid cells for colder and warmer locations within the region based on current conditions (1997–2017). Horizontal grey bars represent the mean GST value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions elsewhere and future conditions in this region, helping to identify future analogue regions. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change over time (for example, if the rate of warming rapidly increases, useful information can still be extracted from these figures by using the shade boxes instead of the timeseries).

Figure 5: Distribution of Growing Season Temperature. Grey shapes represent the probability distribution of GST for contrasting regions during 1997–2017. A shift to the right (left) indicates warmer (cooler) conditions.

Figure 6: Probability distribution of growing year maximum GDD for 20-year time periods from 2001 to 2100. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of growing year maximum GDD for contrasting regions during 1997–2017. A shift to the right (left) indicates warmer (cooler) conditions.

Figure 7: Cumulative Growing Degree Days (GDD) across the growing year (July–June). Dashed lines show GDD values (1000, 1500, 2000, 2500) for some example phenological thresholds. Each growing year is represented by a coloured line. In future time periods, heat accumulates faster, thresholds are reached earlier and maximum GDD reached is higher.

Figure 8: Probability distributions showing the range of dates at which the example phenological thresholds (1000, 1500, 2000, 2500) are reached for each time period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates earlier (later) harvest dates. A wider (narrow) curve indicates a larger (smaller) range of harvest dates. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
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EDEN VALLEY

Moisture

Figure 1: Observed mean Growing Season Rainfall (Oct–Apr) across all growing years from 1997–2017.

Figure 2: Change in Growing Season Rainfall (Oct–Apr) between the current (1997–2017) and historical (1961–1990) periods. Negative values indicate a trend towards drier conditions. Positive values indicate a trend towards wetter conditions.

Figure 3: Projected mean Growing Season Rainfall for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Observed mean Growing Season Rainfall (Oct–Apr) across all growing years from 1997–2017.

Figure 5: Projected Growing Season Rainfall (October to April). 1°C indicates the expected probability distribution of rainfall for each 20-year period from 2001 to 2100. Each violin represents the actual values for each grid cell, for each of the 6 ensemble members. Horizontal grey bars represent the mean Growing Season Rainfall value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions and future conditions in this region and help identify future analogue regions. Coloured bars represent the projected mean global temperature increase into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time.

Figure 6: Projected Non-Growing Season Rainfall (May to September). Horizontal grey bars represent the mean Non-Growing Season Rainfall value during 1997–2017 in selected regions across Australia.

Figure 7: Violin plots of monthly rainfall (mm) for 20-year time periods from 2001 to 2100. Each violin represents monthly totals for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. In each panel the mean grey violin indicates the expected probability distribution of rainfall across the growing year. The current period (2001–2020) is shadowed underneath the future time periods to highlight any differences expected into the future. Dots represent the mean monthly rainfall for each violin. If the violin shifts lower (higher) this indicates a change towards drier (wetter) conditions.

Figure 8: Number of rainy days during harvest for each 20-year period. Harvest refers to the date when Growing Degree Days (GDD) reach example phenological thresholds (1000, 1500, 2000, 2500) which were chosen to reflect development time of different grape styles and varieties. Rainy days during harvest were defined as days with >10mm of rain from 7 days before to 7 days after the date each GDD threshold was reached. Variability can occur spatially within the region, across years, or between ensemble members. A shift in the curve to the left (right) indicates fewer (more) rainy days during harvest. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
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**EDEN VALLEY**

**Aridity**

**Figure 1**: Observed mean annual Aridity Index across all growing years from 1997–2017. Aridity Index is a scale that characterises the ratio between the mean annual rainfall and mean annual evaporation. Low (high) values indicate drier (wetter) conditions.

**Figure 2**: Observed percentage change in mean annual Aridity Index between the current (1997–2017) and historical (1961–1990) periods. This shows the change already experienced across the region. Negative (positive) values indicate a trend towards drier (wetter) conditions.

**Figure 3**: Projected mean annual Aridity Index for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Decreasing (increasing) values indicate a trend towards drier (wetter) conditions.

**Figure 4**: Time series of annual Aridity Index. Points are the annual means for each grid cell in the region, for each of the 6 ensemble members. Aridity Index values >2 all indicate very wet conditions. There is no meaningful difference past this value, so higher values were not presented. Horizontal grey bars represent the mean annual Aridity Index from selected regions across Australia — these provide an example of conditions the region may transition towards in the future. Coloured bars represent the projected global temperature increase expected in the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than time (for example, if the rate of warming rapidly increases, where temperature changes are experienced earlier, useful information can still be extracted from these figures by using the coloured boxes instead of the time-axis).

**Figure 5**: Violin plots of monthly Aridity Index for 20-year time periods from 2001 to 2100. Each violin represents monthly averages for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. The current period (2001–2010) is shadowed underneath the future time periods to highlight any differences expected into the future. Dots represent the mean monthly Aridity Index for each violin. If the violin shifts lower (higher) this indicates a change towards drier (wetter) conditions.

**Figure 6**: Seasonal Aridity Index (Winter, Spring, Summer, Autumn), presented as a probability distribution for each 20-year period. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of seasonal aridity for contrasting regions during 1997–2017. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates drier (wetter) conditions. Aridity Index values >2 all indicate very wet conditions.

**Figure 7**: Mean annual Aridity Index accumulated from start of the growing season (July) to date of harvest, presented as a probability distribution for each 20-year period. Date of harvest refers to the date at which Growing Degree Days reach some example phenological thresholds (1000, 1500, 2000, 2500), chosen to reflect development time of different grape styles and varieties. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates drier (wetter) conditions. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
Figure 1: Observed mean excess heat factor (EHF) during heatwaves (as per Nairn and Fawcett (2013)), across all growing years from 1997–2017. EHF is an index that characterises heatwaves; high values indicate more intense heatwaves. The mean EHF is the mean value from all heatwaves that occurred from 1997–2017.

Figure 2: Change in mean EHF during heatwaves between the current (1997–2017) and historical (1961–1990) periods. Positive (negative) values indicate a trend towards more (less) intense heatwaves.

Figure 3: Projected mean excess heat factor (EHF) during heatwaves for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards more (less) intense heatwaves.

Figure 4: Time series of the number of days per growing year with temperatures greater than 30°C, 35°C, 40°C and 45°C. Areas indicate the number of days each threshold is exceeded per growing year. Values are averaged across all grid cells and the 6 ensemble members. Colours indicate each of the extreme threshold values. Generally increasing frequencies reflect a warming climate.

Figure 5: Time series of the number of days per growing year of high human heat stress. This is defined as days when daily maximum temperatures are >30°C and daily minimum humidity is <60%. These conditions cause severe risk of heat stress to humans (and potentially low productivity) for those working in exposed areas. Humans cannot work in high temperatures, high humidity environments without appropriate adaptive behaviours and equipment. Points are for each grid cell from each of the 6 ensemble members. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than time.

Figure 6: Violin plots of high temperatures (°C) per growing year for 20-year time periods from 2001 to 2100. Colours indicate extreme threshold values (90th, 95th and 99th percentile) of temperature during each growing year. The 99th percentile value reflects the 4th hottest day each growing year; the 95th percentile is the 18th hottest day each growing year; and the 90th percentile is the 36th hottest day each growing year. Generally increasing values reflect a warming climate.
Figure 1: Observed mean frost risk days

Figure 2: Observed change in mean frost risk days

Figure 3: Projected mean frost risk days

Figure 4: Projected monthly minimum temperature

Figure 5: Projected monthly frost risk days

Figure 6: Projected accumulated frost intensity

Figure 7: Projected mean number of extreme cold days

Figure 8: Violin plots of daily minimum temperature (°C) for each month for 20 year periods from 2001 to 2020. Each violin represents daily data for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period; e.g. the top-left most violin represents the daily minimum temperature for every January day in the period 2001–2020, for each grid cell in the region, for each of the 6 ensemble members. The current period (2001–2020) has been shadowed underneath future time periods to highlight any differences expected into the future. Dots represent the means for each violin. If the violin shifts lower (higher) this indicates a change towards colder (warmer) conditions.

Figure 9: Cumulative frost days for 20 year periods from 2001 to 2020. Values are a summary across all grid cells, for all years with each 20 year period, for each of the 6 ensemble members. This reflects how frost risk varies across the year within each 20 year period. The current period (2001–2020) has been shadowed underneath future time periods to highlight any differences expected into the future.

Figure 10: Timeseries of accumulated frost intensity, which is the cumulative total of temperatures less than 2°C over a growing season. This index characterizes exposure to cold conditions. High values indicate cold winters/springs. Points are for each grid cell, averaged across the 6 ensemble members.

Figure 11: Time-series of the number of days per growing year when temperature falls below selected thresholds (<2°C, <0°C, <−2°C). Areas indicate the number of days temperatures fall below each threshold per growing year. Values are averaged across all grid cells and the 6 ensemble members. Fewer instances reflect a warming climate.
RIVERLAND

RAINFALL
Projected Mean Growing Season Rainfall
- 148 mm (1997–2017)
- 140 mm (2041–2060)
- 134 mm (2081–2100)

TEMPERATURE
Projected Mean Growing Season Temperature
- 22.4 °C (2041–2060)
- 23.9 °C (2081–2100)

EXTREME COLD
Projected Mean Growing Season Frost Risk Days
- 0.3 days (1997–2017)
- 0.0 days (2041–2060)
- 0.0 days (2081–2100)

EXTREME HEAT
Projected Mean Excess Heat Factor
- 18.2 EHF (2041–2060)
- 19.0 EHF (2081–2100)

ARIDITY
Projected Mean Annual Aridity Index
- 0.14 (1997–2017)
- 0.12 (2041–2060)
- 0.10 (2081–2100)
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RIVERLAND

Heat

Figure 1: Observed mean Growing Season Temperature (Oct–Apr) across all growing years from 1997–2017.

Figure 2: Observed change in mean Growing Season Temperature between the current (1997–2017) and historical (1961–1990) periods. Growing Season Temperature has increased across the region over recent decades. These provide a comparison between current conditions and future conditions in this region, helping to identify future analogue regions. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time (for example, if the rate of warming rapidly increases, useful information can still be extracted from these figures by using the shade boxes instead of the time-axis).

Figure 3: Projected mean Growing Season Temperature for 20-year time periods from 2021 to 2100. Growing Season Temperature is expected to increase steadily into the future. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Growing Season Temperature (GST) over time. Blue points are the values for each grid cell for each of the 6 ensemble members. Solid lines are time-series representing grid cells for colder and warmer locations within the region based on current conditions (1997–2017). Horizontal grey bars represent the mean GST value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions and future conditions in this region, helping to identify future analogue regions. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time (for example, if the rate of warming rapidly increases, useful information can still be extracted from these figures by using the shade boxes instead of the time-axis).

Figure 5: Distribution of Growing Season Temperature. Grey shapes represent the probability distribution of GST for contrasting regions during 1997–2017. A shift to the right (left) indicates warmer (cooler) conditions.

Figure 6: Distribution of Growing Year Maximum GDD. Grey shapes represent the probability distribution of growing year maximum GDD for contrasting regions during 1997–2017. A shift to the right (left) indicates warmer (cooler) conditions.

Figure 7: Cumulative Growing Degree Days (GDD) across the growing year (July–June). Dashed lines show GDD values (1000, 1500, 2000, 2500) for some example phenological thresholds. Each growing year is represented by a colored line. In future time periods, heat accumulates faster, thresholds are reached earlier and maximum GDD reached is higher.

Figure 8: Distribution of date when Growing Degree Days reaches threshold.
Figure 1: Observed mean Growing Season Rainfall (October–April) across all growing years from 1997–2017.

Figure 2: Change in Growing Season Rainfall (October–April) between the current (1997–2017) and historical (1961–1990) periods. Negative values indicate a trend towards drier conditions. Positive values indicate a trend towards wetter conditions.

Figure 3: Projected mean Growing Season Rainfall for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Time series of Growing Season Rainfall (mm). Blue points are the annual values for each grid cell, for each of the 6 ensemble members. Horizontal grey bars represent the mean Growing Season Rainfall value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions (1997–2017) elsewhere and future conditions in this region and help identify future analogue regions. Coloured bars represent the projected mean global temperature increase into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time.

Figure 5: As with Figure 4, but for Non-Growing Season Rainfall (November–March). Horizontal grey bars represent the mean Non-Growing Season Rainfall value during 1997–2017 in selected regions across Australia.

Figure 6: Violin plots of monthly rainfall (mm) for 20-year time periods from 2001 to 2100. Each violin represents monthly totals for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. In each panel the monthly violins indicate the expected probability distribution of rainfall across the growing year. The current period (2001–2020) is shadowed underneath the future time periods to highlight any differences expected into the future. Dots represent the mean monthly rainfall for each violin. If the violin shifts lower (higher) this indicates a change towards drier (wetter) conditions.

Figure 7: Distribution of seasonal rainfall (Winter, Spring, Summer, Autumn) (mm), presented as a probability distribution for each 20-year period. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of seasonal rainfall for contrasting regions during 1997–2017. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates an increase in drier (wetter) conditions.

Figure 8: Number of rainy days during harvest for each 20-year period. Harvest refers to the date when Growing Degree Days (GDD) reach example phenological thresholds (1000, 1500, 2000, 2500) which were chosen to reflect development time of different grape styles and varieties. Rainy days during harvest were defined as days with >10mm of rain from 7 days before to 7 days after the date each GDD threshold was reached. Variability can occur spatially within the region, across years, or between ensemble members. A shift in the curve to the left (right) indicates fewer (more) rainy days during harvest. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
Figure 1: Observed mean annual Aridity Index across all growing years from 1997–2017. Aridity Index is a value that characterises the ratio between the mean annual rainfall and mean annual evaporation. Low (high) values indicate drier (wetter) conditions.

Figure 2: Observed percentage change in mean annual Aridity Index between the current (1997–2017) and historical (1961–1990) periods. This shows the change already experienced across the region. Negative (positive) values indicate a trend towards drier (wetter) conditions.

Figure 3: Projected mean annual Aridity Index for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Decreasing (increasing) values indicate a trend towards drier (wetter) conditions.

Figure 4: Time series of annual Aridity Index. Points are the annual means for each grid cell in the region, for each of the 6 ensemble members. Aridity Index values >2 all indicate very wet conditions. There is no meaningful difference past this value, so higher values were not presented. Horizontal grey bars represent the mean annual Aridity Index from selected regions across Australia — these provide an example of conditions the region may transition towards in the future. Coloured bars represent the projected global temperature increase expected in the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than time (for example, if the rate of warming rapidly increases, where temperature changes are experienced earlier, useful information can still be extracted from these figures by using the coloured boxes instead of the time-axis).

Figure 5: Violin plots of monthly Aridity Index for 20-year time periods from 2001 to 2100. Each violin represents monthly averages for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. In each 20-year panel the violin indicates the expected probability distribution of Aridity Index within each month across the growing year. The current period (2001–2020) is shadowed underneath the future time periods to highlight any differences expected into the future. Dots represent the mean monthly Aridity Index for each violin. If the violin shifts lower (higher) this indicates a change towards drier (wetter) conditions.

Figure 6: Seasonal Aridity Index (Winter, Spring, Summer, Autumn), presented as a probability distribution for each 20-year period. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of seasonal aridity for contrasting regions during 1997–2017. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates an increase in drier (wetter) conditions. Aridity Index values >2 all indicate very wet conditions.

Figure 7: Mean annual Aridity Index accumulated from start of the growing season (July) to date of harvest, presented as a probability distribution for each 20-year period. Date of harvest refers to the date at which Growing Degree Days reach some example phenological thresholds (1000, 1500, 2000, 2500), chosen to reflect development times of different grape styles and varieties. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates drier (wetter) conditions. A missing time period indicates that the specific phenological threshold was not reached within the growing season (July–June).
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RIVERLAND
Extremes — Hot

Figure 1: Observed mean Excess Heat Factor (EHF) during heatwaves (as per Nairn and Fawcett (2013)), across all growing years from 1997–2017. EHF is an index that characterises heatwaves; high values indicate more intense heatwaves. The mean EHF is the mean value from all heatwaves that occurred from 1997–2017.

Figure 2: Observed change in mean Excess Heat Factor (EHF) during heatwaves between the current (1997–2017) and historical (1961–1990) periods. Positive (negative) values indicate a trend towards more (less) intense heatwaves.

Figure 3: Projected mean EHF during heatwaves for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards more (less) intense heatwaves.

Figure 4: Time series of the number of days per growing year with temperatures greater than 30°C, 35°C, 40°C and 45°C. Areas indicate the number of days each threshold is exceeded per growing year. Values are averaged across all grid cells and the 6 ensemble members. Colours indicate each of the extreme threshold values. Generally increasing frequencies reflect a warming climate.

Figure 5: Time series of the number of days per growing year of High human heat stress. This is defined as days when daily maximum temperatures are >30°C and daily minimum humidity is >60%. These conditions cause severe risk of heat stress to humans (and potentially low productivity) to those working in exposed areas. Humans cannot work in high temperature, high humidity environments without appropriate adaptive behaviours and equipment. Points are for each grid cell from each of the 6 ensemble members. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than time.

Figure 6: Violins plots of high temperatures (°C) per growing year for 20-year time periods from 2001 to 2100. Colours indicate extreme threshold values (90th, 95th and 99th percentile) of temperature during each growing year. The 99th percentile value reflects the 4th hottest day each growing year; the 95th percentile is the 18th hottest day each growing year; and the 90th percentile is the 36th hottest day each growing year. Generally increasing values reflect a warming climate.
Figure 1: Observed mean number of days at risk of frost during the growing season (October to April) over the period 1997–2017. Days at risk of frost are those with a daily minimum temperature < 2°C. High (low) values indicate high (low) frost risk.

Figure 2: Change in the mean number of days at risk of frost during the growing season (October to April) between the current (1997–2017) and historical (1961–1990) periods. Days at risk of frost are days with a minimum temperature < 2°C. High (low) values indicate increased (decreased) frost risk.

Figure 3: Projected mean number of days at risk of frost during the growing season (October to April) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards higher (lower) frost risk.

Figure 4: Violin plots of daily minimum temperature (°C) for each month for 20-year periods from 2001 to 2100. Each violin represents daily data for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. E.g., the top-left most violin represents the daily minimum temperature for every January day in the period 2001–2020, for each grid cell in the region, for each of the 6 ensemble members. The current period (2001–2020) has been shadowed underneath future time periods to highlight any differences expected into the future. Dots represent the means for each violin. If the violin shifts lower (higher) this indicates a change towards colder (warmer) conditions.

Figure 5: Projected monthly frost risk days

Figure 6: Projected accumulated frost intensity

Figure 7: Projected mean number of extreme cold days

Figure 8: Timeseries of accumulated frost intensity, which is the cumulative total of temperatures less than 2°C over a growing season. This index characterizes exposure to cold conditions. High values indicate cold winters/springs. Points are for each grid cell, averaged across the 6 ensemble members.

Figure 9: Time-series of the number of days per growing year when temperature falls below selected thresholds (< −2°C, < −3°C, < −4°C). Areas indicate the number of days temperatures fall below each threshold per growing year. Values are averaged across all grid cells and the 6 ensemble members. Fewer instances reflect a warming climate.
ADELAIDE PLAINS

RAINFALL
Projected Mean Growing Season Rainfall

- 182 mm (1997–2017)
- 170 mm (2041–2060)
- 156 mm (2081–2100)

TEMPERATURE
Projected Mean Growing Season Temperature

- 21.6 °C (2041–2060)
- 23.1 °C (2081–2100)

EXTREME COLD
Projected Mean Growing Season Frost Risk Days

- 0.0 days (1997–2017)
- 0.0 days (2041–2060)
- 0.0 days (2081–2100)

EXTREME HEAT
Projected Mean Excess Heat Factor

- 22.5 EHF (2041–2060)
- 25.7 EHF (2081–2100)

ARIDITY
Projected Mean Annual Aridity Index

- 0.25 (1997–2017)
- 0.19 (2041–2060)
- 0.15 (2081–2100)
Australia’s Wine Future — A Climate Atlas

ADELAIDE PLAINS

Heat

Figure 1: Observed mean Growing Season Temperature (Oct–Apr) across all growing years from 1997–2017.

Figure 2: The change in Growing Season Temperature between the current (1997–2017) and historical (1961–1990) periods. Growing Season Temperature has increased across the region over recent decades.

Figure 3: Projected mean Growing Season Temperature (Oct–Apr) for 20-year time periods from 2021 to 2100. Growing Season Temperature is expected to increase steadily into the future. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Growing Season Temperature (GST) over time. Blue points are the values for each grid cell for each of the 6 ensemble members. Solid lines are timeseries representing grid cells for colder and warmer locations within the region based on current conditions (1997–2017). Horizontal grey bars represent the mean GST value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions elsewhere and future conditions in the region, helping to identify future analogue regions. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time (for example, if the rate of warming rapidly increases, useful information can still be extracted from these figures by using the shaded boxes instead of the time-scale).

Figure 5: Probability distribution of GST for 20-year time periods from 2001 to 2100. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of GST for contrasting regions during 1997–2017. A shift to the right (left) indicates warmer (cooler) conditions.

Figure 6: Probability distribution of growing year maximum GDD for 20-year time periods from 2001 to 2100. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of growing year maximum GDD for contrasting regions during 1997–2017. A shift to the right (left) indicates warmer (cooler) conditions.

Figure 7: Cumulative Growing Degree Days (GDD) across the growing year (July–June). Dashed lines show GDD values (1000, 1500, 2000, 2500) for some example phenological thresholds. Each growing year is represented by a colored line. In future time periods, heat accumulates faster, thresholds are reached earlier and maximum GDD reached is higher.

Figure 8: Distribution of date when Growing Degree Days reaches threshold.
Figure 1: Observed mean Growing Season Rainfall (Oct–Apr) across all growing years from 1997–2017.

Figure 2: Observed change in Growing Season Rainfall (1997–2017 minus 1961–1990). Negative values indicate a trend towards drier conditions. Positive values indicate a trend towards wetter conditions.

Figure 3: Projected mean Growing Season Rainfall (October to April) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Observed mean Growing Season Rainfall (Oct–Apr) for 20-year time periods from 2001 to 2100. Each grid cell is the mean of the 6 ensemble members. Horizontal grey bars represent the mean Growing Season Rainfall value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions (1997–2017) elsewhere and future conditions in this region and help identify future analogue regions. Coloured bars represent the projected mean global temperature increase into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time.

Figure 5: Projected Non-Growing Season Rainfall (mm). Horizontal grey bars represent the mean Non-Growing Season Rainfall value during 1997–2017 in selected regions across Australia.

Figure 6: Violin plots of monthly rainfall (mm) for 20-year time periods from 2001 to 2100. Each violin represents monthly totals for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. In each panel the monthly viaducts indicate the expected probability distribution of rainfall across the growing year. The current period (2001–2020) is shadowed underneath the future time periods to highlight any differences expected into the future. Dots represent the mean monthly rainfall for each violin. If the violin shifts lower (higher) this indicates a change towards drier (wetter) conditions.

Figure 7: Distribution of seasonal rainfall. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of seasonal rainfall for contrasting regions during 1997–2017. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates an increase in drier (wetter) conditions.

Figure 8: Number of rainy days during harvest for each 20-year period. Harvest refers to the date when Growing Degree Days (GDD) reach example phenological thresholds (1000, 1500, 2000, 2500) which were chosen to reflect development time of different grape styles and varieties. Rainy days during harvest were defined as days with >10mm of rain from 7 days before to 7 days after the date each GDD threshold was reached. Variability can occur spatially within the region, across years, or between ensemble members. A shift in the curve to the left (right) indicates fewer (more) rainy days during harvest. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
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ADELAIDE PLAINS

Aridity

Figure 1: Observed mean annual Aridity Index across all growing years from 1997–2017. Aridity Index is a value that characterises the ratio between the mean annual rainfall and mean annual evaporation. Low (high) values indicate drier (wetter) conditions.

Figure 2: Observed percentage change in mean annual Aridity Index between the current (1997–2017) and historical (1961–1990) periods. This shows the change already experienced across the region. Negative (positive) values indicate a trend towards drier (wetter) conditions.

Figure 3: Projected mean annual Aridity Index for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Decreasing (increasing) values indicate a trend towards drier (wetter) conditions.

Figure 4: Projected Aridity Index

> 1°C  > 2°C  > 3°C  > 4°C

Figure 5: Violin plots of monthly Aridity Index for 20-year time periods from 2001 to 2010. Each violin represents monthly averages for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. Each violin panel shows the probability distribution of Aridity Index values within each month across the growing year. The current period (2001–2010) is shaded underneath the future time periods to highlight any differences expected into the future. Coloured bars represent the projected global temperature increase expected in the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than time. If the violin shifts lower (higher) this indicates a change toward drier (wetter) conditions.

Figure 6: Seasonal Aridity Index (Winter, Spring, Summer, Autumn), presented as a probability distribution for each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of seasonal aridity for contrasting regions during 1997–2017. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates drier (wetter) conditions. Aridity Index values > 2 all indicate very wet conditions.

Figure 7: Mean annual Aridity Index accumulated from start of the growing season (July) to date of harvest, presented as a probability distribution for each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of seasonal aridity for contrasting regions during 1997–2017. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates drier (wetter) conditions. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
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ADELAIDE PLAINS
Extremes — Hot

Figure 1: Observed mean Excess Heat Factor (EHF) during heatwaves (as per Nairn and Fawcett (2013)), across all growing years from 1997–2017. EHF is an index that characterises heatwaves, high values indicate more intense heatwaves. The mean EHF is the mean value from all heatwaves that occurred from 1997–2017.

Figure 2: Change in mean EHF during heatwaves between the current (1997–2017) and historical (1961–1990) periods. Positive (negative) values indicate a trend towards more (less) intense heatwaves.

Figure 3: Projected mean EHF during heatwaves for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards more (less) intense heatwaves.

Figure 4: Observed mean excess heat factor (EHF) during heatwaves during the current 1997–2017 and historical 1961–1990 periods. Positive (negative) values indicate a trend towards more (less) intense heatwaves.

Figure 4: Time series of the number of days per growing year with temperatures greater than 30°C, 35°C, 40°C and 45°C. Arrows indicate the number of days each threshold is exceeded per growing year. Values are averaged across all grid cells and the 6 ensemble members. Colours indicate each of the extreme threshold values. Generally increasing frequencies reflect a warming climate.

Figure 5: Time series of the number of days per growing year of high human heat stress. This is defined as days when daily maximum temperatures are >30°C and daily minimum humidity is >60%. These conditions cause severe risk of heat stress to humans (and potentially low productivity) to those working in exposed areas. Humans cannot work in high temperature, high humidity environments without appropriate adaptive behaviours and equipment. Points are for each grid cell from each of the 6 ensemble members. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than time.

Figure 6: Violins plots of high temperatures (°C) per growing year for 20-year time periods from 2001 to 2100. Colours indicate extreme threshold values (90th, 95th and 99th percentile) of temperature during each growing year. The 99th percentile value reflects the 4th hottest day each growing year; the 95th percentile is the 18th hottest day each growing year; and the 90th percentile is the 36th hottest day each growing year. Generally increasing values reflect a warming climate.

Figure 7: Distribution of daily minimum and maximum temperature during a heatwave. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the right (left) indicates higher (lower) temperature heatwaves.

Figure 8: Distribution of date of heatwave days. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the right (left) indicates heatwaves occurring earlier (later).


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ADelaide Plains
Extremes — Cold

Figure 1: Observed mean number of days at risk of frost during the growing season (October to April) over the period 1997–2017. Days at risk of frost are those with a daily minimum temperature <2°C. High (low) values indicate high (low) frost risk.

Figure 2: Change in the mean number of days at risk of frost during the growing season (October to April) between the current (1997–2017) and historically (1961–1990) periods. Days at risk of frost are days with a minimum temperature <2°C. High (low) values indicate increased (decreased) frost risk.

Figure 3: Projected mean number of days at risk of frost during the growing season (October to April) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards higher (lower) frost risk.

Figure 4: Observed minimum temperature (°C) for each month for 20-year time periods from 2001 to 2100. Each violin represents daily data for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period; e.g. the top-left most violin represents the daily minimum temperature for every January day in the period 2001–2020, for each grid cell in the region, for each of the 6 ensemble members. The current period (2001–2020) has been shadowed underneath future time periods to highlight any differences expected into the future. Dots represent the means for each violin. If the violin shifts lower (higher) this indicates a change towards colder (warmer) conditions.

Figure 5: Projected monthly minimum temperature

Figure 6: Projected accumulated frost intensity

Figure 7: Projected mean number of extreme cold days

Figure 8: Timeseries of accumulated frost intensity, which is the cumulative total of temperatures less than 2°C over a growing season. This index characterises exposure to cold conditions. High values indicate cold winters/springs. Points are for each grid cell, averaged across the 6 ensemble members.

Figure 9: Time-series of the number of days per growing year when temperature falls below selected thresholds (<2°C, <0°C, <−2°C). Areas indicate the number of days with temperatures below each threshold for each growing year. Values are averaged across all grid cells and the 6 ensemble members. Fewer instances reflect a warming climate.

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ADELAIDE HILLS

Heat

Figure 1: Observed mean Growing Season Temperature (Oct–Apr) across all growing years from 1997–2017.

Figure 2: Observed change in mean Growing Season Temperature (Oct–Apr) across all growing years from 1997–2017.

Figure 3: Projected mean Growing Season Temperature (Oct–Apr) for 20-year time periods from 2021 to 2100. Growing Season Temperature is expected to increase steadily into the future. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Projected Growing Season Temperature (October to April)

Figure 5: Distribution of Growing Season Temperature

Figure 6: Distribution of Growing Degree Days

Figure 7: Cumulative Growing Degree Days (GDD) across the growing year (July–June)

Figure 8: Distribution of date when Growing Degree Days reaches threshold
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ADELAIDE HILLS

Moisture

Figure 1: Observed mean Growing Season Rainfall (Oct–Apr) across all growing years from 1997–2017.

Figure 2: Observed change in mean Growing Season Rainfall 1997–2017 (May–Nov) across all growing years from 1997–2017. Negative values indicate a trend towards drier conditions. Positive values indicate a trend towards wetter conditions.

Figure 3: Projected mean Growing Season Rainfall for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Time series of Growing Season Rainfall (mm). Blue points are the annual values for each grid cell, for each of the 6 ensemble members. Horizontal grey bars represent the mean Growing Season Rainfall value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions (1997–2017) elsewhere and future conditions in the region and help identify future analogue regions. Coloured bars represent the projected mean global temperature increase into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time.

Figure 5: As with Figure 4, but for Non-Growing Season Rainfall (mm). Horizontal grey bars represent the mean Non-Growing Season Rainfall value during 1997–2017 in selected regions across Australia.

Figure 6: Violin plots of monthly rainfall (mm) for 20-year time periods from 2001 to 2100. Each violin represents monthly totals for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. In each panel the area under each violin indicates the expected probability distribution of rainfall across the growing year. The current period (2001–2020) is shadowed underneath the future time periods to highlight any differences expected into the future. Dots represent the mean monthly rainfall for each violin. If the violin shifts lower (higher) this indicates a change towards drier (wetter) conditions.

Figure 7: Violin plots of seasonal rainfall (Winter, Spring, Summer, Autumn) (mm), presented as a probability distribution for each 20-year period. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of seasonal rainfall for contrasting regions during 1997–2017. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates an increase in drier (wetter) conditions.

Figure 8: Number of rainy days during harvest for each 20-year period. Harvest refers to the date when Growing Degree Days (GDD) reach specific phenological thresholds (1000, 1500, 2000, 2500) which were chosen to reflect development time of different grape styles and varieties. Rainy days during harvest were defined as days with >10mm of rain from 7 days before to 7 days after the date each GDD threshold was reached. Variability can occur spatially within the region, across years, or between ensemble members. A shift in the curve to the left (right) indicates fewer (more) rainy days during harvest. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
Figure 1: Observed mean annual Aridity Index across all growing years from 1997–2017. Aridity Index is a value that characterises the ratio between the mean annual rainfall and mean annual evaporation. Low (high) values indicate drier (wetter) conditions.

Figure 2: Observed percentage change in mean annual Aridity Index between the current (1997–2017) and historical (1961–1990) periods. This shows the change already experienced across the region. Negative (positive) values indicate a trend towards drier (wetter) conditions.

Figure 3: Projected mean annual Aridity Index for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Decreasing (increasing) values indicate a trend towards drier (wetter) conditions.

Figure 4: Time series of annual Aridity Index. Points are the annual means for each grid cell in the region, for each of the 6 ensemble members. Aridity Index values >2 all indicate very wet conditions. There is no meaningful difference past this value, so higher values were not presented. Horizontal grey bars represent the mean annual Aridity Index from selected regions across Australia — these provide an example of conditions the region may transition towards in the future. Coloured bars represent the projected global temperature increase expected in the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than time (for example, if the rate of warming rapidly increases, where temperature changes are experienced earlier, useful information can still be extracted from these figures by using the coloured bars instead of the time-axis).

Figure 5: Violin plots of monthly Aridity Index for 20-year time periods from 2001 to 2100. Each violin represents monthly averages for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. Different violin panels show the expected probability distribution of Aridity Index within each month across the growing year. The current period (2001–2020) is shadowed underneath the future time periods to highlight any differences expected into the future. Dots represent the mean monthly Aridity Index for each violin. If the violin shifts lower (higher) this indicates a change towards drier (wetter) conditions.

Figure 6: Seasonal Aridity Index (Winter, Spring, Summer, Autumn), presented as a probability distribution for each 20-year period. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of seasonal aridity for contrasting region-time (1997–2017). Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates an increase in drier (wetter) conditions. Aridity Index values >2 all indicate very wet conditions.

Figure 7: Mean annual Aridity Index accumulated from start of the growing season (July) to date of harvest, presented as a probability distribution for each 20-year period. Date of harvest refers to the date at which Growing Degree Days reach some example phenological thresholds (1000, 1500, 2000, 2500), chosen to reflect development timing of different grape style and varieties. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates drier (wetter) conditions. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
Figure 1: Observed mean Excess Heat Factor (EHF) during heatwaves (as per Nairn and Fawcett (2013)), across all growing years from 1997–2017. EHF is an index that characterises heatwaves, high values indicate more intense heatwaves. The mean EHF is the mean value from all heatwaves that occurred from 1997–2017.

Figure 2: Observed change in mean EHF during heatwaves between the current (1997–2017) and historical (1961–1990) periods. Positive (negative) values indicate a trend towards more (less) intense heatwaves.

Figure 3: Projected mean EHF during heatwaves for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards more (less) intense heatwaves.

Figure 4: Time series of the number of days per growing year with temperatures greater than 30°C, 35°C, 40°C and 45°C. Arrows indicate the number of days each threshold was exceeded per growing year. Values are averaged across all grid cells and the 6 ensemble members. Colours indicate each of the extreme threshold values. Generally increasing frequencies reflect a warming climate.

Figure 5: Time series of the number of days per growing year of high human heat stress. This is defined as days when daily maximum temperatures are >30°C and daily minimum humidity is >60%. These conditions cause severe risk of heat stroke (and potentially low productivity) to those working in exposed areas. Humans cannot work in high temperature, high humidity environments without appropriate adaptive behaviours and equipment. Points are for each grid cell from each of the 6 ensemble members. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than heat.

Figure 6: Violin plots of high temperatures (°C) per growing year for 20-year time periods from 2001 to 2100. Colours indicate extreme threshold values (90th, 95th and 99th percentile) of temperature during each growing year. The 99th percentile value reflects the 4th hottest day each growing year; the 95th percentile is the 18th hottest day each growing year; and the 90th percentile is the 36th hottest day each growing 1 year. Generally increasing values reflect a warming climate.

Figure 7: Distribution of daily minimum and maximum temperature during a heatwave. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the right (left) indicates higher (lower) temperature heatwaves.

Figure 8: Distribution of date of heatwaves. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the right (left) indicates heatwaves occurring earlier (later).
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ADELAIDE HILLS

Extremes — Cold

Figure 1: Observed mean number of days at risk of frost during the growing season (October to April) over the period 1997–2017. Days at risk of frost are those with a daily minimum temperature ≤2°C. High (low) values indicate high (low) frost risk.

Figure 2: Observed change in the mean number of days at risk of frost during the growing season (October to April) between the current (1997–2017) and historical (1961–1990) periods. Days at risk of frost are days with a minimum temperature ≤2°C. High (low) values indicate increased (decreased) frost risk.

Figure 3: Projected mean number of days at risk of frost during the growing season (October to April) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards higher (lower) frost risk.

Figure 4: Violin plots of daily minimum temperature (°C) for each month for 20-year periods from 2001 to 2100. Each violin represents daily data for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period; e.g. the top-left most violin represents the daily minimum temperature for every January day in the period 2001–2020, for each grid cell in the region, for each of the 6 ensemble members. The current period (2001-2020) has been shadowed underneath future time periods to highlight any differences expected into the future. Dots represent the means for each violin. If the violin shifts lower (higher) this indicates a change towards colder (warmer) conditions.

Figure 5: Projected monthly cumulative frost days for 20-year periods from 2001 to 2100. Values are a summary across all grid cells, for all years with each 20-year period, for each of the 6 ensemble members. This reflects how frost risk varies across the year within each 20-year period. The current period (2001-2020) has been shadowed underneath future time periods to highlight any differences expected into the future.

Figure 6: Timeseries of accumulated frost intensity, which is the cumulative total of temperatures below 2°C over a growing season. This index characterizes exposure to cold conditions. High values indicate cold winters/springs. Points are for each grid cell, averaged across the 6 ensemble members.

Figure 7: Timeseries of the number of days per growing year when temperature falls below selected thresholds (≤2°C, ≤0°C, ≤-2°C). Areas indicate the number of days, averaged across all grid cells, of each of the thresholds. Fewer instances reflect a warming climate.
Figure 1: Observed mean Growing Season Temperature (Oct–Apr) across all growing years from 1997–2017.

Figure 2: The change in Growing Season Temperature between the current (1997–2017) and historical (1961–1990) periods. Growing Season Temperature has increased across the region over recent decades.

Figure 3: Projected mean Growing Season Temperature (Oct–Apr) for 20-year time periods from 2021 to 2100. Growing Season Temperature is expected to increase steadily into the future. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Growing Season Temperature (GST) over time. Blue points are the values for each grid cell for each of the 6 ensemble members. Solid lines are timeseries representing grid cells for colder and warmer locations within the region based on current conditions (1997–2017). Horizontal grey bars represent the mean GST value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions and future conditions in this region, helping to identify future analogue regions. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time (for example, if the rate of warming rapidly increases, useful information can still be extracted from these figures by using the shade boxes instead of the time-axis).

Figure 5: Probability distribution of GST for 20-year time periods from 2001 to 2100. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of GST for contrasting regions during 1997–2017. A shift to the right (left) indicates warmer (cooler) conditions.

Figure 6: Probability distribution of growing year maximum GDD for 20-year time periods from 2001 to 2100. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of growing year maximum GDD for contrasting regions during 1997–2017. A shift to the right (left) indicates warmer (cooler) conditions.

Figure 7: Cumulative Growing Degree Days (GDD) across the growing year (July–June). Dashed lines show GDD values (1000, 1500, 2000, 2500) for some example phenological thresholds. Each growing year is represented by a colored line. In future time periods, heat accumulates faster, thresholds are reached earlier and maximum GDD reached is higher.

Figure 8: Probability distributions showing the range of dates at which the example phenological thresholds (1000, 1500, 2000, 2500) are reached for each time period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates earlier (later) harvest dates. A wider (thinner) curve indicates a larger (smaller) range of harvest dates. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
Figure 1: Observed mean Growing Season Rainfall (Oct–Apr) across all growing years from 1997–2017.

Figure 2: Change in Growing Season Rainfall (Oct–Apr) between the current (1997–2017) and historical (1961–1990) periods. Negative values indicate a trend towards drier conditions. Positive values indicate a trend towards wetter conditions.

Figure 3: Projected mean Growing Season Rainfall (Oct–Apr) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Time series of Growing Season Rainfall (mm). Blue points are the annual values for each grid cell, for each of the 6 ensemble members. Horizontal grey bars represent the mean Growing Season Rainfall value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions (1997–2017) elsewhere and future conditions in the region and help identify future analogue regions. Coloured bars represent the projected mean global temperature increase into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time.

Figure 5: As with Figure 4, but for Non-Growing Season Rainfall (mm). Horizontal grey bars represent the mean Non-Growing Season Rainfall value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions (1997–2017) elsewhere and future conditions in this region and help identify future analogue regions.

Figure 6: Violin plots of monthly rainfall (mm) for 20-year time periods from 2001 to 2100. Each violin represents monthly totals for each grid cell, for each of the 6 ensemble members, and for each year within the time period. In each panel the median values indicate the expected probability distribution of rainfall across the growing year. The current period (2001–2020) is shadowed underneath the future time periods to highlight any differences expected into the future. Dots represent the mean monthly rainfall for each violin. If the violin shifts lower (higher) this indicates a change towards drier (wetter) conditions.

Figure 7: Distribution of seasonal rainfall across each 20-year period. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of seasonal rainfall for contrasting regions during 1997–2017. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates an increase in drier (wetter) conditions.

Figure 8: Number of rainy days during harvest for each 20-year period. Harvest refers to the date when Growing Degree Days (GDD) reach example phenological thresholds (1000, 1500, 2000, 2500) which were chosen to reflect development time of different grape styles and varieties. Rainy days during harvest were defined as days with >10mm of rain from 7 days before to 7 days after the date each GDD threshold was reached. Variability can occur spatially within the region, across years, or between ensemble members. A shift in the curve to the left (right) indicates fewer (more) rainy days during harvest. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
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MCLAREN VALE

Aridity

Figure 1: Observed mean annual Aridity Index across all growing years from 1997–2017. Aridity Index is a value that characterizes the ratio between the mean annual rainfall and mean annual evaporation. Low (high) values indicate drier (wetter) conditions.

Figure 2: Observed percentage change in mean annual Aridity Index between the current (1997–2017) and historical (1961–1990) periods. This shows the change already experienced across the region. Negative (positive) values indicate a trend towards drier (wetter) conditions.

Figure 3: Projected mean annual Aridity Index from 2021–2040. Each grid cell is the mean of the 6 ensemble members. Decreasing (increasing) values indicate a trend towards drier (wetter) conditions.

Figure 4: Observed mean annual Aridity Index across all growing years from 1997–2017. Aridity Index is a value that characterizes the ratio between the mean annual rainfall and mean annual evaporation. Low (high) values indicate drier (wetter) conditions.

Figure 5: Violin plots of monthly Aridity Index for 20-year time periods from 2001 to 2100. Each violin represents monthly averages for each grid cell in each of the 6 ensemble members, and for each growing year within the time period. This shows the expected probability distribution of Aridity Index within each month across the growing year. The current period (2001–2020) is shaded underneath the future time periods to highlight any differences expected into the future. Dots represent the mean monthly Aridity Index for each violin. If the violin shifts lower (higher) this indicates a change towards drier (wetter) conditions.

Figure 6: Distribution of seasonal Aridity Index. The probability distribution for each 20-year period, presented as a probability distribution for each season (Winter, Spring, Summer, Autumn), is shown. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of seasonal aridity for contrasting regions during 1997–2017. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates an increase in drier (wetter) conditions. Aridity Index values > 2 all indicate very wet conditions.

Figure 7: Mean annual Aridity Index accumulated from start of the growing season (July) to date of harvest, presented as a probability distribution for each 20-year period. Date of harvest refers to the date at which Growing Degree Days reach some example phenological thresholds (1000, 1500, 2000, 2500), chosen to reflect development time of different grape styles and varieties. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates drier (wetter) conditions. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
Figure 1: Observed mean Excess Heat Factor (EHF) during heatwaves (as per Nairn and Fawcett (2013)), across all growing years from 1997–2017. EHF is an index that characterises heatwaves; high values indicate more intense heatwaves. The mean EHF is the mean value from all heatwaves that occurred from 1997–2017.

Figure 2: Observed change in mean Excess Heat Factor

Figure 3: Projected mean Excess Heat Factor

Figure 4: Projected mean number of extreme heat days

Figure 5: Projected number of days with severe risk to humans working outside

Figure 6: Projected range of hot summer days

Figure 7: Distribution of daily minimum and maximum temperature during a heatwave

Figure 8: Distribution of date of heatwave days
Australia’s Wine Future — A Climate Atlas

MCLAREN VALE
Extremes — Cold

Figure 1: Observed mean number of days at risk of frost during the growing season (October to April) over the period 1997–2017. Days at risk of frost are those with a daily minimum temperature <2°C. High (low) values indicate high (low) frost risk.

Figure 2: Change in the mean number of days at risk of frost during the growing season (October to April) between the current (1997–2017) and historical (1961–1990) periods. Days at risk of frost are days with a minimum temperature <2°C. High (low) values indicate increased (decreased) frost risk.

Figure 3: Projected mean number of days at risk of frost during the growing season (October to April) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards higher (lower) frost risk.

Figure 4: Violin plots of daily minimum temperature (°C) for each month for 20-year periods from 2001 to 2100. Each violin represents daily data for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. e.g. the top-left most violin represents the daily minimum temperature for every January day in the period 2001–2020, for each grid cell in the region, for each of the 6 ensemble members. The current period (2001–2020) has been shadowed underneath future time periods to highlight any differences expected into the future. Dots represent the means for each violin. If the violin shifts lower (higher) this indicates a change towards colder (warmer) conditions.

Figure 5: Monthly average cumulative frost days for 20-year periods from 2001 to 2100. Values are a summary across all grid cells, for all years with each 20-year period, for each of the 6 ensemble members. This reflects how frost risk varies across the year within each 20-year period. The current period (2001–2020) has been shadowed underneath future time periods to highlight any differences expected into the future.

Figure 6: Timeseries of accumulated frost intensity, which is the cumulative total of temperatures less than 2°C over a growing season. This index characterises exposure to cold conditions. High values indicate cold winters/springs. Points are for each grid cell, averaged across the 6 ensemble members.

Figure 7: Time-series of the number of days per growing year when temperature falls below selected thresholds (<2°C, <0°C, <-2°C). Areas indicate the number of grid cells that fell below each threshold each year. Fewer instances reflect a warming climate.
KANGAROO ISLAND

**RAINFALL**
Projected Mean Growing Season Rainfall
- 199 mm (1997–2017)
- 211 mm (2041–2060)
- 195 mm (2081–2100)

**TEMPERATURE**
Projected Mean Growing Season Temperature
- 17.6°C (1997–2017)
- 18.7°C (2041–2060)
- 20.0°C (2081–2100)

**EXTREME COLD**
Projected Mean Growing Season Frost Risk Days
- 0.0 days (1997–2017)
- 0.0 days (2041–2060)
- 0.0 days (2081–2100)

**EXTREME HEAT**
Projected Mean Excess Heat Factor
- 17.4 EHF (2041–2060)
- 19.7 EHF (2081–2100)

**ARIDITY**
Projected Mean Annual Aridity Index
- 0.39 (1997–2017)
- 0.32 (2041–2060)
- 0.26 (2081–2100)
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KANGAROO ISLAND

Heat

Figure 1: Observed mean Growing Season Temperature (Oct–Apr) across all growing years from 1997–2017.

Figure 2: Observed change in mean Growing Season Temperature between the current (1997–2017) and historical (1961–1990) periods. Growing Season Temperature has increased across the region over recent decades.

Figure 3: Projected mean Growing Season Temperature (Oct–Apr) for 20-year time periods from 2021 to 2100. Growing Season Temperature is expected to increase steadily into the future. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Projected Growing Season Temperature (October to April). Growing Season Temperature (GST) over time. Blue points are the values for each grid cell for each of the 6 ensemble members. Solid lines are terciles representing grid cells for colder and warmer locations within the region based on current conditions (1997–2017). Horizontal grey bars represent the mean GST value during 1997–2017 in selected regions across Australia. These provide a comparison between current climate conditions and future conditions in this region, helping to identify future analogue regions. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time (for example, if the rate of warming rapidly increases, useful information can still be extracted from these figures by using the shade boxes instead of the time-axis).

Figure 5: Distribution of Growing Season Temperature. Probability distribution of GST for 20-year time periods from 2001 to 2100. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of GST for contrasting regions during 1997–2017. A shift to the right (left) indicates warmer (cooler) conditions.

Figure 6: Distribution of Growing Year Maximum GDD. Probability distribution showing the range of dates at which the example phenological thresholds (1000, 1500, 2000, 2500) are reached for each time period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates earlier (later) harvest dates. A wider (thinner) curve indicates a larger (smaller) range of harvest dates. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).

Figure 7: Cumulative Growing Degree Days (GDD) across the growing year (July–June). Dashed line shows GDD values (1000, 1500, 2000, 2500) for some example phenological thresholds. Each growing year is represented by a colored line. In future time periods, heat accumulates faster, thresholds are reached earlier and maximum GDD reached is higher.

Figure 8: Distribution of date when Growing Degree Days reaches threshold. Probability distribution showing the range of dates at which the example phenological thresholds (1000, 1500, 2000, 2500) are reached for each time period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates earlier (later) harvest dates. A wider (thinner) curve indicates a larger (smaller) range of harvest dates. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
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KANGAROO ISLAND

Figure 1: Observed mean Growing Season Rainfall

Figure 2: Observed change in mean Growing Season Rainfall

Figure 3: Projected mean Growing Season Rainfall

Figure 4: Projected Growing Season Rainfall (October to April)

Figure 5: Projected Non-Growing Season Rainfall (May to September)

Figure 6: Projected monthly rainfall

Figure 7: Distribution of seasonal rainfall

Figure 8: Number of rainy days during harvest

Figure 9: Seasonal rainfall (Winter, Spring, Summer, Autumn) (mm), presented as a probability distribution for each 20-year period. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of seasonal rainfall for contrasting regions during 1997–2017. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates an increase in drier (wetter) conditions.

Figure 10: Number of rainy days during harvest for each 20-year period. Harvest refers to the date when Growing Degree Days (GDD) reach specific phenological thresholds (1000, 1500, 2000, 2500) which were chosen to reflect development time of different grape styles and varieties. Rainy days during harvest were defined as days with >10mm of rain from 7 days before to 7 days after the date each GDD threshold was reached. Variability can occur spatially within the region, across years, or between ensemble members. A shift in the curve to the left (right) indicates fewer (more) rainy days during harvest. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
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KANGAROO ISLAND

Aridity

Figure 1: Observed mean annual Aridity Index

Figure 2: Observed change in mean annual Aridity Index

Figure 3: Projected mean annual Aridity Index

Figure 4: Projected Aridity Index

Figure 5: Violin plots of monthly Aridity Index for 20-year time periods from 2001 to 2010.

Figure 6: Distribution of seasonal Aridity Index

Figure 7: Distribution of mean Aridity Index from July until harvest

Figure 8: Seasonal Aridity Index (Winter, Spring, Summer, Autumn), presented as a probability distribution for each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. Grey shadings represent the probability distribution of seasonal aridity for contrasting region timing 1997–2017. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates drier (wetter) conditions. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
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KANGAROO ISLAND

Extremes — Hot

Figure 1: Observed mean Excess Heat Factor

Figure 2: Observed change in mean Excess Heat Factor

Figure 3: Projected mean Excess Heat Factor

Figure 4: Projected mean number of extreme heat days

Figure 5: Projected number of days with severe risk to humans working outside

Figure 6: Projected range of hot summer days

Figure 7: Distribution of daily minimum and maximum temperature during a heatwave

Figure 8: Distribution of date of heatwave days

Figure 1: Observed mean Excess Heat Factor (EHF) during heatwaves (as per Nairn and Fawcett (2013)), across all growing years from 1997–2017. EHF is an index that characterises heatwaves; high values indicate more intense heatwaves. The mean EHF is the mean value from all heatwaves that occurred from 1997–2017.

Figure 2: Change in mean EHF during heatwaves between the current (1997–2017) and historical (1961–1990) periods. Positive (negative) values indicate a trend towards more (less) intense heatwaves.

Figure 3: Projected mean EHF during heatwaves for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards more (less) intense heatwaves.

Figure 4: Time series of the number of days per growing year with temperatures greater than 30°C, 35°C, 40°C and 45°C. Arrows indicate the number of days each threshold is exceeded per growing year. Values are averaged across all grid cells and the 6 ensemble members. Colours indicate each of the extreme threshold values. Generally increasing frequencies reflect a warming climate.

Figure 5: Time series of the number of days per growing year of high human heat stress. This is defined as days when daily maximum temperatures are >30°C and daily minimum humidity is >60%. These conditions cause severe risk of heat stress to humans (and potentially low productivity) to those working in exposed areas. Humans cannot work in high temperature, high humidity environments without appropriate adaptive behaviours and equipment. Points are for each grid cell from each of the 6 ensemble members. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario) which can be used to make climate-based decisions on projected temperature change rather than time.

Figure 6: Violins plots of high temperatures (°C) per growing year for 20-year time periods from 2001 to 2100. Colours indicate extreme threshold values (90th, 95th and 99th percentile) of temperature during each growing year. The 99th percentile value reflects the 4th hottest day each growing year; the 95th percentile is the 18th hottest day each growing year; and the 90th percentile is the 36th hottest day each growing year. Generally increasing values reflect a warming climate.

Figure 7: Probability distributions of daily maximum temperatures and minimum overnight temperatures during heatwaves. Colour of each curve indicates different 20-year periods. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the right (left) indicates higher (lower) temperature heatwaves.

Figure 8: Probability distribution of the date when heatwaves occur. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates heatwaves occurring earlier (later).
Figure 1: Observed mean number of days at risk of frost during the growing season (October to April) over the period 1997–2017. Days at risk of frost are those with a daily minimum temperature \(< 2\, ^\circ C\). High (low) values indicate high (low) frost risk.

Figure 2: Change in the mean number of days at risk of frost during the growing season (October to April) between the current (1997–2017) and historical (1961–1990) periods. Days at risk of frost are days with a minimum temperature \(< 2\, ^\circ C\). High (low) values indicate increased (decreased) frost risk.

Figure 3: Projected mean number of days at risk of frost during the growing season (October to April) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards higher (lower) frost risk.

Figure 4: Projected monthly minimum temperature

Figure 5: Projected monthly frost risk days

Figure 6: Projected accumulated frost intensity

Figure 7: Projected mean number of extreme cold days

Figure 8: Violin plots of daily minimum temperature (\(^\circ C\)) for each month for 20-year periods from 2001 to 2100. Each violin represents daily data for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. E.g., the top-left violin represents the daily minimum temperature for every January day in the period 2001–2020, for each grid cell in the region, for each of the 6 ensemble members. The current period (2001–2020) has been shadowed underneath future time periods to highlight any differences expected into the future. Dots represent the means for each violin. If the violin shifts lower (higher) this indicates a change towards colder (warmer) conditions.

Figure 9: Monthly average cumulative frost days for 20-year periods from 2001 to 2100. Values are a summary across all grid cells, for all years with each 20-year period, for each of the 6 ensemble members. This reflects how frost risk varies across the year within each 20-year period. The current period (2001–2020) has been shadowed underneath future time periods to highlight any differences expected into the future.

Figure 10: Timeseries of accumulated frost intensity, which is the cumulative total of temperatures less than \(2\, ^\circ C\) over a growing season. This index characterises exposure to cold conditions. High values indicate cold winters/springs. Points are for each grid cell, averaged across the 6 ensemble members.

Figure 11: Time series of the number of days per growing year when temperatures fall below selected thresholds (\(< -2\, ^\circ C\), \(< -3\, ^\circ C\), \(< -4\, ^\circ C\)). Areas indicate the number of days temperatures fall below each threshold per growing year. Values are averaged across all grid cells and the 6 ensemble members. Fewer instances reflect a warming climate.
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SOUTHERN FLEURIEU

Heat

Figure 1: Observed mean Growing Season Temperature (Oct–Apr) across all growing years from 1997–2017.

Figure 2: Observed change in mean Growing Season Temperature between the current (1997–2017) and historical (1961–1990) periods. Growing Season Temperature has increased across the region over recent decades.

Figure 3: Projected mean Growing Season Temperature for 20-year time periods from 2021 to 2100. Growing Season Temperature is expected to increase steadily into the future. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Projected Growing Season Temperature (October to April). Growing Season Temperature has increased across the region over recent decades. Each grid cell is the mean of the 6 ensemble members.

Figure 5: Distribution of Growing Season Temperature. Probability distribution of GST for 20-year time periods from 2001 to 2100. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of GST for contrasting regions during 1997–2017. A shift to the right (left) indicates warmer (cooler) conditions.

Figure 6: Distribution of Growing Degree Days. Probability distribution showing the range of dates at which the example phenological thresholds (1000, 1500, 2000, 2500) are reached for each time period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates earlier (later) harvest dates. A wider (thinner) curve indicates a larger (smaller) range of harvest dates. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).

Figure 7: Projected cumulative Growing Degree Days. Cumulative Growing Degree Days (GDD) across the growing year (July–June). Dashed lines show GDD values (1000, 1500, 2000, 2500) for some example phenological thresholds. Each growing year is represented by a coloured line. In future time periods, heat accumulates faster, thresholds are reached earlier and maximum GDD reached is higher.

Figure 8: Distribution of date when Growing Degree Days reaches threshold. Probability distributions showing the range of dates at which the example phenological thresholds (1000, 1500, 2000, 2500) are reached for each time period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates earlier (later) harvest dates. A wider (thinner) curve indicates a larger (smaller) range of harvest dates. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
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SOUTHERN FLEURIEU

Figure 1: Observed mean Growing Season Rainfall (Oct–Apr) across all growing years from 1997–2017.

Figure 2: Observed change in mean Growing Season Rainfall between the current (1997–2017) and historical (1961–1990) periods. Negative values indicate a trend towards drier conditions. Positive values indicate a trend towards wetter conditions.

Figure 3: Projected mean Growing Season Rainfall (Oct–Apr) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Projected Growing Season Rainfall (October to April) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members.

Figure 5: Projected Non-Growing Season Rainfall (May to September) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members.

Figure 6: Projected monthly rainfall for 20-year time periods from 2001 to 2100. Each violin represents monthly totals for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. In each panel the monthly violins indicate the expected probability distribution of rainfall across the growing year. The current period (2001–2010) is shaded underneath the future time periods to highlight any differences expected into the future. Dots represent the mean monthly rainfall for each violin. If the violin shifts lower (higher) this indicates a change towards drier (wetter) conditions.

Figure 7: Violin plots of monthly rainfall (mm) for 20-year time periods from 2001 to 2100. Each violin represents monthly totals for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. In each panel the monthly violins indicate the expected probability distribution of rainfall across the growing year. The current period (2001–2010) is shaded underneath the future time periods to highlight any differences expected into the future. Dots represent the mean monthly rainfall for each violin. If the violin shifts lower (higher) this indicates a change towards drier (wetter) conditions.

Figure 8: Projected distribution of seasonal rainfall (Winter, Spring, Summer, Autumn) (mm), presented as a probability distribution for each 20-year period. The shape of the curves is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of seasonal rainfall for contrasting regions during 1997–2017. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates an increase in drier (wetter) conditions.

Figure 9: Distribution of number of rainy days during harvest

Figure 10: Number of rainy days during harvest for each 20-year period. Harvest refers to the date when Growing Degree Days (GDD) reach example phenological thresholds (1000, 1500, 2000, 2500) which were chosen to reflect development time of different grape styles and varieties. Rainy days during harvest were defined as days with >10mm of rain from 7 days before to 7 days after the date each GDD threshold was reached. Variability can occur spatially within the region, across years, or between ensemble members. A shift in the curve to the left (right) indicates fewer (more) rainy days during harvest. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
Figure 1: Observed mean annual Aridity Index across all growing years from 1997–2017. Aridity Index is a value that characterizes the ratio between the mean annual rainfall and mean annual evaporation. Low (high) values indicate drier (wetter) conditions.

Figure 2: Observed percentage change in mean annual Aridity Index between the current (1997–2017) and historical (1961–1990) periods. This shows the change already experienced across the region. Negative (positive) values indicate a trend towards drier (wetter) conditions.

Figure 3: Projected mean annual Aridity Index for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Decreasing (increasing) values indicate a trend towards drier (wetter) conditions.

Figure 4: Time series of annual Aridity Index. Points are the annual means for each grid cell in the region, for each of the 6 ensemble members. Aridity Index values > 2 all indicate very wet conditions. There is no meaningful difference past this value, so higher values were not presented. Horizontal grey bars represent the mean annual Aridity Index from selected regions across Australia — these provide an example of conditions this region may transition towards in the future. Coloured bars represent the projected global temperature increase expected in the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than risk (for example, if the rate of warming rapidly increases, where temperature changes are experienced earlier, useful information can still be extracted from these figures by using the coloured bars instead of the time-axis).

Figure 5: Violin plots of monthly Aridity Index for 20-year time periods from 2001 to 2100. Each violin represents monthly averages for each grid cell for each of the 6 ensemble members, and for each growing year within the time period. In each violin panel the violins indicate the expected probability distribution of Aridity Index within each month across the growing year. The current period (2001–2020) is shadowed underneath the future time periods to highlight any differences expected into the future. Dots represent the mean monthly Aridity Index for each violin. If the violin shifts lower (higher) this indicates a change towards drier (wetter) conditions.

Figure 6: Seasonal Aridity Index (Winter, Spring, Summer, Autumn), presented as a probability distribution for each 20-year period. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of seasonal aridity for contrasting regions during 1997–2017. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates drier (wetter) conditions. Aridity Index values > 2 all indicate very wet conditions.

Figure 7: Mean annual Aridity Index accumulated from start of the growing season (July) to date of harvest, presented as a probability distribution for each 20-year period. Date of harvest refers to the date at which Growing Degree Days reach some example phenological thresholds (1000, 1500, 2000, 2500), chosen to reflect development time of different grape styles and varieties. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates drier (wetter) conditions. A missing time period indicates that the specific phenological threshold was not reached within the growing season (July–June).
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SOUTHERN FLEURIEU
Extremes — Hot

Figure 1: Observed mean Excess Heat Factor (EHF) during heatwaves (as per Nairn and Fawcett (2013)), across all growing years from 1997–2017. EHF is an index that characterises heatwaves; high values indicate more intense heatwaves. The mean EHF is the mean value from all heatwaves that occurred from 1997–2017.

Figure 2: Change in mean EHF during heatwaves between the current (1997–2017) and historical (1961–1990) periods. Positive (negative) values indicate a trend towards more (less) intense heatwaves.

Figure 3: Projected mean EHF during heatwaves for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards more (less) intense heatwaves.

Figure 4: Time series of the number of days per growing year with temperatures greater than 30°C, 35°C, and 40°C. Areas indicate the number of days each threshold is exceeded per growing year. Values are averaged across all grid cells and the 6 ensemble members. Generally increasing frequencies reflect a warming climate.

Figure 5: Time series of the number of days per growing year of high human heat stress. This is defined as days when daily maximum temperatures are >30°C and daily minimum humidity is >60%. These conditions cause severe risk of heat stress to humans (and potentially low productivity) to those working in exposed areas. Humans cannot work in high temperature, high humidity environments without appropriate adaptive behaviours and equipment. Points are for each grid cell from each of the 6 ensemble members. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than time.

Figure 6: Violins plots of high temperatures (°C) per growing year for 20-year time periods from 2021 to 2100. Colours indicate extreme threshold values (90th, 95th, and 99th percentile) of temperature during each growing year. The 99th percentile value reflects the 4th hottest day each growing year; the 95th percentile is the 18th hottest day each growing year; and the 90th percentile is the 36th hottest day each growing year. Generally increasing values reflect a warming climate.

Figure 7: Probability distributions of daily maximum temperatures and minimum overnight temperatures during heatwaves. Colour of each curve indicates different 20-year periods. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the right (left) indicates higher (lower) temperature heatwaves.

Figure 8: Distribution of date of heatwave days. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates heatwaves occurring earlier (later).
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SOUTHERN FLEURIEU
Extremes — Cold

Figure 1: Observed mean number of days at risk of frost during the growing season (October to April) over the period 1997–2017. Days at risk of frost are those with a daily minimum temperature < 2°C. High (low) values indicate high (low) frost risk.

Figure 2: Observed change in mean number of days at risk of frost during the growing season (October to April) between the current (1997–2017) and historical (1961–1990) periods. Days at risk of frost are days with a minimum temperature < 2°C. High (low) values indicate increased (decreased) frost risk.

Figure 3: Projected mean number of days at risk of frost during the growing season (October to April) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards higher (lower) frost risk.

Figure 4: Violin plots of daily minimum temperature (°C) for each month for 20-year periods from 2001 to 2100. Each violin represents daily data for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. E.g. the top-left violin represents the daily minimum temperature for every January day in the period 2001–2020, for each grid cell in the region, for each of the 6 ensemble members. The current period (2001–2020) has been shadowed underneath future time periods to highlight any differences expected into the future. Dots represent the means for each violin. If the violin shifts lower (higher) this indicates a change towards colder (warmer) conditions.

Figure 5: Projected mean number of days at risk of frost during the growing season (October to April) for 20-year periods from 2001 to 2100. Values are a summary across all grid cells, for all years within each 20-year period, for each of the 6 ensemble members. This reflects how frost risk varies across the year within each 20-year period. The current period (2001–2020) has been shadowed underneath future time periods to highlight any differences expected into the future.

Figure 6: Timeseries of accumulated frost intensity, which is the cumulative total of temperatures less than 2°C over a growing season. This index characterises exposure to cold conditions. High values indicate cold winters/springs. Points are for each grid cell, averaged across the 6 ensemble members.

Figure 7: Timeseries of the number of days per growing year when temperature falls below selected thresholds (< 2°C, < 0°C, < -2°C). Areas indicate the number of days temperatures fall below each threshold per growing year. Values are averaged across all grid cells and the 6 ensemble members. Fewer instances reflect a warming climate.
**CURRENCY CREEK**

**RAINFALL**
Projected Mean Growing Season Rainfall
- 198 mm (1997–2017)
- 219 mm (2041–2060)
- 205 mm (2081–2100)

**TEMPERATURE**
Projected Mean Growing Season Temperature
- 19.4°C (2041–2060)
- 20.7°C (2081–2100)

**EXTREME COLD**
Projected Mean Growing Season Frost Risk Days
- 0.0 days (1997–2017)
- 0.0 days (2041–2060)
- 0.0 days (2081–2100)

**EXTREME HEAT**
Projected Mean Excess Heat Factor
- 19.9 EHF (2041–2060)
- 21.4 EHF (2081–2100)

**ARIDITY**
Projected Mean Annual Aridity Index
- 0.36 (1997–2017)
- 0.29 (2041–2060)
- 0.24 (2081–2100)
Australia’s Wine Future — A Climate Atlas

Heat

Figure 1: Observed mean Growing Season Temperature

Figure 2: Observed change in mean Growing Season Temperature

Figure 3: Projected mean Growing Season Temperature

Figure 4: Projected Growing Season Temperature (October to April)

Figure 5: Distribution of Growing Season Temperature

Figure 6: Distribution of Growing Degree Days

Figure 7: Projected cumulative Growing Degree Days

Figure 8: Distribution of date when Growing Degree Days reaches threshold
Figure 1: Observed mean Growing Season Rainfall

Figure 2: Observed change in mean Growing Season Rainfall

Figure 3: Projected mean Growing Season Rainfall

Figure 4: Projected Growing Season Rainfall (October to April)

Figure 5: Projected Non-Growing Season Rainfall (May to September)

Figure 6: Projected monthly rainfall

Figure 7: Distribution of seasonal rainfall

Figure 8: Distribution of number of rainy days during harvest
Figure 1: Observed mean annual Aridity Index

Figure 2: Observed change in mean annual Aridity Index

Figure 3: Projected mean annual Aridity Index

Figure 4: Projected Aridity Index

Figure 5: Violin plots of monthly Aridity Index for 20-year time periods from 2001 to 2100.

Figure 6: Distribution of seasonal Aridity Index

Figure 7: Mean annual Aridity Index from July until harvest

Figure 8: Observed mean mean Aridity Index across all growing years from 1997–2017. Aridity Index is a value that characterizes the ratio between the mean annual rainfall and mean annual evaporation. Low (high) values indicate drier (wetter) conditions.

Figure 9: Observed percentage change in mean annual Aridity Index between the current (1997–2017) and historical (1961–1990) periods. This shows the change already experienced across the region. Negative (positive) values indicate a trend towards drier (wetter) conditions.

Figure 10: Projected monthly Aridity Index

Figure 11: Projected mean annual Aridity Index for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members, and for each growing year within the time period. The current period (2001–2020) is shadowed underneath the future time periods to highlight any differences expected into the future. Dots represent the mean monthly Aridity Index for each violin. If the violin shifts lower (higher) this indicates a change towards drier (wetter) conditions.

Figure 12: Projected seasonal Aridity Index (Winter, Spring, Summer, Autumn). Presented as a probability distribution for each 20-year period. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of seasonal aridity for continuous regions during 1997–2017. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates an increase in drier (wetter) conditions. Aridity Index values >2 all indicate very wet conditions.
Australia’s Wine Future — A Climate Atlas

CURRENCY CREEK

Extremes — Hot

Figure 1: Observed mean Excess Heat Factor (EHF) during heatwaves (as per Nairn and Fawcett (2013)), across all growing years from 1997–2017. EHF is an index that characterises heatwaves, high values indicate more intense heatwaves. The mean EHF is the mean value from all heatwaves that occurred from 1997–2017.

Figure 2: Change in mean EHF during heatwaves between the current (1997–2017) and historical (1961–1990) periods. Positive (negative) values indicate a trend towards more (less) intense heatwaves.

Figure 3: Projected mean EHF during heatwaves for 20-year time periods from 2021 to 2100. Increasing (decreasing) values indicate a trend towards more (less) intense heatwaves.

Figure 4: Time series of the number of days per growing year with temperatures greater than 30°C, 35°C, and 40°C. Bars indicate the number of days each threshold is exceeded per growing year. Values are averaged across all grid cells and the 6 ensemble members. Colours indicate each of the extreme threshold values. Generally increasing frequencies reflect a warming climate.

Figure 5: Time series of the number of days per growing year with temperatures greater than 30°C and daily minimum humidity < 60%. These conditions cause severe risk of heat stress to humans and potentially low productivity to those working in exposed areas. Humans cannot work in high temperature, high humidity environments without appropriate adaptive behaviours and equipment. Points are for each grid cell from each of the 6 ensemble members. colours indicate the projected global temperature increase expected into the future (following the RCP 8.5 scenarios) which can be used to make decisions based on projected temperature change rather than frequencies.

Figure 6: Violin plots of high temperatures (°C) per growing year for 20-year time periods from 2001 to 2100. Colours indicate extreme threshold values (90th, 95th and 99th percentile) of temperature during each growing year. The 90th percentile value reflects the 4th hottest day each growing year; the 95th percentile is the 18th hottest day each growing year; and the 99th percentile is the 36th hottest day each growing year. Generally increasing values reflect a warming climate.

Figure 7: Distribution of daily minimum and maximum temperature during a heatwave. Likely values are for each grid cell from each of the 6 ensemble members. A shift to the right (left) indicates higher (lower) temperature heatwaves.

Figure 8: Distribution of date of heatwave days. Likely values are for each grid cell from each of the 6 ensemble members. A shift to the right (left) indicates extreme heatwaves occurring earlier (later).
Figure 1: Observed mean number of days at risk of frost during the growing season (October to April) over the period 1997–2017. Days at risk of frost are those with a daily minimum temperature $< 2\,^\circ C$. High (low) values indicate high (low) frost risk.

Figure 2: Change in the mean number of days at risk of frost during the growing season (October to April) between the current (1997–2017) and historical (1961–1990) periods. Days at risk of frost are days with a daily minimum temperature $< 2\,^\circ C$. High (low) values indicate increased (decreased) frost risk.

Figure 3: Projected mean number of days at risk of frost during the growing season (October to April) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend toward higher (lower) frost risk.

Figure 4: Violin plots of daily minimum temperature (°C) for each month for 20-year periods from 2001 to 2020. Each violin represents daily data for each grid cell, for each of the 6 ensemble members, and for each growing year within the timeframe. Each violin’s density indicates the daily minimum temperature for every January day in the period 2001–2020, for each grid cell in the region, for each of the 6 ensemble members. The current period (2001–2020) has been shadowed underneath future time periods to highlight any differences expected into the future. Dots represent the means for each violin. If the violin shifts lower (higher) this indicates a change towards colder (warmer) conditions.

Figure 5: Monthly average cumulative frost days for 20-year periods from 2001 to 2020. Values are a summary across all grid cells, for all years within each 20-year period, for each of the 6 ensemble members. This reflects how frost risk varies across the year within each 20-year period. The current period (2001–2020) has been shadowed underneath future time periods to highlight any differences expected into the future.

Figure 6: Timeseries of accumulated frost intensity, which is the cumulative total of temperatures less than $2\,^\circ C$ over a growing season. This index characterises exposure to cold conditions. High values indicate cold winters/springs. Points are for each grid cell, averaged across the 6 ensemble members.

Figure 7: Timeseries of the number of days per growing year when temperature falls below selected thresholds ($< 2\,^\circ C$, $< 0\,^\circ C$, $< -2\,^\circ C$). Areas indicate the number of days temperatures fall below each threshold per growing year. Values are averaged across all grid cells and the 6 ensemble members. Fewer instances reflect a warming climate.
Figure 1: Observed mean Growing Season Temperature (Oct–Apr) across all growing years from 1997–2017.

Figure 2: The change in Growing Season Temperature between the current (1997–2017) and historical (1961–1990) periods. Growing Season Temperature has increased across the region over recent decades.

Figure 3: Projected mean Growing Season Temperature (Oct–Apr) for 20-year time periods from 2021 to 2100. Growing Season Temperature is expected to increase steadily into the future. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Projected Growing Season Temperature (October to April) for 20-year time periods from 2021 to 2100. Growing Season Temperature has increased across the region over recent decades. Growing Season Temperature is expected to increase steadily into the future. Each grid cell is the mean of the 6 ensemble members.

Figure 5: Distribution of Growing Season Temperature

Figure 6: Distribution of Growing Degree Days

Figure 7: Projected cumulative Growing Degree Days

Figure 8: Distribution of date when Growing Degree Days reaches threshold
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Figure 1: Observed mean Growing Season Rainfall (Oct–Apr) across all growing years from 1997–2017.

Figure 2: Change in Growing Season Rainfall (Oct–Apr) between the current (1997–2017) and historical (1961–1990) periods. Negative values indicate a trend towards drier conditions. Positive values indicate a trend towards wetter conditions.

Figure 3: Projected mean Growing Season Rainfall (Oct–Apr) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Time series of Growing Season Rainfall (mm). Blue points are the annual values for each grid cell, for each of the 6 ensemble members. Horizontal grey bars represent the mean Growing Season Rainfall value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions (1997–2017) elsewhere and future conditions in this region and help identify future analogue regions. Coloured bars represent the projected mean global temperature increase into the future (following the RCP 8.5 scenario). They can be used to make decisions based on projected temperature change rather than time.

Figure 5: As with Figure 4, but for Non-Growing Season Rainfall (mm). Horizontal grey bars represent the mean Non-Growing Season Rainfall value during 1997–2017 in selected regions across Australia.

Figure 6: Violin plots of monthly rainfall (mm) for 20-year time periods from 2001 to 2100. Each violin represents monthly totals for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. In each panel the monthly violins indicate the expected probability distribution of rainfall across the growing year. The current period (2001–2020) is shadowed underneath the future time periods to highlight any differences expected into the future. Dots represent the mean monthly rainfall for each violin. If the violin shifts lower (higher) this indicates a change towards drier (wetter) conditions.

Figure 7: Violin plots of monthly rainfall (mm) for 20-year time periods from 2001 to 2100. Each violin represents monthly totals for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. In each panel the monthly violins indicate the expected probability distribution of rainfall across the growing year. The current period (2001–2020) is shadowed underneath the future time periods to highlight any differences expected into the future. Dots represent the mean monthly rainfall for each violin. If the violin shifts lower (higher) this indicates a change towards drier (wetter) conditions.

Figure 8: Number of rainy days during harvest for each 20-year period. Harvest refers to the date when Growing Degree Days (GDD) reach example phenological thresholds (1000, 1500, 2000, 2500) which were chosen to reflect development time of different grape styles and varieties. Rainy days during harvest were defined as days with >10 mm of rain from 7 days before to 7 days after the date each GDD threshold was reached. Variability can occur spatially within the region, across years, or between ensemble members. A shift in the curve to the left (right) indicates fewer (more) rainy days during harvest. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
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LANGHORNE CREEK

Aridity

Figure 1: Observed mean annual Aridity Index across all growing years from 1997–2017. Aridity Index is a value that characterizes the ratio between the mean annual rainfall and mean annual evaporation. Low (high) values indicate drier (wetter) conditions.

Figure 2: Observed percentage change in mean annual Aridity Index between the current (1997–2017) and historical (1961–1990) periods. This shows the change already experienced across the region. Negative (positive) values indicate a trend towards drier (wetter) conditions.

Figure 3: Projected mean annual Aridity Index for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Decreasing (increasing) values indicate a trend towards drier (wetter) conditions.

Figure 4: Time series of annual Aridity Index. Points are the annual means for each grid cell in the region, for each of the 6 ensemble members. Aridity Index values >2 indicate very wet conditions. There is no meaningful difference past this value, so higher values were not presented. Horizontal grey bars represent the mean annual Aridity Index from selected regions across Australia. These provide an example of conditions the region may transition towards in the future. Coloured bars represent the projected global temperature increase expected in the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than time (for example, if the rate of warming rapidly increases, where temperature changes are experienced earlier, useful information can still be extracted from these figures by using the coloured bars instead of the time-axis).

Figure 5: Violin plots of monthly Aridity Index for 20-year period from 2001 to 2100. Each violin represents monthly averages for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. The current period (2001–2020) is shadowed underneath the future time periods to highlight any difference expected into the future. Dots represent the mean monthly Aridity Index for each violin. If the violin shifts lower (higher) this indicates a change towards drier (wetter) conditions.

Figure 6: Seasonal Aridity Index (Winter, Spring, Summer, Autumn), presented as a probability distribution for each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of seasonal aridity for contrasting regions during 1997–2017. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates drier (wetter) conditions. Aridity Index values >2 all indicate very wet conditions.

Figure 7: Mean annual Aridity Index accumulated from start of the growing season (July) to date of harvest, presented as a probability distribution for each 20-year period. Date of harvest refers to the date at which Growing Degree Days reach some example phenological thresholds (1000, 1500, 2000, 2500), chosen to reflect development time of different grape styles and varieties. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates drier (wetter) conditions. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
Australia’s Wine Future — A Climate Atlas

LANGHORNE CREEK
Extremes — Hot

Figure 1: Observed mean excess heat factor (EHF) during heatwaves (as per Nairn and Fawcett (2013)), across all growing years from 1997–2017. EHF is an index that characterises heatwaves; high values indicate more intense heatwaves. The mean EHF is the mean value from all heatwaves that occurred from 1997–2017.

Figure 2: Observed change in mean excess heat factor (EHF) during heatwaves between the current (1997–2017) and historical (1961–1990) periods. Positive (negative) values indicate a trend towards more (less) intense heatwaves.

Figure 3: Projected mean EHF during heatwaves for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards more (less) intense heatwaves.

Figure 4: Time series of the number of days per growing year with temperatures greater than 30°C, 35°C, 40°C and 45°C. Areas indicate the number of days each threshold is exceeded per growing year. Values are averaged across all grid cells and the 6 ensemble members. Colours indicate each of the extreme threshold values. Generally increasing values reflect a warming climate.

Figure 5: Time series of the number of days per growing year of high human heat stress. This is defined as days when daily maximum temperatures are >30°C and daily minimum humidity is >60%. These conditions cause severe risk of heat stress to humans (and potentially low productivity) to those working in exposed areas. Humans cannot work in high temperatures, high humidity environments without appropriate adaptive behaviours and equipment. Points are for each grid cell from each of the 6 ensemble members. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than time.

Figure 6: Violins plots of high temperatures (°C) per growing year for 20-year time periods from 2001 to 2100. Colours indicate extreme threshold values (90th, 95th and 99th percentile) of temperature during each growing year. The 99th percentile value reflects the 4th hottest day each growing year; the 95th percentile is the 18th hottest day each growing year; and the 90th percentile is the 36th hottest day each growing year. Generally increasing values reflect a warming climate.

Figure 7: Distribution of daily minimum and maximum temperature during a heatwave

Figure 8: Distribution of date of heatwave days

Figure 4: Observed mean number of extreme heat days

Figure 5: Projected number of days with severe risk to humans working outside

Figure 6: Projected range of hot summer days
Figure 1: Observed mean number of days at risk of frost during the growing season (October to April) over the period 1997–2017. Days at risk of frost are those with a daily minimum temperature $<2\,^\circ C$. High (low) values indicate high (low) frost risk.

Figure 2: Change in the mean number of days at risk of frost during the growing season (October to April) between the current (1997–2017) and historical (1961–1990) periods. Days at risk of frost are days with a minimum temperature $<2\,^\circ C$. High (low) values indicate increased (decreased) frost risk.

Figure 3: Projected mean number of days at risk of frost during the growing season (October to April) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards higher (lower) frost risk.

Figure 4: Violin plots of daily minimum temperature ($^\circ C$) for each month for 2-year periods from 2001 to 2000. Each violin represents daily data for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period; e.g. the top-left most violin represents the daily minimum temperature for every January day in the period 2001–2000, for each grid cell in the region, for each of the 6 ensemble members. The current period (2001–2020) has been shadowed underneath future time periods to highlight any differences expected into the future. Dots represent the means for each violin. If the violin shifts lower (higher) this indicates a change towards colder (warmer) conditions.

Figure 5: Monthly average cumulative frost days for 20-year periods from 2001 to 2020. Values are a summary across all grid cells, for all years within each 20-year period, for each of the 6 ensemble members. This reflects how frost risk varies across the year within each 20-year period. The current period (2001–2020) has been shadowed underneath future time periods to highlight any differences expected into the future.

Figure 6: Timeseries of accumulated frost intensity, which is the cumulative total of temperatures less than $2\,^\circ C$ over a growing season. This index characterises exposure to cold conditions. High values indicate colder winters/springs. Points are for each grid cell, averaged across the 6 ensemble members.

Figure 7: Timeseries of the number of days per growing year when temperature falls below selected thresholds ($2\,^\circ C$, $0\,^\circ C$, $-2\,^\circ C$). Areas indicate the number of days temperatures fall below each threshold per growing year. Values are averaged across all grid cells and the 6 ensemble members. Fewer instances reflect a warming climate.
Figure 1: Observed mean Growing Season Temperature (Oct–Apr) across all growing years from 1997–2017.

Figure 2: The change in Growing Season Temperature between the current (1997–2017) and historical (1961–1990) periods. Growing Season Temperature has increased across the region over recent decades.

Figure 3: Projected mean Growing Season Temperature (Oct–Apr) for 20-year time periods from 2021 to 2100. Growing Season Temperature is expected to increase steadily into the future. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Growing Season Temperature (GST) over time. Blue points are the values for each grid cell for each of the 6 ensemble members. Solid lines are timeseries representing grid cells for cooler and warmer locations within the region, based on current conditions (1997–2017). Horizontal grey bars represent the mean GST value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions and future conditions in this region, helping to identify future analogue regions. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time (e.g., if the rate of warming rapidly increases, useful information can still be extracted from these figures by using the shade boxes instead of the time-axis).

Figure 5: Probability distribution of GST for 20-year time periods from 2001 to 2100. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of GST for contrasting regions during 1997–2017. A shift to the right (left) indicates warmer (cooler) conditions.

Figure 6: Probability distribution of growing year maximum GDD for 20-year time periods from 2001 to 2100. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of growing year maximum GDD for contrasting regions during 1997–2017. A shift to the right (left) indicates warmer (cooler) conditions.

Figure 7: Cumulative Growing Degree Days (GDD) across the growing year (July–June). Dashed lines show GDD values (1000, 1500, 2000, 2500) for some example phenological thresholds. Each growing year is represented by a coloured line. In future time periods, heat accumulates faster, thresholds are reached earlier and maximum GDD reached is higher.

Figure 8: Probability distribution showing the range of dates at which the example phenological thresholds (1000, 1500, 2000, 2500) are reached for each time period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates earlier (later) harvest dates. A wider (thinner) curve indicates a larger (smaller) range of harvest dates. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
Figure 1: Observed mean Growing Season Rainfall (Oct–Apr) across all growing years from 1997–2017.

Figure 2: Change in Growing Season Rainfall (Oct–Apr) between the current (1997–2017) and historical (1961–1990) periods. Negative values indicate a trend towards drier conditions. Positive values indicate a trend towards wetter conditions.

Figure 3: Projected mean Growing Season Rainfall for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Time series of Growing Season Rainfall (mm). Blue points are the annual values for each grid cell, for each of the 6 ensemble members. Horizontal grey bars represent the mean Growing Season Rainfall value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions (1997–2017) and future conditions in this region and help identify future analogue regions. Coloured bars represent the projected mean global temperature increase into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time.

Figure 5: As with Figure 4, but for Non-Growing Season Rainfall (mm). Horizontal grey bars represent the mean Non-Growing Season Rainfall value during 1997–2017 in selected regions across Australia.

Figure 6: Violin plots of monthly rainfall (mm) for 20-year time periods from 2001 to 2100. Each violin represents monthly totals for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. In each panel the monthly violins indicate the expected probability distribution of rainfall across the growing year. The current period (2001–2020) is shaded underneath the future time periods to highlight any differences expected into the future. Dots represent the mean monthly rainfall for each violin. If the violin shifts lower (higher) this indicates a change towards drier (wetter) conditions.

Figure 7: Distribution of seasonal rainfall (Winter, Spring, Summer, Autumn) (mm), presented as a probability distribution for each 20-year period. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. Coloured shapes represent the probability distribution of seasonal rainfall for contrasting regions during 1997–2017. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates an increase in drier (wetter) conditions.

Figure 8: Number of rainy days during harvest for each 20-year period. Harvest refers to the date when Growing Degree Days (GDD) reach example phenological thresholds (1000, 1500, 2000, 2500) which were chosen to reflect development time of different grape styles and varieties. Rainy days during harvest were defined as days with rainfall >10mm of rain from 7 days before to 7 days after the date each GDD threshold was reached. Variability can occur spatially within the region, across years, or between ensemble members. A shift in the curve to the left (right) indicates fewer (more) rainy days during harvest. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
Figure 1: Observed mean annual Aridity Index across all growing years from 1997–2017. Aridity Index is a value that characterises the ratio between the mean annual rainfall and mean annual evaporation. Low (high) values indicate drier (wetter) conditions.

Figure 2: Observed percentage change in mean annual Aridity Index between the current (1997–2017) and historical (1961–1990) periods. This shows the change already experienced across the region. Negative (positive) values indicate a trend towards drier (wetter) conditions.

Figure 3: Projected mean annual Aridity Index for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Decreasing (increasing) values indicate a trend towards drier (wetter) conditions.

Figure 4: Time series of annual Aridity Index. Points are the annual means for each grid cell in the region, for each of the 6 ensemble members. Aridity Index values >2 all indicate very wet conditions. There is no meaningful difference past this value, so higher values were not presented. Horizontal grey bars represent the mean annual Aridity Index from selected regions across Australia — these provide an example of conditions the region may transition towards in the future. Coloured bars represent the projected temperature increase expected in the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than time (for example, if the rate of warming rapidly increases, where temperature change are experienced earlier, useful information can still be extracted from these figures by using the coloured boxes instead of the time-axis).

Figure 5: Violin plots of monthly Aridity Index for 20-year time periods from 2001 to 2100. Each violin represents monthly averages for each grid cell in each of the 6 ensemble members, and for each growing year within the time period. The current period (2001–2020) is shadowed underneath the future time periods to highlight any differences expected into the future. Dots represent the mean monthly Aridity Index for each violin. If the violin shifts lower (higher) this indicates a change towards drier (wetter) conditions.

Figure 6: Seasonal Aridity Index (Winter, Spring, Summer, Autumn), presented as a probability distribution for each 20-year period. The shape of the curves is driven by the level of variability experienced within each 20-year period. Grey shapes represent the probability distribution of seasonal aridity for contrasting regions during 1997–2017. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates a trend towards drier (wetter) conditions. Aridity Index values >2 all indicate very wet conditions.
Australia's Wine Future — A Climate Atlas

PADTHAWAY
Extremes — Hot

Figure 1: Observed mean Excess Heat Factor (EHF) during heatwaves (as per Nairn and Fawcett (2013)), across all growing years from 1997–2017. EHF is an index that characterises heatwaves, high values indicate more intense heatwaves. The mean EHF is the mean value from all heatwaves that occurred from 1997–2017.

Figure 2: Observed change in mean Excess Heat Factor from 1997–2017 minus 1961–1990. Positive (negative) values indicate a trend towards more (less) intense heatwaves.

Figure 3: Projected mean Excess Heat Factor for the period 2021–2040. EHF is projected to increase, indicating more intense heatwaves.

Figure 4: Projected number of days per growing year when temperatures are greater than 30°C, 35°C, and 40°C. Areas indicate the number of days each threshold is exceeded per growing year.

Figure 5: Projected number of days per growing year with temperatures greater than 30°C and daily minimum humidity greater than 60%. These conditions cause severe risk of heat stress to humans and potentially lower productivity to those working in exposed areas. Humans cannot work in high temperature, high humidity environments without appropriate adaptive behaviours and equipment.

Figure 6: Violins plots of high temperatures per growing year for 20-year time periods from 2001 to 2100. Colours indicate extreme threshold values (90th, 95th, and 99th percentiles) of temperature during each growing year. The 99th percentile value reflects the 4th hottest day each growing year; the 95th percentile is the 18th hottest day each growing year; and the 90th percentile is the 36th hottest day each growing year. Generally increasing values reflect a warming climate.

Figure 7: Probability distributions of daily maximum temperatures and minimum overnight temperatures during heatwaves. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the right (left) indicates higher (lower) temperature heatwaves.

Figure 8: Distribution of date when heatwaves occur. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the right (left) indicates heatwaves occurring earlier (later).
Figure 1: Observed mean number of days at risk of frost during the growing season (October to April) over the period 1997–2017. Days at risk of frost are those with a daily minimum temperature < 2°C. High (low) values indicate high (low) frost risk.

Figure 2: Change in the mean number of days at risk of frost during the growing season (October to April) between the current (1997–2017) and historical (1961–1990) periods. Days at risk of frost are days with a minimum temperature < 2°C. High (low) values indicate increased (decreased) frost risk.

Figure 3: Projected mean number of days at risk of frost during the growing season (October to April) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards higher (lower) frost risk.

Figure 4: Violin plots of daily minimum temperature (°C) for each month for 20-year periods from 2001 to 2100. Each violin represents daily data for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period; e.g. the top-left most violin represents the daily minimum temperature for every January day in the period 2001–2020, for each grid cell in the region, for each of the 6 ensemble members. The current period (2001–2020) has been shadowed underneath future time periods to highlight any differences expected into the future. Dots represent the means for each violin. If the violin shifts lower (higher) this indicates a change towards colder (warmer) conditions.

Figure 5: Projected monthly frost risk intensity, which is the cumulative total of temperatures less than 2°C over a growing season. This index characterises exposure to cold conditions. High values indicate cold winters/springs. Points are for each grid cell, averaged across the 6 ensemble members.

Figure 6: Time series of accumulated frost intensity, which is the cumulative total of temperatures less than 2°C over a growing season. This index characterises exposure to cold conditions. High values indicate cold winters/springs. Points are for each grid cell, averaged across the 6 ensemble members.

Figure 7: Timeseries of the number of days per growing year when temperature falls below selected thresholds (< -2°C, < -3°C, < -4°C). Areas indicate the number of days temperatures fall below each threshold per growing year. Values are averaged across all grid cells and the 6 ensemble members. Fewer instances reflect a warming climate.
Mount Benson

Rainfall
Projected Mean Growing Season Rainfall
- 213 mm 1997–2017
- 205 mm 2041–2060
- 185 mm 2081–2100

Temperature
Projected Mean Growing Season Temperature
- 17.1 ºC 1997–2017
- 18.4 ºC 2041–2060
- 19.8 ºC 2081–2100

Extreme Heat
Projected Mean Excess Heat Factor
- 15.6 EHF 1997–2017
- 18.8 EHF 2041–2060
- 22.2 EHF 2081–2100

Extreme Cold
Projected Mean Growing Season Frost Risk Days
- 0.0 days 1997–2017
- 0.0 days 2041–2060
- 0.0 days 2081–2100

Aridity
Projected Mean Annual Aridity Index
- 0.43 1997–2017
- 0.35 2041–2060
- 0.28 2081–2100
Figure 1: Observed mean Growing Season Temperature (Oct–Apr) across all growing years from 1997–2017.

Figure 2: The change in Growing Season Temperature between the current (1997–2017) and historical (1961–1990) periods. Growing Season Temperature has increased across the region over recent decades.

Figure 3: Projected mean Growing Season Temperature (Oct–Apr) for 20-year time periods from 2021 to 2100. Growing Season Temperature is expected to increase steadily into the future. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Growing Season Temperature (GST) over time. Blue points are the values for each grid cell, for each of the 6 ensemble members. Solid lines are timeseries representing grid cells for colder and warmer locations within the region based on current conditions (1997–2017). Horizontal grey bars represent the mean GST value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions elsewhere and future conditions in this region, helping to identify future analogue regions. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature increase rather than time (for example, if the rate of warming rapidly increases, useful information can still be extracted from these figures by using the shade boxes instead of the time-axis).

Figure 5: Probability distribution of GST for 20-year time periods from 2001 to 2100. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of GST for contrasting regions during 1997–2017. A shift to the right (left) indicates warmer (cooler) conditions.

Figure 6: Probability distribution of growing year maximum GDD for 20-year time periods from 2001 to 2100. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of growing year maximum GDD for contrasting regions during 1997–2017. A shift to the right (left) indicates warmer (cooler) conditions.

Figure 7: Cumulative Growing Degree Days (GDD) across the growing year (July–June). Dashed lines show GDD values (1000, 1500, 2000, 2500) for some example phenological thresholds. Each growing year is represented by a colored line. In future time periods, heat accumulates faster, thresholds are reached earlier and maximum GDD reached is higher.

Figure 8: Distribution of date when Growing Degree Days reaches threshold.

Figure 9: Observed Growing Season Temperature (Oct–Apr) for selected locations across Australia.
Australia’s Wine Future — A Climate Atlas

MOUNT BENSON

Moisture

Figure 1: Observed mean Growing Season Rainfall (Oct–Apr) across all growing years from 1997–2017.

Figure 2: Observed change in mean Growing Season Rainfall 1997–2017 minus 1961–1990.

Figure 3: Projected mean Growing Season Rainfall 2021–2040.

Figure 4: Projected Growing Season Rainfall (October to April) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members.

Figure 5: Projected Non-Growing Season Rainfall (May to September) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members.

Figure 6: As with Figure 4, but for Non-Growing Season Rainfall (May–September). Vertical bars represent the mean Growing Season Rainfall value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions (1997–2017) and future conditions in this region and help identify future analogue regions. Coloured bars represent the projected mean global temperature increase into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time.

Figure 7: Violin plots of monthly rainfall (mm) for 20-year time periods from 2001 to 2100. Each violin represents monthly totals for each grid cell, for each of the 6 ensemble members. Horizontal grey bars represent the mean Growing Season Rainfall value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions (1997–2017) and future conditions in this region and help identify future analogue regions. Coloured bars represent the projected mean global temperature increase into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time.

Figure 8: Violin plots of monthly rainfall (mm) for 20-year time periods from 2011 to 2100. Each violin represents monthly totals for each grid cell, for each of the 6 ensemble members. Horizontal grey bars represent the mean Growing Season Rainfall value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions (1997–2017) and future conditions in this region and help identify future analogue regions. Coloured bars represent the projected mean global temperature increase into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time.

Figure 9: As with Figure 4, but for Non-Growing Season Rainfall (May–September). Vertical bars represent the mean Growing Season Rainfall value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions (1997–2017) and future conditions in this region and help identify future analogue regions. Coloured bars represent the projected mean global temperature increase into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time.

Figure 10: Violin plots of monthly rainfall (mm) for 20-year time periods from 2001 to 2100. Each violin represents monthly totals for each grid cell, for each of the 6 ensemble members. Horizontal grey bars represent the mean Growing Season Rainfall value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions (1997–2017) and future conditions in this region and help identify future analogue regions. Coloured bars represent the projected mean global temperature increase into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time.

Figure 11: Projected monthly rainfall 2021–2040.

Figure 12: Projected monthly rainfall 2041–2100.

Figure 13: Projected monthly rainfall 2051–2100.

Figure 14: Projected monthly rainfall 2061–2100.

Figure 15: Projected monthly rainfall 2071–2100.

Figure 16: Projected monthly rainfall 2081–2100.

Figure 17: Projected monthly rainfall 2091–2100.

Figure 18: Violin plots of monthly rainfall (mm) for 20-year time periods from 2001 to 2100. Each violin represents monthly totals for each grid cell, for each of the 6 ensemble members. Horizontal grey bars represent the mean Growing Season Rainfall value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions (1997–2017) and future conditions in this region and help identify future analogue regions. Coloured bars represent the projected mean global temperature increase into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time.

Figure 19: Projected monthly rainfall 2021–2040.

Figure 20: Projected monthly rainfall 2041–2100.

Figure 21: Projected monthly rainfall 2051–2100.

Figure 22: Projected monthly rainfall 2061–2100.

Figure 23: Projected monthly rainfall 2071–2100.

Figure 24: Projected monthly rainfall 2081–2100.

Figure 25: Projected monthly rainfall 2091–2100.

Figure 26: Projected monthly rainfall 2021–2040.

Figure 27: Projected monthly rainfall 2041–2100.

Figure 28: Projected monthly rainfall 2051–2100.

Figure 29: Projected monthly rainfall 2061–2100.

Figure 30: Projected monthly rainfall 2071–2100.

Figure 31: Projected monthly rainfall 2081–2100.

Figure 32: Projected monthly rainfall 2091–2100.
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MOUNT BENSON

Aridity

Figure 1: Observed mean annual Aridity Index from 1997–2017. Aridity Index is a value that characterises the ratio between the mean annual rainfall and mean annual evaporation. Low (high) values indicate drier (wetter) conditions.

Figure 2: Observed change in mean annual Aridity Index from 1997–2017 minus 1961–1990. The change shows the difference in aridity between the current and historical periods. Negative (positive) values indicate a trend towards drier (wetter) conditions.

Figure 3: Projected mean annual Aridity Index for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Decreasing (increasing) values indicate a trend towards drier (wetter) conditions.

Figure 4: Time series of annual Aridity Index. Points are the annual means for each grid cell in the region, for each of the 6 ensemble members. Aridity Index values $>2$ all indicate very wet conditions. There is no meaningful difference past this value, so higher values were not presented. Horizontal grey bars represent the mean annual Aridity Index from selected regions across Australia — these provide an example of conditions the region may transition towards in the future. Coloured bars represent the projected global temperature increase expected in the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than time (for example, if the rate of warming rapidly increases, information can be still extracted from these figures by using the coloured boxes instead of the time-axis).

Figure 5: Violin plots of monthly Aridity Index for 20-year time periods from 2001 to 2100. Each violin represents the probability distribution for each of the 6 ensemble members, for each growing year within the time period. The current period (2001–2010) is shadowed underneath the future time periods to highlight any differences expected into the future. Dots represent the mean monthly Aridity Index for each violin. If the violin shifts lower (higher) this indicates a change towards drier (wetter) conditions.

Figure 6: Seasonal Aridity Index (Winter, Spring, Summer, Autumn), presented as a probability distribution for each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of seasonal aridity for contrasting regions during 1997–2017. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates an increase (decrease) in seasonal conditions. Aridity Index values $>2$ all indicate very wet conditions.

Figure 7: Mean annual Aridity Index accumulated from start of the growing season (July) to date of harvest, presented as a probability distribution for each 20-year period. Date of harvest refers to the date at which Growing Degree Days (for each example phenological threshold: 1000, 1500, 2000, 2500) chosen to reflect development of different grape styles and varieties, were reached. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates drier (wetter) conditions. A missing time period indicates that the specific phenological threshold was not reached within the growing season (July–June).
Figure 1: Observed mean Excess Heat Factor (EHF) during heatwaves (as per Nairn and Fawcett (2013)), across all growing years from 1997–2017. EHF is an index that characterises heatwaves; high values indicate more intense heatwaves. The mean EHF is the mean value from all heatwaves that occurred from 1997–2017.

Figure 2: Change in mean EHF during heatwaves between the current (1997–2017) and historical (1961–1990) periods. Positive (negative) values indicate a trend towards more (less) intense heatwaves.

Figure 3: Projected mean EHF during heatwaves for 20-year time periods from 2001 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards more (less) intense heatwaves.

Figure 4: Projected mean number of extreme heat days.

Figure 5: Projected number of days with severe risk to humans working outside.

Figure 6: Violins plots of high temperatures (°C) per growing year for 20-year time periods from 2001 to 2100. Colours indicate extreme threshold values (90th, 95th and 99th percentile) of temperature during each growing year. The 99th percentile value reflects the 4th hottest day each growing year; the 95th percentile is the 18th hottest day each growing year; and the 90th percentile is the 36th hottest day each growing year. Generally increasing values reflect a warming climate.

Figure 7: Distribution of daily minimum and maximum temperature during a heatwave.

Figure 8: Distribution of date of heatwave days.

Figure 4: Time series of the number of days per growing year with temperatures greater than 30°C, 35°C and 40°C. Arrows indicate the number of days each threshold is exceeded per growing year. Values are averaged across all grid cells and the 6 ensemble members. Colours indicate each of the extreme threshold values. Generally increasing frequencies reflect a warming climate.

Figure 5: Time series of the number of days per growing year of high human heat stress. This is defined as days when daily maximum temperatures are >30°C and daily minimum humidity is <60%. These conditions cause severe risk of heat stress to humans (and potentially low productivity) to those working in exposed areas. Humans cannot work in high temperatures, high humidity environments without appropriate adaptive behaviours and equipment. Points are for each grid cell from each of the 6 ensemble members. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than time.

Figure 6: Violin plots of high temperatures (°C) per growing year for 30-year time periods from 2000 to 2300. Colours indicate extreme threshold values (90th, 95th and 99th percentile) of temperature during each growing year. The 99th percentile value reflects the 4th hottest day each growing year; the 95th percentile is the 18th hottest day each growing year; and the 90th percentile is the 36th hottest day each growing year. Generally increasing values reflect a warming climate.
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Figure 1: Observed mean number of days at risk of frost during the growing season (October to April) over the period 1997–2017. Days at risk of frost are those with a daily minimum temperature < −2°C. High (low) values indicate high (low) frost risk.

Figure 2: Change in the mean number of days at risk of frost during the growing season (October to April) between the current (1997–2017) and historical (1961–1990) periods. Days at risk of frost are those with a minimum temperature < −2°C. High (low) values indicate increased (decreased) frost risk.

Figure 3: Projected mean number of days at risk of frost during the growing season (October to April) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards higher (lower) frost risk.

Figure 4: Violin plots of daily minimum temperature (°C) for each month for 20-year periods from 2001 to 2020. Each violin represents daily data for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. E.g. the top-left most violin represents the daily minimum temperature for every January day in the period 2001–2020, for each grid cell in the region, for each of the 6 ensemble members. The current period (2001–2020) has been shadowed underneath future time periods to highlight any differences expected into the future. Dots represent the means for each violin. If the violin shifts lower (higher) this indicates a change towards colder (warmer) conditions.

Figure 5: Monthly average cumulative frost days for 20-year periods from 2001 to 2020. Values are a summary across all grid cells, for all years with each 20-year period, for each of the 6 ensemble members. This reflects how frost risk varies across the year within each 20-year period. The current period (2001–2020) has been shadowed underneath future time periods to highlight any differences expected into the future.

Figure 6: Timeseries of accumulated frost intensity, which is the cumulative total of temperatures less than −2°C over a growing season. This index characterizes exposure to cold conditions. High values indicate cold winters/springs. Points are for each grid cell, averaged across the 6 ensemble members.

Figure 7: Time series of the number of days per growing year when temperature falls below selected thresholds (< −2°C, < −6°C, < −10°C). Arrows indicate the number of days when temperature falls below thresholds for the first time in the growing year, and the last time in the growing year. Values are averaged across all grid cells and the 6 ensemble members. Fewer instances reflect a warming climate.
WRATTONBULLY

RAINFALL
Projected Mean Growing Season Rainfall

- 229 mm (1997–2017)
- 223 mm (2041–2060)
- 202 mm (2081–2100)

TEMPERATURE
Projected Mean Growing Season Temperature

- 17.5°C (1997–2017)
- 19.0°C (2041–2060)
- 20.6°C (2081–2100)

EXTREME COLD
Projected Mean Growing Season Frost Risk Days

- 5.2 days (1997–2017)
- 1.5 days (2041–2060)
- 0.4 days (2081–2100)

EXTREME HEAT
Projected Mean Excess Heat Factor

- 21.4 EHF (2041–2060)
- 24.4 EHF (2081–2100)

ARIDITY
Projected Mean Annual Aridity Index

- 0.38 (1997–2017)
- 0.31 (2041–2060)
- 0.25 (2081–2100)
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WRATTONBULLY

Heat

Figure 1: Observed mean Growing Season Temperature (Oct–Apr) across all growing years from 1997–2017.

Figure 2: Observed change in mean Growing Season Temperature between the current (1997–2017) and historical (1961–1990) periods. Growing Season Temperature has increased across the region over recent decades. Growing Season Temperature is expected to increase steadily into the future. Each grid cell is the mean of the 6 ensemble members.

Figure 3: Projected mean Growing Season Temperature for 20-year time periods from 2021 to 2100. Growing Season Temperature is expected to increase steadily into the future. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Projected Growing Season Temperature (October to April) for 20-year time periods from 2001 to 2100. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of Growing Degree Days for contrasting regions during 1997–2017. A shift to the right (left) indicates warmer (cooler) conditions.

Figure 5: Probability distribution of Growing Degree Days for 20-year time periods from 2001 to 2100. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of Growing Degree Days for contrasting regions during 1997–2017. A shift to the right (left) indicates warmer (cooler) conditions.

Figure 6: Distribution of Growing Degree Days.

Figure 7: Cumulative Growing Degree Days (GDD) across the growing year (July–June). Dashed lines show GDD values (1000, 1500, 2000, 2500) for some example phenological thresholds. Each growing year is represented by a colored line. In future time periods, heat accumulates faster, thresholds are reached earlier and maximum GDD reached is higher.

Figure 8: Distribution of date when Growing Degree Days reaches threshold.
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WRATTONBULLY

Moisture

Figure 1: Observed mean Growing Season Rainfall (Oct–Apr) across all growing years from 1997–2017.

Figure 2: Change in Growing Season Rainfall (Oct–Apr) between the current (1997–2017) and historical (1961–1990) periods. Positive values indicate a trend towards wetter conditions. Negative values indicate a trend towards drier conditions.

Figure 3: Projected mean Growing Season Rainfall for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Time series of Growing Season Rainfall (mm). Blue points are the annual values for each grid cell, for each of the 6 ensemble members. Horizontal grey bars represent the mean Growing Season Rainfall value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions (1997–2017) and future conditions in the region and help identify future analogue regions. Coloured bars represent the projected mean global temperature increase into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time.

Figure 5: As with Figure 4, but for Non-Growing Season Rainfall (mm). Horizontal grey bars represent the mean Non-Growing Season Rainfall value during 1997–2017 in selected regions across Australia.

Figure 6: Violin plots of monthly rainfall (mm) for 20-year time periods from 2001 to 2100. Each violin represents monthly totals for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. In each panel the grey violin represents the expected probability distribution of rainfall across the growing year. The current period (2001–2020) is shadowed underneath the future time periods to highlight any differences expected into the future. Dots represent the mean monthly rainfall for each violin. If the violin shifts lower (higher) this indicates a decrease (increase) in the mean monthly rainfall.

Figure 7: Seasonal rainfall (Winter, Spring, Summer, Autumn) (mm), presented as a probability distribution for each 20-year period. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of seasonal rainfall for contrasting regions during 1997–2017. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates an increase in drier (wetter) conditions.

Figure 8: Number of rainy days during harvest for each 20-year period. Harvest refers to the date when Growing Degree Days (GDD) reach example phenological thresholds (1000, 1500, 2000, 2500) which were chosen to reflect development time of different grape styles and varieties. Rainy days during harvest were defined as days with >10mm of rain from 7 days before to 7 days after the date each GDD threshold was reached. Variability can occur spatially within the region, across years, or between ensemble members. A shift in the curve to the left (right) indicates fewer (more) rainy days during harvest. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).

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Figure 1: Observed mean annual Aridity Index across all growing years from 1997–2017. Aridity Index is a value that characterises the ratio between the mean annual rainfall and mean annual evaporation. Low (high) values indicate drier (wetter) conditions.

Figure 2: Observed percentage change in mean annual Aridity Index between the current (1997–2017) and historical (1961–1990) periods. This shows the change already experienced across the region. Negative (positive) values indicate a trend towards drier (wetter) conditions.

Figure 3: Projected mean annual Aridity Index for 20-year time periods from 2021 to 2100. Decreasing (increasing) values indicate a trend towards drier (wetter) conditions.

Figure 4: Time series of annual Aridity Index. Points are the annual means for each grid cell in the region, for each of the 6 ensemble members. Aridity Index values >2 all indicate very wet conditions. There is no meaningful difference past this value, so higher values were not presented. Horizontal grey bars represent the mean annual Aridity Index from selected regions across Australia — these provide an example of conditions this region may transition towards in the future. Coloured bars represent the projected global temperature increase expected in the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than rates (for example, if the rate of warming rapidly increases, where temperature changes are experienced earlier, useful information can still be extracted from these figures by using the coloured bars instead of the time-axis).

Figure 5: Violin plots of monthly Aridity Index for 20-year time periods from 2001 to 2100. Each violin represents monthly averages for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. In each violin panel the violins indicate the expected probability distribution of Aridity Index within each 20-year period. The current period (2001–2020) is shaded underneath the future time periods to highlight any differences expected into the future. Points represent the mean monthly Aridity Index for each violin. If the violin shifts lower (higher) this indicates a change towards drier (wetter) conditions.

Figure 6: Seasonal Aridity Index (Winter, Spring, Summer, Autumn), presented as a probability distribution for each 20-year period. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates a trend towards drier (wetter) conditions. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).

Figure 7: Mean annual Aridity Index accumulated from start of the growing season (July) to date of harvest, presented as a probability distribution for each 20-year period. Date of harvest refers to the date at which Growing Degree Days reach some example phenological thresholds (1000, 1500, 2000, 2500), chosen to reflect development time of different grape styles and varieties. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates drier (wetter) conditions. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
Figure 1: Observed mean Excess Heat Factor (EHF) during heatwaves (as per Nairn and Fawcett (2013)), across all growing years from 1997–2017. EHF is an index that characterises heatwaves, high values indicate more intense heatwaves. The mean EHF is the mean value from all heatwaves that occurred from 1997–2017.

Figure 2: Change in mean EHF during heatwaves between the current (1997–2017) and historical (1961–1990) periods. Positive (negative) values indicate a trend towards more (less) intense heatwaves.

Figure 3: Projected mean EHF during heatwaves for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards more (less) intense heatwaves.

Figure 4: Time series of the number of days per growing year with temperatures greater than 30°C, 35°C, and 40°C. Areas indicate the number of days each threshold is exceeded per growing year. Values are averaged across all grid cells and the 6 ensemble members. Colours indicate each of the extreme threshold values. Generally increasing frequencies reflect a warming climate.

Figure 5: Time series of the number of days per growing year of High human heat stress. This is defined as days when daily maximum temperatures are >30°C and daily minimum humidity is >60%. These conditions pose severe risk of heat stress to humans (and potentially low productivity) to those working in exposed areas. Humans cannot work in high temperature, high humidity environments without appropriate adaptive behaviours and equipment. Points are for each grid cell from each of the 6 ensemble members. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than on time.

Figure 6: Violins plots of high temperatures (°C) per growing year for 20-year time periods from 2001 to 2100. Colours indicate extreme threshold values (90th, 95th, and 99th percentile) of temperature during each growing year. The 99th percentile value reflects the 4th hottest day each growing year; the 95th percentile is the 18th hottest day each growing year; and the 90th percentile is the 36th hottest day each growing year. Generally increasing values reflect a warming climate.

Figure 7: Distribution of daily minimum and maximum temperature during a heatwave. Likelihood of each curve indicates different 20-year periods. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the right (left) indicates higher (lower) temperature heatwaves.

Figure 8: Distribution of the date when heatwaves occur. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the right (left) indicates heatwaves occurring earlier (later).
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WRATTONBULLY
Extremes — Cold

Figure 1: Observed mean frost risk days 1997–2017. Days at risk of frost are those with a daily minimum temperature < 2°C. High (low) values indicate high (low) frost risk.

Figure 2: Change in the mean number of days at risk of frost during the growing season (October to April) between the current (1997–2017) and historical (1961–1990) periods. Days at risk of frost are days with a minimum temperature < 2°C. High (low) values indicate increased (decreased) frost risk.

Figure 3: Projected mean number of days at risk of frost during the growing season (October to April) for 20-year periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards higher (lower) frost risk.

Figure 4: Violin plots of daily minimum temperature (°C) for each month for 20-year periods from 2001 to 2100. Each violin represents daily data for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. High (low) values indicate higher (lower) temperatures.

Figure 5: Monthly average cumulative frost days for 20-year periods from 2001 to 2100. Values are a summary across all grid cells for each year within each 20-year period. This reflects how frost risk varies across the year within each 20-year period. The current period (2001–2020) has been shadowed underneath future time periods to highlight any differences expected into the future.

Figure 6: Timeseries of accumulated frost intensity, which is the cumulative total of temperatures less than 2°C over a growing season. High values indicate cold winters/springs. Points are for each grid cell, averaged across the 6 ensemble members.

Figure 7: Time-series of the number of days per growing year when temperatures fall below selected thresholds (< 2°C, < 0°C, < -2°C). Areas indicate the number of days temperatures fall below each threshold per growing year. Values are averaged across all grid cells and the 6 ensemble members. Fewer instances reflect a warming climate.
ROBE

RAINFALL
Projected Mean Growing Season Rainfall
- 223 mm (1997–2017)
- 217 mm (2041–2060)
- 197 mm (2081–2100)

TEMPERATURE
Projected Mean Growing Season Temperature
- 17.0°C (1997–2017)
- 18.2°C (2041–2060)
- 19.6°C (2081–2100)

EXTREME COLD
Projected Mean Growing Season Frost Risk Days
- 0.2 days (1997–2017)
- 0.1 days (2041–2060)
- 0.0 days (2081–2100)

EXTREME HEAT
Projected Mean Excess Heat Factor
- 18.8 EHF (2041–2060)
- 21.9 EHF (2081–2100)

ARIDITY
Projected Mean Annual Aridity Index
- 0.47 (1997–2017)
- 0.38 (2041–2060)
- 0.31 (2081–2100)
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ROBE Heat

Figure 1: Observed mean Growing Season Temperature (Oct–Apr) across all growing years from 1997–2017.

Figure 2: The change in Growing Season Temperature between the current (1997–2017) and historical (1961–1990) periods. Growing Season Temperature has increased across the region over recent decades.

Figure 3: Projected mean Growing Season Temperature (Oct–Apr) for 20-year time periods from 2021 to 2100. Growing Season Temperature is expected to increase steadily into the future. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Growing Season Temperature (GST) over time. Blue points are the values for each grid cell for each of the 6 ensemble members. Solid lines are timeseries representing grid cells for colder and warmer locations within the region based on current conditions (1997–2017). Horizontal grey bars represent the mean GST value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions elsewhere and future conditions in the region, helping to identify future analogue regions. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time (for example, if the rate of warming rapidly increases, useful information can still be extracted from these figures by using the shade boxes instead of the time-axis).

Figure 5: Probability distribution of GST for 20-year time periods from 2001 to 2100. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of GST for contrasting regions during 1997–2017. A shift to the right (left) indicates warmer (cooler) conditions.

Figure 6: Probability distribution of growing year maximum GDD for 20-year time periods from 2001 to 2100. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of growing year maximum GDD for contrasting regions during 1997–2017. A shift to the right (left) indicates warmer (cooler) conditions.

Figure 7: Cumulative Growing Degree Days (GDD) across the growing year (July–June). Dashed lines show GDD values (1000, 1500, 2000, 2500) for some example phenological thresholds. Each growing year is represented by a colored line. In future time periods, heat accumulates faster, thresholds are reached earlier and maximum GDD reached is higher.

Figure 8: Distribution of date when Growing Degree Days reaches threshold.
Figure 1: Observed mean Growing Season Rainfall (Oct–Apr) across all growing years from 1997–2017.


Figure 3: Projected mean Growing Season Rainfall (October to April) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Projected Growing Season Rainfall (October to April) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members.

Figure 5: Projected Non-Growing Season Rainfall (May to September) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members.

Figure 6: Violin plots of monthly rainfall (mm) for 20-year time periods from 2001 to 2100. Each violin represents monthly totals for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. In each panel the violin width indicates the expected probability distribution of rainfall across the growing year. The current period (2001–2020) is shadowed underneath the future time periods to highlight any differences expected into the future. Dots represent the mean monthly rainfall for each violin. If the violin shifts lower (higher) this indicates a change towards drier (wetter) conditions.

Figure 7: Sales rainfall (Winter, Spring, Summer, Autumn) (mm), presented as a probability distribution for each 20-year period. The shape of the curves is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of seasonal rainfall for contrasting regions during 1997–2017. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates an increase in drier (wetter) conditions.

Figure 8: Number of rainy days during harvest for each 20-year period. Rainy days during harvest were defined as days with >10mm of rain from 7 days before to 7 days after the date each GDD threshold was reached. Variability can occur spatially within the region, across years, or between ensemble members. A shift in the curve to the left (right) indicates fewer (more) rainy days during harvest. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
Figure 1: Observed mean annual Aridity Index across all growing years from 1997–2017. Aridity Index is a value that characterises the ratio between the mean annual rainfall and mean annual evaporation. Low (high) values indicate drier (wetter) conditions.

Figure 2: Observed percentage change in mean annual Aridity Index between the current (1997–2017) and historical (1961–1990) periods. This shows the change already experienced across the region. Negative (positive) values indicate a trend towards drier (wetter) conditions.

Figure 3: Projected mean annual Aridity Index for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Decreasing (increasing) values indicate a trend towards drier (wetter) conditions.

Figure 4: Time series of annual Aridity Index. Points are the annual means for each grid cell in the region, for each of the 6 ensemble members. Aridity Index values >2 all indicate very wet conditions. There is no meaningful difference past this value, so higher values were not presented. Horizontal grey bars represent the mean annual Aridity Index from selected regions across Australia — these provide an example of conditions the region may transition towards in the future. Coloured bars represent the projected global temperature increase expected in the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than rate (for example, if the rate of warming rapidly increases, where temperature change are experienced earlier, useful information can still be extracted from these figures by using the coloured boxes instead of the time-axis).

Figure 5: Violin plots of monthly Aridity Index for 20-year time periods from 2001 to 2100. Each violin represents monthly averages for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates an increase in dry (wetter) conditions. Aridity Index values >2 all indicate very wet conditions.

Figure 6: Distribution of seasonal Aridity Index (Winter, Spring, Summer, Autumn), presented as a probability distribution for each 20-year period. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of seasonal aridity for contrasting regimes during 1997–2017. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates an increase in dry (wetter) conditions. Aridity Index values >2 all indicate very wet conditions.

Figure 7: Mean annual Aridity Index accumulated from start of the growing season (July) to date of harvest, presented as a probability distribution for each 20-year period. Date of harvest refers to the date at which Growing Degree Days reach some example phenological thresholds (1000, 1500, 2000, 2500), chosen to reflect development times of different grape styles and varieties. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates drier (wetter) conditions. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
Australia’s Wine Future — A Climate Atlas

ROBE
Extremes — Hot

Figure 1: Observed mean excess heat factor (EHF) during heatwaves (as per Nairn and Fawcett (2013)), across all growing years from 1997–2017. EHF is an index that characterises heatwaves, high values indicate more intense heatwaves. The mean EHF is the mean value from all heatwaves that occurred from 1997–2017.

Figure 2: Observed change in mean EHF during heatwaves from 1997–2017 minus 1961–1990. Positive (negative) values indicate a trend towards more (less) intense heatwaves.

Figure 3: Projected mean EHF during heatwaves for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards more (less) intense heatwaves.

Figure 4: Observed number of days per growing year with temperatures greater than 30°C, 35°C, 40°C and 45°C. Areas indicate the number of days each threshold is exceeded per growing year. Values are averaged across all grid cells and the 6 ensemble members. Colours indicate each of the extreme threshold values. Generally increasing frequencies reflect a warming climate.

Figure 5: Observed number of days per growing year of High human heat stress. This is defined as days when daily maximum temperatures are >30°C and daily minimum humidity is >60%. These conditions cause severe stress to humans (and potentially low productivity) to those working in exposed areas. Humans cannot work in high temperatures, high humidity environments without appropriate adaptive behaviours and equipment. Points are for each grid cell from each of the 6 ensemble members. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than time.

Figure 6: Time series of the number of days per growing year with temperatures greater than 30°C, 35°C, 40°C and 45°C. Areas indicate the number of days each threshold is exceeded per growing year. Values are averaged across all grid cells and the 6 ensemble members. Colours indicate each of the extreme threshold values. Generally increasing frequencies reflect a warming climate.

Figure 7: Probability distribution of daily maximum temperatures and minimum overnight temperatures during heatwaves. Colour of each curve indicates different 20-year periods. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the right (left) indicates higher (lower) temperature heatwaves.

Figure 8: Probability distribution of the date when heatwaves occur. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the right (left) indicates heatwaves occurring earlier (later).

Figure 1: Observed mean excess heat factor (EHF) during heatwaves (as per Nairn and Fawcett (2013)), across all growing years from 1997–2017. EHF is an index that characterises heatwaves, high values indicate more intense heatwaves. The mean EHF is the mean value from all heatwaves that occurred from 1997–2017.

Figure 2: Change in mean EHF during heatwaves between the current (1997–2017) and historical (1961–1990) periods. Positive (negative) values indicate a trend towards more (less) intense heatwaves.

Figure 3: Projected mean EHF during heatwaves for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards more (less) intense heatwaves.

Figure 4: Time series of the number of days per growing year with temperatures greater than 30°C, 35°C, 40°C and 45°C. Areas indicate the number of days each threshold is exceeded per growing year. Values are averaged across all grid cells and the 6 ensemble members. Colours indicate each of the extreme threshold values. Generally increasing frequencies reflect a warming climate.

Figure 5: Time series of the number of days per growing year of High human heat stress. This is defined as days when daily maximum temperatures are >30°C and daily minimum humidity is >60%. These conditions cause severe stress to humans (and potentially low productivity) to those working in exposed areas. Humans cannot work in high temperatures, high humidity environments without appropriate adaptive behaviours and equipment. Points are for each grid cell from each of the 6 ensemble members. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than time.

Figure 6: Velocity plots of high temperatures (°C) per growing year for 20-year time periods from 2001 to 2100. Colours indicate extreme threshold values (90th, 95th and 99th percentile) of temperature during each growing year. The 99th percentile value reflects the 4th hottest day each growing year, the 95th percentile is the 18th hottest day each growing year, and the 90th percentile is the 36th hottest day each growing year. Generally increasing values reflect a warming climate.
Australia’s Wine Future — A Climate Atlas

ROBE
Extremes — Cold

Figure 1: Observed mean number of days at risk of frost during the growing season (October to April) over the period 1997–2017. Days at risk of frost are those with a daily minimum temperature <2°C. High (low) values indicate high (low) frost risk.

Figure 2: Observed change in mean frost risk days between the current (1997–2017) and historical (1961–1990) periods. Days at risk of frost are days with a minimum temperature <2°C. High (low) values indicate increased (decreased) frost risk.

Figure 3: Projected mean number of days at risk of frost during the growing season (October to April) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards higher (lower) frost risk.

Figure 4: Violin plots of daily minimum temperature (°C) for each month for 20-year periods from 2001 to 2100. Each violin represents daily data for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period, e.g. the top-left most violin represents the daily minimum temperature for every January day in the period 2001–2020, for each grid cell in the region, for each of the 6 ensemble members. The current period (2001–2020) has been shadowed underneath future time periods to highlight any differences expected into the future. Dots represent the means for each violin. If the violin shifts lower (higher) this indicates a change towards colder (warmer) conditions.

Figure 5: Projected monthly minimum temperature

Figure 5: Projected monthly frost risk days

Figure 6: Projected accumulated frost intensity

Figure 7: Projected mean number of extreme cold days

Figure 6: Timeseries of accumulated frost intensity, which is the cumulative total of temperatures less than 2°C over a growing season. This index characterizes exposure to cold conditions. High values indicate colder winters/springs. Points are for each grid cell, averaged across the 6 ensemble members.

Figure 7: Timeseries of the number of days per growing year when temperature falls below selected thresholds (<2°C, <0°C, <−2°C). Areas indicate the number of days temperatures fall below each threshold per growing year. Values are averaged across all grid cells and the 6 ensemble members. Fewer instances reflect a warming climate.
COONAWARRA

Heat

Figure 1: Observed mean Growing Season Temperature

Figure 2: Observed mean Growing Season Temperature

Figure 3: Projected mean Growing Season Temperature

Figure 4: Projected Growing Season Temperature (October to April)

Figure 5: Probability distribution of Growing Degree Days for 20-year time periods from 2001 to 2100. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of Growing Degree Days for contrasting regions during 1997-2017. A shift to the right (left) indicates warmer (cooler) conditions.

Figure 6: Distribution of Growing Degree Days

Figure 7: Cumulative Growing Degree Days (GDD) across the growing year (July–June). Dashed lines show GDD values (1000, 1500, 2000, 2500) for some example phenological thresholds. Each growing year is represented by a colored line. In future time periods, heat accumulates faster, thresholds are reached earlier and maximum GDD reached is higher.

Figure 8: Distribution of date when Growing Degree Days reaches threshold

Growing Year (July–June)

Growing Year Max GDD

Cumulative GDD

Period

COONAWARRA
Figure 1: Observed mean Growing Season Rainfall (Oct–Apr) across all growing years from 1997–2017.

Figure 2: Observed change in mean Growing Season Rainfall between the current (1997–2017) and historical (1961–1990) periods. Negative values indicate a trend towards drier conditions. Positive values indicate a trend towards wetter conditions.

Figure 3: Projected mean Growing Season Rainfall for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Time series of Growing Season Rainfall (mm). Blue points are the annual values for each grid cell, for each of the 6 ensemble members. Horizontal grey bars represent the mean Growing Season Rainfall value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions (1997–2017) elsewhere and future conditions in this region and help identify future analogue regions. Coloured bars represent the projected mean global temperature increase into the future (following the RCP 4.5 scenario). These can be used to make decisions based on projected temperature change rather than time.

Figure 5: As with Figure 4, but for Non-Growing Season Rainfall (mm). Horizontal grey bars represent the mean Non-Growing Season Rainfall value during 1997–2017 in selected regions across Australia.

Figure 6: Violin plots of monthly rainfall (mm) for 20-year time periods from 2001 to 2100. Each violin represents monthly totals for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. In each panel the monthly violins indicate the expected probability distribution of rainfall across the growing year. The current period (2001–2020) is shadowed underneath the future time periods to highlight any differences expected into the future. Dots represent the mean monthly rainfall for each violin. If the violin shifts lower (higher) this indicates a change towards drier (wetter) conditions.

Figure 7: Distribution of seasonal rainfall

Figure 8: Distribution of number of rainy days during harvest

COONAWARRA

Moisture

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Figure 1: Observed mean annual Aridity Index across all growing years from 1957–2017. Aridity Index is a value that characterises the ratio between the mean annual rainfall and mean annual evaporation. Low (high) values indicate drier (wetter) conditions.

Figure 2: Observed percentage change in mean annual Aridity Index between the current (1997–2017) and historical (1961–1990) periods. This shows the change already experienced across the region. Negative (positive) values indicate a trend towards drier (wetter) conditions.

Figure 3: Projected mean annual Aridity Index for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Decreasing (increasing) values indicate a trend towards drier (wetter) conditions.

Figure 4: Time series of annual Aridity Index. Points are the annual means for each grid cell in the region, for each of the 6 ensemble members. Aridity Index values > 2 all indicate very wet conditions. There is no meaningful difference past this value, so higher values were not presented. Horizontal grey bars represent the mean annual Aridity Index from selected regions across Australia — these provide an example of conditions the region may transition to in the future. Coloured bars represent the projected global temperature increase expected in the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than time (for example, if the rate of warming rapidly increases, where temperature changes are experienced earlier, useful information can still be extracted from these figures by using the coloured bars instead of the time-axis).

Figure 5: Violin plots of monthly Aridity Index for 20-year time periods from 2001 to 2100. Each violin represents monthly means for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. The current period (2001–2020) is shadowed underneath the future time periods to highlight any differences expected into the future. Dots represent the mean monthly Aridity Index for each violin. If the violins shift lower (higher) this indicates a change towards drier (wetter) conditions.

Figure 6: Distribution of seasonal Aridity Index (Winter, Spring, Summer, Autumn), presented as a probability distribution for each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates drier (wetter) conditions. The shape of the curves is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution for seasonal aridity for contrasting regions during 1997–2017. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates drier (wetter) conditions. Aridity Index values > 2 all indicate very wet conditions.

Figure 7: Mean annual Aridity Index accumulated from start of the growing season (July) to date of harvest, presented as a probability distribution for each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates drier (wetter) conditions. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
Figure 1: Observed mean excess heat factor (EHF) during heatwaves (as per Nairn and Fawcett (2013)), across all growing years from 1997–2017. EHF is an index that characterises heatwaves; high values indicate more intense heatwaves. The mean EHF is the mean value from all heatwaves that occurred from 1997–2017.

Figure 2: Change in mean EHF during heatwaves between the current (1997–2017) and historical (1961–1990) periods. Positive (negative) values indicate a trend towards more (less) intense heatwaves.

Figure 3: Projected mean EHF during heatwaves for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards more (less) intense heatwaves.

Figure 4: Time series of the number of days per growing year with temperatures greater than 30°C, 35°C, 40°C and 45°C. Areas indicate the number of days each threshold is exceeded per growing year. Values are averaged across all grid cells and the 6 ensemble members. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than time.

Figure 5: Time series of the number of days per growing year of high human heat stress. This is defined as days when daily maximum temperatures are >30°C and daily minimum humidity is >60%. These conditions cause severe risk of heat stress to humans (and potentially low productivity) to those working in exposed areas. Humans cannot work in high temperatures, high humidity environments without appropriate adaptive behaviours and equipment. Points are for each grid cell from each of the 6 ensemble members. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than time.

Figure 6: Violins plots of high temperatures (°C) per growing year for 20-year time periods from 2001 to 2100. Colours indicate extreme threshold values (90th, 95th and 99th percentile) of temperature during each growing year. The 99th percentile value reflects the 4th hottest day each growing year; the 95th percentile is the 18th hottest day each growing year; and the 90th percentile is the 36th hottest day each growing year. Generally increasing values reflect a warming climate.
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**COONAWARRA Extremes — Cold**

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**Figure 1:** Observed mean number of days at risk of frost during the growing season (October to April) over the period 1997–2017. Days at risk of frost are those with a daily minimum temperature <2°C. High (low) values indicate high (low) frost risk.

**Figure 2:** Change in the mean number of days at risk of frost during the growing season (October to April) between the current (1997–2017) and historical (1961–1990) periods. Days at risk of frost are days with a minimum temperature <2°C. High (low) values indicate increased (decreased) frost risk.

**Figure 3:** Projected mean number of days at risk of frost during the growing season (October to April) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards higher (lower) frost risk.

**Figure 4:** Violin plots of daily minimum temperature (°C) for each month for 20-year periods from 2001 to 2100. Each violin represents daily data for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. For example, the top-leftmost violin represents the daily minimum temperature for every January day in the period 2001–2020, for each grid cell in the region, for each of the 6 ensemble members. The current period (2001-2020) has been shadowed underneath future time periods to highlight any differences expected into the future. Dots represent the means for each violin. If the violin shifts lower (higher) this indicates a change towards colder (warmer) conditions.

**Figure 5:** Monthly average cumulative frost days for 20-year periods from 2001 to 2100. Values are a summary across all grid cells, for all years with each 20-year period, for each of the 6 ensemble members. This reflects how frost risk varies across the year within each 20-year period. The current period (2001–2020) has been shadowed underneath future time periods to highlight any differences expected into the future.

**Figure 6:** Timeseries of accumulated frost intensity, which is the cumulative total of temperatures less than 2°C over a growing season. This indexcharacterizes exposure to cold conditions. High values indicate cold winters/springs. Points are for each grid cell, averaged across the 6 ensemble members.

**Figure 7:** Time series of the number of days per growing year when temperature falls below selected thresholds (<2°C, <0°C, <−2°C). Areas indicate the number of days temperatures fall below each threshold per growing year. Fewer instances reflect a warming climate.
Australia’s Wine Future — A Climate Atlas

MOUNT GAMBIER

Heat

Figure 1: Observed mean Growing Season Temperature (Oct–Apr) across all growing years from 1997–2017.

Figure 2: The change in Growing Season Temperature between the current (1997–2017) and historical (1961–1990) periods. Growing Season Temperature has increased across the region over recent decades.

Figure 3: Projected mean Growing Season Temperature (Oct–Apr) for 20-year time periods from 2021 to 2100. Growing Season Temperature is expected to increase steadily into the future. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Growing Season Temperature (GST) over time. Blue points are the values for each grid cell for each of the 6 ensemble members. Solid lines are trajectories representing grid cells for colder and warmer locations within the region based on current conditions (1997–2017). Horizontal grey bars represent the mean GST value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions elsewhere and future conditions in this region, helping to identify future analogue regions. Coloured bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time (for example, if the rate of warming rapidly increases, useful information can still be extracted from these figures by using the shade boxes instead of the time-series).

Figure 5: Probability distribution of GST for 20-year time periods from 2001 to 2100. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of GST for contrasting regions during 1997–2017. A shift to the right (left) indicates warmer (cooler) conditions.

Figure 6: Probability distribution of growing year maximum GDD for 20-year time periods from 2001 to 2100. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of growing year maximum GDD for contrasting regions during 1997–2017. A shift to the right (left) indicates warmer (cooler) conditions.

Figure 7: Cumulative Growing Degree Days (GDD) across the growing year (July–June). Dashed lines show GDD values (1000, 1500, 2000, 2500) for some example phenological thresholds. Each growing year is represented by a colored line. In future time periods, heat accumulates faster, thresholds are reached earlier and maximum GDD reached is higher.

Figure 8: Distribution of date when Growing Degree Days reaches threshold.
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MOUNT GAMBIER

Moisture

Figure 1: Observed mean Growing Season Rainfall (Oct–Apr) across all growing years from 1997–2017.

Figure 2: Change in Growing Season Rainfall (Oct–Apr) between the current (1997–2017) and historical (1961–1990) periods. Negative values indicate a trend towards drier conditions. Positive values indicate a trend towards wetter conditions.

Figure 3: Projected mean Growing Season Rainfall (Oct–Apr) for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members.

Figure 4: Time series of Growing Season Rainfall (mm). Blue points are the annual values for each grid cell, for each of the 6 ensemble members. Horizontal grey bars represent the mean Growing Season Rainfall value during 1997–2017 in selected regions across Australia. These provide a comparison between current conditions (1997–2017) elsewhere and future conditions in this region and help identify future analogue regions. Coloured bars represent the projected mean global temperature increase into the future (following the RCP 8.5 scenario). These can be used to make decisions based on projected temperature change rather than time.

Figure 5: As with Figure 4, but for Non-Growing Season Rainfall (mm). Horizontal grey bars represent the mean Non-Growing Season Rainfall value during 1997–2017 in selected regions across Australia.

Figure 6: Violin plots of monthly rainfall (mm) for 20-year time periods from 2001 to 2100. Each violin represents monthly totals for each grid cell, for each of the 6 ensemble members, and for each growing year within the time period. In each panel the monthly violins indicate the expected probability distribution of rainfall across the growing year. The current period (2001–2020) is shadowed underneath the future time periods to highlight any differences expected into the future. Dots represent the mean monthly rainfall for each violin. If the violin shifts lower (higher) this indicates a change towards drier (wetter) conditions.

Figure 7: Distribution of seasonal rainfall

Figure 8: Number of rainy days during harvest. Harvest refers to the date when Growing Degree Days (GDD) reach a phenological threshold (1000, 1500, 2000, 2500) which were chosen to reflect development time of different grape styles and varieties. Rainy days during harvest were defined as days with >10mm of rain from 7 days before to 7 days after the date each GDD threshold was reached. Variability can occur spatially within the region, across years, or between ensemble members. A shift in the curve to the left (right) indicates fewer (more) rainy days during harvest. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).

Figure 9: Distribution of number of rainy days during harvest

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MOUNT GAMBIER

Aridity

Figure 1: Observed mean annual Aridity Index across all growing years from 1997–2017. Aridity Index is a value that characterises the ratio between the mean annual rainfall and mean annual evaporation. Lower values indicate drier conditions.

Figure 2: Observed change in mean annual Aridity Index between the current (1997–2017) and historical (1961–1990) periods. This shows the change already experienced across the region. Negative values indicate a trend towards drier conditions.

Figure 3: Projected mean annual Aridity Index for 20-year time periods from 2021 to 2100. Each grid cell is the mean of the 6 ensemble members. Lower values indicate a trend towards drier conditions.

Figure 4: Time series of annual Aridity Index. Points are the annual means for each grid cell, for each of the 6 ensemble members. Aridity Index values ≤2 all indicate very wet conditions. There is no meaningful difference past this value, so higher values were not presented. Horizontal grey bars represent the mean annual Aridity Index from selected regions across Australia — these provide an example of conditions the region may transition towards in the future. Coloured bars represent the expected global temperature change (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than time. Aridity Index values >2 all indicate very wet conditions.

Figure 5: Seasonal Aridity Index (Winter, Spring, Summer, Autumn), presented as a probability distribution for each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. Grey shapes represent the probability distribution of seasonal Aridity Index for contrasting regions during 1997–2017. Differences in the shape of curves between the current and future periods indicate a change in the typical conditions. A shift to the left (right) indicates an increase in drier (wetter) conditions. Aridity Index values >2 all indicate very wet conditions.

Figure 6: Mean annual Aridity Index accumulated from start of the growing season (July) to date of harvest, presented as a probability distribution for each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the left (right) indicates drier (wetter) conditions. A missing time period indicates that the specific phenological threshold was not reached within the growing year (July–June).
Figure 1: Observed mean excess heat factor (EHF) during heatwaves (as per Nairn and Fawcett (2013)), across all growing years from 1997–2017. EHF is an index that characterises heatwaves, high values indicate more intense heatwaves. The mean EHF is the mean value from all heatwaves that occurred from 1997–2017.

Figure 2: Change in mean EHF during heatwaves between the current (1997–2017) and historical (1961–1990) periods. Positive (negative) values indicate a trend towards more (less) intense heatwaves.

Figure 3: Projected mean EHF during heatwaves for 20-year time periods from 2021 to 2100. Colors indicate the mean of the 6 ensemble members. Increasing (decreasing) values indicate a trend towards more (less) intense heatwaves.

Figure 4: Time series of the number of days per growing year with temperatures greater than 30°C, 35°C, 40°C and 45°C. Areas indicate the number of days each threshold is exceeded per growing year. Values are averaged across all grid cells and the 6 ensemble members. Colors indicate each of the extreme threshold values. Generally increasing frequencies reflect a warming climate.

Figure 5: Time series of the number of days per growing year of high human heat stress. This is defined as days when daily maximum temperatures are >30°C and daily minimum humidity is >60%. These conditions cause severe risk of heat stress to humans (and potentially low productivity) to those working in exposed areas. Humans cannot work in high temperatures, high humidity environments without appropriate adaptive behaviours and equipment. Points are for each grid cell from each of the 6 ensemble members. Colored bars represent the projected global temperature increase expected into the future (following the RCP 8.5 scenario) which can be used to make decisions based on projected temperature change rather than time.

Figure 6: Violins plots of high temperatures (°C) per growing year for 20-year time periods from 2001 to 2100. Colors indicate extreme threshold values (90th, 95th and 99th percentile) of temperature during each growing year. The 99th percentile value reflects the 4th hottest day each growing year; the 95th percentile is the 18th hottest day each growing year; and the 90th percentile is the 36th hottest day each growing year. Generally increasing values reflect a warming climate.

Figure 7: Distribution of daily minimum and maximum temperature during a heatwave. Color of each curve indicates different 20-year periods. The shape of the curve is driven by the level of variability experienced within each 20-year period. Variability can occur spatially within the region, across years, or between ensemble members. A shift to the right (left) indicates higher (lower) temperature heatwaves.
Australia’s Wine Future — A Climate Atlas

MOUNT GAMBIER
Extremes — Cold

Figure 1: Observed mean frost risk days

Figure 2: Observed change in mean frost risk days

Figure 3: Projected mean frost risk days

Figure 4: Projected monthly minimum temperature

Figure 5: Projected monthly frost risk days

Figure 6: Projected accumulated frost intensity

Figure 7: Projected mean number of extreme cold days

Figure 8: Time-series of accumulated frost intensity, which is the cumulative total of temperatures less than -2°C over a growing season. This index characterises exposure to cold conditions. High values indicate cold winters/springs. Points are for each grid cell, averaged across the 6 ensemble members.

Figure 9: Time-series of the number of days per growing year when temperature falls below selected thresholds (-2°C, -5°C, -10°C). Areas indicate the number of days temperatures fall below each threshold per growing year. Values are averaged across all grid cells and the 6 ensemble members. Fewer instances reflect a warming climate.