6. Victoria under the Paris Agreement targets and beyond 2100

This chapter covers projections outside the framework of model projections under RCP greenhouse gas emissions scenarios to 2100, namely change under the Paris Agreement target of 2°C global warming since pre-industrial times and change beyond 2100 (to 2300 and even 3000). Victoria is projected to experience significant change even under the ambitious Paris Agreement target, and how we would reach the target will also strongly affect the future of Victoria. Furthermore, the climate is expected to change long after 2100 especially under the higher emissions scenarios.

6.1 Paris Agreement targets – the ambitious 'best-case' scenario

The emissions pathway we follow is the largest determinant of change to many variables beyond the next few decades; it makes a larger difference to the temperature, sea level and other variables than the uncertainty in climate response or natural variability. The focus of previous sections has been on emissions scenarios of medium emissions (RCP4.5) and ongoing high emissions (RCP8.5) as plausible scenarios of change to assess impacts and make adaptation plans. However, to make balanced decisions, we need to account for all possibilities of future change, including the best and worst cases.

The Paris Agreement (2015) sets an ambition to keep global mean temperature well below 2°C (relative to pre-industrial times) with the aim to keep it to 1.5°C. This ambitious target is a convenient 'best case' in terms of emissions. It differs from the RCP2.6 both in terms of concept and implications. RCP2.6 is a low emissions scenario, for which we calculate a range of plausible climate responses given our current understanding, including a range of global warming amounts. The Paris Agreement targets are specific levels of global warming, and there is uncertainty in the level of emissions needed to get there. Analyses show that very strong mitigation down to zero emissions, as well as greenhouse gas removal, are needed to achieve the target but the exact carbon budget is not clear due to uncertainties in things such as climate sensitivity. Various lines of evidence suggest that the world could reach the 1.5°C Paris Agreement target between 2030 and 2052 if warming continues at the current rate (IPCC 2018).

Using the range of CMIP5 models as a guide, there is a greater than 60% chance of meeting the Paris Agreement target of global warming of 2°C since pre-industrial times under RCP2.6, but a greater than 30% chance of exceeding it. Again, using CMIP5 models as a guide, under the moderate RCP4.5, 80% of models exceed 2°C global warming by 2100, and for RCP8.5 all models exceed 2°C global warming by 2060. The projected range of change for southern Victorian under RCP2.6 from the national climate projections (CSIRO and Bureau of Meteorology 2015) is 0.5 to 1.4°C under RCP2.6 by 2080–2099 relative to 1986–2005. Adding the warming since 1910 of around 0.5°C warming, plus an estimated 0.2°C prior to this estimated from models, means a total change of around 1.2 to 2.1°C since pre-industrial times (further detail on the equivalent on the target below).

The following discussion uses the Paris Agreement target of 2°C specifically, rather than RCP2.6, since the Paris Agreement has political relevance and provides a simple climate target rather than a spread of results.

6.1.1 Physical changes in Victoria at 2°C global warming

Assuming the world meets the Paris Agreement targets and global warming plateaus at 2°C since pre-industrial with no overshoot, what can Victoria expect? There are a number of different methods to estimate the equivalent warming of the average annual temperature.

First, we can estimate the warming of the average temperature in Victoria compared to the globe in the period 1910–2018 (using ACORN-SATv2 for Victoria, HadCRUT4 for the globe). Over this period, for every 1°C rise in global warming, Victoria warmed by 1.2 to 1.3°C (depending on specific methods used to quantify warming as a linear trend, non-linear smoother or the difference between periods). This suggests that at 2°C global warming, Victoria could expect to be 2.4 to 2.6°C warmer than pre-industrial.

Second we examine the targeted modelling from the BRACE project from the US National Centre for Atmospheric Research (Sanderson et al. 2018), where a set of 15 model simulations were run so that global warming plateaus at around 2°C, and we can then compare regional changes and patterns. Figure 56 shows when global warming plateaus at around 2°C, in BRACE, Victorian average annual temperature is a little above 2°C, relative to the 1920–1940 baseline (the historical runs from 1850 indicated change from 1850–1920 of less than 0.1°C). There is regional variation, however (Figure 57) and the changes range from 2.2 to 2.5°C, with a mean of 2.3°C.

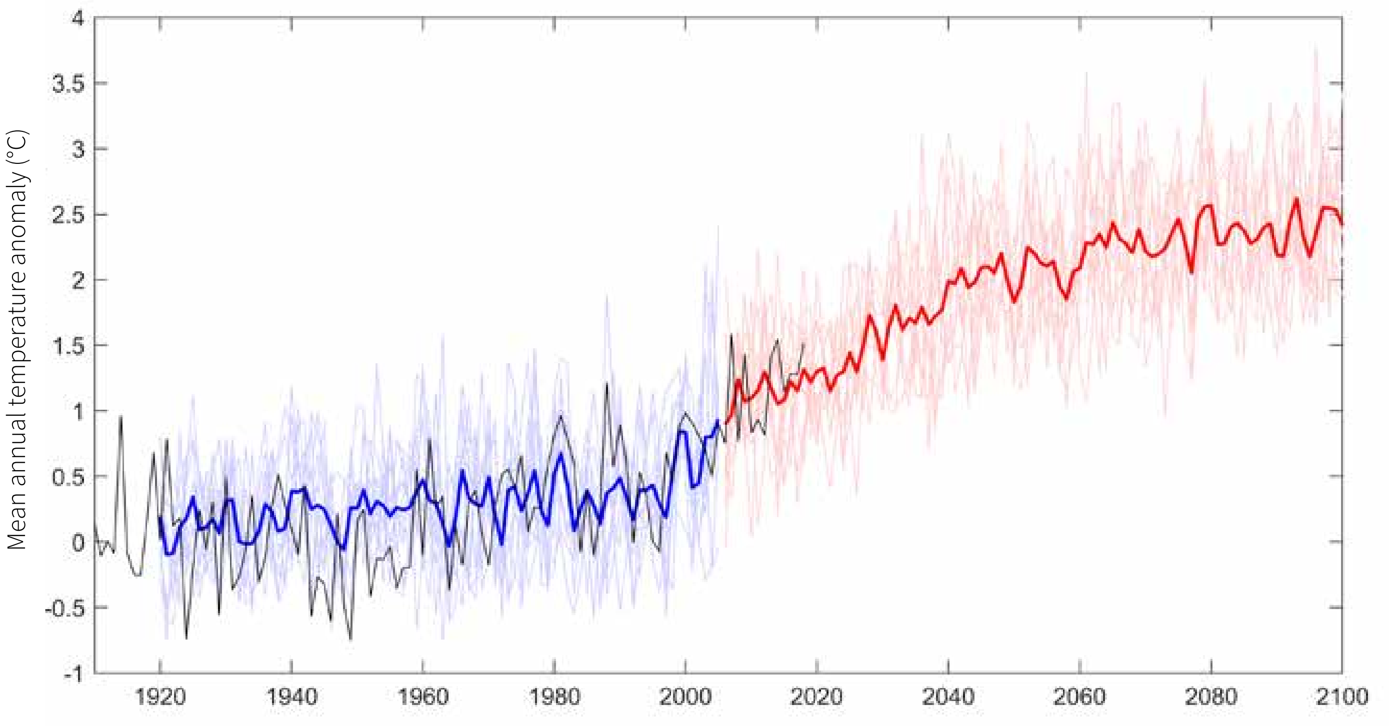

Figure 56. Victorian average annual temperature anomaly (relative to 1920-1940) in 11 simulations under the BRACE program where global mean temperature plateaus at +2°C from the pre-industrial era (blue is historical, red is projected, dark lines are the average off 11 simulations) and ACORN-SAT-v2 (black)

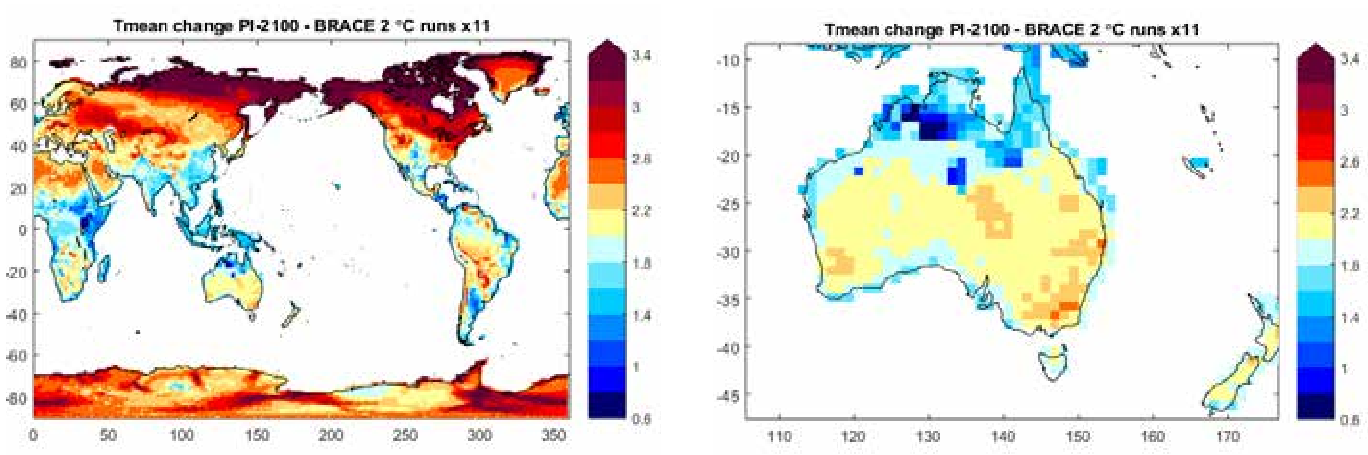

Figure 57. Change in mean annual temperature from pre-industrial era to the end of the 21st century when global mean temperature plateaus at 2°C for land areas in the mean of 11 BRACE simulations (right panel shows detail over Australia). Scale is centred on 2°C to show which areas are projected to warm more than the global average, and which areas less. Note the broad spatial patterns of change are consistent between models (e.g. the Arctic warms by much more than the global average), but some regional details are specific to the BRACE model (e.g. northern Australia warming less than the global average due to increased rainfall imparting a cooling effect).

Lastly we sample a wider set of 16 GCMs[8], examining the years when each model's decadal average global temperature was 2°C warmer than pre-industrial, using the models, time slices and methods of King et al. (2017). This approach gives a lower estimate of projected change for Victoria at 1.5°C (with values from 1.2 to 2.0°C). This lower estimate from sampling a range of models using different methods is notable and worth further investigation. The higher projection from VCP19 runs compared to the host GCMs suggests that this value might be a little higher once downscaled in some cases.

Therefore, different methods give different estimates, some showing a warming of a little lower than the global average and some a little higher. However, all these values from 1.5 to 2.3°C can be considered to be close to the global average, as they are far lower than values in the hotspots of warming such as the Arctic (with warming two to three times the global average), or areas of minimal warming such as the Southern Ocean (changes of half global warming or less). The results are consistent with the pattern scaling methods used to generate a change per degree of global warming in the Australian climate projections from 2007 (CSIRO and Bureau of Meteorology 2007) and in the IPCC report on 1.5°C (IPCC 2018), which found a similar range.

This warming results in increases in heat extremes that are greater than the mean change and lead to new temperature records under the 2°C target (Lewis et al. 2017). Sampling of GCM models at the relevant global warming target suggests there is a 70–84% increase in the odds of a summer like the 2012–13 'Angry Summer' and a 67–81% increase in the odds of occurrence of the heat conditions during the 2006 drought (King et al. 2017).

Changes to rainfall and rainfall extremes are less clear than for temperature changes at +2°C global warming. Sampling CMIP5 GCMs using the methods above indicate that Victorian rainfall at 2°C global warming since pre-industrial times compared to the recent baseline of 1986–2005 are similar to RCP2.6 projections: annual rainfall -11 to +2%, and winter rainfall -16 to +8%. If the globe meets the even more ambitious target of 1.5°C global warming since pre-industrial, climate changes and associated impacts will be significantly less in several key respects (IPCC 2018), including heatwaves and other temperature extremes.

8 ACCESS-1.3, BCC-CSM1.1, CanESM2, CCSM4, CESM1-CAM5, CNRM-CM5, CSIRO-Mk3.6, GFDL-CM3, GISS-E2-H, GISS-E2-R, HadGEM2-ES, IPSL-CM5A-LR, IPSL-CM5A-MR, MIROC-ESM, MRI-CGCM3, NorESM1-M

6.2 How we get there matters

If the world meets the Paris Agreement, the exact means by which we get there matters. The mix of methods to keep the global temperature to below 2°C from pre-industrial times makes a big difference to not only the climate, but also the socio-economic world that we will inhabit. Emissions mitigation to zero emissions by 2100 is essential to meet the Paris Agreement target, so any consideration of meeting the target assumes this transition with all that that entails (a transition to a net zero carbon economy). Also, all plausible pathways to meet the target use some mix of carbon dioxide removal (BCR), bioenergy with carbon capture and storage (BECCS) and removals in the Agriculture, Forestry and Other Land Use (AFOLU) sector (IPCC 2018). While the global temperature may end up the same, the regional climate change may be different depending on the specific mix of actions taken, and of course the effect of the actions will strongly affect the natural world, human society and economy in different ways. The effect of the mix of action is crucial to consider along with the physical risk of changing climate.

As well as carbon dioxide removal, there is a possibility that some type of climate engineering will be attempted, through techniques such as solar radiation management (e.g. injecting aerosol particles into the stratosphere). The effect of these measures is still very uncertain and is not included in any set of analyses – meaning there is more need to consider climate engineering using a scenario approach, rather than quantitative projections (Knutti 2018). Also, there is the possibility of 'overshoot' and return to 2°C, which results in higher impacts and associated challenges compared to pathways with no or limited overshoot (IPCC 2018).

6.3 Worst-case scenarios

Climate model simulations may not present the worst-case scenarios for climate change. Even early climate projections have been tracking quite closely to observations for average annual temperature (Grose et al. 2017b); however, this may not be the case in the future as we move further away from the historical climate. Projections may not capture the full range of change in other climate variables or in extremes (e.g. higher sea-level rise than the current projected range cannot be ruled out). Also, models may not show large enough changes in response to climate drivers, or in other words they may not be sensitive enough. For example, modelled strengthening and southerly movement of the subtropical ridge of high pressure in the Victorian sector is weaker than observed, possibly due to natural variability but possibly due to weaker sensitivity of the processes, meaning that models may underestimate the associated rainfall change (Grose et al. 2015c). Also, climate projections typically do not include strong non-linear or step changes to the climate.

For these, reasons, risk-averse applications may wish to consider a 'worst-case' scenario with a storyline that includes stronger or more rapid changes in the climate than in the projections given here. Scenarios are a powerful method of communication and method to start visualising the future (Shepherd et al. 2018). This worst-case scenario can then be used in planning and response exercises, such as in a 'war-gaming' framework. For example, for the drought and operational planning scenarios for water planning, DELWP recommend a resampling of baseline climate to create hypothetical droughts more extreme than were observed but potentially possible given conditions in past years, rather than the use of climate model outputs (see DELWP Water: https://www.water.vic.gov.au/water-for-victoria).

6.4 Change beyond 2100

Climate change does not stop at 2100. We expect to see ongoing changes to the climate after 2100 and even after greenhouse gas concentrations stop rising. A sub-set of CMIP5 GCMs were run to 2300 using the extended trajectory of RCPs known as Extended Concentration Pathways (ECPs) shown in Figure 58. The higher RCPs continue on a high trajectory before plateauing (e.g. ECP12 is an extension of RCP8.5 and reaches 12 Wm^{-2} of enhanced greenhouse effect), the lower RCP2.6 shows a decrease in greenhouse forcing as greenhouse gases are removed from the atmosphere. Global changes were presented in the last IPCC assessment report (Collins et al. 2013), and we use the same models and techniques to present projected change over Victoria specifically. Victoria's temperature response follows the same relationships as for projections to 2100: temperature rise is proportional to the greenhouse gas concentration, and the range of change widens for larger changes as uncertainty in climate feedbacks leads to wider ranges of possible change (Figure 59). A single run from an example model for the year 3000 under the very high ECP12 illustrates changes long after the forcing plateaus (Figure 60). Further warming of over 2°C occurs as the climate system slowly moves towards true equilibrium under this much higher greenhouse gas world. Changes over hundreds to thousands of years in the future could be in fact larger than typical model simulations suggest. Models generally only include the faster climate feedbacks in the atmosphere, ocean and ice, whereas over longer time-scales the slower 'Earth system' feedbacks become important. These Earth system feedbacks include those linked to melting ice sheets, changes to vegetation zones and the biogeochemistry of the deep ocean and earth. A useful metric of the response of the climate system to forcings is 'climate sensitivity', which describes the change in global average near-surface (2 m) temperature to a doubling of CO_2. Equilibrium climate sensitivity based on various lines of evidence is thought to *likely* be between 1.5 and 4.5°C, and this plays out over the scale of decades to centuries (IPCC 2013b). Over longer time-scales the Earth system sensitivity could be up to twice as high. However, this sensitivity depends strongly on the initial state – for example, the shift from the ice age into the current inter-glacial saw a large temperature change partly because of the melting of large ice sheets in the northern hemisphere creating a very large ice-albedo feedback that would not be as large for future warming.

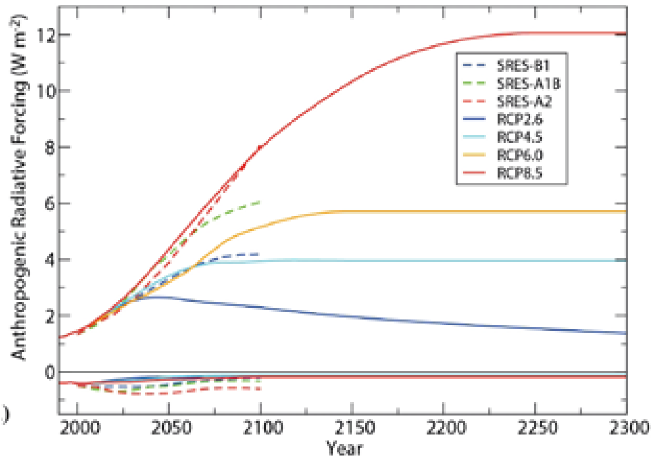

Figure 58. The anthropogenic radiative forcing under the Extended Concentration Pathways, showing greenhouse gas (positive) and anthropogenic aerosol (negative) forcing. The previous generation SRES scenarios are also shown for reference. Source: IPCC AR5 Chapter 12 (Collins et al. 2013)

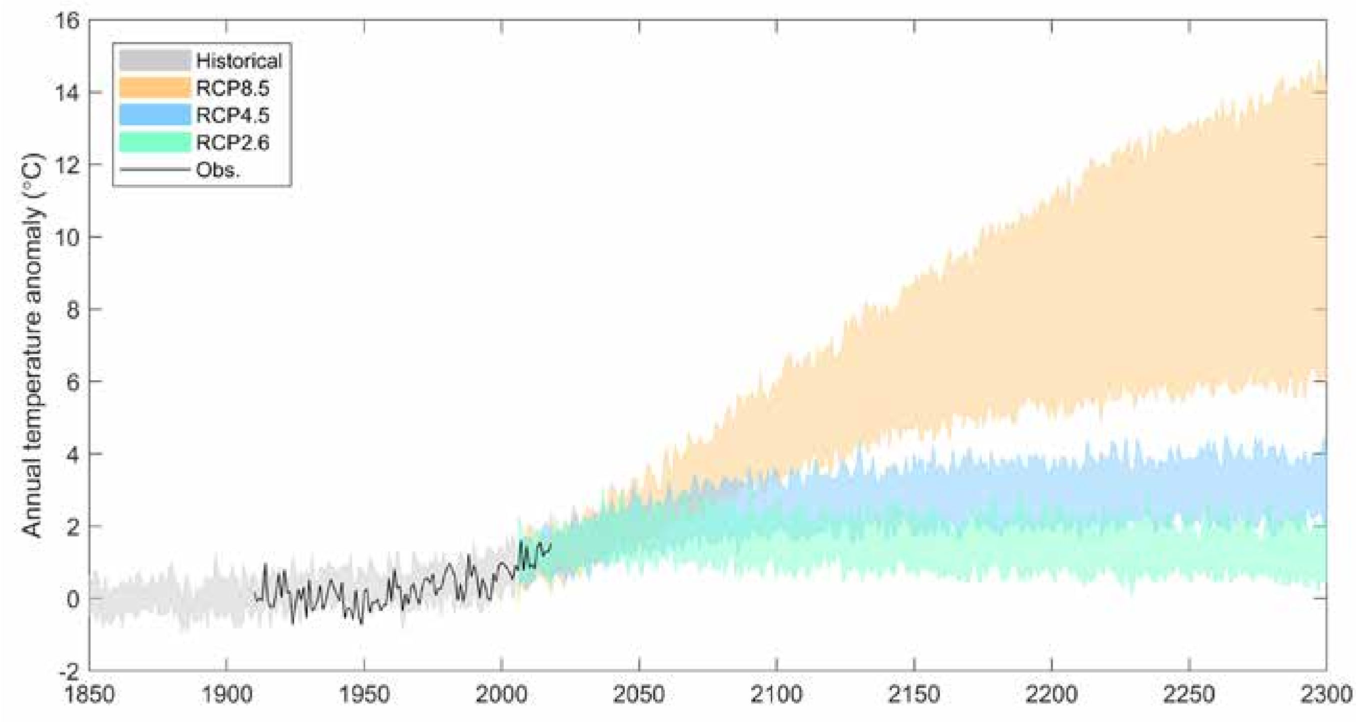

Figure 59. Victorian average annual temperature anomaly from pre-industrial (1850–1900 baseline) from CMIP5 models with data available for all ECPs (15 models)

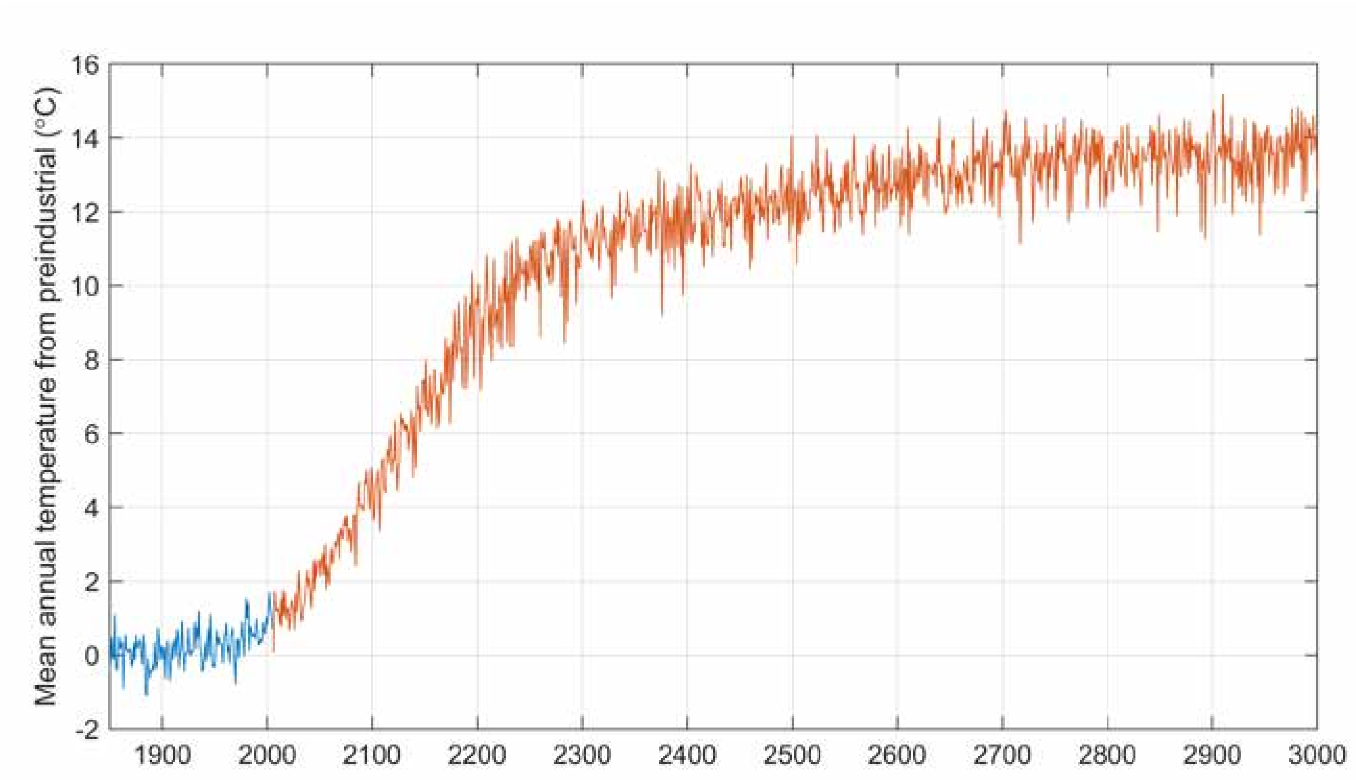

Figure 60. Victorian average annual temperature anomaly from 1850–1900 from a long simulation from a single model (EC-EARTH) from 1850 to 3000 under ECP12 (following RCP8.5 to 2100, and increasing to a radiative forcing of 12 Wm^{-2} by 2250, then remaining steady until 3000)