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Research that matters.

Out of Season

Expanding summers and shrinking winters in subtropical and temperate Australia

Over the last two decades, summers in the most populous areas of Australia are a month longer than in the 1950s and 1960s. Summers over the last five years were longer still, reaching twice the length of winters in those years. Longer, more extreme summers will have increasingly profound impacts on Australian health, food production and quality of life.

Discussion paper

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Summary

If it feels like Australian summers are getting longer and hotter, that is probably because they are. The summers many Australians grew up with no longer exist.

Climate change has already altered the Australian seasonal calendar. Since the middle of last century, summers have expanded and become more extreme, while other seasons have contracted. These trends will continue unless emissions are reduced and until emissions reach net zero.

This report examines changing seasons using data from the Bureau of Meteorology (BOM). Temperatures that once marked the start and end of summer are shown to occur much earlier and later.

Data is drawn from 70 weather stations across southern Queensland and WA, NSW, Victoria, ACT, South Australia and Tasmania. These subtropical and temperate areas are were most Australians live.

The analysis compares daily average temperatures over two periods: the most recent two decades with available data (1999-2018), and a benchmark from the mid twentieth century (1950-1969). The analysis also examines more recent heating, comparing the last five years (2014-2018) against the historical benchmark.

Results are presented for all capital cities and selected regional areas. National results are averaged across all 70 weather stations.

Across the country, all seasons are now hotter, with increases in average and extreme temperatures, particularly in summer.

Over the last two decades, summer was on average one month longer than it was half a century before. Temperatures that marked the start of summer now come around two weeks earlier; temperatures that marked the end of summer now come around two weeks later. Spring and autumn have shifted and winter is now more than three weeks shorter.

In every capital city, summers have grown longer and winters have grown shorter.

The trend was more pronounced in some regional areas. In some areas summer has become even longer and winters even shorter. Summers in Port Macquarie have increased by 48 days. While the catastrophic 2019 fires near Port Macquarie occurred before summer as defined by the calendar, they occurred well within the new summer as defined by new temperatures in a changing climate. In some areas, winters are around one month long.

Looking at the last five years, summers are on average close to 50% longer than they were in the middle of the twentieth century. These most recent summers were twice as long as the most recent winters.

Every capital city saw summers grow longer in the last five years, compared with the last two decades. Across the area winters grew shorter over the 5 years, but there was more variation in the length of winter between capital cities, winters in some cities halving in length while in others growing longer.

The analysis does not include 2019, as the data is not yet complete in the dataset. However, other BOM data shows 2019 was by far the hottest year on record. It is highly likely that summers have grown even longer and winters shorter over this period.

Caution is needed extrapolating to the future from past observations, especially over short time frames, due to weather and natural cycles. Nonetheless, it is highly likely over the medium and longer them that summers will continue to get longer and hotter.

The continuing changes in seasons will have increasingly profound implications for life in Australia. Longer hotter summers mean longer hotter fires seasons, more heatwaves and greater exposure to heat related illnesses. People working outdoors or in un-airconditioned spaces will be particularly at risk. Outdoor activities that we take for granted such as socialising and playing sport will become less enjoyable and more dangerous. Agricultural crops will be damaged and livestock will suffer. Entire ecosystems are at risk.

These trends are likely to continue indefinitely unless greenhouse gas emissions are decisively reduced, ultimately to net-zero.

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Introduction

If it feels like the seasons are changing, that's probably because they are.

Autumn was abnormally warm in 2018. According to the Bureau of Meteorology (BOM):

> The heat, which was more characteristic of mid-summer than mid-autumn, was unprecedented in many areas in April…[1]

The summer of 2018-19 saw Australians swelter through the hottest summer on record, with wide-spread heatwaves and record high temperatures, accompanied by low rainfall and dry conditions in parts of every state and territory.

By the end of spring in 2019, persistent and extreme heat and dryness created conditions for catastrophic bushfires across much of the country. On 11 November the Victorian emergency services minister, Lisa Neville, compared the spring conditions to the "worst conditions you'd see in February or March."[2] The NSW Rural Fire Services Commissioner said it was

> the most dangerous bushfire week this nation has ever seen… We have got the worst of our fire season still ahead of us. We're not even in summer yet.[3]

When summer 2019-20 officially arrived, Australians were hit with yet further record breaking extreme heat and catastrophic fires.

Seasons are defined on our calendars and in our experience of weather, but as global heating increases, these are diverging. Temperatures that once characterised the beginning of summer are lasting much later, while summer temperatures are also getting more extreme. Reports that temperatures have increased by around 1 degree can tend to downplay the changes underway. The reality is the summers many Australians grew up with no longer exist.

This report analyses how much change has already occurred over the last half century.

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[1] Hannam (2018) *'It's weird': Return of summer sends plants into confusion* https://www.smh.com.au/environment/weather/it-s-weird-return-of-summer-sends-plants-into-confusion-20180413-p4z9ew.html

[2] Ibid.

[3] Doherty (2019) *Australia fires: nation braces for 'most dangerous bushfire week ever seen'* https://www.theguardian.com/australia-news/2019/nov/11/australia-fires-nation-braces-for-most-dangerous-bushfire-week-ever-seen

Methodology

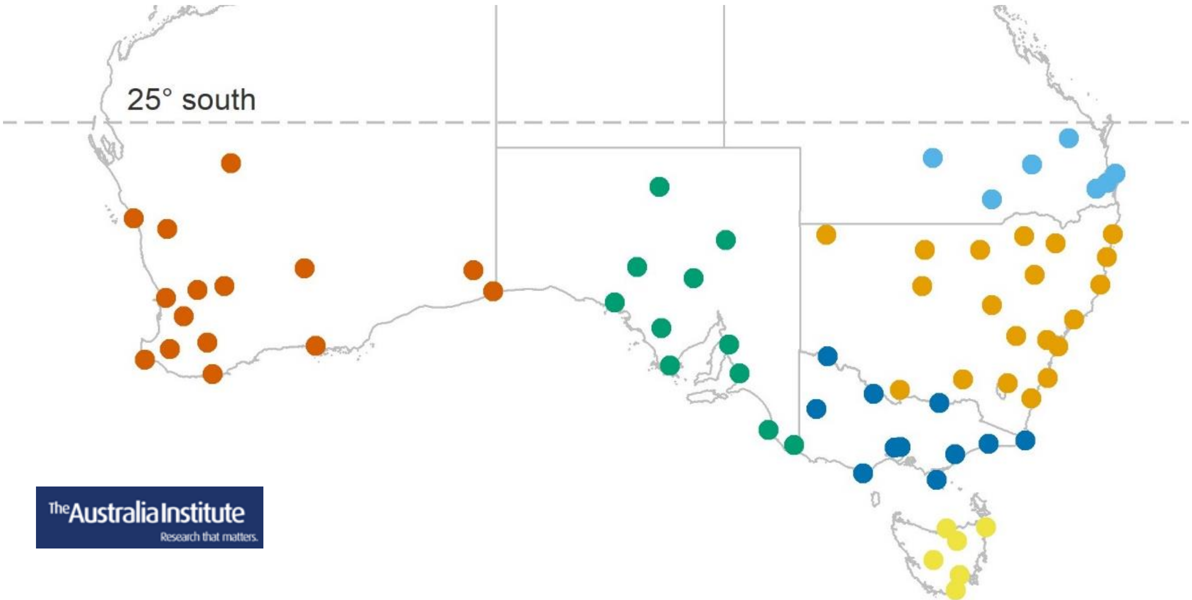
This section describes the methodology in brief. More detail and discussion of data are provided in an Appendix.

The report uses BOM data from the *Australian Climate Observations Reference Network – Surface Air Temperature* (BOM ACORN-SAT).[4]

Data is drawn from weather stations across temperate and subtropical Australia, south of the 25th parallel, where most Australians live, shown in Figure 1. The areas selected have a seasonal calendar of summer, autumn, winter and spring. Tropical areas are excluded; seasons there generally revolve around "the wet" and "the dry", rather than the four season calendar.

70 weather stations in temperate and subtropical Australia have data from 1950-2018, shown in Figure 1. The data from these stations meets requirements for data completeness discussed in the appendix.

Figure 1: Weather stations used in analysis of season changes in sub-tropical and temperate Australia.



Source: BoM ACORN-SAT stations south of 25 degrees S with data 1950-2018
http://www.bom.gov.au/climate/data/acorn-sat/

Analysis is conducted for the average of all stations, and for weather stations individually.

[4] BoM (2019) ACORN-SAT, http://www.bom.gov.au/climate/data/acorn-sat/

Daily average temperatures are calculated for each day over the last two decades (1999-2018) and for two decades in the middle of the twentieth century (1950-1969). In other words, the analysis produces two sets of average temperatures for each day of the year (for 1 January, 2 January, 3 January and so on). To smooth out natural variability from weather events, average temperatures for each day are calculated by averaging over a 21 day period, from 10 days earlier to 10 days later from each day.

The beginning of each season is defined by reference to the historical daily average temperature on the first day of the season. Seasons are defined as per the traditional seasonal calendar:

- summer starts 1 December,
- autumn starts 1 March,
- winter starts 1 June, and
- spring starts 1 September.

For each weather station, the average temperature on each of these dates in 1950-1969 is the temperature that marks the beginning of the season. The dates on which these benchmark temperatures were reached over the last twenty years are the dates on which the seasons are said to now begin.

The mid-century was chosen as it enabled data from a greater number of weather stations (70) to be used for the combined station analysis. It is also a conservative baseline for seasonal temperatures. As discussed in the Appendix, earlier recorded temperatures are the same or lower.

The period is also significant as it marks the birth and coming of age of the “baby boomer” generation. It was also the beginning of the post-war acceleration of greenhouse gas emissions.

Using a twenty year average smooths out variability in the data, from both weather events and natural climate variability, for example due to La Nina/ El Nino cycles. Using a twenty year average is also a conservative approach: temperatures have increased over the most recent twenty year period.

To illustrate this more recent heating, the analysis is replicated for the five most recent years for which the dataset contained complete data (2014-18).

The exceptionally hot weather in 2019 is further discussed by reference to other data from BOM, noting that data from one year is likely to reflect extremes and underlying trends should not be extrapolated on any linear basis.

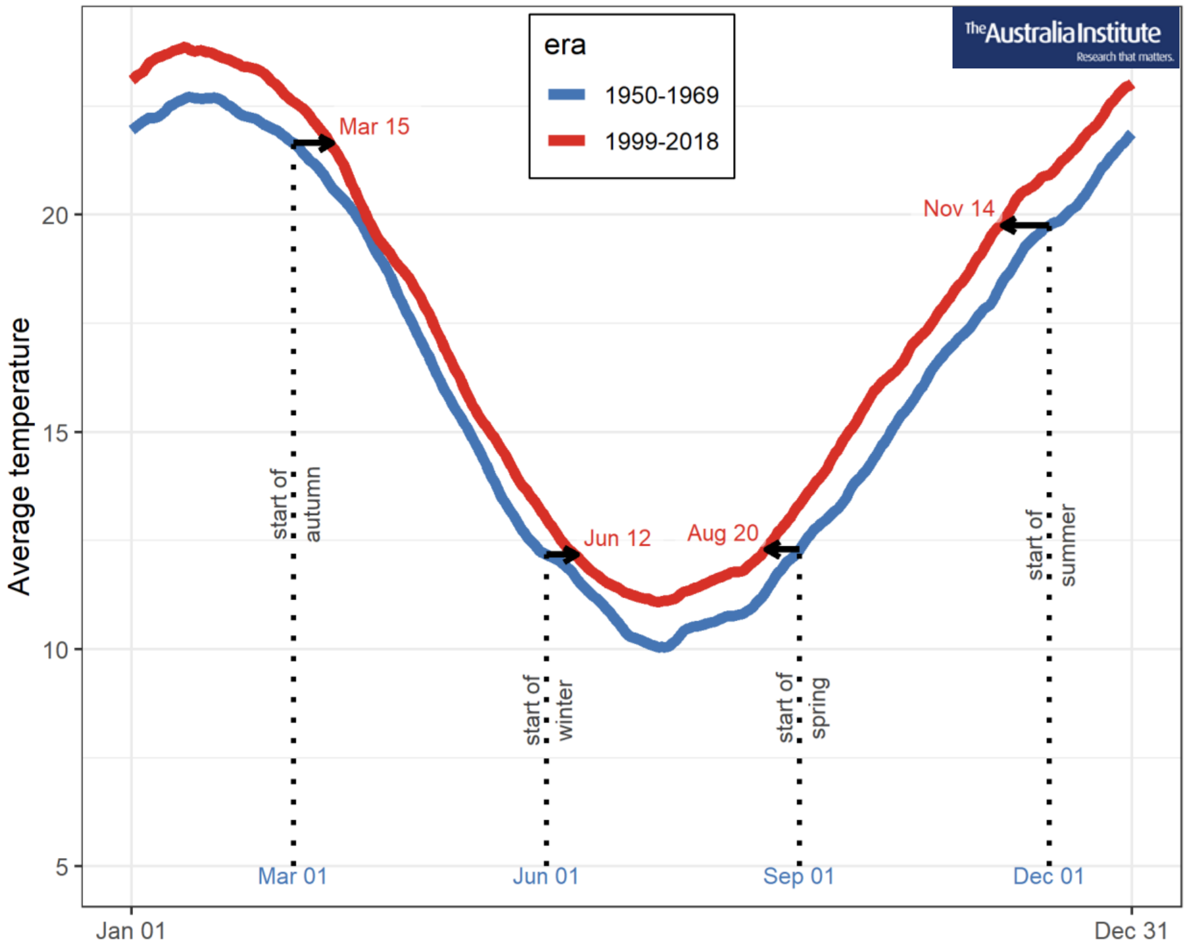
Results: longer summers, shorter winters

ACROSS TEMPERATE AND SUBTROPICAL AUSTRALIA

Across temperate and subtropical Australia – averaging data for all weather stations – we see substantial changes in temperatures and seasons over the last half century.

Figure 2 below shows that across temperate and subtropical Australia over the last two decades, temperatures are now higher on average for every day of the year than they were in the middle of the 20th Century.

Figure 2: Change in temperatures and seasons - temperate and subtropical Australia



Source: Combining results using 70 stations, BOM ACORN-SAT, as described in text

Summer-starting temperatures – the average 1 December temperature mid-20th century – now arrive two weeks earlier.

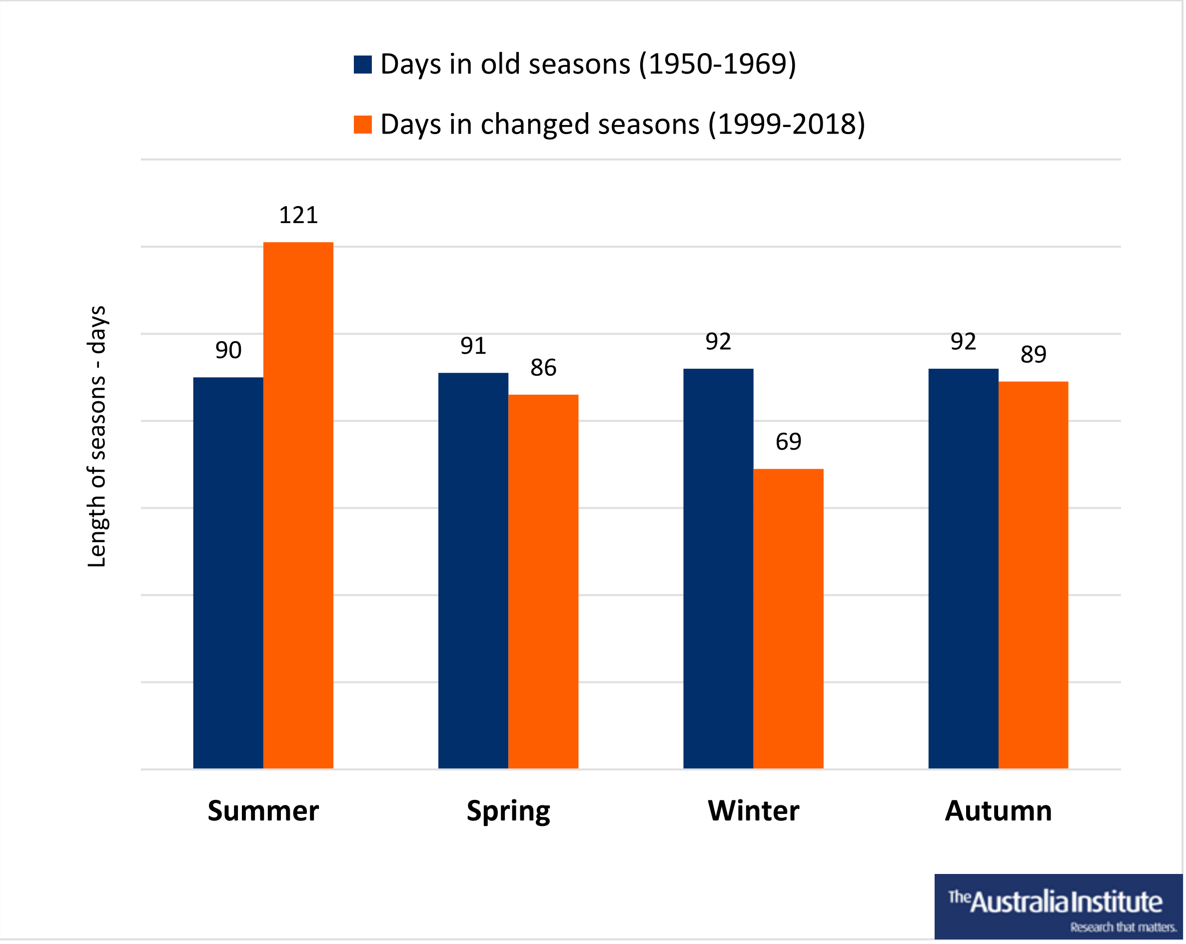
Summer-ending temperatures – the average on 1 March over 1950-69 (– now arrives two weeks later.

Winter started 12 days later and finished 11 days earlier, by comparison with winters over the mid-twentieth century.

Across most of Australia, summers are now four weeks longer than they were, while winters have shrunk by three weeks. Summers are now nearly double the length of winters.

Figure 3 below summarises these changes to the length and timing of the seasons for temperate and subtropical Australia as a whole.

Figure 3: Changing seasons for temperate and subtropical Australia



Source: BOM ACORN-SAT, as described in text

Summer has grown longer in all locations. All weather stations recorded an increase in the length of summer and a shortening of winter in the last 20 year period.

However there were variations in how much longer summer has become in different locations. 41 weather stations saw summers increase by more than one month.

CAPITAL CITIES

Table 1 below shows the extent of the changes in Australia's capital cities. Melbourne and Adelaide had the largest increase in summer with 38 and 36 days respectively. Brisbane had the smallest increase in summer (11 days) but the largest reduction in winter (31 days).

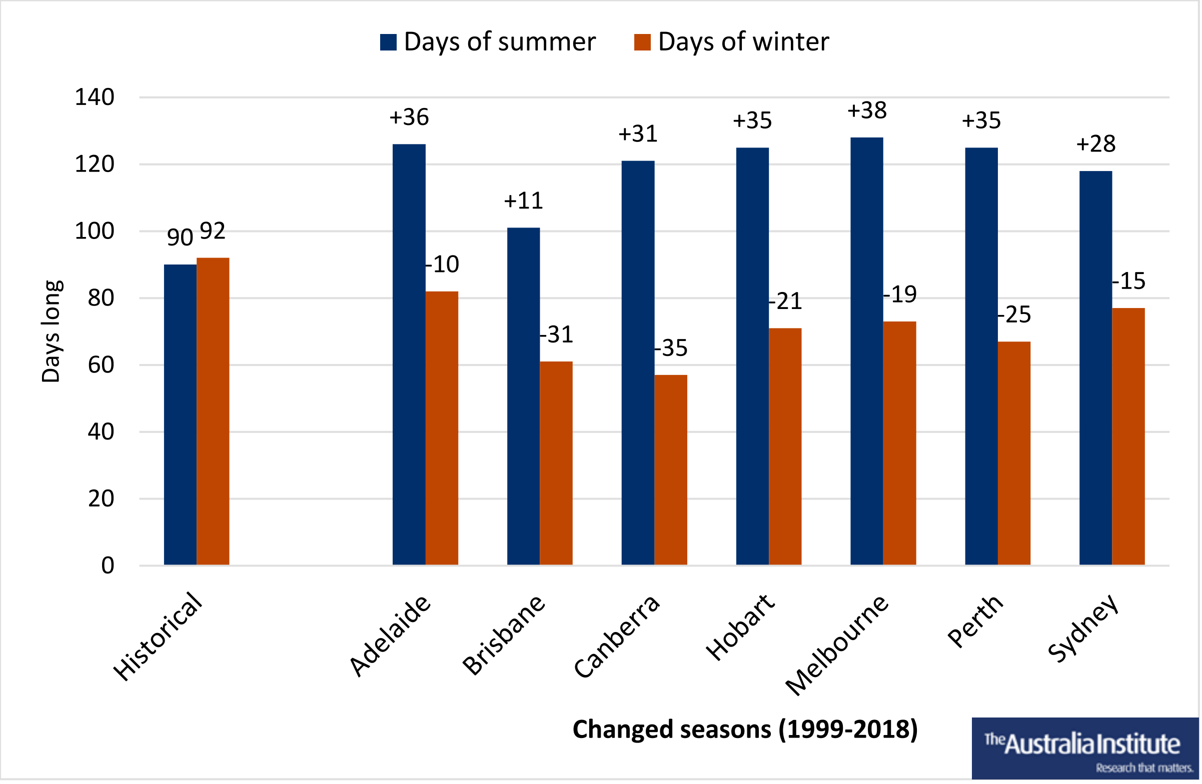
The detailed charts for all capital cities can be seen in Appendix A.

Table 1: Summary of season changes in Australian capital cities

	Summer				Winter			
	Starts	***Last day***	***Change days***	***Total days***	***Starts***	***Last day***	***Change days***	***Total days***
Adelaide	10-Nov	16-Mar	+36	126	2-Jun	23-Aug	-10	82
Brisbane	25-Nov	6-Mar	+11	101	16-Jun	16-Aug	-31	61
Canberra	11-Nov	12-Mar	+31	121	23-Jun	19-Aug	-35	57
Hobart	13-Nov	18-Mar	+35	125	13-Jun	23-Aug	-21	71
Melbourne	9-Nov	17-Mar	+38	128	9-Jun	21-Aug	-19	73
Perth	11-Nov	16-Mar	+35	125	10-Jun	16-Aug	-25	67
Sydney	21-Nov	19-Mar	+28	118	8-Jun	24-Aug	-15	77

Source: BoM ACORN-SAT, analysed as described in text

Figure 4: Changing length of summer and winter in capital cities



REGIONAL AREAS WITH BIGGEST CHANGES

Some regional areas had an even larger increase in the length of summer since the middle of the last century.

Ten weather stations show summers have reached 130 days or longer. For example, summers in Port Macquarie have grown by 47 days (almost 7 weeks), while winters are only 51 days long. While the most devastating fires near Port Macquarie in 2019 occurred before summer as defined by the calendar, they were within summer when benchmarked to historical summer temperatures.

Winters have more than halved in seven areas. In many of areas, average daily temperatures in winter do not fall below those previously experienced at the start of spring. (See Appendix 2 for how this is treated in the analysis.)

Table 2 shows the longest summers and shortest winters; the two lists overlap substantially.

Table 2: Top 10 longest summers and shortest winters

Longest summers			Shortest winters		
Days	Location	State	Days	Location	State
139	Eucla	WA	23	Cape Bruny	Tas
138	Port Macquarie	NSW	25	Cape Leeuwin	WA
136	Cape Bruny	Tas	33	Gabo Island	Vic
136	Ceduna	SA	35	Geraldton	WA
132	Esperance	WA	36	Laverton	WA
132	Laverton	WA	43	Wandering	WA
131	Cape Otway	Vic	45	Cape Otway	Vic
131	Charleville	Qld	47	Katanning	WA
130	Cape Leeuwin	WA	50	Port Lincoln	SA
130	Mt Gambier	SA	51	Esperance	WA

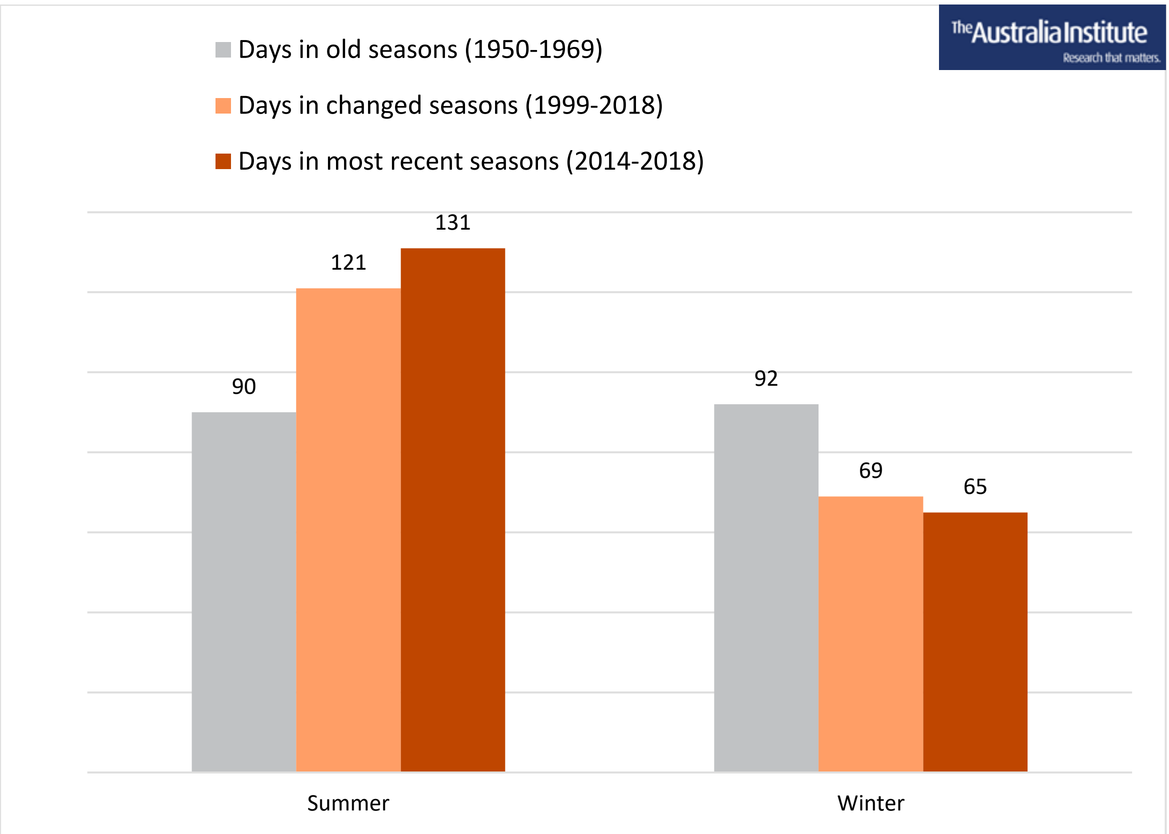
Source: BoM ACORN-SAT, analysed as described in text

Recent summers: longer still

The analysis above compares temperatures over the last two decades (1999-2018) to a benchmark period 50 years prior. While averaging over two decades provides a robust basis for analysis that smooths out variability and natural cycles, it also obscures the significant heating that has occurred even within the last two decades.

To illustrate, the same analysis was conducted comparing the benchmark period to the last five years in the dataset (2014-2018). The averaged results are shown in Figure 5.

Figure 5: Longer summers and shorter winters in non-tropical Australia, last 20 and 5 years



Source: BoM, ACORN-SAT, analysis of data as described in text.

Summers at the relevant weather stations were on average 131 days long over this five year period, or four and a half months. That is, summers were almost 50% longer than they are defined on the standard calendar.

Comparing the average temperatures over the past five years to those over the whole two decades, the most recent five years saw summers that were two weeks longer.

The most recent summers were twice as long as the most recent winters.

Natural variability and cycles are more likely to influence season length in a shorter period. Nonetheless, it is likely this nearer term increase is part of a longer term and ongoing trend caused by global heating that will see summers continue to start earlier and end later.

Similarly, winters were on average 65 days long, or a month shorter than defined on the calendar.

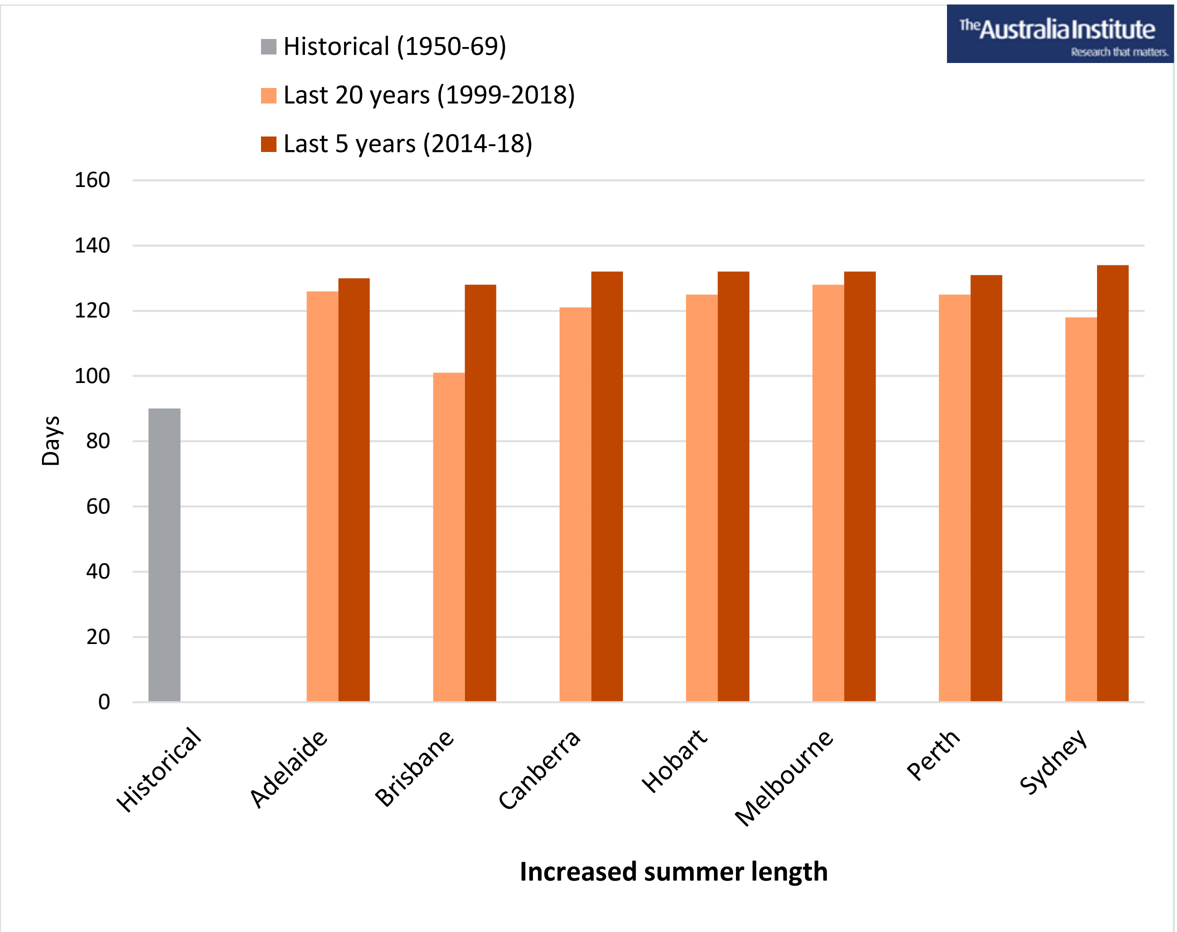
Table 3 compares season lengths over the two time periods, for the capital cities, while Figure 6 and Figure 7 show summers and winters respectively.

Table 3: Seasonal changes over last 20 and 5 years - number of days

	Summer		Winter	
	Last 20 years	*Last 5 years*	*Last 20 years*	*Last 5 years*
Adelaide	126	130	82	78
Brisbane	101	128	61	30
Canberra	121	132	57	58
Hobart	125	132	71	72
Melbourne	128	132	73	83
Perth	125	131	67	35
Sydney	118	134	77	76

Source: BoM, ACORN-SAT, analysis of data as described in text.

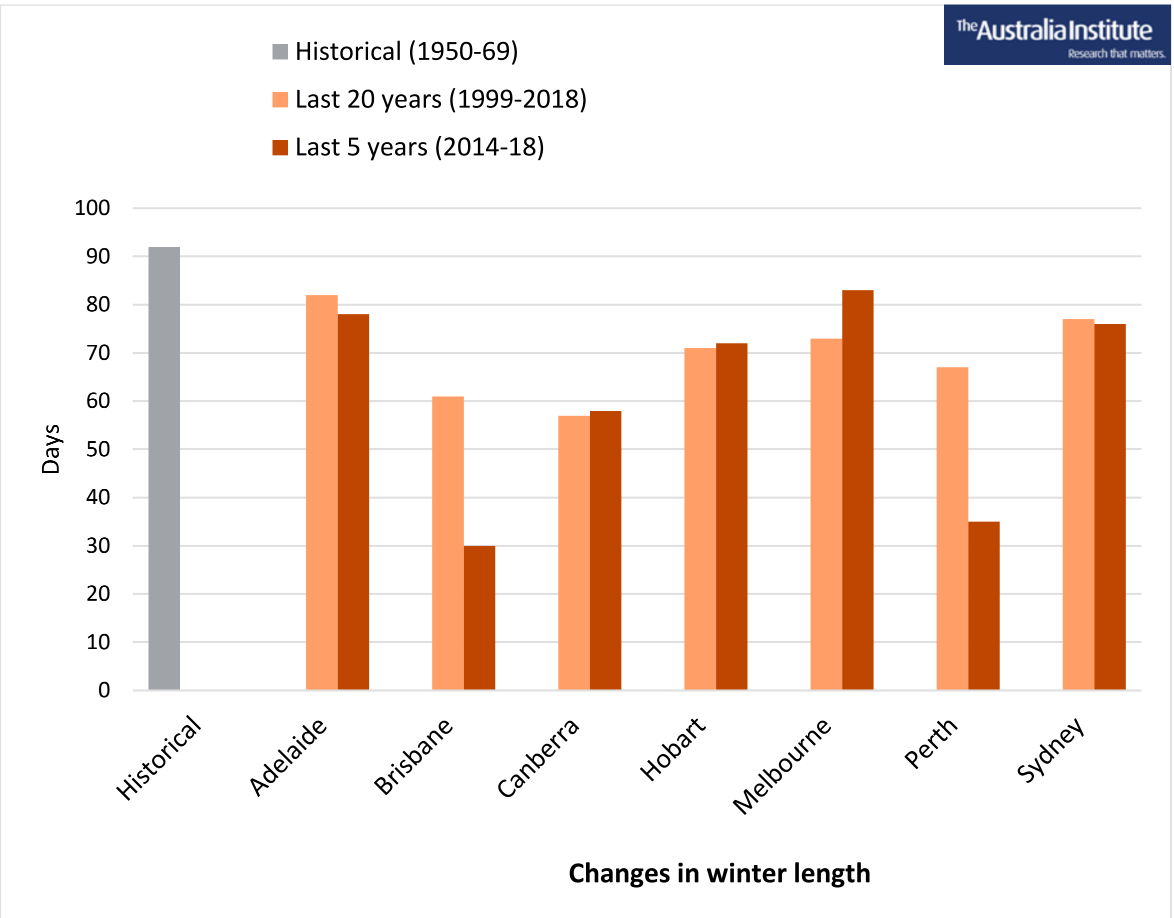
Figure 6: Summers have got longer even in the last five years



Source: BoM, ACORN-SAT, analysis of data as described in text.

All capitals had longer summers over the last five years, compared with over the last two decades. The difference is especially marked for Brisbane, but all capitals had at least a modest increase.

Figure 7: Winters were more variable than summers over the last two decades



Source: BoM, ACORN-SAT, analysis of data as described in text.

Winters have been more variable with Brisbane and Perth exhibiting much shorter winters. Brisbane's winters over the last five years were only one month long. For many capitals there were barely any changes over the last five years compared with the two decade period. For Melbourne, winters over the last five years were longer than over the last two decades.

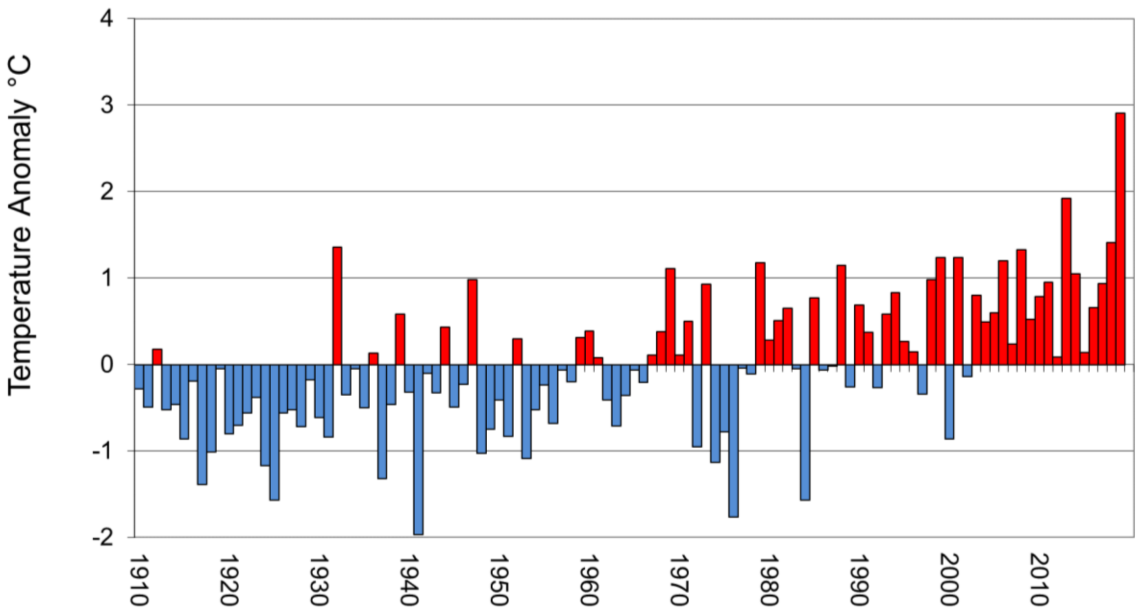
2019

The analysis above leaves out 2019, as full data is not yet included in the datasets used. 2019 was exceptionally hot. In the January 2020 holiday period, as catastrophic fires burnt across much of Australia's temperature forests, BOM reported:

> 2019 was Australia's warmest year on record. Australia's area-averaged mean temperature for 2019 was 1.52 C above the 1961–1990 average.... Mean maximum temperatures were the warmest on record at 2.09 °C above average[5]

January 2019 was especially extreme, with average temperatures nearly 3 degrees above the 1910-2019 average.

Figure 8: BOM: Australian January Mean Temperature



Source: BOM (2019) *Summer 2019 sets new benchmarks for Australian temperatures* http://media.bom.gov.au/social/blog/2020/summer-2019-sets-new-benchmarks-for-australian-temperatures/

The subsequent summer, December onwards, saw maximum heat records fall yet again. The record for Canberra was broken three times in one week.

Temperatures in any particular year are subject to many sources of variability and have to be seen in the context of longer term trends. Nonetheless it is clear that subsequent seasonal analysis including 2019 will likely find summers have increased further still.

[5] BOM (2020) *Annual climate statement 2019*, https://web.archive.org/save/http://www.bom.gov.au/climate/current/annual/aus/

Implications

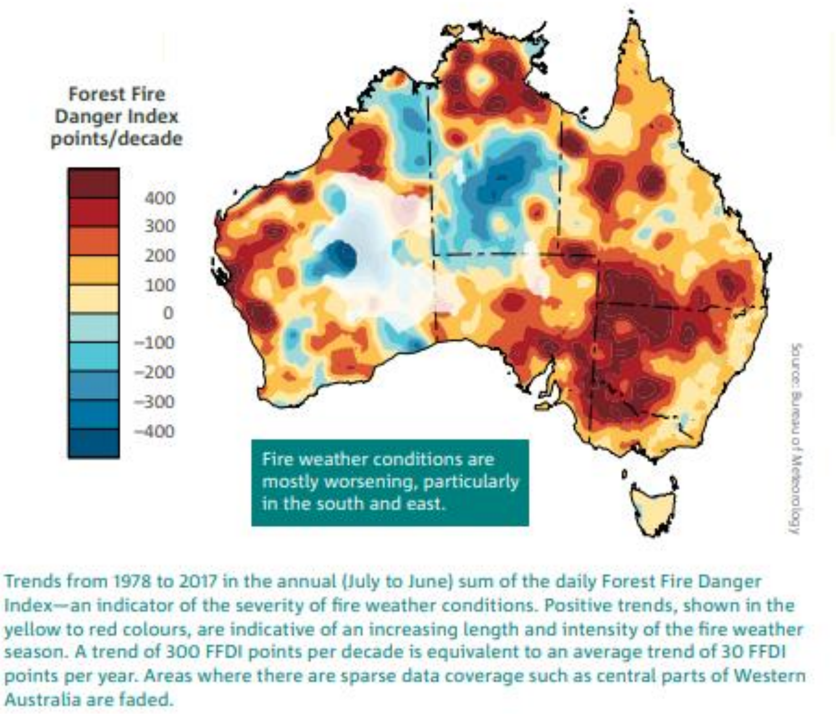
Longer hotter summers will have increasingly profound implications for life in Australia.

FIRE DANGER

Longer and hotter summers increase the length and intensity of the bushfire season. The BOM has identified a long term increase in the length of the fire season and extreme fire weather.[6] Combined with long-term drying, longer periods of higher temperature is increasing fire danger in much of the country.

The Forest Fire Danger Index estimates the fire danger on a given day based on observations of temperature, rainfall, humidity and wind speed. The trend in worsening fire weather over the last 40 years is shown in Figure 9 below. The red and yellow areas show an increase on bush fire danger over that period.

Figure 9: Trends in Forest Fire Danger Index 1978-2017



Source: BoM (2018), State of the Climate 2018

[6] BoM (2018) *State of the climate 2018*, http://www.bom.gov.au/state-of-the-climate/State-of-the-Climate-2018.pdf

Over November 2019 areas on the NSW central and northern coasts have experienced catastrophic bushfires. While the most devastating bush fire days began before the start of summer as traditionally defined, they have largely fallen within the new reality of our extended summer. For example, summer in Port Macquarie now starts on 4 November and lasts for 138 days. Fires were bearing down on Port Macquarie in early November, before summer as defined on the calendar, but well within the new summer as caused by climate change.

HEALTH

Longer summers mean more extreme temperatures and heatwaves. Temperatures above 35 degrees are considered extreme, and heatwaves are defined as three or more days of unusually high maximum and minimum temperatures in any area.[7] Increasing extreme temperatures and heatwaves have significant implications for people's health.

At temperatures above 35 degrees, the human body's main cooling mechanism – sweating – is far less effective. Sweating exchanges heat from the body to the atmosphere. This heat exchange process diminishes significantly beyond 35 degrees, so body temperature rises. This results in a range of heat related illnesses, from mild to severe, including heat stroke that can cause permanent damage to the brain and other vital organs and can even result in death.[8]

Longer and hotter summers will increase the incidence of heatwaves and heat related illnesses.

Heatwaves are responsible for more deaths than all other natural disasters combined.[9] Besides the increase in heat related illnesses, heatwaves cause psychological stress,[10] affect patterns of domestic violence,[11] interrupt sleep patterns and reduce capacity and willingness to exercise. All carry broad ramifications, such as increased accident risk, sedentary lifestyle-induced diabetes and cardio vascular disease.[12]

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[7] BoM website, About the Heatwave Service. http://www.bom.gov.au/australia/heatwave/about.shtml

[8] Hanna and Tait (2015) *Limitations to thermoregulation and acclimatisation challenges human adaptation to global warming,* Int J Environ Res Public Health, https://academic.oup.com/heapro/article/30/2/239/561863; Australian Mining Review (November 2017) *WA miners urged to guard against heat stress,* https://www.miningreview.com.au/wa-miners-urged-guard-heat-stress/

[9] Queensland Government (2019) *Queensland State Heatwave Assessment 2019*, https://www.disaster.qld.gov.au/dmp/Documents/QFES-Heatwave-Risk-Assessement.pdf

[10] Queensland Health (2015) *Heatwave Response Plan* https://www.health.qld.gov.au/__data/assets/pdf_file/0032/628268/heatwave-response-plan.pdf

[11] Auliciems and Di Bartolo (1995*) Domestic violence in a subtropical environment: police calls and weather in Brisbane, International Journal of Biometeorology* 39 (1).

[12] Kjellstrom et al. (2009*) The Direct Impact of Climate Change on Regional Labor Productivity*, Archives of Environmental & Occupational Health 64 (4); World Health Organisation (2017) Preventing

WORK AND PRODUCTIVITY

The health impacts of increasing extreme heat and heatwaves have significant implications for workplace productivity and health and safety, including the risk of heat-related illness which can be fatal.[13] Longer hotter summers increase these risks.

A significant proportion of the Australian workforce is exposed to the heat. Construction and manufacturing are two of Australia's largest employing industries. These occupations often require work to be undertaken outdoors or within indoor spaces lacking air-conditioning. In addition, workers are often required to undertake strenuous activities wearing heavy protective clothing for health and safety reasons. Strenuous activity in extreme hot weather increases the risk of heat related illness including heatstroke. Additionally, carrying heavy equipment increases the level of exertion.

In some states, including Queensland, there is no temperature threshold for halting heavy outdoor work.

The cost of lost productivity because of extreme heat in Australia has been estimated at almost $7 billion in 2013-14 alone.[14]

LIVEABILITY

Increasing extreme heat and heatwaves make many of the activities we take for granted less enjoyable and potentially dangerous.

Last year heatwaves disrupted prominent sporting events including the Tour Down Under[15] and the Australian Open.[16]

However, it is not only elite sport that will be disrupted, but the myriad of sporting events and outdoor activities that are an essential part of children's physical education and community life.

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noncommunicable diseases (NCDs) by reducing environmental risk factors, https://apps.who.int/iris/bitstream/handle/10665/258796/WHO-FWC-EPE-17.01-eng.pdf;jsessionid=4E7CD6157CC879B57F179B388D89706A?sequence=1

[13] WorkCover QLD, Heat Stress, https://www.worksafe.qld.gov.au/injury-prevention-safety/hazardous-exposures/heat-stress

[14] Zander, Opperman and Garnet (2015) *Extreme heat poses a billion-dollar threat to Australia's economy,* https://theconversation.com/extreme-heat-poses-a-billion-dollar-threat-to-australias-economy-41153

[15] InDaily (January 2018) Heatwave forces more Tour Down Under changes, https://indaily.com.au/sport/2018/01/18/tour/

[16] Press Association (January 2018), Australian Open extreme heat policy to be reviewed as concerned players suffer, https://www.theguardian.com/sport/2018/jan/19/australian-open-extreme-heat-policy-concerned-players-40c

Socialising outdoors and enjoying the natural environment are also important for the wellbeing of individuals and the community. Long hotter summers and increasing extreme heat and heatwaves will diminish these activities and in some cases make them dangerous.

The Australia Institute's update of the *Climate of the Nation* research, conducted during the 2019-20 bushfire crisis, found the fires had impacts far beyond the tragic loss of life and property experienced on the fire fronts. In mid-January 2020, 57% of Australians had experienced some form of smoke or fire related impact, from widespread disruption, though to 26% reporting some kind of negative heath impact and the equivalent of 1.8 million workers missing some amount of work.[17] These sorts of impacts will become more likely and more costly if summers continue to get hotter and longer.

PLANTS AND ANIMALS

Plants have evolved to seasonal cycles. Seasonal temperature changes trigger flowering and pollinations which are essential to reproduction. Changes in the seasons as a result of global warming can have serious consequences on plants and ecosystems.[18]

Plants can only survive in a certain range of temperatures. If that range is exceeded plants will die. Around 47% of native vegetation across Australia is potentially at risk from increases in mean annual temperature by 2070, with tropical regions most vulnerable.[19]

Increasing temperatures can also increase pests and pathogens causing dieback. When bushfires occur outside the ordinary range, some plants do no survive.[20]

Animals are also at risk from both increasing average temperatures and heatwaves.[21]

AGRICULTURE

Our crops, livestock and farming practices have evolved within seasonal and temperature conditions. Changes to seasons and increasing temperatures can have a range of serious

[17] Swann (2020) *Polling–Bushfire crisis and concern about climate change,* https://www.tai.org.au/sites/default/files/Polling%20-%20January%202020%20-%20bushfire%20impacts%20and%20climate%20concern%20%5Bweb%5D.pdf

[18] Land Trust Alliance (nd) Conservation in a changing climate, Shifting seasons, https://climatechange.lta.org/climate-impacts/shifting-seasons/

[19] Gallagher at al (2019), Safety margins and adaptive capacity of vegetation to climate change, https://www.nature.com/articles/s41598-019-44483-x

[20] Fulloon (2019), Nearly half of Australia's native plants are under threat from climate change, https://www.sbs.com.au/news/nearly-half-of-australia-s-native-plants-are-under-threat-from-climate-change

[21] Williams and Scheffers (2013), As climate changes, animals move fast to escape the heat, https://theconversation.com/as-climate-changes-animals-move-fast-to-escape-the-heat-18511

consequences including disrupting flowering and pollination[22], pests and disease,[23]and soil moisture.

Recent CSIRO research has found potential wheat yields in Australia have already declined by 27% from 1990 to 2015 below what they would otherwise have been, due to climate impacts. This has mainly been due to the decrease in rainfall and increasing temperatures over this period.[24]

A recent CSIRO report examined 25 locations in south eastern Australia and found that without adaptation, meat production could be reduced by up to 92% by 2050 and wool production by up to 95% as a result of climate change, including rising temperatures.[25]

Extreme heat damages fruit crops and can cause extensive losses,[26]reduces yield and quality of a variety of other crops, and causes up to 40% reduction in milk production.[27]

INFRASTRUCTURE AND INDUSTRY

Heatwaves can damage essential infrastructure including electricity, water and sewerage and transport infrastructure.[28]

Coal and gas power stations in particular are highly vulnerable to extreme heat, experiencing reduced output.[29] The impact of breakdowns at gas and coal fired power

[22] Memmott et al (2007), Global warming and the disruption of plant-pollinator interactions, https://www.researchgate.net/publication/6243895_Global_warming_and_the_disruption_of_plant-pollinator_interactions

[23] Land Trust Alliance website, Conservation in a changing climate, Shifting seasons, https://climatechange.lta.org/climate-impacts/shifting-seasons/

[24] Hochman et al (2017) *Climate trends account for stalled wheat yields in Australia since 1990*, https://onlinelibrary.wiley.com/doi/full/10.1111/gcb.13604

[25] Gaharamani and Moore (2014) *Systemic adaptations to climate change in southern Australian grasslands and livestock: Production, profitability, methane emission and ecosystem function,* https://www.researchgate.net/publication/269106683_Systemic_adaptations_to_climate_change_in_southern_Australian_grasslands_and_livestock_Production_profitability_methane_emission_and_ecosystem_function

[26] Schremmer (2019) *Extreme temperatures burn stone fruit from inside out, causing severe loss,* https://www.abc.net.au/news/rural/2019-01-16/heatwave-burns-stonefruit-from-inside-out/10717496

[27] Barlow et al (2015) *Appetite for change: Global warming impacts on food and farming regions in Australia,* https://sustainable.unimelb.edu.au/__data/assets/pdf_file/0009/2752272/MSSI_AppetiteForChange_Report_2015.pdf

[28] Queensland Government (2019) *Queensland State Heatwave Risk Assessment 2019,* https://www.disaster.qld.gov.au/dmp/Documents/QFES-Heatwave-Risk-Assessement.pdf

[29] Ogge and Aulby (2017) *Can't stand the heat: The energy security risk of Australia's reliance on coal and gas generators in an era of increasing heatwaves*, https://www.tai.org.au/sites/default/files/P454%20Can%27t%20stand%20the%20heat%20FINAL%202.31.pdf

stations, removing large amounts of generation unexpectedly, during higher temperatures as they tend to be periods of high electricity demand, due to heavy use of air conditioning.

In 2018 there were 135 breakdowns of coal and gas power stations in the National Electricity Market (NEM). There was a higher rate of breakdowns over the summer months of 2018 (one third of all breakdowns),[30] and significant blackouts caused by a series of breakdowns at Victoria's brown coal power stations in late January.[31]

Power system failure in heatwaves can have a serious flow on effect to building infrastructure. Air-conditioning can be critical to people's wellbeing during extreme heat. Electricity blackouts during heatwaves can lead to the loss of air-conditioning when it is most essential.

During the 2009 Heatwave in Melbourne on the evening of the 30th of January, 500,000 people were left without power on a day that reached 44 degrees. There were 374 deaths recorded as a result of this heatwave overall. The estimated economic cost of the heatwave was $800 million.[32]

An efficient transport system is fundamental to a well-functioning economy. Extreme heat can also disrupt transport infrastructure. It can cause roads to melt,[33]rails to buckle,[34] and disruption to airlines.[35]

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[30] The Australia Institute (2018) *Gas and coal watch monitoring*, research available on request.

[31] Parkinson (2019) *Brown coal generators failed the grid in Victoria heat-wave, blackouts*, https://reneweconomy.com.au/brown-coal-generators-failed-the-grid-in-victoria-heat-wave-blackouts-55696/

[32] NCCARF (2010) *Impacts and adaptation responses of infrastructure communities to heatwaves,* https://www.nccarf.edu.au/business/sites/www.nccarf.edu.au.business/files/attached_files_publications/Pub%2013_10%20Southern%20Cities%20Heatwaves%20-%20Complete%20Findings.pdf

[33] Cheer (2018) *Traffic delays after 10 kilometers of Victoria's Hume Freeway melts,* https://www.sbs.com.au/news/traffic-delays-after-10-kilometres-of-victoria-s-hume-freeway-melts

[34] Lauder (2009) *Melbourne railway buckles under heat,* http://www.abc.net.au/worldtoday/content/2008/s2477350.htm

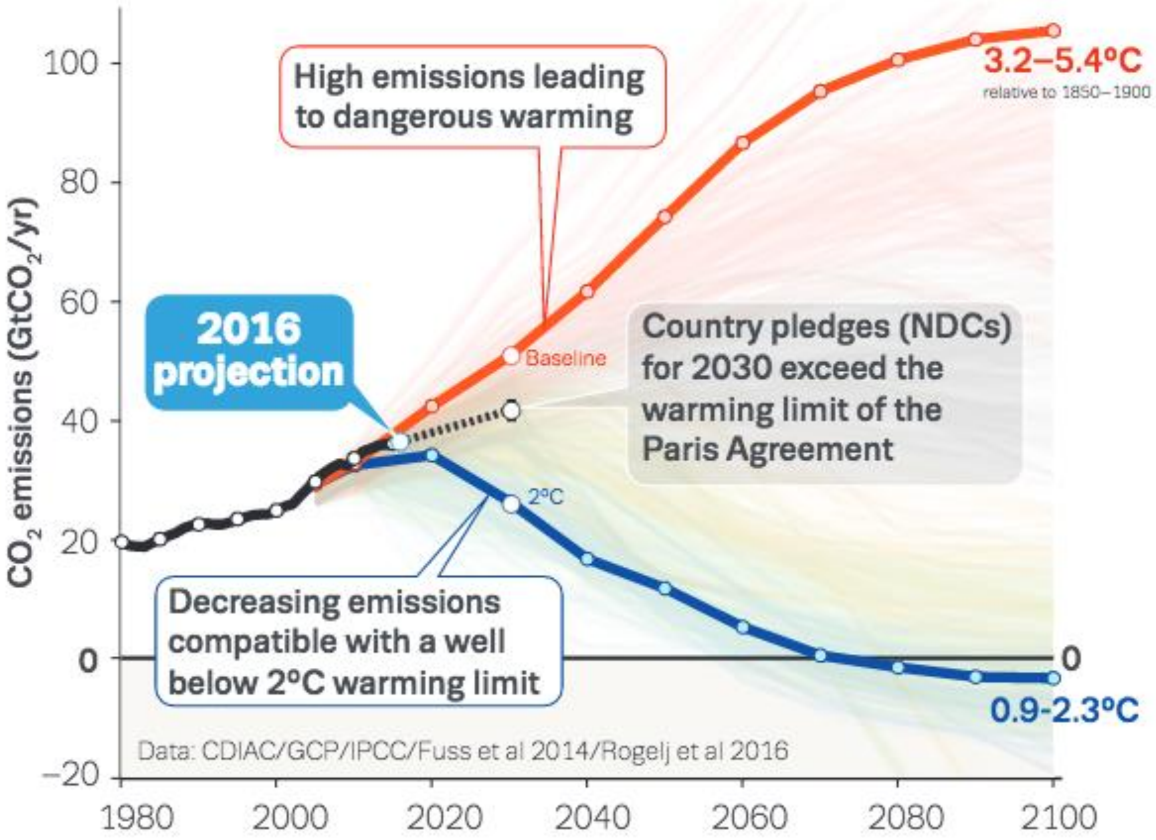
[35] Coffell and Horton (August 2017) *How hot weather – and climate change – affect airline flights*, https://theconversation.com/how-hot-weather-and-climate-change-affect-airline-flights-80795

Slowing the changes in seasons

The temperature increases driving the season changes in Australia are influenced by the concentration of greenhouse gases in the atmosphere.

Current temperatures have risen by around 1 degree on average in Australia (relative to the period 1961-1990).[36] As shown in Figure 10 below, if the current trajectory of global emissions (orange line) continues, temperatures could rise by up to 5.4 degrees by the end of the century (relative to 1850-1900). Countries have pledged actions that would still see emissions increase out to 2030; if those pledges are kept warming would still be very damaging and far beyond the agreed limits. However the Intergovernmental Panel on Climate Change believe it is still possible to keep warming well below 2 degrees if governments act decisively (approximated by the blue line).[37]

Figure 10: Emissions scenarios



Source: Carbon Brief (2016) *Analysis: What global emissions in 2016 mean for climate change goals*, https://www.carbonbrief.org/what-global-co2-emissions-2016-mean-climate-change

[36] BoM (2019) *Annual climate statement 2018*, http://www.bom.gov.au/climate/current/annual/aus/

[37] IPCC (2019) *Special report: Global Warming of 1.5 ºC*, https://www.ipcc.ch/sr15/

Australia's emissions are currently rising.[38] The Australian Government's current policies are consistent with up to 4 degrees warming,[39] a scenario the World Bank describes as

> …devastating: the inundation of coastal cities; increasing risks for food production potentially leading to higher malnutrition rates; many dry regions becoming dryer, wet regions wetter; unprecedented heat waves in many regions, especially in the tropics; substantially exacerbated water scarcity in many regions; increased frequency of high-intensity tropical cyclones; and irreversible loss of biodiversity, including coral reef systems.[40]

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[38] Long (2019) *Australia's carbon emissions continue to rise despite Government assurances about climate change policy*, https://www.abc.net.au/news/2019-08-30/emissions-drop-but-year-long-trend-on-the-rise/11464816

[39] Climate Action Tracker (2019) *Country reports: Australia* https://climateactiontracker.org/countries/australia/

[40] World Bank (2013) *Turn down the heat: Why a 4°C Warmer World Must be Avoided*, p 10, https://openknowledge.worldbank.org/handle/10986/11860

Conclusion

Climate change has already led to significant changes in Australia's seasons, including the expansion of summer by one month.

These changes have profound implications for life in Australia. Longer hotter summers mean longer bushfire seasons and more heatwaves. Heatwaves have serious health impacts, damage important industries and particularly affect workers required to undertake activities outside or in un-air-conditioned spaces. Disruption to the seasons and increasing temperatures are a threat to many plants, in our gardens and natural environment, as well as the agricultural crops we rely on for food.

Ordinary activities that we currently take for granted like sport or socialising outdoors will become less enjoyable and sometimes dangerous.

This trend will continue unless emissions are reduced decisively. Australia is one of the highest per capita emitters in the world, as well as the largest coal and Liquefied Natural Gas exporter globally. The emissions from Australia's coal and gas exports are double the amount of emissions produced domestically in Australia.

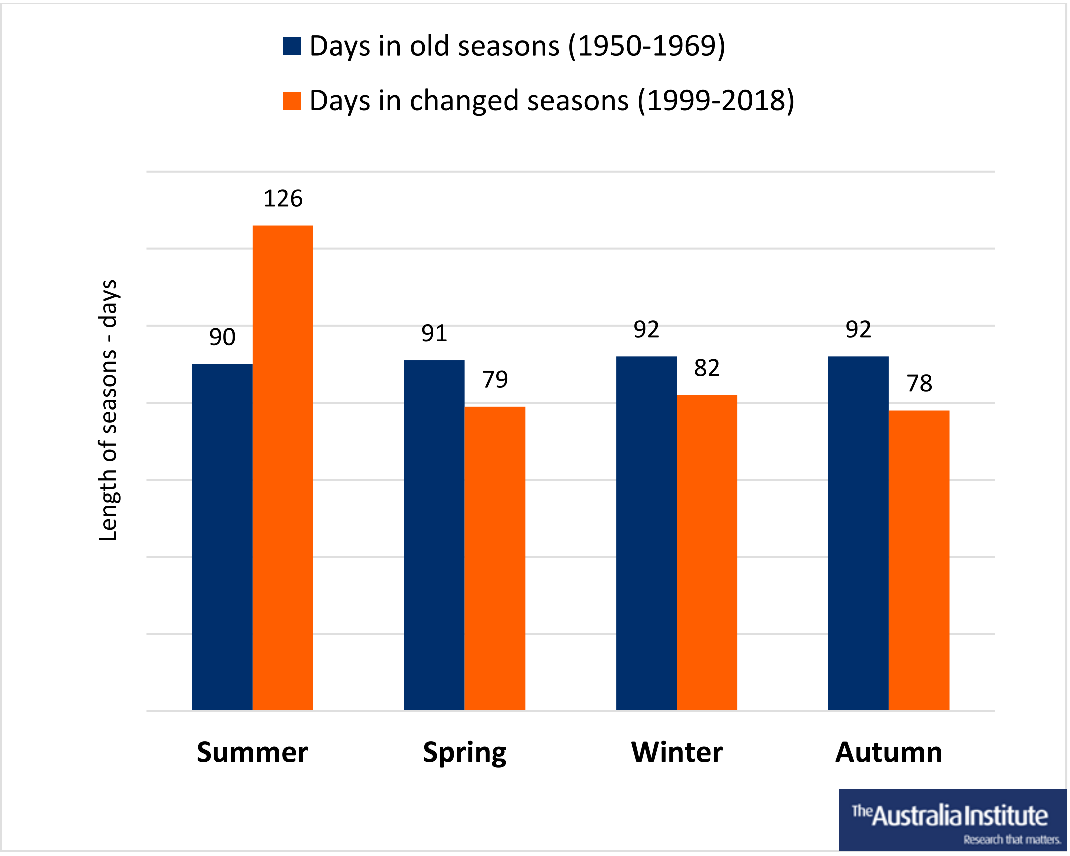
These changes have happened with warming of around 1 degree Celsius to date. Current Australian Government policies are consistent with 3-4 degrees warming within the lifetime of today's young Australians.

Appendix 1: Season changes in Australian cities

ADELAIDE

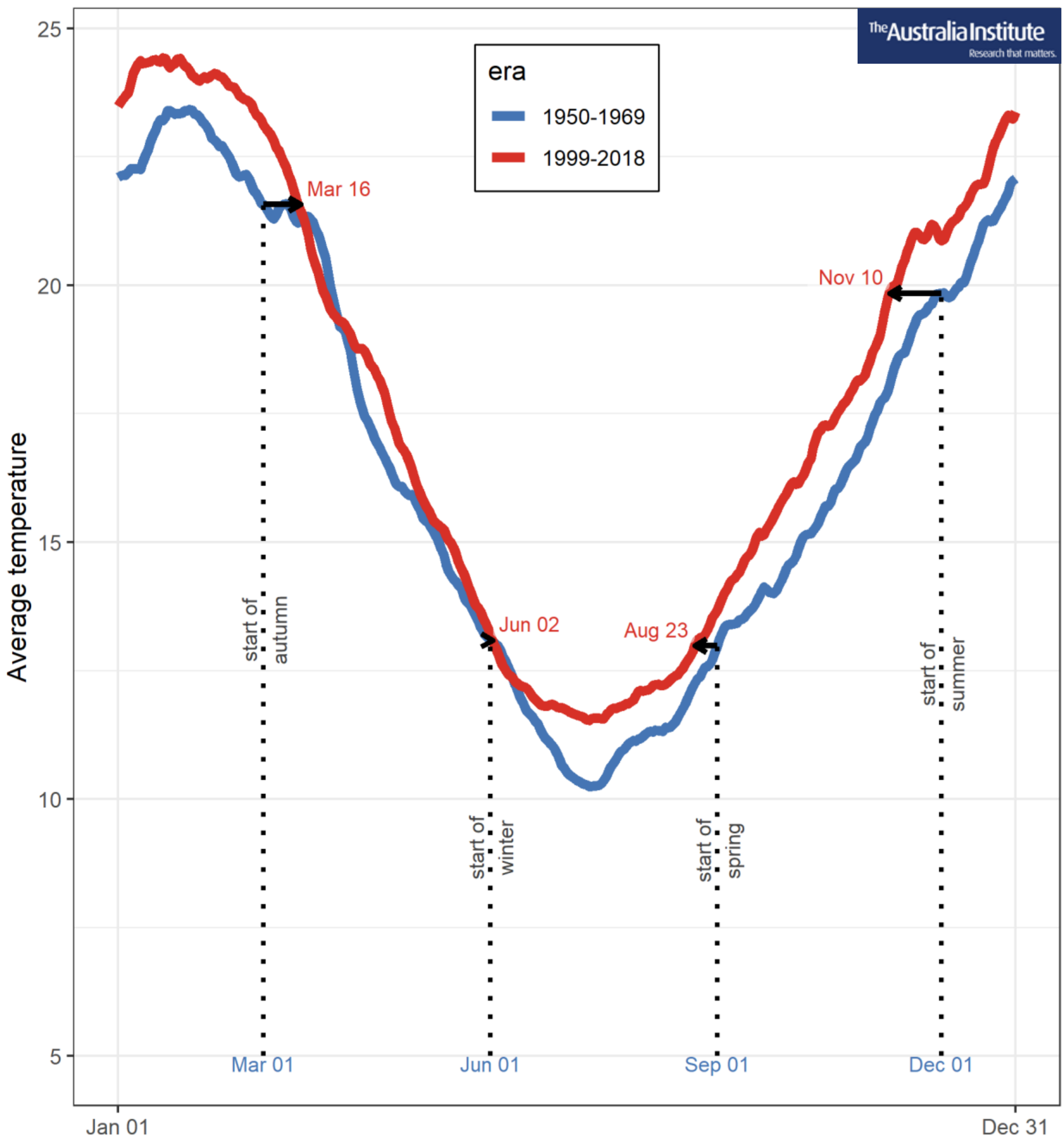
Data is from Kent Town weather station.

Figure 11: Changes in length of seasons for ADELAIDE



Source: BoM, ACORN-SAT, comparing daily average temperatures 1999-2018 vs those at the start of each season in benchmark period 1950-69; described in text.

Figure 12: Changing seasons and average daily temperature in Adelaide



Source: BoM, ACORN-SAT, analysis of data as described in text.

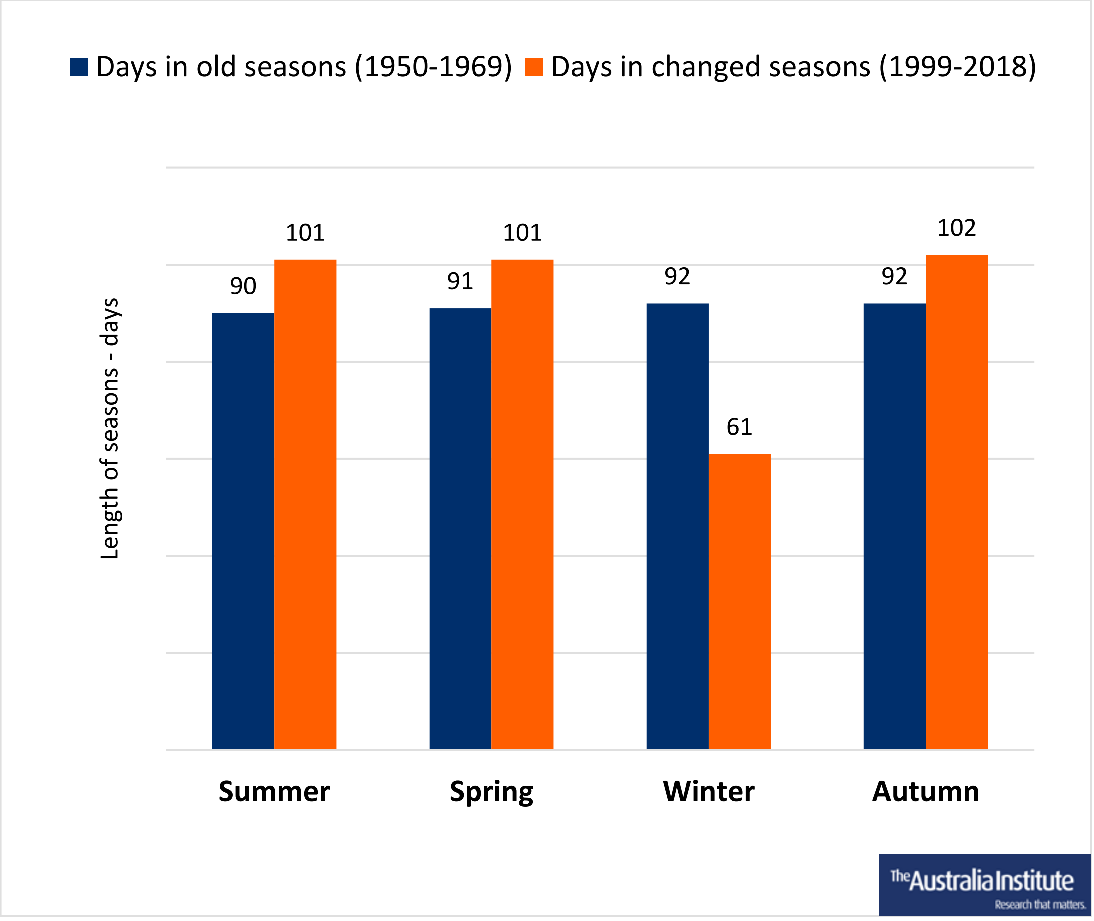
Starting temperatures:

- Summer: 19.8°C
- Autumn: 21.5°C
- Winter: 13.0°C
- Spring: 12.9°C

BRISBANE

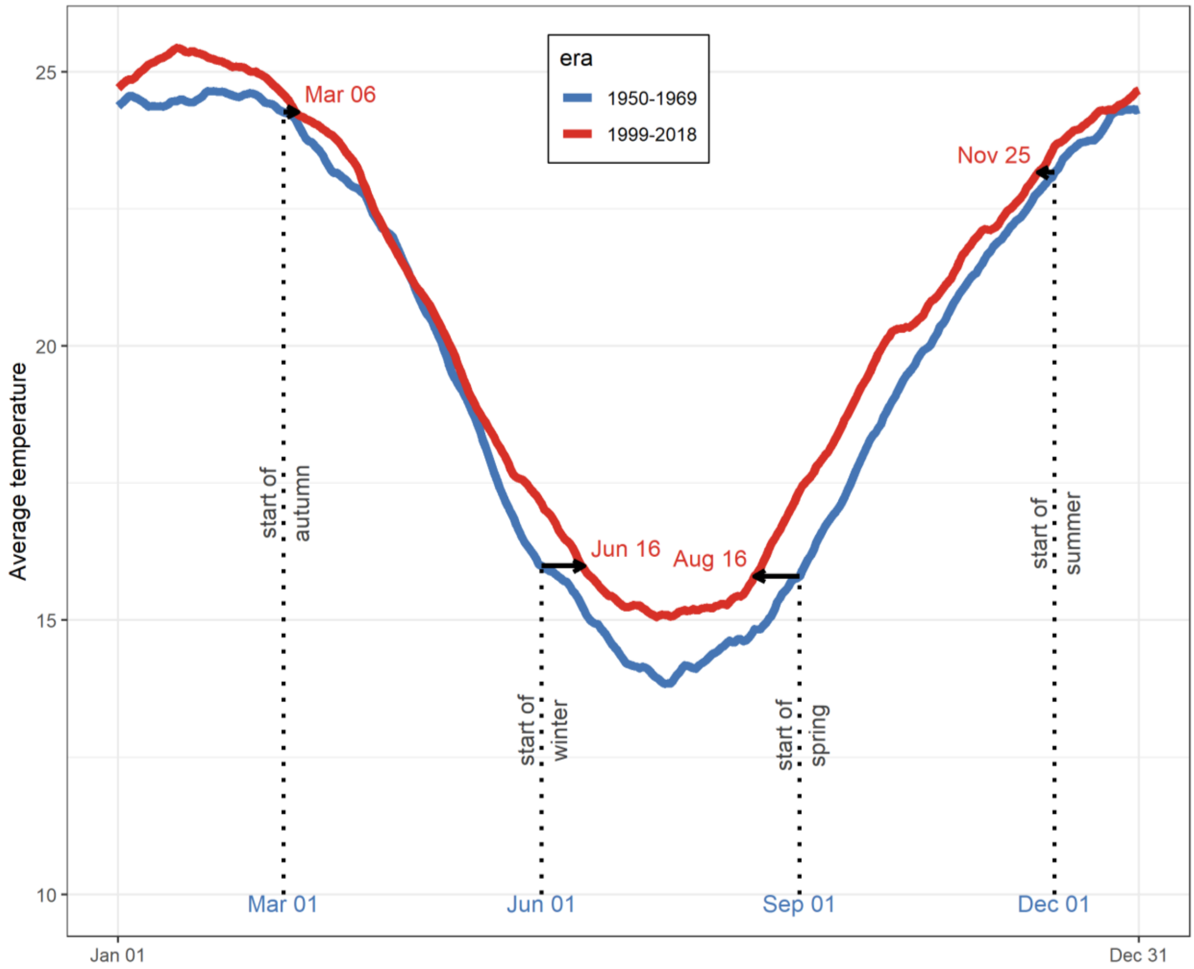
Data is from Brisbane Airport.

Figure 13: Changes in length of seasons for BRISBANE.



Source: BoM, ACORN-SAT, comparing daily average temperatures 1999-2018 vs those at the start of each season in benchmark period 1950-69; described in text.

Figure 14: Changing seasons and average daily temperature in Brisbane



Source: BoM, ACORN-SAT, analysis of data as described in text.

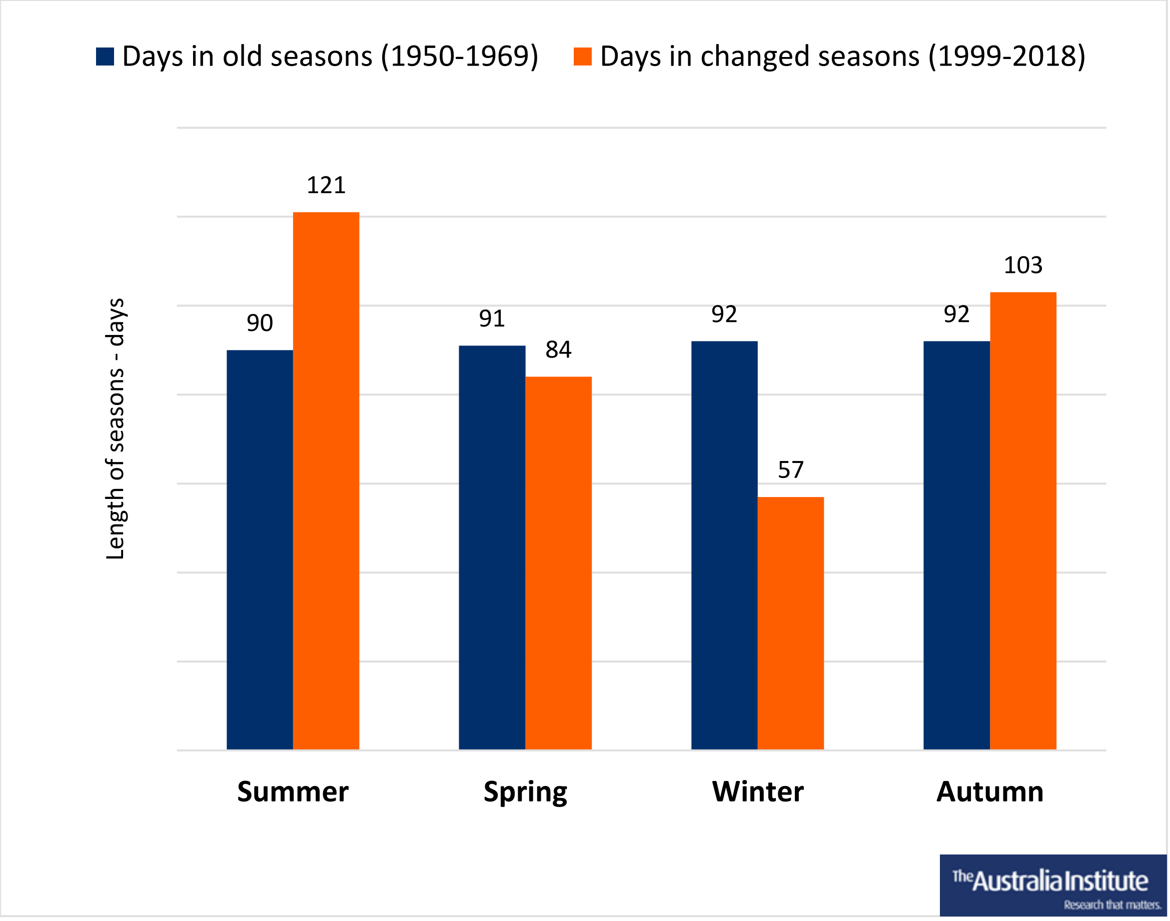
Starting temperatures:

- Summer: 23.1°C
- Autumn: 24.2°C
- Winter: 15.9°C
- Spring: 15.8°C

CANBERRA

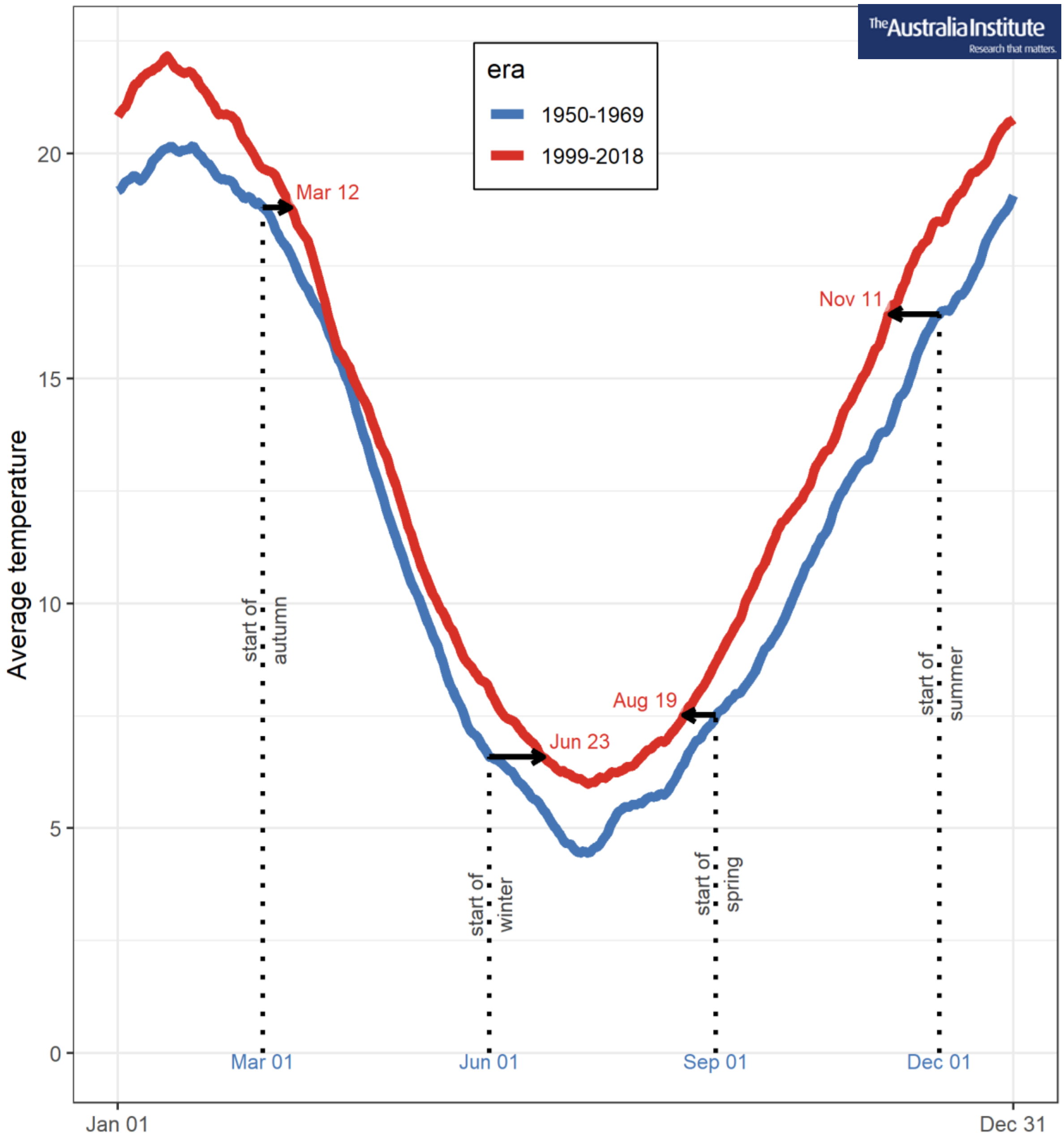
Data is drawn from Canberra Airport weather station.

Figure 15: Changes in length of seasons for CANBERRA



Source: BoM, ACORN-SAT, comparing daily average temperatures 1999-2018 vs those at the start of each season in benchmark period 1950-69; described in text.

Figure 16: Changing seasons and average daily temperature in Canberra



Source: BoM, ACORN-SAT, analysis of data as described in text.

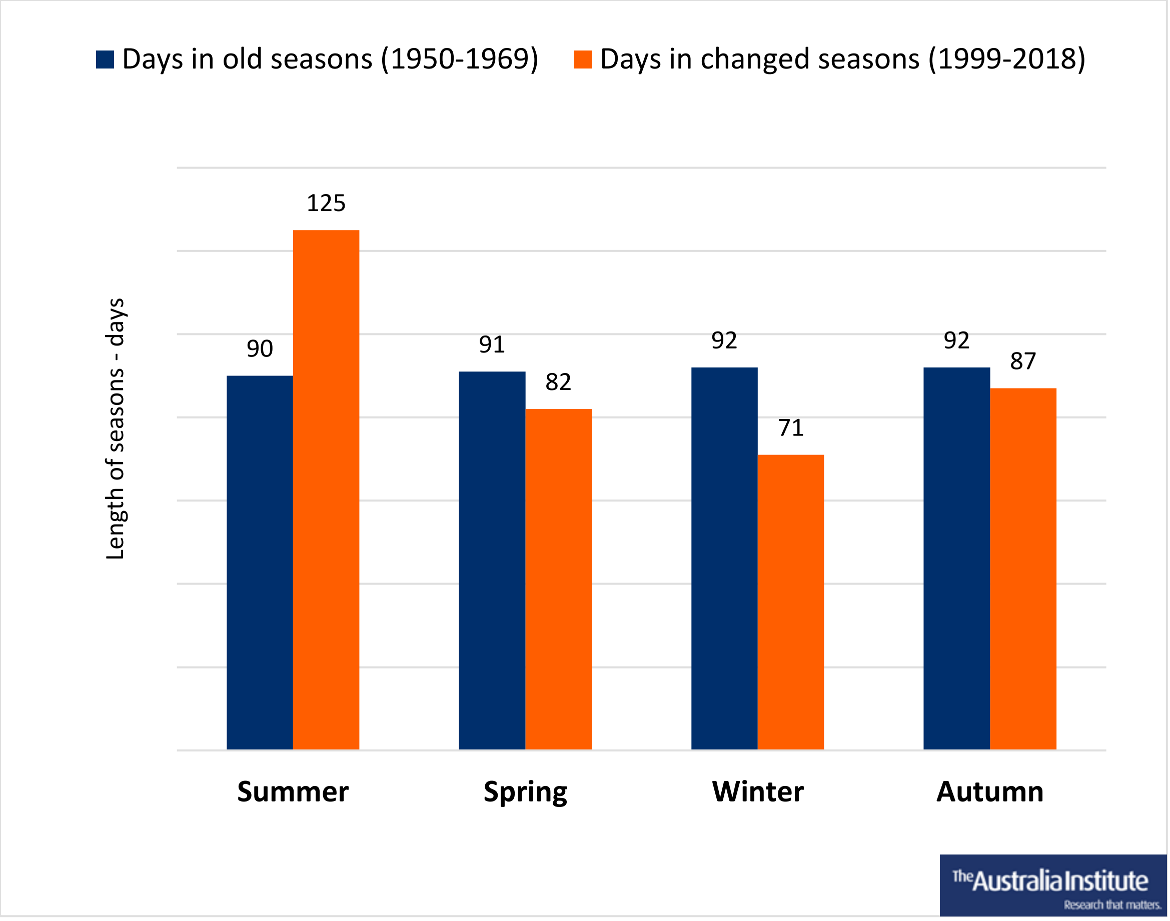
Starting temperatures

- Summer: 16.4°C
- Autumn: 18.8°C
- Winter: 6.58°C
- Spring: 7.51°C

HOBART

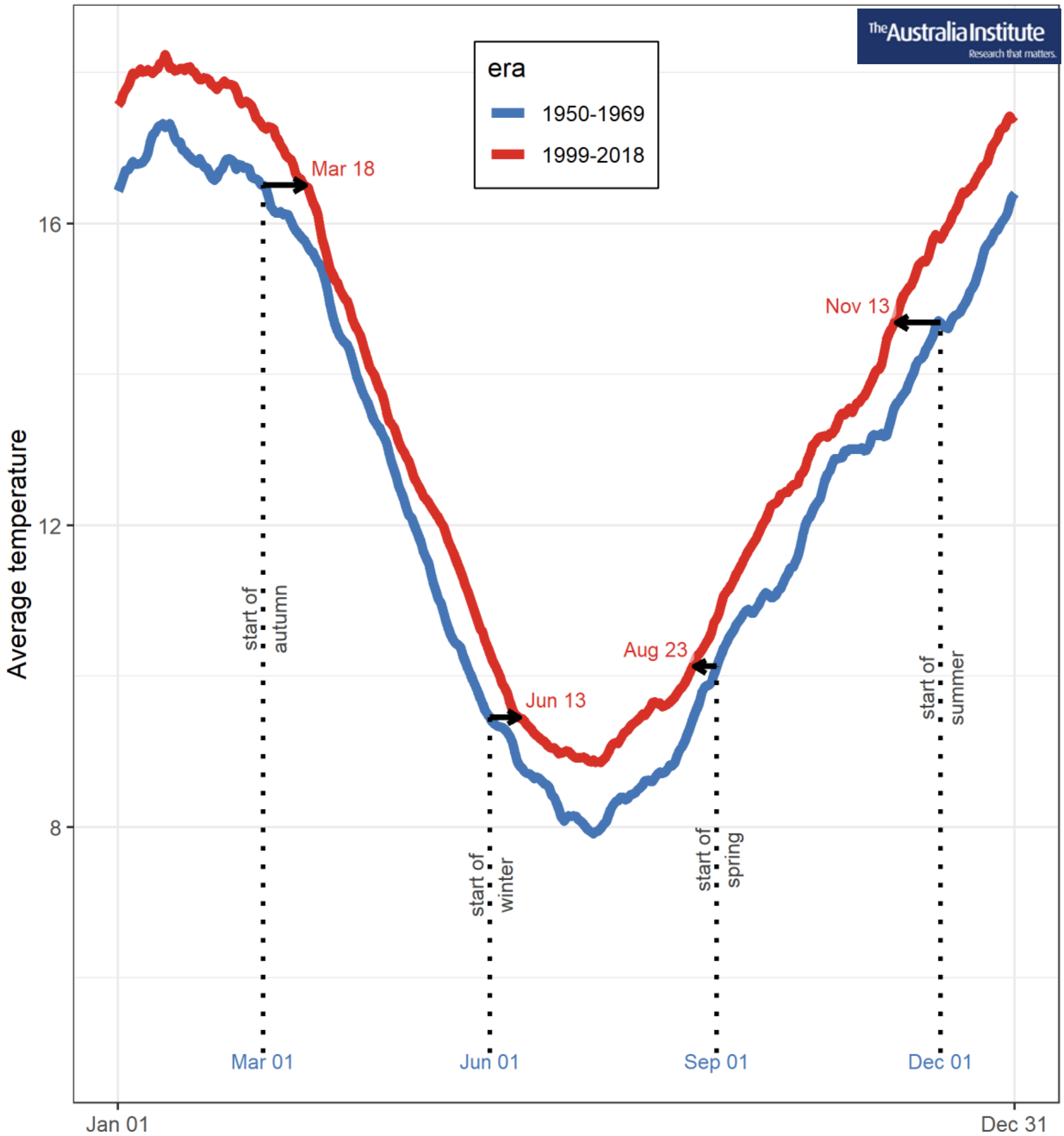
Data is drawn from the Ellerslie Road weather station.

Figure 17: Changes in length and starting time of seasons for HOBART



Source: BoM, ACORN-SAT, comparing daily average temperatures 1999-2018 vs those at the start of each season in benchmark period 1950-69; described in text.

Figure 18: Changing seasons and average daily temperature in Hobart



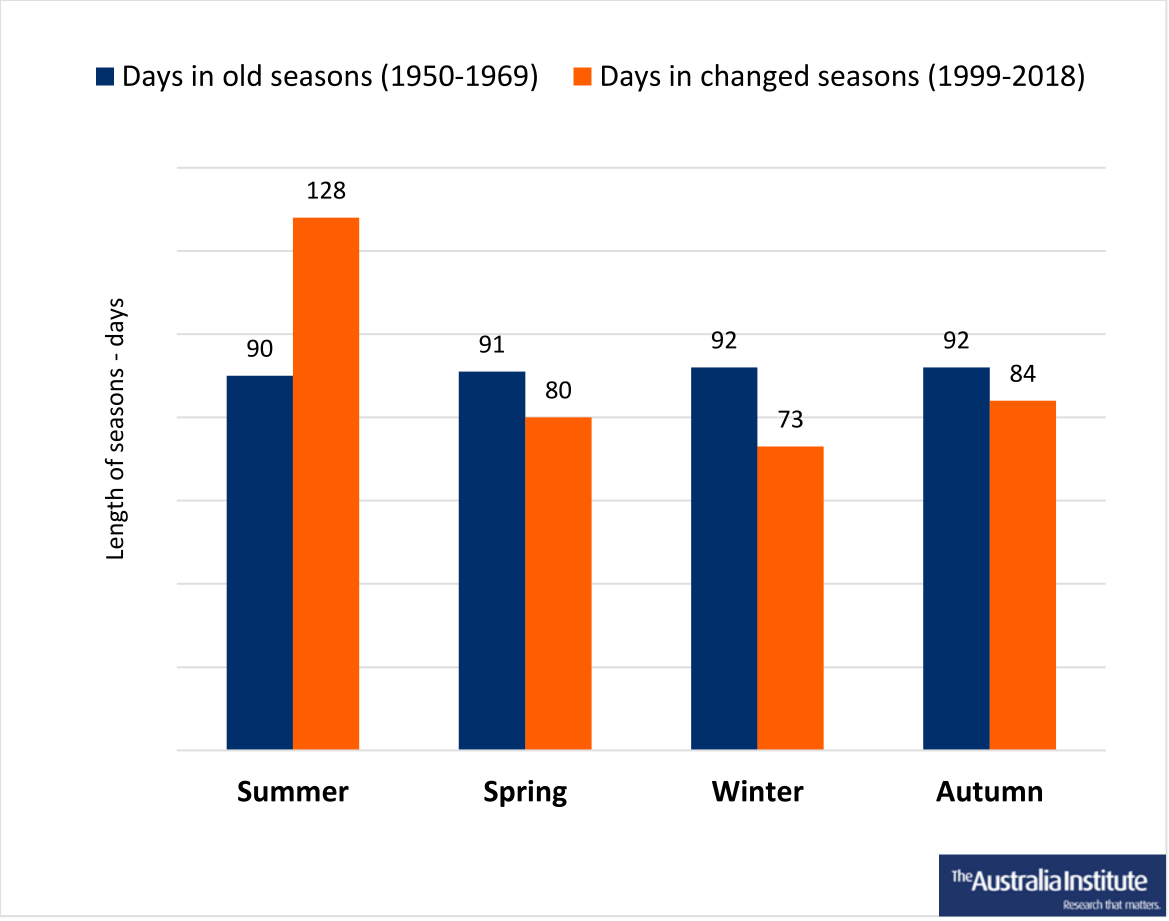
Starting temperatures

- Summer: 14.6°C
- Autumn: 16.5°C
- Winter: 9.45°C
- Spring: 10.1°C

MELBOURNE

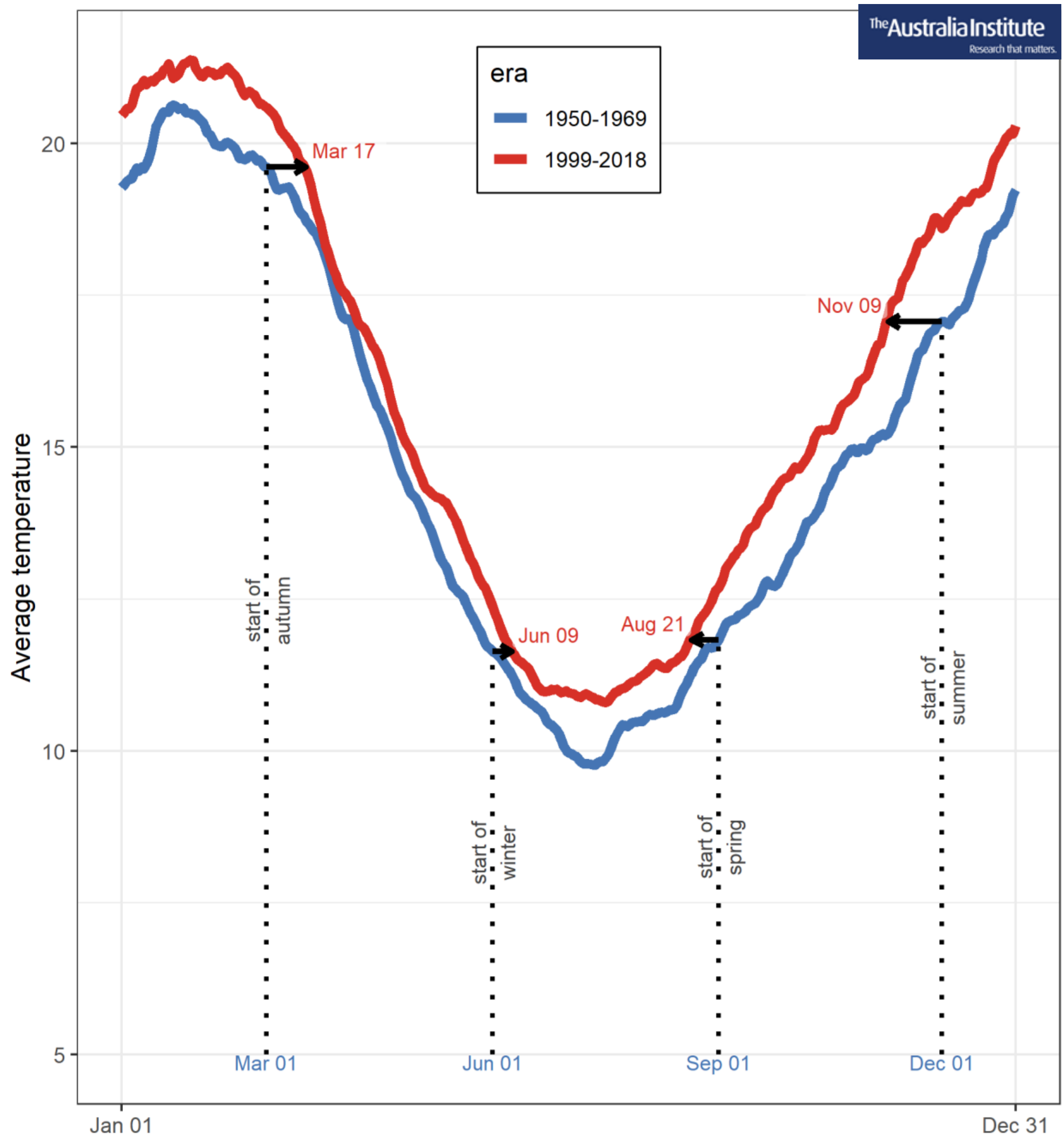
Data is from the Olympic Park weather station.

Figure 19: Changes in length and starting time of seasons for MELBOURNE.



Source: BoM, ACORN-SAT, comparing daily average temperatures 1999-2018 vs those at the start of each season in benchmark period 1950-69; described in text.

Figure 20: Changing seasons and average daily temperature in Melbourne



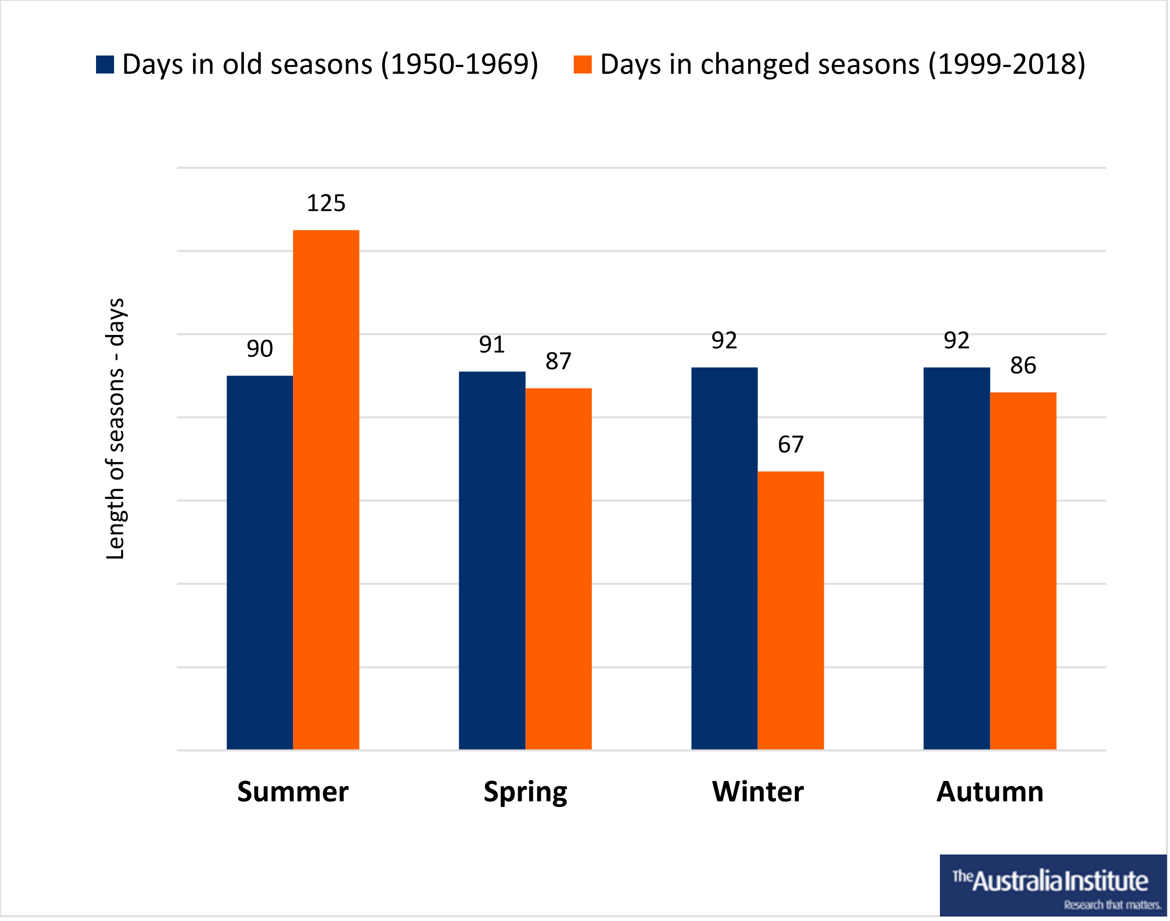
Starting temperatures

- Summer: 17.0°C
- Autumn: 19.6°C
- Winter: 11.6°C
- Spring: 11.8°C

PERTH

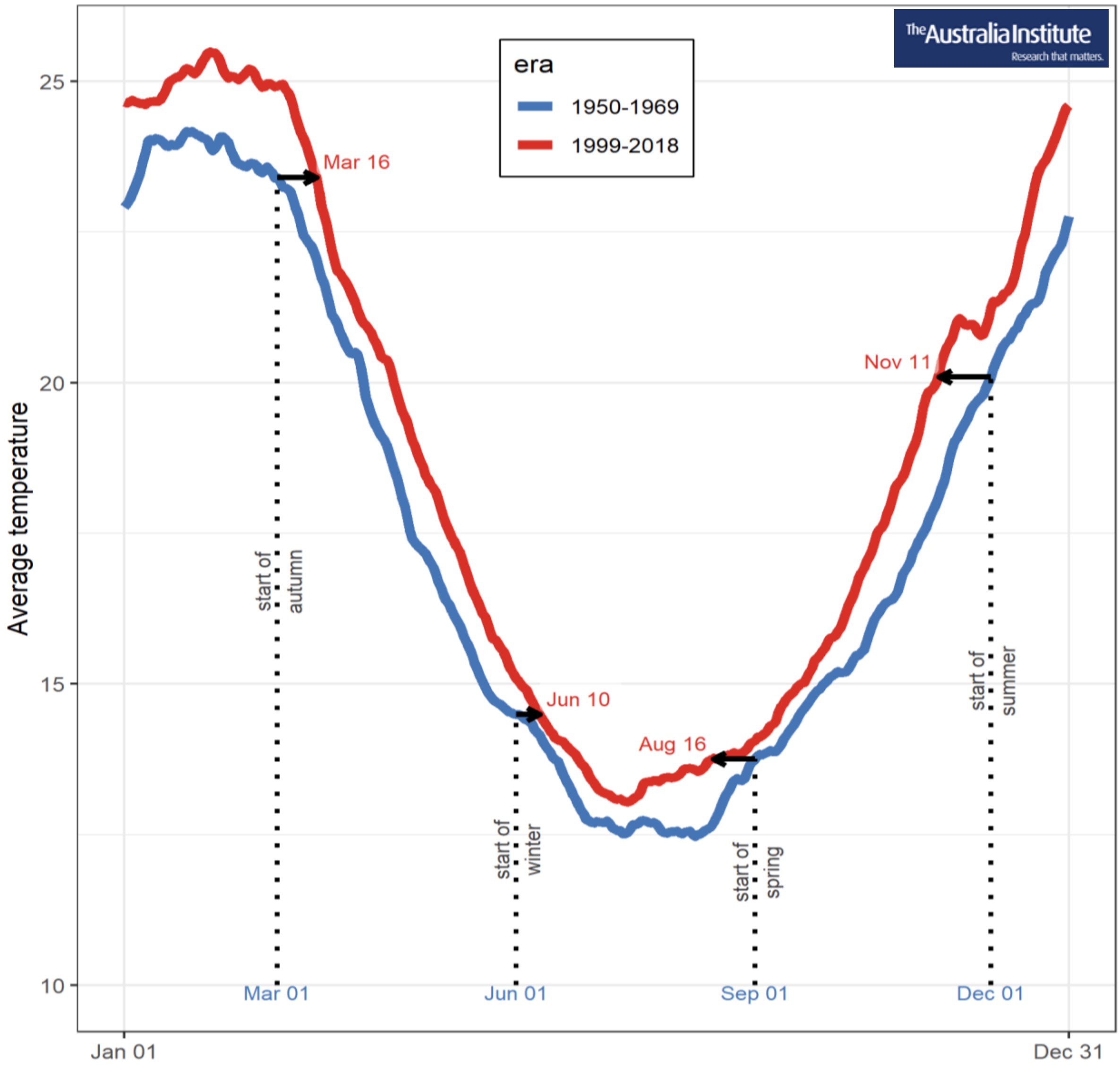
Data is drawn from Perth Airport weather station.

Figure 21: Changes in length and starting time of seasons for PERTH



Source: BoM, ACORN-SAT, comparing daily average temperatures 1999-2018 vs those at the start of each season in benchmark period 1950-69; described in text.

Figure 22: Changing seasons and average daily temperature in Perth



Source: BoM, ACORN-SAT, analysis of data as described in text.

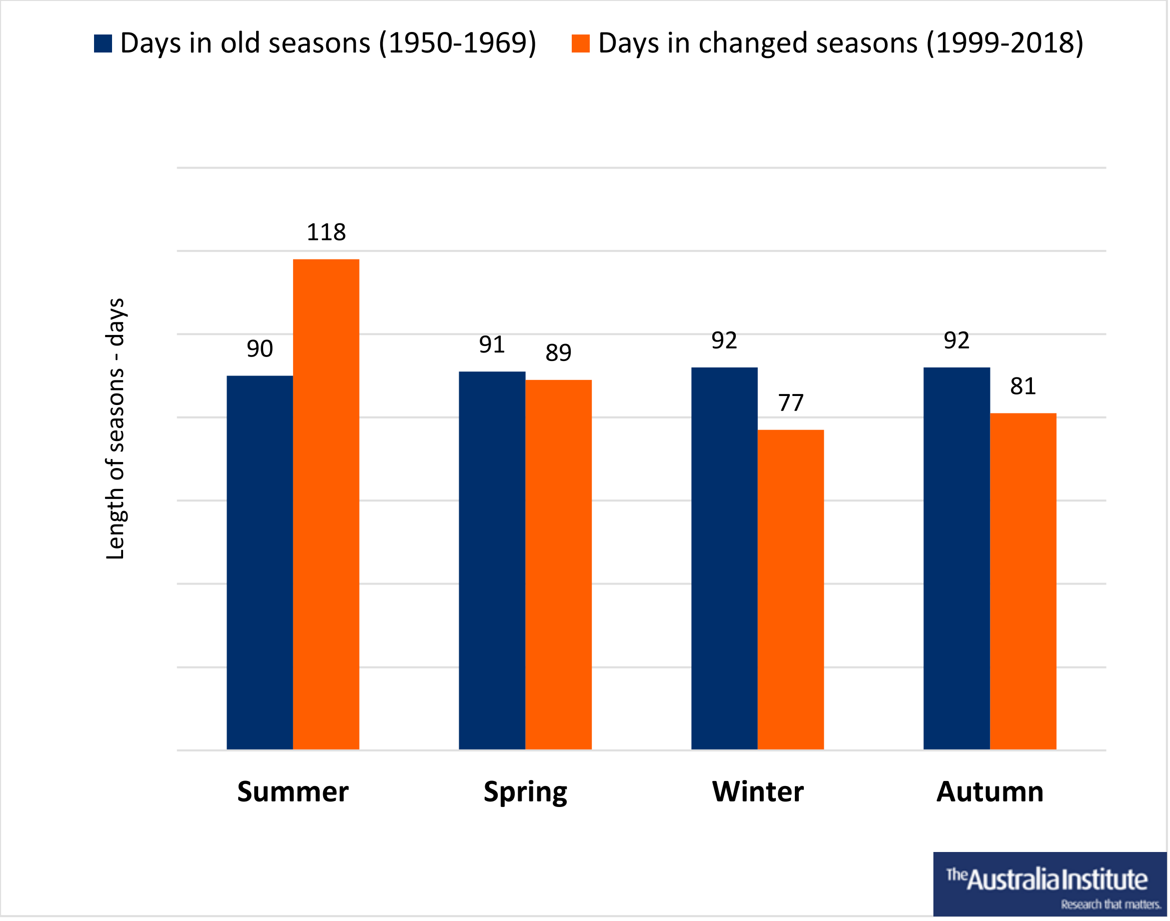
Starting temperatures

- Summer: 20.0°C
- Autumn: 23.4°C
- Winter: 14.4°C
- Spring: 13.7°C

SYDNEY

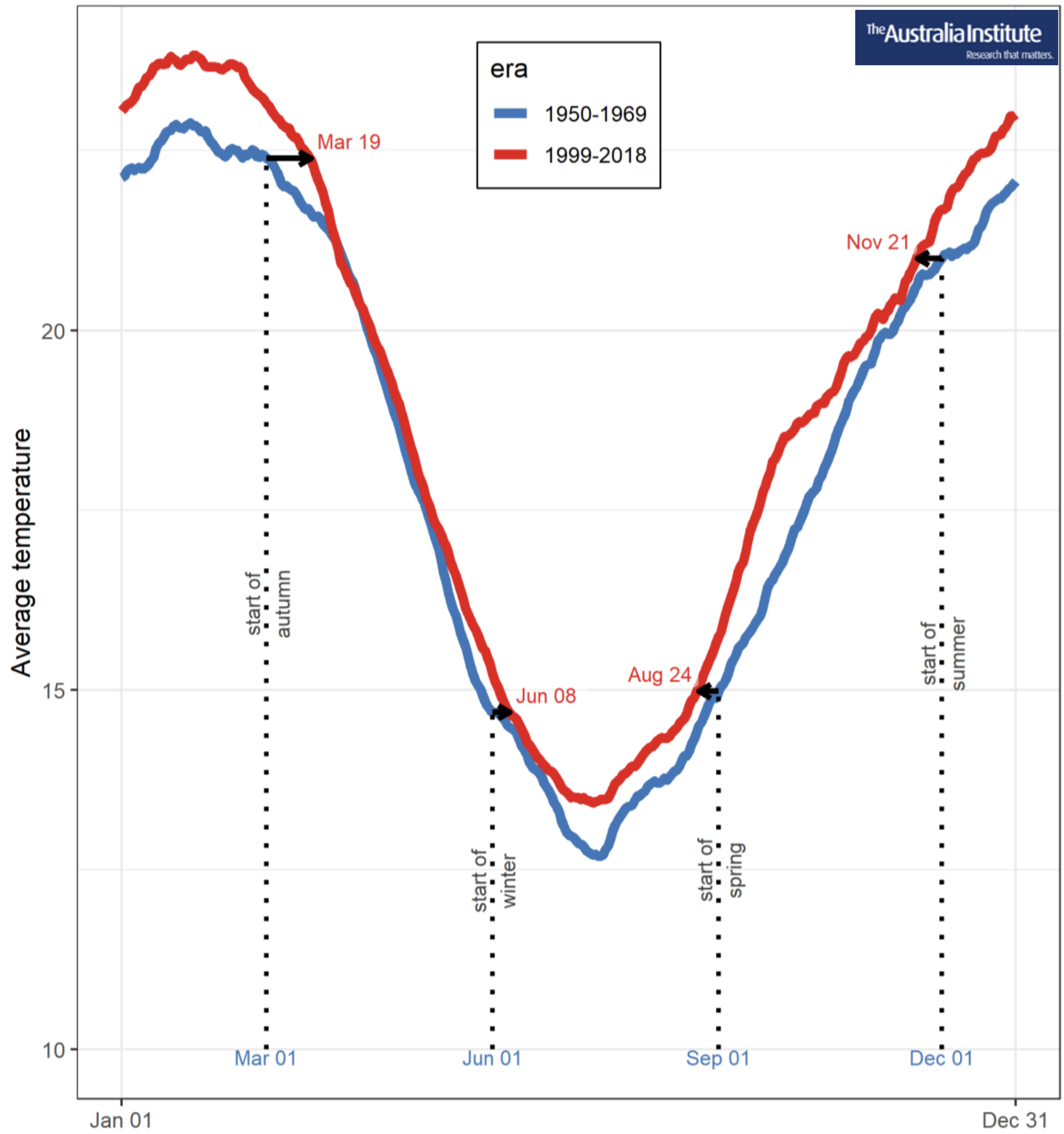
Data is from the Observatory Hill weather station.

Figure 23: Changes in length of seasons for SYDNEY



Source: BoM, ACORN-SAT, comparing daily average temperatures 1999-2018 vs those at the start of each season in benchmark period 1950-69; described in text.

Figure 24: Changing seasons and average daily temperature in Sydney



Source: BOM ACORN-SAT, as described in method section

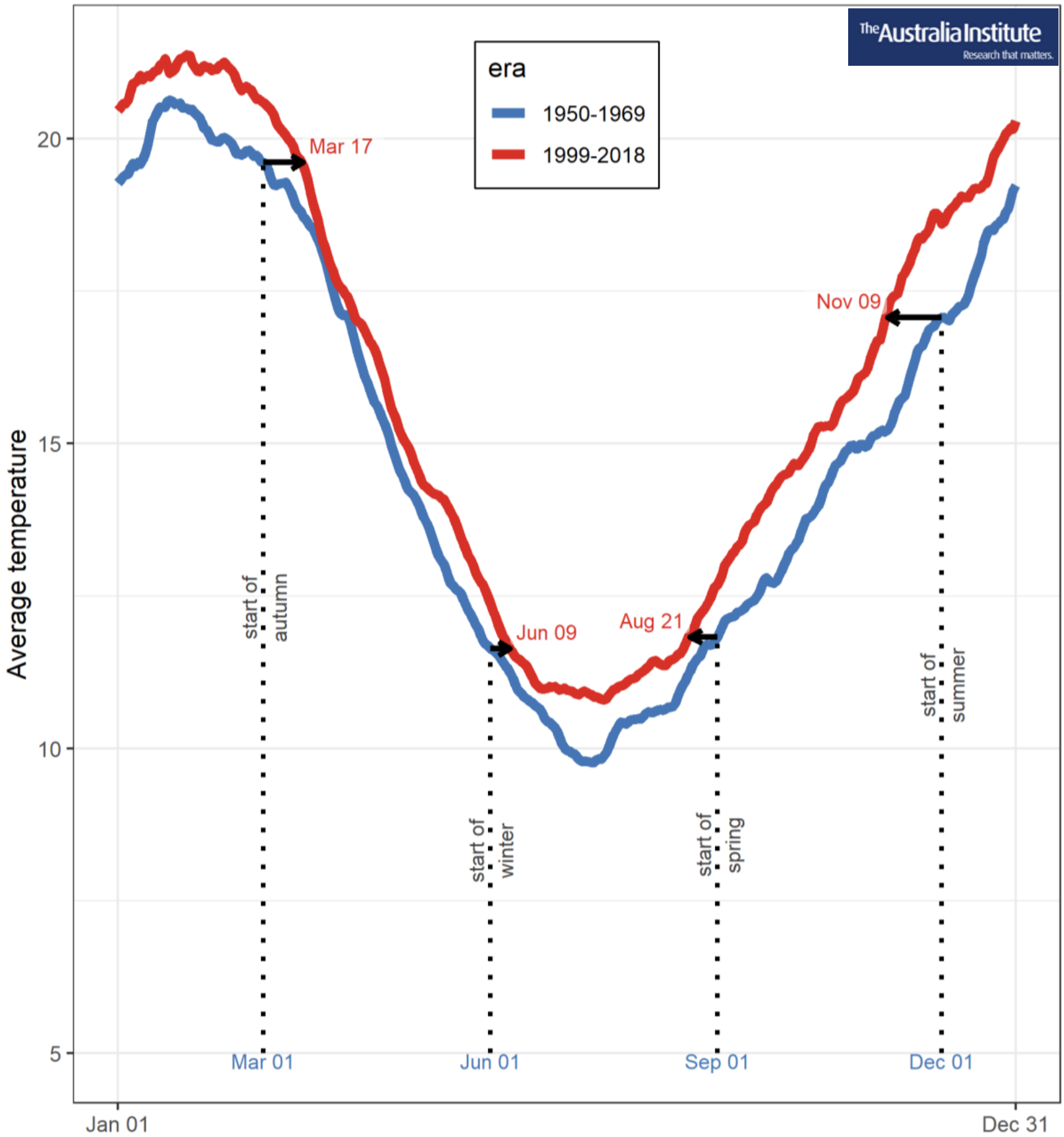
Starting temperatures

- Summer: 20.9°C
- Autumn: 22.3°C
- Winter: 14.6°C
- Spring: 14.9°C

Appendix 2: Detailed methodology

Figure 1 below for Melbourne illustrates the basic methodology. The blue line shows the average temperatures measured at the Melbourne Olympic Park weather station from 1950-69, and the red line shows average temperatures for 1999-2018. The average temperatures for virtually every day of the year are higher over the last 20 years than during the 1950s and 60s.

Figure 25: Melbourne - change in temperatures and seasons, 1950-69 and 1999-2018



Source: BoM, ACORN-SAT, analysis of data as described in text.

Analysis was conducted for 66 individual weather stations where the data for 1950 was missing data for no more than 10% of the days.

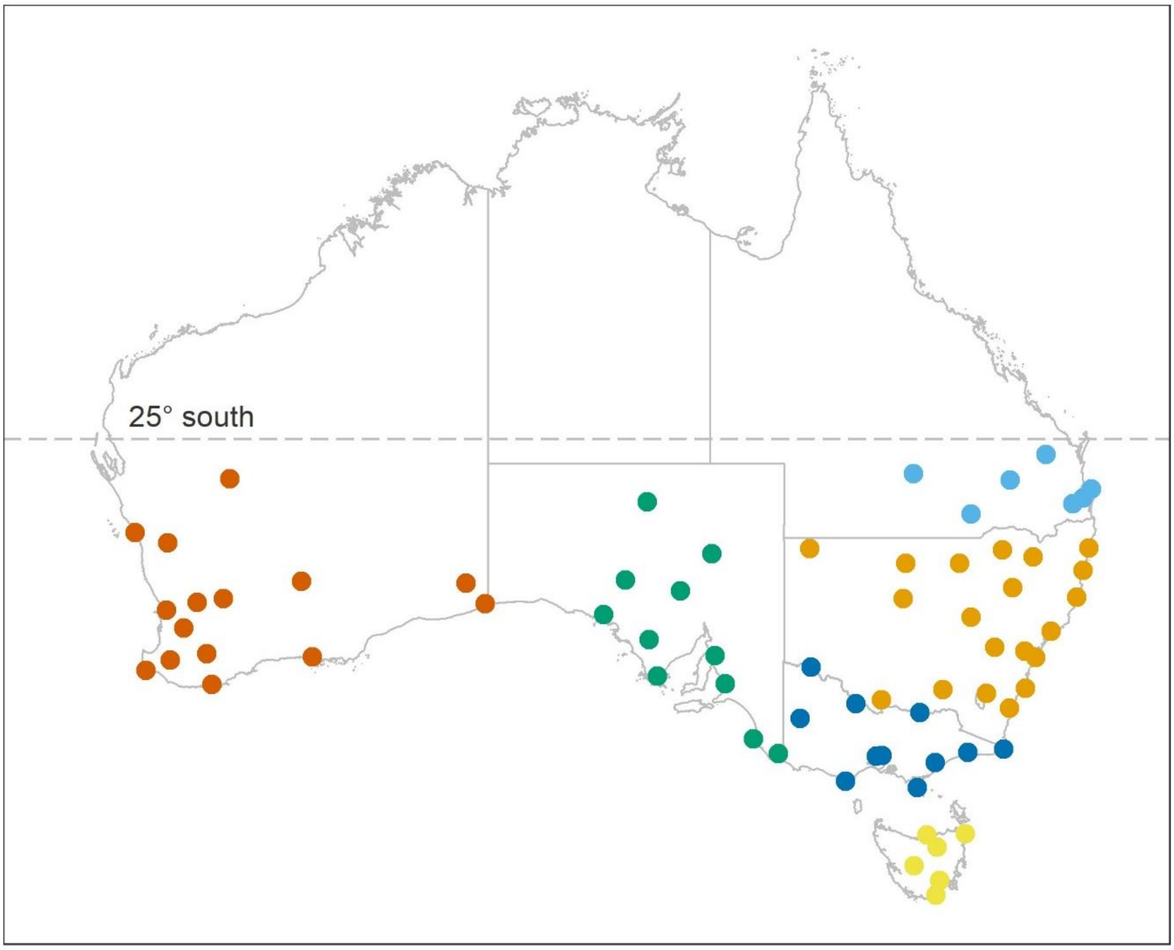
In each era (1950-1969 or 1999-2018), the average temperature line in the graph above was calculated as follows:

1. For each date (e.g. 15 July 1950), calculate the average of the observed daily maximum and daily minimum temperatures (the Daily Mean Temperature (DMT)).
2. For each day of the year (such as 15 July) in each of the two decade eras, calculate the mean of the DMTs on that day across all years in the era (The Average Daily Mean Temperature (ADMT))
3. For each day of the year, calculating the mean of all ADMTs within 10 days of each day in each era (the Average Temperature (AT)). For example, the AT for 15 July in the era 1950-1969 is the mean of all ADMTs between 5 July and 25 July across all 20 years.
4. The start of each season (autumn, winter, spring, summer) for any given era is defined as being the first day of the year when the AT line crosses the corresponding AT for 1 March, 1 June, 1 September and 1 December in the reference period 1950-1969.

COMBINED RESULTS

Data was drawn from ACORN-SAT stations south of 25 degrees latitude south with observations going back to 1950. There are 70 such stations, shown in Figure 26 below. These are the stations where temperature observations started before or in the year 1950.

Figure 26: Weather stations used in analysis of season changes



Source: BoM ACORN-SAT stations south of 25 degrees S with data 1950-2018

The observations from all 70 stations were combined in the following way:

1. The AT for each day of the year was calculated for each station as described above.
2. For each day of the year and era, the mean of the ATs across all 70 stations was calculated. This gives the combined AT for each day of the year and era.
3. This allows the construction of the average temperature graph and subsequent calculation of seasonal changes, as per the method described above.

The starting temperatures for each month, defined in the benchmark period, were

- Autumn: 21.7°C
- Winter: 12.2°C
- Spring: 12.3°C
- Summer: 19.8°C

This combined analysis was tested for robustness by using different criteria for including weather stations. In the test, weather stations were included only if each day of the year had no more than 5 missing observations within a 20 year era. The resulting lengths of the seasons differed by a day or less when compared with the present analysis.

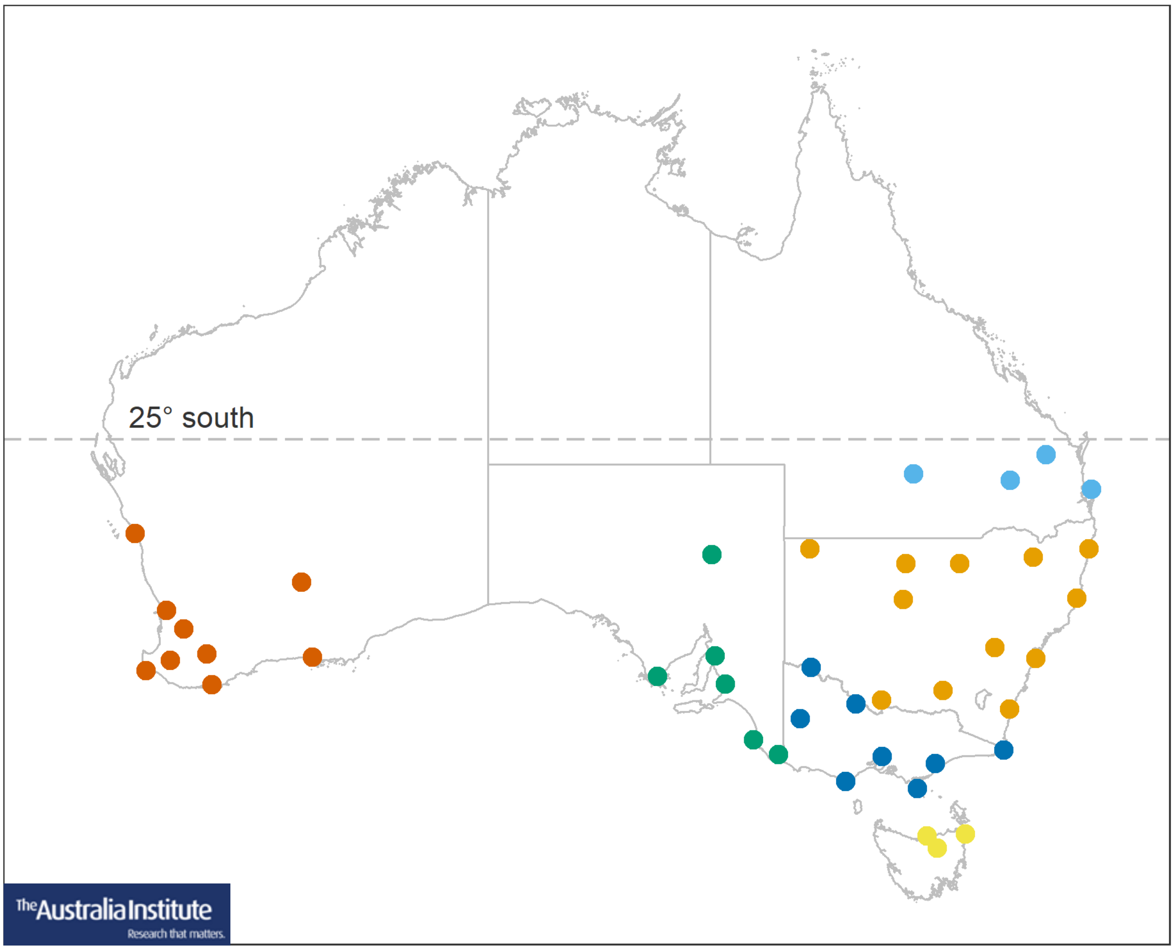
The analysis was also conducted with weather stations both above and below 25 degrees latitude south. This analysis found similarly long summers to the analysis conducted only with stations below 25 degrees, confirming that the result was not an result of choice of stations. However as tropical seasons centre on the wet and the dry, rather than summer and winter, the results presented here focus on the southern, non-tropical stations.

CHOICE OF BENCHMARK ERA

The benchmark era 1950-1969 is a conservative choice as the basis for historical comparison, with a larger number of weather stations from which to draw data than earlier benchmark choices.

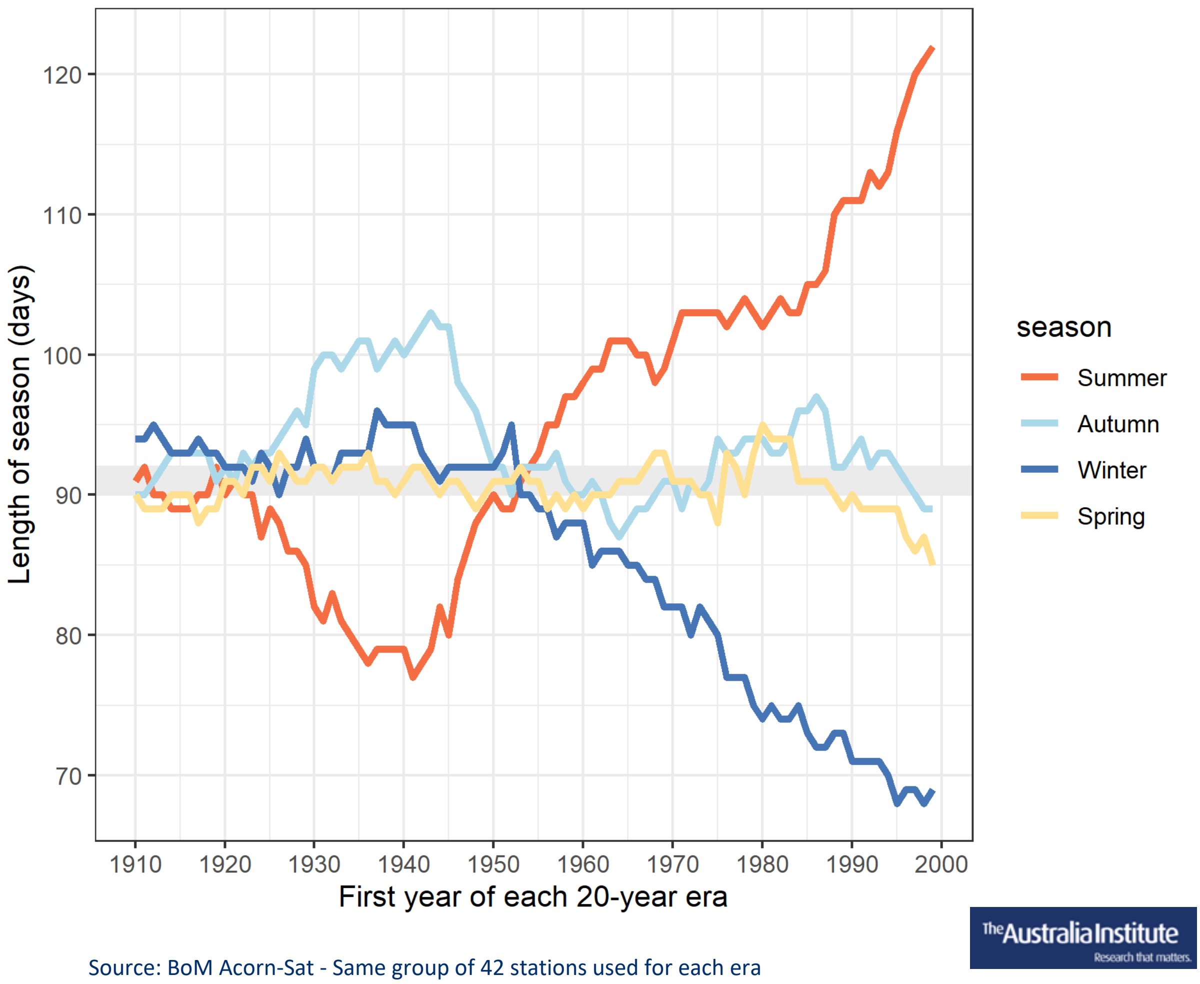
The conservative nature of the choice can be seen by comparing the benchmark era compares with earlier eras. Using 1950-1969 as the benchmark, we calculated the length of summer for every 20-year era starting from 1910-1929 with yearly increments. To allow direct comparison between eras, only the 42 stations that had data for all eras were used. These stations are shown on the map in Figure 27 below.

Figure 27: Location of weather stations for analysis of season changes 1910-1929



The length of the seasons, benchmarked against 1950-1969 temperatures, for each era is shown in the Figure 28 below. The labels on the horizontal axis give the first year of each era (so that, for example, winter for the era 1940-1959 was 95 days long).

Figure 28: Length of seasons in temperate and subtropical Australia vs 1950-69



Source: BoM Acorn-Sat - Same group of 42 stations used for each era

The general trend since the 50s and 60s is an increase in the length of summer at the expense of winter. In the early part of the twentieth century, season lengths were similar to the 1950-1969 benchmark era, followed by a dip in the length of summer during the late 20s to the 40s which was largely balanced by an increase in the length of Autumn.

An earlier benchmark era could have been chosen, with the disadvantage that fewer stations would be included in the analysis. For example, if the benchmark era were 1910-1929 (the earliest possible 20-year era that can be analysed with the ACORN-SAT temperature data), only 42 stations could be used in the analysis, in contrast to 70 stations in the present study.

Two further points to note:

- The lengths of the seasons for the era 1999-2018 using the 42 station data set are very similar to those using the 70 station dataset (which forms the main basis for this study).

- The results using the 1950-1969 era as a benchmark are very similar to those obtained using a benchmark era in the early part of the twentieth century (for example, the era 1922-1941).

Beyond these considerations, the benchmark era is significant as it reflects the period that saw the post-war acceleration of greenhouse gas emissions, as well as the birth and coming of age of large cohort of the Australia population, the baby boomers. This study emphasises changes that have occurred in their lifetime.

TECHNICAL NOTES

Leap years

To simplify calculations, all observations on 29 February were removed. The annual calendar is treated as having 365 days only. Leap years were included in the analysis but with 29 February removed.

When new winter temperatures do not reach the historical start of spring temperatures

In some instances, the average temperature on 1 September over 1950-69 is no longer within the range of average temperatures over the period 1999-2018. Figure 29 below shows an example from Cape Leeuwin in Western Australia.

In such cases case, the start of spring for 1999-2018 can be defined to be the minimum average temperature of that era. This is typically the point in the annual cycle in which average temperatures begin to increase again.

Both the average temperatures recorded on 1 June and 1 September in the 50s and 60 were observed during the period 1999-2018 at each of the stations measured. But if (or when) that were to occur, it would result in the exclusion of winter from the seasonal calendar.

Figure 29: Cape Leeuwin - change in average temperatures and seasons