QUANTIFYING THE IMPACT OF CLIMATE CHANGE ON **EXTREME HEAT IN AUSTRALIA**

The Climate Council is an independent, crowd-funded organisation providing quality information on climate change to the Australian public.

CLIMATECOUNCIL.ORG.AU

Authorship:
Will Steffen

Published by the Climate Council of Australia Limited

ISBN: 978-0-9942453-1-1 (print)
978-0-9942453-0-4 (web)

This report is printed on 100% recycled paper.

Professor Will Steffen
Climate Councillor

Key Findings

1. **Climate change is making Australia hotter. Hot days are happening more often while heatwaves are becoming hotter, longer and more frequent.**

   - The annual number of record hot days across Australia has doubled since 1960. Over the past 10 years the number of record hot days has occurred three times more frequently than the number of record cold days.
   - The annual occurrence of very hot days across Australia has increased strongly since 1950 and particularly sharply in the last 20 years.
   - Over the 1950-2013 period many characteristics of heatwaves have changed across Australia. They are becoming hotter, lasting longer, occurring more often and starting earlier.
   - All extreme heat events are now occurring in an atmosphere that is significantly hotter than it was 50 years ago.

2. **While it has been clear for many years that climate change is a major factor in intensifying heat, recent scientific advances now allow us to understand the extent of the impact on individual extreme events. Climate change has significantly worsened recent extreme heat events in Australia.**

   - The record hot year of 2013 in Australia was virtually impossible without climate change.
   - Climate change tripled the odds that the heatwaves of the 2012/2013 Australian summer would occur as frequently as they did.
   - Climate change doubled the odds that the 2012/2013 heatwaves would be as intense as they were.

3. **The new research showing the strong influence of climate change on heat events strengthens the case for strong action on climate change.**

   - Carbon emissions must be reduced rapidly and deeply if the worst of extreme heat in the second half of the century is to be avoided.
   - Clean energy technologies are advancing rapidly and international action is ramping up, building momentum towards a decarbonised future.

1. Climate change and extreme heat

New ground-breaking scientific research in 2014 can now tell us just how much of an influence climate change has on a single heatwave or heat records.

Climate change is increasing the intensity and frequency of many extreme weather events, with adverse impacts on Australians. Extreme heat is one the most important of these events. In fact, more Australians die every year from extreme heat than from any other type of natural disaster. Extreme heat can damage infrastructure such as electricity distribution and transport systems, while hot, dry conditions have a major influence on bushfires (Figure 1).

For many years it has been clear that climate change is making Australia hotter. Hot days are happening more often while heatwaves are becoming hotter, longer and more frequent. However, new ground-breaking scientific research in 2014 can now tell us just how much of an influence climate change has on a single heatwave or heat records. Understanding this shows us just how damaging climate change has already become.

More Australians die every year from extreme heat than from any other type of natural disaster

Figure 1: Firefighters at work in Belrose, NSW. Hot, dry conditions have a major influence on bushfires in Australia.

2. Observing long-term changes in extreme heat

The recent research showing the strong influence of climate change on individual heat events comes on top of an increasingly strong body of observations that clearly show the link between extreme heat and climate change.

Climate change is stacking the odds towards record heat. Record hot days have doubled in Australia in the last 50 years, while record cold days have declined by a similar fraction (CSIRO and BoM 2012). Over the last decade, hot weather records were set three times more often than cold weather records (Trewin and Smalley 2013). The exceptionally large number of record high temperatures set during the Angry Summers of 2012/2013 and 2013/2014 are further evidence of this pronounced trend (Climate Commission 2013; Climate Council 2014a).

Climate change is stacking the odds towards record heat. Record hot days have doubled in Australia in the last 50 years, while record cold days have declined by a similar fraction.

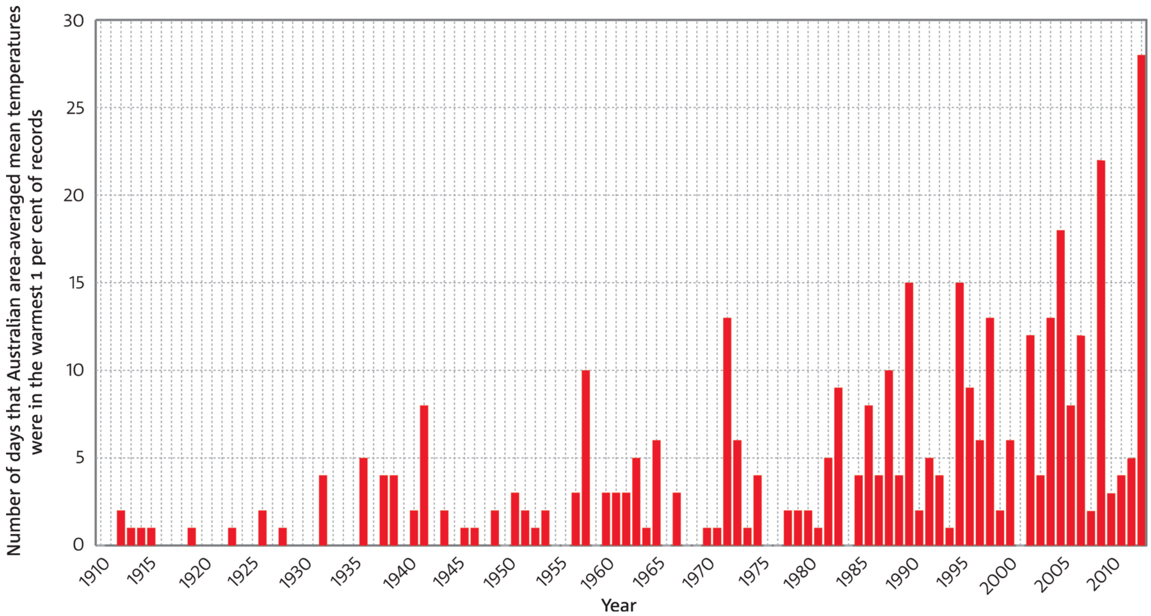

Figure 2: The number of days each year where the Australian area-averaged daily mean temperature is above the 99th percentile for the period 1910-2013. The data are calculated from the number of days above the climatological 99th percentile for each month and then aggregated over the year. This metric reflects the spatial extend of extreme heat across the continent and its frequency. Half of these events have occurred in the past twenty years. Source: CSIRO and BoM 2014.

As shown in Figure 2, days where extreme heat is widespread across Australia has increased markedly over the past century, especially after 1950 (CSIRO and BoM 2014). In fact, half of these extreme heat events have occurred in the last 20 years.

Over the 1950-2013 period many characteristics of heatwaves have changed across Australia (Perkins and Alexander 2013; Climate Council 2014b):

› The number of heatwave days has increased over much of Australia, particularly the eastern half.

› Heatwaves are occurring more frequently in terms of the number of heatwave events per summer.

› The duration of the longest yearly heatwave is increasing.

› The first heatwave in the season is occurring earlier over almost all of Australia.

› The hottest day in a heatwave – its peak - is becoming even hotter over almost all of Australia below the tropics.

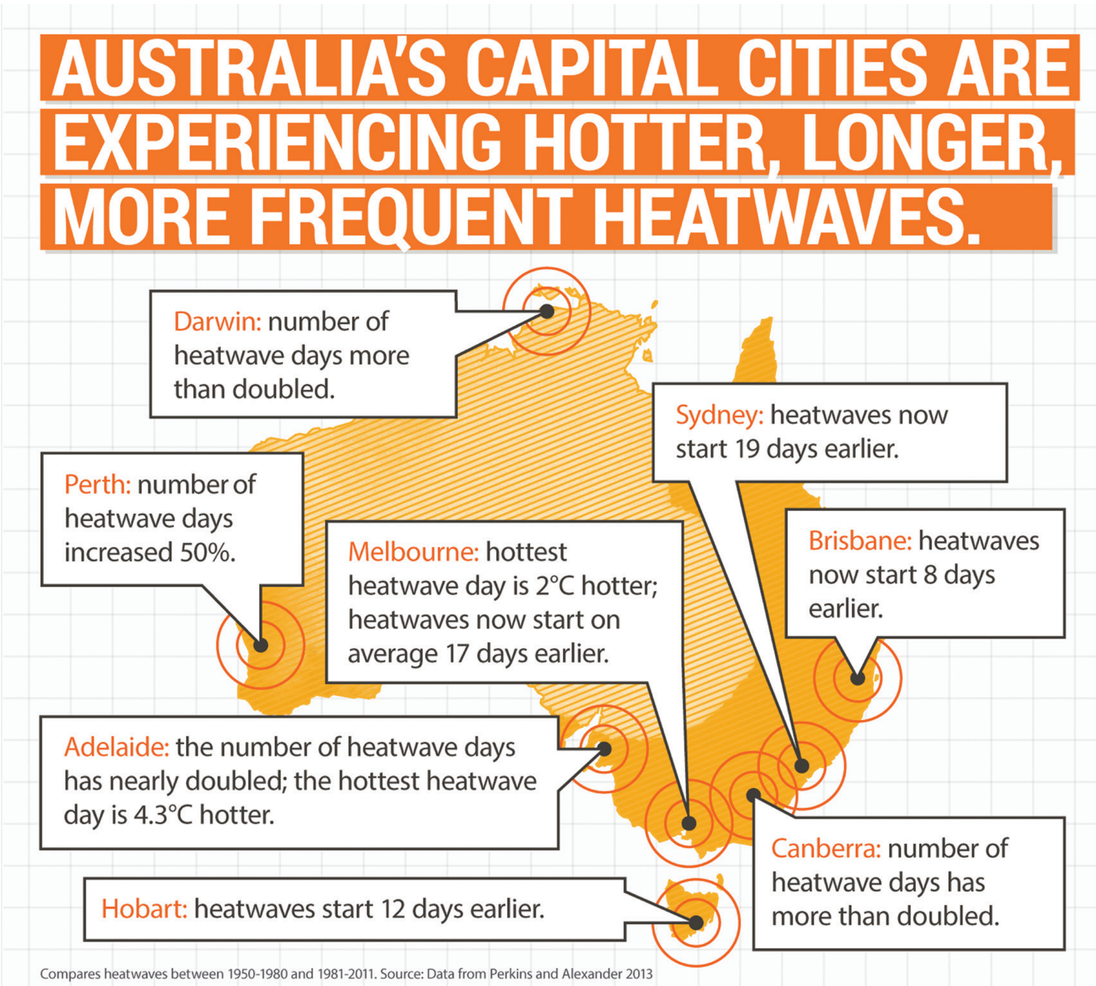

Figure 3: Australia's capital cities are experiencing hotter, longer or more frequent heatwaves, based on a comparison of heatwaves during the 1950-1980 period with those during the 1980-2011 period

Australia's capital cities have already experienced hotter, longer or more frequent heatwaves (Figure 3). The average intensity of heatwaves in Melbourne is 1.5°C hotter and they occur on average 17 days earlier than between 1950 – 1980. In Sydney heatwaves now start 19 days earlier on and the number of heatwave days has increased by 50%. In Adelaide the number of heatwave days has nearly doubled while the average intensity of heatwaves is 2.5°C hotter (Table 1).

City	Number of heatwave days		Number of heatwaves (events)		Length of longest event		Changes in average intensity of the heatwave (°C)	Changes in average intensity of the peak day (°C)	Changes in timing of first event (days)
	1950–1980	1981–2011	1950–1980	1981–2011	1950-1980	1981–2011			
Sydney	6	9	1-2	2-3	4	5	1.5	1.5	-19
Melbourne	5	6	1-2	1-2	4	4	1.5	2	-17
Brisbane	10	10	2-3	2-3	6	6	1	1.5	-8
Perth	6	9	1-2	2-3	4	5	1.5	1.5	+3
Adelaide	5	9	1-2	1-2	4	6	2.5	4.3	-2
Hobart	4	5	1	1-2	4	4	-1.5	1.7	-12
Darwin	3	7	1	1-2	4	5	0	1	-7
Canberra	6	13	1-2	2-3	5	7	0	1.5	-3

Source: Climate Council 2014b

Table 1: The average number of heatwave days, number of events, length of the longest event, average heatwave intensity, average intensity of the peak heatwave day, and change in the timing of the first summer heatwave for Australia's capital cities (Perkins and Alexander 2013). Statistics were calculated from the high-quality ACORN-SAT temperature dataset for the period 1951-2011 (Trewin 2013), using the Excess Heat Factor heatwave definition (Nairn and Fawcett 2013; Perkins and Alexander 2013). All statistics are rounded to the nearest integer. The first column for each characteristic is for the 1950–1980 period and the second is for the 1981–2011 period. Changes in average intensity and peak intensity are calculated by subtracting the respective average from 1950–1980 and 1981–2011. Changes in timing are calculated by subtracting the average start date during 1981–2011 from that of 1950–1980.

3. How much of an influence does climate change have on single heat events?

While climate change is already increasing the intensity and likelihood of hot days and heatwaves, recently scientists have been studying specific heat events and asking: just how much of an influence did climate change have? As the following examples show, the answer is that climate change has been a major factor in recent heat events.

Climate change has been a major factor in recent heat events.

The most common approach to linking individual heat events to climate change is to mathematically analyse the likelihood that such events would occur in the absence of the additional greenhouse gases, primarily carbon dioxide, in the atmosphere from human activities. Scientists use state-of-the-art climate models to simulate temperature changes due to the internal variability of the climate system and to natural forcings such as solar variability and aerosols from volcanoes. They then run the climate models again, this time adding in the additional greenhouse gases from human activities.

As additional greenhouse gases accumulate in the atmosphere, the simulated temperature trends begin to diverge from those due to natural forcings and variability alone, as shown in Figure 4. The increased temperatures resulting from climate change compared to the "natural only" climate model simulations allow scientists to calculate the influence of climate change on specific events, such as the record hot year of 2013 in Australia, or our record heat in the spring of 2013 and in September 2013.

Figure 4 shows results of the simulations by multiple climate models to test the influence of greenhouse gases from human beings versus natural factors. The blue line shows model simulations of global temperature over the last 130 years with just natural factors. You can see that global temperature fluctuates around zero degrees, indicating no long term warming. The dark red line shows what happens when greenhouse gases emitted by humans are added to natural factors in the model simulations. You can see the steep increase in simulated temperature from the mid-20th century. The black line shows the temperature trend that has actually been observed, so only when human-driven greenhouse gases are added into the models does their simulated temperature trend closely follow the temperature rise we've actually experienced.

The influence of climate change is often expressed mathematically as "fraction of attributable risk" (FAR) – the fraction of risk of exceeding a particular climatic threshold that can be attributed to a particular cause, in this case climate change. For example, what is the FAR due to climate change that 2013 would break the 2005 record for the hottest year in Australia? In only 1 year out of over 12,300 years of model simulations without human forcing was the 2005 record exceeded (Lewis and Karoly 2014). That is, without the human influence on climate, the record temperature Australia experienced in 2013 would occur only once in 12,300 years. So the FAR is effectively 100%; the 2013 record would not have occurred in the absence of climate change.

Australia Region Annual Surface Temperature Anomalies Through 2013

Relative to 1881-1920 mean. CMIP5 Historical/RCP4.5 experiments

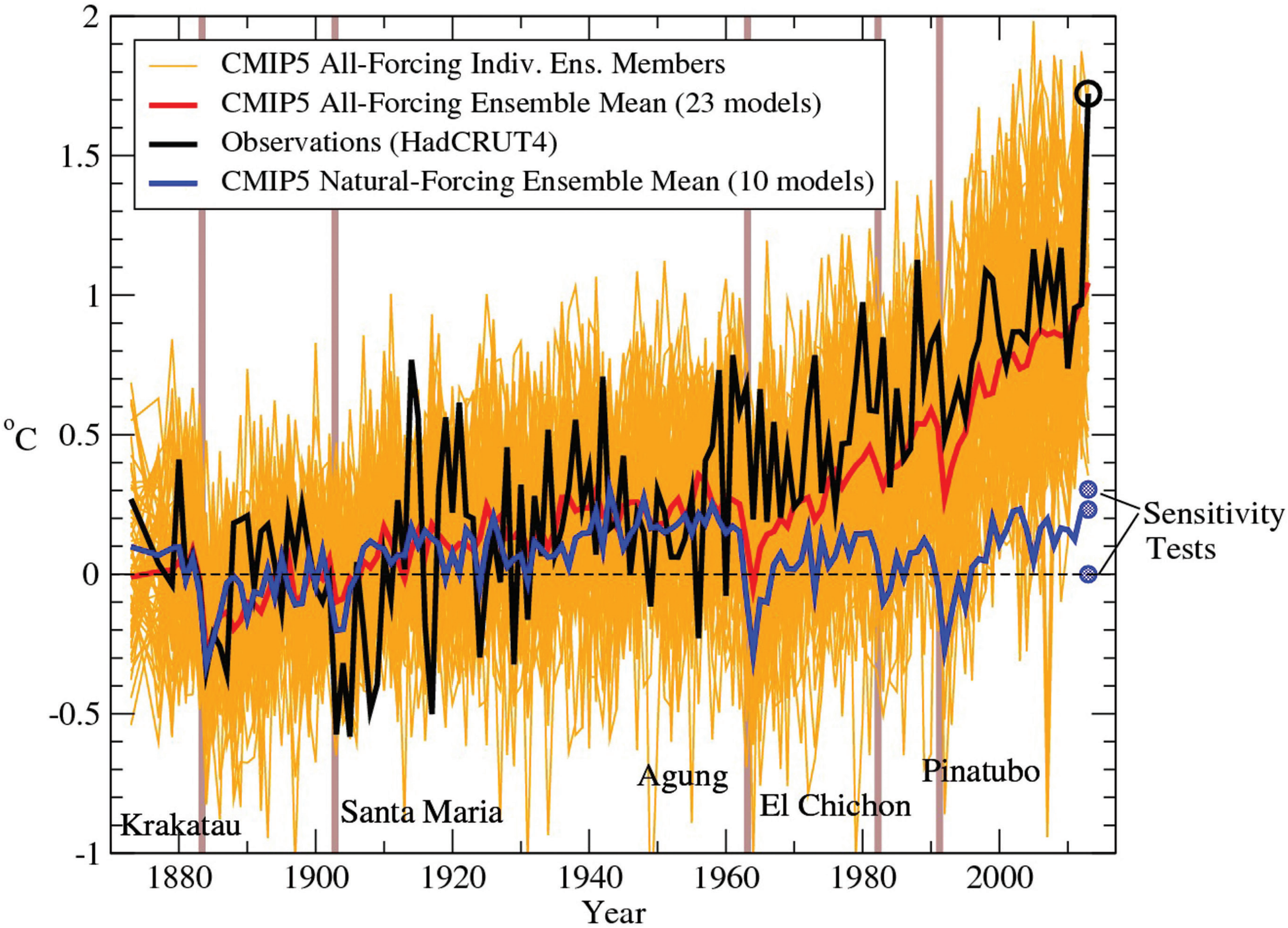

Figure 4: Times series of annual averaged surface temperature anomalies (°C) over Australia. The black curve depicts the observed (HadCRUT4) anomalies; the dark red curve depicts the multi-model ensemble anomalies from the CMIP5 All-Forcing runs, while the blue line depicts the Natural Forcing-only runs. Each of the available models (23 for All-Forcing and 10 for Natural Forcing-only) is weighted equally. The three blue circles labeled "Sensitivity Tests" depict low, medium and high estimates of the Natural Forcing-only response for 2013. The All-Forcing simulations included both anthropogenic and natural forcings from about 1860 to the present, with data from RCP4.5 runs used to extend the time series through 2013 where necessary. All time series shown are adjusted to have zero mean over the period 1881-1920. Source: Knutson et al. 2014.

Without the human influence on climate, the record temperature Australia experienced in 2013 would occur only once in 12,300 years

A similar approach by Knutson et al. (2014) comparing temperature trends from 1860 to the present (Figure 4) yielded the same conclusion – the record hot year of 2013 in Australia was virtually impossible without the influence of climate change.

Other studies (Arblaster et al. 2014; King et al. 2014) explored several factors that could be implicated in the record-breaking 2013 heat events in Australia. One of these studies three factors played significant roles, and concluded that "...anthropogenic climate change played an important role in the record Australian maximum temperatures in September 2013".

King et al. (2014) also explored the role of severe drought along with climate change in driving the extreme heat of 2013 (Figure 5). They found that the extreme heat that much of Australia experienced in 2013 was made much more likely by important contributions

The extreme heat that much of Australia experienced in 2013 was made much more likely by important contributions from both climate change and very dry conditions

(Arblaster et al. 2014) used both long-term observations and simulations by a seasonal forecasting model to examine the relative effects of natural variability, the unusually dry conditions in inland eastern Australia in 2013 and the background warming due to climate change on the record-breaking heat of 2013, especially in the spring and in September. They found that all

from both climate change and the very dry conditions over the eastern inland region of the continent. Their precise results were (i) the risk of the record 2013 heat exceeding a high temperature threshold (they used 2002 as the threshold) is extremely likely to be 23 times greater now than in the late 19th century due to climate change; and (ii) that the risk of extreme heat is 25 times greater in dry years than wet years.

Figure 5: A parched landscape in South Australia in 2013. Research has found that severe drought along with climate change played a role in the extreme heat of 2013.

The FAR approach has also been applied by Perkins et al. (2014) to two heatwave characteristics – the total number of heatwaves (frequency) and the hottest heatwave day (intensity) – for the 2012/2013 Australian summer. Their simulations compared three time periods (1955-83, 1955-2012 and 1984-2012) to explore the influence of human-driven climate change on these heatwave characteristics. The results showed that there is a "calculable" human influence on the hot Australian summer of 2012/2013 in terms of both heatwave characteristics. The comparison of the first and third time periods showed that the risk of increased frequency rose 3-fold and the risk of increased intensity 2-fold compared to a climate with no human forcing.

There is a "calculable" human influence on the hot Australian summer of 2012/2013

4. Without substantial reductions in emissions, climate change will continue to exacerbate extreme heat.

The trend toward more frequent and more severe heatwaves in Australia is part of a larger global trend which requires international action on climate change.

All extreme weather events, including extreme heat events, are now occurring in an atmosphere that is significantly hotter than it was 50 years ago (Trenberth and Fasullo 2012). The additional heat in the atmosphere and surface ocean from human emissions of greenhouse gases drives up the risk of more intense heat and more frequent extreme heat events. The trend toward more frequent and more severe heatwaves in Australia is part of a larger global trend which requires international action on climate change.

As even more greenhouse gases accumulate in the atmosphere over the coming decades, the fundamental physics of the climate system points towards an escalating risk of extreme heat. Across Australia, 1-in-20 year extreme hot days are expected to occur every two to five years by the middle of the century (IPCC 2012); that is, extreme hot days are expected to occur four to ten times more often. Towards the end of the century, the occurrence and intensity of extreme heat will depend strongly on our success, or not, in reducing greenhouse gas emissions, mainly emissions of carbon dioxide. Without effective action on climate change, today's extreme heat will become commonplace, occurring every summer across the continent in the last decade or two of this century.

Without effective action on climate change, today's extreme heat will become commonplace, occurring every summer across the continent in the last decade or two of this century

5. The need for action to deal with extreme heat

The evidence on the link between climate change and extreme heat is stronger than ever, and in fact is overwhelming

The evidence on the link between climate change and extreme heat is stronger than ever, and in fact is overwhelming. Whether one considers the fundamental physics, the observed long-term trends in extreme heat, or the new model- and observation-based analyses of record years or individual events, the answer is absolutely clear. Extreme heat is becoming more frequent and more severe, and climate change is the primary reason.

The case for action is just as overwhelming. Carbon emissions will need to be reduced rapidly and deeply, with most of the world's economies essentially decarbonised by the middle of the century, if the climate system is to be stabilised and the worst of extreme heat in the second half of the century is to be avoided.

But there is good news on the horizon as we reach the halfway point of the Critical Decade in 2015. Clean energy technologies, such as solar and wind, are advancing rapidly and are now competitive in price with fossil fuel technologies in many places (Citigroup 2013; IRENA 2014). International action is ramping up with stronger commitments from the world's two biggest emitters, China and the USA. The challenge for the second half of the decade is clear – build on this momentum towards a decarbonised future and ramp up action even further in the second half of the decade. The UN Climate Summit in Paris in December 2015 provides an opportunity for nations, including Australia, to increase their domestic action on climate change.

Now, more than ever, we need action on climate change.

References

Arblaster JM, Lim E-P, Hendon HH, Trewin BC, Wheeler MC, Liu G and Braganza K (2014) Understanding Australia's hottest September on record. *Bulletin of the American Meterological Society* 95(9): S37-S41.

Citigroup (2013) Energy Darwinism: The Evolution of the Energy Industry. Channell J, Jansen H, Syme A, Savvantidou S, Morse E and Yuen A.

Climate Commission (2013) The Angry Summer. Steffen W.

Climate Council (2014a) Angry Summer 2013/2014. Accessed at http://www.climatecouncil.org.au/angry-summer.

Climate Council (2014b) Heatwaves: Hotter, longer, more often. Steffen W, Hughes L and Perkins S. Accessed at http://www.climatecouncil.org.au/uploads/9901f6614a2cac7b2b888f55b4dff9cc.pdf.

CSIRO and BoM (2012) State of the Climate 2012. CSIRO and Bureau of Meteorology, Melbourne. Accessed at http://www.csiro.au/Outcomes/Climate/Understanding/State-of-the-Climate-2012.aspx.

CSIRO and BoM (2014) State of the Climate 2014. CSIRO and Bureau of Meteorology, Melbourne. Accessed at http://www.bom.gov.au/state-of-the-climate/.

IPCC (2012) Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Field CB, Barros V, Stocker TF, Qin D, Dokken D, Ebi KL, Mastrandrea MD, Mach KJ, Plattner G-K, Allen SK, Tignor M and Midgley PM (eds.), Cambridge University Press, Cambridge and New York, 582 pp.

IRENA (International Renewable Energy Agency) (2014) Rethinking Energy. Accessed at http://www.irena.org/rethinking/.

King AD, Karoly DJ, Donat MG and Alexander LV (2014) Climate change turns Australia's 2013 Big Dry into a year of record-breaking heat. Bulletin of the American Meteorological Society 95(9): S41-S45.

Knutson TR, Zeng F and Wittenberg AT (2014) Multimodel assessment of extreme annual-mean warm anomalies during 2013 over regions of Australia and the western tropical Pacific. *Bulletin of the American Meteorological Society* 95(9): S26-S30.

Lewis SC and Karoly DJ (2014) The role of anthropogenic forcing in the record 2013 Australia-wide annual and spring temperatures. *Bulletin of the American Meteorological Society* 95(9): S31-S34.

Nairn J and Fawcett R (2013) Defining Heatwaves: Heatwave defined as a heat-impact event servicing all community and business sectors in Australia. CAWCR Technical Report, No. 060. CSIRO and Australian Bureau of Meteorology, p 96.

Perkins S and Alexander L (2013) On the measurement of heat waves. *Journal of Climate* 26:4500-4517.

Perkins SE, Lewis SC, King AD and Alexander LV (2014) Increased simulated risk of the hot Australian summer of 2012/13 due to anthropogenic activity as measured by heat wave frequency and intensity. *Bulletin of the American Meteorological Society* 95(9): S34-S37.

Trenberth KE and Fasullo JT (2012) Climate extremes and climate change: The Russian heat wave and other climate extremes of 2010. *Journal of Geophysical Research: Atmospheres* 117:D17103.

Trewin B (2013) A daily homogenized temperature data set for Australia. *International Journal of Climatology* 33:1510-1529, doi: 10.1002/joc.3530.

Trewin B and Smalley R (2013) Changes in extreme temperatures in Australia, 1910 to 2011. In: 19th AMOS National Conference, Melbourne, pp 11-13.

Image Credits

Cover photo: "Fat Old Sun" by Flickr user Harry Hoopman licensed under CC by 2.0

Page 2: Figure 1 "A hazard reduction burn being conducted by the NSW RFS in Belrose, 2011" by Flickr user NSW RFS Media Services licensed under CC by – NC-ND 2.0

Page 9: Figure 5 "Dead trees (10 year drought)" by Flickr user Gary Sauer-Thompson licensed under –NC –ND 2.0.