Climate change: a brief overview of the science and health impacts for Australia

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In 2017, *The Lancet* reported that "human symptoms of climate change are unequivocal and potentially irreversible — affecting the health of populations around the world today" and added that the "delayed response to climate change over the past 25 years has jeopardised human life and livelihoods".[1] The gravity of this situation warrants inspection, and urgent action. In this article, our aim is to provide an overview of the most recent scientific and organisational literature to inform readers about the current state of knowledge on climate change and its relationship to human health. The issue has global relevance, but here we focus primarily on Australia.

The ambient climate shapes cultural life, so the relationship between human societies and their climate is extremely powerful. Ecological services such as food and water resources, strategies required to feed a community throughout the year, clothing, and housing design are all determined by climate and its direct threats of heat, droughts, fires, storms and floods. Indeed, human survival and societal flourishing depend on successful adaptation to the proclivities of regional climate.

More than a century ago, science accurately explained the relationship between atmospheric carbon dioxide (CO_2) levels, greenhouse effect and planetary energy balance, and in the 1930s global warming was observed.[2] Yet, the prevailing public thinking was that humans could never significantly influence planetary forces or the climate.

During the past 2.6 million years (Pleistocene and Holocene), atmospheric CO_2 levels have oscillated between about 180 parts per million (ppm) during ice ages, and about 280 ppm during warmer interglacial periods.[3] Closely aligned with atmospheric CO_2 levels is global mean temperature. Importantly, a mere 5°C differentiates ice ages from interglacial periods[4] (Box 1).

Summary

- The scientific relationship between atmospheric CO_2 and global temperatures has been understood for over a century.
- Atmospheric concentrations of CO_2 due to burning of fossil fuels have contributed to 75% of the observed 1°C rise in global temperatures since the start of the industrial era (about 1750).
- Global warming is associated with intensifying climatic extremes and disruption to human society and human health.
- Mitigation is vital for human health as continued current emission rates are likely to lead to 4°C of warming by 2100.
- Further escalation of Australia's hot and erratic climate will lead to more extreme climate-related disasters of heatwaves, droughts, fires and storms, as well as shifts in disease burdens.

The evidence for human influence on climate change

Human interference in the global climate is now apparent. Over the past 150 years, atmospheric CO_2 concentrations have risen rapidly from a 12 000 year steady level of 280 ppm to 410 ppm,[6] a level not seen since the Pliocene (5.3–2.6 million years ago).[7] As projected by the laws of thermodynamics, this 46% rise in atmospheric CO_2 has been accompanied by rising global average temperatures. Human influences on climate change arise primarily from combustion of fossil fuels and changes in land use.[8]

The capacity of a gas or other agent to affect atmospheric energy balance, thereby contributing to climate change, is measured as radiative forcing (watts per square metre). Human activities cause significant changes in concentrations of long-lived gases (eg, CO_2, halocarbons, nitrous oxide), short-lived gases (eg, methane that lingers in the atmosphere for a year to a few decades), surface albedo, aerosols and contrails in the atmosphere. Box 2 provides a summary of these principal components of the radiative forcing of climate change for 2011 relative to the start of the industrial era (about 1750). Positive forcings lead to warming of climate and negative forcings lead to cooling. Anthropogenic emissions elicit a warming effect, whereas atmospheric aerosols cool the atmosphere by blocking incoming energy from the sun. Natural variation in solar radiance provides a relatively very small positive forcing (warming) effect. Box 3 shows the effective radiative forcing, which is the net effect of the positive forcing of greenhouse gases, moderated by the cooling effect of aerosols to give the total anthropogenic forcing in watts per square metre over the Earth.

Despite growing awareness, by 2017 emissions had not yet stabilised. Over the past two years, global emissions have continued to increase at a record rate of almost 3 ppm per year.[10] This is more than 100 times faster than when the last ice age ended.[11]

Future warming is dependent on levels of economic and population growth, and future emission trajectories. Developed in 2010,[12] the Intergovernmental Panel on Climate Change in its most recent assessment report adopted scenarios to serve as the basis for modelling and describing climate projections.[13] These four representative concentration pathways (RCPs) are based on possible radiative forcing values. The RCPs range from the worst-case scenario of business as usual with continued high growth and high emissions (RCP8.5), to the best-case scenario where emissions stabilise at 2013 levels until 2020, followed by decline and becoming negative by 2100 (RCP2.6), and include two intermediary scenarios (Box 4).

The urgent need to reduce emissions

The urgency of initiating emissions reductions is well recognised as scientists are increasingly arguing that limiting warming to 2°C is no longer feasible; yet this level of warming may have unacceptable social and environmental costs and trigger irreversible climate feedbacks.[14,15] Mitigating climate change now is less disruptive than the consequences of not mitigating; moreover,

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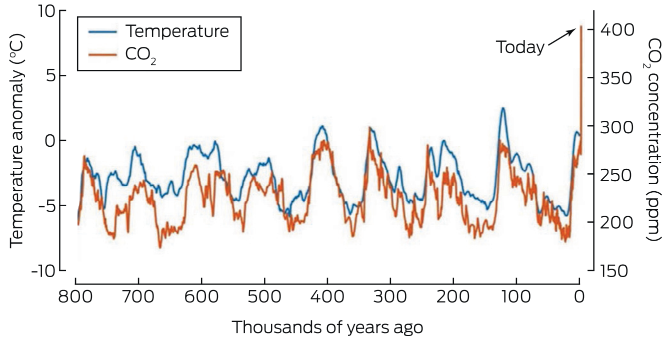
1 Global average temperatures and atmospheric CO_2 levels for the past 800 000 years



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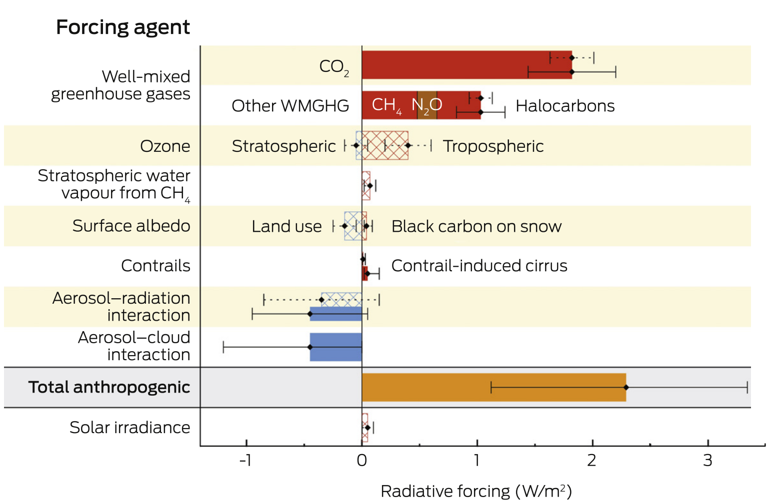
delayed mitigation will need to be very drastic. For example, palaeoclimate records indicate that temperatures matching 2016 did, when sustained, correspond to a global sea level between 6 and 9 metres higher than that of today,[16] a change which would likely create millions of climate refugees seeking refuge in Australia. Currently, 30% of the world's population are exposed to climatic conditions exceeding lethal heat thresholds (defined as precipitating multiple heat deaths) for at least 20 days a year. By 2100, this proportion is projected to increase to 48% with drastic reductions of greenhouse gas emissions, and to 74% under a scenario of growing emissions.[17]

Even if drastic emission reductions were immediately introduced, embedded climate system inertia dictates that observed global trends such as rainfall anomalies, extreme temperatures and sea level rises will continue for many millennia.[18] Control of future global warming therefore depends upon global cooperation and efficacy in reducing carbon emissions.

Evidence that the combustion of fossil fuels is responsible for about 75% of the additional atmospheric carbon[19] is found in the carbon embedded within tree rings and bubbles within ice cores.[20] These show that the atmospheric ^{13}C:^{12}C isotope ratio has distinctively decreased since the industrial revolution.[21] The photosynthetic process alters the ^{13}C:^{12}C ratio in plants from the atmospheric ratio, and burning fossilised plant material releases the ^{12}C isotopes that plants absorbed millions of years ago into the atmosphere in the form of CO_2 molecules.[22]

2 Radiative forcing of climate for the period 1750–2011



Reproduced with permission from Working Group I Contribution to IPCC AR5 (Figure 8.15).[9] Radiative forcing is shown as hatched and effective radiative forcing as solid. Uncertainties (95% CI) are shown for radiative forcing as dotted lines and for effective radiative forcing as solid lines. ◆

In addition to absorbing 90% of the additional heat,[23] global oceans have absorbed about 27% of anthropogenic CO_2 emissions since the beginning of the industrial revolution,[19] which has lowered ocean pH by 0.1 units.[24] Marine organisms and ecosystems are particularly sensitive to ocean acidification.[25] For example, exoskeleton formation of krill, at the base of the marine food web, relies on a stable marine carbonate system. Currently, 3.1 billion people derive at least 20% of their animal protein sources from fish.[26] Significant nutritional deficits could arise from marine fisheries stock losses when acidification and warming sea temperatures compound existing threats from overfishing.

Climate change threats to the health of Australians

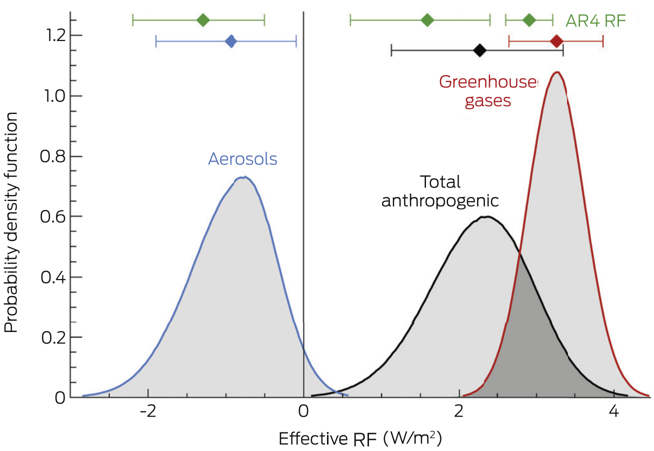
Despite being a wealthy developed nation, Australia is highly vulnerable to climate change, due largely to its unique geoclimatic features. Australia is the driest inhabited continent on earth[27] and has the greatest variability of rainfall of any country. Further, Australia's average daily temperature is 13.7°C warmer than the global average of 8.1°C[28] and is getting hotter, with newly observed hot-to-cold temperature records now at a ratio of 12:1.[29] Heat extremes are the most risky. Box 5 demonstrates the almost fivefold increase in frequency of extreme temperatures (> 2 standard deviations above the average) despite relatively small increases in mean temperatures.[30]

Claiming at least 5332 fatalities between 1844 and 2010, heat exposure is more lethal than any other natural disaster[31] and represents Australia's greatest current climate-related health burden. Winter cold-related deaths arise predominantly through respiratory diseases, often with contributing socio-economic determinants, rather than through direct exposure.[32] In contrast, heat deaths are exposure related. Heat death occurs when heat gain exceeds the capacity to shed heat to a hot ambient environment. Thermoregulatory response fails, and cardiac compromised patients succumb due to the inability of the heart to meet perfusion needs of increased shunting of blood for temperature control, especially when dehydrated.[33] Heat gain ultimately results in multi-organ failure.

Entire populations cannot exist permanently in air-conditioned environments during heat waves. Human thermoregulatory limitations therefore place upper boundaries to human heat tolerance and thus survivability in a warming climate.[33] International consistency exists in the temperature–mortality relationship as a J-shaped curve. Adaptation to cold environments is reflected in variability and a relative shallow rise, whereas above the comfort threshold, heat mortality rises steeply, indicating thermotolerance and adaptation limitations (Box 6).

A combination of heat and drought precipitates high fire risk. In the period 1901–2011, 260 Australian bushfires resulted in 825 reported civilian and firefighter fatalities.[36] The number of admitted and non-admitted injuries and burns cases since 1901 remains unknown. Large fires exacerbate existing respiratory conditions[37] and elicit chronic mental health morbidity secondary to loss and grief, and sometimes guilt.[38] Extreme fire

3 Probability density function of effective radiative forcing (RF) of climate for the period 1750–2011

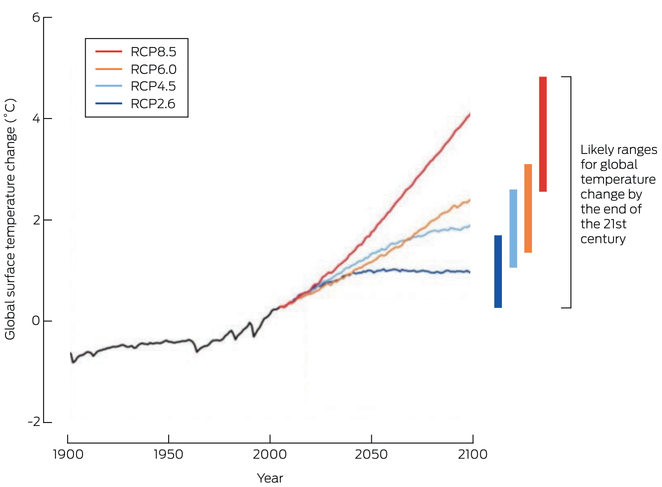


Reproduced with permission from Working Group I Contribution to IPCC AR5 (Figure 8.16).[9] Lines at the top of the figure compare the best estimates and uncertainty ranges (95% CI) for aerosol, greenhouse gas and total anthropogenic change with RF estimates from Climate change 2007: synthesis report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva: IPCC, 2007 (AR4). ◆

weather has increased over recent decades, and across large parts of Australia, the fire season now extends further into spring and autumn.[30,39]

Climate change influence on Australia's rainfall variability has led to increased droughts and floods.[39] May–July rainfall has reduced by about 19% since 1970 in the southwest of Australia, whereas the continental southeast has experienced an 11% decline in rainfall since the mid-1990s during the important April–October growing season. All climate models project increases in extreme droughts across Southern Australia (occurring between 1.5 and 2.7 times every 20 years), and by 2090, time spent in drought ranges from 35% to 80%.[30,39] Droughts reduce water supply and quality, posing

4 Global mean temperature change projections to 2100 relative to 1986–2005 for the four representative concentration pathway (RCP) scenarios: RCP2.6, RCP4.5, RCP6.0 and RCP8.5



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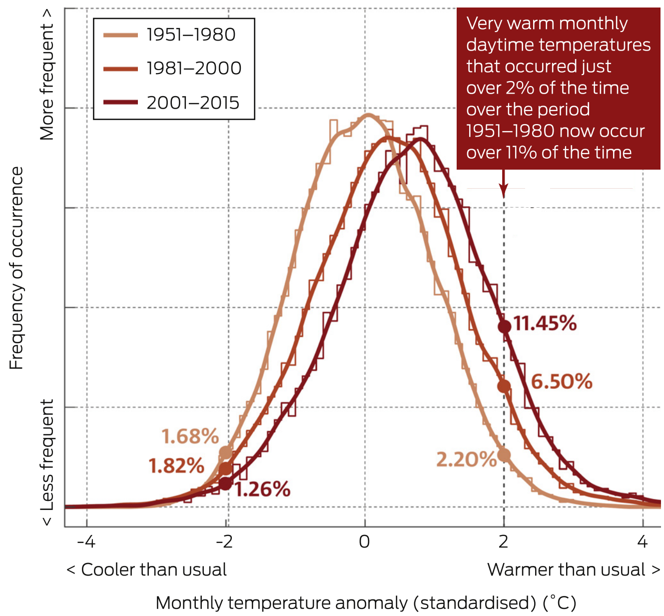
5 Distribution of Australian monthly daytime temperature anomalies (standardised with respect to the 1951–1980 base period) aggregated across 104 locations and all months of the year, for 1951–1980, 1981–2010 and 2001–2015



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health risks to stock and to communities reliant on inland river systems for their water supply[40] and economic livelihood.

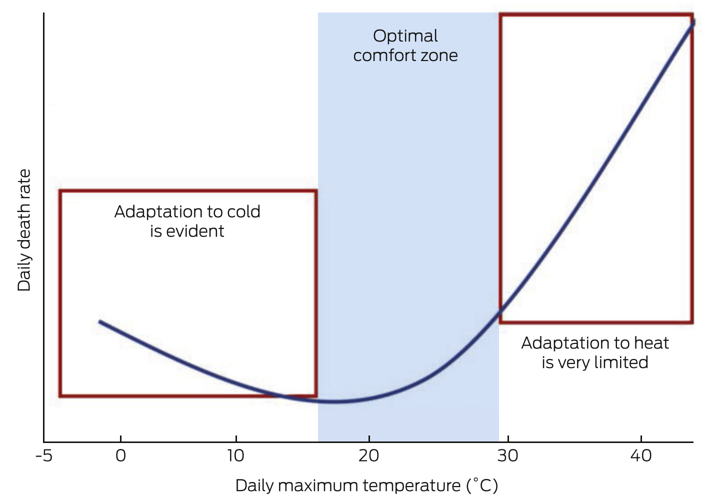
Despite near-national water restrictions during the protracted Millennium drought, many farmers and rural townships ran out of water, and some were listed as unviable. Rural families and regional communities suffered deep economic losses and rural suicides spiked.[41] About 9% of total deaths in New South Wales men aged 30–49 years between 1970 and 2007 were drought-related suicides.[41]

Between 1900 and 2015, the total number of recorded deaths from floods in Australia was 1859, an average national annual death rate of 2.91 fatalities per 100 000 people per year.[42] Death rates have steadily declined over time. The Queensland floods of 2011 claimed the lives of 23 people, and generated 56 200 insurance claims, with payouts totalling $2.55 billion.[43] Many were uninsured, and pay-outs do not fully recompense loss and wide scale lingering grief among affected communities. Emergency and recovery response capacities can be overwhelmed in natural disasters.

Attributing probability risks of rainfall changes to climate change is a more difficult task than attributing temperature changes. This is especially so in Australia, where intrinsic rainfall variability on interannual and interdecadal timescales is uncommonly large. Notwithstanding, studies suggest that the high sea surface temperatures currently contribute 20% (mean estimate) of rainfall anomalies.[39] Continued current high emission scenarios will result in more severe flooding events.[44]

Australia's large geographical landmass delivers variation in regional rainfall patterns and differentiated future climate projections. Excluding southwestern Western Australia, extreme rainfall events (wettest day of the year and wettest day in 20 years) are projected to increase in intensity with high confidence (defined

6 Schematic representation of temperature–mortality curve based on study data[34,35]



by the Intergovernmental Panel on Climate Change as > 80% probability of being correct).[39]

Tropical cyclones are the most devastating weather systems affecting northern Australia. Strong natural variability prevents detection of statistically robust trends; however, a 50% increase in the proportion of tropical cyclones reaching category 3 or higher was recorded from the period 1960–85 to the period 1985–2010.[45] The low frequency of tropical cyclones making landfall in Australia prevents statistical certitude in projecting future probabilities. The physical science, however, suggests clear risks: higher sea surface temperatures are associated with more energy, higher wind speeds, more intense tropical cyclones and higher rainfall intensity,[46] and thus likely greater damage to human systems. The total numbers of tropical cyclones are expected to be similar or decline in frequency in the Australian region by 2050, yet their severity will potentially increase, with an associated poleward shift in the regions of both genesis and dissipation.[47]

Extensive flooding and cyclone damage impede essential services, delivery of health care, repairs to infrastructure and economic recovery. Affected communities face a gauntlet of associated health problems including acute effects of drownings, falls, electrocutions, bites, skin infections and mosquito- and gastrointestinal-borne illnesses, as well as protracted grief and psychological health issues.

A growing body of literature links climate change to food and water insecurity and increased disease burden.[48] Recent and historical experiences indicate that infectious disease outbreaks often follow extreme rainfall events,[49] although Australians' health risk is considerably less than that of developing countries.[50] Many vector-borne diseases are climate sensitive, as mosquito densities relate to rainfall and temperature. In Australia, Ross River virus, Barmah Forest virus and dengue fever are three of the most common and clinically important vector-borne diseases,[51] yet the relationship between disease outbreaks and climate change is less clear. For example, rainfall was the weakest predictor of vector-borne disease burden in a recent Australian study that explored climate variables on Ross River virus, Barmah Forest virus and dengue transmission rates, as the homophilic vector breeding cycle responds also to human intervention such as travel, habitation patterns, water containers[51] and prevention campaigns.

Locally acquired dengue transmission only occurs in urban areas of north Queensland from Townsville to the Torres Strait, where the vector (*Aedes aegypti*) is present.[52] Australia's increasing incidence of dengue fever is thought to result primarily from the long term growth in the travel sector, notably to South East Asian locations where dengue is endemic.[51] With global increases in vectorial capacity since the late 1970s of *A. aegypti* and *A. albopictus*,[48] endemicity of dengue fever in northern Queensland is regarded as a very real possibility.[52] A warming world suggests that the environmental niche for mosquitos will move southward, yet the complexities of human–environment interactions and efficacy of prevention campaigns, surveillance and medical management make future disease burdens difficult to quantify.

Conclusion

Australia's climate is changing. Adaptation is required and, perhaps more importantly, mitigation to avoid the worst of future health burdens. Current trends suggest a future of increasing heatwaves, even greater rainfall variability, and more fires. Additional heat is likely to generate fewer winter respiratory deaths yet more heat exposure morbidity and mortality. Further exacerbations of Australia's extreme rainfall variability will intensify water shortages and storm and flood damage, compounded by likely societal interruptions and health challenges. The picture for climate-sensitive vector-borne diseases remains unclear, although cases spreading to southern regions remain possible. A realignment of health services to address the shift in disease burden is required to secure Australia's current high level of health care.

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