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DEGREES OF GLOBAL WARMING

Australia in a hot world

Edited by

PETER CHRISTOFF

earthscan
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Four Degrees of Global Warming

At the UN Climate Conference in Copenhagen in December 2009, the international community agreed to limit global warming to below 2°C to avoid the worst impacts of human-induced climate change. However, climate scientists agree that current national emissions targets collectively will still not achieve this goal. Instead, the 'ambition gap' between climate science and climate policy is likely to lead to average global warming of around 4°C by or before 2100. If a Four Degree World is the *de facto* goal of policy, we urgently need to understand what this world might look like.

Four Degrees of Global Warming: Australia in a Hot World outlines the expected consequences of this world for Australia and its region. Its contributors include many of Australia's most eminent and internationally recognized climate scientists, climate policy makers and policy analysts. They provide an accessible, detailed, dramatic, and disturbing examination of the likely impacts of a Four Degree World on Australia's social, economic and ecological systems.

The book offers policy makers, politicians, researchers, students and anyone interested in climate change access to the most recent research on potential Australian impacts of global warming, and possible responses.

Peter Christoff is a political scientist and Associate Professor who teaches Climate Change Politics and Policy and Environmental Policy at the University of Melbourne, Australia. From 2005 to 2013 he was also the Vice President of the Australian Conservation Foundation, Australia's largest national environmental NGO.

This is an important book that addresses the defining question of the 21st century: Can we really afford to let the world slip down the warming slope – towards the 4 degrees mark or even beyond? The authors provide compelling evidence from the Australian perspective that the answer reads "no". Peter Christoff should be praised for initiating and editing this colossal intellectual effort.

–Hans Joachim Schellnhuber, Director of the Potsdam Institute for Climate Impact Research (PIK) and Chair of the German Advisory Council on Global Change (WBGU), Germany

'Four Degrees' reveals what might become of Australians and their country if global average temperatures are allowed to increase by 4 degrees above that of 200 years ago. It paints a 'bleak vision of a continent under assault.' And that will be out future if we do nothing – just keep going along as we are today. Thankfully the book is also full of clear and realistic solutions, which makes it a must-read for all caring Australians.

–Tim Flannery, Chief Commissioner, Climate Commission, Australia

This important book, though ostensibly about climate change, raises profound and personal questions about the type of world we wish to bequeath our children. Setting out stark and scientifically informed choices, the authors provide a cogent framing of the challenging issues facing Australian policy makers, businesses and civil society.

–Kevin Anderson, University of Manchester, UK

Despite a generation of talks, the international community has failed to stem the global increase in greenhouse gas pollution that is causing climate change. Consequently, the earth is set to get hotter, and Australia is in the eye of the storm. In this important new book, Peter Christoff brings together the insights of distinguished scholars, scientists and analysts. They explore the ecological, social and economic impacts for Australia of a much warmer world, in the process providing a valuable guide to the future.

–Paul G. Harris, Hong Kong Institute of Education

Four Degrees of Global Warming

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The Melbourne conference provided a significant opportunity for substantial intellectual collaboration between some of Australia's finest climate scientists and other thinkers grappling with different elements of Australian climate policy. That work became the substance of this book. The conference could not have occurred without the generosity of the Vice Chancellor's Office at the University of Melbourne, and of the Melbourne Sustainable Societies Institute, the Melbourne Energy Institute and the Monash Sustainability Institute, as well as the strong support of their respective directors at that time – Professor Craig Pearson, Professor Mike Sandiford and Professor Dave Griggs. The conference also received generous assistance from Rob Purves and the Purves Environmental Fund.

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Acronyms and abbreviations

4AR	Fourth Assessment Report of the IPCC
+4C	Four degrees or more (Celsius)
ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABS	Australian Bureau of Statistics
ACF	Australian Conservation Foundation
ACORN	Australian Climate Observations Reference Network
ACOSS	Australian Council of Social Services
ADB	Asian Development Bank
ADF	Australian Defence Forces
AIMS	Australian Institute of Marine Science
AOSIS	Alliance of Small Island States
ARI	Average recurrence interval
BAU	Business as Usual
BCC	Brisbane City Council
BoM	Bureau of Meteorology (Australia)
CC	Climate Commission (Australia)
CCA	Climate Change Authority (Australia)
CDM	Clean Development Mechanism
CFCs	Chlorofluorocarbons
CHS	Commission on Human Security
CMIP	Coupled Model Intercomparison Project
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
COAG	Council of Australian Governments
CSIRO	Commonwealth Scientific and Industrial Research Organization (Australia)
DCC	Department of Climate Change (Australia)
DCCEE	Department of Climate Change and Energy Efficiency (Australia)
DFAT	Department of Foreign Affairs and Trade (Australia)
EAC	East Australian Current
EEA	European Environment Agency

ENSO	El Nino-Southern Oscillation
FAO	Food and Agriculture Organization (United Nations)
FAR	Fourth Assessment Report (IPCC)
FFDI	Forest Fire Danger Index
GBR	Great Barrier Reef
GBRMPA	Great Barrier Reef Marine Park Authority
GCMs	Global Climate Models (atmospheric/oceanic)
GDP	Gross Domestic Product
GEF	Global Environmental Facility
GFDI	Grass Fire Danger Index
GHG	Greenhouse gas
Gt	gigatonne (billion tonnes)
GW	Global warming
GWP	Global warming potential
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LDC	Least Developed Countries
LULUCF	Land Use and Land Use Factors
m	metre
MDB	Murray-Darling Basin
MEA	Millenium Ecosystem Assessment
Mha	million hectares
mm	millimetres
NASA	National Aeronautics and Space Administration (US)
NDRC	National Development and Reform Commission (China)
NOAA	National Oceanic and Atmospheric Administration (US)
NRDC	National Resource Defence Council (US)
OECD	Organisation for Economic Cooperation and Development
PCMDI	Program for Climate Model Diagnosis and Intercomparison
QFCI	Queensland Floods Commission of Inquiry
QRA	Queensland Reconstruction Authority
RAMS	Regional Atmospheric Modelling System
R&D	Research and development
SEI	Stockholm Environment Institute
SIDS	Small Island Developing States
SLR	Sea level rise
SoE	State of Environment
SPP	State Planning Policy
SPREP	Secretariat of the Pacific Regional Environment Program
$Tmax^{99}$	99th percentile of maximum temperature (hottest 1 percent of events)
UN	United Nations
UNDP	United Nations Development Program
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific

UNFCCC	United Nations Framework Convention on Climate Change
UNGA	United Nations General Assembly
VBRC	Victorian Bushfires Royal Commission
WA	Western Australia
WCRP	World Climate Research Program (WMO)
WGBU	German Advisory Council on Global Change
WHO	World Health Organization
WMO	World Meteorological Organisation
WWF	World Wide Fund for Nature

1 Introduction

Four degrees or more?

Peter Christoff

This book is based on a simple premise. Public debate and policy choices about climate change should be based on the best available evidence about the risks we face. Decisions about how much and when we should cut our emissions, and how much we should spend on adaptation, should be determined by what we understand and accept are the costs and consequences of *failing* to take sufficient action.

Australia has committed itself to trying to help limit global warming to 2°C. Yet there is widespread agreement that current mitigation efforts – including Australia's – will lead to global average warming of 4°C or more from pre-industrial levels by the end of this century … to a Four Degree World.

The central aim of this book is to make us aware of the likely social, ecological and economic implications of catastrophic climate change for Australia and its region. If 4°C of global warming is the outcome – the *de facto* goal – of present policy settings, we should look at what we will encounter in a Four Degree World. If we don't like these prospects, then perhaps this book may encourage us to think differently about our current commitments and to choose an alternative future.

A heat like no other

Summer in Australia is often marred by hellishly hot days. However, the summer of 2013 was exceptional in several ways. January 2013 produced the hottest month on record. It started fires and broke temperature records across the country. It prompted international media coverage.

Following four months of very warm temperatures, an 'extensive dome of heat' hung over the continent (Braganza, in Hannam, 2013). Successive days of extreme heat covering most of the continent are rare and isolated. Yet for seven days, from 2 January to 8 January, the continental average temperature exceeded 39°C. Previously, Australia had only once seen four days in a row over 39°C, in 1972.

On Monday 7 January the continental average temperature rose to 40.3°C (105°F), the hottest maximum on record, breaking the previous high of 40.17°C on 12 December 1976. The next day, Sydney reached 42.3°C, and on 18 January,

45.8°C – almost 20° above the monthly average and breaking the previous record of 45.3°C set in 1939. Hobart hit 41.8°C, its highest temperature on record, while in Perth, suffering its fiercest heatwave in 80 years, hospitals experienced a wave of admissions of people suffering from heat-related symptoms.

These days also created extreme wildfire conditions across the country. The New South Wales fire service issued 'catastrophic' fire warnings – the highest level on the scale – in four areas of the State. In Victoria, the Country Fire Authority's fire warning website crashed under unprecedented community demand for information as temperatures rose above 40°C in parts of that state.

Across Australia, over 500 wildfires were ignited. Towns and lives were lost. When 100 homes in Dunalley, Tasmania, were incinerated, 2,700 people sheltered on beaches and were stranded at community refuges on the Tasmanian Peninsula, many later evacuated by sea. Images of the aftermath and stories about tragedies of individual and community loss appeared in media footage.

Climate scientists stress that while the cause of an individual weather event, including heatwaves, is always linked to specific weather conditions, 'it is possible to determine the influence of climate change on the frequency of occurrence of such an event' (Plummer et al., 2013). Changes in the frequency and intensity of extreme events are the most obvious manifestations of a changing climate. The extreme weather events of January 2013 in Australia – and others elsewhere – display the influence of a warming world. Plummer et al. (2013) report that 'Australia has warmed steadily since the 1940s, and the probability of extreme heat has now increased almost five-fold compared with 50 years ago.'

Recent research has shown Australia's preparedness for even gradual, low-level climate change is poor. In Canberra in 2003, fires killed 4 people and destroyed 500 homes. In Victoria, the Black Saturday fires in 2009 killed 173 people and more than a million animals, destroyed over 2,000 homes and caused over $4.4 billion damage (VBRC, 2010). Much is required to adapt to even low levels of warming.

Prime Minister Gillard, touring the fire-ravaged ruins of towns in Tasmania, warned that 'we need to prepare for more scorchers' and that extreme bushfires were a part of life in a hot and dry country, and that 'we do know over time that as a result of climate change we are going to see more extreme weather events' (Darby, 2013).

But for what exactly should we prepare?

* * *

Our planet now is only some 0.8°C warmer than it was in pre-industrial times. This change seems slight, especially when considered against the fluctuations in temperature we experience daily. Yet, even with such a small increase, since the start of the twenty-first century we have already witnessed many climate change-related impacts. These include record-breaking weather events in both the southern and northern hemispheres, such as the hottest summer on record in Europe in 2003, in which some 70,000 are estimated to have died (Robine et al.,

2007) and the wettest summer in England and Wales in 2007. In 2010, the worst recorded flood in Pakistan directly affected the lives of some 20 million people. It was accompanied the hottest summer in Russia, which caused massive wildfires and led to the deaths of an estimated 56,000 people. Record-breaking heatwaves occurred in a number of states in the United States in 2011, and 2012 was its warmest year on record. Australia too just has had its longest and most severe drought on historical record, a series of devastating fires, floods and damaging cyclones, and now an unprecedented national heatwave.

Scientists agree that these events are highly unlikely to have occurred without the influence of global warming. What, then, if global warming reaches much higher levels? In this coming century, extreme events and significant underlying changes in temperatures, rainfall, storms and to the productivity of our oceans and landscapes will challenge our ability to live comfortably on this continent.

Negotiating blindly

Until relatively recently, the idea of a Four Degree World seemed fanciful – the stuff of alarmism, a genre of horror–science fiction. Scientists, science journalists and climate commentators increasingly talked and wrote about critical systemic thresholds and global tipping points and the risks of 'dangerous' and runaway climate change (e.g. CACC et al., 2002; Schellnhuber et al., 2006; Lynas, 2007; Pearce, 2007; MacCracken et al., 2008). But until the failure of negotiations at Copenhagen, these discussions remained peripheral to the mainstream debate over the prospect of global warming in the twenty-first century, the carefully phrased reports of the InterGovernmental Panel on Climate Change (IPCC) and slow progress with international climate negotiations.

When the international community adopted the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, it committed itself to preventing 'dangerous anthropogenic interference with the climate system' (Article 2). Defining what such dangerous interference or 'dangerous climate change' might be depends on a value judgement about danger and impact, which will vary geographically (with climate change threatening earlier and more 'dangerous' consequences in northern latitudes, low-rainfall and low-lying areas, and for poorly adapted communities [e.g. Crowley, 2011]). Concerted action depends on reaching consensus about these definition.

Parties to the Convention agreed they would accept their 'common but differentiated responsibilities' in reducing greenhouse emissions and dealing with adaptation. Under the treaty, developed industrialized countries – the major contributors to greenhouse emissions and historical beneficiaries of fossil fuel use – would act first.

In 1997, the Kyoto Protocol was established to enable implementation of the UNFCCC's goals. It required developed countries to adopt mitigation targets during its first commitment period. These targets, determined through political agreement in a multilateral forum, reflected neither scientific advice

nor principles for equitable burden-sharing between nations. The agreement was criticized by environmental NGOs for doing too little in this first period: the developed countries' targets lacked ambition; aggregate reduction of global emissions during the first commitment period would have been about one per cent of the total.

The Protocol was immediately rejected by the United States, which refused to ratify it because the Protocol failed to set emissions reductions targets for major developing economies, notably China (despite this claim being explicitly at odds with the requirements of the UNFCCC). Although the US failed to destroy the Protocol, it managed to delay the agreement coming into force until 2005 and thereby postponed concerted international action to reduce emissions. The Protocol's first commitment period only began in 2008 and ran until the end of 2012.

Once Kyoto was in force, the prospect of its second commitment period – or of a successor post-2012 agreement – loomed. This new arrangement would be conditioned by changing global conditions, including China's growing global economic role and ecological footprint. In 2006 China overtook the United States as the world's largest annual aggregate emitter of carbon dioxide, (although the United States' cumulative and per capita emissions remain much greater). This reflected both its rapid internal economic development and growing wealth and the effects of economic globalization, which since 1992 had turned China into the manufacturing hub of an ever more intensely trade-oriented and carbon-intensive world (see Davis and Caldeira, 2010). Along with other major emergent developing countries, such as India and Brazil, China's growing contribution to aggregate global emissions, along with that of other major emergent developing countries such as India and Brazil, could not be overlooked.

From 2007 onwards the prospects for timely and effective international climate agreement improved and then faltered. In 2007, the 13th Conference of Parties (COP) to the UNFCCC decided on the Bali Action Plan, a roadmap for developing a successor to the Kyoto Protocol's first commitment period and its targets. The Plan would be developed over the next three years and finalized at Copenhagen in 2009.

By 2007 there was emergent agreement in policy and scientific circles that 2°C warming above the pre-industrial global average was the highest level that could be endured before the risks of dangerous climate change, including abrupt and catastrophic climatic shifts, became too high.

In response, the IPCC's Fourth Assessment Report (4AR, published in 2007) suggested that developed countries need to reduce their emissions by 25 per cent to 40 per cent below 1990 levels in 2020, and by −80 to −95 per cent by 2050, with developing countries contributing 'a substantial deviation from their baseline', if we are to stabilize long-term levels of greenhouse gas concentration levels at 450 parts per million (ppm) CO_2 equivalent (Box 13.7) (IPCC, 2007b). Even so, this concentration level would merely offer around a 50-per cent chance of limiting global average warming to 2°C (Meinshausen. 2006a, 2006b).

The *Copenhagen Diagnosis*, produced by an eminent body of climate scientists to update the IPCC's 4AR (Allison et al., 2009), confirmed that global emissions

would need to peak between 2015 and 2020 and then decline rapidly if warming was to be limited to a maximum of 2°C. Greenhouse emissions – if stabilized at 2009 levels for 20 years – would mean the planet had less than a one in four chance of staying below 2°C.

The climate negotiations in 2009 in Copenhagen spectacularly failed to produce a new agreement containing legally binding and targets that reflected best scientific advice and equity principles. The story of Copenhagen is well known: its failure – involving a standoff between the United States and China, the overwhelming influence of national political constraints on ambitious international commitments and the occluded decision-making processes of the UNCCC – threatened the very future of ongoing multilateral climate negotiations.

Nevertheless, last-minute wrangling between the heads of state of the major emitters produced an informal political statement – the Copenhagen Accord – that saved the conference from collapse (Christoff, 2010). Signatories to the Copenhagen Accord for the first time formally agreed to a definition of dangerous climate change, 'recognising the scientific view that the increase in global temperature should be below 2 degrees Celsius' (Para 1, UNFCCC, 2010). They also agreed that 'deep cuts in global emissions are required according to science … so as to hold the increase in global temperature below 2 degrees Celsius' (Para 2, UNFCCC, 2010).[1]

The Accord process also produced non-binding 'unconditional' and 'conditional' pledges from most developed and some major developing states for 2020 emissions targets but it failed to deliver longer-term targets for 2050. Rather than being the product of a negotiated agreement reflecting scientific advice and equity-based formula to produce a robust and defensible target, these 'bottom-up' pledges were what individual nations decided they could manage based on their domestic political circumstances and economic capacity.

This has generated a crisis for international climate negotiations. In effect, expedient unilateralism has replaced concerted multilateralism. Negotiators continue to hope that this 'bottom-up' process of target setting will somehow manage to stagger slowly and blindly towards a collective goal capable of meeting the objective of averting dangerous climate change, at a time when the time available for effective action is rapidly diminishing.

The targets pledged included some within the range suggested by the IPCC (Norway's, Germany's and the EU's are in line with the IPCC's conservative reduction range of −25 to −40 per cent), but most were not. In all, the aggregate reduction pledged would make achieving the aggregate global reductions necessary to keep below 2°C impossible.

Following Copenhagen, most Annex I countries pledged an unconditional national target and also a more ambitious conditional target dependent on other countries pledging comparable reductions. The Netherlands Environmental Assessment Agency and consultancy Ecofys noted that the unconditional ('low') pledges would result in a total Annex I emission reduction target of 4 per cent to 18 per cent below 1990 levels by 2020. The conditional ('high') pledges amount

to a reduction target of 9 per cent to 21 per cent (den Elzen et al., 2010: 11). In all, these pledges fall well short of the cuts suggested by the IPCC.

Even if current pledges are fully implemented, global total greenhouse gas emissions in 2020 are likely to be between 53 and 55 billion tonnes CO_2 eq per year (Schellnhuber et al., 2012: 6).

In all, there is a substantial ambition gap of about 14 billion tonnes CO_2 eq per annum between current commitments and what is required in 2020 to stay on an emission reduction pathway consistent with meeting the 2°C target (and more if the target is 1.5°C). This gap is approximately the equivalent of the emissions of the USA and China combined.

Since Copenhagen, climate negotiations at Cancun, Durban and Doha have sought to restore faith in the multilateral negotiation process and cautiously to re-establish momentum toward a successor to Kyoto's first commitment period. But progress has been slow and tentative.

At Durban in 2011, the parties to the UNFCCC agreed to a new negotiating process – the Durban Platform for Enhanced Action – for 'a protocol, another legal instrument or an agreed outcome with legal force', to be finalized in 2015, to include all major emitters, and to be implemented from 2020 (UNFCCC, 2012). The parties also formally amended the Kyoto Protocol to include the 2020 pledge targets from Copenhagen. Significantly, major developed and developing countries – including the US, China and India – accepted that the new agreement would contain targets for them all. Crucially, the Durban conference also formally noted the 'ambition gap' between these targets and what is needed to limit warming to 2°C or 1.5°C above pre-industrial levels – but no adjustments to the pledges are expected before 2015 at earliest.

There are different interpretations of value of this new process, which can be seen optimistically as getting the negotiations on the road again or, pessimistically and more realistically, as an agreement to produce an agreement on a timetable that ignores the urgency of the problem.

The ambition gap – and the contrast between the glacial pace of international negotiations and current commitments and the need for rapid emissions reductions outlined by recent climate science reports – is threatening to become a chasm. Despite pledges and commitments, global aggregate greenhouse emissions have remained above the highest projected range under the IPCC's modeled scenarios, bouncing back to a new annual record in the period following the Global Financial Crisis in 2008.

The Netherlands Environmental Assessment Agency reports that, instead of progress since the start of this century, we are slipping further behind:

> Global emissions of carbon dioxide (CO_2) – the main cause of global warming – increased by 3% in 2011, reaching an all-time high of 34 billion tonnes in 2011 … With a decrease in 2008 and a 5% surge in 2010, the past decade saw an average annual increase of 2.7% …
>
> In many OECD countries, CO_2 emissions in fact decreased – in the European Union by 3%, in the United States by 2% and in Japan by 2% …

> [However] CO_2 emissions from OECD countries now account for only one third of global emissions – the same share as that of China and India, where emissions increased by 9% and 6%, respectively, in 2011.
>
> (Olivier et al., 2012)

Clearly, to ensure adequate emissions reductions which do much more than leave the planet with a 50/50 risk of exceeding 2°C, and to have a chance of meeting safer lower targets, developed and developing nations and economies will have to adopt far more aggressive emissions reduction paths than those currently conceived – and do so before 2020.

Further, international action undertaken from 2020 onwards will have to be particularly substantial if we are still to achieve the goal even of remaining below 2°C . Analysis suggests a reduction in global emissions of between 3.7 per cent and 9 per cent per annum is required between 2020 and 2050 if this goal is to be achieved, depending on when global emissions peak (WBGU, 2009, Figure 3.2-1).

In the absence of concerted and effective multilateralism, and in the absence of effective international limits on emissions, there is an increasing urgency for more immediate, more powerful and unilateral mitigation action from every country that can do so. The implications of this prospect will be considered for Australia at the conclusion of this book.

A Four Degree World?

Interest in what would happen when the planet warms beyond 2°C has grown only slowly, as if considering the consequences of such a world is one traumatic step too far for human imagination.

Successive IPCC reports have underlined the contribution of human activities to global warming through the production of greenhouse gas emissions. As a consequence of such activity, atmospheric greenhouse gases have increased from pre-industrial concentrations of 260–80 ppm to around 400 ppm in 2013.

The observed increase in global average temperature over the past century can be largely attributed to human influences (IPCC, 2007a). This warming, and the increase in atmospheric greenhouse gases, has also begun to contribute to rising sea levels, warming oceans and ocean acidification, increasing melting of ice from Greenland and Antarctica and loss of Arctic sea ice (Allison et al., 2009) and – as already discussed – to new records for heat waves, extreme temperatures and other forms of extreme weather (Trenberth, 2010).

Climate modeling undertaken since the start of this century has provided a guide to the probable consequences of increasing emissions, including from fossil fuel use. While successive IPCC reports remain the most authoritative summary of this work, they have also proved to be conservative in their assessment of likely trends and impacts.

Without effective action to mitigate anthropogenic (human-induced) greenhouse gas emissions, it is likely that atmospheric CO_2 concentration will double

(from pre-industrial levels) sometime this century (IPCC, 2007a). Global CO_2 emissions have risen by 1.9 per cent per year in the 1980s, 1.0 per cent per year in the 1990s and 3.1 per cent since 2000 (Peters et al., 2012). These growth rates are at the high end of the emissions scenarios used by the IPCC.[2] They would lead to a global-average warming of 4.2–5.0°C by the year 2100 (Peters et al., 2012). While some of the changes associated with this warming would be gradual, others could be abrupt and non-linear, catalyzing changes in the state of the planet that would be largely irreversible and sometimes dramatic.

In 2006 the Stern Review commented on the likely impacts of increasing levels of warming for different ecosystems, geographical regions and for human growth and development. It highlighted the increased risks of four degrees of warming to vulnerable communities, with potentially 30–50 per cent decrease in water availability in Southern Africa and the Mediterranean; agricultural yields declining by 15–35 per cent in Africa; and entire region out of production (e.g. Australia); up to 80 million more people exposed to malaria; and 7–300 million more people affected by coastal flooding each year (see Stern, 2007: 57 [Table 3.1] and Figure 2 [Executive Summary]).

In the following year, science journalist Mark Lynas spent several months in the Radcliffe Library at Oxford. He reviewed the scientific literature on the impacts of warming and produced a degree-by-degree guide to our planet's future (Lynas, 2007). Lynas reported that, based on geological evidence, at 4°C of global warming, the whole planet would be without ice cover for the first time in 40 million years. Over time sea levels would rise by some 65 metres, but well before then oceans would threaten deltaic cities from Mumbai to Shanghai, submerge a third of Bangladesh, and displace tens of millions living coastal regions and the inhabitants of low-lying islands. Such warming would cause agricultural production to crash, including in highly populous countries such as China. New deserts would spread in Southern Europe, while droughts would be the norm across parts of the north. Summers would be dreaded and the extreme temperatures of 2003 would seem normal, perhaps cool. The book was well received but hardly created a stir.

The Hadley Centre and British Met Office also addressed the question of 'When could global warming reach 4°C?' (Betts et al., 2009). Its authors concluded that:

> While much political attention is focused on the potential for global warming of 2°C relative to pre-industrial, the [IPCC's] AR4 [Fourth Assessment Report] projections clearly suggest that much greater ranges of warming are possible by the end of the 21st Century in the absence of mitigation. The centre of the range of AR4 projected global warming was approximately 4°C …
>
> (Betts et al., 2009: 1)

The report went on to examine the consequences of emissions continuing along the high (A1FI) trajectory, which was one used by the IPCC – and which

currently is slightly less than the emissions trajectory occurring in reality. It concluded that:

> our best estimate is that the A1FI emissions scenario would lead to a warming of 4°C relative to pre-industrial times during the 2070s. If carbon feedback cycles are stronger, which appears less likely but still credible, then 4°C warming could be reached by 2060.
>
> (Betts et al., 2009: 1)

Four Degrees and Beyond: Implications of Global Climate Change of 4+ Degrees for People, Ecosystems and the Earth-system was a scientific conference held at Oxford University, late in 2009, The Oxford Conference was driven by concern about the growing gap between the emerging target of 2°C and languid emissions reduction policies. It provided further insights into impacts for specific ecosystems, water, agriculture and the growing risks of reaching 4°C (New et al., 2011), and received some international media coverage. Nevertheless, its findings were reported as 'fringe science' – a side-note of disciplinary concern to be registered while the international community moved to seal an agreement to deal with just such a problem … at Copenhagen.

Since Copenhagen, however, with momentum towards effective mitigation faltering, the potential for catastrophic climate policy failure has become a tangible reality and anxiety. This shift in perspective was reflected in the national and global media coverage received by the *Four Degrees or More?* Conference in Melbourne in 2011, and by the recent report *Turn Down the Heat: Why a 4°C Warmer World Must be Avoided*, written for the World Bank in 2012 (Schellnhuber et al., 2012).

The report for the World Bank concludes that even if the current Copenhagen/Cancun commitments and pledges are fully implemented, there is roughly a 20 per cent likelihood of exceeding 4°C by 2100. If they are not met, then there is a much higher likelihood – more than 40 per cent – of warming exceeding 4°C by 2100, and a 10 per cent chance of this occurring in the 2070s (Schellnhuber et al., 2012: 23). It also reminds us that on the IPCC's high fossil fuel intensive pathway (SRESA1F) – the trend we are currently pursuing – warming exceeds 4°C earlier in the twenty-first century. Moreover:

> Warming would not stop there. Because of the slow response of the climate system, the greenhouse gas emissions and concentrations that would lead to warming of 4°C by 2100 would actually commit the world to a much higher warming, exceeding 6°C or more, in the longer term, with several metres of sea-level rise ultimately associated with this warming.
>
> (Schellnhuber et al., 2012: xiii)

This Four Degree World is one of almost unimaginable social, economic and ecological consequences and catastrophes. The report confirms that, at 4°C, there is a greater risk of rapid, abrupt and irreversible change associated with loss of Arctic sea ice, rising seas caused by melting of ice from Greenland and the

West Antarctic Ice Sheet, increasing drought and aridity and extreme temperatures in many regions (Africa, Europe, the Middle East, Americas, Australia and South-East Asia), increasing ocean acidification and decarbonization of large-scale ecosystems like the Amazon forest. It also notes that the risk of global impacts on food supplies would be great, with greater-than-predicted adverse impacts associated with warming already being observed in crop production (Schellnhuber et al., 2012: 15).

Four Degrees and Australia in a hot world

Currently, international economic and energy policy settings make a Four Degree World an impending reality. So we must ask: what does this mean for Australia? This book reflects research, discussions and debates that occurred before, during and after the conference *Four Degrees or More? Australia in a Hot World*, held at Melbourne University in 2011 and inspired by the Oxford conference held two years earlier. It is divided into four parts.

Part One lays the scientific foundations of the book. It introduces the climate science that frames our understandings of what our continent will be like in a Four Degree World. This section clarifies the assumptions and understandings which underpin the book, and provides scientific reference points for the sections and chapters that follow.

Chapter 2 considers the implications of four degrees of warming for longer-term shifts in the continental incidence and distribution of temperature and rainfall, and the prospects for drought.

Chapter 3 considers historical patterns and projected changes to events such as intense rainfall and hail, storms and floods, extreme temperatures, droughts and heatwaves, and extreme sea-level events.

Part Two then presents an overview of what these climatic changes might mean for Australia's physical environment – its terrestrial and marine ecosystems and its plants and animals, and its farmed landscapes and agricultural productivity.

Chapter 4 examines impacts on Australia's land-based plants and animals. It considers the resilience that has been 'built' into Australia's ecosystems by previous periods of climate-related hardship and whether this resilience might serve it well in a future in which rapid climate-related transformations and impacts place significant demands on species and systems.

Chapter 5 looks at the impacts of warming seas, sea-level rise and ocean acidification for the survival and productivity of Australia's marine ecosystems, with special attention to coral reef systems – such as the Great Barrier Reef – already stressed by human activity.

Chapter 6 examines how Australian agricultural systems, which have developed robust productive responses to already highly variable weather and challenging landscapes, might be affected by projected substantial changes in temperature and rainfall. The chapter considers the effect of the relocation