CLIMATE
COMMISSION

The Critical Decade 2013: A summary of climate change science, risks and responses

Two years ago in its report *The Critical Decade: Climate science, risks and responses*, the Climate Commission stated that this decade, 2011-2020, is the decade to decisively begin the journey to decarbonise our economy, thereby reducing the risks posed by climate change. One quarter of the way into the critical decade the Climate Commission has prepared an update of our current knowledge of climate change - the scientific evidence, the risks to our communities and the responses required to prevent significant harm. This summary is drawn from *The Critical Decade 2013: Climate change science, risks and responses*. References to the scientific literature have not been included here to enhance readability, but they can be found in the detailed report, which is thoroughly referenced.

The overall message of the report is clear.

One quarter of the way through the Critical Decade, many consequences of climate change are already evident, and the risks of further climate change are better understood. To meet the widely accepted policy goal of limiting climate change to a temperature rise of no more than 2°C above pre-industrial levels, global society must virtually decarbonise in the next 30-35 years. This means that most of the fossil fuel reserves must stay in the ground.

The changing climate is affecting people and the natural world we live in.

It is now clear that the climate system has already shifted, changing conditions for all weather. While extreme weather events have always occurred naturally, the global climate system is hotter and wetter than it was 50 years ago. This has loaded the dice toward more frequent and forceful extreme weather events. In Australia the influence of climate change on extreme weather events is clear, with observed effects on heatwaves and hot weather, heavy rainfall events, extreme fire weather and droughts. More intense and/or frequent extreme weather events pose serious risks to our health and well-being, to our societies and economies, and to natural ecosystems.

The Australian summer of 2012/2013 was remarkable in the number of high temperature records that were set and the intensity and extent of the extreme heat (see the Climate Commission's *The Angry Summer* report). The extreme temperatures experienced during the 2012/13 Australian summer are part of a longer-term pattern. The duration and frequency of heatwaves across Australia has increased over the period 1971-2008, and the hottest days during a heatwave have become even hotter. The number of record hot days has more than doubled in Australia in the last 50 years.

Global average surface air temperatures are projected to continue to increase by between 1.3 and 6.1°C by 2100 compared to a 1980-1999 baseline. As even more heat continues to accumulate in the atmosphere, the number of heatwaves and very hot days across Australia is projected to increase significantly by the end of the century.

Many parts of Australia, including southern New South Wales, Victoria, Tasmania and parts of South Australia, have experienced an increase in extreme fire weather over the last 30 years.

Changes in extreme rainfall events have also been observed across Australia and globally. For example, northwest Australia has experienced a significant increase in the frequency of heavy rainfall events. The La Niña events in 2010 and 2011 brought the highest two-year Australian-average rainfall total on record.

In stark contrast, the Millennium Drought of 1997-2009 was one of Australia's most severe droughts and since the 1970s southwest Western Australia has experienced a long-term drying trend. It is likely that southern Australia will continue to experience dry conditions in the future, especially in winter, while many estimates project little change in annual average precipitation over the far north of the continent. It is more likely than not that heavy rainfall events will become more frequent over much of Australia.

Changes in extreme weather such as these are having health, social, economic and environmental consequences across Australia and around the world.

Our health is affected directly by increased temperatures. Recent heatwaves around Australia have contributed to increased hospital admissions and fatalities. Overall across Australia, heat-related deaths, already the cause of more deaths than any other type of natural hazard in Australia, are likely to increase even further. Indirect health impacts from a regionally warmer and wetter climate are also important, such as a southward expansion in the range of the mosquito that carries dengue fever.

Climate change is likely to affect Australia's infrastructure, including commercial and residential buildings, utilities (such as energy and water services) and transportation systems. For example, the prolonged extreme heat in Melbourne in January 2009 caused substantial damage to critical infrastructure. Unprecedented electricity demand and faults in the transmission system made the entire grid vulnerable to collapse and the train and tram networks suffered widespread failures.

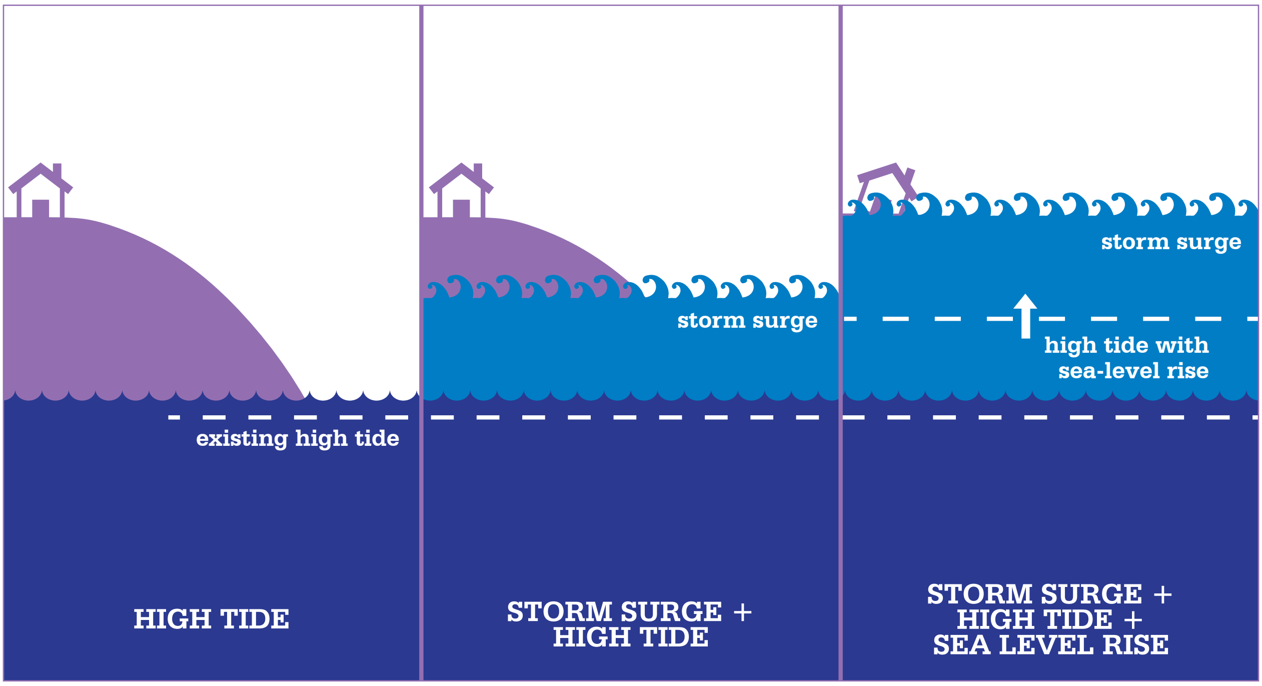


Figure 1: Rising sea level is increasing the base level for a storm surge.

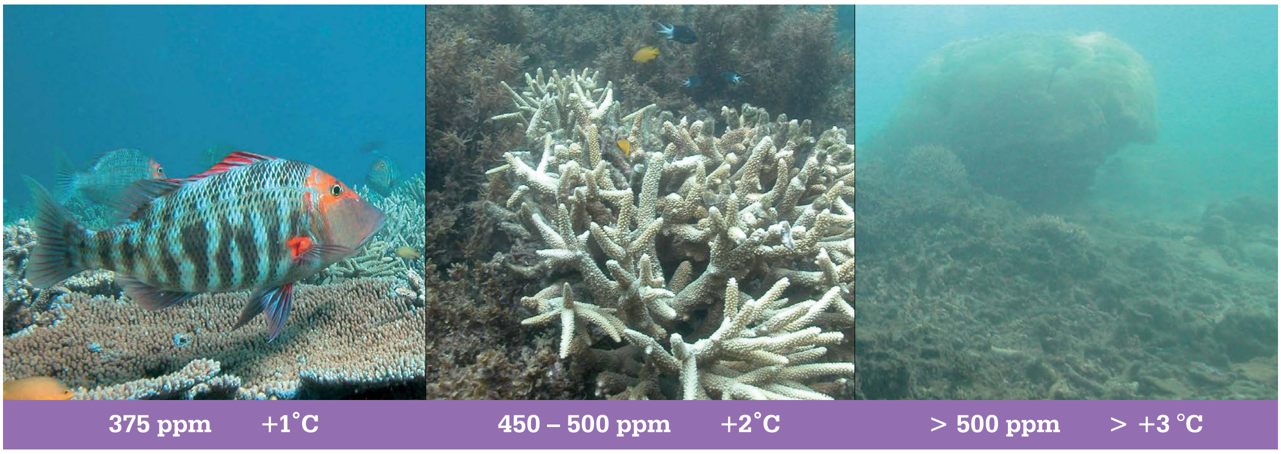


Figure 2: Anticipated reef states under varying carbon dioxide concentrations
Source: modified from Hoegh-Guldberg et al., 2007

Sea-level rise poses serious risks to Australia's coastal infrastructure by increasing the risk of flooding from storm surges and high tides (*Figure 1*). The combined value of commercial, light industrial, transport and residential buildings at risk from a sea-level rise of 1.1 m was valued at approximately $226 billion (2008 replacement value), with exposure highest in Queensland in terms of both replacement value and total number of properties and infrastructure.

Australia's agricultural producers already have to deal with a highly variable climate, and climate change will pose some additional serious challenges. For example, rising temperatures are likely to have adverse effects for cattle by increasing the frequency of heat stress, especially for those cattle in feedlots, and reduce overall productivity in the beef, sheep and wool sector. Changing rainfall patterns may affect crop productivity, for example in irrigation areas of the Murray-Darling Basin.

Australia is one of the most biologically diverse countries in the world, and many of its natural ecosystems are at risk from a changing climate, often acting in combination with other stresses. Heatwaves on both land and in the sea have already had severe impacts. For instance, on a single day in 2002, air temperatures exceeded 42°C in areas of southeast Australia, killing over 3,500 flying foxes. Marine heatwaves affect many species, especially on coral reefs (*Figure 2*), where they can lead to coral bleaching. The Great Barrier Reef has experienced at least seven bleaching events since 1979. The most serious of these, in 1998 and 2002, affected up to 60% of individual reefs.

Human actions, mainly the burning of fossil fuels, are destabilising the climate.

Since the Industrial Revolution, and especially over the past 60 years, human activities have become so significant that they are changing the climate on a global scale. The primary cause is the burning of fossil fuels such as coal, gas and oil to generate energy for electricity, transport, heating and cooking. The waste gases produced from fossil fuel combustion, mainly carbon dioxide (CO_2), are destabilising the climate system. These gases are altering the energy balance at the Earth's surface by enhancing the greenhouse effect.

The greenhouse effect is one of the most important natural features of the climate system. *Figure 3* shows how it works. Incoming solar radiation penetrates through the Earth's atmosphere, with some of this radiation reflected back out to space by clouds and by bright surfaces, such as the white polar ice sheets. But much of this incoming energy is absorbed by land and water at the Earth's surface.

To maintain its energy balance, the Earth emits the same amount of energy back into space as the amount that is absorbed. But this energy is emitted in a different form to how it arrived from the sun, as heat, not light. This is where the greenhouse gases come in. Although they are mostly transparent to the incoming solar radiation, they trap some of the outgoing heat, keeping the Earth's atmosphere, and hence the surface also, warmer than they would otherwise be. The most important long-lived greenhouse gases are CO_2, methane and nitrous oxide.

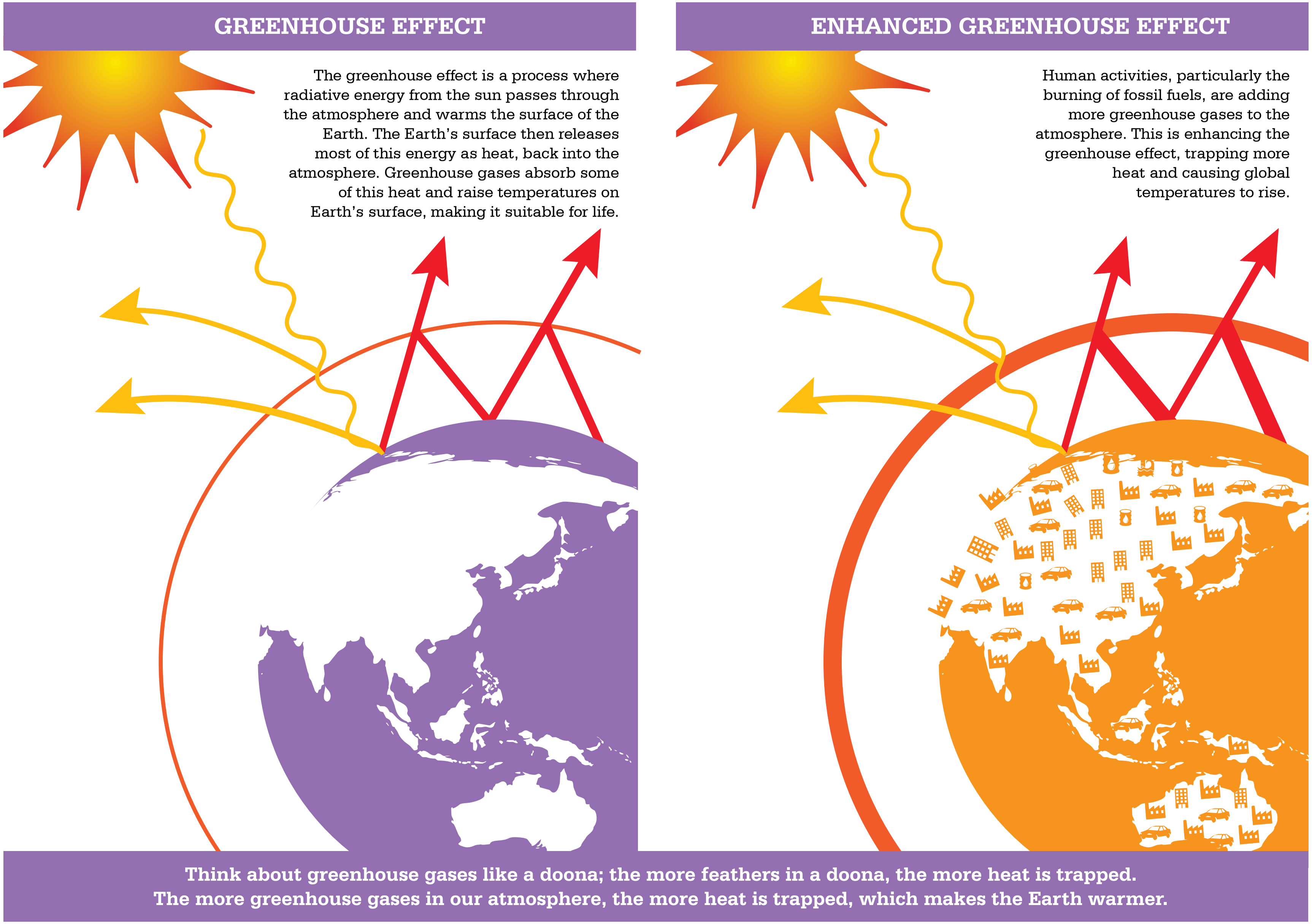


Figure 3: The influence of increased concentrations of greenhouse gas emissions on the greenhouse effect.

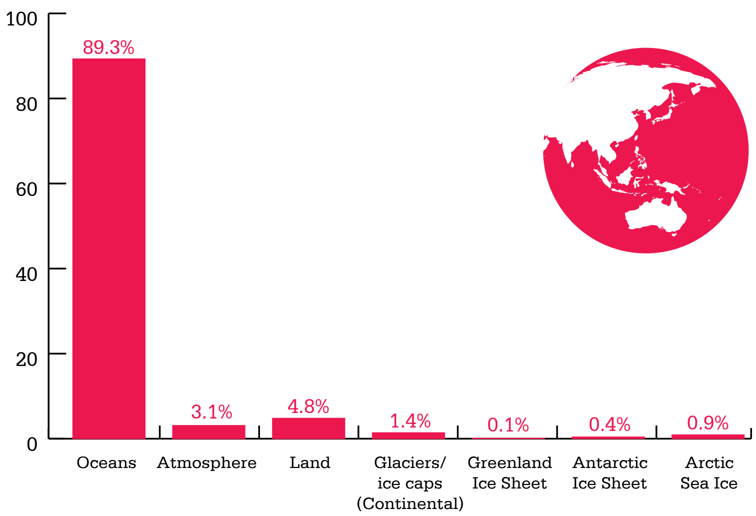


Figure 4: The partioning of the extra heat from the enhanced greenhouse effect to the various parts of the climate system for the period 1961-2003. As indicated in the graph, the ocean has taken up about 90% of the extra heat in the climate system.

Source: IPCC, 2007

This natural greenhouse effect is very important. Without it, the Earth's surface would be over 30°C colder than it is today, and would be frozen, even at the equator. Under these conditions, life as we know it, and certainly human life, could not exist.

Humanity has benefited greatly from a stable climate, based on a stable energy balance, over the past 10,000 years, developing agriculture; villages and cities; and complex civilisations over that period. Ironically, over just the past 200 years, our own activities have upset the Earth's energy balance and rapidly destabilised the climate.

The rapidly rising concentration of greenhouse gases in the atmosphere is enhancing the greenhouse effect, trapping more heat and causing global temperatures to rise. The greenhouse gases act much like a doona; the more feathers in a doona, the more heat is trapped. The more greenhouse gases in our atmosphere, the more heat is trapped, which makes the Earth warmer. Because we have never before increased CO_2 by such a large amount in such a short space of time, it is difficult to know exactly how the climate system will respond to all the extra heat being trapped by greenhouse gases.

In fact, the last time CO_2 was this high was in the Pliocene about 3 to 4 million years ago, well before modern humans evolved. The climate then was very different than today's climate. The global average temperature was 2-3°C higher and sea level was 10-20 m higher. A global environment of that nature is outside of human evolutionary experience.

Scientific understanding of human-driven changes in the climate has strengthened.

Scientific observations confirm that the climate is changing, and changing at a very fast rate compared to the slow, natural swings in climate over geological time periods. The ocean and the air are heating up, rainfall patterns are changing, the area of Arctic sea ice is decreasing, the large polar ice sheets are losing mass, sea level is rising and the distributions and life cycles of many plants and animals are changing.

Relating the observed changes in the climate to the altered energy balance requires a stocktake of where the extra heat from the enhanced greenhouse effect actually goes. By far the largest absorber of this extra heat is the ocean, which has taken up about 90% (*Figure 4*). The other 10% is distributed among the atmosphere, the land, glaciers and ice caps, sea ice and the large polar ice sheets. Only about 3% of the extra heat is being stored in the atmosphere.

Figure 5 shows how ocean heat content has been increasing steadily since 1955 to the present. The surface waters of the ocean have warmed over the 20^{th} century and continue to warm, with the average temperature of the 0-700 m layer increasing by 0.18°C between 1955 and 2010. While this increase may seem minor, a small change in ocean temperature requires a massive amount of heat compared to that required to warm the atmosphere. Warming at greater depths has become increasingly important, with 30% of the warming over the last decade occurring in waters below 700 m. Substantial warming has occurred in

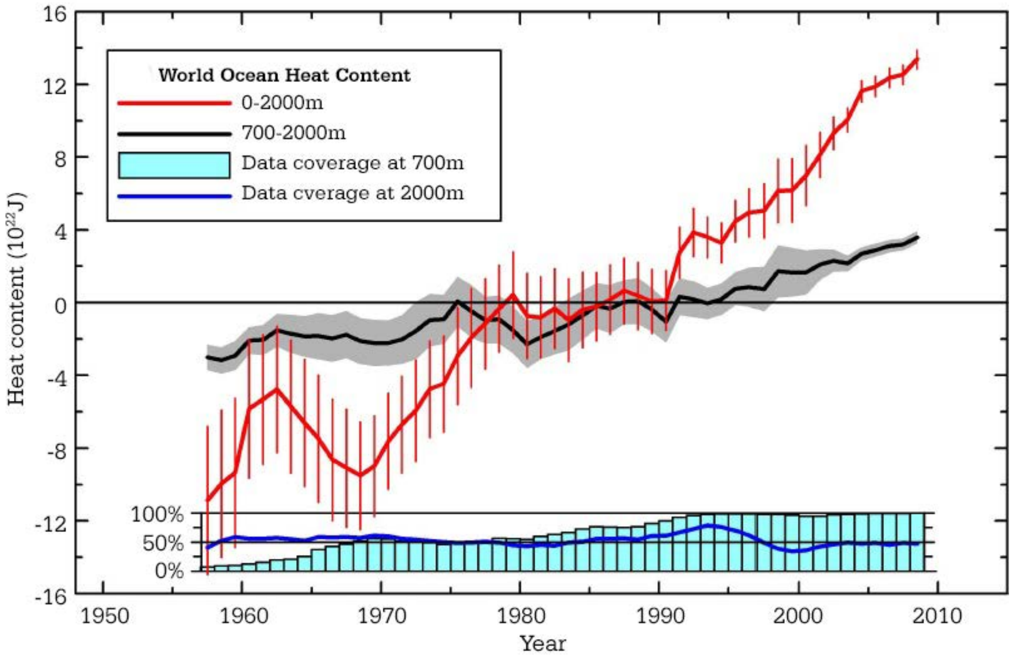


Figure 5: Time series of global ocean heat content demonstrating an increase in heat content (measure as 10^{22}J) for both the 0-2,00 m and 700-2,00 m layers of the ocean since 1955. The red line demonstrates the 0-2,000 m layer and the black line demonstrates the 700-2,000 m layer. Measurements are based on running averages over five-year periods, relative to 1955-2006. The vertical red bars represent +/- 2 times the standard error of the mean 0-2,000 m estimates and the grey-shaded area represents +/- 2 times the standard error about the 700-2,000 m estimates. The bar chart at the bottom represents the percentages of one-degree squares (globally) that have at least four 5-year on-degree square anomaly values used in their computation at 700 m depth. Blue line is the same as for the bar but for 2,000 m depth.

Source: Levitus et al., 2012

the oceans surrounding Australia, with a particularly large warming associated with changes in the East Australian Current.

Over the last 50 years air temperature has been increasing; every decade has been warmer than the decade before. In fact, 2000-2009 was the hottest decade since records began. Global average air temperature has risen by about 0.8°C over the past century. The air temperature trend for Australia over the last century largely mirrors the global trend, with a rise of about 0.9°C from 1910 to the present. The accumulation of heat in the climate system has led to significant changes in other features of the climate. Global changes in rainfall have been observed, including in Australia. Southwest Western Australia and the far southeast of the continent, along with Tasmania, have become drier (*Figure 6*).

Even during the very wet conditions associated with the La Niña events of 2010-11 and 2011-12 across much of Australia, including the devastating Queensland floods, the longer-term regional drying trends over the southwest and southeast continued.

Increased heat is also causing significant global changes in snow and ice. Snow and ice are particularly important because they help regulate the Earth's temperature by reflecting back some of the radiation received by the sun. Loss of snow and ice reduces the reflection of incoming solar radiation, enhancing regional warming.

The melting of land-based ice, including the large polar ice sheets, is an important contributor to sea-level rise. Over the past two decades the Greenland and Antarctic ice sheets have experienced a combined net loss of ice with an average rate of about 600 billion tonnes per year for the 2008-2010 period. The rate at which ice is being lost is increasing.

Changes in floating sea ice are also occurring, with a dramatic downward trend observed in Arctic sea ice for several decades, particularly over summer. The extent of Arctic sea ice reached a record low during the northern hemisphere summer of 2012, and is decreasing at a rate faster than the most pessimistic climate model projections.

As expected with a warming ocean and loss of land-based ice, sea level is rising, Global average sea level was 20 cm (+/- 3 cm) above the 1880 level in 2011. Several low-lying areas of the Australian coast are particularly vulnerable to sea-level rise, including areas inhabited by remote Indigenous communities in northern Australia; Kakadu National Park;

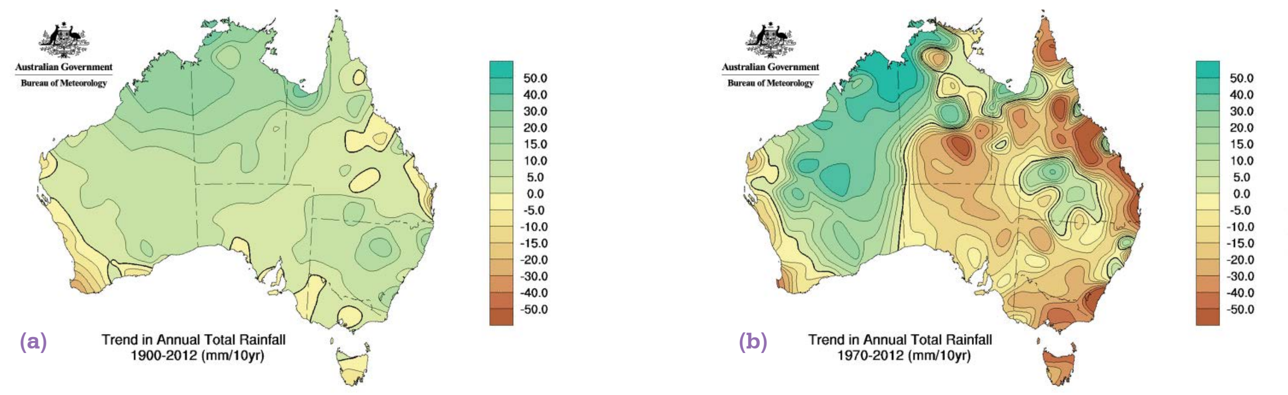


Figure 6: Trend in annual rainfall across Australia for the periods 1900-2012 (a) and 1970-2012 (b). Source: BoM, 2013c

the Torres Strait islands; the Great Barrier Reef; the Gippsland Lakes area in Victoria; the central coast of New South Wales; and southeast Queensland.

As well as taking up heat, the ocean is increasing its uptake of CO_2 from the atmosphere. Dissolved CO_2 reacts with water to form carbonic acid, making the ocean more acidic. The average acidity of the ocean has already increased by approximately 30% since pre-industrial times. Increasing ocean acidity decreases the concentrations of carbonate ions, an essential building block for many marine organisms such as coral. This impact of increasing ocean acidity is already evident. For example, some species of calcifying zooplankton in the Southern Ocean now have shells 30-35% lighter than their counterparts in pre-industrial times. Increasing acidity has also led to a decline in growth rates of corals in the Great Barrier Reef, although thermal stress and other factors may have contributed to this trend.

This is the critical decade for action on climate change

Climate change is much more than just an environmental problem. It is an economic, technological and social challenge that requires a fundamental transformation of our societies, in particular our means of generating energy, if we are to stabilise the climate at a level that is safe for future generations. Our scientific understanding of the nature of climate change and the risks that it poses can help us to determine what constitutes 'dangerous' climate change, assess the magnitude and urgency of the emissions reduction task, and manage the carbon cycle in the best way possible.

The so-called 2°C limit, widely accepted by most nations around the world, including Australia, is an estimate of the level beyond which dangerous climate change lies (*Figure 7*). The 2°C limit is based on assessment of the risks of increasing levels of climate change. As our scientific understanding has strengthened over the past decades, the case for the 2°C limit has also strengthened.

Adopting the 2°C limit allows us to assess the magnitude of the emissions reductions that are required to achieve this goal. The most commonly used approach for doing this is the 'targets and timetables' approach, which involves a number of complexities. Scientists have developed the more robust and simple 'budget approach', which works by converting the 2°C limit into a CO_2 emission budget over a given period of time, regardless of national source. To account for uncertainty around the sensitivity of the climate system, the relationship between emissions and the associated temperature rise is expressed as a probability.

The budget approach shows that to have a 75% chance of staying within the 2°C limit, we can emit no more than 1,000 billion tonnes of CO_2 from 2000 to mid-century. In the first 13 years of this period, we have already emitted nearly 400 billion tonnes, about 40% of the total allowable budget (*Figure 8*). That leaves a budget of just over 600 billion tonnes of CO_2 for the next 35-40 years, after which the world economy needs to be completely decarbonised. Worse yet, the rate at which we are spending the budget is still much too high, and is growing. For example, from 2011 to 2012, global CO_2 emissions rose by 2.6%. Under a business-as-usual model, with emissions growing at 2.5% per annum, we are on track to have completely used up the allowable global emissions budget within the next 16 years, that is, by 2028.

Over recent years the discovery and exploitation of new reserves of fossil fuels has surged in Australia and elsewhere, with the prospect of new coal fields being developed and non-conventional sources such as coal-seam gas and shale oil being exploited.

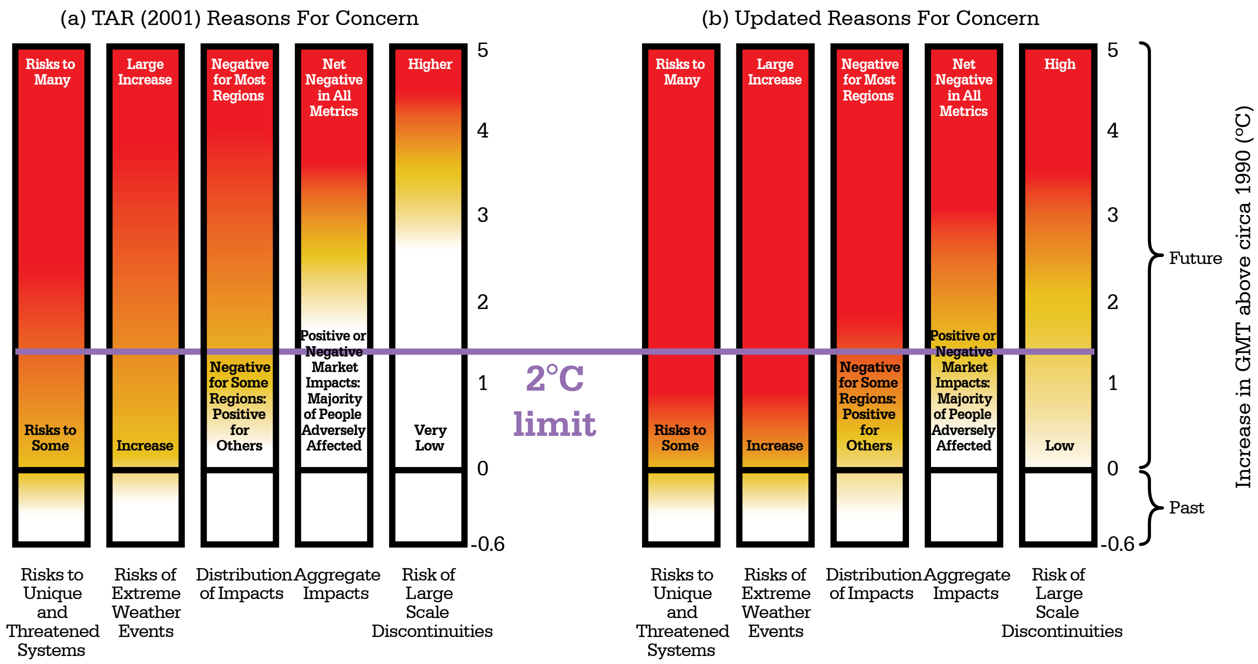


Figure 7: Risks from climate change by reason for concern (RFC) for 2001 compared with updated data. Climate change consequences are plotted against increases in global mean temperature (GMT) (°C) after 1990. Each column corresponds to a specific RFC and represents additional outcomes associated with increasing global mean temperature. The colour scheme represents progressively increasing levels of risk. The historical period 1900 to 2000 warmed by about 0.6°C and led to some impacts. (A) RFCs from the IPCC Third Assessment Report as described in Smith et al., 2011.
(B) Updated RFCs derived from IPCC Fourth Assessment Report as discussed in Smith et al., 2009.

The current amount of carbon embedded in the world's indicated fossil fuel reserves (coal, oil and gas) would, if all were burned, emit an estimated 2,860 billion tonnes of CO_2. This is nearly five times the remaining allowable budget of about 600 billion tonnes to stay within the 2°C limit.

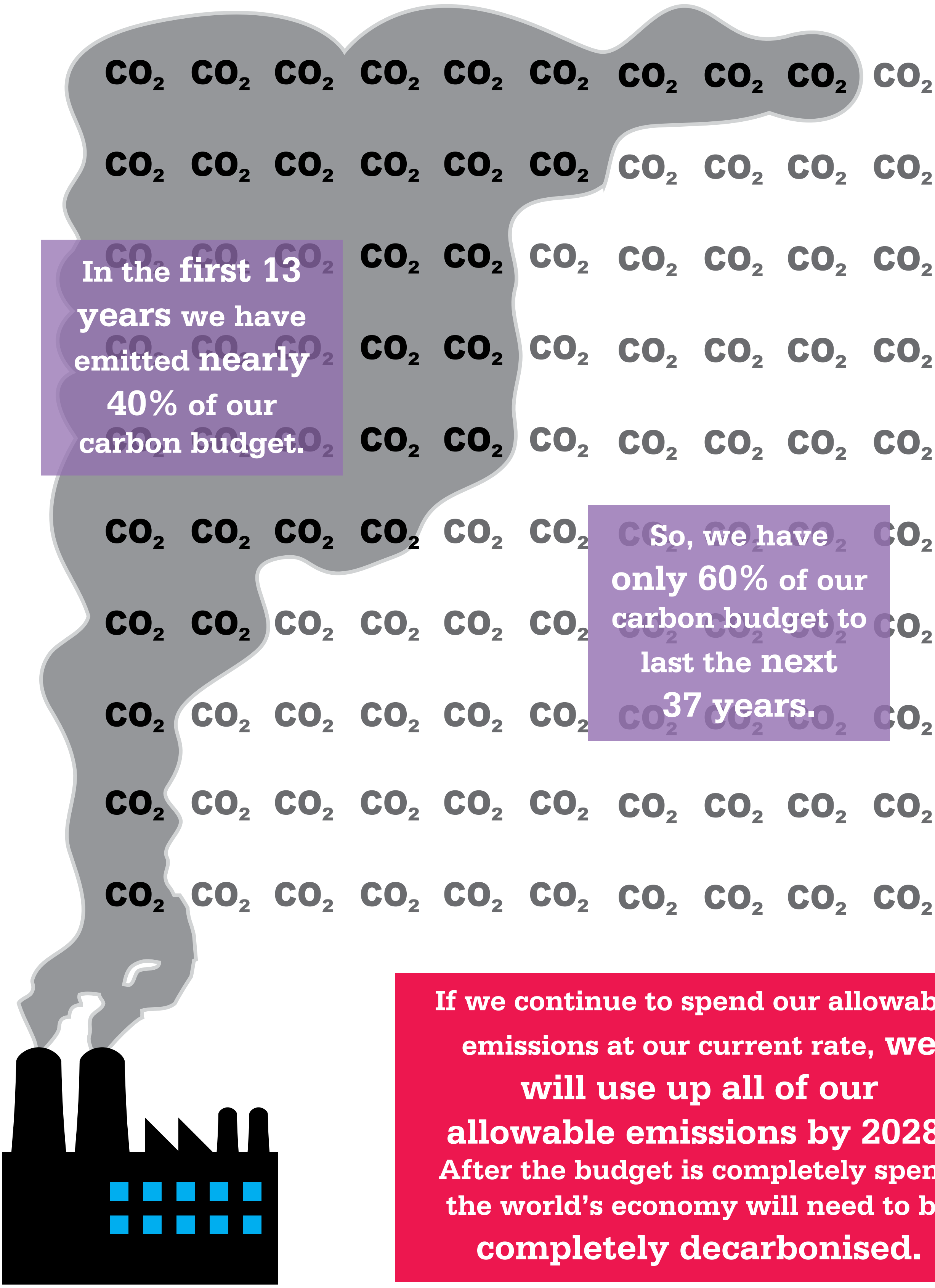
The carbon budget is clear and compelling. The trend of increasing global emissions must be slowed and halted in the next few years and emissions must be trending downwards by 2020 at the latest. Investments in and installations of renewable energy must therefore increase rapidly. And, critically, most of the known fossil fuel reserves must remain in the ground. The budget approach focuses attention away from interim emission reduction targets such as those for 2020 and squarely on the end game – the decarbonisation of the world's economies by mid-century.

There are some promising signs that the first steps are being taken towards decarbonising the global economy. Renewable energy technologies are being installed at increasing rates in many nations. The world's biggest emitters – China and the United States – are beginning to take meaningful actions to limit and reduce emissions (for further information see the Climate Commission's *The Critical Decade: Global action building on climate change*). However, the rapid consumption of the carbon budget, not to mention the discovery of many new fossil fuel reserves, highlights the enormity of the task. Much more needs to be done to reduce emissions… and quickly.

The scientific basis for urgent action on climate change is clear. Whether we act decisively and rapidly now will influence the kind of world people live in for generations to come.

We are living in the critical decade.

For a 75% chance of meeting the 2°C limit we can emit no more than 1,000 billion tonnes of CO_2 between 2000 and 2050.



If we continue to spend our allowable emissions at our current rate, we will use up all of our allowable emissions by 2028. After the budget is completely spent, the world's economy will need to be completely decarbonised.

Figure 8: Overspend in the carbon budget. Each CO_2 represents 10 billion tonnes of CO_2.

Common questions about climate change

The following answers to common questions are included to help readers talk about climate change with family, friends and colleagues. For further information refer to the sections of the detailed report *The Critical Decade 2013: Climate change science, risks and responses* identified under each answer.

What is climate change?

Climate change is any significant change in the measures of climate lasting for several decades or longer, including changes in temperature, precipitation, or wind patterns. Historically, the Earth's climate has changed continually, but it is widely agreed the recent observed changes have been contributed to by human activities.

For further information refer to *1. The science of climate change*.

How much has the global temperature changed?

Long-term air and ocean temperature records clearly show that the Earth is warming. Over the past century, the global air temperature has increased by about 0.8°C. From about 1970, the air temperature trend has strongly increased. The oceans are absorbing around 90% of the additional heat with ocean heat content showing strong increases; on average the temperature of the ocean layer 0-700 m deep increased by 0.18°C between 1955 and 2010.

For further information refer to *2.1 Observations of a changing climate*.

Why does only a few degrees of warming matter?

Warming of a few degrees may seem minor, but it is much larger than any of the climatic changes experienced during the past 10,000 years. The increase in average temperature creates a much greater likelihood of very hot weather and a much lower likelihood of very cold weather. A warming of only a few degrees in average temperature means we will see weather events that have never been observed since instrumental records were begun, and heat events that were rare in the previous climate will become more common. For comparison, the difference in global average air temperature between an ice age and a warm period in recent Earth history is only 5 to 6°C.

For further information refer to *2.4 Back to the future: Insights from past climate changes* and *3.1 Changes in the climate system that cause impacts*.

How are human activities contributing to climate change?

Human activities, particularly the burning of fossil fuels, agriculture and land clearing, are increasing the concentration of greenhouse gases in the atmosphere. This increase in greenhouse gases is enhancing the greenhouse effect, which in turn is warming the Earth.

For further information refer to *1.2 How are human activities changing the climate?*

How is the climate expected to change in the future?

Scientists expect that global warming and associated changes will continue if greenhouse gas emissions keep rising. It is very likely there will be continue to be increases in air and ocean temperatures, changing rainfall patterns, rising sea-level and increasing intensity and frequency of many extreme weather events through the 21st century. However, reducing greenhouse gas emissions now and in the coming decades will have a major influence on the degree of climate change that occurs, particularly in the second half of this century.

For further information refer to *2.2 Projections of future change*.

How does climate change affect us?

Changes have already been observed in our climate and have caused serious impacts in Australia. There has been an increase in the number of hot days and record-breaking heatwaves and heavy rainfall.

Climate change is likely to continue to affect Australians in a number of ways, including:

- rising temperatures and more hot days
- greater risk of bushfire
- increased frequency and severity of extreme weather events including heavy rainfall and drought
- sea-level rise leading to more coastal flooding and erosion.

For further information refer to *3. Risks of a changing climate*.

How do scientists know the climate is changing?

Scientists collect detailed and accurate data on the climate system, including air and ocean temperature, precipitation, sea level, ocean salinity and acidity, changes in ice mass, to name a few. Direct measurements of temperature and precipitation have been taken for over 150 years. Since the 1970s satellites have measured global temperatures and since the 1990s global sea level. Proxy records such as ice cores, tree rings, marine sediments, pollen and others provide insight into the climate of hundreds or thousands of years ago. Analysis of this climate data is used to put today's climate change in a longer term context and to explore the response of the climate system to change in radiative forcing in the past.

For further information refer to *2.1 Observations of a changing climate* and *2.4 Back to the future: Insights from past climate changes.*

How is the warming observed over the last century different from previous changes in the Earth's climate?

The most significant difference between recent warming and previous changes in the Earth's climate is the speed of the change, and the role of humans in changing greenhouse gases. Ice cores from Antarctica provide a record of 800,000 years of atmospheric CO_2; in all that time the concentration has never increased so quickly and by so much as during this climate era of human influence; the so-called 'Anthropocene.' For further information refer to *1.3 How are humans changing the climate?*

How do scientists make projections of the future climate?

Scientists estimate how the climate may change in the future using knowledge of climate system processes, how the climate is affected by increasing concentrations of greenhouse gases, observations of past changes and scenarios of future changes in greenhouse gas concentrations. Scientists integrate this knowledge using climate models – mathematical representations of the climate system. The models simulate the behaviour of the climate system and project possible futures under different scenarios of greenhouse gas levels.

For further information refer to *2.2 Projections of future change*.

How reliable are climate models?

Climate models are the best tools that we have for projecting future climate change. They are based on laws of physics; they have been tested against observational data and accurately represent current and past climate, including observed changes over the past century. Climate models are continuously improving in their ability to simulate the behaviours of the climate system, building more confidence in their projections of the future.

For further information refer to *Box 3: How do climate models work*.

This document has been produced as a supplementary material to *The Critical Decade 2013: Climate change science, risks and responses*. For further information on the topics discussed in this paper and for references refer to the detailed report.

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