# climatechange in Australia



## science update 2009

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This document provides a succinct update of recently published climate change science.

Since these results are ‘new’, in some cases there has been only limited opportunity for assessment by the wider scientific community. Some findings may change in future in the light of subsequent research. This is, of course, part of the normal development of climate (or any other) science.

Information is aimed at policy makers, government agencies, scientists, science communicators and media. The information presented comes from research within the Australian Climate Change Science Program, Australian universities and international research agencies.

All papers are referenced within the text.

Views expressed are those of the researchers quoted and do not necessarily represent the views of, and should not be attributed to, the Bureau of Meteorology and/or CSIRO.

## Recent research has shown that:

- Some measures of climate change are tracking at or above the worst case scenarios considered possible just a couple of years ago.
- Climate extremes are pushing new boundaries, for example the unprecedented heat wave in south-eastern Australia experienced early in 2009.
- Changes to ice sheet dynamics could raise sea levels beyond current IPCC estimates.
- Ocean acidification could lead to permanent changes to marine ecosystems.
- Climate change is likely to be more rapid and severe, and more costly and dangerous than previously thought.

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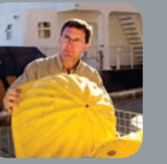
# Summary of recent climate change science



## 1 Greenhouse gases

- Temperatures do not drop significantly for at least 1,000 years after emissions stop.
- Methane clathrates appear more stable than previously thought.
- The quantity of carbon stored in permafrost has been vastly underestimated.
- Greenhouse gas induced climate change impacts on ozone recovery.

## 2 Climate extremes

- Australia shows a shift towards temperature extremes.
- It is very likely that climate change has increased the likelihood of extreme fire danger in south-east Australia.
- Fire seasons are likely to be more intense, start earlier and end later.

## 3 Sea levels and ice sheets

- Current estimates of sea-level rise range from 0.50 m to over 2 m by 2100.
- The Greenland and Antarctic continental ice sheets are losing mass and contributing to sea level rise at rates beyond those projected in the IPCC AR4.
- There are significant regional differences in Antarctic temperatures.

  i. The West Antarctic Peninsula already shows considerable warming (2.5 °C)

  ii. Slight cooling has been observed in East Antarctica.

## 4 Oceanic processes

- The Southern Ocean may become permanently damaging to some calcifying marine organisms, and associated food chains.
- Southern Ocean winds are strengthening, but have not been found to affect ocean circulation .


# 1 Greenhouse gas concentrations

Greenhouse gas emissions and many aspects of the climate have been changing near the upper boundary of the IPCC range of projections.[1].

Climate change, due to increases in carbon dioxide concentration, is largely irreversible for 1,000 years after emissions stop[2]. Atmospheric carbon dioxide concentrations of 450–600 ppm over the coming century will likely lead to irreversible dry-season rainfall reductions in several regions and inexorable sea-level rise[2].

The level of greenhouse gas emissions that corresponds to 2°C warming (relative to pre-industrial levels) is hard to quantify, given uncertainties in the carbon cycle and the climate response[3]. One estimate finds that halving global greenhouse gas emissions (relative to 1990) by 2050 provides a 12–45% probability of exceeding 2°C global warming[3].

Many ‘slow’ climate feedback processes such as ice sheet disintegration, vegetation change, and greenhouse gas release from soils, tundra or ocean sediments, are not likely to be well presented in current climate models[4]. A recent study estimates that atmospheric carbon dioxide concentrations will need to be reduced from the current 385 ppm to 350 ppm or less in order to preserve a planet similar to that on which life on Earth is adapted[4].

Achieving peak emissions in 2015 and 3% global emissions cuts annually thereafter, has been estimated to leave an even chance of exceeding 2 °C of warming[5]. To adapt to 90% of the risk implied by delaying mitigation action until 2035, implies planning to adapt to at least 4 °C of warming[5].

## Methane

There are three significant methane stores:

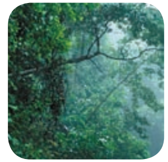
1. Methane clathrates, which consist of frozen methane mostly in the deep ocean.
2. Organic matter in permafrost (frozen soil) that can decompose, producing methane.
3. Natural gas.

Methane clathrates appear to be stable in a warming world[6], while permafrost carbon appears increasingly vulnerable[5].

Ice core evidence from the end of the last glacial period suggests that emissions from wetlands were the cause of the then rapid atmospheric methane increase, not methane clathrates as previously suspected[6].

The quantity of carbon in frozen soils in the northern circumpolar region is double previous estimates[7]. These soils have the potential to release vast quantities of carbon dioxide and methane into the atmosphere and subsequently influence carbon-climate feedbacks[8]. Carbon stored in soils at high latitudes is increasingly vulnerable to exposure to the atmosphere[7].

The potential for significant feedbacks from permafrost carbon could be realised with only a small fraction of currently frozen carbon released to the atmosphere. For example, if only 10% of the permafrost melts, the resultant feedback could result in an additional 80 ppm




carbon dioxide equivalent released into the atmosphere, generating about 0.7°C further warming[7].

## Stratospheric ozone levels

Increasing levels of atmospheric greenhouse gases have been shown to affect the ozone layer's recovery, hastening recovery in some areas while slowing – or even preventing – it in others[9]. Modelling suggests that stratospheric ozone recovery, at mid latitudes, is enhanced by greenhouse gases[9]. In contrast, ozone recovery in the polar stratosphere is hindered by greenhouse gases.

The ozone hole is currently limiting the effects of climate change on eastern Antarctica[10]. As ozone levels recover by the end of the 21st Century, there is likely to be around one-third less Antarctic sea ice[10].

## Equivalent carbon dioxide $CO_2$[e]

It is important to distinguish between atmospheric carbon dioxide concentrations and equivalent carbon dioxide concentrations $CO_2$[e].

To calculate the relative concentration of the major greenhouse gases, equivalent carbon dioxide is used. The IPCC used the equivalent carbon dioxide forcing of six greenhouse gases (carbon dioxide, methane, nitrous oxide, HFCs, PFCs and SF6) in the latest assessment report.

**Table 1 >** Comparison of atmospheric concentrations of carbon dioxide and equivalent carbon dioxide concentrations.

| Concentrations of greenhouse gases – parts per million (ppm) | Atmospheric $CO_2$ | $CO_2$[e] ▲ | Radiative forcing |
|---|---|---|---|
| Also referred to as ppmv (parts per million by volume) | The carbon dioxide concentration in the air. Very accurate | Including carbon dioxide, methane, nitrous oxide, HFCs, PFCs and $SF_6$ Best estimate | Warming in the entire climate system (oceans, atmosphere and land) compared to preindustrial times (Watts per metre$^2$) |
| Pre-industrial | 280^ | 280* | 0 |
| 2005 | 379# | 445# | 2.48+ |
| 2007 | 383^ | 462* | 2.68+ |

▲ This measure of $CO_2$(e) includes GHGs only. Anthropogenic aerosol forcing partly offsets this, although the magnitude of this is currently very uncertain. The best estimate for aerosol forcing (2007) is a reduction of $CO_2$(e) by around 87ppm #

* Pers com: David Karoly (Melbourne University)

# IPCC AR4 Synthesis Report, notes to Table 5.1, p.67b

^ Global Carbon Budget: www.globalcarbonproject.org/carbonbudget/07/index.htm

+ Pers com: Paul Fraser (CSIRO)

# 2 Climate extremes

Australia is experiencing more high temperature extremes, particularly a significant increase in the number of warm nights and heat waves[11].

There was a significant increase in the duration of heat waves in Australia from 1957 to 1999 and increased temperature extremes[11].

The observed trends in extremes are projected to continue into the future. A substantial increase in warm nights and heat wave duration and decrease in frost days are projected by the end of this century under the IPCC-SRES scenarios[11].

Indicators of rainfall extremes are set to more than double within the next 100 years, with longer dry spells interspersed with heavier precipitation events[11]. The magnitude of changes in both temperature and rainfall extremes generally scale with the strength of emissions[11].

## Heat waves

An exceptional heat wave affected south-eastern Australia during Jan-Feb 2009. Many records were set for day and night time temperatures and duration of extreme heat[9].

Record high temperatures for February were set over 87% of Victoria on Feb 7[12]. Seven of the eight highest temperatures on record in Tasmania occurred during this heat wave[12]. Adelaide experienced its warmest night on record with a minimum temperature of 33.9ºC on Jan 29[12]. The dry conditions during this heat wave further reinforced very long-term rainfall deficits in much of south-eastern Australia[12].

## Severe fire seasons

Climate change is increasing the likelihood of environmental conditions associated with extreme fire danger in south-east Australia and other parts of the world[13]. The pattern of recent extreme fire danger is part of a broader shift towards more severe fire seasons in central Victoria[12]. It is very likely that climate change has increased the likelihood of extreme fire danger in south-east Australia[13].

The climatic conditions experienced in Victoria on February 7 2009 were unprecedented[12,13]. The area north-east of Melbourne had experienced a 12-year drought before the fires, as well as record high temperatures, a record heat wave two weeks earlier, record low rainfall and record low humidity[12]. The area was also experiencing an unprecedented sequence of days without rain[13].

An increase in fire danger in Australia is likely to be associated with a reduced interval between fires, increased fire intensity, a decrease in fire extinguishments and faster fire spread[14]. The number of ‘very high’ and ‘extreme’ fire danger days in south-east Australia could increase by 4-25% by 2020 and 15-70% by 2050[15]. Fire seasons are likely to start earlier and end slightly later, while being generally more intense[15].

# 3 Sea level rise

Several new estimates of projected 21st century sea level rise, including ice dynamic effects, have been made. These vary from an increase of 0.50–1.40 m[18] to up to 2 m by 2100[19]. Contributions from glaciers and ice sheets to future sea level rise are uncertain but may equal or exceed several metres over the next millennium or longer[2].

*Sea ice and ice sheets are different substances and form through very different processes. Sea ice forms in winter and melts within a few years. The melting and freezing process drives ocean circulation, but does not contribute to sea-level rise. In contrast, ice sheets are thick layers of compacted snow that form over land and move through glacial processes. When they reach the sea, they form ice shelves and eventually ice bergs. Changes in ice sheet dynamics may contribute to sea-level rise*[20,21].

## Ice sheet dynamics

Both the Greenland and Antarctic ice sheets are losing ice mass and contributing to sea-level rise[20]. There is concern that the contribution of ice sheets to sea level rise over the 21st century could be higher than the IPCC AR4 projections[22]. Rapid changes have been observed over substantial areas of both Greenland and Antarctica[22,23]. However, the error range of estimates of mass change in both Antarctica and Greenland is large[22].

### *Greenland ice sheets*

Greenland was approximately in mass balance during the 1970s and 1980s, but since 1997 the ice sheet has been losing mass at an accelerating rate[24]. However, there can be large variability from year to year in the surface melt in Greenland[25].

### *Antarctic ice sheets*

Large uncertainties remain regarding the current and future contribution to sea level rise from Antarctica[26]. Warming may increase snowfall in the continent's interior but enhance glacier discharge at the coast where warmer air and ocean temperatures erode the buttressing ice shelves[26].

In West Antarctica, ice sheet loss has increased dramatically[26]. In East Antarctica, a combination of small glacier losses and gains combine to a near-zero loss of ice sheets[26].

## Antarctic temperatures

Monitoring at three sites in Australia's Antarctic territory and at Macquarie Island indicate minor warming since the mid-1950s. Sparse sites and the short duration of the observations do not provide a complete record for the continent and regional differences are apparent[27].

The West Antarctic Peninsula shows extensive and rapid warming, with an average increase of 2.5ºC already observed[21]. A slight cooling trend observed in East Antarctica in the 1980s-1990s is attributed to the interaction of the stratospheric ozone hole with regional climate[10]. As the ozone hole recovers, more rapid warming is expected in this region[9].

## Antarctic sea ice

Sea ice distribution, averaged across Antarctica, shows a slight increase in maximum extent[21]. Regional changes have been much larger. The Weddell and Ross Seas in East Antarctica have slightly increased sea ice mass[21]. The West Antarctic Peninsula has shown a decline in sea ice extent coincident with an increase in average winter air temperature of 5.8ºC from 1950-2005[21].

Climate models predict that by 2100 Antarctic sea ice will reduce by around 24% in total extent and 34% in total volume, with possible delays in observed reduction until stratospheric ozone recovers[21].


# 4 Ocean processes

## Ocean acidification

Oceans are becoming more acidic as they absorb carbon dioxide[28,29]. Ocean acidification is decreasing the ability of many marine organisms to build shells and skeletal structure[28,29].

By the time that atmospheric carbon dioxide reaches 450 ppm, large parts of the ocean system may become corrosive to key marine species, with possible negative flow-on impacts for wider marine ecosystems[28,30].

Changes to the oceanic uptake of atmospheric carbon dioxide may also occur[29].

Reef-building corals are under increasing physiological stress from a changing climate and increasing uptake of carbon dioxide by the oceans[31]. Skeletal records of corals in the Great Barrier Reef show that calcification has declined by 14.2% since 1990[31]. The data suggest that such a severe and sudden decline in calcification is unprecedented in at least the past 400 years.

## Ocean winds

Winds in the southern hemisphere have a vital role in climate, causing the movement of millions of cubic metres of ocean water every second[32]. Winds can influence the rate at which oceans take up carbon dioxide, along with exchanges of other entities such as heat and trace gases[32]. Changes in the Southern Annular Mode (a mode of climate variability between the sub-Antarctic and mid latitudes that leads to changes in wind and storm activity) are currently causing winds to increase in strength. There are predictions that this will continue in the coming decades[32].

Strengthening westerly winds in the Southern Ocean do not appear to have affected the Antarctic Circumpolar Current or the overturning circulation. Small-scale eddies may be counteracting the wind changes, stabilising the ocean circulation[32].

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