To Councillors for their information from Richard Phair.

The attached pages are sourced from the

"Australian Bureau of Meteorology" website via a link to

"Climate Change in Australia" ***climatechangeinaustralia.com.au/***

which is a publication from the CSIRO and the Bureau of Meteorology in partnership with the Australian Greenhouse Office and the Australian Climate Change Science Program.

Pages 1a to 7a are on " impact and risk assessment" which is particularly relevant to coastal inundation and rising sea levels.

Pages 1b to 3b are on "past climate change". It addresses the fact that not all climate change is human induced (refer Figure 3.2 and Councillor Hinds) but makes it clear that our current lifestyles are not sustainable and also shows the variations that occur using different data simulations.

Page 1c refers to "sea level rise" and the IPCC estimate of 18 to 59cm by 2100.

Hope this may be of interest and help in your deliberations.

Rick Phair

Attachment 8.1.2

Chapter 6 Application of climate projections in impact and risk assessments

Risk management is an iterative process, where a process of scoping and risk identification usually takes place before more detailed assessments are carried out. Care must be exercised when using the projections from Chapter 5 in any risk assessment, particularly when selecting climate variables, determining temporal and/or spatial resolution, and dealing with uncertainty.

Detailed risk assessments generally require purpose-built climate projections, including time series, or probabilistic representations of future climate. Various tools have been developed which represent different methods for enhancing the delivery of climate information to stakeholders both for education and for risk assessment and management. Nevertheless, significant challenges remain for communicating climate risk in ways that can be effectively used in risk management.

The major purpose behind constructing and using climate change projections is to aid decision-making in an environment of uncertainty. There are subtle but important differences between the development of climate change projections and the use of such information for impact and risk assessment.

The context of an assessment determines the information required and how it can best be used: who it is for, what it is about, where it is located and how the results are to be used. Specific methods for treating uncertainty are largely dictated by context and the needs of stakeholders. Such needs also include the development and sharing of a conceptual framework, i.e. sharing the researchers' and stakeholders' understanding of how the system in question operates, creating a viable assessment process, and communicating assumptions and confidence levels as part of the assessment process.

Climate change risk assessment and management is an emerging and inherently inter-disciplinary science. New approaches and methods for incorporating information about future climates into assessments are constantly being developed. Appropriate methods and tools are largely dictated by an assessment's context, rather than through a 'best practice' set of recipes. This chapter summarises the use of climate information to inform impact assessment and risk management.

6.1 Climate change and risk management

Climate risk is the product of the *consequences* of climate change and the *likelihood* of those consequences (Jones 2001; ISO 2002; Figure 6.1). In the past, climate change impact assessment has been dominated by analysis of the consequence component of climate change risk, especially in testing the consequences of unmitigated climate change. The estimation of impacts independently of likelihood continues to be a mainstream research activity. However, as questions regarding risk have become more sophisticated, such as 'how much climate change needs to be adapted to by when', more decision-makers are seeing climate change as a risk management issue. This development is increasing the need to assess the likelihood of specific risks. However, great care is warranted because likelihoods need to be developed appropriately: all relevant uncertainties need to be managed carefully and underlying assumptions clearly stated to avoid under- or over-confidence, incorrect framing of the problem or misapplication of the results.

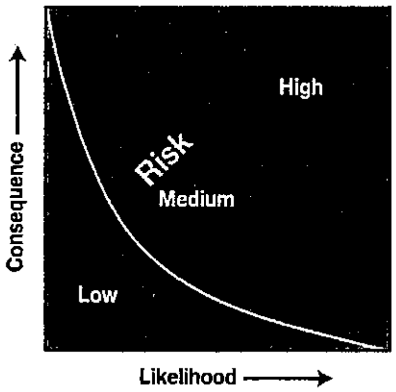

Figure 6.1: Conceptual model of the likelihood – consequence relationship

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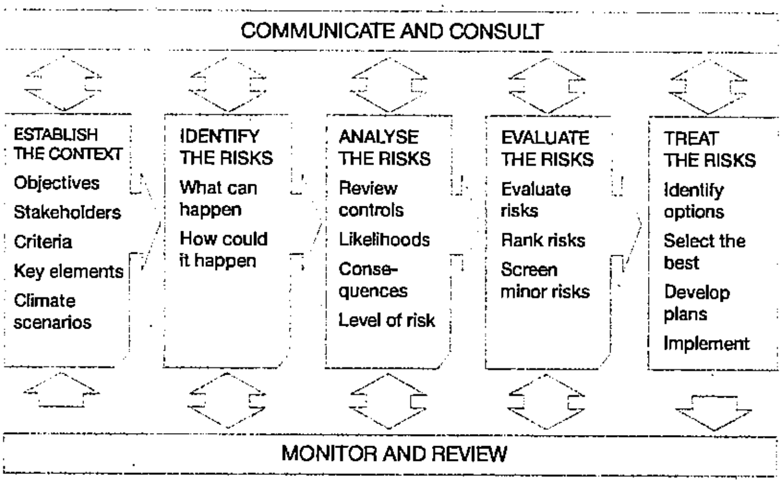
Risk management applies scientific and technical analyses to estimate the likelihood of different outcomes. The process is often conceptualised as a series of steps, which identify the context, characterise the hazards and/or potential consequences, assess the likelihood of different outcomes, evaluate risk, and, ultimately, implement appropriate method(s) for reducing risk (Box 6.1).

Box 6.1 A risk management framework

A number of frameworks exist that provide guidance on applying the principles of risk assessment and management in decision-making. In Australia, the principal framework is the Australia/New Zealand Risk Management Standard (Australian Standards 2004), which has recently been adapted to provide guidance specific to managing climate risk (AGO 2006a). The Risk Management Standard divides the process of risk management into five steps:

1. **Establish the context** – identification of the decision-making event and the associated challenges, establishment of the approach to risk management that is to be used as well as the information and data requirements (including climate projections);
2. **Risk identification** – identification of the potential climate hazards and downstream consequences of concern to stakeholders;
3. **Risk analysis** – qualitative or quantitative analysis of the likelihood of different outcomes, including the probability of exceeding stakeholder-identified thresholds;
4. **Risk evaluation** – assessment of whether risks are tolerable, prioritisation of multiple risks (if present), and judgment regarding whether risks require treatment; and
5. **Risk treatment** – selection and implementation of risk management actions (e.g. through methods such as stakeholder forums, multi-criteria analysis, cost-effectiveness).

In addition, communication and consultation with stakeholders occurs throughout the entire process. Clarity and transparency surrounding underlying concepts and assumptions is required. All participants need to understand the different ways in which the system is conceptualised and used by various stakeholders. Monitoring and review ensures that a learning-by-doing ethos is developed and communicated among all parties. Risk management should not be a one-off event, but a process that is engaged over time and updated with changing information and stakeholder preferences.



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The two main strategies for managing climate risk are: *mitigation* of climate change via the abatement and sequestration of greenhouse gas emissions and *adaptation* to climate impacts emanating from the unmitigated component of climate change (IPCC 2007b,c). For each there are myriad specific policies and measures that could be implemented. Combined with the uncertainties associated with future climate change, they form a complex decision-making environment. Both public and private institutions need to navigate this complexity to manage climate risk, whether it is in assessing the benefits of avoided damages via mitigation (Preston and Jones 2006; Jones and Preston 2006) or the potential for adaptation options to reduce societal vulnerability. This has increased the demand for climate information.

Climate risks can be divided into two broad categories (Sarewitz *et al.* 2003):

1. **Event risk** – The risk of occurrence of natural hazards such as sea level rise, storm surge, or extreme rainfall events. *Consequence* is expressed as the occurrence of a discreet event of a particular size or duration and may be integrated with *likelihood* through the quantification of an event return period. For example, the identification of a 1-in-100 year storm event communicates the frequency or likelihood (once every hundred years) of an event as well as its magnitude (in terms of wind speeds or rainfall totals). Event risk is often quantified as hazard times likelihood and is typical of assessments carried out by the natural disaster and insurance communities.
2. **Outcome risk** – Risks associated with environmental or societal outcomes of climatic changes such as species extinctions, loss of agricultural productivity or heat-related human mortality. *Consequences* are expressed as impacts for one or more scenarios of climate change, and may be integrated with *likelihood* through uncertainty analysis (e.g. generation of a probability distribution) or the quantification of the likelihood of exceeding a vulnerability threshold (Jones 2001). Outcomes may also incorporate risk from non-climatic sources, allowing climate change to be assessed in a broader social and environmental context.

Both types of risk are useful to stakeholders for risk management, their choice depending on how rigorously they can be quantified and the form in which that information can be produced, subject to requirements. Risk management is iterative, where a process of scoping and risk identification usually takes place before more detailed assessments are carried out to manage specific risks identified by those initial assessments.

National to regional scale climate projections provide valuable information at this initial stage, which helps establish the context for risk management and scope the potential consequences (Box 6.1). Quantification of event risk is typically a first step in a risk analysis, which requires integrating information on climate events into impact models that predict the resulting system responses. Outcome risks, or clear links between event risks and outcomes, are generally preferred for assessing adaptation needs. Most adaptation measures are designed to reduce negative or enhance positive consequences.

More detailed risk assessments generally require purpose-built climate scenarios or probabilistic representations of future climate. These are discussed in sections 6.2 and 6.3.

When assessing climate risk, caution must be exercised to avoid over-investment in analytical precision. Due to uncertainties associated with climate change and limits to time, expertise, system knowledge, or funding, it may be difficult to derive robust estimates of risks, especially outcome risks, which may also be heavily influenced by the evolution of future adaptive capacity (Patt *et al.* 2005). In such situations, effort may be best-invested in identifying least-cost strategies for achieving risk reduction, rather than exhaustive attempts to reduce uncertainty or to rigorously quantify the risk itself. Identifying and reducing existing system vulnerabilities to climate variability may also help to manage future climate risks (Sarewitz *et al.* 2003; Allen Consulting 2005), especially where risks under current climate are consistent with future risks identified during scoping exercises.

6.1.1 Framing climate risks

A range of different assessments of climate risk can be carried out, such as:

- Impact assessments of unmitigated climate change, testing what may happen if no specific climate policies are enacted; this covers most of the assessments within the IPCC Working Group II contribution to the Fourth Assessment Report (IPCC 2007b);
- Assessing the benefits of greenhouse gas emission policies through avoided damages measured as the difference in climate-related risks associated with a reference emissions scenario (e.g. the unmitigated SRES scenarios) and those associated with a mitigation policy scenario (e.g. Jones and Preston 2006); integrated assessments will consider benefits from both adaptation and mitigation (e.g. Stern *et al.* 2007);

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- Assessing adaptation needs over a range of policy and planning horizons for specific activities and regions;
- Assessing how specific development pathways or policies may be affected by climate change and developing adaptation options to make them more sustainable. Integrating adaptation options into ongoing plans and activities, especially into current risk management activities, is referred to as *mainstreaming*.

In general, the benefits of mitigation are longer-term (decades) and the benefits of adaptation are shorter term (years to decades), but not exclusively so (Figure 6.3). Key to assessing adaptation needs is planning horizons:.what is the rate and magnitude of change anticipated within a given planning horizon that needs to be adapted to?

When assessing adaptation, it is important to take a whole of climate approach by representing *both* human-induced climate change and background climate variability. The change may be linear, graduated non-linear, or a step change. Many subsequent risks will follow a similar pattern. Background variability may also alter in response to climate change but this possibility needs to be investigated on a case-by-case basis.

Planning horizons mark how far into the future adaptation measures may be needed. Timing is informed by both operational and aspirational goals. Aspirational goals relate to what is desired (e.g. sustainable operations, profitability) or should be avoided (e.g. critical levels of harm, system failure). Operational goals relate to the pathway that is taken to achieve that goal.

Incremental adaptation allows a learning-by-doing approach to be taken, informing the process along the way and allowing it to adjust to new information. Up-front responses, or the need to anticipate outcomes in advance, are most relevant to adaptations that require large initial planning and investment, those with a long operational life (and where retrofitting is too expensive) or if the damage to be avoided is irreversible and/or unacceptable. The 'wait and see' response is thought in most cases to be the most expensive option and will not cope with irreversible impacts.

Figure 6.3 shows a sample of planning horizons for different activities (lower scale) and operational pathways towards achieving a specific goal (upper scale). These are not intended to represent a complete set of pathways – many paths are possible depending on circumstance. The process for deciding which adaptation(s) to implement may also assess which type of adaptation pathway is most suitable. If aspirational targets are some decades away, the capacity to carry out an assessment over a range of timescales may be needed to test variable timing of responses. This is a far more sophisticated requirement than is being applied in most existing assessments.

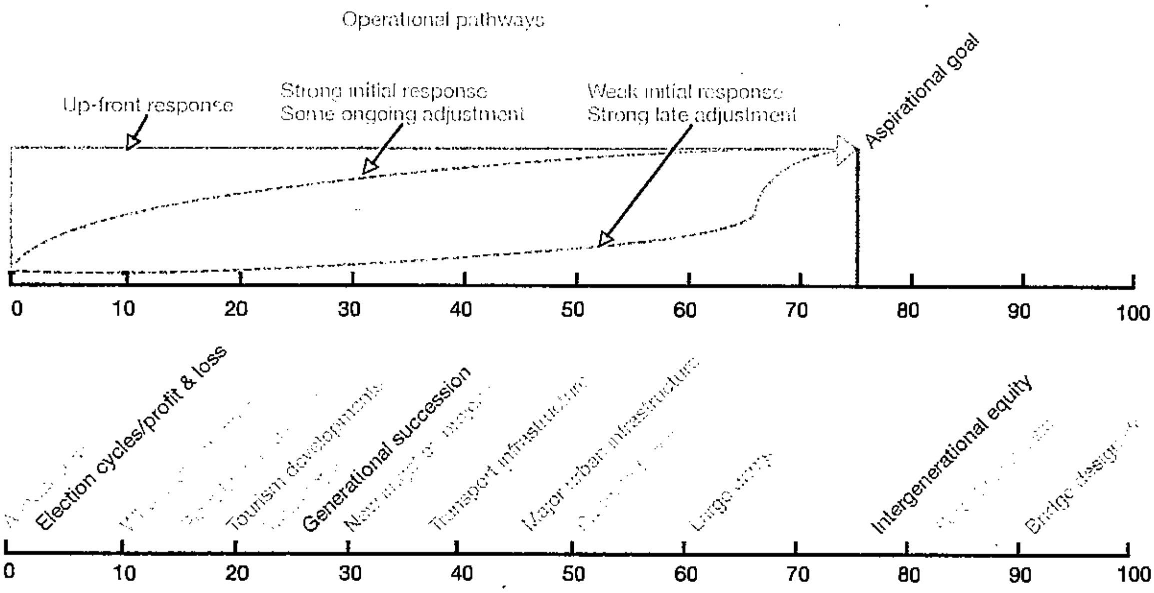

Figure 6.3: Relationship between goals and pathways for adaptation (upper diagram) related to a number of planning horizons of different timescales (lower diagram). The horizontal scale is in years.

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6.2. Key issues in applying climate information

The choice of which climate information may be required for use in any impact or risk assessment is determined by the:

1. climate variable(s) of interest
2. spatial and temporal scale of the assessment
3. management of uncertainty

The first two factors, properly applied, will establish the plausibility of any resulting climate information and the third factor will establish confidence in the results.

Most projections, such as those detailed in this report, are not forecasts but are conditional upon the assumptions incorporated into the input data and model that produced those projections. Many of the assessments listed in section 6.1.1 do not require forecasts. For example, scenarios used in an assessment of unmitigated climate change risks would aim to be physically plausible under the forcing conditions consistent with that change, but would not necessarily be expected to occur. Analyses testing the sensitivity of impacts to specific climate change likewise do not require forecasts.

When assessing adaptation needs over the short to medium term, the aim should be to come as close to the anticipated range of plausible climate change as possible. However, because a whole of climate focus is taken, combining Australia's substantial ongoing climate variability with the uncertainties of climate change, uncertainties will be substantial. Assigning likelihoods to specific outcomes is becoming increasingly possible with model improvements and more sophisticated approaches and methods. However, the large inherent uncertainties remain a reason as to why off-the-shelf estimates and the uncritical use of climate projections are not advised.

6.2.1 Climate variables

A major task in any assessment is to identify the relevant climate variables, either associated with event risk or those that drive subsequent responses of societal and environmental systems (Table 6.1). Although the projections developed for this report span a broad range of variables, for any given application or risk of concern often only a subset of these is required. A robust physical relationship between the selected variables and the outcome of interest should be ensured. Appropriate variables may be identified by stakeholders, conceptual models of the system of interest, or through the use of more detailed process models where prior research and experience has elucidated the key climate drivers of the system.

The form of a selected variable will differ from system to system; for example:

- Species richness in the wet tropics is a function of maximum and minimum temperatures and rainfall during summer and winter seasons as well as intra-annual variability in temperature, rainfall and radiation (Williams *et al.* 2003).
- Maximum average January temperature is the most sensitive indicator of grape quality for a number of varieties (Webb 2006).
- Changes in alpine snow conditions depend on daily precipitation and temperature (Hennessy *et al.* 2003).

Although most event-based risks will be in response to changes in extreme conditions (IPCC 2007b), it is often difficult to provide reliable estimates of such changes. Instead, changes to mean conditions have most often been relied upon. For example, while past assessments of coastal impacts applied average sea level change in Bruun Rule-like algorithms (CIU 1992; Zhang *et al.* 2004), the interaction of higher sea levels with extreme tides resulting from natural climatic variability and/or anthropogenic climate changes are more realistic (McInnes *et al.* 2003, 2005a,b). Similarly, projections of changes in extreme rainfall events are central to understanding flood risk (Hennessy *et al.* 2004; Abbs *et al.* 2006), extreme heat for understanding heat-related mortality (McMichael *et al.* 2002), and fire weather for understanding bushfire risk (Hennessy *et al.* 2005).

To develop meaningful estimates of the risk of such climatic events, simulations using low-resolution climate models to derive average changes in climatic conditions are not sufficient. Instead, high-resolution modelling through statistical or dynamical downscaling and nested modelling techniques is often required to simulate such events (Abbs *et al.* 2006). However, there is a trade-off between the application of simple and easy to apply methods and the time, money and effort needed to provide more realistic detail that each assessment must confront. Ideally, scenarios should be constructed using the simplest information required to make the decision under consideration, but this is not always an easy task.

When identifying climate variables and selecting the relevant climate models used for generating climate scenarios, each scenario used in a risk assessment should be internally consistent. For example, all projections of rainfall and temperature changes applied in an agricultural impact model should be incorporated under a consistent set of assumptions, including the choice of global climate models, time period, and greenhouse gas emissions scenario. Arbitrary mixing-and-matching of projections degrades the realism of the outcome and limits comparability of different impact and risk assessments (Box 6.2).

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Table 8.1: Common climate variables used in impact and risk assessment

Impact area	Impact	Climate variables	Examples
Agriculture	• Dryland wheat production • Grape quality	• Temperature • Rainfall	• Howden *et al.* (1999) • Howden and Jones (2001) • Luo *et al.* (2005) • Webb (2006)
Water resources	• Stream flows • Storage inflows	• Rainfall • Evaporation	• Jones and Page (2001) • Jones and Durack (2005)
Coasts	• Sustainable yields • Storm surge return periods and area inundated	• Sea level rise • Winds • Pressure	• Kirono *et al.* (2007) • CIU (1992) • Cowell *et al.* (2006) • McInnes *et al.* (2003) • McInnes *et al.* (2006)
Infrastructure	• Impacts to buildings • Road maintenance costs • Energy production	• Temperature • Rainfall • Radiation • Winds • Sea level rise	• Amitrano *et al.* (2007) • Austroads (2004) • PIA (2004) • PB Associates (2007) • Victorian Government (2007)
Terrestrial biodiversity	• Primary production • Population extinctions	• Temperature • Rainfall • Radiation	• Pickering *et al.* (2004) • Williams *et al.* (2003)
Marine biodiversity	• Coral bleaching and mortality	• Sea surface temperature	• Hoegh-Guldberg (1999) • Done *et al.* (2003)
Health impacts	• Heat-related mortality • Infectious disease	• Temperature • Rainfall • Humidity	• McMichael *et al.* (2002) • Woodruff *et al.* (2005)
Fire weather	• Fire intensity & frequency • Length of fire season • Period suitable for controlled burning	• Precipitation • Temperature • Relative humidity • Wind	• Hennessy *et al.* (2005)
Alpine snow conditions	• Snow cover • Snow depth • Snow duration	• Precipitation • Temperature	• Hennessy *et al.* (2003)

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Box 6.2 Applying internally consistent climate change scenarios

Because different global and regional climate models display marked differences with respect to future climate projections, multiple models are often used to generate climate scenarios for impact assessment. This enables the uncertainty in future climate conditions to be reflected in estimates of impact and risk assessments, often by identifying of potential 'best' and 'worst' case impact scenarios. Care must be exercised to preserve the internal consistency of a model's projections of different climate variables. Variables such as temperature, rainfall, evaporation, and humidity are highly interactive, meaning a change in one variable has an effect on other variables. As such, mixing variables from different models in a single scenario may result in physically implausible (or impossible) combinations.

For example, to identify the worst possible outcome from an impact model, it may be tempting to identify the most pessimistic rainfall projection from any climate model and pair that scenario with the most pessimistic temperature projection (Figure 6.4a). However, because the projections for the variables were derived from different climate models, they may be physically inconsistent, providing a spurious estimate of future impacts. The magnitude of projected impacts would therefore be larger than that derived from internally consistent projections.

Instead, estimates of impacts should first be calculated independently for each climate model under consideration (Figure 6.4b). This results in a range of impact estimates that are representative of plausible climate futures which can then be ranked according to their relative impact. Low, high and/or intermediate outcomes, or combinations of those in probability distributions, can be selected for further application.

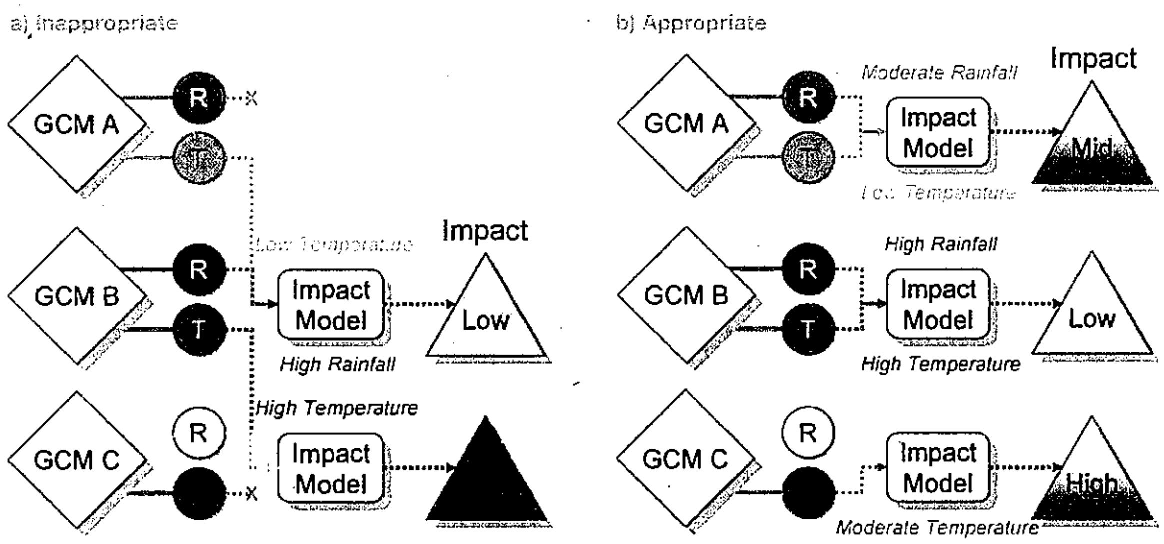

Figure 6.4. Example of appropriate and inappropriate use of climate model projections in impact assessment. For both of the above figures, rainfall (R) and temperature (T) projections from three different global climate models (GCMs) are applied in a hypothetical impact model. In (a), each pair of global climate model scenarios is applied independently to the impact assessment model, resulting in a range of different climate impacts. In (b), projections of rainfall and temperature from different models are paired to yield extreme scenarios of climate change, which are then applied to the impact mode.

Chapter 3 Causes of past climate change

The climate of the Earth changes continually on a range of timescales due to 'internal' and 'external' factors. Internal factors are natural and arise from complex interactions within the climate system. In general, internal variability on short time-scales (days to weeks - what we know as 'weather') is generated by atmospheric instability. Variability on longer time-scales (intraseasonal, interannual and decadal to centennial) can be enhanced by complex interactions between the atmosphere and other components of the climate system (mostly the oceans, see e.g. Power *et al.* 1995, but also the terrestrial biosphere and the cryosphere).

Natural external factors include the Earth's rotations that produce diurnal and seasonal cycles, variations in the amount of radiant energy emitted by the Sun (e.g. sunspot cycles have a period of about 11 years), volcanic eruptions and changes in the Earth's orbital parameters (e.g. due to Milankovic cycles, which have a dominant period of 100,000 years). Substantial global warming at the end of ice ages over the past half million years was triggered by changes in the Earth's orbit and subsequently enhanced by natural increases in greenhouse gases.

Humans are also responsible for external factors which are referred to as 'anthropogenic'. For example:

- Changes in atmospheric composition (e.g. in concentrations of stratospheric ozone and greenhouse gases: carbon dioxide, methane, nitrous oxide, chlorofluorocarbons and tropospheric ozone).
- Release of atmospheric particulates (e.g. sulfate aerosols, black carbon).
- Modification of the terrestrial ecosystems (e.g. by land clearance and agricultural practices).

Radiative forcing is the term given to an externally imposed change in the radiation balance (the balance between incoming solar radiation and outgoing heat radiation) such as changes in atmospheric concentrations of greenhouse gases (See section 4.1.3).

The largest change in radiative forcing in the climate system since 1750 has been due to the increase of carbon dioxide (Figure 3.1) followed by an increase in concentrations of other greenhouse gases (IPCC 2007a). There is now "very high confidence level that the globally averaged net effect of human activities since 1750 has been one of warming, with a radiative forcing of +1.6 W/m² (with an uncertainty range of +0.6 to +2.4 W/m²)".

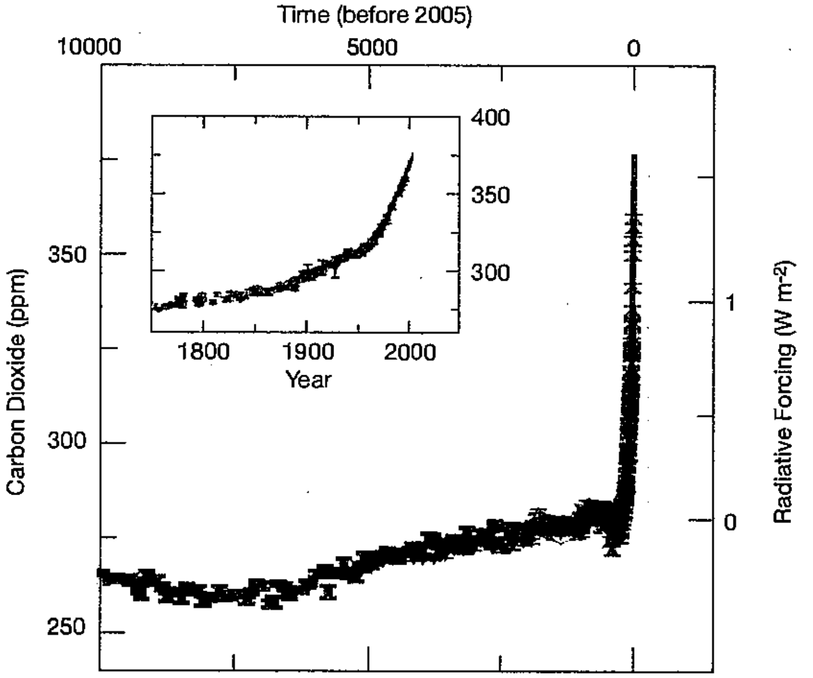

Figure 3.1: Atmospheric concentrations of carbon dioxide over the last 10.000 years (large panel) and since 1750 (inset panel). Measurements are shown for air extracted from ice cores (symbols with different colours for different studies) and atmospheric samples (red lines). The corresponding radiative forcings are shown on the right hand axes of the large panel (from IPCC (2007a) Figure SPM-1).

3.1 Detection and attribution of observed climate change

Detection of climate change is "the process of demonstrating that climate has changed in some defined statistical sense, without providing a reason for that change" (IPCC 2001). A change (the 'signal') is *detected* in observations if its likelihood of occurrence by random chance from internal variability alone (the 'noise') is small enough to be regarded as unlikely. To filter out the noise and detect a statistically significant trend, the climate record has to be of sufficient length. 'Sufficient' will vary according to the magnitude of the trend (i.e. smaller signals are harder to detect) and the importance of the noise (i.e. it is more difficult to detect changes in highly variable quantities such as rainfall as opposed to temperature). Because detection studies are necessarily statistical in nature, they are never absolutely certain. Detection does not, by itself, establish the cause of the climate change.

Attribution is "the process of establishing the most likely causes of the detected change with some defined level of confidence" (IPCC 2001). From a practical perspective, IPCC (2001) recommended that attribution of anthropogenic climate change requires:

- The detection of a change to a significant statistical level
- Demonstration that the detected change is "consistent with the estimated responses to the given combination of anthropogenic and natural forcing"; and
- Demonstration that the detected change is "not consistent with alternative, physically-plausible explanations".

Climate models are the major tools used to determine the causes of observed climate change. Climate model simulations can be used to explain recent climatic changes and separate the impact of anthropogenic factors from natural forcings. However, many observed variations are at least partly random in nature and are not expected to be replicated. Indeed, climate models exhibit effectively stochastic (random) behaviour as does the climate system (e.g. Power and Colman 2006). So to attribute a signal in model studies to any external forcing it is a common practice to use an ensemble of several simulations to filter out the naturally occurring internal climate variability within the model from the underlying trends. The differences between simulations reflect the model's estimate of the natural internal variability of the climate system.

Evidence of a human influence on recent climate has accumulated steadily during the past two decades. Despite clear evidence of changes in the composition of the global atmosphere, the first IPCC Assessment Report (IPCC 1990) contained little observational evidence of a detectable anthropogenic influence on climate. However, six years later the Second Assessment Report (IPCC 1996) concluded that "*the balance of evidence*" suggested there had been a "discernible" human influence on the climate of the 20th century. Considerably more evidence accumulated during the subsequent five years, leading the Third Assessment Report (IPCC 2001) to the stronger conclusion that "*most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations*".

More detection and attribution studies were carried out in the subsequent years and the Fourth Assessment Report (IPCC 2007a) concluded that "*most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations. Discernible human influences now extend to other aspects of climate, including ocean warming, continental average temperatures, temperature extremes and wind patterns*".

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3.2 Attribution of observed climate changes in Australia

3.2.1 Temperature

Australian surface temperatures have warmed significantly over the past century. Warming since the middle of the 20th century is likely to be mostly due to anthropogenic increases in greenhouse gases.

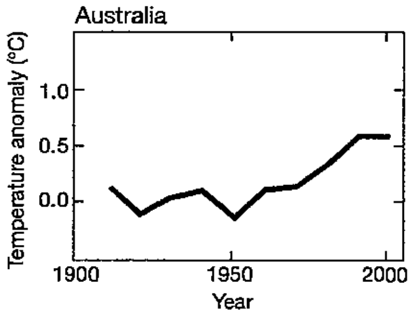

Figure 3.2: Comparison of Australia-wide observed trends in decadal averages of surface temperature (black line) with averages of model results from 14 climate models using natural only (blue shaded band) and natural plus anthropogenic forcings (pink shaded band). Changes are relative to the average for 1901–1950. Both shaded bands show the 5–95% range of values evident in the simulations, from IPCC (2007a) Fig. 4, SPM-4.

Temperature has increased over most of Australia since 1950 (Figures 2.1 and 2.2 and discussion in Chapter 2). As part of the IPCC Fourth Assessment Report, 19 simulations from five climate models from a number of different research groups around the world using only natural forcings and 58 simulations from 14 climate models using both anthropogenic and natural forcings were analysed. Only the ensemble of simulations that includes the anthropogenic forcing in addition to the natural forcing is able to capture the observed warming during the second half of the century (Figure 3.2). The ensemble incorporating natural forcing tracks the decadal averages of the Australia-wide observed temperature only until the 1970s but does not capture the subsequent acceleration of the warming.

This new result confirms an earlier study based on a smaller range of climate models but examining a variety of simple temperature indices. Australian temperature changes over the 20th century appear "very unlikely" to be due to natural climate variations alone, and it was "likely that there has been a significant contribution to the observed warming during the second half of the century from increasing atmospheric greenhouse gases and sulfate aerosols" (Karoly and Braganza 2005a). This work, in turn, advanced earlier work that noted consistency between observed trends and the response of climate models to enhanced greenhouse forcing (Pittock 1988; Power *et al.* 1998b).

It was also demonstrated that the recent increase in temperatures was not a consequence of rainfall change (unlike past changes) and therefore inconsistent with natural climate trends (Nicholls *et al.* 1996; Nicholls 2003; Power *et al.* 1998a,b). Indeed, once the rainfall-related component of the temperature variations is removed, "trends in the residual variations of maximum, mean and minimum temperature over the last 50 years are not explained by natural climate variations and are consistent with the response to increasing greenhouse gases and sulfate aerosols in climate models" (Karoly and Braganza 2005b).

This latter approach is able to enhance the signal-to-noise ratio for anthropogenic temperature change signals in the Australian region and shows that there is a clear anthropogenic warming signal in observed regional temperature trends, even for regions as small as the south-east of Australia. At small regional scales it is not always possible to attribute these regional features to a specific cause as more than one factor may be contributing to the change in the climate. An exception is the central part of the south-east of Australia which has warmed during the second half of the 20th century but by a much smaller amount than the rest of the continent. This reduced rate of warming was related to changes in the Southern Annular Mode. (Hendon *et al.* 2007).

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5.7 Sea level rise

An increase in mean sea level and changes in sea level extremes will mainly affect the terrestrial landscape, increasing the risk of inundation of low-lying coastal terrain. However, increases in coastal inundation can impact upon marine ecosystems through changes to coastal wetlands and tidal plains that provide breeding grounds for marine life.

5.7.1 Mean sea level rise

Global sea level rise is projected by the IPCC to be 18-59 cm by 2100, with a possible additional contribution from ice sheets of 10 to 20 cm. However, further ice sheet contributions that cannot be quantified at this time may increase the upper limit of sea level rise substantially. Global climate models indicate that mean sea level rise on the east coast of Australia may be greater than the global mean sea level rise.

Mean sea level rise occurs as a result of two main processes - the melting of land-based ice, which increases the height of the ocean, and a decrease in ocean density, which increases the volume and hence the height of the ocean. Increases in ocean density in most parts of the world, including Australia, occur largely due to increases in the heat content of the ocean rather than reductions in salinity and so the density change component is often referred to as thermal expansion. The amount of thermal expansion is non-uniform due to the influence of ocean currents and spatial variations in ocean warming.

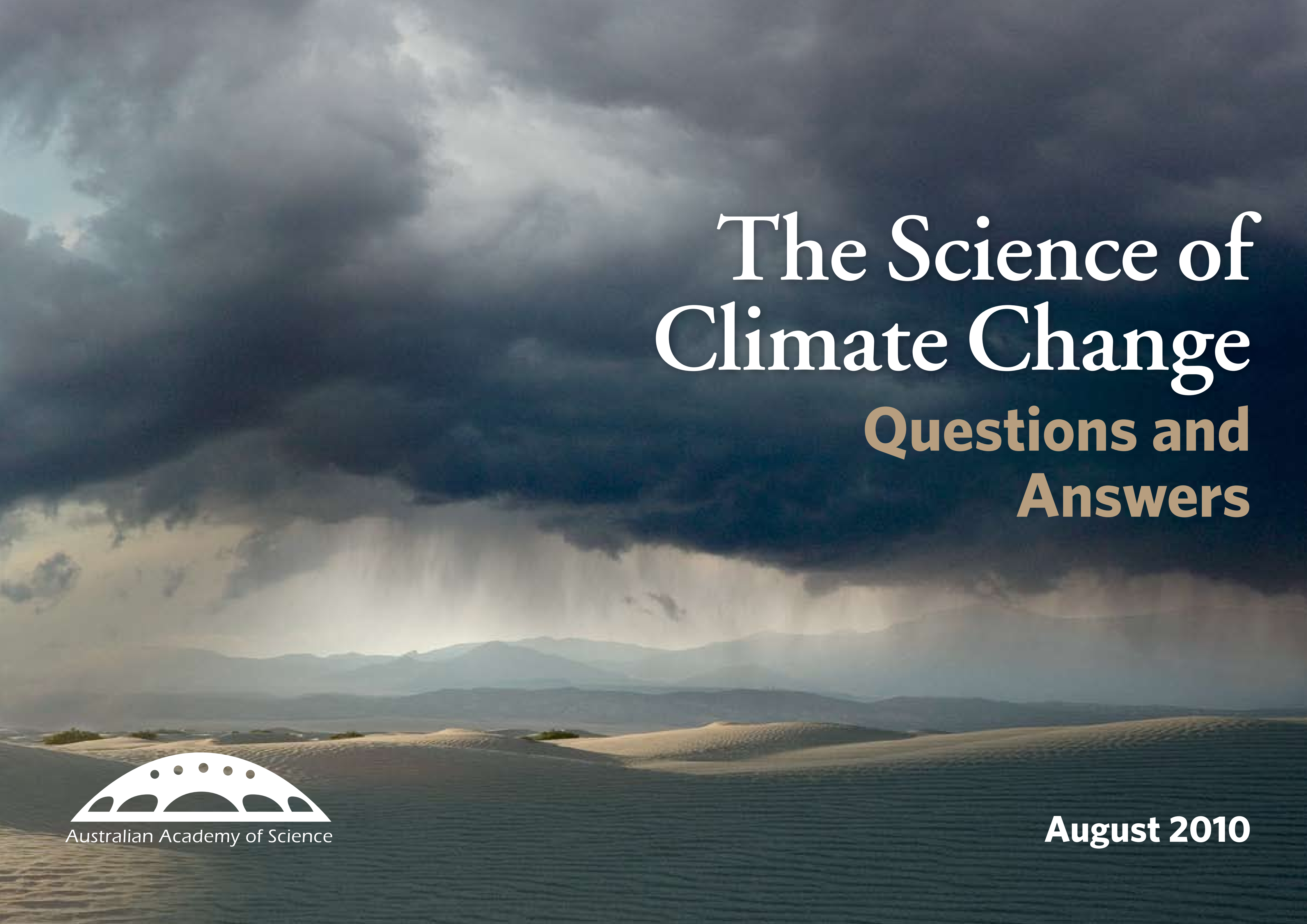
From 1961-2003, the rate of sea level rise was 1.8 mm per year, with a rise of 3 mm per year from 1993-2003. This rate of increase is an order of magnitude faster than the average rate of rise over the previous several thousand years. Around Australia the rate of sea level rise was about 1.2 mm per year during the 20th century (Church *et al.* 2006).

This rise in sea level has mainly been attributed to thermal expansion of the upper ocean. Overlying this global sea level rise is a large regional variability. The oceans surrounding Australia are particularly influenced by two dominant climate variations: the El Niño – Southern Oscillation (ENSO) and the Southern Annular Mode (SAM). These two climate variations overlay the global mean sea level rise, resulting in significant regional variability in the magnitude and trend of sea level rise in the oceans surrounding Australia. For example, ENSO results in sea level variability in the western Indian Ocean and eastern tropical Pacific Ocean, while the SAM is a major driver of sea level variability in the Southern and mid-latitude Indian and Pacific Oceans. The impact of ENSO and SAM results in a regionally complex pattern of sea level rise and variability in the Indian and Pacific Oceans.

Throughout the 21st century and beyond, sea levels across the world's oceans are expected to continue rising due to thermal expansion of sea water, melting of land-based glaciers and ice caps and contributions from the ice-sheets of Antarctica and Greenland. Relative to the 1990 level, global average mean sea level is projected to increase by 18 to 59 centimetres by 2100 (Table 5.8). If ice flow rates from Greenland and Antarctica during 1993-2003 were to continue to grow linearly with global warming, then the upper ranges of sea level rise would increase by a further 10 to 20 cm (IPCC 2007a). There is a risk that the contribution of ice sheets to sea level rise this century will substantially higher than this (IPCC 2007a; Hansen 2007).

Table 5.8: IPCC Fourth Assessment Report estimates of global average sea level rise by 2100, relative to 1990 (from IPCC (2007a) Table SPM-3) for six IPCC emissions scenarios. Larger changes are possible (see text).

Emissions scenario	Central estimate	Estimate range
B1	28 cm	18-38 cm
A1T	33 cm	20-45 cm
B2	32 cm	20-43 cm
A1B	35 cm	21-48 cm
A2	37 cm	23-51 cm
A1FI	43 cm	26-59 cm



The Science of Climate Change

Questions and Answers

August 2010

Australian Academy of Science

Prof. Kurt Lambeck
President, Australian
Academy of Science
May 2006 – May 2010

Foreword

The science of climate is at the intersection of a number of science disciplines and sub-disciplines. At its heart are physics, chemistry, biology and mathematics – each with their sub-disciplines of atmospheric physics and chemistry, oceanography, hydrology, geology etc – and each of which can be considered as mature within the framework required to discuss climate. It is at this intersection of the disciplines where uncertainty can and will arise, both because of the yet poorly understood feedbacks between the different components of the climate system and because of the difficulty of bringing these components together into a single descriptive and predictive model. This would include, for example, the biological consequences of how increasing carbon dioxide (CO_2) feeds back into climate and into the climate model, or how the consequences of atmospheric warming on water vapour, cloud cover, ocean warming and circulation feedback can be described and quantified in a coherent and integrated theory. It is these feedbacks and interactions that make it difficult to realistically quantify the uncertainty in the outputs of climate models at levels that the experimental scientist is usually accustomed to. In a process as intrinsically complex as climate it should not be surprising that the path to understanding is long and arduous.

In many other areas of experimental science the paths to full understanding are equally complex. What makes climate change different is that the consequences are not only potentially global and serious but also that they occur over long time scales (decades to centuries) so that actions need to be contemplated before full understanding is achieved. These actions themselves are built on economic, social and political models each with their own inherent assumptions and difficulties with data and observations. In the presence of uncertain scientific uncertainty, it should not be surprising that, when it comes to recommendations about how to respond to a threat of climate change, the spectrum of opinions is broad indeed.

The Australian Academy of Science is strongly committed to enhancing public understanding of scientific issues and how these may impact on society and the planet. Through its members and through its National Committees for Science it is able to draw on expertise from across a broad sector of the Australian science community to report on important scientific issues.

This includes climate science. The Academy recognises that decisions on how to respond to climate change will have to be made by our society as a whole. These decisions need to consider the findings of climate change together with many considerations that go beyond the science and must include, amongst others, ethics and equity, economics, risk management and politics. The purpose of this document is to contribute to the public understanding of the state of the science and to attempt to tread a path through the often contradictory public commentary on the science. It is not a formulation of a policy response but an attempt to improve the public understanding of the science upon which any policy response should be constructed.

To this effect the Academy's Council established two committees to address some of the major questions that are frequently asked about climate change science. First, an expert Working Group carefully formulated the questions and answers about the science of climate change. This group consists of internationally recognised scientists who have contributed extensively to the underpinning science, including contribution to the successive IPCC assessments. Seven 'big' questions were identified within each of which 'lower-level' questions have also been addressed. Second, an Oversight Committee comprehensively reviewed the answers provided to ensure that they are authoritative within the current state of knowledge. This Committee consists of eminent Fellows of the Academy and other experts with both extensive research experience in related fields and in the leadership of climate-related programs and organisations.

While it is important to emphasise that it is not possible to provide definitive answers to many of the questions that are being asked about climate change, it is also important to stress that considerable progress has been made in understanding climate change and why it occurs. The role of greenhouse gases in the atmosphere is qualitatively well understood. It is known that increasing the atmospheric concentration of the principal anthropogenic greenhouse gas, CO_2, leads to higher mean global surface temperatures. It is known that CO_2 has increased very substantially during the last century, to the highest levels seen in the past 800,000 years, and that this increase is primarily of anthropogenic origin. It is also beyond serious question that some CO_2 from human activities remains in the atmosphere for a very long time, as is the message that unless greenhouse gas emissions are reduced, an upward trend in global temperature will continue.

The uncertainties in the science do not affect such major conclusions but they will affect the precise timescales or magnitudes of the change and they will affect the global distribution of its impact. It is important therefore that extensive research and rigorous scientific debate continue within the expert scientific community and that the communication of that research to the broader community be effective. The Academy therefore hopes that this report will provide a firmer basis for understanding the science of climate change and its implications.

The Academy is very appreciative of the contributions made to this report by the members of the Working Group and Oversight Committee to provide authoritative answers to these important questions on the science of climate change. The Academy also thanks the Department of Climate Change and Energy Efficiency for providing financial support to prepare this document.

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Summary

The Earth's climate has changed. The global average surface temperature has increased over the last century and many other associated changes have been observed. The available evidence implies that greenhouse gas emissions from human activities are the main cause. It is expected that, if greenhouse gas emissions continue at business-as-usual rates, global temperatures will further increase significantly over the coming century and beyond.

The science behind these statements is supported by extensive studies based on four main lines of evidence:

Physical principles established more than a century ago tell us that greenhouse gases, such as carbon dioxide (CO_2), trap heat and keep the planet warmer than it would otherwise be. Increasing greenhouse gas levels raise the temperature of the Earth's surface.

The record of the *distant* past (millions of years) tells us that we cannot take a stable climate for granted. Climate has varied greatly through the Earth's history. It has, for example, gone through 10 major ice age cycles over approximately the past million years. The past few thousand years have been unusually stable. Together with our understanding of physical principles, evidence from the past shows that climate can be sensitive to small external influences.

Measurements from the *recent* past (the last 100 years) tell us that the Earth's surface is warming along with rising levels of greenhouse gases from human activities, and that this warming is leading to other environmental changes. Although climate varies from year to year and decade to decade, the overall upward trend of average global temperature over the last century is clear.

Climate models, together with physical principles and knowledge of past variations, tell us that, unless greenhouse gas emissions are reduced and greenhouse gas concentrations in the atmosphere are stabilised, global warming will continue.

Climate models estimate that, by 2100, the average global temperature will be between 2°C and 7°C higher than pre-industrial temperatures, depending on future greenhouse gas emissions and on the ways that models represent the sensitivity of climate to small disturbances. Models also estimate that this climate change will continue well after 2100.

A 2°C global warming would lead to a significantly different world from the one we now inhabit. Likely consequences would include more heat waves, fewer cold spells, changes to rainfall patterns and a higher global average rainfall, higher plant productivity in some places but decreases in others, disturbances to marine and terrestrial ecosystems and biodiversity, disruption to food production in some regions, rising sea levels, and decreases in Arctic ice cover. While aspects of these changes may be beneficial in some regions, the overall impacts are likely to be negative under the present structure of global society.

A warming of 7°C would greatly transform the world from the one we now inhabit, with all of the above impacts being very much larger. Such a large and rapid change in climate would likely be beyond the adaptive capacity of many societies and species.

There are uncertainties in climate science. For example, a precise value cannot be given for the likely range of warming because of uncertainties in climate sensitivity to small disturbances, although climate models and evidence from past climate change provide a plausible range of values. Climate changes over small regions and changes in rainfall patterns are very hard to estimate. Tipping points or rapid climate transitions associated with overall global warming are possible but cannot yet be predicted with confidence. These uncertainties work in both directions: there is a chance that climate change will be less severe than the current estimates of climate science, but there is also a chance that it will be more severe.

This document aims to summarise and clarify the current understanding of the science of climate change for non-specialist readers. The document is structured around seven questions.

1 What is climate change?

Climate is a statistical description of weather conditions and their variations, including both averages and extremes. Climate change is a change in the average pattern of weather over a long period of time. Greenhouse gases play an important role in determining climate and causing climate change.

2 How has Earth's climate changed in the *distant* past?

Global climate has varied enormously through Earth's history. Evidence from the past shows that global climate can be sensitive to small influences. Past records also show that climates can shift abruptly.

3 How has climate changed during the *recent* past?

Global average temperature has increased over the past century. Evidence for this comes from instrumental temperature records in the air and the ocean. Temperature observations are not the only evidence of recent climate change: other sources include trends in sea levels, glaciers, ice caps and atmospheric water vapour that are consistent with global warming. Australia's climate has changed along with global climate.

4 Are human activities causing climate change?

Human activities are increasing greenhouse gas levels in the atmosphere. It is very likely that most of the recent observed global warming is caused by this increase in greenhouse gases.

5 How do we expect climate to evolve in the future?

Climate models and studies of past climates indicate that global warming and associated changes will continue if greenhouse gas levels keep rising as they are now. It is very likely there will be significant warming through the 21st century and beyond. Reduction of greenhouse gas emissions could significantly reduce long-term warming.

6 What are the consequences of climate change?

Climate change will have significant impacts on our society and environment, both directly and by altering the impacts of other stresses.

7 How do we deal with the uncertainty in the science?

Although climate forecasts are uncertain and will remain so, the broad conclusions of climate change science as outlined above are based on many lines of evidence which together give a high degree of confidence. Partly because of scientific uncertainty but also because many aspects of human life are involved, decisions about action on climate change will need to involve extensive consideration of issues beyond science, including ethics, economics and risk management.

1

What is climate change?

Climate change is a change in the average pattern of weather over a long period of time

Climate is a statistical description of weather conditions and their variations, including both averages and extremes. Climate change refers to a change in these conditions that persists for an extended period, typically decades or longer.

Weather variables such as temperature and rainfall fluctuate naturally (see **Box 1**). These changes in weather from day to day, between seasons, and from one year to the next, do not represent climate changes. The period for estimating climate is usually 30 years or more, long enough to sample a full range of weather.

Climate can be defined for a particular place or region, usually on the basis of local rainfall patterns or seasonal temperature variations. Climate can also be defined for the entire Earth. For global climate, a key variable is the average surface temperature.

BOX 1

Could the 20th century warming be just a part of the natural variability of climate?

Climate varies naturally on many timescales. Much of this variation arises from the exchange of heat and water between the deep oceans and upper ocean layers (typically the top 50 to 100 metres), which in turn has an impact on the atmosphere. A well-known example is the El Niño oscillation in the tropical Pacific Ocean, which influences temperatures and rainfall patterns throughout the tropical Pacific region and far beyond. Other ocean basins have similar oscillations. Such phenomena typically change the global average temperature by no more than a few tenths of a degree, and only for up to a year or two.

In principle, a natural fluctuation could last for a century. However, evidence going back up to 20 centuries does not show changes in global temperature resembling those that have taken place in the last 100 years [1-3]. Moreover, there is compelling independent evidence (**see Question 4**) that this warming is being caused largely by the enhanced greenhouse effect due to human activities. The response of the climate system to human causation was foreseen by scientists more than a century ago [4]. If this warming continues as now projected, it will soon dwarf any change in the last 10,000 years.

Sustained and truly global changes in average temperature require some global heating or cooling influence such as variations in heat output by the Sun, changes to the Earth's orbit around the Sun, changes in cloudiness, changes to the extent of ice on Earth's surface, or changes in greenhouse gas concentrations in the atmosphere.

Identifying climate change that is truly global in extent requires simultaneous observations from a network of locations around the world (see **Question 3**). Such a network of instrumental observations has only been available since the second half of the 19th century. Climate changes that occurred before this time can be identified by reconstructing records from climate-sensitive indicators like ocean sediments, ice-cores, tree rings and coral reefs.

Greenhouse gases play an important role in determining climate and causing climate change

Greenhouse gases include water vapour, carbon dioxide (CO_2), methane, nitrous oxide and some industrial gases such as chlorofluorocarbons (CFCs). These gases act like an insulating blanket, keeping the Earth's surface warmer than it would be if they were not present in the atmosphere. Except for water vapour, the atmospheric concentrations of all of these gases are being directly influenced by human activities (see **Question 4**). Once released into the atmosphere, many of these gases remain there for a long time: in particular, a significant fraction of CO_2 emissions remains in the climate system for hundreds to thousands of years.

Water vapour is an important greenhouse gas but it is not like the greenhouse gases affected directly by human activities. Its concentration in the atmosphere is controlled by the climate itself, rather than by human activities. Water vapour therefore reacts to,

BOX 2

If water vapour is the most important greenhouse gas, why all the fuss about CO_2?

Water vapour accounts for about half the present-day greenhouse effect. Its global average concentration in the troposphere (where most water vapour is found) is controlled mainly by the atmospheric temperature and winds, with warmer temperatures causing higher water vapour concentrations. This is in contrast with other greenhouse gases, for which concentrations are strongly influenced by human-induced inputs to the atmosphere.

If other factors warm the atmosphere, then water vapour concentrations are expected to increase and, because water vapour is a greenhouse gas, the increased concentrations would amplify the initial warming (**see Figure 2.1**). This is known as a positive feedback.

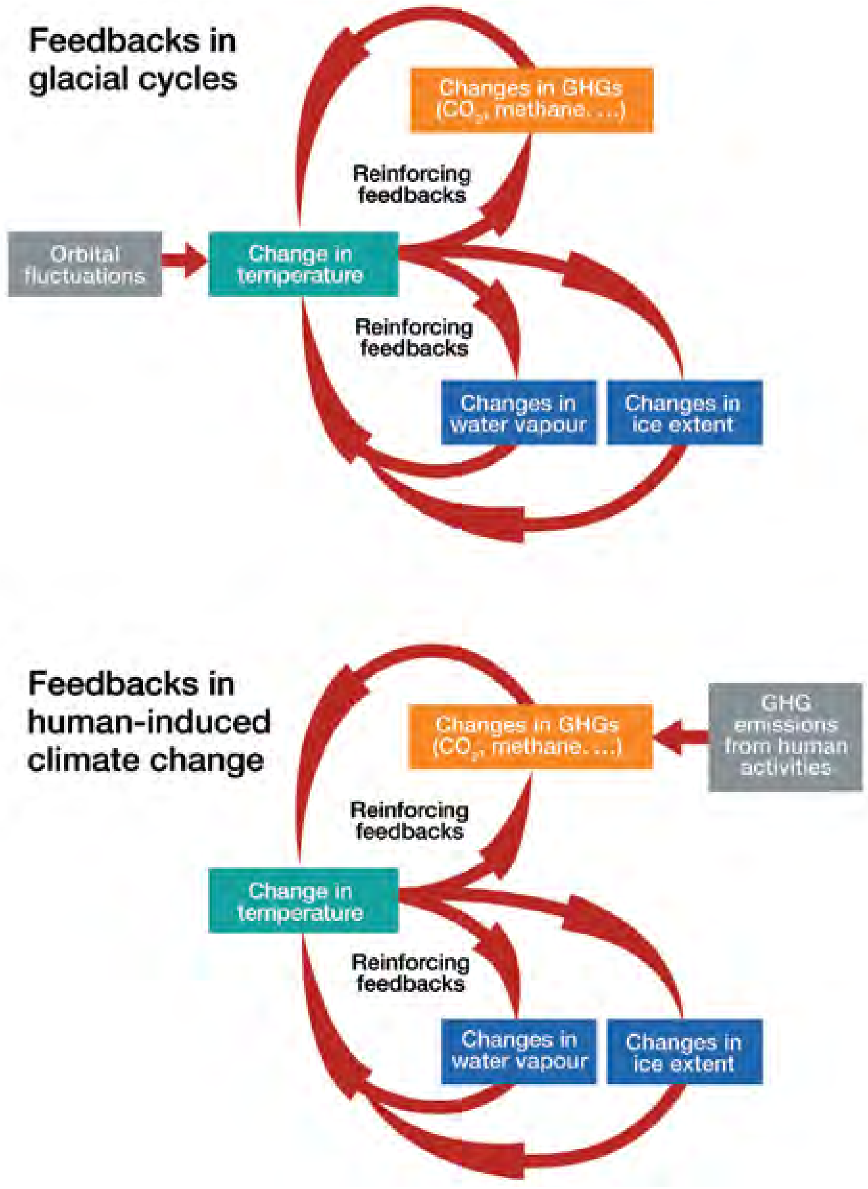
The water vapour feedback is supported by most evidence and analyses so far [5-11], although some views are different [12].


NASA

and amplifies, climate change caused by other factors (see **Box 2 and Figure 1.1**).

The effects of changing greenhouse gas levels on climate can be distinguished from the effects of other factors such as changes to the Sun’s radiation. These different causes lead to different patterns or “fingerprints” in the resulting climate changes, which assist in identifying the cause of observed changes. For example, increases in solar radiation would be expected to warm both the upper and lower parts of the atmosphere and result in days warming more than nights. On the other hand, increases in greenhouse gases would be expected to result in a cooling, not a warming, in the stratosphere (the layer of the atmosphere above 15 km elevation), and cause nights to warm more than days. The observed patterns of change more nearly match those expected from increasing greenhouse gases.

Figure 1.1 Feedbacks in the climate system



There are close connections between global temperature, atmospheric water vapour, the extent of polar ice caps and levels of greenhouse gases (GHGs) in the atmosphere. When one of these is disturbed, the others react through processes that amplify the original disturbance until a new, different climate equilibrium is reached. In the glacial cycles over the past million years, the disturbance came from fluctuations in the Earth’s orbit around the Sun (grey box in upper diagram). This caused temperatures to change (green box), in turn inducing rapid changes in water vapour (left blue box), and much slower changes in ice caps (right blue box) and greenhouse gas levels (orange box), which together amplified the temperature change. In modern climate change, the disturbance comes from human-induced changes in atmospheric CO_2 and other greenhouse gas levels (grey box in lower diagram). In both cases, the disturbance is amplified by similar reinforcing processes.


PHOTOLIBRARY

2 How has Earth's climate changed in the *distant* past?

Climate has varied enormously through Earth's history
Since the Earth was formed 4.5 billion years ago, the global climate has changed dramatically many times due to the changing configuration of continents and oceans, natural variations in the levels of greenhouse gases in the atmosphere, the Sun's intensity, and the Earth's orbit around the Sun [13-20].

Evidence from the past shows that global climate is sensitive to small influences
During the past million years, the average temperature of the Earth's surface has risen and fallen by about 5°C, through 10 major ice age cycles. The last 8,000 years have been relatively stable at the warmer end of this temperature range [21]. These cycles were initiated by subtle variations in the Earth's orbit that altered the pattern of absorbed sunlight. Measurements from ice cores and other sources strongly suggest that as temperatures changed, other changes were triggered that had an amplifying effect: during warm periods, CO_2 and methane were released into the atmosphere, and ice sheets receded and so reflected less sunlight to space [14, 22-24]. This meant that small influences were amplified into larger changes (see **Figure 1.1**).

An important implication of this finding from past climate changes is that similar processes are likely to amplify current human influences on climate.

Past temperature changes affected the world dramatically. For example, in the coldest period of the last ice age (approximately 20,000 years ago) sea level was at least 120 metres lower [25]. The atmosphere was also very dusty, probably because of dramatic regional reductions in vegetation cover associated with the colder climate and reduced CO_2 [26-27]. In even earlier times, several million years ago, global temperature was several degrees higher than today and warm, tropical oceans may have reached much farther from the equator, causing significant changes to atmospheric flow patterns [28].

Past records also show that climates can shift abruptly
The largest global temperature changes evident in the geologic record have typically occurred fairly slowly over tens of thousands or millions of years, much more gradually than the warming over the past century [14]. However, some rapid changes have been documented both in very warm past climates and in more recent ice ages.

One of these rapid changes took place 56 million years ago, when the global temperature increased by about 5°C, accompanied by an unexplained release of greenhouse gases into the atmosphere [29]. This release may have been so rapid as to be comparable to the current human release of fossil fuels [14, 30, 31]. Other rapid changes during the last ice age, of 5°C or more over as little as a few decades, were probably mostly regional and due to sudden collapses of ice sheets or changes in ocean currents [14, 29, 32-34].

Although the millennium before the industrial revolution was relatively stable, there were variations in climate over that period
The Medieval Warm Period (AD 800-1300) and Little Ice Age (AD 1500-1800) are two well-known climate episodes during the past thousand years. The Northern Hemisphere may have been up to 1°C warmer on average during the former period than during the latter. However, several assessments indicate that Northern Hemisphere average temperatures over the last fifty years have been warmer than during the Medieval Warm Period, and temperatures over the last decade are warmer still. Records are sparse in the Southern Hemisphere, but those available indicate little or no correlation with warming in the Northern Hemisphere during the Medieval Warm Period, unlike the more globally coherent cooling in the Little Ice Age and warming over the past century [1, 14, 35-40].

There have also been regional variations in climate, particularly rainfall, that are not associated with global changes. For example, regional droughts appear to have contributed to the collapse of the ancient Akkadian empire in the Middle East and the Mayans in Mexico [41, 42].

3 How has climate changed during the *recent* past?

Global average temperatures have increased over the past century
Measurements from many hundreds of thermometers around the globe, on land and over the ocean, show that the average near-surface air temperature increased over the 100 years to 2009 by more than 0.7°C [43-46].

Many of these instrumental records, which began in the second half of the 19th century, were not initially designed to be used for climate monitoring. This means they have to be carefully analysed to deal with changes in instruments, observational practice, location, and the growth of cities (**see Box 3**). After accounting for these issues, temperature increases are largest in the continental interiors of Asia and north Africa, regions which are distant from major population growth areas (**see Figure 3.1 and Figure 3.2**) [43-46].

The rates of observed near-surface warming increased in the mid-1970s. Since then, the global land surface has warmed at about double the rate of the ocean surface. Measured warming over the past 50 years was nearly twice the rate of that for the past 100 years. The last decade has been the warmest yet recorded [43-46] (**see Box 4**).

The overall warming has led to an increase in the number of record high temperatures, and decrease in frost frequency and the number of record low temperatures over the past century [46, 47] (**see Figure 3.3**).

Over the past three decades, satellite observations of temperature at the Earth's surface and in the lower atmosphere have also shown warming [46, 48, 49] (**see Box 5**). In contrast to the surface warming, the atmosphere above about 15 km elevation (the stratosphere) has cooled over the past four decades [46, 50-52]. This provides one clue that the observed warming is due to human activities (**see Question 4**).

The upper 700 m of the ocean is storing about 90% of the additional heat absorbed by the Earth's whole climate system since 1961 [53]. The surface ocean has warmed by 0.5°C from the 1970s to the early 2000s. Averaged over the upper 700 m of the ocean, the average warming is much

BOX 3

Does warming in cities affect global temperature records?

The temperatures recorded by some weather stations in cities have been affected by non-climate related changes, including warming due to their proximity to buildings and other structures that emit, absorb and radiate heat.

Climate researchers have made extensive efforts to avoid or correct such problems, and several tests show that this has minimised any effects on long-term trends, particularly when averaged over large regions [59-61]. Nonetheless regional and year-to-year variability is not known precisely, especially earlier in the record.

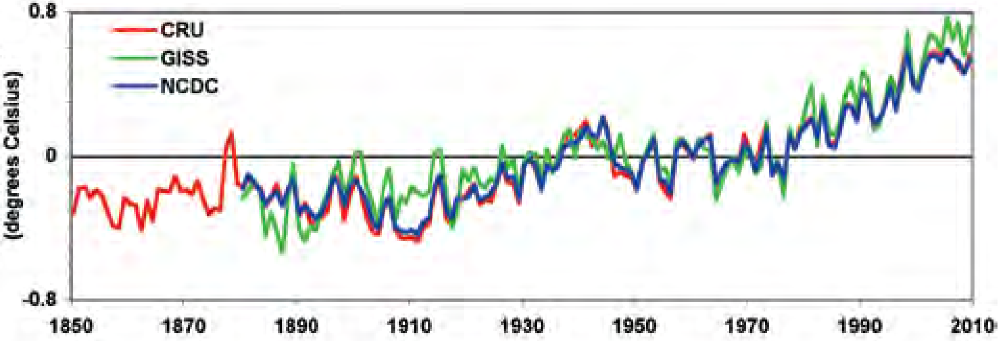


Figure 3.1 Global surface temperature anomalies relative to 1951–1980, from surface air measurements at meteorological stations and ship and satellite sea surface temperature measurements. Differences between the series arise from different ways of deriving a global average surface temperature from measurements at numerous points.
Data from: Climate Research Unit, University of East Anglia (*www.cru.uea.ac.uk/cru/data/temperature/*); Goddard Institute for Space Studies (*http://data.giss.nasa.gov/gistemp/*); National Climate Data Center, NOAA (*www.ncdc.noaa.gov/cmb-faq/anomalies.html*)

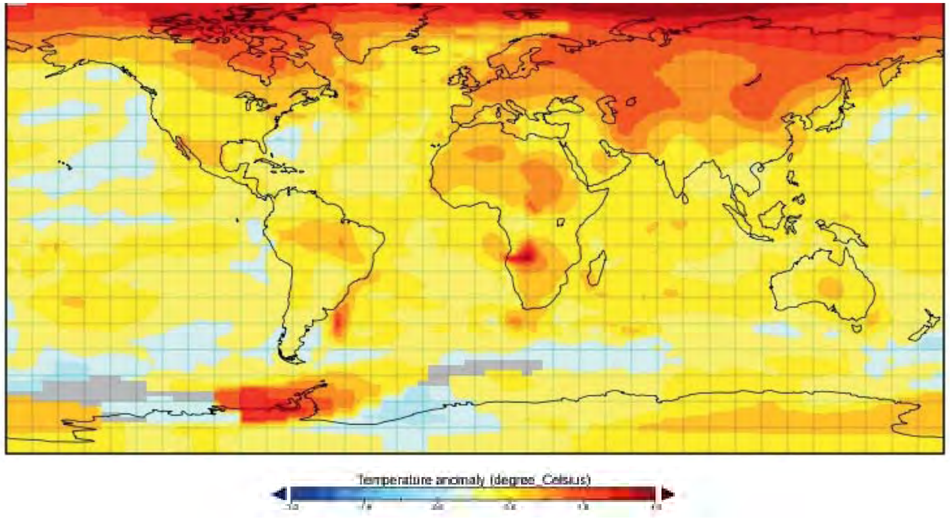


Figure 3.2 Distribution of global surface temperature anomalies for the period 2005-2009, relative to 1951-1980 as a baseline, from surface air measurements at meteorological stations and ship and satellite sea surface temperature measurements. Note that warming is greatest over continental interiors and where there is no urban heat island effect (e.g. Antarctic Peninsula, Siberia).
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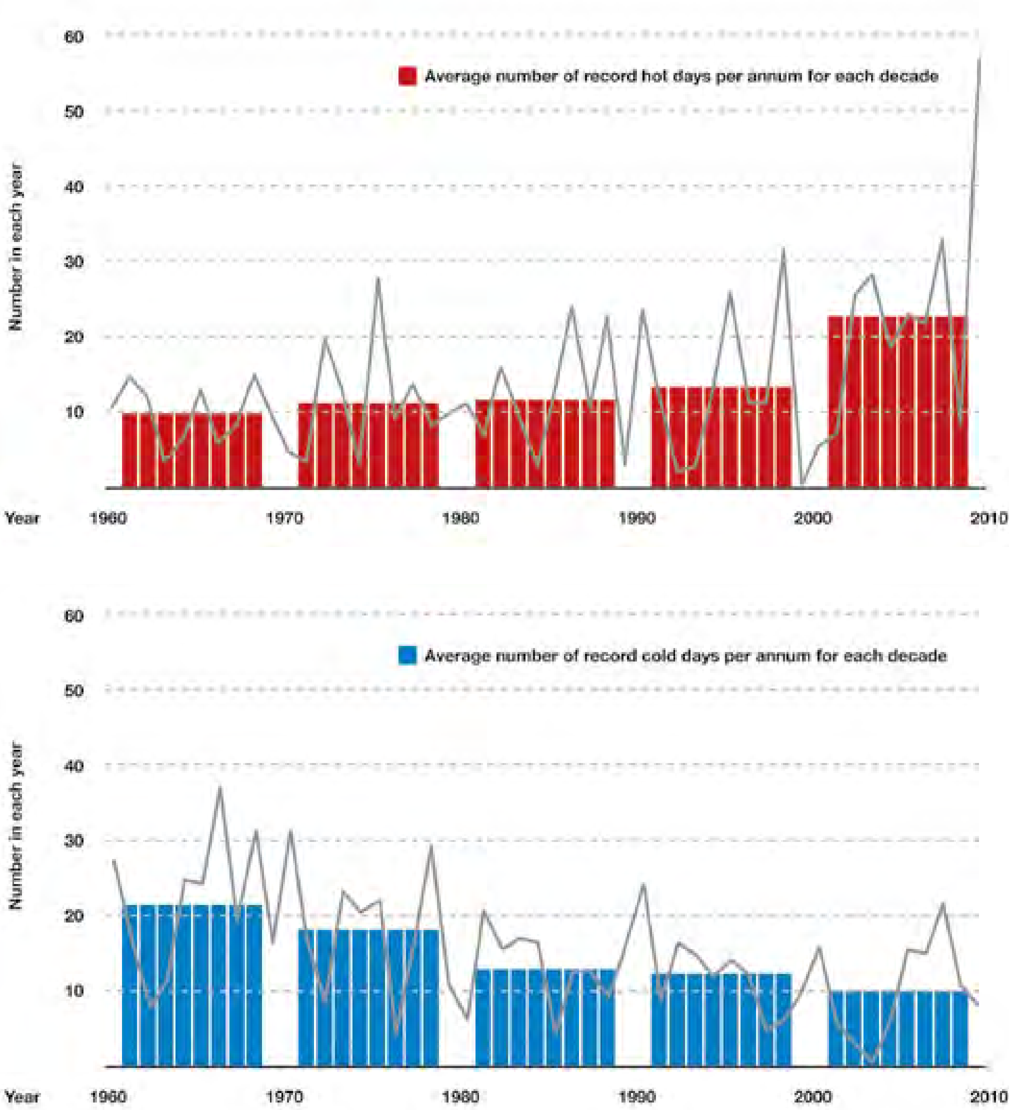


Figure 3.3 Changes in the number of record hot day maxima and record cold day maxima at Australia's climate reference stations. The number of days with record hot temperatures has increased each decade over the past 50 years; there have been fewer record cold days each decade; and 2000 to 2009 was Australia's warmest decade on record. Source: CSIRO, Bureau of Meteorology (2010) "State of the Climate".

smaller, only about 0.1°C, but very important because of the large amount of stored heat this represents [53-58].

Temperature observations are not the only evidence of recent climate change

Many other changes have been observed that are consistent with the recorded increase in global average temperature, and indicate some of its consequences:

- There has been widespread melting of mountain glaciers and ice caps. While many of these have been shrinking since about 1850, there has been a significant increase in the rate of average glacier melt since the 1990s [63-66].
- Satellite instruments show that the Greenland ice sheet is losing more ice than it gains by snowfall, due to increased surface melting and increased flow of ice into the ocean. The rate of loss of ice from Greenland has risen since the mid-1990s. There are strong indications that West Antarctica has also been recently losing ice due to increased ice flow. Most recent estimates show Antarctica as a whole is losing ice [67, 68].
- Sea level rise is an inevitable consequence of global warming because ocean water expands as it warms, and because melted ice from the land adds more water to the oceans. The rate of rise increased from the 19th to the 20th centuries, with the result that ocean levels are now more than 20 cm higher than in 1870 [69, 70]. Satellite and coastal measurements show that the rate of sea level rise since the early 1990s has been substantially larger than the average rate for the 20th century, and larger than for any similar length period in the historical record [69] (**see Figure 3.4**). The observed rise is consistent with increased rates of ice melt and ocean warming [55].
- Arctic sea ice extent has decreased significantly in all seasons, but particularly in summer, since satellite records began in 1979. Submarine observations suggest that the Arctic Ocean sea ice thickness has decreased since 1958, and satellite measurements indicate a thickness decrease of about 0.6 m between 2003 and 2008 [71, 72]. However, in the Southern Ocean, total sea ice extent has increased slightly [70, 73].
- The average water vapour content in the atmosphere, both at the Earth's surface and higher in the atmosphere, has been increasing at a rate of 1–2% per decade since reliable measurements began in the 1980s [9, 46]. The greater intensity of heavy rains expected from this increasing humidity has been observed in some regions [74]. Observed changes in ocean salinity are consistent with intensification of the water cycle over the oceans [75].
- There is evidence of a shift in weather systems toward the Earth's polar regions, and an apparent strengthening in the winds over the Southern Ocean over the last 40 years. This is believed to have contributed to observed warming over the Antarctic Peninsula and Patagonia, to cooling over eastern Antarctica and the Antarctic plateau [76],

BOX 4

Has there been a global cooling trend since 1998?

No, 1998 was an extremely warm year but the overall warming trend has continued over the past decade. The temperature trend in any given 10-year interval (such as 1 January 1990 to 31 December 1999, or 1 January 1998 to 31 December 2007) can be determined by a standard statistical process called linear regression. Since the 1970s, decadal global temperature trends have consistently demonstrated warming in almost all such 10-year intervals, although the magnitude of the trend varies because of natural climate variability **(see Box 1)** [62]. The decadal temperature trends over recent 10-year intervals remain positive.

to associated changes in sea ice and the ocean [73, 77], and probably to the decreases in rainfall over south-western Australia [78, 79].

- There are indications of recent changes in the temperatures and salinities of deep ocean currents such as those which carry North Atlantic water southward at depth and Antarctic bottom water north [80].

Australia's climate has changed along with the global climate

In Australia, the average surface temperature has increased by about 0.7°C since 1960, with some areas having warmed faster and some showing relatively little warming (**see Figure 3.5**) [81]. The warming has caused an Australia-wide average increase in the frequency of extremely hot days and a decrease in the frequency of cold days [81, 82] (**see Figure 3.3**).

While the longer term trends in rainfall are less marked, there have been significant increases over north-western Australia, and decreases over south-western and south-eastern Australia since 1960 (**see Figure 3.6**) [81]. The warming and decreased rainfall over south-east Australia have exacerbated the background conditions conducive to fire [83]. In southwest Western Australia and the southeast coast, there is evidence for a systematic decline in rainfall in recent decades [79], and for declining trends in storminess [84]. It is likely that these trends are related to shifts in pressure patterns over southern Australia, particularly the intensification of the subtropical high pressure belt [85].

Regional ocean currents have also changed. For example there has been a southward shift of the Antarctic Circumpolar Current [86] and an increasing southward penetration of the East Australian Current, associated with wind changes in the South Pacific [87].

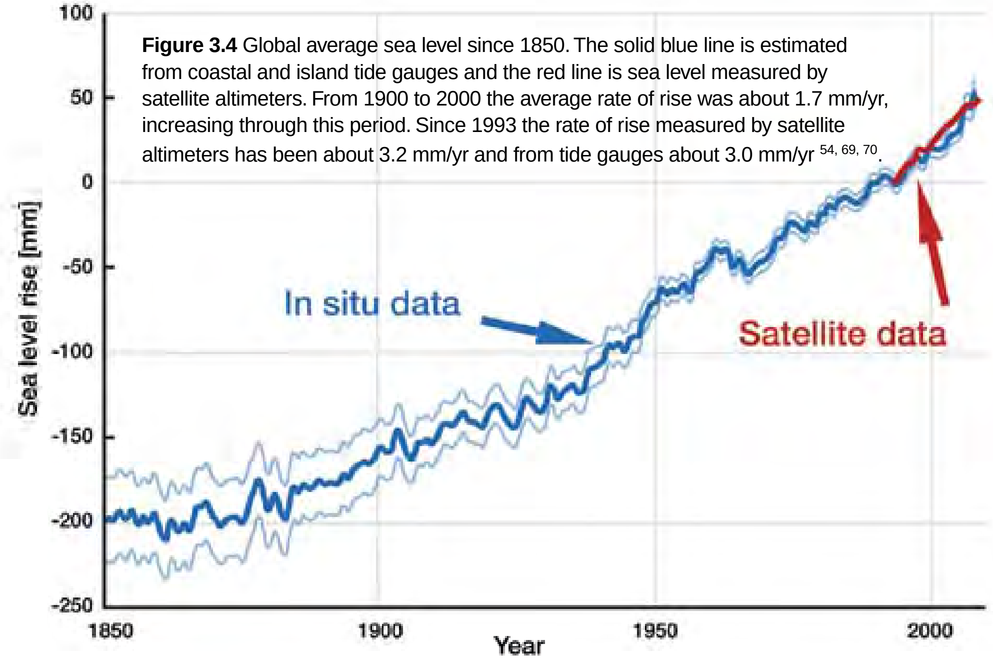


Figure 3.4 Global average sea level since 1850. The solid blue line is estimated from coastal and island tide gauges and the red line is sea level measured by satellite altimeters. From 1900 to 2000 the average rate of rise was about 1.7 mm/yr, increasing through this period. Since 1993 the rate of rise measured by satellite altimeters has been about 3.2 mm/yr and from tide gauges about 3.0 mm/yr [54, 69, 70].

Sea level has risen around Australia at a rate of about 1.2 mm per year since 1920, resulting in coastal inundation events becoming more frequent [88]. Since the establishment of the Australian Baseline Sea-level Monitoring Project in the early 1990s, sea level measured relative to the land has risen at about 2 mm per year in the south east, and over 8 mm per year in the north west [89].

BOX 5

Is there a disagreement between satellite and surface temperature records?

Not any more. While a disagreement did exist in the 1990s, it has largely been resolved by correction of biases in the satellite data, for example to account for drift in satellite orbits over time [48, 49]. Given the remaining uncertainties in satellite-derived trends, there is now acceptable agreement between satellite and ground-based measurements of surface temperature.

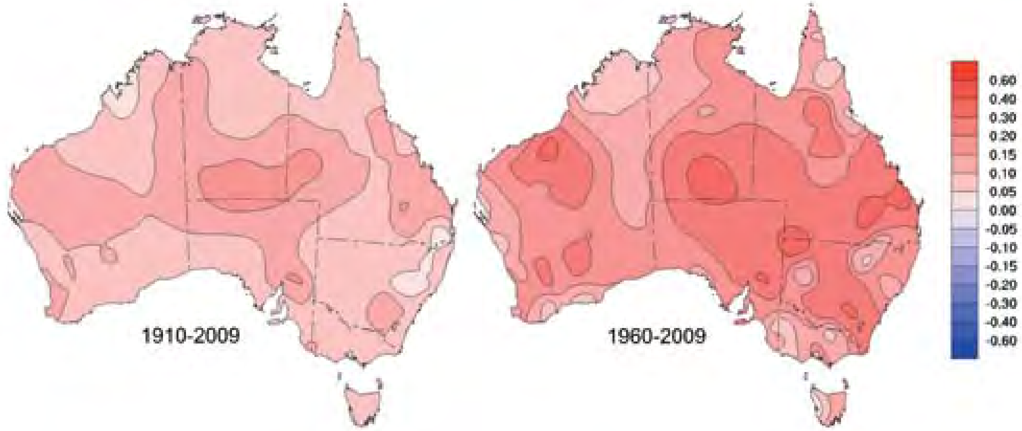


Figure 3.5 Trends in Australian annual temperature (°C/decade) over the periods 1910–2009 (left) and 1960–2009 (right). Source: Australian Bureau of Meteorology (*http://www.bom.gov.au/cgi-bin/climate/change/trendmaps.cgi*)

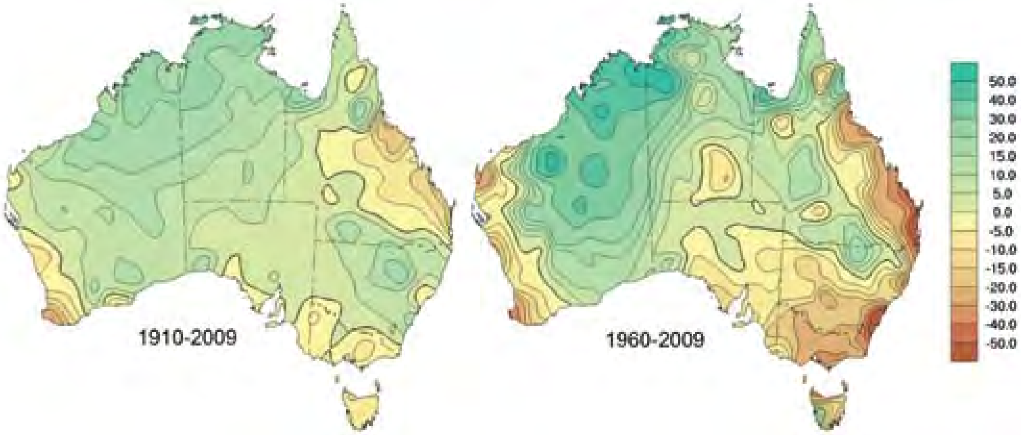


Figure 3.6 Trends in Australian annual rainfall (in mm per decade) over the periods 1910–2009 (left) and 1960–2009 (right). Source as for Figure 3.5.

4 Are human activities causing climate change?

Human activities are increasing greenhouse gas levels in the atmosphere

The concentrations of greenhouse gases in the atmosphere are well known, both from modern measurements [90-94] and by analysis of the air from past eras, trapped as bubbles in ice from Antarctica and Greenland [95, 96] (**see Figure 4.1**). These observations tell us that atmospheric concentrations of CO_2, methane and nitrous oxide began to rise two to three hundred years ago, after changing relatively little since the end of the last Ice Age thousands of years earlier.

This increase in greenhouse gas concentration happened around the same time as industrialisation, when the global human population began growing rapidly and farming also increased. The growth in greenhouse gases has accelerated through the 20th century to the present [90-96] (**see Figure 4.1**). Studies of the stores and sources of these gases, both natural and human-induced, show that the main causes of the increasing concentrations are emissions from human activities [97-101] (**see Figure 4.2**).

BOX 6

Why are CO_2 emissions from human activities regarded as so significant?

Large amounts of CO_2 are continually transferred to and from the atmosphere, which exchanges carbon with the oceans and vegetation on land. Until around 200 years ago, these natural exchanges were in rough balance, shown by the nearly constant concentrations of atmospheric CO_2 for most of the last two thousand years. The importance of human-caused CO_2 emissions is that they are disturbing this balance, adding carbon to the atmosphere faster than it can be removed by uptake by vegetation, the slow mixing of CO_2 into the deep oceans, or the even slower weathering processes that control the carbon balance on geological timescales.

Human activities cause CO_2 input to the atmosphere from fossil fuel burning, other industrial sources such as cement production, and deforestation. Measurements over the past 50 years show that only about 45% of the combined CO_2 emissions from these sources remain in the air to cause atmospheric CO_2 to rise [102, 103]. About 25% of the total CO_2 input is being absorbed by the oceans, making sea water more acidic [104, 105], and the remaining 30% is being taken up on land, with the largest probable cause being increased growth of plants [99] (**see Box 6**). This is shown by a wide range of measurements and models [99, 101-103, 106, 107].

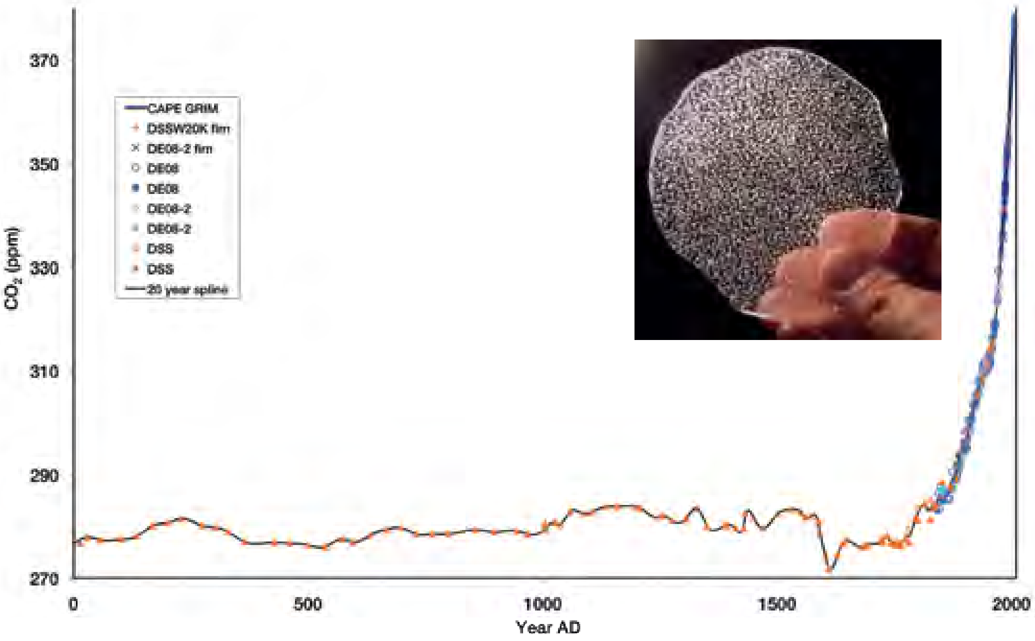
There has been a recent acceleration in the growth rate of CO_2 emissions from fossil fuels and industrial sources. From 2000 to 2007 these emissions grew by 3.5% per year, exceeding almost all assumed scenarios generated in the late 1990s [99, 108, 109]. This pulse of CO_2 emissions growth coincided with a period of rapid global economic growth. There will be a small, temporary downturn in CO_2 growth, associated with the 2008–09 global financial crisis [99, 109].

It is very likely that most of the recent observed global warming is caused by increasing greenhouse gas levels

It was predicted more than a century ago that increases in CO_2 would act like added insulation in the Earth's atmosphere, trapping more heat near the surface [4]. This extra CO_2 was also predicted to make the stratosphere colder [110] (**see Question 1**).

Satellite measurements over recent decades have confirmed the extra insulating effect not only of CO_2, but also of each additional greenhouse gas [111]. Moreover, trends over the last 40 years, superimposed on natural year-to-year variations, have been observed which show that the upper atmosphere has cooled and the surface of the Earth and the lower atmosphere have warmed significantly (**see Question 3 and Boxes 1, 4 and 5**). These are the predicted consequences of the additional levels of greenhouse gases [46, 48, 50]. In contrast, both the lower and upper atmosphere might have been expected to have warmed if the amount of the

Figure 4.1 Atmospheric CO_2 over the last 2000 years, based on direct measurements in the atmosphere at Cape Grim, Tasmania, older air extracted from Antarctic snow (firn) and from air bubbles trapped in various ice cores (various symbols). The inset shows the air bubbles in Antarctic ice. Image: Australian Antarctic Division. Data: CSIRO



BOX 7

Could changes in the Sun be causing global warming?

Not much of it. Most estimates show that solar output has not significantly increased since 1979, when satellites began measuring it accurately [121, 122]. Indeed, some estimates indicate that the Sun has grown slightly cooler since 1960, a period during which global temperatures have risen. While there have been some suggestions of a significant solar contribution to the observed warming over the past 20 years, all the trends in the Sun that could have had an influence on the Earth's climate have been in the opposite direction to that required to explain the observed rise in global average temperatures [123, 124]. Indirect estimates for earlier times suggest that the Sun has contributed only about 10% of the global warming since 1750 [125, 126].

Sun's energy being received by the Earth had increased (see **Question 1 and Box** 7).

As well as emitting greenhouse gases, human activities affect climate through the release of small particles in industrial haze, which reflect sunlight. The amount of cooling by this pollution is not known precisely, but is likely to be offsetting some of the warming from the increases in greenhouse gases [112-116].

Another way humans change local climates is by changing land use, building cities, or introducing irrigation. These changes can affect the amount of sunlight reflected from the surface, local wind flow and evaporation. The impact of these effects in recent decades has been small on a global scale [112, 117].

Natural factors that have changed climate in the distant past, such as the brightness of the Sun or volcanic activity, have made only a small contribution to recent climate change (see **Boxes** 7 **and** 8).

Putting all these factors together, the observed global warming during the past century has been consistent with that expected [26, 118, 119] from the combination of increasing greenhouse gases and increasing particulates [112, 117, 120], with small contributions from other factors.

Some recent Australian climate changes have been linked to rising greenhouse gases

Modelling studies indicate that rising greenhouse gases have made a clear contribution to the recent observed warming across Australia [117, 127, 128].

Decreases in atmospheric ozone over Antarctica and increases in greenhouse gases are also likely to have contributed significantly to climate trends that have been observed over the Southern Ocean in the past few decades, including stronger westerly winds and the southward shift of weather systems [76, 129, 130].

The human contribution to the recent observed rainfall increases in northwest Australia and decreases in southern Australia cannot as yet be clearly separated from natural climate variations [79, 82]. However, the decreases in rainfall in southern Australia have been linked to stronger high pressure weather systems [82]. The overall pattern of increasing pressure in mid-latitudes and decreasing pressure at high latitudes over time in the Southern Hemisphere is consistently seen in climate model projections and is therefore likely to be due to human-induced climate change through a combination of increases in greenhouse gases and decreases in stratospheric ozone [130-133].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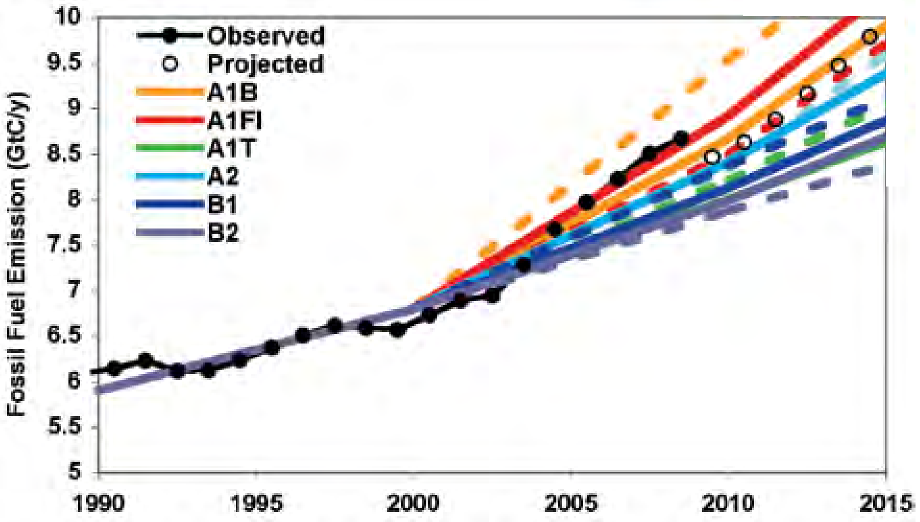

Figure 4.2: Observed past emissions of CO_2 from fossil fuels and other industrial processes (black points) with economics-based projections to 2014 (open circles). Coloured lines represent emissions futures from a range of IPCC scenario families representing combinations of economic (A) versus environmental (B) and globalised (1) versus localised (2) orientations for world development in the 21st century. Solid and dashed coloured lines respectively represent averages of scenarios within families and particular "marker" scenarios used in climate projections. Data: Carbon Dioxide Information and Analysis Center (*http://cdiac.esd.ornl.gov/trends/emis/em_cont.htm*). Figure adapted from published sources [99, 108, 109].

BOX 8

Do volcanoes emit more CO_2 than human activities?

No. The combined annual emissions from volcanoes on land and under the sea [117, 127, 128], averaged over several decades, are less than 1% of CO_2 emissions in 2009 from fossil fuels, industrial processes and deforestation [99].


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5 How do we expect climate to evolve in the future?

Climate models and studies of past climates indicate that global warming and associated changes will continue if greenhouse gas levels keep rising as they are now

Basic physical principles tell us that rising levels of greenhouse gases will warm the Earth's surface. To answer more complex questions, computer simulations, or models, of the Earth's climate are used. These models incorporate the many factors that affect our climate, using mathematical equations based on fundamental laws of nature, together with approximations of some physical processes that cannot be represented exactly (**see Box 9**).

Models simulate reasonably well the broad features of the present climate and the 20th century warming. This, however, does not guarantee accurate predictions into the future; changes could be more rapid or more gradual than projected. Overall, there is good agreement between models and observations at global and continental scales, but simulations are less reliable at the local scale [133]. Some properties of climate are better captured by models than others; for example, temperature is generally more accurately simulated than rainfall.

Independent of climate models, another important way to estimate the implications of greenhouse gas increases is to examine how climate has responded to such increases in the past, both over geological time (**see Question 2**) and in recent centuries (**see Question 3**) [14].

While these two approaches – modelling and studying the past – rely on markedly different methodologies, they both yield broadly similar indications of where global climate is headed. For example, both methods project a long-term warming of global air temperature of around 3°C (within an uncertainty range of 2°C to 4.5°C) in response to a doubling of the concentration of CO_2 in the atmosphere [134]. Evidence from Earth's past (**see Question 2**) indicates that changes of this magnitude can have major long-term ramifications, such as sea level rise of many metres [135-137].

Continued increases in greenhouse gas levels are expected to lead to significant warming through the 21st century and beyond

Continued "business as usual" reliance on fossil fuels is expected to lead to a doubling of pre-industrial CO_2 levels by about 2050, and possibly a tripling by about 2100 [138]. This emission pathway for CO_2, coupled with rises in the other greenhouse gases, would be expected to produce a warming of around 4.5°C by 2100, but possibly as low as 3°C or as high as 7°C [139, 140].

If society were to shift rapidly away from using fossil fuels, there would be little reduction in the rate of global warming in the first couple of decades, but warming later this century and beyond would be significantly reduced (**see Figure 5.1**).

Climate models and basic physical principles indicate that global warming will generally be accompanied by increases in global-average humidity; more extreme hot

BOX 9

If we can't forecast the weather 10 days in advance, why should we believe long-term climate forecasts?

Weather and climate are not the same: weather is chaotic and unpredictable over times longer than a week or two (**see Box 1**), whereas climate is the average of weather over time. Therefore, the challenges of predicting weather and climate are very different. Predicting the weather is akin to predicting how a particular eddy will move in a turbulent river: it is possible over short timescales by extrapolating the previous path of the eddy, but eventually the eddy is influenced by neighbouring eddies and currents to the extent that predicting its exact path becomes impossible. This is analogous to the predictive limit for individual weather systems in the atmosphere, which is around 10 days. On the other hand, predicting climate is akin to predicting the flow of the whole river, which requires a consideration of the major forces controlling the river, such as valleys and dams. Projections of climate change over decades to centuries are possible because of our progressively improving understanding of the forces affecting climate, including global warming caused by greenhouse gases.

events such as heat waves but fewer cold extremes; further decreases in the extent and thickness of Arctic sea-ice; shifts in rainfall (generally an increase in the tropics and high latitude regions and a decrease in the subtropics); further ocean warming; melting of mountain glaciers and polar ice sheets; and rising sea levels [118]. Most of these impacts have already been observed (**see Question 3**).

Warming rates and other climate changes are not expected to be the same everywhere, due to changes in atmospheric circulation or other regional influences. Projections of future climate for individual regions remain much less certain than global-scale projections. Different models often disagree, so definitive localised projections are not yet possible [118]. This is particularly the case for regional rainfall projections.

Some models also project substantial changes to phenomena such as El Niño or dramatic changes to vegetation [141]. Many aspects of climate change will likely remain difficult to foresee despite continuing modelling advances, leaving open the possibility of climate change “surprises” [142].

Some climate change will continue for centuries, and some change will be essentially irreversible on a 1,000-year timescale

Stabilisation of climate requires stabilisation of greenhouse gas concentrations. However, the inertia of the climate system, particularly the oceans and the ice sheets, means that climate change will continue for centuries after greenhouse gas concentrations have stabilised.

Even if human societies completely ceased greenhouse gas emissions at some time in the future, atmospheric temperatures would not be expected to fall significantly for a thousand years, as CO_2 and heat are only gradually absorbed by the deep oceans [143]. Sea level rise is also expected to continue for many centuries due to the ongoing melting of ice sheets and the gradual thermal expansion of the oceans in response to atmospheric warming [143].

Global warming above some threshold, believed to lie between about 2°C and 4.5°C, would lead to an ongoing melting of the Greenland ice sheet. If sustained for thousands of years, this would virtually eliminate the ice sheet, raising sea level by about seven metres [144]. Most of the Antarctic ice sheet, by contrast, is expected to remain too cold for widespread melting. It is possible that increased snowfall over Antarctica may partially offset other contributions to sea level rise [145].

In addition, accelerated outflow of ice has been observed from Greenland and West Antarctica. This is poorly understood, but could make these ice sheets more vulnerable to future warming [135].

Reduction of greenhouse gas emissions could significantly reduce long-term warming

To have a better than even chance of preventing the global average temperature from eventually rising more than 2°C above pre-industrial temperatures, the world would need to be emitting less than half the amount of CO_2 by 2050 than it did in 2000 [138, 146]. To do this on a smooth pathway, global emissions (which are still rising) would need to peak within the next 10 years and then decline rapidly [147].

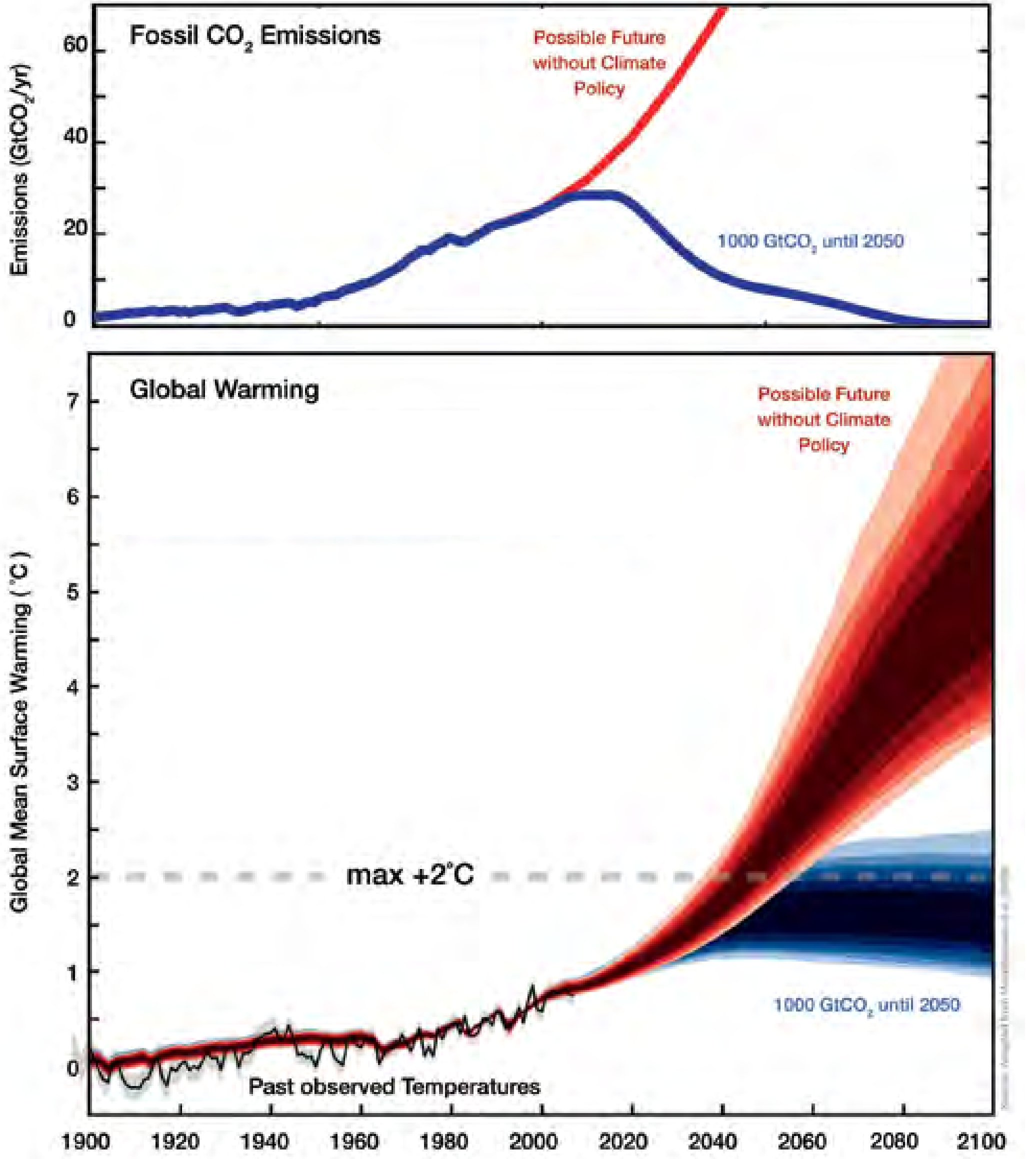

Figure 5.1 Top panel: Fossil-fuel CO_2 emissions for two scenarios: one “business as usual” [red] and the other with net emissions peaking before 2020 and then reducing rapidly to near zero emissions by 2100, with the cumulative emission between 2000 and 2050 capped at 1000 billion tonnes of CO_2 [blue]. **Bottom panel:** Median projections and uncertainties of global-mean surface air temperature based on these two emissions scenarios out to 2100. The darkest shaded range for each scenario indicates the most likely temperature rise (50% of simulations fall within this range). Adapted from Meinshausen *et al.* (2009) [138].

6 What are the consequences of climate change?

Climate change will have significant impacts on our society and environment

Historically, the Australian climate has been highly variable. This variability makes it challenging to predict the future consequences of human-induced climate change. However, climate models and past experience provide some guidance.

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By around 2030, Australian temperatures are likely to be a half degree or more higher than 1990 and the frequency of hot days and nights will have increased[148, 149]. Sea level is expected to be about 15 cm higher and there is some evidence to suggest that tropical cyclones will become more severe, but less frequent[150].

It is likely that future rainfall patterns across Australia will be different from today. Changes in rainfall patterns are hard to predict: regional rainfall projections from different climate models (or between different runs of the same model with different starting conditions) are frequently quite different from one another (**see Question** 7). Nevertheless, some future trends are projected fairly consistently, including increases in rainfall in northern Australia and decreases in Victorian and southwest WA coastal regions[148, 151, 152]. The projections for rainfall trends across the entire Murray-Darling basin remain uncertain[153].

It is likely that higher temperatures and changing patterns of wind and rainfall will change the patterns and frequency of extreme fire weather[149, 154], and also lead to more heat-related deaths and fewer cold-related deaths[155, 156].

Farming in Australia is vulnerable to climate change but skilful management is expected to be able to alleviate some of this vulnerability[157]. Higher CO_2 levels, fewer frosts and changed rainfall patterns may be beneficial to agriculture in some parts of Australia, but decreases in rainfall in other Australian regions are likely to have a detrimental effect on agriculture.

Warmer ocean temperatures will lead to further changes in the distribution of marine animals and plants, with some tropical fish moving progressively southward[158]. As a result of increased CO_2 in the atmosphere, oceans will become more acidic and, in combination with the higher temperatures, coral bleaching events are likely to become more frequent and severe around northern Australia[159, 160].

Sea level will increase, inundating parts of the Kakadu freshwater wetlands[160, 161] and causing increased coastal flooding[88, 162], with consequent change to sandy coastlines. As sea levels rise, coastal infrastructure around Australia will become more susceptible to damage[163-165]. Tourism may be adversely affected, in part due to the sector's dependence on natural assets and the built environment, both of which are vulnerable to the physical impacts of climate change[166].

The impact of climate change on plants and animals will be variable. Habitat will expand for some species, while for others it will contract[160]. However, the inability of many species to migrate as a result of both land use change and habitat fragmentation means that biodiversity is likely to decline overall[167], in line with observed global trends[168]. Higher temperatures on the forested mountaintops of north-east Queensland, for example, may exceed the heat tolerance of some endemic species in the wet tropics, resulting in their extinction[169].

Climate change will exacerbate the impacts of other stresses

The world's population is approaching seven billion people, and is expected to increase to around nine billion by mid-century, with two thirds of the world's population living in the Asia-Pacific region[170]. This population growth will place additional stress on the planet and its people. For example, half of all readily available fresh water is already appropriated for human use[171, 172].

Without major changes to population growth policies, land use, city development, and economic and social systems, the additional potential burdens of climate change impacts could lead to social unrest across large parts of the world. Further pressures arise because there is now little room for many populations to relocate in response to climate change[173, 174]. These factors are likely to affect developed and well as developing nations[173, 175].

The recent global financial crisis has demonstrated how interconnected the world

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has become. It is also dependent on a finite resource base. All of these factors demonstrate the need for an integrated approach to understanding how a sustainable planet can be attained in the presence of population pressures, risks from climate change, and other stresses [176].

Future impacts are expected to be more severe

If emissions continue unabated, current mid-range estimates are for 4.5°C higher global average temperatures by 2100 (**see Question 5**), which would mean that the world would be hotter than at any time in the last few million years. Sea level would continue to rise for many centuries. The impacts of such changes are difficult to predict, but are likely to be severe for human populations and for the natural world. The further climate is pushed beyond the envelope of relative stability that has characterised the last several millennia, the greater becomes the risk of passing tipping points that will result in profound changes in climate, vegetation, ocean circulation or ice sheet stability.

Figure 6.1 Climate change may have severe impacts across Australia. Days of extreme fire danger are likely to increase (**top right**).

Rainfall patterns are likely to change, leading to changes in river environments: the **image on the far left** shows stranded reeds and saline mud flats in September 2007, caused by the rapidly retreating waters of Lake Bywater (near Walkers Flat, SA). This lake is fed by the River Murray, which has seen major falls in level since 2000, particularly below Lock 1. The **image on the top left shows** heavy rain in the Northern Territory.

The **centre left image** shows healthy coral and the **centre right image** shows bleached coral near Keppel Island.

Biodiversity is likely to decrease: the **image to the right** shows the endangered lemuroid possum from North Queensland.


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7 How do we deal with the uncertainty in the science?

No scientific conclusion can ever be absolutely certain

However, a balanced assessment of the available evidence and prior knowledge allows us to attach levels of confidence to the findings of climate science.

There is a high degree of confidence in the broad conclusions of climate science

We are very confident of several fundamental conclusions about climate change: that human activities since the industrial revolution have sharply increased greenhouse gas concentrations; that these added gases have a warming effect; and that the Earth's surface has indeed warmed since the Industrial Revolution. Therefore, we are very confident that human-induced global warming is a real phenomenon.

Another important conclusion is supported unambiguously by all the evidence so far: "business as usual" emissions, with continuing high reliance on fossil fuels, will lead to a significantly warmer world.

Some aspects of climate science are still quite uncertain

The exact amount of warming that will result from any particular trajectory for future greenhouse gas emissions cannot be projected precisely, because it depends on details of processes that reinforce or dampen disturbances to the climate system. Important processes involve clouds, water vapour, ocean circulations and natural influences on greenhouse gas levels in the atmosphere. However, future warming can be specified within plausible bounds, not only from climate models but also from interpretations of climate changes in the past.

How climate change will affect individual regions is very hard to project in detail, particularly future changes in rainfall patterns, and such projections are highly uncertain. Neither can "tipping points" or rapid climate transitions be projected with any confidence, although they involve high risks should they occur.

Uncertainty about future climate change works in both directions: there is a chance that climate change will be less severe than current best estimates, but there is also a roughly equal chance that it will be worse.

Despite the uncertainties, climate science has an important role to play in informing public policy on climate change

Decisions on when and how to respond to climate change involve many factors that lie outside the realm of science, including ethical and economic considerations. An appropriate response will depend on value judgements and an assessment of the risks of various courses of action. Just as in any other sphere of human activity, decisions will need to be made before we have absolute certainty about the future. The role of climate science is to inform these decisions by providing the best possible knowledge of climate outcomes and the consequences of alternative courses of action.

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