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Observations of global and Australian climate

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Key messages

- There is a great deal of evidence that the Earth's climate has warmed over the last century. Warming is apparent in a range of climate indicators including increasing temperatures over land and in the oceans, and increases in sea level.
- Global average temperatures have risen in line with climate model projections for the last 20 years, while global average sea levels are rising near the upper end of the climate model projections.
- There is evidence that the observed changes to the climate system are consistent with changes expected due to increasing greenhouse gases. It is very likely that most of the warming over the last 60 years is due to increases in greenhouse gas emissions due to human activity.

Observations of temperature (on land and in the oceans), rainfall, sea level, ocean acidity and salinity, and other aspects of the climate system combine to give us a picture of our climate over time and enable us to identify trends and changes in key climate features. Instrumental observations are used in conjunction with climate models and palaeo-climate data to help us understand the causes of climate variability and change.

Global and Australian climate records extend over varying periods and depend on the number, location, and quality of instrumental observations. Observational data sets are continually and extensively analysed, to ensure they provide the best possible picture of global and Australian climate.

Australian terrestrial temperature

Surface temperature has been recorded at many sites across Australia since the mid-to-late 19th century. A network of standard thermometers and standard thermometer shelters was progressively introduced throughout Australia between 1890 and 1910.[1, 2] This network has provided an accurate picture of temperature changes since 1910. The Australian temperature record has been extensively analysed by the Bureau of Meteorology and researchers at CSIRO, Australian universities, and international research institutions.

These records show that surface temperatures in Australia rose by just under 1ºC over the 100 years from 1910 to 2009. Global average temperatures have risen by about 0.7ºC over the past century. Warming was modest in Australia in the early part of the 20th century, followed by a slight decline from around 1935 to 1950, and then a rapid increase until 2010. Australian average temperature has increased by around 0.7ºC since the middle of the 20th century.[3] This trend is continuing: the second half of 2009 was the warmest on record for Australia and 2010 was one of the hottest years in the instrumental climate record. The past decade (2000 to 2009) was Australia's warmest decade on record.

Temperature changes during the 20th century have varied across the continent owing to a number of different factors. For instance, years of high rainfall are typically associated with cooler than average temperatures, while years of low rainfall and drought are typically warmer than average.[4] Season-to-season and year-to-year changes in prevailing weather systems also cause significant temperature variability across the continent.

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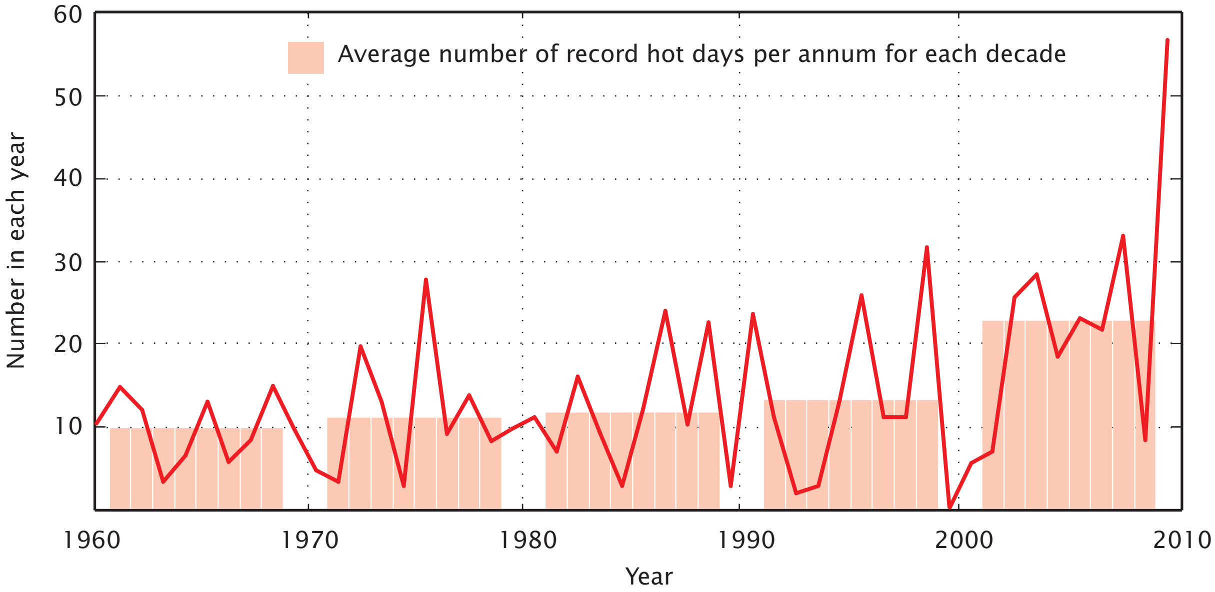
Almost all of Australia has warmed over the 50 years since 1960. Some regions have experienced temperature increases of up to 2ºC over this time, while other regions have experienced little or no change. The weakest warming trends are in north-western Australia, which has also seen an increase in rainfall since 1960. The long-term trend in Australia-wide average temperature, however, is clear and distinct from the observed background variability. Warming has occurred in all seasons, with the strongest warming occurring in spring (0.9ºC) and the weakest in summer (0.4ºC). Minimum (night-time) temperatures increased more rapidly than maximum (day-time) temperatures over most of the 20th century.

Overall, the frequency of extreme cold weather has decreased across most of Australia, while the frequency of warm weather has increased. For example, the number of days with record hot temperatures has increased each decade over the past 50 years (Figure 1.1). Evidence is emerging of increased frequency of severe heatwaves and warm extremes.[5, 6] The strongest trends in the frequency of hot days and warm nights have occurred in the north-east of the country since the mid-20th century, while the strongest declines in the frequency of cold days have occurred across the south.



▲ ***Figure 1.1**: Average number of record hot days per year for each decade for the period 1960 to 2010.*

Australian sea surface temperature

Temperatures measured at the surface of the oceans show that they have also warmed considerably in the past 120 years. As with land temperatures, changes in local sea surface temperatures are affected by both long-term global warming and year-to-year influences, such as the El Niño-Southern Oscillation.

Globally averaged sea surface temperatures have increased by about 0.7ºC. Temperatures of the surface waters surrounding Australia have warmed by about 0.9ºC since 1900, with about 0.4ºC of that warming having taken place in the past 50 years. Changes in sea surface temperatures also display regional variation, as with temperature over land. The south-eastern coastal regions of Australia have experienced the strongest warming over the 20th century. Significant seasonal warmth caused notable episodes of coral bleaching on the Great Barrier Reef in both 1998 and 2002.

Australian rainfall

Australia is an island-continent and different regions have quite different patterns of rainfall, both in terms of seasonality and the amount of rainfall. Rainfall in the tropical north is generally monsoonal, with a pronounced wet season over the summer months and dry for the remainder of the year. Rainfall in the south of the continent, by contrast, is dominated by winter storm activity. Much of the rest of the continent, particularly the interior, is either arid or semi-arid. This very large regional variability means that Australian average rainfall is not such a meaningful national measure as Australian average temperature.

Australia is subject to extreme rainfall variability compared with many regions of the world, including other arid regions such as the Sahara or Gobi deserts. Incursions of moist tropical air and tropical cyclones result in occasional deluges across the desert and semi-desert interior. Similarly, vast movements of oceanic heat and atmospheric circulation over the Pacific Ocean, known as the El Niño-Southern Oscillation, are associated with periodic droughts (El Niño) and, alternatively, heavy rainfall (La Niña) across the eastern and southern parts of the continent. Sea surface temperatures in the Indian and Southern oceans, as well as atmospheric circulation around the Southern Hemisphere as a whole, also make strong contributions to Australian rainfall variability.[7–9]

It is difficult to characterise long-term changes in Australian rainfall amidst this background of large, natural, year-to-year and decade-to-decade variability. For instance, while much of southern Queensland and northern New South Wales experienced (on average) severe and prolonged dry periods in recent decades, the longer term trend is not sufficiently clear to be able to distinguish whether these recent dry periods are different from the large decade-to-decade variability that is a natural feature of climate in these regions. Indeed, record- and drought-breaking rain during 2010 across Queensland and NSW is consistent with long-term natural variability.

Cool season (April to November) rainfall in the south-west of Western Australia (SWWA) and in south-eastern Australia over the last 15 to 30 years has shown changes that are large compared with natural variability. This is particularly true for SWWA, where winter season rainfall has declined by around 15% since the mid-1970s.

The rainfall declines across south-eastern parts of the country, including the lower Murray–Darling Basin (MDB), have been associated with widespread, long-term drought. As with SWWA, the most statistically significant rainfall reductions have occurred during the autumn and winter seasons, and have occurred since the mid-1990s. While heavy rainfall across the south-east during 2010 brought an end to a 13-year sequence of below average annual rainfall in Victoria, the heavy rainfall mostly occurred during spring and summer.

Significantly, the 15% decline in autumn/winter rainfall has been associated with much larger reductions in stream flow (up to 60% for SWWA and the lower MDB).[10, 11] Several factors have most likely caused the dramatic reduction in stream flow, and hence water storages, in southern drought-affected regions. There is a general tendency for changes in rainfall to be amplified in changes in stream flow. The timing of the rainfall deficits is important, because this can amplify the impact on soil moisture, water storages, and stream flows. Typically, rainfall in autumn and early winter soaks the catchments so that surface water runs off into creeks and water storages during late winter and spring. Catchments are generally drier during the winter season when autumn rain fails. This means that more winter rainfall is taken up by vegetation and dry soils, resulting in less rainfall making its way into water storages. It is notable that, despite heavy rainfall in Victoria during the second half of the year, Melbourne recorded its 14th consecutive year of below average inflows to water storages during 2010.

Attribution of observed climate changes

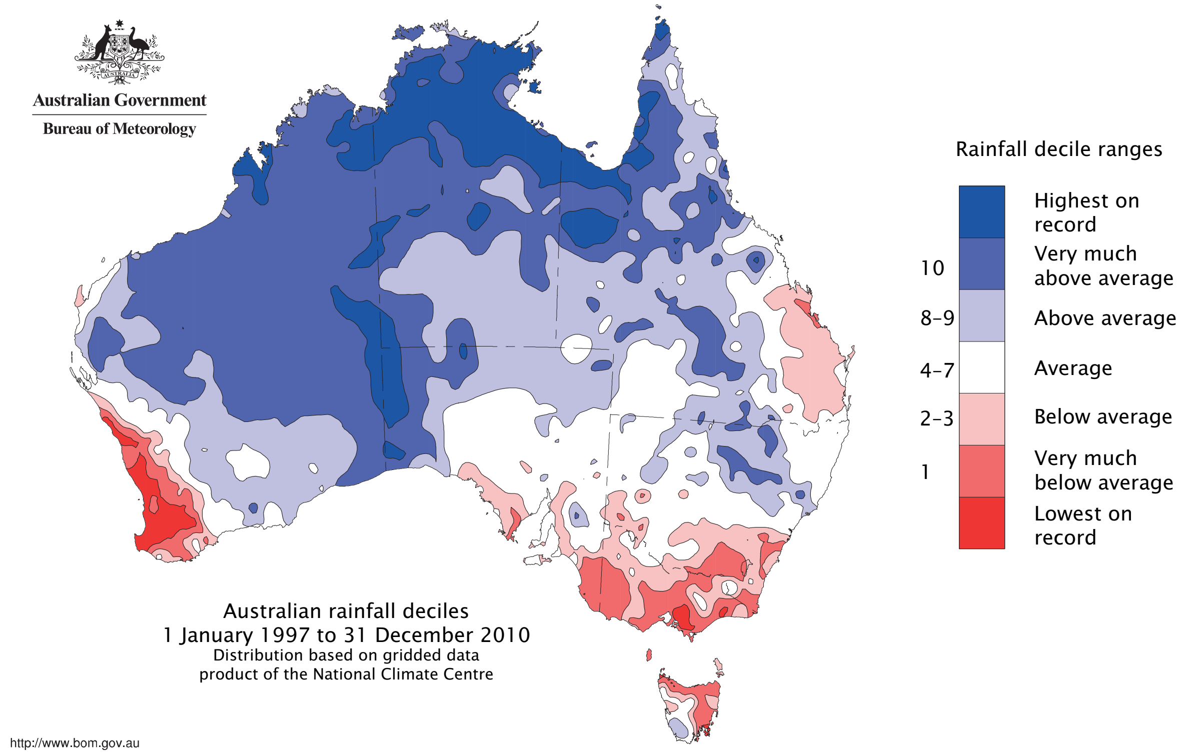
Climate change attribution is a field of climate science that seeks to determine cause and effect in the climate system. Attribution studies investigate the role that increasing greenhouse gases have played in climate change during the 20th century. Such studies compare changes in observed climate with various simulations or experiments using coupled atmosphere–ocean general circulation models, also known as Coupled Global Climate Models or Earth System Models (see Chapter 3).

The combination of observations and climate models are currently the best tools available to differentiate the natural and human-induced effects on the climate system because experimentation with real climate systems is not practically possible. Experiments using climate models typically include increasing greenhouse gases, changing solar radiation, changing atmospheric aerosols due to volcanoes and industrial pollution, and changing stratospheric ozone. These models, harnessing the strength of modern computing power, have been shown to be skilful enough in their representation of the real climate system to provide meaningful insights into the causes of recent climate change.

Studies have linked most of the warming in global temperatures in the past 100 to 120 years, especially in the last 50 years, to increasing greenhouse gases and the enhanced greenhouse effect.[12] It is extremely unlikely that the observed global-scale warming is due to natural variability. Simulations of the last 100 years of climate that include both human and natural influences on climate successfully reproduce observed patterns of global temperature change, whereas simulations that do not include human factors fail to reproduce the observed patterns. This contrast indicates that recent changes in temperature cannot be explained adequately by natural causes alone. Consistency between warming over land and warming over oceans during the 20th century provides further evidence that temperature changes are real rather than an artefact of recording practices. This is because land and sea temperatures are recorded very differently and are influenced by quite different factors, yet they reveal the same patterns of warming.

It generally is easier to attribute changes in temperature over large regions, such as the globe or a hemisphere, to greenhouse gas increases than it is to attribute regional temperature changes. This is because natural variability from year to year in individual regions is larger than it is over the globe as a whole, thereby making it more difficult to separate the effect of longer term changes from natural variability. Nonetheless, studies have shown that changes in Australian regional temperatures are most likely due to greenhouse gas increases and not due to natural processes alone.[4, 13, 14]

Scientists have a much more difficult task attributing Australian rainfall changes to human-induced climate change because it is difficult to separate naturally occurring drought from long-term declines in rainfall. The issue of largest interest has been the causes of the recent, long-term drought in the south-west and south-east of the continent.[15] Drought conditions persisted in the south-east from around 1996 to 2010 (see Figure 1.2). Research has shown that some aspects of this drought are consistent with global warming, but it has not been possible to unequivocally attribute this dry period to the enhanced greenhouse effect.[16] The drought in the south-west of WA has been particularly prolonged, such that it is often characterised as a long-term decline in rainfall, or an increase in aridity, rather than drought. The reduction in rain has been linked with shifts in prevailing weather patterns (e.g. storms and cold fronts) and a general reduction in rainfall associated with those systems. Some of these changes have been shown to be consistent with human influences (greenhouse gas increases and decreases in stratospheric ozone) in combination with natural climate variability.[17–23] Similarly, increased atmospheric pressure in the region, particularly in the subtropical ridge (a zone of high pressure or descending dry air across the southern half of the continent, associated with clear skies and low rainfall), has also been shown to be associated with the decline in rainfall across southern Australia, as well as being consistent with human-induced climate change.[24–26]



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▲ ***Figure 1.2***: *Summary of rainfall 1 January 1997 to 31 December 2010.*

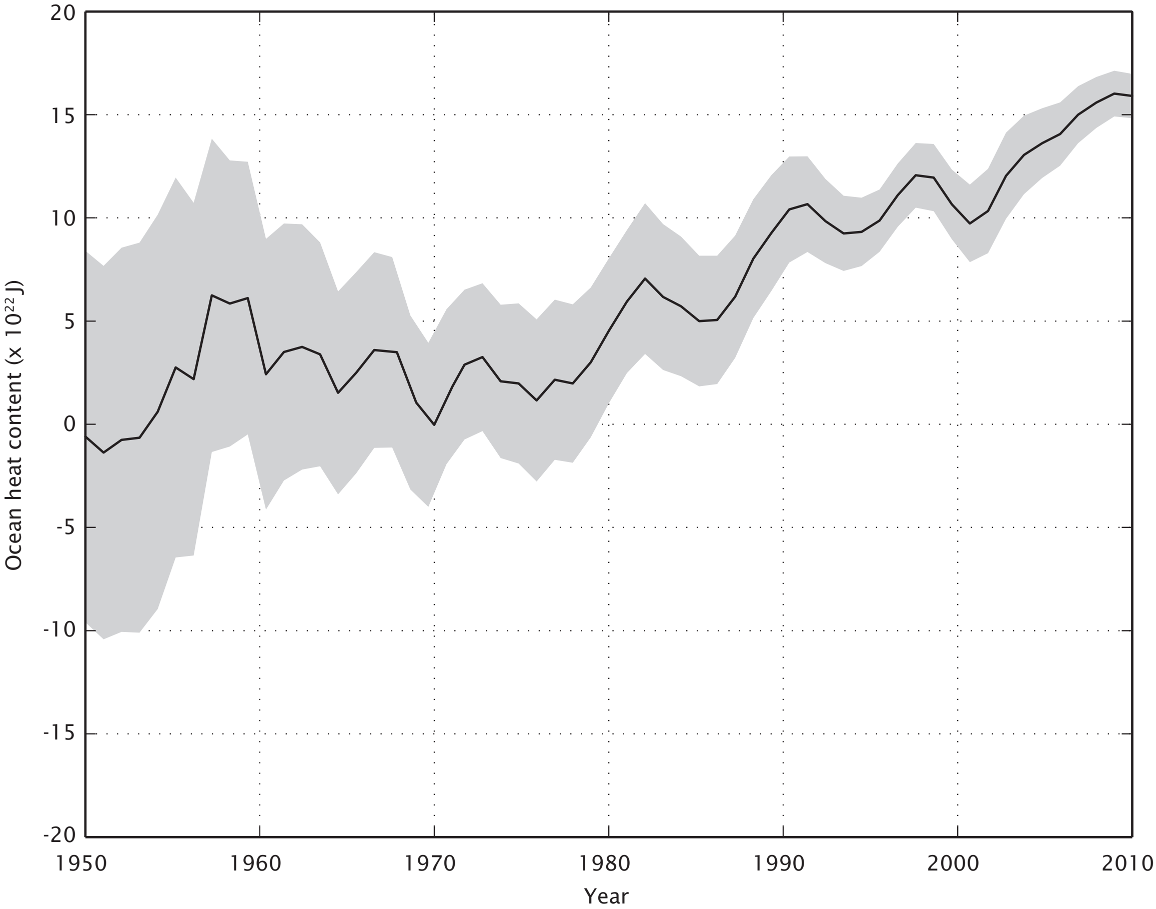
There is no unequivocal evidence that long-term changes in the Indian and Pacific oceans, such as changes to the El Niño-Southern Oscillation, have had a major influence on rainfall trends over Australia, despite studies that have identified possible changes over the 20th century in these large features of climate variability.[27] This is an area of active research in Australia, and internationally.

Observations from the oceans

Temperature

The oceans are the Earth's true thermometer. Their changing heat content provides measurable evidence of the warming of the planet. The vast amounts of heat that the oceans have absorbed in recent decades are causing them to expand and therefore to rise – just as heat makes the mercury in a thermometer rise – and to change in profound ways.[28]

The change in heat content of the world's oceans is prodigious: observations between 1961 and 2008 indicate that the upper few hundred metres of the ocean absorbed well over 100 billion trillion joules of energy (Figure 1.3).[29–31] This vast heat storage slows the rate of warming in the atmosphere and affects the regional distribution of these changes.

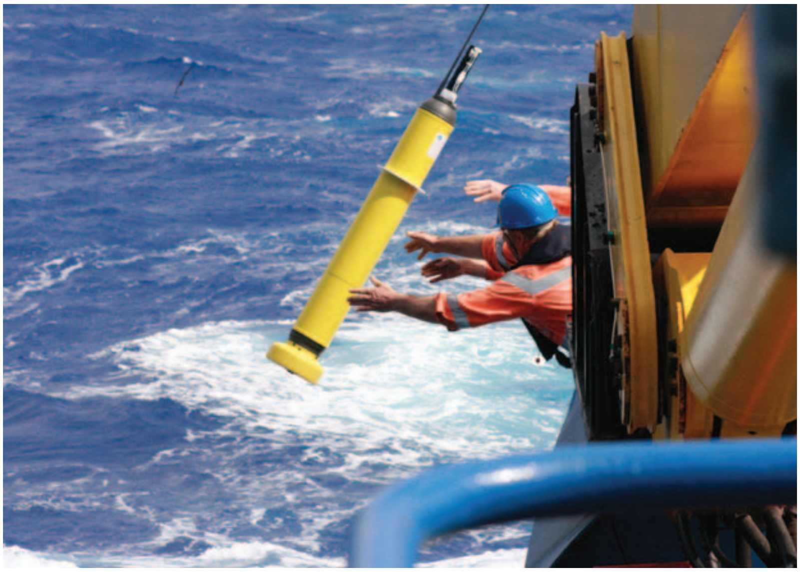


▲ ***Figure 1.3****: Updated estimates of changes in upper ocean heat content relative to 1970. The time series updated by Domingues* et al. *(2008)*[29] *is shown in black, with one standard deviation uncertainty estimates indicated by the shading. Uncertainties for recent periods are smaller than earlier periods because recent observations of ocean temperature are both more numerous and accurate.*

Salinity

Another measure of the changing oceans and climate are changes in ocean salinity. Parts of the sea that are naturally quite saline have become measurably saltier owing to increased evaporation or less rainfall, or both, while other parts have become fresher as they are diluted by increased rainfall or decreased evaporation, or both. These patterns taken together point to far-reaching changes in the global hydrological cycle.[32]

Regional ocean currents are also changing. For example, there has been a southward shift of the Antarctic Circumpolar Current – the vast current that circles the planet around Antarctica[33] – and an increasing southward extension of the East Australian Current associated with wind changes in the southern Pacific.[34] There also are indications of recent changes in the temperatures and salinities of deep ocean currents, such as those that carry cold bottom water northwards away from Antarctica.[35] These currents bear careful watching because they are key components in the distribution of heat around the planet.



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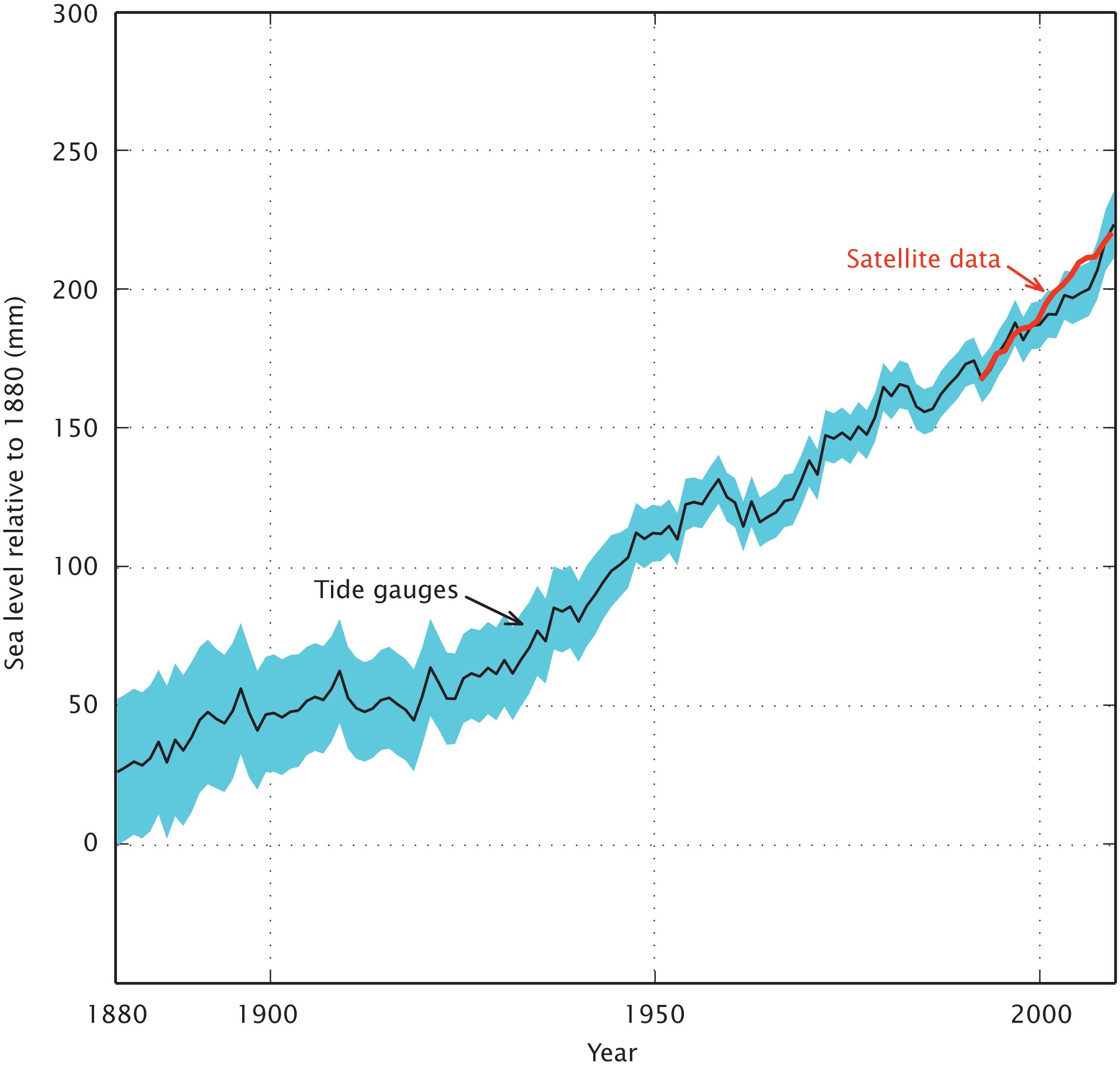
Acidification

The oceans also absorb vast amounts of CO_2, as well as storing heat. They currently remove about 25% of the emissions of CO_2 produced by human activities, as described further in Chapter 2. However, this sequestration comes at a price. A direct result of this CO_2 uptake is the gradual acidification of the oceans. Ocean absorption of CO_2 in the last 250 years has decreased near-surface ocean pH by about 0.1 and is expected to decrease it by a further 0.2–0.3 by 2100. This could have profound effects on corals and plankton, and other marine organisms with carbonate skeletons. These organisms span the entire marine food chain.

Sea levels

Sea-level rise and fall is nothing new and earlier populations have experienced large fluctuations in sea level.

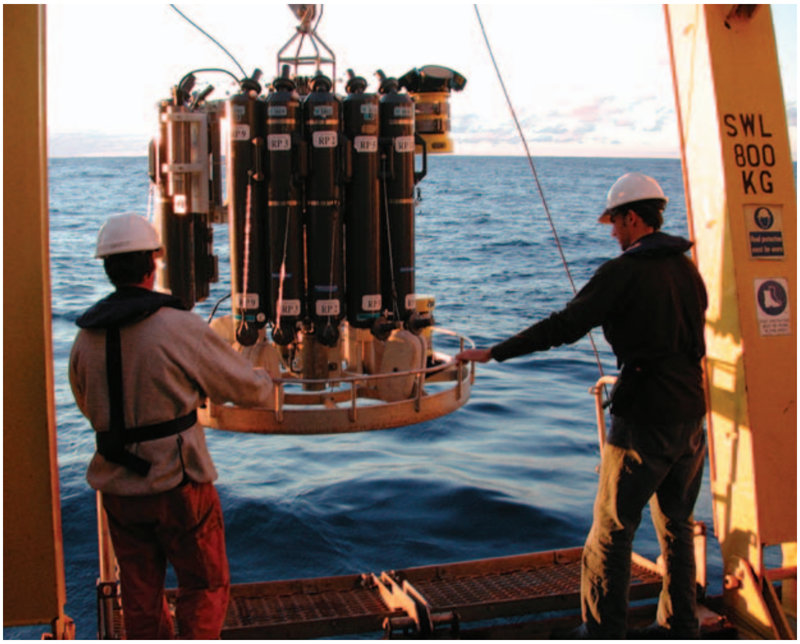
Geological records indicate that sea level peaked at between 6 m and 9 m higher than today during the last interglacial period, about 125 000 years ago.[36] Sea level was more than 120 m below today's levels at the peak of the last ice age (about 20 000 years ago).[37] Rates of sea-level rise coming out of the last ice age averaged about 1 m per century for many thousands of years, with maximum rates of 2–4 m a century.[38] Sea level stabilised around 3000 years ago and archaeological data indicate a period of small rates of change in global averaged sea level for the 2000 years before about 1800. Sea level began to rise again in the late 19th century.[39]



Sedentary coastal societies have developed during this period of stable sea level and they are potentially vulnerable to future sea-level changes. About 150 million people live within about a metre of high tide levels today and the near-coastal zone generates some US$1 trillion of global economic activity.[40]

Global sea levels are currently rising at around 3.2 mm a year, nearly twice the average rate (1.7 mm per year) experienced during the 20th century as a whole (Figure 1.4)[28, 41] and at a rate near the upper end of the Intergovernmental Panel on Climate Change projections. Rising sea levels have already significantly increased the frequency of high coastal sea-level events in Australia[42] and overseas. These occur when storms and strong onshore winds coincide with high tides.

Current climate models project that by 2100 sea level could be about 20 to 60 cm above 1990 values.[43] However, current models do not adequately represent the recently observed contribution of the ice sheets in response to warming. If this contribution was to grow linearly with temperature, then sea level could rise a further 10 to 20 cm (for a total range in 2100 of about 20 to 80 cm).[43] Note, however, that current understanding of ice sheet processes is inadequate



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◂ ***Figure 1.4***: *Global averaged sea-level anomalies relative to 1880. The solid black line is estimated from coastal and island tide gauges and the red line is sea level measured by satellite altimeters. The average rate of rise from 1900 to 2000 was about 1.7 mm/year. The rate of rise measured by satellite altimeters since 1993 has been about 3.2 mm/year and from tide gauges about 2.8 mm/year.*[41]

and larger values cannot be excluded.[43] There have been a number of attempts to better quantify this upper end of the potential sea-level rise during the 21st century. For example, a study for the Netherlands Government suggested a high end value for sea-level rise of 110 cm above 1990 levels by 2100.[44]

The main contributions to sea-level rise in the past half century have been expansion of the upper layers of the oceans as they warm and increased discharge from glaciers worldwide.[45] Ice sheets over Greenland and Antarctica have played a comparatively smaller role in raising sea level so far, but there are indications they may contribute more in the future. The future evolution of ice sheets is critically important because the Greenland ice sheet alone contains enough water to raise the global sea levels by about 7 m and the West Antarctic ice sheet could add about a further 5 m. An ice-sheet's contribution to sea level is a balance between snowfall accumulating on the ice sheet (which is likely to increase in a warming world) and melting of the snow and ice and the sliding of ice sheets into the ocean. Melting is increasing in Greenland and there are indications of a recent increase of the flow of ice into the ocean from both Greenland and Antarctica (particularly in West Antarctica). This follows the penetration of warm ocean water onto the continental shelf under the ice shelves, which is melting the ice shelves at their base and contributing to their decay with a resultant more rapid flow of ice into the ocean. This phenomenon has been observed already in the Antarctic Peninsula. One of the major uncertainties in our knowledge of how much ice sheet loss will contribute to future rises in sea level is how much these rapid dynamic responses of the ice sheets will add to other contributions to sea-level rise. This uncertainty remains controversial because the contributing processes are not well understood.[43] Current rates of emissions of

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greenhouse gases mean that global average temperature is likely, late in the 21st century, to cross the threshold that leads to ongoing and potentially irreversible melting of the Greenland Ice Sheet, even without the above dynamic response, committing the world to metres of sea-level rise.[46]

The rise in sea level projected for the 21st century would be likely to cause coastal flooding events that now occur once a century to occur more than once a year by 2100 at many Australian locations. Tens of millions more people worldwide will be exposed to the hazards and cost of adapting to increased coastal flooding and erosion.[45] Many of the world's megacities, from Dhaka and Shanghai to New York, would be threatened by a sea-level rise of metres over the longer term if greenhouse gas emissions continue unabated.

Longer term commitment

The huge heat and carbon storage capacity of the ocean and the long time scales over which the ocean responds to changes in atmospheric conditions mean that the oceans will continue to warm and affect the Earth's climate for centuries to come, even if greenhouse gas emissions are stabilised at levels substantially lower than in the late 20th century.

Conclusion

High-quality climate observational data sets will continue to play a significant role in our quest to understand our changing climate. This is particularly the case as we endeavour to determine the full extent of the impact of greenhouse gases, aerosols, and climate feedbacks, which we explore further in the following chapter.

Further reading

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