Australian Meteorological and Oceanographic Society (AMOS) Statement on Climate Change

This statement provides a summary of some aspects of climate change and its uncertainties, with particular focus on Australia. It has been compiled by atmospheric and oceanographic scientists, reviewed by Members of the Australian Meteorological and Oceanographic Society (AMOS), and approved by the AMOS Council as an official AMOS position statement. The statement will expire 5 years from its approval, or earlier as determined by AMOS Council.

Climate science uses the same scientific method as any other physical, chemical or biological science, a method that is rigorous and thorough and based on the peer review process. New findings are considered tentative until tested by others and there is an ongoing effort of refinement. AMOS scientists conduct research and assessments in climate science along with scientists around the world, to improve and refine our understanding of how our climate system operates. The analyses of climate data, the methodologies employed in climate assessments and the climate models used to test hypotheses have improved over the past 50 years, such that we now have a high degree of confidence in the findings from climate science. Uncertainties regarding the response of the climate system to human influence will always exist, but despite inevitable uncertainties, there is much useful information that can be supplied with confidence.

Global climate has changed substantially
Global climate change and global warming are real and observable. The global mean surface temperature of the Earth increased by around 0.9°C from 1880 to 2012. The first decade of the 21st century was warmer than any other decade since at least 1850, around the time that useful instrumental observations first became available from parts of the world other than Europe and North America. The rate of warming has been largest in the latter part of the 20th century. Global surface temperatures warmed by about 0.7°C from 1951–2012. Since the 1980s every decade has been warmer than any other decade since 1850 and each successive decade has been warmer than the previous one. Moreover, as of early-2016, 2015, 2014, 2010, 2005, 2013, and 1998 were the six warmest years on record.

Increasing temperatures have been observed both over land and in the oceans, in rural areas and cities, at the surface and in the lower atmosphere by satellites and radiosondes[1]. Decreases in the frequency of cool temperature extremes and increases in the frequency of warm temperature extremes and heatwave events have accompanied the rise in mean temperatures over most areas. The warming has been accompanied by a decrease in the number of frosts, a rapid contraction of almost all alpine glaciers, a reduction in global sea-ice, and a reduction in global snow cover (especially in spring). The absorption of carbon dioxide by the oceans has reduced its pH by approximately 0.1 units compared to pre-industrial levels – a process known as ocean acidification. Global sea level rose by approximately 1.7 mm per year over the 20th century, with an increased rate of approximately 3 mm per year measured since 1993.

Australia's climate is changing
Since the introduction of robust, instrumental surface temperature measurements in the early 20th century the mean surface temperature of Australia has increased by about 0.9°C, which is similar to the global average increase, with warming slightly stronger in nighttime minimum temperatures than in daytime maximum temperatures. The warming has been concentrated in the post-1950 period with little trend prior to 1950. Mean temperatures have warmed in all parts of Australia, with the strongest warming trends in the central and eastern interior of Australia and the weakest in parts of northern Western Australia and some parts of New South Wales. The year 2013 was Australia's hottest year on record, with 2014 ranking third, and 2015 ranking fifth. During the instrumental record, Australia's three hottest years, and eight of the ten hottest, have occurred since 2002.

The overall warming has been accompanied by marked changes in the frequency of extreme temperatures at a variety of timescales, with warm extremes generally becoming more frequent and cold extremes less frequent. Examples include:

- increased numbers of individual hot days and decreased numbers of cool nights;
- an increase in the frequency, intensity and duration of heatwaves in many parts of the country;

[1] Measuring devices attached to balloons.

- a marked increase in the occurrence of extreme warm months with a simultaneous decrease in the occurrence of extreme cool months.
- a large difference in recent years between the number of record high temperatures and the number of record low temperatures (with record high temperatures outnumbering record low temperatures since 2001 by a ratio of 3 to 1 or greater);

Sea surface temperatures in the Australian region have also increased by about 0.8°C since 1910. Since 1993, the sea level has risen by between 2–4 mm per year over much of the southern part of Australia, which is in agreement with the global average. Northern parts of Australia have seen a sea-level increase more than twice the global average since 1993, though much of this enhanced increase may be related to natural variability.

Rainfall in Australia is highly variable from year to year, and from region to region. Averaged over the continent as a whole, rainfall has shown a slight increase over the period from 1900 to 2014, with notably wet periods in the 1950s, 1970s and around 2010.

This national rainfall average conceals substantial regional and seasonal differences. Warm season (October to April) rainfall has increased strongly since the early 1970s across many parts of northern and central Australia, although the statistical significance of trends in warm season rainfall is difficult to determine due to high intrinsic variability in the Australian summer monsoon. In contrast, cool season (April to September) rainfall has declined strongly in many parts of southern Australia. This decrease has been most substantial in the southwest of Western Australia, where rainfall has been declining since about 1970 with a total reduction of 10 to 20 per cent. Similar reductions have occurred since the mid-1990s in parts of southern Australia, especially southern Victoria and adjacent parts of southeast South Australia.

The trends in extreme rainfall and drought remain uncertain due to their highly variable nature in time and space and the fact that they are also strongly influenced by natural, large-scale climate phenomena such as El Niño and La Niña events.

Tropical cyclones are a major natural hazard on and near the coasts of northern Australia. Consistent region-wide data on tropical cyclone occurrence,especially over the open ocean and on sparsely inhabited parts of the Western Australia and Northern Territory coast, are only available since the introduction of modern satellite records in the late 1970s. This makes it difficult to draw firm conclusions on trends given the large interannual variability in tropical cyclone occurrence.

We understand the causes of climate change
The climate varies naturally from year to year and decade to decade due to natural changes in the Earth's climate system. The climate also varies naturally on time scales of centuries and longer because of changes in factors such as the amount of sunlight available, small variations in the Earth's orbit around the Sun and changes to the gases comprising our atmosphere. The composition of gases in our atmosphere is crucial to maintaining a warm planet and life on Earth and even small changes to this composition can have a big effect on our climate.

About half the sunlight intercepted by the Earth is either absorbed by the atmosphere or reflected to space by clouds, aerosols[2] and the air itself, the most important of these reflectors being clouds. The other half of the intercepted sunlight is transmitted through the atmosphere, ultimately warming the Earth's surface. At the same time, the land, the oceans and the atmosphere continuously absorb and emit infrared radiation. Water vapour, carbon dioxide and other gases that are present in small amounts (often collectively called greenhouse gases) increase the capacity of the atmosphere to absorb and emit infrared radiation. The mean surface temperature increases as the atmospheric concentration of greenhouse gases increases because the atmosphere emits more infrared radiation (both upwards and downwards), some of which is absorbed by the Earth's surface. It is for this reason that the mean surface temperature is higher than it would otherwise be without an atmosphere or greenhouse gases. This process, called the natural greenhouse effect, keeps the surface of the Earth and the lower atmosphere warm enough to sustain the mean global surface temperature of about 15°C.

---

[2] Small particles suspended in the air such as dust and soot, produced by both natural and man-made processes.

Without the greenhouse effect the surface of the Earth would have a mean temperature of about −18°C. With greenhouse gases, but no clouds or aerosols, the mean temperature would be about 30°C. Clouds and, to a lesser extent, aerosols, reduce the global mean surface temperature to its current value of about 15°C. About three-quarters of the natural greenhouse effect is due to water vapour, with the remainder coming from other greenhouse gases such as carbon dioxide. While clouds absorb infrared radiation, which increases the greenhouse effect, they reflect sunlight, so that on balance they mostly reduce the surface temperature.

Human influence has been detected in the warming of the atmosphere and the ocean globally, and in Australia

It is now certain that the human activities that have increased the concentration of greenhouse gases in the atmosphere contribute significantly to observed warming. Further it is extremely likely[3] that these human activities are responsible for most of the observed global warming since 1950. The warming associated with increases in greenhouse gases originating from human activity is called the enhanced greenhouse effect. The atmospheric concentration of carbon dioxide has increased by around 40% since the start of the industrial age and has been measured as higher now than at any time in at least the past 800,000 years. In 2015 the amount of carbon dioxide in the atmosphere exceeded 400 ppm, which is a level likely last seen 2–4 million years ago. The increase in carbon dioxide is a direct result of burning fossil fuels, broad-scale deforestation and other human activity. Concentrations of a range of other potent greenhouse gases, such as CFCs[4], methane and nitrous oxide, have increased also as a result of human activity, and have contributed to the observed warming. Some other by-products of human activity, most notably industrial aerosols, have had a cooling effect on the atmosphere, and have offset some of the warming from the enhanced greenhouse effect.

At a regional scale, it is likely that human activities have made a substantial contribution to the observed warming of each of the inhabited continents, including Australia. Furthermore, evidence increasingly suggests that human activities have also substantially increased the risk of years and seasons of very hot temperatures at the continental scale, for example the Australian record hot year and spring of 2013. The influence of human activity on other observed climatic trends, such as those of rainfall, remains less clear.

Why are we confident that the warming is due to human activity rather than natural climate variability?

First, the observed warming in recent decades is consistent with the fundamental theories of the physics of the atmosphere and its behaviour.

Second, estimates of past climates indicate that it is likely[3] that the mean surface temperature of the Northern Hemisphere in the late 20th and early 21st centuries exceeds the temperature of any time during at least the last 1,400 years. This suggests that the recent warming is larger and more rapid than might be expected from natural processes alone. Changes in natural influences on the climate such as volcanic emissions, variations in solar radiation and internal climatic variations, such as the El Niño – Southern Oscillation (ENSO), can dominate climate changes on approximately decadal and shorter time scales. For example, climate models suggest that these three natural factors are likely to have reduced the rate of warming from 1998 to 2013. However, on time scales longer than one or two decades, widespread warming dominates the shorter term variability and is clearly evident. In the lower atmosphere, over the icy regions of the planet, over the land surface, and in the oceans the pattern of this warming is unlike the response to any known natural internal cause of climate variability, but is the pattern expected from an enhanced greenhouse effect.

Third, climate models incorporate the fundamental physics of how the atmosphere behaves, including fluid mechanics, radiation, and cloud processes. These climate models are based upon the same physics, and share algorithms and techniques with the computer models used every day around the world to successfully predict daily weather. Climate models correctly simulate the temperature record of the 20th century (including some periods of relative cooling) when both natural factors (internal climate variability, volcanic

---

[3] Extremely likely indicates more than 95% likelihood, likely indicates a 66-100% likelihood.
[4] CFCs (chlorofluorocarbons), the gases responsible for the ozone hole, are also greenhouse gases.

emissions and variations in solar radiation) and human influences (increased greenhouse gases and aerosols, and decreased stratospheric ozone) are included. However, they do not accurately simulate the temperature record of the 20th century if human influences are omitted. These same climate models can also correctly capture the short-term cooling effect of large volcanic events such as the eruption of Mt Pinatubo, which adds to our confidence in their ability to correctly predict how the climate will respond to changes in the concentration of greenhouse gases and aerosols.

What are the uncertainties?
Predictions of the Earth's climate are based on scientific understanding of the climate system, represented in climate models and there is a range of uncertainties in these models. Limits on the capacity of today's computers restrict climate models to resolving horizontal scales no smaller than approximately 100 km, although some improvement in resolution can be obtained using nested regional models[5]. Many of the physical processes that ultimately determine the Earth's climate and its variation, however, operate on scales smaller than the grid size of the models, and are thus not resolved by current models. Such subgrid-scale processes must be approximated, a process known as parameterisation. Parameterisations use observations, physical laws, simplifying assumptions, and empirical formulae to relate the sub-grid processes to the properties that are captured by the models at the more coarse resolution. Parameterisations always involve simplifications and assumptions about the physical processes and, along with interactions in parameterised processes, are important uncertainties in climate models. For example, while the direct effect of increasing carbon dioxide on atmospheric infrared radiation can be accurately calculated, the resulting changes in the water vapour, clouds and surface reflectance are more complex and less certain. The difficulties are especially pronounced for clouds and lead to inevitable uncertainties in the predicted temperature changes.

The change in the global mean surface temperature for a doubling in carbon dioxide concentration has an estimated uncertainty in the range of 1.5 to 4.5°C. Although the uncertainties are large, they do not change the fact that an increase in temperature is still predicted to accompany an increase in greenhouse gases. It is also noteworthy that this range can be derived from the basic physics of climate without modeling, and this range emerges from a very wide range of approaches to calculating how climate would respond to a doubling of carbon dioxide.

Our climate is very likely to continue to change as a result of human activity
Global temperature increases are already set to continue until at least the middle of this century even if emissions were reduced to zero. The magnitude of warming and related changes can be limited depending on the total amount of carbon dioxide and other greenhouse gases ultimately emitted as a result of human activities; future climate scenarios depend critically on future changes in emissions. Global mean temperatures averaged over the period 2016–2035 are likely to be 0.3°C to 0.7°C warmer than the period 1986–2005. Projected warming and sea-level rise by the end of the 21st century are influenced both by uncertainty in climate models and emissions scenarios. By the end of the 21st century, with a rapid transition away from fossil fuels climate models suggest warming ranging from 0.3–1.7°C and sea-level rise ranging from approximately 0.3–0.6 m. With ongoing intensive use of fossil fuels the projected ranges of warming and sea-level rise are approximately 2.6–4.8°C and 0.5–0.9 m, respectively. Out to 2030, most of the uncertainty in these projections is due to the uncertainty in the way climate models represent physical processes. Later in the century, the economic and population growth and the future level of greenhouse gas emissions and anthropogenic aerosols become the dominant uncertainties.

The mean Australian surface temperature is likely to increase by between 0.6 and 1.3°C by 2030 when compared to the period 1986–2005. This range of warming for 2030 is similar for all emissions scenarios. However, the rate and amount of carbon dioxide produced into the future becomes more influential by 2090. Continued intensive emissions, a so-called high emissions scenario, is likely to produce an increase in Australian average temperatures of 2.8°C –5.1°C by 2090. A rapid reduction in the amount of carbon dioxide emitted is likely to result in temperature increases that are limited to between 0.6°C and 1.7°C.

---

[5] Climate models implemented over a small region of the globe, with information from global climate models fed in at their boundaries.

Climate models suggest that the warming in inland Australia will be larger than coastal areas, with the least warming (on an annual mean basis) expected in southern Australia. There are also seasonal differences in warming, with the greatest warming likely to occur in the spring. The number of days classified as extremely hot, including multi-day heatwaves, is projected to increase, and the temperatures on the hottest days will typically be hotter than at present. However, there will generally be a reduction in frost events. Many areas where frost typically occurs only a few times a year are likely to be nearly frost-free on average by 2030. These projected changes of extremes will be especially important as many of the most significant impacts of climate change will be manifested through the occurrence of extreme events, some of which are expected to be unprecedented in the historical record.

Rainfall in Australia will continue to be highly variable from year-to-year and decade-to-decade throughout the 21st century. Future trends in rainfall differ depending on the location and are generally uncertain. There is some confidence that winter and spring rainfall will decline in southern Australia, with the largest reductions expected in southwest Western Australia. An increase in the length of droughts is likely to accompany the decline in average rainfall in southern Australia. This drying, along with warmer temperatures, in southern Australia will likely lead to an increase in days classified as having severe fire danger. At a global level, there is a tendency for climate models, particularly for high-emissions scenarios, to project increased rainfall over land in higher latitudes and equatorial latitudes as the global climate warms, with decreased rainfall in the subtropics. These projections are consistent with observed trends in many such regions over the late 20th and early 21st centuries.

Across Australia, climate models also generally indicate an increase in very heavy rainfall events. Confidence in this projection varies across Australia, and is lowest in those areas where a general drying trend is expected. There is still considerable uncertainty around changes to tropical and non-tropical storms and cyclones in Australia, with, at most, medium confidence in the trends in these weather systems. There is a tendency for climate models to show that tropical cyclones will become less frequent, but also that many of the storms that do form will have stronger winds and more rainfall on average.

There is very high confidence that Australian sea levels will continue to rise during the 21st century and that the oceans surrounding Australia will become more acidic, affecting marine ecosystems. Extreme sea levels episodes will also rise with changes in average sea level. However, aspects such as storm surges are more uncertain and are also dependent on changes in tropical and extratropical storms. Ocean temperatures are expected to warm around Australia, and current work is investigating how this might affect marine heatwaves.

Finally, analyses conducted by scientists with expertise on the impacts of extreme weather and climate episodes have shown how risks associated with those episodes increase disproportionately as the temperature increases. These disproportionate risks can arise from extreme heat, floods, droughts, strong winds and coastal oceanic events, all of which have the potential to adversely affect individuals, societies and ecosystems.

Sources of information and further reading:

Climate Change in Australia: http://www.climatechangeinaustralia.gov.au

Marine Climate Change Impacts & Adaptation Report Card 2012: http://www.oceanclimatechange.org.au

Intergovernmental Panel on Climate Change – 5th Assessment Report: http://www.ipcc.ch

Australian Academy of Science - The Science of Climate Change, Questions & Answers.
https://www.science.org.au/learning/general-audience/science-booklets-0/science-climate-change