Australian Meteorological and Oceanographic Society (AMOS)
Statement on Sea-Level Change

This statement provides a summary of past and projected sea-level change, with particular focus on Australia. It has been compiled by 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.

SUMMARY

Observations indicate that loss of mass from glaciers and the ice sheets, and thermal expansion of the ocean is resulting in an ongoing acceleration in the rate of sea-level rise. This rise is largely in response to ongoing emissions of greenhouse gases and will continue through the 21st century and beyond. The sea-level rise is already causing impacts around the world. Significant and urgent mitigation of greenhouse gas emissions is required to avoid a sea-level rise of many metres over coming centuries. Even with mitigation, we will have to adapt to the sea-level rise we cannot avoid.

Introduction

About half the Australian population live within 7 km of the coast and about 200,000 homes in Australia are potentially exposed to flooding for a sea-level rise of 1.1 metres. Globally, many of the world's mega cities are situated on the coast, with about 150 million people living within 1 metre of current high tide level and over a trillion dollars of infrastructure in this region. With people living ever closer to the coast, rising sea levels are a serious issue. Particularly vulnerable are people living on deltas (for example millions in Bangladesh and Vietnam) and on small low-lying islands in the Pacific and elsewhere.

What controls sea level?

Changes in global sea level are largely the result of two factors:
1) changes in the mass of the ocean as water is transferred between the ocean and ice sheets, glaciers, and other terrestrial water storages (e.g. lakes, reservoirs, aquifers), and
2) changes in the volume of ocean water from expansion or contraction as it warms or cools.

Regional sea-level change may differ from the global average because of:
1) climate variability, changes in ocean currents and regional atmospheric pressure, and
2) the vertical movement of land, and changes in the Earth's gravitational field and rotation as a result of the redistribution of water, particularly from ice sheets, on the Earth. Local factors can also be important for changes in sea level relative to the land, and may dominate at some locations. These include local subsidence resulting from the extraction of ground water or hydrocarbons, and the compaction of sediments. Variations in sediment supply can affect local erosion/accretion of the coastline.

How are sea levels observed?

Beginning in the 17th century, sea level was measured relative to the coast by tide gauges, mainly to support shipping services. Today, sea levels are also measured relative to the centre of the Earth by satellites, giving near global coverage. Prehistoric relative sea levels are inferred by various geological indicators such as the heights of preserved coral reefs, sediment layers and coastal rock platforms.

THE PAST

Large changes in sea level are generally a result of changes in the size of the ice sheets.

Over the glacial cycles of the past 800,000 years, sea level varied by more than 120 metres. During past warm periods, sea level was metres above present-day values. During cold periods, major ice sheets formed over North America and northern Europe and Asia and increased in size in Antarctica. As a result, sea level fell to more than 120 metres below present day values. After the last glacial maximum about 20,000 years ago, sea level rose at over 1 metre/century for many thousands of years (with peak rates of about 4 metres/century) as these ice sheets decayed. About 6,000 years ago sea levels stabilised with only small rates of change over the last thousand years.

In past warmer climates, sea level was higher than today.

Globally and around Australia, sea level was between about 5 metres and 10 metres above current levels during the last interglacial (warm) period (129,000 to 116,000 years ago). During this time, global average surface temperatures were less than 2°C warmer than just before the mid-19th century. The size of the estimated contributions to sea-level change from ocean thermal expansion, glacier loss and the Greenland Ice Sheet are insufficient to explain the higher sea level, implying a contribution from Antarctica.

HISTORICAL CHANGES

Globally, sea levels are currently rising.

For two thousand years before the mid-19th century, the long-term global sea-level change was small, only a few centimetres per century. Since the late 19th century, the rate of rise has increased substantially; from 1900 to 2012, sea level rose by a global average of about 19 centimetres (Figure 1). Measured by satellites since 1993, satellite and in situ sea-level data indicate a further increase in the rate of rise.

The two largest contributions to sea-level rise since 1900 were the expansion of ocean water as it warmed, and the addition of water to the ocean due to loss of ice from glaciers. Since 1990, there have been further contributions from surface melting of the Greenland ice sheet. Anthropogenic climate change is the dominant cause of sea-level rise since about 1970, explaining about 70% of the observed rise. Increased discharge of ice into the ocean from both the Greenland and Antarctic ice sheets since 1990 is related to increases in ocean temperatures underneath and adjacent to the floating ice shelves and glacier tongues that fringe the coast of Antarctica and Greenland. The mass loss from the ice sheets is the main reason for the acceleration of the rate of rise since 1993.

The sum of storage of water in terrestrial reservoirs and the depletion of ground water have made a small contribution to sea-level change during the 20th century. Naturally occurring climatic variations, such as the El Niño-Southern Oscillation and the interdecadal Pacific Oscillation, lead to variability in global sea level as water is stored in flood waters, or as lands dry during droughts.

Climate fluctuations also lead to local sea-level variability as water is moved around the ocean in response to changes in surface winds, atmospheric pressure and transfer of heat and freshwater between the atmosphere and ocean.

Australian sea levels are rising.

Around the Australian coastline, sea levels rose relative to the land throughout the 20th century, with a faster rate over recent decades. During the 20th century, the rise around Australia was generally at a slightly lower rate (by few centimetres per century) than the globally-averaged rise because of ongoing changes in the height of the land and ocean following the large loss of mass from the ice sheets of the last ice age. These ongoing changes were also responsible for a slow fall of Australian sea levels relative to the land over the last several thousand years, again at rates of a few centimetres per century.

The rate of sea-level rise off north-western Australia was larger than the globally-averaged rate over recent decades (Figure 2). This enhancement is thought to be primarily a result of decadal variability affecting the Pacific and Indian oceans rather than a pattern of anthropogenic climate change. The larger rate of rise offshore from southern New South Wales (but not at the coast) is thought to be related to local ocean warming caused by a strengthening and southward penetration of the East Australian Current (Figure 2).

THE FUTURE

Sea levels are projected to rise at a faster rate during the 21st century than during the 20th century.

By 2100, it is currently projected that sea level will *likely* rise by a global average of 28 to 61 centimetres relative to the average level over 1986–2005 if greenhouse gas emissions are low (strong mitigation), and by 52 to 98 centimetres if emissions are high (business-as-usual; Figure 1). For the high emissions scenario, the rate of rise increases to between 7.5 and 15.7 cm/decade over the last two decades of the 21st century, similar to average rates of sea-level rise at the end of the last ice age and much larger than the rate of about 3 cm/decade over the last two decades.

The largest contributions to this projected rise are ocean thermal expansion and the loss of ice from glaciers. Increased surface melting of the Greenland ice sheet and increased flow of ice from both Greenland and Antarctica will also contribute. Recent observations and models suggest that parts of the West Antarctic Ice Sheet that are resting on rock well below sea level may have entered a phase of ongoing mass loss. The relevant ocean and ice-sheet processes are poorly understood and an additional rise of several tens of centimetres by 2100 might be possible. Indeed, several recent modelling studies have suggested a dynamic Antarctic contribution in 2100 ranging from only slightly larger than that used in the last set of projections from the Intergovernmental Panel on Climate Change (2013) to about 0.3 m larger, and with one outlier indicating an Antarctic contribution of the order of a metre by 2100. Beyond 2100, substantially larger ice sheet contributions are expected for non-mitigation scenarios.

For Australia, 21st century sea-level rise is likely to be close to the global average rise. Fluctuations in the rate of rise due to natural climate variability (such as larger rates in northern Australia in recent decades) will continue.

Rising sea levels result in a greater coastal flood and erosion risk.

Rising sea levels result in increased coastal flooding, inundation, erosion and impacts on coastal ecosystems, with the greatest impacts felt during extreme events, including surges and large waves driven by storms. Rising average sea levels mean that extreme sea-level thresholds are exceeded more often. For Australia, this happened three times more often in the second half of the 20th century compared to the first half. This effect will continue. Even if greenhouse gas emissions are markedly reduced (as in the low emissions scenario), there is likely to be more than a ten-fold increase in the frequency of exceeding these extreme sea-level thresholds by 2100 and, as a result, a much higher risk of coastal flooding and erosion. We will need to adapt to these impacts even for a low (strong mitigation) greenhouse gas emissions scenario. The increase in the frequency of coastal flooding events and their impact will be substantially larger for higher emissions.

Sea levels will continue to rise for centuries.

Because of the long time-scales of oceans and ice sheets, sea level will continue to rise for many centuries under all emission scenarios. It might be possible to limit this long-term sea-level rise to the order of a metre with the most stringent emission reductions. However, for high greenhouse gas emissions, global sea level is projected to rise by as much as 3 metres or more by 2300, with recent studies suggesting a substantially larger, ongoing and potentially irreversible loss of ice from the Antarctic and Greenland ice sheets.

Irreversible Commitments

Sustained warming above a threshold (estimated to be between 1 and 4°C) would lead to the near-complete loss of the Greenland ice sheet over a thousand years or more, contributing up to about 7 metres to global average sea-level rise. The world is likely to cross the warming threshold committing the world to this rise this century for unmitigated emissions. Because of delays in the climate system and in mitigating emissions, crossing of the cumulative greenhouse gas threshold leading to this warming may have already occurred or could occur within decades. It is possible that an even larger sea-level rise could also result from a collapse of sectors of the Antarctic ice sheet resting on land below sea level. Our understanding is currently insufficient to assess the timing or magnitude of such a multi-century contribution from Antarctica, although there is increasing evidence that it may already have commenced and could be substantial (many metres or even tens of metres).

Risks and Uncertainties

Significant and urgent mitigation of greenhouse gas emissions will be required to avoid the worst-case projections of metres of sea level rise over coming centuries. However, we cannot prevent all sea-level rise and it will be necessary to adapt to the rise we cannot avoid.

The amount of warming leads directly to the amount of ocean thermal expansion and glacier mass loss, but with significant uncertainties. The largest scientific uncertainties in projecting future sea-level rise relate to the dynamic response of the Antarctic Ice Sheet to warming. These uncertainties mean that there could be a substantially larger rise than currently estimated if there is a rapid response of the ice sheet. Several uncertainties remain in our current best estimates of the regional distribution of sea-level rise, of changes in coastal storm surges and of the impacts of rising sea levels on coastal flooding and erosion.

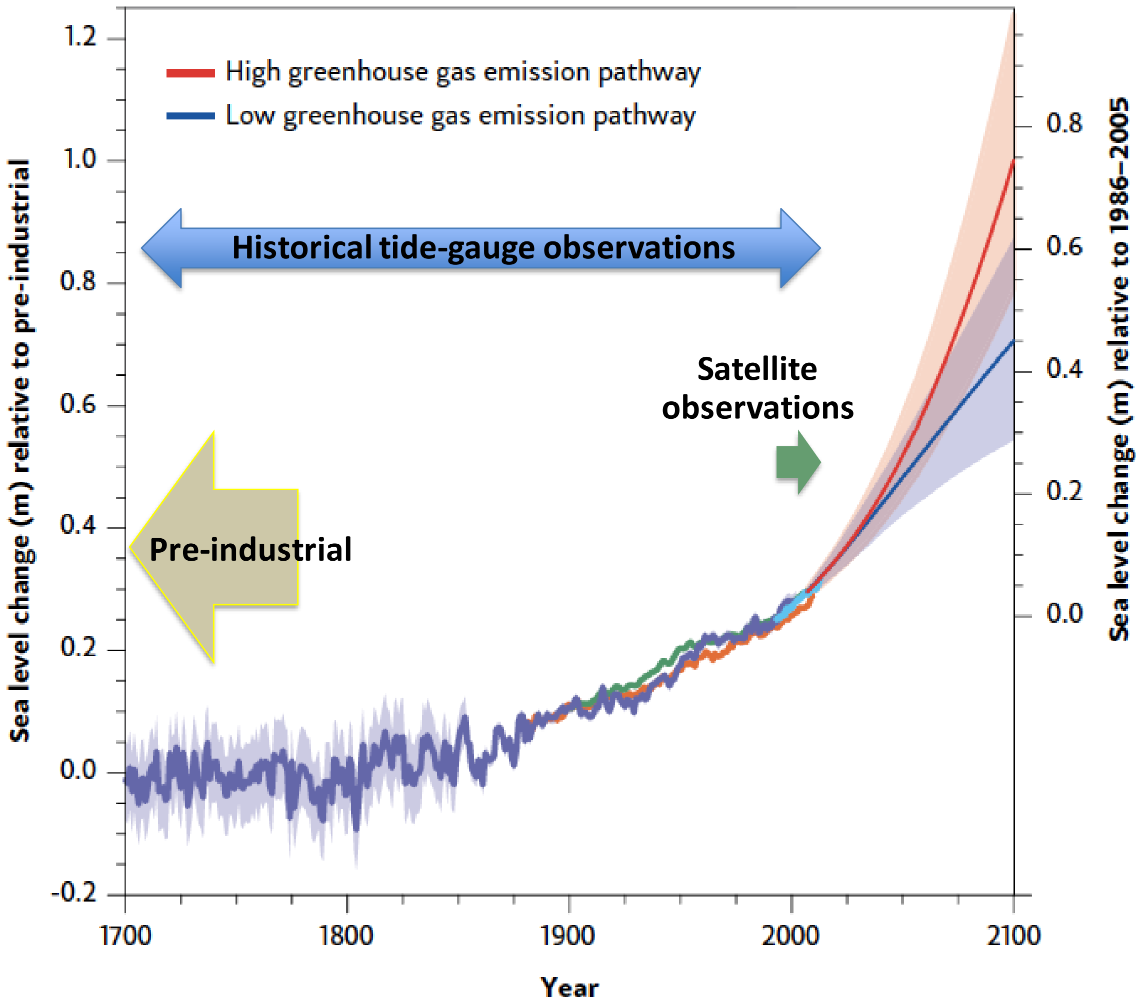

Figure 1. Global average sea level has increased from estimated pre-industrial levels and is projected to rise at a faster rate during the 21st century. The blue, orange and green curves up to 2010 are different estimates of global average sea-level change, relative to the pre-industrial level (left-hand axis), based on historical tide-gauge observations. The light blue curve is the satellite altimeter observations from 1993 to 2012. Projections, shown from 2006 to 2100, are relative to the average over 1986–2005 for high and low greenhouse gas emission scenarios. The shading indicates the *likely*[1] range of sea-level rise, but higher values are possible from the poorly understood contribution from the Antarctic Ice Sheet. Adapted from IPCC (2013), Fifth Assessment Report, Working Group 1, Figure 13.27. ([1]covering two thirds of the probabilities).

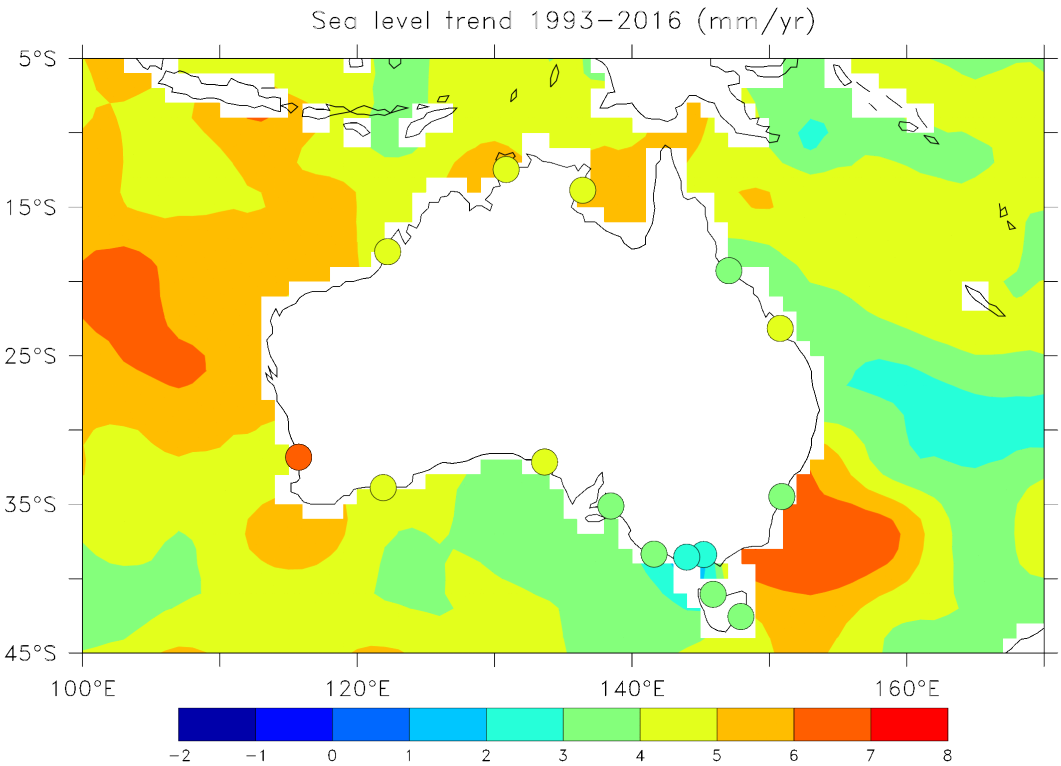

Figure 2: Rate of change in Australian sea level (mm/yr) for 1993-2016. The dots on the coastline are from the Australian Baseline Sea Level Monitoring Network and the offshore data from high quality satellite altimetry. The two data sets are in broad agreement with the exception of Hillarys (north of Perth) where the land is subsiding and at Port Kembla where the larger off shore rates are a result of increased southward penetration of the East Australian Current. Source: CSIRO Oceans and Atmosphere (2018).

Much of the material in this AMOS position statement has been drawn (with updates) from "The Science of Climate Change: Questions and Answers." AASc February 2015.

Further Reading:

Church, J. A., P. U. Clark, A. Cazenave, J. M. Gregory, S. Jevrejeva, A. Levermann, M. A. Merrifield, G. A. Milne, R. S. Nerem, P. D. Nunn, A. J. Payne, W. T. Pfeffer, D. Stammer and A. S. Unnikrishnan, 2013: Sea Level Change. Pages 1137-1216, In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T. F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.