Preparing for sea-level rise

Around the world sea-level rise is already making an impact, and expectations are that it's going to get worse. With about 6 per cent of addresses occurring within 3 km of the coast,[1] Australia is vulnerable to the various threats higher sea levels pose. However, mixed media coverage and scientific uncertainty over critical glaciological processes have seen a range of sea-level projections reported – from centimetres to metres – by 2100. So what sort of sea-level rise should we prepare for, and how is Australia planning to mitigate the inevitable impacts? Wendy Pyper reports.

The past 12 months have seen a deluge of newspaper articles, scientific papers and reports on climate change and global sea-level rise. One of the most anticipated was the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report – Summary for Policymakers, released in February, whose projections, with respect to sea-level rise, have been variously supported and criticised.

Key factors in the disagreement over the projections are scientific uncertainty about the future response of polar ice sheets to global warming and their subsequent contribution to sea level, and the way this uncertainty was reported by the IPCC.

'When you've got an unknown and you don't know how to quantify it, you're going to get disagreement on it,' says oceanographer and IPCC reviewer, Dr John Hunter, of the Antarctic Climate and Ecosystems Cooperative Research Centre (ACE CRC). 'Some people will come up with a big number; others will come up with a smaller one.'

What is agreed is that global sea levels have risen about 20 cm since 1870,[2] due mainly to the thermal expansion of the ocean[3] and melting of non-polar glaciers,[4] and with a small contribution from the melting of the Greenland and Antarctic ice sheets, at least over the last decade. In 2001, the IPCC Third Assessment Report

1 Chen K and McAneny J (2006). High resolution estimates of Australia's coastal population. *Geophysical Research Letters* **33**, L16601, doi:10.1029/2006GL026981.
2 Church JA and White NJ (2006). A 20th century acceleration in global sea-level rise. *Geophysical Research Letters* **33**, L01602, doi:10.1029/2005GL024826.
3 0.42 mm/year from 1961–2003, increasing to 1.6 mm/year from 1993–2003. IPCC Fourth Assessment Report, Working Group 1, Summary for Policymakers, p. 7, 2007.
4 0.5 mm/year from 1961–2003, increasing to 0.77 mm/year from 1993–2003. IPCC Fourth Assessment Report, Working Group 1, Summary for Policymakers, p. 7, 2007.

High seas buffet the Gold Coast. This community is already considering sea-level rise strategies. Bruce Miller

projected that these processes would see the global average sea level rise another 9–88 cm between 1990 and 2100.

Early this year, world renowned sea-level rise expert, Dr John Church, of the CSIRO and ACE CRC, along with international colleagues, compiled the most recent observed climate trends for carbon dioxide concentration, mean air temperature and sea level, and compared these to the 2001 IPCC model projections.[5] They found that sea-level rise is occurring faster than models projected and closely follows the upper trajectory towards an 88 cm rise by 2100.

'Sea-level data from satellites and tide gauges show that between 1993 and 2003 the rate of sea-level rise was about 3.1 mm/year,' Church says.

'This is more than 50 per cent larger than the average rate (1.7 mm/year) over the 20th century. However, it is still unclear whether this increase reflects a further acceleration in sea-level rise or a natural fluctuation on a multi-decadal timescale.'

The IPCC Fourth Assessment Report projects a global sea-level rise of between 18 and 59 cm to 2095, relative to 1990 sea levels. At first these numbers seem significantly less than the range projected in the Third Assessment Report. But they come with an important caveat: a further 10–20 cm rise in sea levels could occur due to increased loss of ice from Greenland and, to a lesser extent, Antarctica, and 'larger values cannot be excluded' from these sources.

'If these 10 to 20 cm are added to the projections, the upper limit result is close to the upper limit in the Third Assessment Report of 88 cm by 2100,' Church says.

The '10–20 cm or more' caveat stems from the present inability to comprehensively model the ice sheets' responses to warming, and as a result the IPCC projections 'do not include the full effects of changes in ice sheet flow' because a basis in published literature is lacking.

'The IPCC is working from published data and has made its assessment based on the recent published material on accelerated ice sheet melt,' says Professor Nick Harvey, a lead author of the second volume of the IPCC's Fourth Assessment Report.

'Some scientists are warning of the potential for a greater sea-level rise, but the IPCC felt that there was not sufficient evidence at the time of its report to quantify the impact on projections.'

Professor Will Steffen, former Executive Director of the International Geosphere-Biosphere Program and an advisor to the Australian Greenhouse Office, says the uncertainty in the projections needs to be carefully interpreted.

'The Fourth Assessment Report has better estimates for the contribution of thermal expansion and glacier loss to sea level, which provides a narrower projection range, but a larger potential contribution of the polar ice sheets is not included,' he says.

'So, unless one carefully reads the caveats, the projections could give a misleading impression of what sea-level rise might be by the end of the century.'

NASA climate scientist and physicist, Dr James Hansen, expressed some disappointment with the report.

'I was very disappointed that their comments about sea level didn't make clear that there's been a huge change in our understanding of that situation, and it's a much more dangerous problem than we had realised.'[6]

Ice sheet responses

These different perspectives underscore the uncertainty surrounding how the ice sheets will respond to global warming. Glaciologists refer to 'dynamical processes' and 'dynamical instabilities' when they talk about ice sheets, which relate to positive feedbacks that can accelerate melting once it begins.

For example, in Greenland the melting of surface snow exposes darker, wet ice underneath, which absorbs more heat from the sun, causing further melting. Some of this melt water flows through crevasses in the ice sheet, lubricating its base and potentially allowing glaciers to slide more rapidly into the ocean.

While our current understanding and models are too incomplete to predict the fate of the West Antarctic ice sheet, direct contact of the warming ocean with the underside of ice shelves fringing the ice sheet could cause them to melt, thin and break away, allowing inland glaciers to flow faster towards the coast. The combined effects of surface melt and ice shelf thinning from below were dramatically demonstrated in 2002 when the Larsen B ice shelf, on the Antarctic Peninsula, collapsed and disintegrated.

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Evidence that these processes are at work is also apparent from satellite observations indicating accelerated ice-mass loss in recent years in the coastal regions of southern Greenland and West Antarctica.[7]

21st century sea-level rise

So what sort of sea-level rise should we prepare for this century?

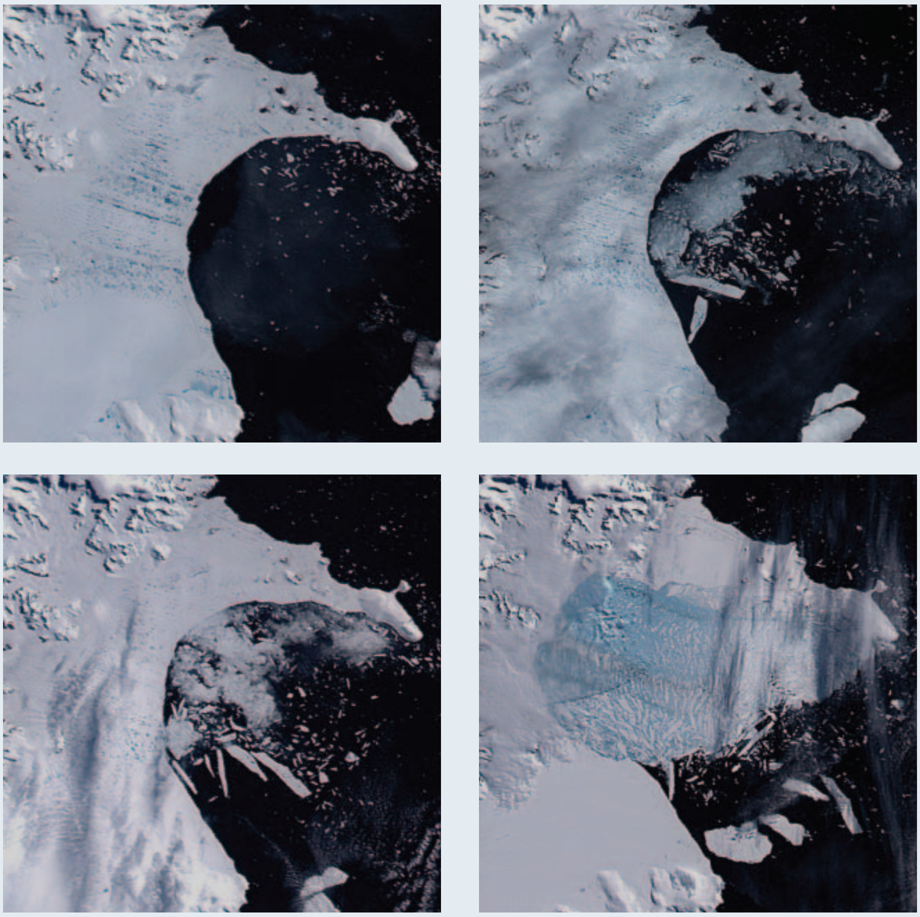
'One estimate I've seen, which includes the contribution from the ice sheets, is from 50 cm to 1.4 m above 1990 levels by 2100, with a mid-range of 1 m,'[8] Steffen says.

'This is consistent with the current trajectory of observed sea-level rise, which is tracking towards about 1 m by 2100.'

In an interview with the *7.30 Report* in March, Hansen said, 'If we get warming of two or three degrees Celsius, then I would expect that both West Antarctica and parts of Greenland would end up in the ocean, and the last time we had an ice sheet disintegrate, sea level went up at a rate of five metres in a century, or one metre every 20 years'.

The West Antarctic ice sheet contains enough water to raise sea level by another 5–6 m but the timescale on which this potential dynamic response could occur is uncertain. Snowfall is projected to increase in Antarctica, offsetting some of the sea-level rise from other contributions. However, to date this increased precipitation has not been detected.[9]

5 Rahmstorf S, Cazenave A, Church JA *et al.* (2007). Recent climate observations compared to projections. *Science* **316**, 709.
6 Sheppard K (2007). Clarion Caller. *Grist*, 15 May. www.grist.org
7 Cazenave A (2006). How fast are the ice sheets melting? *Science* **314**, 1250–1252.
8 Rahmstorf S (2007). A semi-empirical approach to projecting future sea-level rise. *Science* **315**, 268–370.
9 Monaghan AJ, Bromwich DH, Fogt RL *et al.* (2006). Insignificant change in Antarctic snowfall since the International Geophysical Year. *Science* **313**, 827–831.



Satellite images of the Larsen B ice shelf collapse over January, February and March 2002, from late summer to autumn. The first image (top left) was taken on 31 January. The next two images taken on 17 & 23 February (top right and bottom left) show the ice retreating. On 5 March (bottom right) thousands of sliver icebergs and a large light blue area occupy the former shelf area. NASA/Goddard Space Flight Center Scientific Visualization Studio

The Greenland ice sheet contains the equivalent of about 7 m of sea-level rise. The loss of mass from the ice sheet through melting and iceberg discharge is now exceeding the gain in mass through snowfall, but this loss has not yet reached a 'tipping point' where surface melting alone exceeds precipitation. However, Hansen and the IPCC warn that this tipping point could be reached this century if carbon dioxide concentrations exceed 450 ppm (currently 380 ppm) and the average global temperature rises 2–3°C above pre-industrial levels.[10]

'I find it almost inconceivable that business-as-usual climate change would not yield a sea-level change measured in metres on the century timescale,' Hansen says.

It is apparent that poor understanding of these processes makes it impossible to accurately predict sea-level rise on a specific date. Thus, the IPCC projections, established through a consensus of some 2500 scientists, provide the most rigorous scientific estimate upon which to base future planning.

'There is a sound basis for the IPCC projections of 18–59 cm by 2095, with the caveat of a potential further 10–20 cm or more rise,' Church says.

'The current rate of sea-level rise is consistent with projections leading towards values nearer the upper bound of the IPCC projections rather than the lower bound.'

Momentum: longer-term implications

While a precise figure for sea-level rise remains elusive, what is certain is that sea-level rise will continue well beyond 2100.

Contributions from ice sheets aside, past greenhouse gas emissions have committed us to further global warming and thus continuing sea-level rise through thermal expansion of the ocean. Modelling has shown that even if greenhouse gas concentrations had been stabilised at 2000 levels, the world would warm about 0.5°C more, causing sea level to rise some 10 cm more from thermal expansion alone by 2100, with ongoing sea-level rise for centuries.[11]

'Once greenhouse gas emissions are stabilised, surface temperatures should rise only slowly, but sea level will continue to rise for centuries as the ocean comes to a new thermal equilibrium,' Church says.

Extreme impacts

The consequences of sea-level rise will include increased flooding of low-lying areas – potentially causing more deaths, disease and injury – continuing coastal erosion, loss of beaches, and higher storm surges that damage infrastructure and the environment, particularly wetlands, intertidal zones and mangroves. A rough rule of thumb is that for every 1 m of sea-level rise there will be 50–100 m of horizontal erosion. Millions of people may also be forced to flee low-lying nations, including Bangladesh, the Mekong and other deltas, and Pacific islands such as Tuvalu. In Australia, rapidly growing coastal areas, such as northern and south-east Queensland, will be at risk, as well as low-lying wetlands such as Kakadu National Park.

These consequences will affect, among other things, biodiversity, ecosystem function, tourism, traditional culture, real estate prices, insurance premiums, and emergency planning and services.

Dr Kathleen McInnes of the CSIRO and ACE CRC says sea-level rise will be felt first through extreme events – such as the storm surge caused by Hurricane Katrina in 2005 – and the changing frequency of these events. McInnes, a storm surge modeller and researcher on coastal vulnerability due to climate change, recently developed a method to estimate the scale and frequency of extreme events caused by sea-level rise,[12] and applied it to look at the average time between storm surge events in Cairns, northern Queensland, which is vulnerable to flooding even under present climate conditions.

10 Hansen J (2007). Scientific reticence and sea-level rise. *Environmental Research Letters*, March 23.
11 Wigley T (2005). The climate change commitment. *Science* **307**, 1766–1769.
12 Church JA, Hunter JR, McInnes KL and White NJ (2006). Sea-level rise around the Australian coastline and the changing frequency of extreme sea-level events. *Australian Meteorological Magazine* **55**, 253–260.

'We found that the 1-in-100 year sea-level event increases in height from about 2.5 m to 2.9 m by 2050 as a result of a modest future sea-level rise and possible future changes in cyclone intensity, while the average recurrence interval for a 2.5 m event decreased from 100 years to 40,' McInnes says.

'So with no other changes to climate, rising regional sea levels will worsen the impact of extreme events by increasing the base level on which they occur.'

Planning for uncertainty

So how do we plan for the impacts of an uncertain level of sea-level rise? McInnes says many state governments around Australia are working on a 'no regrets' policy.

'They're undertaking works that they would want to do anyway, because they have a range of benefits now,' she says.

'For example, coastal erosion is occurring now, so a good option to prevent this worsening is to ensure we protect the vegetation that's there. One benefit of doing this now is that the coastline looks better.'

Other options include beach 'renourishment', where sand that has washed away is put back. While this is expensive, the sand acts as a buffer to protect the infrastructure behind it, as well as maintaining any tourism or recreational amenity. Harder engineering options, such as sea walls, are not as favoured because of cost and limits to their effectiveness.

'Sea walls protect what's behind them for a while, but you lose what's in front,' McInnes says.

State governments have been researching options for sea-level rise planning for about six years. However, McInnes says there has been an unprecedented level of interest in assessing vulnerability to sea-level rise since mid-2006.

At the state level, a number of studies have identified shorelines susceptible to sea-level rise impacts, such as storm surges, flooding, erosion and cliff rock-fall.[13] One study in New South Wales went further, estimating the value of coastal properties at risk of erosion or inundation, along a 1500 km stretch of coastline, to be worth $1 billion over a 100-year planning period.[14]

At the federal level, the National Coastal Vulnerability Assessment, coordinated by the Australian Greenhouse Office, aims to determine which parts of the Australian coastline will be most vulnerable to climate change. The project will draw together many of the state-level studies as well as provide new information. Critical to this project are digital elevation models, which provide information on topography and bathymetry (depth variation) – essential for predicting the impact and extent of storm surges and flooding. Significant work needs to be done on these models to ensure their accuracy and consistency, and new coastal surveys will be needed to fill gaps in the current data.

Ultimately, research from the national and state levels will inform planning guidelines for local councils. Some coastal councils, such as the Gold Coast City Council, have already commissioned their own studies into sea-level rise impacts in the local area. Other councils incorporate guidelines for sea-level rise planning into local plans. But for some small councils with fewer resources, it is still early days.

A drifting plateau iceberg in calm sea in Antarctica. G. Chapelle, IPF/Alfred Wegener Institute

'I know of someone who recently received building approval from his local council to put a house 50 m from the front of a dune,' Hunter says.

'He called me after he heard me talking about sea-level rise on the radio, and I told him there was a chance that his house would be threatened by erosion in 50 to 100 years. So there is a need to get councils to at least give people advice, even if the planning regulations aren't finalised, to ensure people don't build in vulnerable places.'

Hunter says that for infrastructure already in place and threatened by sea-level rise, it will be a case of either protecting or relocating it if it's valuable, or abandoning it.

Much of our planning will need to be adaptive.

'This problem will not be solved by a one-off study which results in a series of measures you can implement,' Steffen says.

'This is going to require adaptive management over decadal timescales. As we learn more we'll adjust what we do, and as we try different adaptive measures we'll learn from these and they'll feed back into more effective measures in the future.'

Global mitigation

The problem must also be addressed through greenhouse gas emission reduction strategies. A global emission reduction target of at least 60 per cent by 2050 is widely thought necessary to avoid a global average temperature rise above 2.5–3°C, relative to pre-industrial levels, and significant climate change damage.[15] According to the Stern Review[16] – a report for the British Government on the economic impacts of climate change – investments made in the next 10–20 years could either lock in very high emissions for the next 50 years, or 'present an opportunity to move the world onto a more sustainable path'.

After lagging behind other countries in initiatives that take us down the latter path, Steffen believes Australia has turned a corner.

'I'm very encouraged by the discussion in the media and recent developments on both sides of politics,' he reflects.

'I think people understand the issues and I'm encouraged by a high degree of responsibility and forward looking by business, government and the general public. There's a growing feeling that Australia can play a leadership role in climate change mitigation.'

13 Sharples C (2006). Indicative mapping of Tasmanian coastal vulnerability to climate change and sea-level rise: explanatory report. Consultant report to Department of Primary Industries & Water, Tasmania. www.coastalvulnerability.info
14 Department of Natural Resources. Coastal Risk Assessment 2005. pers. comm.
15 The Australian Climate Group (2004). Climate change – solutions for Australia. WWF Australia. http://iag.com.au/pub/iag/sustainability/publications/climate/intro.shtml
16 Stern N (2006). *The Economics of Climate Change: The Stern Review*. www.sternreview.org.uk

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