Chapter 2

Recent trends and projections on the frequency of extreme weather events

2.1 This chapter examines evidence received by the committee relating to trends and projections on the frequency and magnitude of extreme weather events, including drought, bushfires, heatwaves, floods and storm surges.[1] The focus of the chapter is on trends and projections in the Australian context, rather than the global context. It also focusses on evidence presented to the committee during this inquiry: relevant recent reports have been outlined in the background discussion in Chapter 1.

2.2 This chapter first examines the general concept of 'extreme weather', followed by general trends and projections on the frequency of extreme weather events. It then considers in turn the trends and projections in Australia in relation to particular extreme weather events, including:

- temperature extremes and heatwaves;
- rainfall extremes, including floods and droughts;
- bushfires;
- tropical cyclones; and
- storm surges and coastal flooding.

2.3 Finally, this chapter briefly considers the gaps and uncertainties in relation to those trends and projections, and areas where further research might be needed.

What is 'extreme weather'?

2.4 Evidence to this inquiry focussed on extreme weather events such as heatwaves, bushfires, droughts, floods and cyclones. The Intergovernmental Panel on Climate Change (IPCC) has defined 'extreme weather' as:

> The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable.[2]

---

1 See terms of reference (a) and (b)(i) for the inquiry.

2 IPCC, *Special Report of the IPCC: Managing the risks of extreme events and disasters to advance climate change adaptation* (SREX), 2012, p. 5 and see also pp 115–117, http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml#SREX (accessed 4 July 2013).

2.5 The Climate Commission has described an 'extreme weather event' as:

> …a weather or climate event which is unusually intense or long, occasionally beyond what has been experienced before. Examples include very high (and low) temperatures, very heavy rainfall (and snowfall in cold climates), and very high wind speeds.[3]

2.6 The Climate Commission has explained that extreme events occur only rarely, but are noticeable because they are so different from the usual weather and climate, and are associated with adverse impacts on humans, infrastructure and ecosystems. It further noted that extreme weather events are often short-lived abrupt events lasting hours or days—for example, extremely hot days, very heavy rainfall, hail storms, and tropical cyclones. Other extreme events can last much longer, such as drought, which is a 'significant lack of rainfall over a period of months to years'.[4]

2.7 There was some discussion during the committee's inquiry about the difference between 'weather' and 'climate'. The Climate Commission explains that 'climate is what you'd expect, and weather is what you get':

> Weather is what we get, day to day, which can vary in the short term. Climate is the long-term average of the weather patterns we experience, usually taken over 30 years or longer. The long-term average gives us a sense of what we can expect the weather to be.[5]

2.8 Professor Neville Nicholls summed up the difference as follows:

> Climate is in some sense an integration or aggregation of weather…weather is what we feel; climate is what we expect. It is very difficult to discern between them...[6]

---

3 Climate Commission, *The Critical Decade*: *Extreme weather*, April 2013, p. 10; http://climatecommission.gov.au/wp-content/uploads/ExtremeWeatherReport_web.pdf (accessed 6 June 2013).

4 Climate Commission, *The Critical Decade*: *Extreme weather*, April 2013, p. 10.

5 Climate Commission, *Basics: Weather*, http://climatecommission.gov.au/basics/weather/ (accessed 14 June 2013); see also Climate Commission, *The Critical Decade 2013*: *Climate Change Science, Risks and Responses*, June 2013, pp 9–10.

6 Professor Neville Nicholls, Monash University, *Committee Hansard*, 20 February 2013, p. 7.

Trends and projections on the frequency of extreme weather events

General

2.9 It was generally agreed that Australia experiences a highly variable climate.[7] For example, the Australian Research Council's (ARC) Centre of Excellence for Climate System Science submitted that:

> There is large year-to-year variability in the frequency of hot extremes and heavy rain events, heatwaves, droughts and floods across Australia. These are associated with the natural variability of Australia's climate, particularly influenced by large-scale phenomena like El Niño-Southern Oscillation. In eastern Australia El Niño is associated with increased frequency of droughts, while La Niña is associated with increased frequency of heavy rain events and flooding.[8]

2.10 While most Australians are probably familiar with the El Niño-Southern Oscillation, the committee also heard about other natural climate variations that influence Australia's climate, including the Interdecadal Pacific Oscillation, which is a pattern of change detected as warm or cool surface waters in the Pacific Ocean. It shifts phases on a time scale of about 20 to 30 years, and may affect the occurrence of tropical cyclones.[9]

2.11 However, the committee also heard that the climate is changing due to human influences, particularly the burning of fossil fuels.[10] The climate change scenarios put forward by the IPCC and CSIRO show average global temperature increases from 1 to 5 degrees by 2070, depending on the level of greenhouse gas emissions.[11]

2.12 CSIRO submitted that:

> The natural climate variability that underlies all extreme weather events is now influenced and altered by the effect of human-induced warming of the climate system...[12]

---

7 See, for example, CSIRO, *Submission 93*, p. 3; ARC Centre of Excellence for Climate System Science, *Submission 57*, p. 1.

8 ARC Centre of Excellence for Climate System Science, *Submission 57*, p. 2.

9 Mr Jeff Callaghan, Meteorologist, Green Cross Australia, *Committee Hansard*, 22 February 2013, p. 18 and also pp 21–22; Dr Anthony Kiem, *Submission 5*, p. 1; Professor Stewart Franks, *Submission 102*, p. 1, see also Geoscience Australia, OzCoasts, Climate Change, http://www.ozcoasts.gov.au/indicators/climate_change.jsp (accessed 14 June 2013).

10 See, for example, CSIRO, *Submission 93*, p. 4; Dr Andrew Glikson, *Committee Hansard*, 11 April 2013, p. 18; Dr Anthony Kiem, *Committee Hansard*, 11 April 2013, p. 19; Professor Alan Pears, *Submission 3*; Professor Neville Nicholls, *Submission 1*, p. 2; Professor David Karoly, Wentworth Group of Concerned Scientists, *Committee Hansard*, 11 April 2013, p. 34.

11 See, for example, Professor David Karoly, Wentworth Group of Concerned Scientists, *Committee Hansard*, 11 April 2013, p. 34; Dr Andrew Glikson, *Committee Hansard*, 11 April 2013, p. 12; Australian Academy of Science, *Submission 125*, p. 5; The Climate Institute, *Submission 105*, p. 3.

12 CSIRO, *Submission 93*, p. 4; see also Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, p. 4.

2.13 CSIRO further explained that this changing climate will lead 'to changes in the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events'.[13]

2.14 Indeed, the evidence to the committee was that climate change is likely to increase the frequency and intensity of extreme weather events in the coming decades.[14] The Climate Commission reported that:

> Climate change is already increasing the intensity and frequency of many extreme weather events, adversely affecting Australians. Extreme events occur naturally and weather records are broken from time to time. However, climate change is influencing these events and record-breaking weather is becoming more common around the world.[15]

2.15 The committee also heard that climate change will not necessarily be experienced through gradual trends. Several submitters and witnesses pointed out that 'small changes in mean climate lead to larger changes in extremes'.[16] As a result:

> Future climate change impacts will increasingly be experienced first through extreme events rather than gradual changes in mean temperature or rainfall.[17]

2.16 Dr Andrew Glikson agreed that all the evidence is pointing to an 'accelerating series of extreme weather events around the world' and that:

> This is not a gradual trend…When you look at the behaviour of the atmosphere past and present, it reaches tipping points and from a certain degree of energy in the atmosphere you get very rapid events over periods ranging from decades to maybe a century or two.[18]

2.17 Indeed, as outlined in Chapter 1, in recent years Australia has experienced several notable extreme weather events. The Bureau of Meteorology (BoM) submitted that:

---

13 CSIRO, *Submission 93*, p. 4.

14 CSIRO, *Submission 93*, pp 3–4; Department of Climate Change and Energy Efficiency, *Submission* 168, p. 1; see also The Climate Institute, *Submission 105*, p. 2; Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, pp 4 and 5; Dr Andrew Glikson, *Committee Hansard*, 11 April 2013, p. 12 and *Submission 2*, p. 2; Mr Peter Cosier, Convenor, Wentworth Group of Concerned Scientists, *Committee Hansard*, 11 April 2013, p. 29.

15 Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, p. 4.

16 Wentworth Group of Concerned Scientists, *Submission 24*, p. 1; see also ARC Centre of Excellence for Climate System Science, *Submission 57*, p. 6; Department of Climate Change and Energy Efficiency, *Submission* 168, p. 1.

17 CSIRO, *Submission 93*, p. 5.

18 Dr Andrew Glikson, *Committee Hansard*, 11 April 2013, p. 12 and also p. 19; see also, for example, Dr Anthony Kiem, *Committee Hansard*, 11 April 2013, p. 13; CSIRO, *Submission 93*, p. 5; Academy of Science, *Submission 125*, p. 2; Dr Seth Westra, Dr Michael Leonard, Dr Mark Thyer and Professor Martin Lambert (University of Adelaide), *Submission 44*, p. 2.

> Long-term observations show that some extreme weather events are now more common and severe than in the recent past, and model projections of future climate change indicate that further changes are likely.[19]

2.18 The Bureau of Meteorology informed the committee that providing warnings for extreme weather events is its 'core business',[20] and that:

> Over the last decade, the Bureau has been particularly active in issuing severe weather warnings (Figure 1), as Australia has lurched from record drought to record floods and now to record heatwaves. The intensity of each of these events is unprecedented. That they should occur in series within the space of a decade is remarkable.[21]

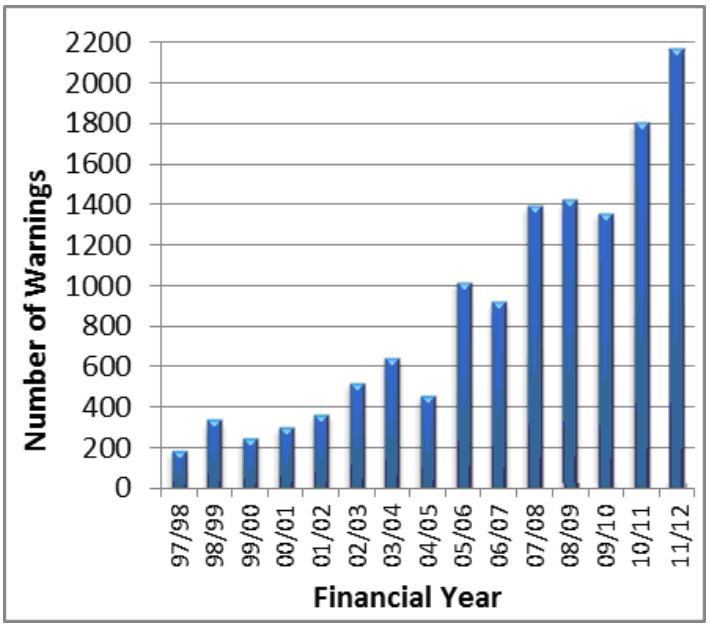


Figure 2.1: Number of severe weather-related warnings issued by the Bureau of Meteorology from July 1997 to June 2012.[22]

19 Bureau of Meteorology (BoM), *Submission 65*, p. 3 and see also p. 7.

20 Dr Neville Smith, Deputy Director, Research and Systems, BoM, *Committee Hansard*, 11 April 2013, p. 53.

21 BoM, *Submission 65*, p. 1.

22 BoM, *Submission 65*, p. 2.

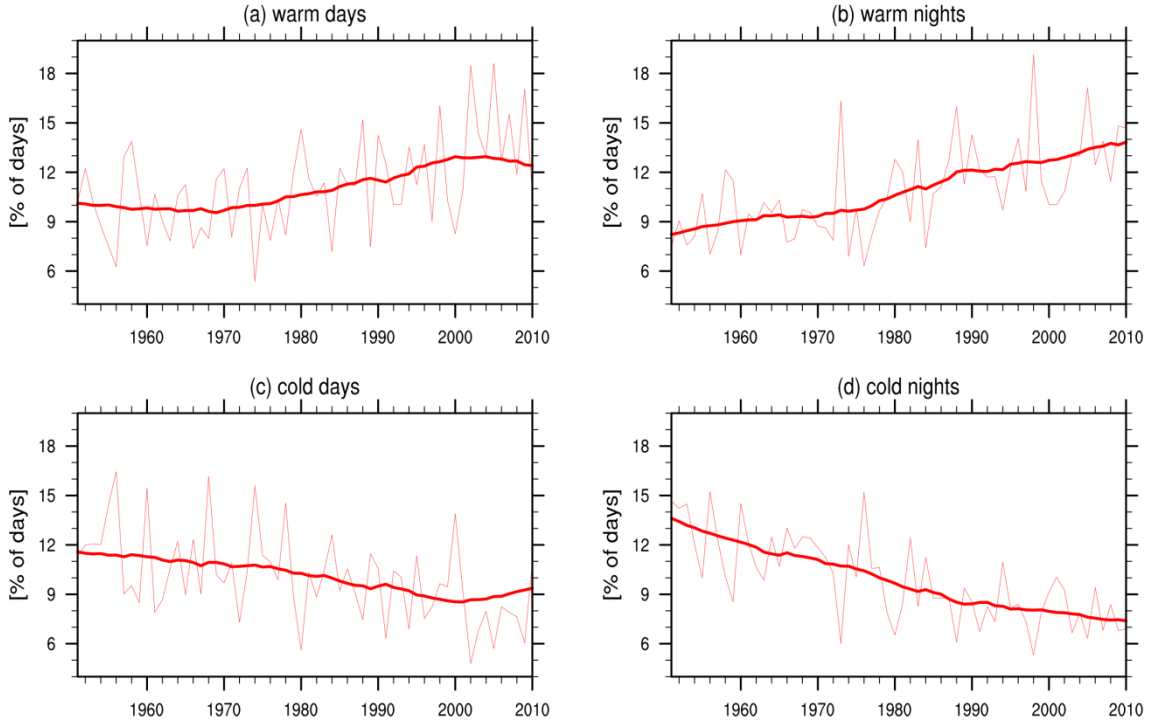
2.19 However, the Bureau noted that 'caution is required in inferring trends in this time series as factors beyond the occurrence of significant weather events may also contribute to these numbers'.[23]

Extreme temperatures and heatwaves

Trends

2.20 The committee heard that, in general, there has been a trend towards warmer weather in Australia. In particular, there is an observed trend of more hot days and hot nights and less cold days and cold nights across Australia in the last 50 years (see Figure 2.2 below).[24]

Figure 2.2: Trends in indices for temperatures in Australia over 1951-2010[25]



2.21 Figure 2.2 shows a time series of indices of the number of warm/cool days (that is, daily maximum temperatures outside the 90th/10th percentile) and warm/cool

23 BoM, *Submission 65*, p. 2.

24 ARC Centre of Excellence for Climate System Science, *Submission 57*, p. 2; Dr Karl Braganza, Manager, Climate monitoring Services, BoM, *Committee Hansard*, 11 April 2013, p. 54; Australian Academy of Science, *Submission 1*, pp 1 and 4; Professor Will Steffen, Commissioner, Climate Commission, *Committee Hansard*, 7 June 2013, p. 9; CSIRO, *Submission 93*, p. 6.

25 ARC Centre of Excellence for Climate System Science, *Submission 57*, p. 5: from Donat, M.G. and L.V. Alexander (2012) "The shifting probability distribution of global daytime and night-time temperatures. *Geophysical Research Letters* 39, L14707.

nights (that is, daily minimum temperatures outside the $90^{th}/10^{th}$ percentile), averaged over Australia for the period 1951-2010).[26]

2.22 As can be seen from Figure 2.1, the warming trend is more pronounced in relation to night-time temperatures—that is, 'we are seeing more record-high minimum temperatures during the night'.[27] For example, Dr Karl Braganza from the Bureau of Meteorology told the committee that:

> In the last decade we are probably setting records for night-time temperatures that are warm at about the rate of five to one compared to cold temperatures. During the day it is about three to one, so record-setting temperatures we have not seen before across the network are three times more likely than cold records.[28]

2.23 In terms of heatwaves,[29] the Bureau of Meteorology submitted that across Australia since the 1950s, there has been a slight increase in the duration of heatwaves, and an increase in the maximum temperatures associated with such events.[30] The Climate Commission has similarly reported that the duration and frequency of heatwaves increased over the period 1971–2008, and that the hottest days during heatwaves have become hotter.[31]

2.24 The Bureau of Meteorology noted, however, that there have been:

> …marked regional variations in the frequency of occurrence of heatwaves over that time, with decreases in parts of southern coastal Australia (especially south-western Western Australia), and strong increases away from coastal regions. The decreases in heatwave duration across some parts of southern coastal Australia contrast with increases in the frequency of single-day high temperature extremes at many of the same locations over the same period.[32]

2.25 The committee also notes that record temperatures in January 2013 resulted in the Bureau of Meteorology adding new colours—purple and pink—to its weather map

---

26 ARC Centre of Excellence for Climate System Science, *Submission 57*, p. 3.

27 Professor Will Steffen, Climate Commission, *Committee Hansard*, 7 June 2013, p. 9.

28 Dr Karl Braganza, BoM, *Committee Hansard*, 11 April 2013, p. 54; see also Professor Will Steffen, Climate Commission, *Committee Hansard*, 7 June 2013, p. 9; The Climate Institute, *Submission 105*, p. 2.

29 A 'heatwave' is generally defined as an extended period—at least three days—with persistent temperatures well above the local average: Climate Commission, *The Critical Decade 2013: Climate Change Science, Risks and Responses*, June 2013, p. 52.

30 BoM, *Submission 65*, p. 10.

31 Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, p. 21; see also Dr Karl Braganza, BoM, *Committee Hansard*, 11 April 2013, p. 54; The Climate Institute, *Submission 105*, p. 2.

32 BoM, *Submission 65*, pp 10–11.

to denote temperatures once considered off the scale: 50–52°C and 52–54°C respectively.[33]

Projections

2.26 The trend of increases in the number of hot days and hot nights and decreases in cold days and cold nights was projected to continue into the future.[34] For example, the Bureau of Meteorology predicted that:

> It is very likely that the observed trends in the frequency and magnitude of warm daily temperature extremes will continue and, depending on emission scenario, potentially accelerate under future global warming. All regions of Australia are likely to experience significant increases in temperature extremes in this century.[35]

2.27 These temperature increases are also associated with projections for increasing frequency and intensity of heatwaves in Australia.[36]

2.28 CSIRO submitted that 'the number of days over 35ºC is expected to increase significantly by 2030 for many locations in Australia'.[37] Indeed, the Climate Commission reported that:

> …for Adelaide, Melbourne and Canberra the observed annual number of hot days is increasing more quickly than the climate models projected. In these cities the annual number of hot days occurring now is at the level projected for around 2030...[38]

2.29 The Antarctic Climate and Ecosystems Cooperative Research Centre submitted that its detailed analysis had found that in Tasmania:

> Hot summer days and heat waves are projected to increase in Tasmania in the future. Under a high greenhouse gas emissions scenario the number of summer days warmer than 25ºC is projected to double or triple that of the recent climate record. The largest increases in extreme temperature are projected to be in spring and autumn, with increases greater than 4ºC leading to a lengthening of the summer season. Heat waves (three days in a

33 See further: ABC, *Heat drives bureau back to the drawing board*, at: http://www.abc.net.au/news/2013-01-09/temperatures-into-uncharted-waters/4458162; and also The Climate Institute, *Submission 105*, p. 2.

34 ARC Centre of Excellence for Climate System Science, *Submission 57*, p. 2; CSIRO, *Submission 93*, p. 12.

35 BoM, *Submission 65*, p. 11.

36 ARC Centre of Excellence for Climate System Science, *Submission 57*, p. 2; see also Professor Nathaniel Bindoff, Program Leader, Climate Futures, Antarctic Climate and Ecosystems CRC (CRC), *Committee Hansard*, 10 April 2013, p. 23; Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, p. 22.

37 BoM, *Submission 65*, p. 3.

38 Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, p. 22 and Table 1.

> row above 28ºC) are expected to become more frequent – up to four times more frequent than historical records for Launceston, for example.[39]

Rainfall extremes: floods and droughts

Trends

2.30 Both the CSIRO and the Bureau of Meteorology submitted that there is evidence of 'systematic changes in rainfall patterns' in Australia. They pointed to the following trends in recent decades:

- decreased late autumn and winter rainfall in southern Australia since the 1980s;
- increased spring and summer monsoonal rainfall in northern Australia; and
- a 15% decline in winter rainfall in southwest Western Australia since the 1970s.[40]

2.31 Professor Will Steffen from the Climate Commission explained that the likely reason behind the decline in southwest Western Australia is that:

> …the rain-bearing fronts off the Southern Ocean that give south-west WA its rainfall…have slipped southward by a degree or two in latitude, and that is because of the warming of the climate system; it pushes the mid-latitude jet streams toward the poles on both sides of the equator.[41]

2.32 The Bureau of Meteorology noted that the 'systematic decline in autumn-winter rainfall across southern Australia likely exacerbated the severity of the Millennium Drought'.[42]

2.33 Dr Braganza from the Bureau of Meteorology told the committee that the reduction of rainfall in the winter months is problematic for water catchments:

> It is an important time of the year to lose the rainfall because it is during that time that we prime the catchment. We get wetter soils during that period. That allows run-off to occur during the subsequent months into winter. So the 10 to 20 per cent reduction in rainfall during that time leads to a 60 per cent reduction in stream flow. You can see that most obviously

---

39 Antarctic Climate and Ecosystems CRC, *Submission 160*, p. 1; see also Dr Anthony Press, Chief Executive Officer, Antarctic Climate and Ecosystems CRC, *Committee Hansard*, 10 April 2013, p. 23.

40 BoM, *Submission 65*, pp 15 and 18; CSIRO, *Submission 93*, pp 6–7; Dr Karl Braganza, Manager, Climate Monitoring Services, BoM, *Committee Hansard*, 11 April 2013, p. 54; see also Australian Academy of Science, *Submission 1*, pp 1 and 5; The Climate Institute, *Submission 105*, p. 3; Conservation Council of Western Australia, *Submission 100*, p. 2; Professor Will Steffen, Climate Commission, *Committee Hansard*, 7 June 2013, p. 10.

41 Professor Will Steffen, Climate Commission, *Committee Hansard*, 7 June 2013, pp 10–11.

42 BoM, *Submission 65*, p.17. Note that the 'Millennium Drought' is discussed in Chapter 1.

> in Perth and south-west WA, where catchments are around the 20 per cent mark.[43]

2.34 Dr Braganza noted that there have also been increases in rainfall intensity, or heavy rainfall events:

> When you go to rainfall intensity—really heavy rainfall events—in the last three years we have had a lot of records set. We have had record sea-surface temperatures around Australia, which is, in some ways, co-variable with the rainfall; it influences how much rainfall we get.[44]

2.35 The Climate Commission reported that, while there is considerable variability in rainfall across Australia, there has been:

- a significant increase in the frequency of heavy rainfall events in northwest Australia; and
- a slight decrease (not statistically significant) in the number of heavy rainfall events in southeast and southwest Australia.[45]

Projections

2.36 In general terms, the Bureau of Meteorology submitted that, with global warming, the planet's hydrological cycle is predicted to intensify, which essentially means 'more heavy rainfall and more severe droughts'.[46] The Bureau explained that, as the Earth's atmosphere warms, the amount of moisture it can hold also increases and that 'this is expected to result in increases in heavy rainfall events and consequent flooding'.[47] At the same time, global warming is also expected to increase evaporation, leading to more severe drought conditions in 'dry' regions of the globe.[48]

2.37 More specifically for Australia, the Bureau of Meteorology explained that 'changes in Australian rainfall and drought patterns are dependent on complex changes in the global atmospheric circulation', and warned that there is uncertainty as to the 'future frequency, timing and spatial extent of those changes' due to the high variability of rainfall in Australia.[49] These, and other, uncertainties are discussed in further detail later in this chapter.

---

43 Dr Karl Braganza, Manager, Climate Monitoring Services, BoM, *Committee Hansard*, 11 April 2013, p. 54.

44 Dr Karl Braganza, BoM, *Committee Hansard*, 11 April 2013, p. 54.

45 Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, p. 27.

46 BoM, *Submission 65*, p. 14; see also, for example, Dr Andrew Glikson, *Submission 2*, p. 6.

47 BoM, *Submission 65*, p. 14; see also Professor Nathaniel Bindoff, Antarctic Climate and Ecosystems CRC, *Committee Hansard*, 10 April 2013, p. 24; Professor Will Steffen, Climate Commission, *Committee Hansard*, 7 June 2013, p. 10.

48 BoM, *Submission 65*, p. 14; see also Professor Will Steffen, Climate Commission, *Committee Hansard*, 7 June 2013, p. 10.

49 BoM, *Submission 65*, p. 14.

2.38 However, the Bureau of Meteorology submitted that most climate model projections indicate:

- rainfall decreases in southern and eastern Australia during the cooler months, particularly in winter and spring;
- increased drought threat for southern Australia as a result of reduced mean rainfall and higher temperatures; and
- rainfall intensity will likely increase across Australia.[50]

2.39 CSIRO submitted the 'changes in seasonal-average rainfall affect the incidence of drought and floods'.[51] So, for example, 'drought occurrence is expected to increase over most of southern Australia, especially in south-western Australia'.[52] CSIRO further submitted that modelling in relation to future drought conditions indicates that:

> …by 2030, it is likely…that a 1-in-20 year drought during the 20th century may become a 1-in-10 year drought over south west Western Australia. By 2050, this could include the Murray-Darling Basin, South Australia and Victoria, and by 2070 this could extend to eastern New South Wales and Tasmania. No significant increases in drought frequency are projected for the northwest WA or northern and central Queensland.[53]

2.40 CSIRO further submitted that climate change projections suggest that 'the Murray-Darling Basin will be on average drier in the future', and that future droughts in the Murray-Darling Basin may be longer, more frequent and more severe.[54]

2.41 The Bureau of Meteorology reported less confidence in predicting future rainfall changes across northern Australia.[55] However, the Bureau stated that:

> [it has] high confidence in projections of warming and increased atmospheric moisture, and associated increases in heavy rainfall will likely contribute to a generalised increased flood threat during the tropical wet season in the future. It is, however, more difficult to predict the future frequency of severe flooding, due to the inherent, and likely increasing, year to year variability of Australian rainfall.[56]

---

50 BoM, *Submission 65*, pp 14–15; see also Professor Will Steffen, Climate Commission, *Committee Hansard*, 7 June 2013, p. 10.

51 CSIRO, *Submission 93*, p. 7.

52 CSIRO, *Submission 93*, p. 13; see also Professor Will Steffen, Climate Commission, *Committee Hansard*, 7 June 2013, p. 10; Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, p. 36.

53 CSIRO, *Submission 93*, p. 13. Note their quotation references a paper by: Kirono D.G.C., Kent D.M., Hennessy, K.J. and Mpelasoka, F., 2011, 'Characteristics of Australian droughts under enhanced greenhouse conditions: Results from 14 global climate models', *Journal of arid environments* 75(6): 566–575.

54 CSIRO, *Submission 93*, p. 13.

55 BoM, *Submission 65*, p. 14.

56 BoM, *Submission 65*, p. 19.

2.42 The Climate Commission reported that research indicates that in Australia:

> …it is more likely than not that heavy rainfall events will become more frequent as the temperature increases…Regionally, increases in heavy rainfall are expected to be less evident in regions where mean rainfall is projected to decline…such as southern Australia.[57]

2.43 At the same, the CSIRO submitted that 'increases in extreme daily rainfall are expected over most of the continent in the future'.[58] The committee was also advised that there is emerging evidence that high intensity, short-duration rainfall bursts, which lead to flash flooding, may be increasing in intensity.[59]

2.44 In Tasmania, the Antarctic Climate and Ecosystems Cooperative Research Centre (CRC) noted that it had conducted a detailed analysis of future extreme events. In relation to rainfall, this analysis found that:

> There will [be] more frequent and more intense extreme rainfall events interspersed with longer dry periods of no rain. It is projected that there will be an increase of about 25% in the number of days of extremely high rainfall in both the south west and north east of Tasmania. Peak intensity rainfall events are projected to increase across Tasmania, leading to increased flash flooding. Accompanying this increased intensity of rainfall will be a decrease in the total number of rain days, and thus longer periods between rain events.[60]

2.45 The centre further noted that extreme and record rainfall events are projected to become more frequent:

> …in some places a 1:200 year event will become a 1:20 year event. Flooding in the Mersey, Forth and Huon Rivers is expected to increase significantly.[61]

Bushfires

Trends

2.46 Recent devastating bushfire seasons in Australia have been outlined in Chapter 1. The committee heard that bushfire danger is likely to increase in the future, and the bushfire season is likely to be longer, particularly as result of the projected increases in hot days and droughts.

2.47 The Bureau of Meteorology explained that:

---

57 Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, p. 29.

58 CSIRO, *Submission 93*, p. 3 and also p. 12.

59 Dr Seth Westra, Dr Michael Leonard, Dr Mark Thyer and Professor Martin Lambert (University of Adelaide), *Submission 44*, p. 3; see also Professor Nathaniel Bindoff, Antarctic Climate and Ecosystems CRC, *Committee Hansard*, 10 April 2013, p. 24.

60 Antarctic Climate and Ecosystems CRC, *Submission 160*, p. 1.

61 Antarctic Climate and Ecosystems CRC, *Submission 160*, p. 2; see also Dr Anthony Press, Antarctic Climate and Ecosystems CRC, *Committee Hansard*, 10 April 2013, p. 23.

> Fire is a natural part of the Australian environment, with some areas (particularly southern and eastern Australia) being prone to catastrophic bushfires. Bushfire threat is typically associated with high temperatures, low humidity, strong winds and high fuel load. Bushfires become catastrophic when all of these conditions occur in combination…[62]

Projections

2.48 The committee received evidence that the projected increases in hot days and in consecutive dry days and droughts will lead to increased frequencies of days with extreme fire danger.[63] For example, the Australian Academy of Science observed that 'there is a clear observed association between extreme heat and catastrophic bushfires'.[64] And that:

> A rise of a few degrees in mean temperature would greatly increase the number of days of extreme heat and extreme or catastrophic bushfire risk, for example from a few days to tens of days per year in southern and eastern Australia.[65]

2.49 The Bureau of Meteorology agreed that:

> Projected rising temperatures and likely decreases in winter and spring rainfall across southern Australia…will also contribute to an increased bushfire threat. In addition, climate modelling shows the potential for an increase in the frequency of the summer-time weather systems that are associated with the most extreme and damaging bushfire activity in south-eastern Australia. However, the change in future fire activity is more difficult to determine because fire behaviour depends also on fuel type and accumulation, which may change in the future due to changes in rainfall, fire frequency and other factors.[66]

2.50 CSIRO noted its projections that warmer and drier conditions are expected in future over southern and eastern Australia, and that 'consequently, an increase in fire weather risk is likely, with more days of extreme risk and a longer fire season'.[67]

---

62 BoM, *Submission 65*, p. 12; see also CSIRO, *Submission 93*, p. 8; Bushfire CRC, *Submission* 71, p. 1; Professor Will Steffen, Climate Commission, *Committee Hansard*, 7 June 2013, p. 10; Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, p. 41.

63 ARC Centre of Excellence for Climate System Science, *Submission 57*, p. 7; Professor Will Steffen, Climate Commission, *Committee Hansard*, 7 June 2013, p. 10; Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, p. 42; Bushfire CRC, *Submission 71*, p. 2.

64 Australian Academy of Science, *Submission 1*, p. 5; The Climate Institute, *Submission 105*, p. 1 and Attachment 1: Lucas, C., K. Hennessy, G. Mills and J. Bathols, 'Bushfire weather in southeast Australia: recent trends and projected climate change impacts', Bushfire CRC and Australian BoM, September 2007.

65 Australian Academy of Science, *Submission 1*, p. 7.

66 BoM, *Submission 65*, p. 12. Note the original quote contains a number of footnoted references. See also Professor Will Steffen, Climate Commission, *Committee Hansard*, 7 June 2013, p. 10.

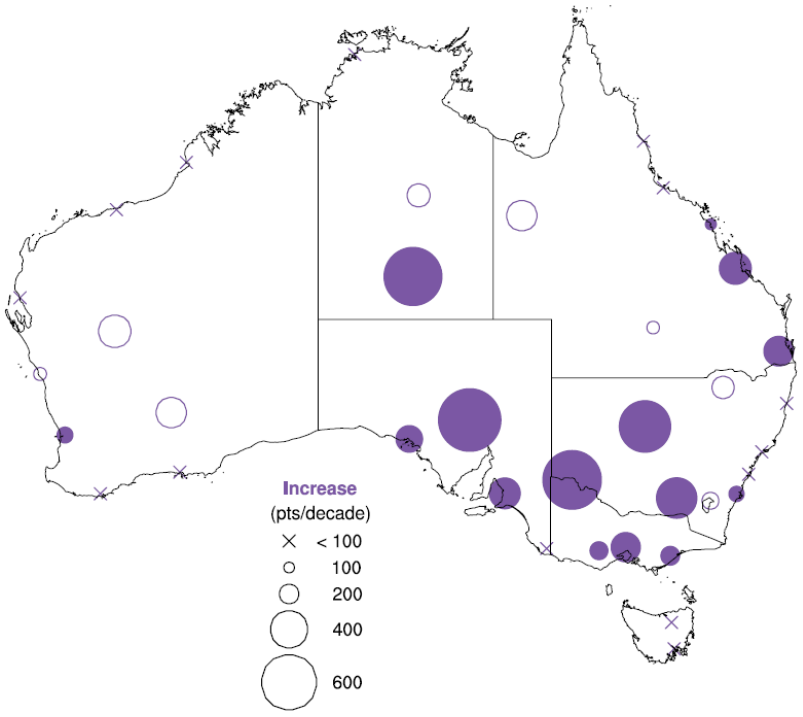
67 CSIRO, *Submission 93*, p. 14.

2.51 The Conservation Council of Western Australia (CCWA) submitted its concern that the drying trend in southwest Western Australia will result in increased risk of bushfire:

> …with WA's southern forests becoming more vulnerable to fire events as they dry out and certain woodland flora (e.g., the Karri forests, which require average rainfall of over 1250ml a year in order to survive) are rendered marginal.[68]

2.52 Several submissions also pointed to the annual cumulative Forest Fire Danger Index (FFDI), which essentially 'sums' daily fire weather danger across the year. For example, the Bureau of Meteorology noted that the FFDI has 'increased *significantly* across many Australian locations since the 1970s'[69] (see Figure 2.2). It was also pointed out that the number of locations with significant increases is greatest in the southeast of Australia, while the strongest trends occurred inland rather than near the coast.[70]

Figure 2.3: Trends in annual cumulative Forest Fire Danger Index[71]



2.53 The ARC Centre of Excellence for Climate System Science explained that:

---

68 Conservation Council of Western Australia, *Submission 100*, p. 2.

69 BoM, *Submission 65*, p. 12; Dr Karl Braganza, BoM, *Committee Hansard*, 11 April 2013, p. 55; Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, p. 41.

70 BoM, *Submission 65*, p. 12; see also CSIRO, *Submission 93*, p. 8; ARC Centre of Excellence for Climate System Science, *Submission 57*, pp 4 and 7; Professor Will Steffen, Climate Commission, *Committee Hansard*, 7 June 2013, p. 10.

71 Source: Clarke, H., Lucas, C and Smith, P., 'Changes in Australian fire weather between 1973 and 2010', *International Journal of Climatology*, 2012; from BoM, *Submission 65*, p. 13; see also CSIRO, *Submission 93*, p. 8.

> …in summer rainfall-dominated tropical north-east Australia, mean and extreme FFDI are projected to decrease or remain close to 20th century levels;
>
> …in south-east continental Australia, FFDI is projected to increase strongly by 2100;
>
> …the fire season is projected to start earlier in [south-east Australia], potentially leading to a longer overall fire season.[72]

2.54 Several submissions noted that the largest increases in seasonal FFDI have occurred during spring and autumn, which indicates a longer fire season.[73]

2.55 The committee also heard that, following the Black Saturday bushfires in Victoria, a new fire risk category of 'catastrophic' had been added to fire danger indicators to allow for conditions that were 'off the record'.[74]

Tropical cyclones

Trends

2.56 Tropical cyclones are defined as:

> …low pressure systems that form over warm, tropical waters and have gale force winds (sustained winds of 63km/h or greater and gusts in excess of 90km/h near the centre)... The gale force winds can extend hundreds of kilometres from the cyclone centre.[75]

2.57 The Bureau of Meteorology reported that, on average, the Australian region experiences about 11 tropical cyclones per year, but the number varies significantly from year to year.[76]

2.58 The committee heard that there is no evidence of significant trends in the total numbers of tropical cyclones in the Australian region.[77] In particular, the Bureau of Meteorology submitted that the 'relatively short time span of consistent records,

---

72 ARC Centre of Excellence for Climate System Science, *Submission 57*, p. 7.

73 BoM, *Submission 65*, p. 12; CSIRO, *Submission* 93, p. 8; Dr Karl Braganza, BoM, *Committee Hansard*, 11 April 2013, p. 55; ARC Centre of Excellence for Climate System Science, *Submission 57*, p. 7.

74 Professor Will Steffen, Climate Commission, *Committee Hansard*, 7 June 2013, p. 10.

75 BoM, *About Tropical Cyclones*, at: http://www.bom.gov.au/cyclone/about/ (accessed 14 June 2013).

76 BoM, *Submission 65*, p. 19.

77 CSIRO, *Submission 93*, p. 8.

combined with high year-to-year variability, makes it difficult to discern any clear trends in tropical cyclone frequency or intensity for the Australian region'.[78]

2.59 On the other hand, Mr Jeff Callaghan from Green Cross Australia observed that tropical cyclones in Queensland are affected by multi-decadal cycles such as the Interdecadal Pacific Oscillation, and that the second half of the 19th century was a much more active period for cyclones than the 20th century.[79]

Projections

2.60 Noting the problems with lack of reliable long-term records for cyclones in Australia, the general consensus in evidence to the committee was that cyclones are likely to be more intense in the future, but there is unlikely to be an increase in the overall number of cyclones. For example, Professor Steffen from the Climate Commission told the committee that:

> In principle, we are going to see a change in cyclone behaviour, and that is pretty obvious because the sea surface temperature is rising. This means there is more energy in those surface waters, and that is where cyclones draw their energy from. However, the interesting thing is that it looks like we will not have more cyclones—in fact we will either have about the same or perhaps a little fewer…but, on balance, they are going to be more intense when they do occur.[80]

2.61 It was explained that the reason cyclones will be more 'intense' is because the wind speeds will be higher and there will be more rainfall.[81] In terms of the frequency of cyclones, the Climate Commission has explained:

> …the vertical gradient in temperature through the atmosphere, that is, the difference between the temperature near the surface of the Earth and the temperature higher up in the atmosphere, is likely to decrease as the atmosphere continues to warm. The formation of tropical cyclones most readily occurs when there are very warm conditions at the ocean surface and when the vertical gradient is strong. As the vertical gradient weakens, it is likely that fewer tropical cyclones will form.[82]

---

78 BoM, *Submission 65*, p. 20; see also Mr Peter Davies, Acting Chief Information Officer, Northern Territory Police, Fire and Emergency Services, *Committee Hansard*, 7 March 2013, p. 3; Dr Neville Smith, Deputy Director, Research and Systems, BoM, *Committee Hansard*, 11 April 2013, p. 56; Dr Karl Braganza, BoM, *Committee Hansard*, 11 April 2013, p. 60; Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, p. 41; Australian Meteorological and Oceanographic Society, *Submission 72*, p. 5.

79 Mr Jeff Callaghan, Green Cross Australia, *Committee Hansard*, 22 February 2013, p. 18, see also p. 21.

80 Professor Will Steffen, Climate Commission, *Committee Hansard*, 7 June 2013, p. 12; Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, p. 56.

81 Professor Will Steffen, Climate Commission, *Committee Hansard*, 7 June 2013, p. 12; see also Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, pp 55–56.

82 Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, p. 55.

2.62 The Bureau of Meteorology similarly submitted that global climate change projections indicate that 'there will be less tropical cyclones in overall number', but a greater number of particularly intense cyclones. It noted that 'this is consistent with recent findings for the Australian region'.[83]

2.63 CSIRO agreed that tropical cyclones in northern Australia 'are likely to become more intense with a decrease in frequency'.[84] CSIRO also noted that sea-surface temperatures are important for cyclone formation, and that sea-surface temperatures have 'been at or near record high values off the western Australian coast in recent years'.[85] CSIRO also noted that the modelling projections indicate southward movement of around 100km in the 'decay' region of cyclones (the region into which weakened tropical cyclones migrate).[86] However, Dr Stafford Smith from CSIRO warned that there is a lot of uncertainty as to whether cyclones will move further south.[87]

2.64 At the same time, Insurance Australia Group told the committee that research by its dedicated meteorology team indicated that over the next 50 years, 'the number of the most destructive category 4 and 5 tropical cyclones forming in waters off Eastern Australia could increase and track further south'.[88]

2.65 The committee was told it is difficult to make projections in relation to thunderstorms, because they tend to be very localised.[89] At the same time, Insurance Australia Group submitted that its research into the future climate impacts of severe hail storms in the Sydney region indicated that there could be 'a doubling of hailstorms with hailstones greater than 10 centimetres in diameter in the greater Sydney region over the next 50 years'.[90]

Storm surges and coastal flooding

Trends

2.66 The committee heard that rising sea levels are likely to cause damage to coastlines by exacerbating coastal flooding and erosion from storm surges and cyclones.

---

83 BoM, *Submission 65*, p. 20.

84 CSIRO, *Submission 93*, p. 3.

85 CSIRO, *Submission 93*, p. 8.

86 CSIRO, *Submission 93*, p. 14.

87 Dr Mark Stafford Smith, Science Director, CSIRO Climate Adaptation Flagship, *Committee Hansard*, 11 April 2013, p. 55.

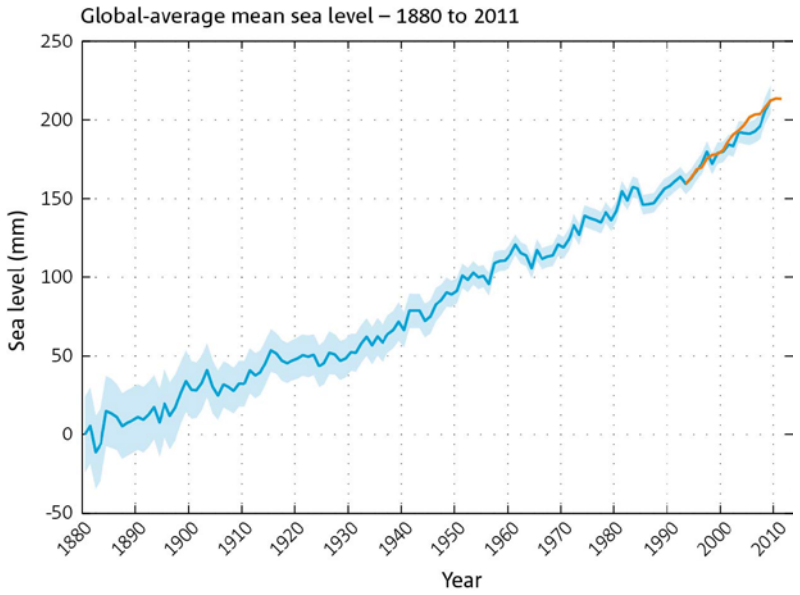
88 Insurance Australia Group, *Submission 144*, p. 14.

89 Australian Meteorological and Oceanographic Society, *Submission* 72, p. 8; see also Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, p. 56.

90 Insurance Australia Group, *Submission 144*, p. 14.

2.67 The Bureau of Meteorology submitted that average sea level globally has risen by around 21cm in total over the last century, and that the rate of sea level rise is now around 3.1mm per year (see Figure 2.4).[91]

Figure 2.4: Global average mean sea level: 1880 to 2011[92]



2.68 The Bureau of Meteorology noted that the projection is for a further average global sea level rise of between 18 and 59 cm by the end of this century, with the eventual rise depending upon the future emissions.[93] It was explained that this sea level rise is due to the expansion of ocean water as it warms, and the addition of new water from the melting of land-based ice such as glaciers and ice sheets.[94]

2.69 Around Australia, the observed sea level rise is slightly greater than the global average, although there is considerable variation around the Australian continent. The Bureau of Meteorology noted that rates of sea level rise in northern Australia are

---

91 BoM, *Submission 65*, p. 20; see also CSIRO, *Submission 93*, p. 9; Australian Academy of Science, *Submission 125*, p. 6; Professor Will Steffen, Climate Commission, *Committee Hansard*, 7 June 2013, p. 11; Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, p. 47.

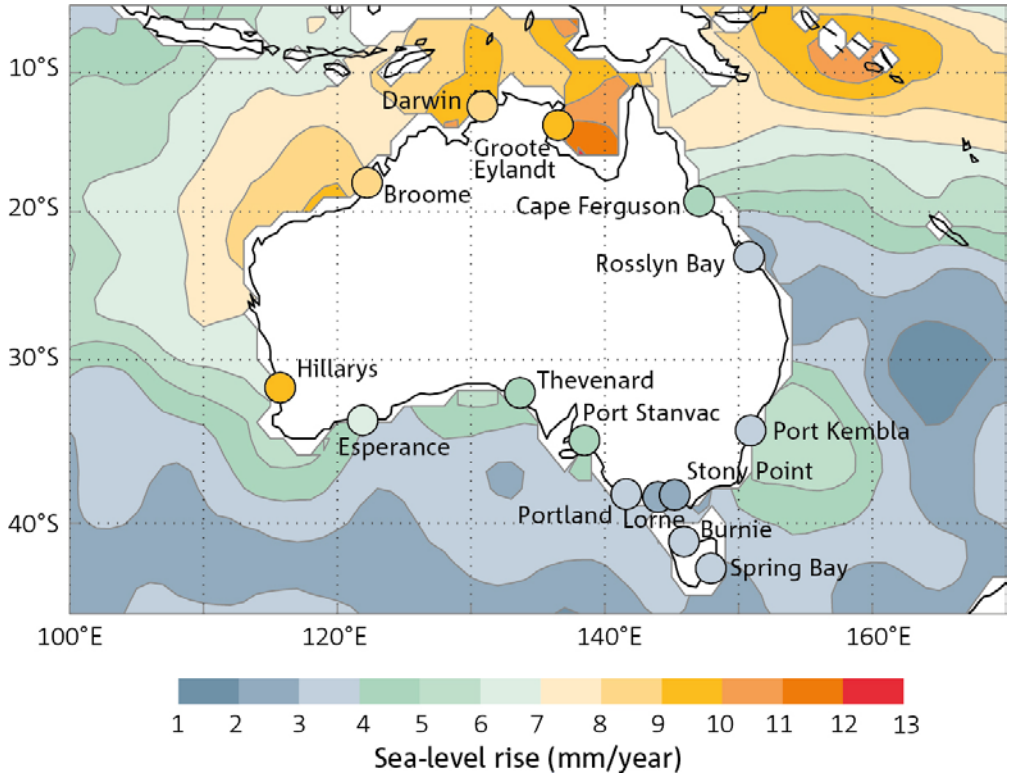
92 BoM, *Submission 65*, p. 21, which states: 'High-quality global sea-level measurements have been available from satellite altimetry since the start of 1993 (red line), in addition to the longer-term records from tide gauges (blue line, with shading providing an indication of the accuracy of the estimates)'. Source: BoM and CSIRO, *State of the Climate 2012*, 2012, Oceans, p. 3.

93 BoM, *Submission 65*, p. 22; see also Australian Academy of Science, *Submission 125*, p. 6; Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, p. 49; Australian Sea Level Rise Partnership, *Submission 172*, p. 1.

94 Australian Sea Level Rise Partnership, *Submission 172*, p. 1; see also Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, p. 49; Dr Andrew Glikson, *Committee Hansard*, 11 April 2013, p. 19.

amongst the highest in the world, with current rates up to 1 cm rise per year (see Figure 2.5).[95]

Figure 2.5: The rate of sea-level rise around Australia from January 1993 to December 2011[96]



95 BoM, *Submission 65*, p. 20.

96 As measured by coastal tide gauges (circles) and satellite observations (contours): BoM, *Submission 65*, p. 22; Source: BoM and CSIRO, 2012, *State of the Climate 2012*, Oceans, p. 3, http://www.csiro.au/en/Outcomes/Climate/Understanding/State-of-the-Climate-2012/Oceans.aspx (accessed 14 June 2013).

2.70 As Professor Steffen from the Climate Commission noted:

> Around the Top End, the rate of sea level rise in Australia is about three times the global average. The Southern Ocean, along the southern coast of Australia, is less than the global average. Around the east coast, it is about the global average.[97]

2.71 Professor Steffen told the committee that 'one of the most certain aspects of climate change is that sea levels are going to rise', but 'there is a lot of uncertainty about how much sea level is going to rise'.[98] He explained that:

> …there is already a lot of heat in the ocean that has not worked its way through the system yet. The water is still expanding in response to that. And then on top of that is we are starting now to get additional water flowing into the ocean from melting glaciers and ice caps.[99]

2.72 The committee heard that rising sea levels will exacerbate coastal flooding and erosion from 'storm surges'. A 'storm surge' is:

> ...a rise above the normal sea level resulting from strong onshore winds and/or reduced atmospheric pressure. Storm surges accompany tropical cyclones as they make landfall but can also be formed by intense low-pressure systems in non-tropical areas, such as 'East Coast Lows' in the Tasman Sea.[100]

2.73 Storm surges can cause extensive flooding of coastal areas, and are worst when they coincide with a particularly high tide.[101] Submitters explained that higher sea levels will amplify the effects of storm surges:

> The frequency and impacts of coastal flooding from extreme events such as storm surges will be significantly amplified by sea level rise, because the surges take place on a higher background sea level.[102]

2.74 The Bureau of Meteorology submitted that 'it has been estimated that an average sea-level rise of 50 cm will result in a 10-1000 times increase in the frequency of coastal flooding depending on the particular location around the Australian coastline'[103] (see Figure 2.6).

---

97 Professor Will Steffen, Climate Commission, *Committee Hansard*, 7 June 2013, p. 11.

98 Professor Will Steffen, Climate Commission, *Committee Hansard*, 7 June 2013, p. 11.

99 Professor Will Steffen, Climate Commission, *Committee Hansard*, 7 June 2013, p. 11.

100 Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, p. 44; see also Griffith Centre for Coastal Management, *Submission 58*, p. 1.

101 Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, p. 44.

102 Australian Academy of Science, *Submission 125*, p. 7; see also Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, p. 44; BoM, *Submission 65*, p. 23; Conservation Council of Western Australia, *Submission 100*, p. 4.

103 BoM, *Submission 65*, p. 23.

Figure 2.6: Projected increase in frequency of flooding events from the sea for a sea-level rise of 0.5m[104]

2.75 CSIRO similarly explained that a sea-level rise of 50 cm might mean that:

> Extreme events that now happen every 10 years, on average, would happen about every 10 days in 2100, and become even more frequent around Sydney, with smaller increases around Adelaide and along parts of the Western Australian coast.[105]

2.76 Professor Steffen noted that these effects are already being observed in areas with reliable records, such as Fremantle and Fort Denison in Sydney, where there has been about a threefold increase in flooding events since 1950.[106] The Climate Commission has also reported that the Torres Strait Islands are also increasingly vulnerable to flooding as a result of increases in sea levels.[107]

---

104 BoM, *Submission 65*, p. 24.

105 CSIRO, *Submission 93*, p. 15, citing Department of Climate Change, *Climate Change Risks to Australia's Coast*: *A First Pass National Assessment*, 2009; see also Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, p. 51; see also Conservation Council of Western Australia, *Submission 100*, p. 4.

106 Professor Will Steffen, Climate Commission, *Committee Hansard*, 7 June 2013, p. 11.

107 Climate Commission, *The Critical Decade 2013: Climate Change Science, Risks and Responses*, June 2013, p. 74; Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, p. 48.

2.77 Another concern related to the increased risk of severe coastal flooding events where coastal settlements are inundated by water from both seaward and landward directions. That is, where there is a combined impact from:

(i) the combination of storm surge, a high tide and a higher sea level, and

(ii) flooding rivers from the catchments behind the settlements.[108]

2.78 For example, the Climate Commission noted that:

> Little research has yet been done to connect these two phenomena and produce an overall change in risk factor for this type of 'double whammy' coastal flooding event. However, the rises in sea level over the 21st century, which are virtually certain, coupled with the projections of a modest increase in the frequency of heavy rainfall events for southern Australia suggest that the risk of these 'double whammy' flooding events will increase.[109]

2.79 The Bureau of Meteorology also submitted that, due to higher sea levels, weak to moderate strength tropical cyclones will be likely to generate more coastal flooding than at present, and severe cyclones are more likely to result in very serious damage to coastlines through flooding and erosion associated with storm surges.[110]

2.80 The committee heard concerns about the impacts of sea level rise in certain states. For example, in Tasmania, analysis of future extreme weather events found that an increase in mean sea level of between 5 and 14 cm by 2030 will lead to:

> …1:100 year storm tide events doubling in frequency. By the end of the 21st century the 1:100 storm tide is projected to be an annual event for higher emissions scenarios...The addition of more intense rainfall events will exacerbate the impacts of sea-level rise on flooding in rivers (and vice versa).[111]

2.81 The Northern Territory Police, Fire and Emergency Services advised that they had done some storm surge mapping of the Darwin area which took into account probable sea level rises over the next 50 to 100 years. This mapping indicated that

---

108 Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, p. 51; see also Insurance Australia Group, *Submission 144*, pp 13–14; Antarctic Climate and Ecosystems CRC, *Submission 160*, p. 2 and Attachment 3.

109 Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, p. 51.

110 BoM, *Submission 65*, p. 24; Source: Hunter, J., Allison, I. and Jakszewicz, T. C., *ACE CRC Report Card: Sea-Level Rise 2012*, Antarctic Climate and Ecosystems CRC, Hobart, Australia, 2012.

111 Antarctic Climate and Ecosystems CRC, *Submission 160*, p. 2 and Attachment 3; see also Dr Anthony Press, Antarctic Climate and Ecosystems CRC, *Committee Hansard*, 10 April 2013, p. 23.

some remote communities may 'go under in a big storm surge event … [but] the effect on Darwin is not really that great'.[112]

Uncertainties in future projections

2.82 There was some discussion during the committee's inquiry about uncertainty in terms of projections of future extreme weather events. However, little uncertainty was expressed about the fact that the climate is changing, and that these changes are being influenced by anthropogenic forces. For example, Dr Glikson told the committee that 'ninety-five point five per cent of the peer-reviewed literature on which the science is based agrees about the effect of greenhouse gases'.[113]

2.83 CSIRO submitted that the two main areas of uncertainty relating to the projections of future climate are:

> …the level of humanity's future greenhouse gas and aerosol emissions; and the response of the Earth's climate system to those emissions. These uncertain factors will affect the speed and extent of expected climate change.[114]

2.84 The Bureau of Meteorology agreed that the rate and magnitude of future changes to climate will be determined by the future level of greenhouse gas emissions, 'and a series of complex environmental feedbacks'.[115]

2.85 The committee heard that there is uncertainty about the specific impacts of climate change—that is, 'how will extreme events change: where will they change, when will they change and what will be the combination'?[116]

2.86 Dr Stafford Smith from the CSIRO told the committee that:

> …the details of future climate change are often perceived as imponderably uncertain, but in reality we have got very high confidence that change is actually happening. Indeed, some variables such as rising temperature extremes are much more certain for the future than others, and even for the ones which are less certain there are a whole range of risk mitigation approaches which are widely used in society in other contexts which are appropriate for different sorts of uncertainty.[117]

2.87 The committee was told that the IPCC uses standard terminology to communicate the degree of uncertainty in its projections of the impacts of climate

---

112 Mr Peter Davies, Northern Territory Police, Fire and Emergency Services, *Committee Hansard*, 7 March 2013, p. 1.

113 Dr Andrew Glikson, *Committee Hansard*, 11 April 2013, p. 18; see also Dr Anthony Kiem, *Committee Hansard*, 11 April 2013, p. 19; CSIRO, *Submission 93*, p. 4.

114 CSIRO, *Submission 93*, p. 10; see also Mr Ian Dunlop, *Submission 86*, p. 4.

115 BoM, *Submission 65*, p. 2.

116 Dr Anthony Kiem, *Committee Hansard*, 11 April 2013, p. 19.

117 Dr Mark Stafford Smith, CSIRO, *Committee Hansard*, 11 April 2013, p. 53; see also CSIRO, *Submission 93*, p. 5.

change.[118] For example, the level of confidence in the evidence is expressed using the qualifiers 'very low, low, medium, high and very high'.[119] The likelihood of a particular outcome is expressed in terms of probability as set out in Table 2.1 below.

Table 2.1: Terms used by the IPCC to indicate the assessed likelihood[120]

Term	**Likelihood of the outcome**
Virtually certain	99-100% probability
Very likely	90-100% probability
Likely	66-100% probability
About as likely	33-66% probability
Unlikely	0-33% probability
Very unlikely	0-10% probability
Exceptionally unlikely	0-1% probability

2.88 So the IPCC has stated that, for example:

- It is *virtually certain* that increases in the frequency and magnitude of warm daily temperature extremes and decreases in cold extremes will occur in the 21st century at the global scale;
- It is *very likely* that the length, frequency, and/or intensity of warm spells or heat waves will increase over most land areas;…
- It is *likely* that the frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase in the 21st century over many areas of the globe;…
- there is *medium confidence* that droughts will intensify in the 21st century in some seasons and areas, due to reduced precipitation and/or increased evapotranspiration;…
- it is *very likely* that mean sea level rise will contribute to upward trends in extreme coastal high water levels in the future; [and]
- There is *high confidence* that locations currently experiencing adverse impacts such as coastal erosion and inundation will continue to do so in

118 See also Professor Neville Nicholls, *Submission 1*, pp 1–4 and *Committee Hansard*, 20 February 2013, p. 8; CSIRO, *Submission 93*, p. 5; IPCC SREX, 2012, p. 21.

119 The IPCC also uses the terms 'limited, medium or robust' to describe the available evidence, and the degree of agreement about the evidence is expressed as 'low, medium or high'.

120 See CSIRO, *Submission 93*, p. 5; IPCC SREX, 2012, p. 21.

> the future due to increasing sea levels, all other contributing factors being equal.[121]

2.89 Professor Nicholls explained that:

> We are confident, for instance, that a hot day that occurs only about once every 20 years currently will occur about every year or two by the end of the century in most parts of the world. On the other hand, although heavy rainfall days are expected to become more frequent and heavier, the magnitude of the change is expected to be much less than for temperature. We are also less confident about this rainfall projection. The actual increase may be substantially more or less than our current expectation. These uncertainties can complicate the development of ways to adapt to our changing climate.[122]

2.90 In terms of projections for Australia, the committee heard that the level of confidence also varies depending on the particular climate variable. For example, the general consensus before the committee was that there is a high degree of confidence in the projections about temperatures, but less confidence in rainfall.[123] In particular, uncertainty was expressed about whether 'flood risk will increase or decrease in the majority of Australia'.[124] Similarly, there is some uncertainty about the future frequency and intensity of tropical cyclones in Australia.[125]

2.91 The uncertainty in the area of rainfall was attributed to higher natural variability in rainfall in Australia due to influences such as the El Niño Southern

---

121 IPCC SREX, 2012, pp 13 and 15 (and see Chapter 1 for more information on the findings of the IPCC SREX); see also Professor Neville Nicholls, *Submission 1*, p. 8; and Australian Meteorological and Oceanographic Society, *Submission 72*, pp 3–4.

122 Professor Neville Nicholls, *Committee Hansard*, 20 February 2013, p. 7.

123 See, for example, CSIRO, *Submission 93*, p. 5; Dr Anthony Kiem, *Committee Hansard*, 11 April 2013, p. 13; Dr Karl Braganza, BoM, *Committee Hansard*, 11 April 2013, pp 54 and 60; Dr Blair Trewin, President, Australian Meteorological and Oceanographic Society, *Committee Hansard*, 20 February 2013, p. 20; Australian Meteorological and Oceanographic Society, *Submission* 72, p. 6; ARC Centre of Excellence for Climate System Science, *Submission 57*, p. 6; Professor Neville Nicholls, *Committee Hansard*, 20 February 2013, p. 7; Dr Seth Westra, Dr Michael Leonard, Dr Mark Thyer and Professor Martin Lambert (University of Adelaide), *Submission 44*, p. 3.

124 Dr Seth Westra, Dr Michael Leonard, Dr Mark Thyer and Professor Martin Lambert (University of Adelaide), *Submission 44*, p. 4; see also BoM, *Submission 65*, p. 19.

125 BoM, *Submission 65*, p. 20.

Oscillation.[126] The committee was told that climate models 'do not currently realistically simulate' these natural cycles.[127]

Areas needing more research and analysis

2.92 The committee heard that there are areas where the knowledge and data is good, while other areas need further research and analysis.

2.93 In terms of collection of information and observations about weather, the committee was told that Australia generally has very good temperature records, rainfall measurements, and sea level records going back 100 years in places.[128] For example, Dr Neville Smith of the Bureau of Meteorology described Australia's climate records as 'pretty sound and robust, though perhaps not to the detail that we want in some regions'.[129] He also stated that Australia has 'both world-class weather forecast models and world-class climate models'.[130]

2.94 Several submitters and witnesses emphasised the need for continued support for the work of existing organisations such as the Bureau of Meteorology, CSIRO, and the Bushfire CRC. For example, witnesses welcomed the work of the Bushfire CRC in relation to bushfires, and the recent announcement of $47 million in funding to turn the Bushfire CRC into the Bushfire and Natural Hazards CRC.[131] Similarly, the Australian Meteorological and Oceanographic Society submitted that:

> Long-term, consistent, high-quality sets of observed climate are critical to the detection of climate change. Many of these observations are derived from the Bureau of Meteorology's routing observing network. Australia is a world leader in the development of such data sets but their continuation is dependent on the existence of a high-standard observations network, and the availability of adequate resources to maintain that network at a high standard.[132]

---

126 See, for example, Professor Will Steffen, Climate Commission, *Committee Hansard*, 7 June 2013, p. 11; Climate Commission, *The Critical Decade: Extreme Weather*, April 2013, p. 28; Australian Academy of Science, *Submission 125*, p. 5; Dr Andrew Glikson, *Committee Hansard*, 11 April 2013, p. 13; Dr Blair Trewin, Australian Meteorological and Oceanographic Society, *Committee Hansard*, 20 February 2013, p. 20; Dr Karl Braganza, BoM, *Committee Hansard*, 11 April 2013, p. 54.

127 Dr Anthony Kiem, *Committee Hansard*, 11 April 2013, p. 13.

128 Dr Neville Smith, BoM, *Committee Hansard*, 11 April 2013, p. 56; Dr Karl Braganza, BoM, *Committee Hansard*, 11 April 2013, p. 60; see also Dr Blair Trewin, Australian Meteorological and Oceanographic Society, *Committee Hansard*, 20 February 2013, p. 21; Australian Meteorological and Oceanographic Society, *Submission 72*, pp 7, 9.

129 Dr Neville Smith, BoM, *Committee Hansard*, 11 April 2013, p. 56.

130 Dr Neville Smith, BoM, *Committee Hansard*, 11 April 2013, p. 58.

131 Mr Gary Morgan, Chief Executive Officer, Bushfire CRC, *Committee Hansard*, 20 February 2013, pp 13-14; Mr Paul Considine, Manager Operations, Australasian Fire and Emergency Services Authorities Council, *Committee Hansard*, 20 February 2013, p. 5.

132 Australian Meteorological and Oceanographic Society, *Submission 72*, p. 9.

2.95 The Wentworth Group of Scientists told the committee that:

> We should harness the high-quality science that this country has invested in over many years to improve our emergency response capabilities to manage extreme weather by improving our capability to predict and monitor the movement and intensity of these weather systems in real time, whether it be droughts, cyclones, bushfires, floods or storm surges.[133]

2.96 Professor Nicholls expressed the view that improved weather forecasts are a good way to reduce the deleterious impacts of weather and climate extremes.[134] Similarly, the Bureau of Meteorology submitted that:

> Early warning systems have proven time and time again to be the most effective and cost efficient approach to mitigating economic losses and loss of life arising from severe weather.[135]

2.97 The committee notes that the Commonwealth government recently conducted an independent review on the Bureau of Meteorology's capacity to respond to future extreme weather and natural disaster events and to provide seasonal forecasting services. That review made a number of recommendations including, for example, the need to improve the arrangements for flood monitoring, forecasting and warning across Australia. The Bureau noted that 'the government is currently giving consideration to the recommendations of this review'.[136] The Bureau also noted in its submission that there are coordination issues in relation to flood river level monitoring, and also flash flood warnings.[137] This is discussed further in Chapter 5.

2.98 The committee heard that there are some areas needing further research. For example, the committee heard that there is a gap in knowledge when it comes to predicting cyclones in Australia. For example, Australian records for tropical cyclones rely on satellites which only go back to the seventies and eighties, and therefore there is only a small sample size.[138] So, for example, WWF-Australia and the Northern Territory emergency services expressed the view that 'more research is required to reduce the levels of uncertainty' around the projections in relation to tropical cyclones in Australia.[139] Mr Peter Davies of the Northern Territory Police, Fire and Emergency Services told the committee that many of the models being used to predict the impact

---

133 Mr Peter Cosier, Wentworth Group of Concerned Scientists, *Committee Hansard*, 11 April 2013, p. 29.

134 Professor Neville Nicholls, *Submission 1*, p. 5 and see also p. 1.

135 BoM, *Submission 65*, Attachment A, p. 2.

136 BoM, *Submission 44*, p. 26; and Department of Sustainability, Environment, Water, Population and Communities, *Review of the Bureau of Meteorology's extreme weather and forecasting capacity*, at: http://www.environment.gov.au/about/bom/ (accessed 20 June 2013).

137 BoM, *Submission 44*, pp 28–29.

138 Dr Neville Smith, BoM, *Committee Hansard*, 11 April 2013, p. 56; and Dr Karl Braganza, BoM, *Committee Hansard*, 11 April 2013, p. 60.

139 WWF-Australia, *Submission 124*, p. 5; Mr Peter Davies, Northern Territory Police, Fire and Emergency Services, *Committee Hansard*, 7 March 2013, p. 3.

of climate change are based on American models of cyclones that haven't been tested in the Australian environment.[140]

2.99 Similarly, Insurance Australia Group submitted that:

> …there are extremely few measurements of the intensity/central pressure, eye size and radius of storm force winds and storm surges of tropical cyclones, despite their potential to inflict extreme damage on communities near their paths. In the USA there is a routine program of aerial reconnaissance to quantify the physical size and intensity of these systems but there is no similar program in Australia.[141]

2.100 However, the committee heard cyclone prediction has improved in recent years due to advances in computing. Dr Smith from the Bureau of Meteorology provided some recent examples:

> If you took us back 10 years, we could not have given the forecast for tropical cyclone Yasi, simply because we did not have the computers. Now both we and other weather agencies have the ability to do tropical cyclone Yasi—and Rusty was the most recent example, off the North-West Gulf—five or even seven days out.[142]

2.101 Further improvements to supercomputing power would allow for high resolution analysis and could improve forecasting of extreme weather events. Such analysis would focus on:

> the probabilities; … the spread of possible outcomes, so you can start to give some guidance about the likelihood that a certain community might be impacted more heavily or less heavily than another community.[143]

2.102 Indeed, several submitters and witnesses, particularly local government associations, expressed a desire for more work to be done to provide data and projections for climate change and extreme weather events at a local level.[144] For example, the Australian Conservation Foundation (ACF) submitted that:

> Extreme weather events are geographically specific, and not consistent across the nation or even within any one state. Wherever possible, extreme weather trends need to be as granular as possible. Specific sea level inundation assessments for vulnerable cities such as Cairns are good examples of local, specific extreme weather assessments. This level of

---

140 Mr Peter Davies, Northern Territory Police, Fire and Emergency Services, *Committee Hansard*, 7 March 2013, p. 3.

141 Insurance Australia Group, *Submission 144*, p. 6.

142 Dr Neville Smith, BoM, *Committee Hansard*, 11 April 2013, p. 58.

143 Dr Neville Smith, BoM, *Committee Hansard*, 11 April 2013, p. 59.

144 Dr Adrian Beresford-Wylie, Chief Executive, Australian Local Government Association, *Committee Hansard*, 11 April 2013, p. 1; Local Government Association of Queensland, *Submission 68*, p. 3; see also discussion of this in Productivity Commission, *Inquiry Report: Barriers to effective climate change adaptation*, March 2013, pp 125–128.

> specificity is not found across the nation and across the spectrum of extreme weather types.[145]

2.103 Dr Smith from the Bureau of Meteorology told the committee that to get forecasting to a more local level:

> [It] just comes down to resolution—how many grid points you can put in your model, and that just depends on the size of the supercomputer.
>
> So there is a decision we have to make with government about how much investment we should put in supercomputing versus the return we get by being able to have higher resolution…[146]

2.104 At the same time, the committee heard that work is being done to provide forecasts and projections at regional and local levels.[147] For example, the Australian Meteorological and Oceanographic Society noted that a number of regional assessments of climate change impacts have been produced, including:

- the Indian Ocean Climate Initiative (for Western Australia);[148]
- Climate Futures for Tasmania;[149] and
- the South-Eastern Australian Climate Initiative.[150]

2.105 However, the Australian Meteorological and Oceanographic Society noted that:

> Neither IOCI nor SEACI, which were both joint projects involving various Commonwealth and State agencies, have received ongoing funding and both have been, or are in the process of being, wound up, which is a concern for the future availability of regionally-specific assessments.[151]

2.106 In terms of regional and local projections, the Griffith Centre for Coastal Management submitted information about its research project to produce a pilot real-time storm surge forecasting system for Queensland.[152] They identified a number of constraints and actions that would improve the accuracy of such forecasting, including

---

145 Australian Conservation Foundation, *Submission 36*, p. 2.

146 Dr Neville Smith, BoM, *Committee Hansard*, 11 April 2013, p. 58; see also BoM, *Submission 65*, Attachment A.

147 Dr Blair Trewin, Australian Meteorological and Oceanographic Society, *Committee Hansard*, 20 February 2013, p. 20; Ms Mara Bunn, Chief Executive Officer, Green Cross, *Committee Hansard*, 22 February 2013, p. 17; Griffith Centre for Coastal Management, *Submission 58*, p. 1.

148 See further: www.ioci.org.au (accessed 20 June 2013).

149 See further: http://www.dpac.tas.gov.au/divisions/climatechange/adapting/climate_futures (accessed 20 June 2013); and Antarctic Climate and Ecosystems CRC, *Submission 125*, p. 1. Noted that some of the results of this initiative have been discussed in this chapter.

150 See further: www.seaci.org (accessed 20 June 2013).

151 Australian Meteorological and Oceanographic Society, *Submission 72*, pp 2–3.

152 Griffith Centre for Coastal Management, *Submission 58*, p. 1.

improvements to data availability and collection in terms of bathymetry,[153] wind, wave and water level measurements; and further research into the dynamics of storm surge propagation through the Great Barrier Reef.[154] For example, the Griffith Centre suggested that 'Australia's network of storm tide gauges is sparse relative to the length of coastline and the expanding vulnerable population'.[155]

2.107 However, the committee notes that the Queensland government reported that Queensland has 25 fully operational storm surge monitoring gauges.[156]

2.108 Others gaps in Australia's observation network were also identified. For example, Dr Todd Lane from the Australian Meteorological and Oceanographic Society noted that there are gaps in Australia's radar network:

> The Bureau of Meteorology have expanded their radar network considerably in recent years and are still expanding the network, but along the coastlines there are still gaps in coverage. There are places in Far North Queensland which do not receive any radar coverage at all and parts of the Northern Territory as well. There are these sizeable gaps in the radar network when you compare it to other countries. The UK is entirely covered by radar. In the US there are only a couple of small gaps around the country. But Australia has some very large gaps. If we are talking about major investment in infrastructure for detecting flooding rains, radar could be one of those things.[157]

2.109 The committee also heard that more research is needed on the interaction between human-induced climate change and large-scale natural climate variations, such as the El Niño/Southern Oscillation and the Pacific Decadal Oscillation/ Interdecadal Pacific Oscillation.[158] Others emphasised the need for more research in the area of rainfall and the drivers of floods and drought. For example, Dr Anthony Kiem told the committee that research funding is needed to increase understanding of

---

153 'Bathymetry' is the study and mapping of seafloor topography. It involves obtaining measurements of the depth of the ocean and is equivalent to mapping the topography on land: See further Geoscience Australia, *Bathymetry*, at: http://www.ga.gov.au/marine/bathymetry.html (accessed 24 June 2013).

154 Griffith Centre for Coastal Management, *Submission 58*, pp 4–5; see also Professor Rodger Tomlinson, Director, Griffith Centre for Coastal Management, Griffith University, *Committee Hansard*, 22 February 2013, p. 24.

155 Griffith Centre for Coastal Management, *Submission 58*, p. 6.

156 Letter from The Hon Ros Bates MP, Minister for Science, Information Technology, Innovation and the Arts, Queensland Government dated 30 January 2013.

157 Dr Todd Lane, Vice President, Australian Meteorological and Oceanographic Society, *Committee Hansard*, 20 February 2013, p. 22.

158 Mr Jeff Callaghan, Green Cross Australia, *Committee Hansard*, 22 February 2013, pp 18 and 22; Dr Anthony Kiem, *Submission 5*, pp 1–2; Professor Stewart Franks, *Submission 102*, p. 1.

'the drivers of flood and drought risk in Australia…especially at the local or catchment scale'.[159] Others agreed that:

> There is currently a lack of substantive research into understanding how the interaction of likely increases in flood-producing rainfall and the net drying of catchments will increase future flood risk…[160]

2.110 In terms of rainfall records, Dr Blair Trewin from the Australian Meteorological and Oceanographic Society informed the committee that:

> For remoter areas, records are often short term and, perhaps surprisingly, some of the coastal areas are not as good for rainfall records as they could be—sites have moved around and that sort of thing.[161]

2.111 The Australian Meteorological and Oceanographic Society suggested that 'the potential exists to reduce such data voids through the strategic opening of new stations'.[162] Others identified a need for more rain gauges to help predict flash flood warnings.[163]

2.112 Insurance Australia Group called for more work in the area of storm surges:

> …the threat of storm surge for most parts of Australia has been limited to simple sea level rise scenarios rather than taking into account potential changes in the weather systems likely to produce a storm surge and the detailed bathymetry and coastal zone features that will modify and, in some cases, increase the threat of storm surge in coastal regions.
>
> There is a need to more accurately quantify the risks facing properties in coastal and estuarine regions, particularly in locations where there is a merging of the riverine floods with coastal storm surge effects.[164]

2.113 Insurance Australia Group further noted that there has been 'no thorough investigations into likely changes in the distribution or seasonality of severe storms in the future' and that:

> This research, with the involvement of the insurance industry, is very important if our major urban centres are to be made more resilient to the impacts of these storms in the future.[165]

---

159 Dr Anthony Kiem, *Committee Hansard*, 11 April 2013, p. 13; see also Australian Meteorological and Oceanographic Society, *Submission 72*, p. 7.

160 Dr Seth Westra, Dr Michael Leonard, Dr Mark Thyer and Professor Martin Lambert (University of Adelaide), *Submission 44*, p. 3.

161 Dr Blair Trewin, Australian Meteorological and Oceanographic Society, *Committee Hansard*, 20 February 2013, p. 21; see also Australian Meteorological and Oceanographic Society, *Submission 72*, pp 7, 9.

162 Australian Meteorological and Oceanographic Society, *Submission 72*, p. 9.

163 Mr Paul Considine, Australasian Fire and Emergency Services Authorities Council, *Committee Hansard*, 20 February 2013, p. 2.

164 Insurance Australia Group, *Submission 144*, pp 13–14.

Committee comment

2.114 The committee recognises the evidence that climate change is likely to increase the frequency and intensity of extreme weather events in the coming decades. The committee also recognises the fundamental importance of being able to predict and monitor extreme weather to enable us to manage and improve our capability to respond to future extreme weather events. In this respect, the committee commends organisations such as the Bureau of Meteorology and CSIRO for their excellent work in this area. The committee considers that this work is fundamental to Australia's future planning to manage extreme weather events and in relative terms Australia is very well served by the extent of work already undertaken. The committee therefore recommends that the Commonwealth government, through the Bureau of Meteorology and CSIRO, continue to support data collection and research to improve forecasting of extreme weather events, especially early warning capabilities.

Recommendation 1

2.115 The committee recommends that the Commonwealth government, through the Bureau of Meteorology and CSIRO, continues to support data collection and research to improve forecasting of extreme weather events, especially early warning capabilities.

2.116 The committee also heard that there is a need for more data and research to make predictions at a more local level for future planning purposes. On that basis, the committee recommends that the Bureau of Meteorology and CSIRO continue their work to improve projections and forecasts of extreme weather events at a more local level, especially in relation to events such as flooding or storm surges.

Recommendation 2

2.117 The committee recommends that the Bureau of Meteorology and CSIRO continue to improve projections and forecasts of extreme weather events at a more local level.

2.118 The committee notes that a number of areas for further research were identified during the course of the committee's inquiry. In particular, the committee acknowledges that there is a need to conduct further research to improve understanding of the interaction between large-scale natural climate variations, climate change and extreme weather events.

The committee recognises that there are areas where there is a high degree of confidence in the projections of future extreme weather, particularly in relation to future temperatures. However, there are other areas where there is less confidence and further research is needed, particularly in relation to changes to future rainfall patterns and the associated floods and droughts. There is also uncertainty in relation to the implications of climate change for tropical cyclones in Australia. The committee therefore recommends that the Bureau of Meteorology and CSIRO conduct further

165 Insurance Australia Group, *Submission 144*, p. 14; see also Australian Meteorological and Oceanographic Society, *Submission 72*, p. 8.

research to increase understanding in these areas and that Australia cooperatively engage, where appropriate, with international research initiatives in these areas.

Recommendation 3

2.119 The committee notes the linkage between climate change and extreme weather events and recommends that the Bureau of Meteorology and CSIRO conduct further research to increase understanding in the areas of:

- **the interaction between large-scale natural variations, climate change and extreme weather events;**
- **the impacts of climate change on rainfall patterns and tropical cyclones; and**
- **that Australia cooperatively engage, where appropriate, with international research initiatives in these areas.**