Chapter 2

Changes in ocean temperatures, currents and chemistry associated with climate change

2.1 This chapter provides an overview of the evidence presented to the committee regarding warming ocean temperatures, changing ocean chemistry and altering ocean currents. Projections of further rises in ocean temperatures, rising sea levels and more extreme weather events due to climate change are also discussed.

Rising ocean temperatures

2.2 The Institute for Marine and Antarctic Studies (IMAS) advised that '[s]ea-surface temperatures trends for the period 1901 to 2012 are rising everywhere except in the northern Atlantic'. Since 1901, the global average temperature change has been recorded as approximately 0.89ºC [0.69–1.08ºC], with an average change of 0.075ºC to 0.083ºC (±0.013ºC) per decade.[1] The Bureau of Meteorology has reported that surface temperatures were the highest on record in 2016 both globally and in the oceans around Australia. For the oceans around Australia, the Bureau reported that the annual mean sea surface temperatures were 0.73°C above average (records date back to 1910). The previous record of 0.64ºC above average occurred in 2010.[2]

2.3 IMAS explained that the largest temperature changes have been recorded in the surface ocean, with smaller changes occurring in deeper layers. Available evidence includes the following:

- the top 75 metres of the ocean has warmed at a rate of 0.11ºC [0.09–0.13ºC] per decade since 1971, which is the same rate, within errors, as the rate of global average surface temperature warming; and
- below the top 75 metres, '[t]here is good evidence that the deep ocean below 3000 metres has warmed, and that the mid-depth ocean (between 2000 to 3000 metres) has not warmed, consistent with our understanding of global ocean circulation'.[3]

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1 Institute for Marine and Antarctic Studies (IMAS), *Submission 1*, p. 11. The research cited is (Stocker et al 2013) TF Stocker et al, 'Technical Summary', in TF Stocker et al (eds), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, 2013, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

2 Bureau of Meteorology, 'Annual climate statement 2016', 5 January 2017, www.bom.gov.au/climate/current/annual/aus/2016 (accessed 5 January 2017).

3 IMAS, *Submission 1*, p. 11.

2.4 IMAS added that the 'south east region of Australia is recognised as one of the fastest warming regions globally'. Evidence supporting this includes:

- direct observations since the 1940s indicating that warming in this region 'is approximately 3.8 times the global average'; and
- sea surface temperatures over a 50-year period indicating that this region 'is warming faster than 90% of the ocean'.[4]

2.5 Professor Stewart Frusher from IMAS observed that although it 'is often very difficult to attribute the exact cause of why something has occurred…the weight of evidence that underpins the changes we are seeing on particularly our south-eastern seaboard indicates that our waters are warming'. To demonstrate, Professor Frusher continued by referring to warming waters off Maria Island, which is located off the east coast of Tasmania. Professor Frusher stated:

> One of the few long-term datasets we have is off Maria Island. Fortunately, they have maintained measuring the water temperature there since the 1940s. The consistent trend in that data is an increase in water temperature over that period to the extent that the water that was off Eden in southern New South Wales in the 1940s is now equivalent to what we see off Maria Island. That water body is now equivalent. When you think about the changes, it includes looking at those ecosystems which were off Eden in the 1940s and the ones off Maria Island now.[5]

2.6 Dr Neville Barrett, also from IMAS, added that the climate predictions for this area of Tasmania is that the climate will be the same as Batemans Bay in New South Wales by 'at best case, 2100 and, at worst case, 2060'.[6]

2.7 High temperatures have also been recorded elsewhere. IMAS explained that the term 'marine heat wave' has been coined to account for observations of extreme temperatures in regions of the oceans.[7] Marine heat wave events were recorded in Western Australia (2011) and the Great Barrier Reef (2016).[8]

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4 IMAS, *Submission 1*, p. 3 (emphasis omitted).

5 Professor Stewart Frusher, IMAS, *Committee Hansard*, 21 February 2017, p. 1.

6 Dr Neville Barrett, IMAS, *Committee Hansard*, 21 February 2017, p. 5.

7 IMAS, *Submission 1*, p. 12. A marine heat wave event has been defined as 'a discrete prolonged anomalously warm water event', where 'discrete implies the [marine heat wave] is an identifiable event with clear start and end dates, prolonged means it has a duration of at least five days and anomalously warm means the water temperature is warm relative to a baseline climatology'. This definition was articulated in A Hobday et al, 'A hierarchical approach to defining marine heatwaves', *Progress in Oceanography*, vol. 141, 2016, pp. 227–238; cited in E Oliver et al, 'The unprecedented 2015/16 Tasman Sea marine heatwave', *Nature Communications*, vol. 8, July 2017, p. 10.

8 Australian Marine Sciences Association, *Submission 5*, p. 2; IMAS, *Submission 1*, p. 12; Fisheries Research and Development Corporation (FRDC), *Submission 2*, p. 5.

2.8 During the major El Niño Southern Oscillation Event of late 2015 to April 2016, the oceanic temperature at Thursday Island reached an average daily peak of 31.90ºC on 13 March 2016, which is 0.4ºC higher than the peak of 2010.[9] The Western Australian marine heat wave event 'resulted in the highest sea surface temperatures off south-western Australia on record'.[10] A journal article on the heat wave event provided the following overview of recorded temperature changes:

> Following temperature anomalies within ±1 °C for most of 2010, as well as the dominantly negative temperature anomalies off the upper west coast during the first half of 2010 (likely a result of the 2009/2010 El Niño event), the water began to warm from October and climbed steadily into summer. There was a rapid phase transition from the "warm pool" El Niño to La Niña conditions in 2010, probably due to the Indian Ocean warming…The peak anomaly at Ningaloo was 3 °C in January, and there were even higher peaks between Shark Bay and the Abrolhos Islands in February. Down at Cape Leeuwin, the peak temperature was about 2.5 °C and occurred in March. These elevated temperatures gradually decayed to more typical levels between April and July.[11]

2.9 The frequency of these marine heat wave events is increasing.[12] Dr Janice Lough, Senior Principal Research Scientist, Australian Institute of Marine Science (AIMS), explained that core records based on isotopic records trapped in coral skeletons indicate that recent warm events 'are exceptional, going back to at least…about 1600'.[13]

2.10 Figure 2.1 illustrates how sea surface temperatures in the oceans around Australia in 2016 compare to historical records. Figure 2.2 provides detailed maps illustrating surface sea temperatures off the coast of Tasmania between 2010 and 2017. Further graphs and charts indicating historical trends in temperature changes were provided by CSIRO.[14]

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9 Torres Strait Regional Authority, *Submission 16*, p. [4].

10 A Pearce and M Feng, 'The rise and fall of the "marine heat wave" off Western Australia during the summer of 2010/2011', *Journal of Marine Systems*, 111–112, 2013, p. 154.

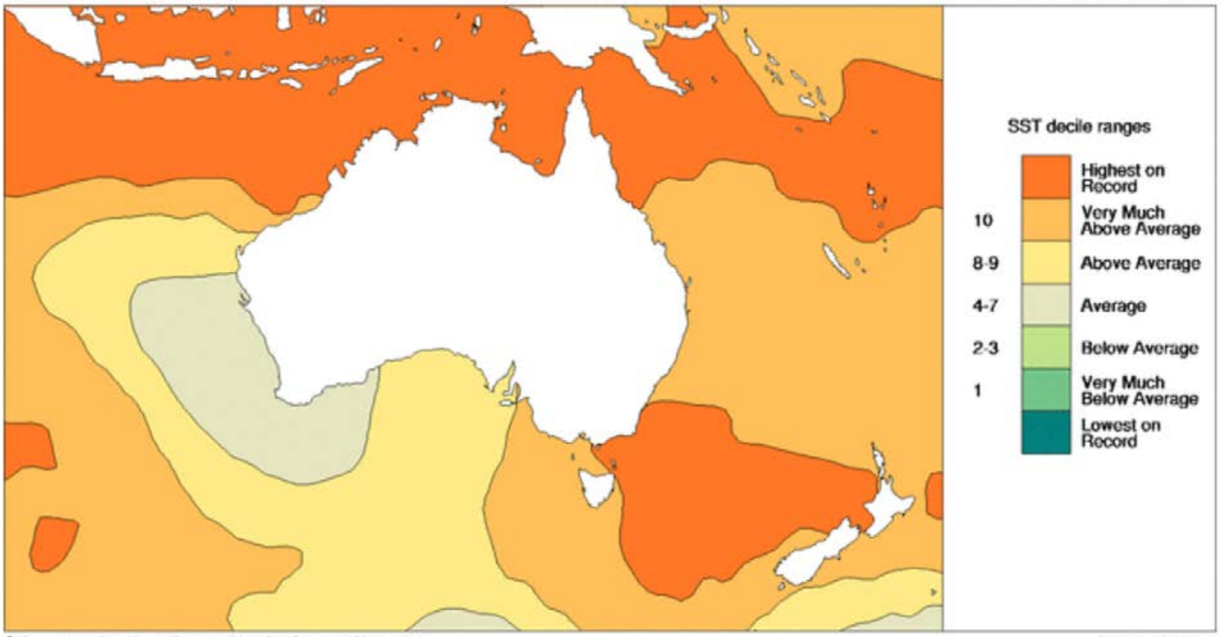
11 A Pearce and M Feng, 'The rise and fall of the "marine heat wave" off Western Australia during the summer of 2010/2011', p. 143.

12 Australian Marine Sciences Association, *Submission 5,* p. 2; IMAS, *Submission 1,* p. 12; FRDC, *Submission 2,* p. 5.

13 Dr Janice Lough, Senior Principal Research Scientist, Australian Institute of Marine Science (AIMS), *Committee Hansard*, 30 August 2017, p. 35.

14 See CSIRO, Answers to questions on notice, 17 March 2017 (received 20 April 2017).

Figure 2.1: Australian region sea surface temperature (SST) deciles: annual 2016



Note: distribution based on gridded data.

Source: Bureau of Meteorology, 'Annual climate statement 2016', 5 January 2017, www.bom.gov.au/climate/current/annual/aus/2016 (accessed 5 January 2017); from the NOAA Extended Reconstructed Sea Surface Temperature dataset, ERSST v4.

2.11 IMAS explained that projected changes in ocean temperatures 'depend very strongly on the emissions pathway taken by society'. IMAS advised that:

- under the Intergovernmental Panel on Climate Change's low emissions pathway (RCP2.6), by the end of the 21st century Australian marine temperatures are projected to rise by a further 0.5–1.0ºC from the 1986–2005 base period; and
- under the high emissions pathway (RCP8.5), it is projected that Australian marine temperatures will rise by 2–4ºC (over the same period as above).[15]

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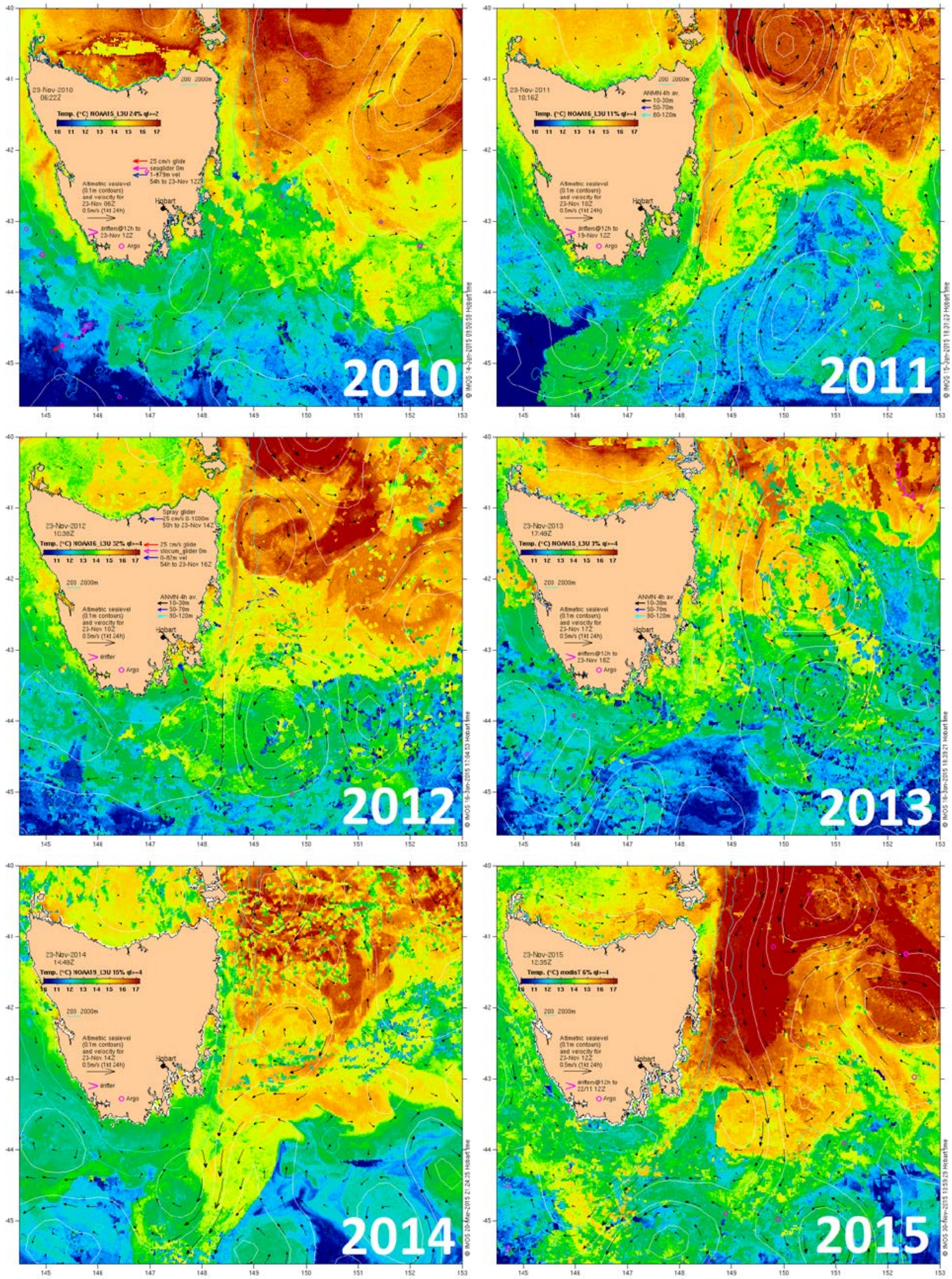
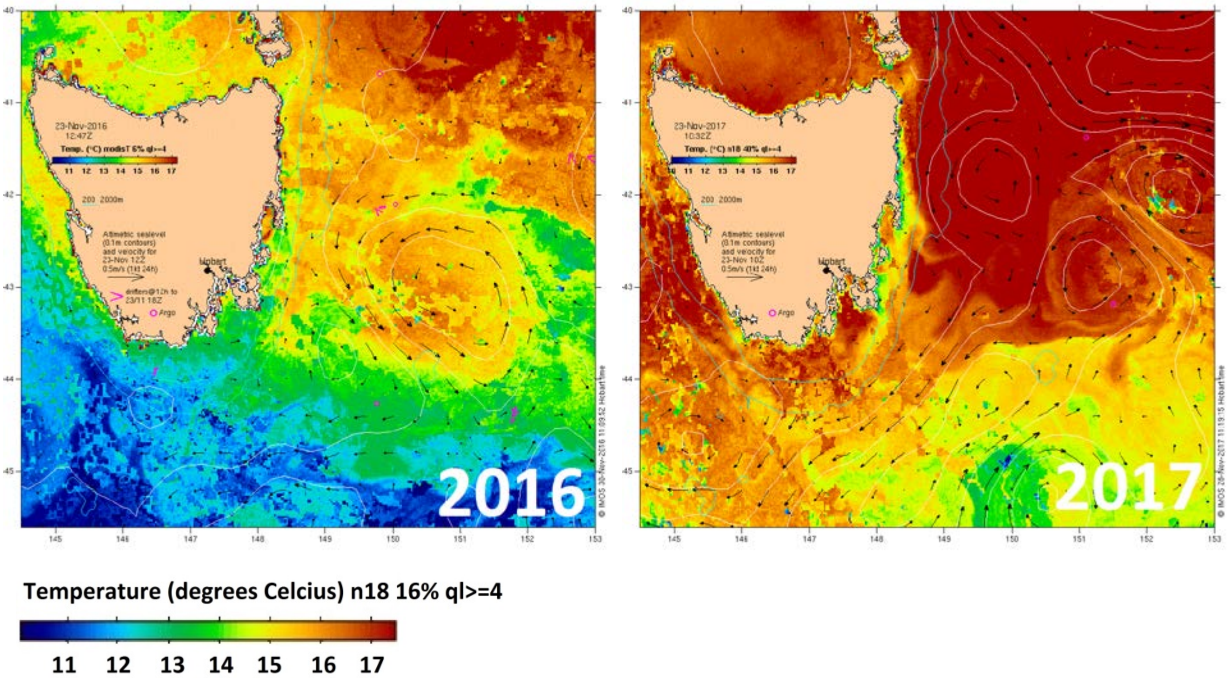
15 IMAS, *Submission 1*, p. 12.

Figure 2.2: Sea surface temperatures on 23 November 2010–2017 off the coast of Tasmania





Source: IMOS, Sea Surface Temperature maps, http://oceancurrent.imos.org.au/sst.php (accessed 28 November 2017).

Changing ocean currents

2.12 Evidence received during this inquiry commented on developments regarding the East Australian Current and the Leeuwin Current.

2.13 The East Australian Current is the largest ocean current close to the Australian coastline. The current is formed from the remnants of the South Equatorial Current that flow southward after crossing the Coral Sea. It has a significant influence on the marine environment off the east coast of Australia due to the warmer ocean water it carries southward. The current is around 100 kilometres wide and transports 40 million cubic metres of water southward each second at up to 3 kilometres per hour.[16]

2.14 The warming observed off Maria Island, Tasmania, since the 1940s referred to in paragraph 2.5 is related to the increased strength of the East Australian Current.[17] CSIRO advised that climate models suggest that, by 2060, the strength of the current will have increased by 12 per cent in the core area and by 35 per cent in the poleward extension.[18]

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16 FRDC, *Submission 2*, p. 29; E van Sebille, E Oliver and J Brown, 'Can you surf the East Australian Current, Finding Nemo-style?', *The Conversation*, 6 June 2014, https://theconversation.com/can-you-surf-the-east-australian-current-finding-nemo-style-27392 (accessed 13 November 2017).

17 IMAS, *Submission 1*, p. 3.

18 CSIRO, *Submission 15*, p. 11 (citations omitted).

2.15 In addition to the evidence of a strengthening East Australian Current with an increased southwards reach, changes in the formation of eddies[19] are also of concern to scientists. IMAS and the Sydney Institute of Marine Science (SIMS) explained that the frequency of eddy formation is a key feature of the East Australian Current.[20] IMAS submitted that 'an increased frequency of sudden warming events off Tasmania's east coast' could occur as a result of potential increases in eddy activity, with eddies lasting longer.[21] The Fisheries Research and Development Corporation (FRDC) provided the following evidence about eddies observed in that region:

> Scientists have noted a trend in eddies off Tasmania becoming larger, stronger and more frequent. Following the 1990s, eddy kinetic energy (EKE) increased gradually both north…and south…of Bass Strait, with a huge spike in eddy activity off Tasmania (8 times the average EKE of the 1990s) in 2014…This trend is in agreement with climate modelling but there has been a dramatic increase over the last couple of years.[22]

2.16 Similarly, CSIRO submitted that:

> For the Tasmanian coast, it is expected the water will continue to warm faster than the rest of the world as more warm East Australian Water moves southward with a strengthening…[East Australian Current] and increased generation of its eddies.[23]

2.17 A detailed description of how changing ocean currents are affecting Australian waters was provided by Dr Barrett as part of an explanation of the attributes that are making Tasmania a global hot spot for ocean warming. Dr Barrett stated:

> A big part of it, really, is the fact that we are at the confluence of a range of different current systems. We have the East Australian Current coming down the eastern Australian coastline, obviously, and influencing Tasmania on that side. Then we have subantarctic water that bathes the southern parts of Tasmania to some degree and we have the tail end of the Leeuwin Current coming over from Western Australia. All these things are in a dynamic balance over the years and have influenced us in various ways.
>
> But as the waters have warmed up in eastern Australia, that East Australian Current is starting to flow more strongly down the eastern Australian coastline and it is starting to overdominate the other current systems that

19 Eddies, which are circular currents of water, cause nutrients in colder, deeper waters to come to the surface. US National Oceanic and Atmospheric Administration, 'What is an eddy?', http://oceanservice.noaa.gov/facts/eddy.html (accessed 13 December 2016).

20 IMAS, *Submission 1*, p. 12; Sydney Institute of Marine Science (SIMS), *Submission 8*, p. 3.

21 IMAS, *Submission 1*, p. 12.

22 FRDC, *Submission 2*, p. 29.

23 CSIRO, *Submission 15*, p. 12.

> typically have influenced us. So we have had a real increase through time of the temperature that this water actually brings onto our coastline.[24]

2.18 Increased eddy formation in this region is expected to have implications for fish stocks, which are discussed in Chapter 3.

2.19 Although the East Australian Current attracted significant comment, evidence was also received about the Leeuwin Current. The Leeuwin Current is off the coast of west and south-western Australia: it 'sweeps down Australia's west coast, from about the North West Cape and can extend as far as the Great Australian Bight and the southwest of Tasmania'.[25] The current 'brings warm, low-salinity tropical waters southwards and then eastwards along the south coast of the continent'.[26] CSIRO explained that, unlike the East Australian Current, the Leeuwin Current has weakened in strength over the past 50 years by 10–30 per cent. The current is predicted to weaken further by 15 per cent by 2060.[27]

Rising sea levels

2.20 Rising sea levels linked to climate change were noted. The Australian Fisheries Management Authority (AFMA) referred to research indicating that, globally, the average sea level has risen by 0.19 metres between 1901 and 2010. Furthermore, the rate of sea level rise has increased: for the period 1901–2010 it was measured at 1.7 millimetres per year whereas over the period 1993–2010 the rate was 3.2 millimetres per year.[28] By 2100, it is projected that sea levels could have risen by up to 0.8 metres.[29]

2.21 Rates of sea level rise that are greater than the global average have been observed in and near Australian waters. In the Torres Strait, research published in 2010 indicated that the sea level had risen at approximately six millimetres per year. In waters near Papua New Guinea, an annual average increase of seven millimetres since 1993 has been measured.[30]

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24 Dr Neville Barrett, IMAS, *Committee Hansard*, 21 February 2017, p. 2.

25 Bureau of Meteorology, 'Forecast help', www.bom.gov.au/oceanography/forecasts/forecast-help.shtml (accessed 13 November 2017).

26 A Pearce and M Feng, 'The rise and fall of the "marine heat wave" off Western Australia during the summer of 2010/2011', p. 139.

27 CSIRO, *Submission 15*, p. 11.

28 Australian Fisheries Management Authority (AFMA), *Submission 9*, p. 8 (citation omitted).

29 AFMA, *Submission 9*, p. 9.

30 Torres Strait Regional Authority, *Submission 16*, p. [3].

Changing ocean chemistry

2.22 Rising carbon dioxide levels in the atmosphere has caused the surface ocean to acidify and this trend is expected to continue. AIMS provided the following explanation of how rising levels of carbon dioxide in the atmosphere leads to ocean acidification:

> Concentrations of carbon dioxide (CO_2) are rising rapidly in the atmosphere, due to the burning of fossil fuels and deforestation, and about 25% of this extra CO_2 added to the atmosphere is being absorbed by the oceans.
>
> When atmospheric CO_2 dissolves in seawater, it first forms carbonic acid and triggers a cascade of other chemical changes. The concentrations of hydrogen ions increase and carbonate ions decline. In fact, the concentrations of hydrogen ions have already increased by 30% in the seawater compared with preindustrial times.[31]

2.23 IMAS explained that the 'pH of surface waters of the ocean has decreased by about 0.1 since the pre-industrial era, an increase of 26% in hydrogen ion concentrations'.[32] AIMS added that the pH of the ocean is 'predicted to further decline by 0.2–0.4 by the end of this century'. This acidification of the ocean reduces the ability of marine organisms such as corals to calcify and may also 'lead to behavioural changes in fishes and invertebrates'.[33]

2.24 IMAS also noted that the 'concentration of oxygen in the oceans is changing'. IMAS explained:

> …in the main thermocline it has decreased and the tropical oxygen minimum zones have expanded, and these changes have also been attributed to human influence.[34]

2.25 The FRDC submitted that changes to ocean chemistry are 'the less understood' of the changes to physical attributes of oceans.[35]

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31 AIMS, *Submission 10*, p. 4.

32 IMAS, *Submission 1*, p. 11.

33 AIMS, *Submission 10*, p. 4.

34 IMAS, *Submission 1*, p. 11.

35 FRDC, *Submission 2*, p. 5.

Extreme weather events

2.26 In tropical Australia, coastal areas are projected 'to experience more intense storms and severe weather events'.[36] An increase in average cyclone intensity is also projected as the climate warms. Incidences of strong tropical cyclones are expected to increase for particular regions as follows:

- southern Great Barrier Reef—from one every 25 or more years at present to one every 6–12 years; and
- Western Australian coast (Pilbara to southern Kimberley)—from one every 10 years to one every 7.5 years.[37]

2.27 Among other things, the increased frequency and intensity of severe weather events are expected to have implications for fish stocks and the health of coral reefs. These consequences are discussed in Chapter 3.

Overview of monitoring arrangements

2.28 This chapter has provided an overview of the recent and projected changes in ocean temperatures, currents and chemistry associated with climate change. This following section briefly outlines the infrastructure used to observe and monitor these changes. Key knowledge gaps and challenges faced in considering changes in ocean temperatures, currents and chemistry associated with climate change are then discussed.

2.29 At present, the Integrated Marine Observing System (IMOS) provides key monitoring infrastructure for observing developments in Australia's marine environment. IMOS, which was established in 2006, is operated by several institutions as a joint venture. It receives core funding from the Australian Government under the National Collaborative Research Infrastructure Strategy (NCRIS). Co-investment from state governments and operational partners also support IMOS.[38]

2.30 IMOS is 'a national collaborative research infrastructure' involving the deployment of a wide range of observing equipment in the oceans around Australia. More specifically, IMOS is 'a fully-integrated, national system, observing at ocean-basin and regional scales, and covering physical, chemical and biological

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36 CSIRO, *Submission 15*, p. 12.

37 AIMS, *Submission 10*, p. 7.

38 Integrated Marine Observing System (IMOS), 'What is IMOS', http://imos.org.au/about/ (accessed 14 November 2017).

variables'.[39] IMOS utilises a wide range of techniques including: Argo Floats (autonomous profiling floats), Ships of Opportunity (volunteer commercial and research vessels), deep water moorings, ocean gliders, autonomous underwater vehicles, a national mooring network,[40] ocean radar, animal tracking, wireless sensor networks and satellite remote sensing.[41] Some of these techniques utilise long-running measurement programs, such as a 70-year history of recording temperature and salinity off Sydney.[42]

2.31 IMOS observations focus on the following five major research themes: long-term ocean change; climate variability and weather extremes; boundary currents; continental shelf and coastal processes; and ecosystem responses. The data collected as part of IMOS are available for use 'by the entire Australian marine and climate science community and its international collaborators'.[43]

2.32 Dr Alan Jordan, Principal Research Scientist, New South Wales Department of Primary Industries, described IMOS as the 'fundamental building block' of the data relied on for ocean temperatures. Dr Jordan explained:

> If we did not have that nationally approved infrastructure process underway, we would not have the sort of data that we collect. It has managed to massively increase our understanding of how the system operates, why we get upwelling events in certain places, and the derivation of the satellite imagery and the temperature loggers. Unless you have got instrumentation out there that is measuring this stuff, it is purely speculative. It is a big water column out there, and the satellites only see about the top five centimetres, so what is going on under that five centimetres is where the whole three-dimensional nature of the ocean works, and having things like the gliders that profile the water column is fundamental. The New South Wales government has supported the IMOS

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39 The Lead Agent of IMOS is the University of Tasmania, which operates IMOS in partnership with CSIRO, AIMS, Bureau of Meteorology, SIMS (encompassing the University of New South Wales, The University of Sydney, Macquarie University and University of Technology Sydney), University of Western Australia, Curtin University and the South Australian Research and Development Institute. IMOS, 'What is IMOS', http://imos.org.au/about/ (accessed 14 November 2017).

40 The moorings network measures physical and biological parameters of Australian coastal waters using a network of national reference stations, regional arrays of shelf moorings, acidification moorings and acoustic observatories. The national reference stations are located at Kangaroo Island, SA; Yongala and Stradbroke Island, QLD; Darwin, NT; Maria Island, TAS; Port Hacking, NSW; Rottnest Island, WA. IMOS, 'National Mooring Network', http://imos.org.au/facilities/nationalmooringnetwork/ (accessed 14 November 2017).

41 IMOS, 'Facilities', http://imos.org.au/facilities/ (accessed 14 November 2017).

42 Professor Iain Suthers, SIMS, *Committee Hansard*, 16 March 2017, p. 20.

43 IMOS, 'What is IMOS', http://imos.org.au/about/ (accessed 14 November 2017).

> program for a long time, and we see no reason not to continue that support. It will be a fundamental component of our long-term monitoring program.[44]

2.33 Research is also informed by the real-time global sea surface temperature (SST) analysis developed in the United States of America by the National Oceanic and Atmospheric Administration. For example, research into the 2011 marine heat wave off the coast of Western Australia utilised Reynolds SST analysis (named after Richard Reynolds from the National Climatic Data Center, now the National Centers for Environmental Information, who developed the analysis). This large-scale SST analysis supplemented local temperature monitoring that also informed the research.[45]

2.34 Another example of long-term monitoring is at the Great Barrier Reef. The long-term monitoring program undertaken by AIMS has been surveying the health of 47 midshore and offshore reefs across the Great Barrier Reef region for over 20 years.[46] In addition to the AIMS monitoring program, Professor David Booth explained that there is a smaller monitoring effort undertaken 'on a shoestring'. Professor Booth advised that, in the early 1990s, he was located with a team undertaking monitoring at the Great Barrier Reef. The professor stated that the team has 'done some amazing work', which enables assessments to be made about causes of change in the Reef, such as the degree to which damage has been caused by crown-of-thorns starfish and coral bleaching.[47]

Knowledge gaps and other considerations

2.35 In considering changes in ocean temperatures, currents and chemistry associated with climate change, it is important to note the difficulties scientists face in determining whether, and to what extent, developments are linked to climate change. This was recognised by the scientific organisations that presented evidence to the committee; for instance, the FRDC noted 'there will always be levels of uncertainty due to the confounding nature of separating climate variability from climate change'.[48]

2.36 Professor Gustaaf Hallegraeff from IMAS also made observations about the difficulties faced by researchers considering the implications of climate change on the marine environment. He stated 'there is no doubt' that Earth's climate has been changing throughout time; however stated that '[t]he only thing that is different is that

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44 Dr Alan Jordan, Principal Research Scientist, New South Wales Department of Primary Industries, *Committee Hansard*, 16 March 2017, p. 51.

45 A Pearce and M Feng, 'The rise and fall of the "marine heat wave" off Western Australia during the summer of 2010/2011', p. 141.

46 AIMS, 'Monitoring Australia's tropical reefs', www.aims.gov.au/docs/research/monitoring/reef/reef-monitoring.html (accessed 14 November 2017).

47 Professor David Booth, *Committee Hansard*, 16 March 2017, p. 6.

48 FRDC, *Submission 2*, p. 5.

it is changing so rapidly now'. The professor explained that this has implications for research conclusions:

> The only thing that is different is that it is changing so rapidly now. We cannot find any precedents in the history of this planet. We are trying desperately to understand what is going on. We are trying to predict what a good spot is going to be or which fisheries could be aquaculture in the future. We have some successes, but in general that is the experience of my discipline: marine ecosystems, under climate change, are becoming much more unpredictable.[49]

2.37 Professor Hallegraeff added that within the scientific community, even at a localised level in cities such as Hobart, there is an ongoing debate about how close the correlation between rising emissions and warming oceans or rising ocean temperatures is. Regarding the warming water temperatures on the east coast of Tasmania, Professor Hallegraeff noted:

> …we can see a global signal of warming, but the much bigger signal is a shift in east Australian currents. Even within our institute there is still a big discussion: is that shift in that warm current part of the global warming signal? A scientist at CSIRO, Andrew Lenton, claims that this actually links to the ozone hole and the atmospheric air currents going faster and spinning with it the east Australian currents signal.
>
> And then, of course, what we had in 2016, this marine heatwave, was yet another warming signal on top of an El Nino event that affected the whole Pacific. The heatwave did not just happen on the east coast of Tasmania; it also happened in Chile, where it did enormous damage to salmon aquaculture, and on the northwest coast of America, where they had all kinds of strange problems with what they call the hot block. So there are a lot of different phenomena that cause this warming, and attribution to greenhouse warming per se—any reputable scientist would say there is lots of uncertainty.[50]

2.38 These comments notwithstanding, Professor Hallegraeff concluded:

> The end product of what we are dealing with now, this warm water, that is what we have to deal with and we have to adapt to it.[51]

49 Professor Gustaaf Hallegraeff, IMAS, *Committee Hansard*, 21 February 2017, p. 2.

50 Professor Gustaaf Hallegraeff, IMAS, *Committee Hansard*, 21 February 2017, p. 3.

51 Professor Gustaaf Hallegraeff, IMAS, *Committee Hansard*, 21 February 2017, p. 3.

2.39 Scientific organisations also noted that there are gaps in knowledge about how climate change will affect the physical attributes of the oceans. They argued that further research is required and, in particular, that there is a need for long-term climate monitoring of the marine environment. For example, IMAS submitted:

> It is crucial that investment in IMOS, sensor arrays, and modelling capacity at the regional scale is maintained to provide us with the physical basis for assessing and understanding changes on ecosystems and fisheries.[52]

2.40 IMAS informed the committee that, due to the small number of long-term data sets, there is a lack of information available for understanding the implications of climate change. Professor Frusher referred to work undertaken by IMAS scientists in marine protected areas, which are 'one of the few areas where we actually have continued long-term monitoring'. He added:

> We have very little long-term monitoring in any other areas, and it would be prudent, I would have thought, to actually have a range of these around Australia as scientific sites. But, of course, being able to maintain science in these areas is not a cheap prospect.[53]

2.41 The FRDC submitted that 'there is an ongoing need for continued science investment', such as the deployment of sensor arrays from RV *Investigator* and using the AIMS Sea Simulator (SeaSim) to understand the implications of changing pH.[54]

2.42 Evidence regarding the need for long-term funding arrangements for climate monitoring and research is considered further in Chapter 6.

2.43 Ocean acidification was highlighted as an issue that, in particular, needs further research. AIMS submitted that although changes to ocean chemistry from carbon dioxide were 'recognised more than 50 years ago', this development has 'only recently emerged as an important knowledge gap in marine science, and has now become a global research priority'. In particular, AIMS noted that although changes in the carbonate chemistry from rising atmospheric carbon dioxide levels 'are relatively well understood' for the open ocean, this is not the case for nearshore and shallow marine environments such as the Great Barrier Reef where 'conditions are more variable due to biological processes'. AIMS advised that the 'evidence base of how the ongoing changes in the seawater chemistry will affect marine ecosystems continues to develop', including as a result of research undertaken by AIMS scientists.[55]

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52 IMAS, *Submission 1*, p. 12.

53 Professor Stewart Frusher, IMAS, *Committee Hansard*, 21 February 2017, p. 7.

54 FRDC, *Submission 2*, p. 5.

55 AIMS, *Submission 10*, pp. 4–5. Research outlined in the submission includes field research at three shallow volcanic carbon dioxide seeps in eastern Papua New Guinea, studies of carbonate chemistry in the Great Barrier Reef and carbon dioxide enrichment experiments in the National Sea Simulator (SeaSim) in Townsville.

2.44 The committee was also informed of efforts to improve the knowledge base and address some of the uncertainties regarding ocean warming hot spots. Regarding the uncertainties and limited knowledge about the hot spot off the south east coast of Australia, Professor Stewart Frusher from IMAS explained that researchers are looking to other hot spot regions globally to attempt to improve their understanding. Professor Frusher stated:

> We have identified the 24 top to see if we can learn and provide lessons for them, as well. We may have to draw a lot of our global community to actually see what happens, because places like the south-eastern seaboard of Australia are almost like global experimental laboratories because they are those things. That is where we are going to see these events happen earliest.[56]

2.45 Finally, it was noted that climate change is one of several stressors on the marine environment. In addition to climate change, Dr Alistair Hobday, Senior Principal Research Scientist, CSIRO, identified coastal development, pollution and marine plastics as the other main risks for the oceans. Dr Hobday added that which risk ranks as the most serious varies in different locations. Dr Hobday stated:

> …for offshore species like tuna, I think climate change is No. 1. For species that rely on estuaries for completing their life cycle, it is coastal development, which is taking away mangroves or salt marsh or seagrass habitat. Plastics I think is a big sleeper, and we are only just starting to become aware of how big a problem plastics might be.[57]

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56 Professor Stewart Frusher, IMAS, *Committee Hansard*, 21 February 2017, p. 13.

57 Dr Alistair Hobday, Senior Principal Research Scientist, CSIRO, *Committee Hansard*, 17 March 2017, p. 6.