CLIMATE COUNCIL

SUPER-CHARGED STORMS IN AUSTRALIA: THE INFLUENCE OF CLIMATE CHANGE

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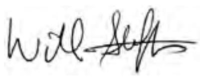

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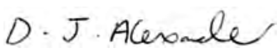

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Key Findings

1 Climate change is fuelling more intense and damaging storms.

- Extreme weather events including tropical cyclones, extreme rainfall, hail/thunderstorms and extra-tropical cyclones (for example, east coast lows) are now occurring in an atmosphere that is packing more energy and carrying more moisture than it did in the 1950s.

- Climate change exacerbates coastal flooding from storm surges both from intensifying coastal storms and from higher sea levels. The risk of coastal flooding from storms has increased significantly as sea levels have risen about 20 cm since the mid-19th century and are projected to increase 0.3-1.0 m by 2100 compared to 2000 levels.

2 The recent storms in South Australia and New South Wales have been influenced by climate change.

- One of the most intense storms to impact SA in 50 years hit in September 2016. This storm resulted in 80,000 lightning strikes, golf-ball sized hailstones and left 1.7 million people without power. All extreme weather events including the SA storms, are occurring in an atmosphere that is warmer and contains more moisture.

- The June 2016 extra-tropical cyclone (east coast low) brought intense rainfall and coastal flooding to the NSW east coast including Sydney. A storm surge of 17.7 m was the highest on record for NSW and caused extensive coastal erosion, flooding and consequent loss of property and housing. The damage caused by the storm surge was exacerbated by sea level rise as a result of climate change.

3 Climate change will continue to exacerbate storms in Australia, increasing the risk of devastating impacts.

- Australia is highly vulnerable to more storms of increasing intensity, especially storm surges associated with tropical cyclones and extra-tropical cyclones, including east coast lows, that are likely to become more intense.
- Australia's infrastructure has been built for the climate of the 20th century and is unprepared for more intense coastal storms and rising sea level.
- Extreme rainfall events are projected to increase in intensity across most of the continent, but the trend may be less prominent in southwest Western Australia, where large reductions in mean rainfall are projected.
- Tropical cyclones are projected to become less frequent but more intense, with stronger winds, higher rainfall and more severe storm surges.
- East coast lows are expected to decrease in number by about 30% towards the end of the century, but the intensity of the most severe east coast lows could increase.
- The annual frequency of severe thunderstorm days is likely to rise by 14% for Brisbane, 22% for Melbourne and 30% for Sydney by 2100.

4 Without strong action on climate change, storms and other extreme weather events will continue to become more intense and more damaging.

- Australia must do its fair share of meeting the global emissions reduction challenge by cutting its emissions rapidly and deeply to help stabilise the world's climate and reduce the risk of more extreme storm events.
- Australia's very weak target of a 26-28% reduction in emissions by 2030 compared to 2005 levels – and we are on track to miss even this target – leaves Australia lagging well behind other OECD countries.

Introduction

Australia has been hit with a series of destructive storms in recent years. In September 2016, a vicious extra-tropical cyclone roared over South Australia, and just a few months earlier, a deep east coast low sent a record-high storm surge pounding onto the New South Wales coast. In 2015, Brisbane suffered its wettest May day in 175 years, which was preceded six months earlier by the worst hailstorm in 30 years.

These storms have left a trail of damage and destruction. The South Australian storm brought the electricity transmission infrastructure to its knees and triggered a state-wide blackout, leaving 1.7 million people without power. The NSW east coast low caused $235 million in damages, five deaths, and loss of coastal property and housing. In Brisbane, the hailstorm resulted in $1.4 billion of insured damages, causing unprecedented damage to cars and homes.

These destructive storms are part of an emerging global pattern. In September this year Hurricane Matthew, the most persistent Category 4-5 cyclone in the East Caribbean on record wreaked havoc along its path, causing more than 1,000 deaths and destroying homes and villages. Earlier this year torrential rain triggered widespread flooding in France, and the US state of Louisiana experienced a 1-in-500 year rainfall event which caused severe flooding. The UK experienced an exceptionally wet and stormy winter in 2013/14.

The evidence for the link between climate change and extreme weather is already very strong for heatwaves and bushfire weather, and it is getting stronger for intense cyclones and heavy rainfall events. All of these severe weather events are now occurring in an atmosphere that is packing more energy and carrying more moisture than it did 70 years ago. Generally, this means more intense storms and more devastation around the world.

As global temperatures continue to rise, many of these storms will continue to become worse. To protect Australians from even more destructive storms, a global effort to rapidly and deeply reduce greenhouse gas emissions is urgently required. In December 2015, world leaders agreed to work together to keep global temperature rise to well below 2°C. As one of the world's top 15 emitters, Australia is expected to do its fair share, and our current actions and pledges are far from meeting that challenge. Our Paris pledge is very weak, and under current policies we are unlikely to meet even that target.

As a well-known climate scientist James Hansen wrote, the actions we take now – or not take – will be felt in the storms experienced by our grandchildren (Hansen 2009).

1. Climate Records Off the Charts

Over the past few years, temperature records have been repeatedly shattered around the world, continuing a long-term trend from the mid-20th century of rising temperatures (Figure 1).

Once again in 2016, record breaking temperature extremes have been occurring at an alarming rate. Some of the most intense, prolonged heatwaves ever recorded have been experienced in the Middle East and the Indian subcontinent. The year-to-date has seen global temperatures 0.99°C above the 20th century average as at the end of September (about 1.2°C above pre-industrial levels, relative to the 1880-1900 average; NOAA 2016a), which is the highest ever recorded temperatures for the January–September period since records began in 1880 (NOAA 2016b). 2016 is virtually certain to be the hottest year on record globally, which would eclipse the record average temperature of 2015.

The rapidly warming climate means that extreme weather events are now occurring in an energetically super-charged atmosphere that is carrying increasing amounts of water vapour (about a 7% increase per 1°C warming; Trenberth 2011) – a recipe for more destructive storms and other extreme

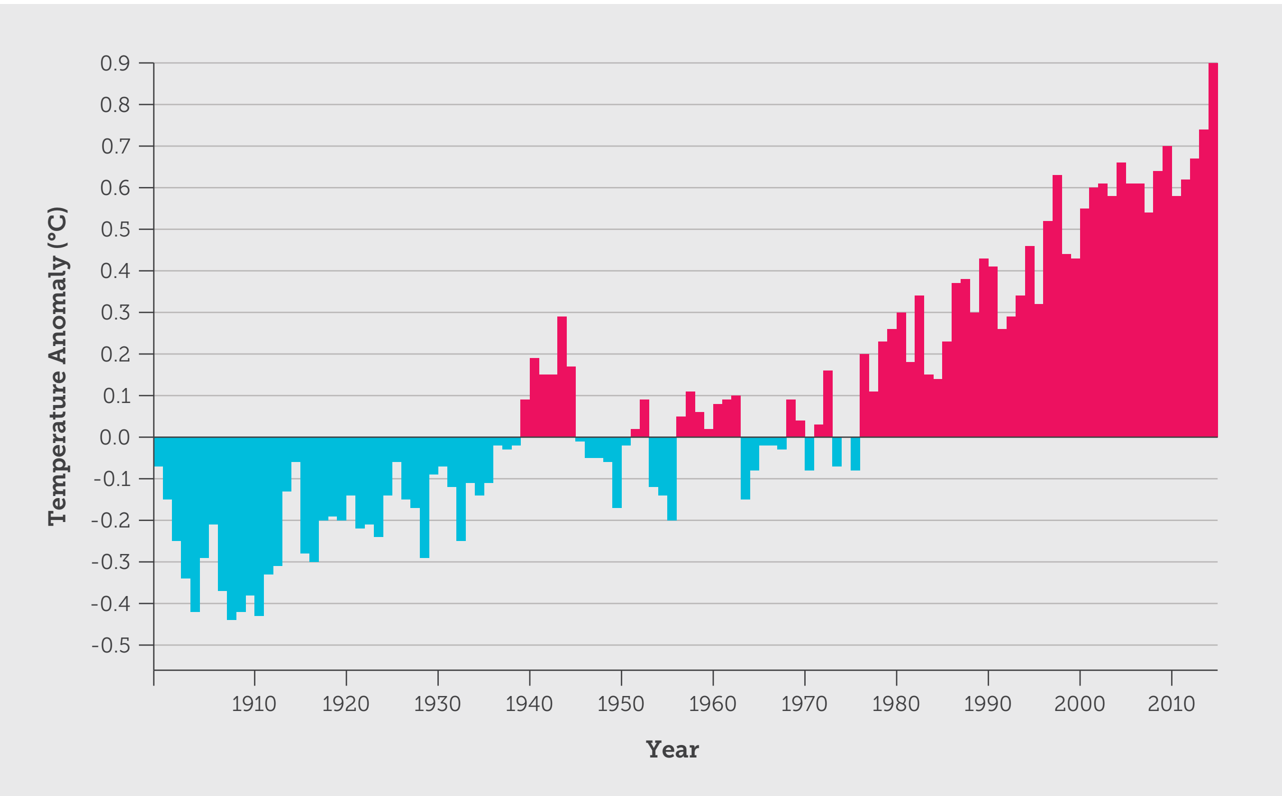

Figure 1: Annual global temperature anomalies to 2015, relative to global annual average temperature 1901-2000 (NOAA 2015).

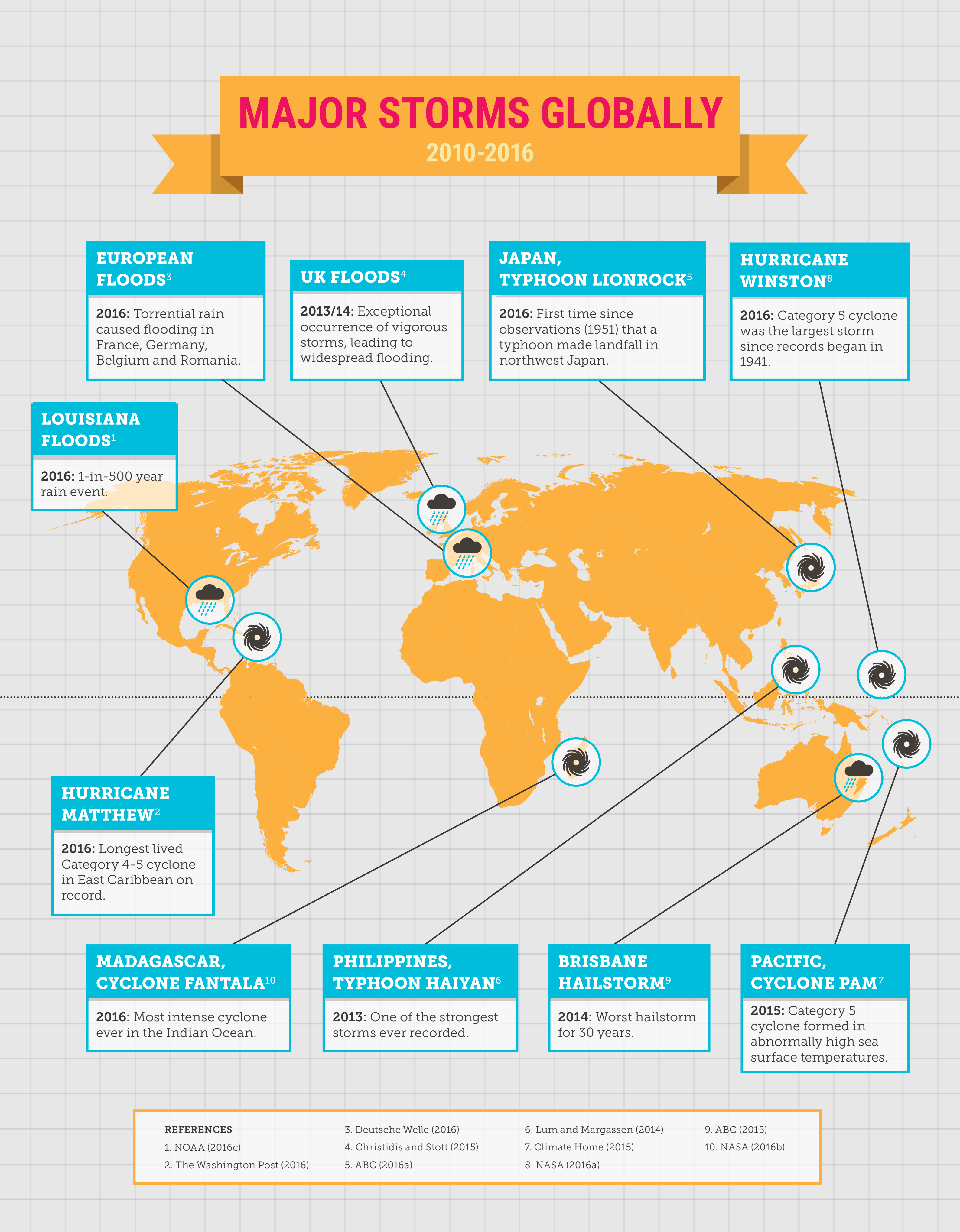

Figure 2: Major storms that have occurred during the 2010-2016 period. These events have caused a significant number of deaths, losses to housing, transport networks and infrastructure, as well as damage to natural ecosystems. Note: hurricanes, cyclones, and typhoons are the same extreme event, they just occur in different ocean basins.

Figure 3: People on the move after Hurricane Matthew causes devastation in Haiti in early October 2016, including flooded streets, downed trees and damaged houses.

weather events. In the first half of this decade alone, the number of destructive storms that have occurred around the world (Figure 2), including Australia, is a clear warning of what lies ahead if greenhouse gas emissions are not reduced rapidly.

These severe storms take their toll on lives, property, infrastructure and natural ecosystems. Torrential rain caused widespread flooding and at least 18 deaths in central Europe including Germany, Belgium and Romania, with France being worst hit, where rivers burst their banks. In the last year, eight rainfall events with a return period of 1-in-500 years have occurred in the US, including intense rainfall that led to severe flooding in Louisiana resulting in six deaths and 20,000 rescues, as well as extreme rainfall in North and South Carolina from Hurricane Matthew (NOAA 2016c).

This storm was the lowest latitude Category 5 hurricane in the Atlantic on record (NOAA 2016d), and carved a path of destruction through Haiti (Figure 3), killing more than 1,000 people, leaving tens of thousands homeless, which led to cholera spreading through rural communities.

The long-term implications of the influence of climate change on extreme weather are worrying. Assessments by the Intergovernmental Panel on Climate Change (IPCC) of the increasing risks of worsening extreme weather events due to climate change over their past three reports (2001, 2009, 2014) consistently show that the risks enter the "moderate" zone at a 1°C temperature rise above pre-industrial (Figure 4). So it is no surprise that the influence of climate change is already evident at current levels of warming.

The rapidly warming climate means that extreme weather events are now occurring in an energetically super-charged atmosphere – a recipe for more destructive storms.

Even modest increases in temperature beyond the current 1°C rise can have a significant effect on the risk profile for extreme events. Figure 4 shows that the risk profile has entered the "high" range when global average temperature rise has reached just 1.5°C. This is much less than 2°C – the so-called "guardrail" temperature to keep the Earth's climate stable and reduce the worst impacts of climate change. Even more worrying, the various national pledges and commitments for emission reductions that were made in Paris, when aggregated, would likely lead to 2.9-3.4°C warming by 2100 (UNEP 2016), and if the rest of the world adopted a level of ambition equivalent to Australian targets and policies, we would be on track for a 3-4°C rise or more by the end of the century (Climate Action Tracker 2016). Those scenarios would push the risks of worsening extreme weather towards the "very high" level.

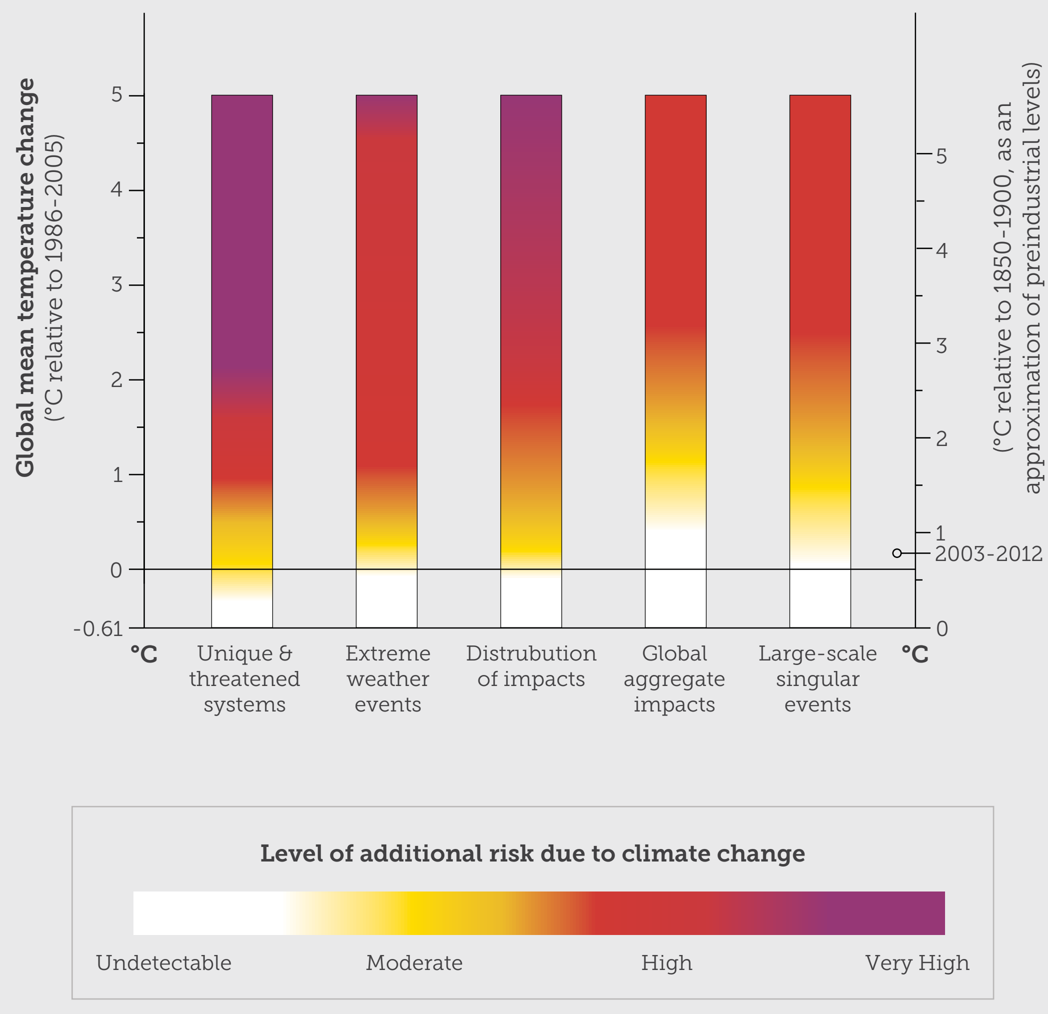

Figure 4: Risks from climate change by 'reason for concern' (RFC) compared with global temperature rise (IPCC 2014a). Each column corresponds to a specific RFC and represents additional outcomes associated with increasing global mean temperatures. The colour scheme represents progressively increasing levels of risk.

2. Stormy Weather in 2010-2016: A Rough Few Years for Australia

Australia has had a rough few years of stormy weather across the country.

We can categorise these storm events as (i) extreme rainfall, (ii) hail and thunderstorms, (iii) tropical cyclones and (iv) extra-tropical cyclones (known as "east coast lows" along Australia's east coast). Associated with tropical cyclones and east coast lows are storm surges, which refer to a short-term rise in sea level driven by strong winds and/or reduced atmospheric pressure. These can cause considerable coastal flooding.

Some of the most damaging storms in Australia since 2010 are highlighted in Table 1. Seven storms in that period have resulted in insured losses of more than $500 million, while five of them resulted in more than $1 billion in insured losses.

Many of the major storms in Table 1 are some of the most economically damaging extreme natural events in Australian history, and many of them are amongst the most intense storms recorded for many decades. For example, the Brisbane 2014 hailstorm was the worst since 1985, while the Melbourne 2010 hailstorm was one of the biggest such storms in the last few decades. A storm of the intensity that recently hit South Australia last occurred more than 50 years ago (See Box 1). East coast lows in April and May 2015 were also exceptional, with 1-in-100 year rainfall occurring in the Hunter Valley region, and the wettest Brisbane day since 1989 was recorded. An associated storm surge from an east coast low that hit the NSW coast in June 2016 was the highest ever recorded for the state at 17.7 m (see Box 2).

Seven storms since 2010 in Australia have resulted in insured losses of more than $500 million, and five of them resulted in over $1 billion in insured losses.

Table 1: Severe storms that have impacted Australia 2010-2016.

Date	Nature of Storm	Location	Severity of Event (Meteorologically)	Impacts, Damages
March 2010	Hailstorm, very large hailstones	Melbourne	Hailstones some of the biggest to hit Melbourne city in the last few decades (Herald Sun 2010)	$1.04 billion in insured losses (Understand Insurance 2016); damage to schools, businesses, houses
March 2010	Hailstorm, strong winds and rain	Perth	One of the biggest storms to hit Perth in years, winds up to 120 km/h (ABC 2010)	$1.05 billion in insured losses (Understand Insurance 2016); property (housing and schools) and vehicle damage; 150,000 homes left without power (ABC 2010)
January 2011	Extreme rainfall and extensive flooding	Brisbane River Catchment: Brisbane, Lockyer Valley, Ipswich	Saturated catchment from strong La Niña in late 2010, with rainfall of 480 mm entering the Wivenhoe Dam over 5 days (van den Honert and McAneney 2011)	$2.4 billion in insured losses; 24 deaths; 18,000 homes inundated; damage to 19,000 km of roads, 28% of QLD rain network and 3 ports (Worthington 2015)
February 2011	Category 5 Tropical Cyclone Yasi	North QLD coast including Cardwell, Tully, Mission Beach and Innisfail	Category 5 cyclone, wind gusts estimated at 285 km/h (Worthington 2015)	$1.4 billion in insured losses; 1 death; homes damaged and destroyed, severe damage to agriculture, mining, infrastructure, marinas and boats (Worthington 2015)
December 2011	Thunderstorms, torrential rain, hailstones, tornadoes	Melbourne (northern and eastern suburbs)	No data available	$729 million in insured losses (Understand Insurance 2016), damage to property, transport and infrastructure
November 2014	Hailstorm and severe wind gusts	Brisbane	Worst hailstorm since 1985 (almost 30 years) and wind gusts up to 140 km/h (ABC 2015)	$1.39 billion insured losses (Understand Insurance 2016); damaged homes, cars, windows, roofs torn off (ABC 2015)
April 2015	East coast low with intense rainfall	Major flooding in the Hunter Valley and elsewhere along the NSW coast	1-in-100 year event; greater than 400 mm in 48 hours; wind gusts of 135 km/h at Newcastle, the highest ever in April in NSW (Naumann 2015)	$950 million in insured losses (Understand Insurance 2016); 3 deaths; 370,000 customers lost power; $110 million lost to tourism industry; 22,000 requests for assistance (Naumann 2015)
May 2015	East coast low, intense rainfall	SE QLD	Wettest Brisbane day in May in 175 years (183 mm in 24 hours) and wettest day since 1989 (Brisbane Times 2015a)	$349 million in insured losses (Understand Insurance 2016); 5 deaths (Brisbane Times 2015b); houses damaged through inundation

June 2016	East coast low with intense rainfall and coastal flooding	NSW east coast including Sydney and southern QLD	Storm surge of 17.7 m, the highest on record for NSW (NSW Government 2016); rainfall in northern NSW of up to 330 mm for 24 hours (BoM 2016a)	$235 million in damages (Insurance Council of Australia); 5 deaths (9news 2016); coastal erosion and loss of coastal property and housing
September 2016	Extreme rainfall, thunderstorms, tornadoes	SA	Last storm of similar intensity in SA occurred over 50 years ago	Damage to energy infrastructure, entire state blackout (1.7 million people) (ABC 2016b)

Figure 5: Some of the impacts of Cyclone Yasi which struck the north Queensland coast in 2011 included felled trees, beach erosion and damaged roads.

BOX 1: SOUTH AUSTRALIA 2016 STORM

A so-called "1-in-50 year" storm hit South Australia on Wednesday 28 September 2016. This severe thunderstorm delivered 80,000 lightning strikes, golf-ball sized hailstones and damaging winds gusting up to 120 km/h. The storm was one of the most severe extreme weather events to hit the state in recent history.

The severe storm resulted in catastrophic failure of power infrastructure, with more than 22 transmission towers taken out (Figure 6). As a standard safety response, the South Australian energy system was isolated from the rest of the east Australian grid, resulting in an unprecedented state-wide blackout causing 900,000 homes and 1.7 million people to lose power.

Climate change is fuelling more severe extreme weather, including storms. This storm formed in an atmosphere that is packing more energy and is holding more moisture a result of climate change.

The storms in South Australia highlight the threat posed to critical infrastructure from more destructive extreme weather driven by climate change. The resilience of all our major infrastructure and essential services needs to be designed for the increasing intensity and severity of the extreme weather that we are experiencing as a result of climate change.

Figure 6: Catastrophic failure of transmission towers in the wake of the South Australian storm.

3. Climate Change is Already Making Storms More Intense and Destructive

Over the past decade climate science has made strong progress in identifying the links between climate change and storms, based on three main lines of evidence:

- The basic physics that govern the behaviour of the climate system show that storms are now occurring in a significantly more energetic atmosphere.
- Where sufficient, long-term data are available, observations show trends towards more intense rainfall and more destructive storms.
- More recently, "attribution studies" based on detailed modelling experiments explore how climate change has already increased the probability that particular storms of extreme intensity would have occurred.

All extreme weather events are now being influenced by climate change.

3.1 The Atmosphere is Packing More Energy

As greenhouse gases increase in the atmosphere, primarily carbon dioxide (CO_2) from the combustion of fossil fuels, the climate system is warming because these gases are trapping more heat. Global average surface temperature has already risen to more than 1.2°C above the pre-industrial level (NOAA 2016a), and this means that the atmosphere is storing more heat than before. The difference in global average surface temperature between the last ice age and the pre-industrial level is only about 4°C (Marcott et al. 2013; Shakun et al. 2012), so the current temperature rise is already very significant in terms of the additional energy stored in the atmosphere.

The oceans are also warming, especially at the surface, and this is driving higher evaporation rates that, in turn, increase the amount of water vapour in the atmosphere (Figure 7). In addition, a warmer atmosphere can hold more water vapour, leading to more intense rainfall. The 1°C temperature rise that has already occurred and increasing evaporation have led to an increase of about 7% in the amount of water vapour in the atmosphere (Hartmann et al. 2013).

Because of the increasing heat and additional water vapour in the atmosphere, the climate system of today is significantly more energetic than it was 60-70 years ago. Storms and other extreme weather events are occurring in this more super-charged atmosphere. Thus, all extreme weather events are now being influenced by climate change (Trenberth 2012).

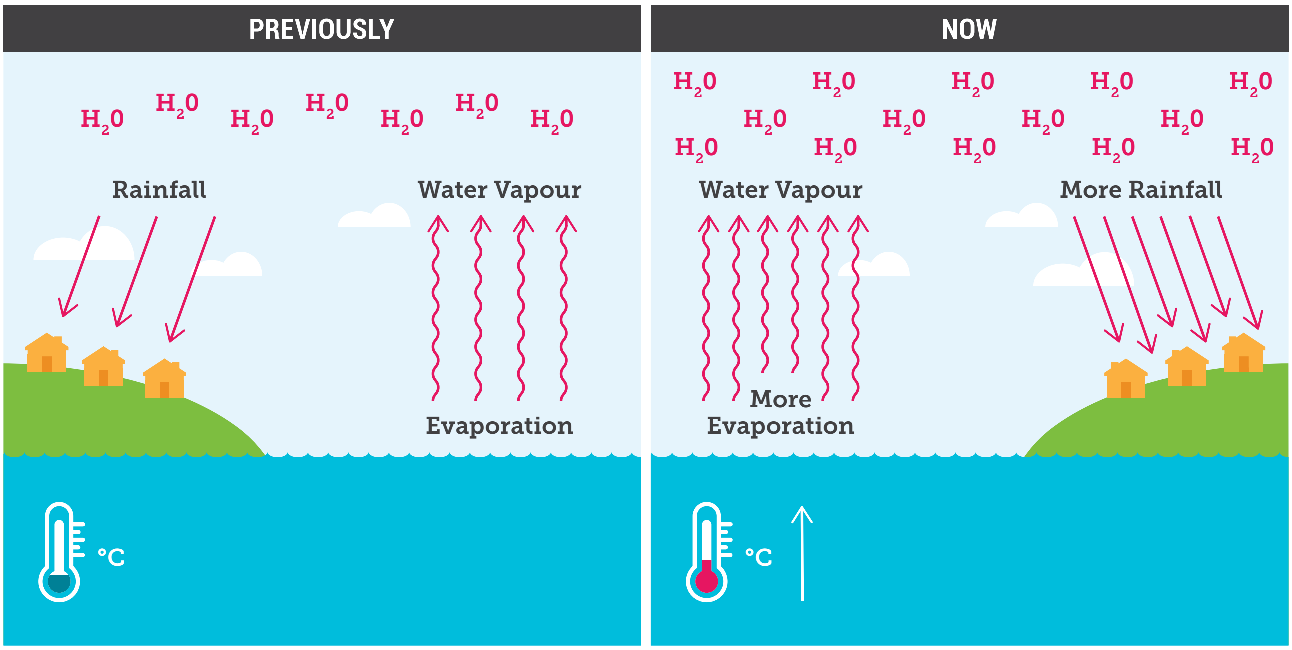

Figure 7: The influence of climate change on the water cycle (Climate Commission 2013). **Left:** The pre-climate change water cycle. **Right:** The water cycle operating under higher surface and ocean air temperatures, leading to more water vapour (H_2O) in the atmosphere, and in turn, more rainfall.

BOX 2: NEW SOUTH WALES 2016 STORM

Storm surges associated with tropical cyclones and extra-tropical cyclones, including east coast lows, are particularly concerning for Australia because infrastructure has been built for the climate of the 20th century. It is vulnerable and unprepared for the changes in climate that are likely to increase the intensity of coastal storms.

The June 2016 extra-tropical cyclone (east coast low) brought intense rainfall and coastal flooding to the NSW coastline, with widespread damage in Sydney. A massive storm surge of 17.7 m – the highest on record for NSW – caused severe coastal erosion, leading to significant loss of exposed property and housing, which culminated in an insurance bill of $235 million (Insurance Council of Australia 2016).

These coastal storms are now occurring in a more energetic atmosphere, stacking the odds towards more intense winds and heavier rainfall. When coupled with higher sea levels as a result of climate change, the storm surges driven by these coastal storms are becoming more damaging as they are able to penetrate further inland (Figure 8). Sea levels have risen about 20 cm since the mid-19th century and are projected to increase by approximately 0.30-1.0 m by 2100 compared to 2000 levels (IPCC 2013).

Australia is highly vulnerable to increasingly intense storms, especially storm surges associated with tropical cyclones and extra-tropical cyclones, including east coast lows. A sea level rise of only 0.5 m by 2100 (at the low end of projected sea level rise for the 21st century) would mean that a 1-in-100 year flood – a very rare event today in Australia – would occur every few months in some locations. The economic impacts of sea level rise are worrying – a 1.1 m sea level rise (high end, business as usual scenario) would put $226 billion of coastal infrastructure at risk in Australia (DCC 2009; DCCEE 2011), and this figure excludes the impacts of storm surges penetrating further inland.

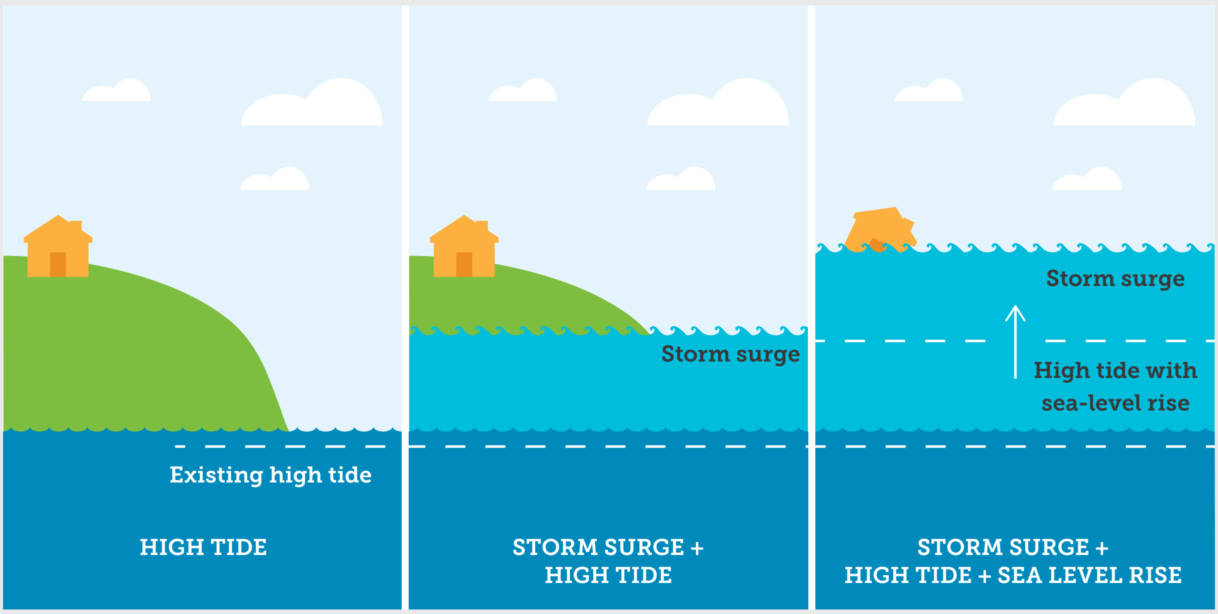

Figure 8: Sea level rise increases the base sea level and thus exacerbates the effects of a storm surge (Climate Commission 2013).

3.2 Long-term Observations of Storm Intensity and Frequency

In addition to the basic physical principles described in Section 3.1, the influence of climate change on storms and other extreme weather events can sometimes be detected in the observational records where observations of extreme weather are long and consistent enough to discern trends from natural, background variability. Because of these data constraints, it is more difficult to discern trends in storm characteristics for Australia than it is at the global level, given our high natural variability and short observational records.

AUSTRALIAN TRENDS

Unless otherwise noted, information on Australian trends and projections (Section 3 and 4) is taken from the 2015 Climate Projections Report of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Bureau of Meteorology (BoM) (CSIRO and BoM 2015), and the State of the Climate 2016 report (CSIRO and BoM 2016).

Heavy rainfall: There is a general long-term trend of increases in extreme one-day rainfall in northern Australia and declines in southern Australia (BoM 2016b). This is consistent with an increase in moisture content affecting summer rainfall regimes and a southward shift in the storm track over the Southern Ocean, reducing storms and heavy rainfall affecting southern Australia. The challenge in discerning a significant, long-term trend is the high decade-to-decade variability in extreme rainfall coupled with the strong influence of La Niña events on heavy rainfall.

Hail and thunderstorms: No consistent, long-term observational records have been cited in relation to trends in either the frequency or intensity of thunderstorms and hail.

Tropical cyclones: There is a trend towards fewer tropical cyclones along Australia's coasts but also a trend towards increasing intensity of cyclones. High variability and a short period of reliable measurements make it difficult to determine the significance of the trend in increasing intensity.

Extra-tropical cyclones: In Australia extra-tropical cyclones along the east coast are commonly known as east coast lows, but they can also occur as deep low pressure systems from the Southern Ocean that can batter South Australia and Victoria, such as the storm that knocked out electricity across South Australia in late September 2016. Observations show a small decreasing trend in the number of east coast lows (Dowdy et al. 2013).

Figure 9: Heavy rainfall in Sydney in April 2015. Over the last 100 years, trends show that extreme one-day rainfall has increased in northern Australia, while there have been declines in Southern Australia.

GLOBAL TRENDS

Long-term observations, particularly in Europe and North America, allow estimates of changes in extreme weather events over multi-decadal timeframes at the global level, providing some insights into how climate change is already influencing the nature of extreme weather events. Although more is known about changes in temperature extremes, our focus here is on storms – heavy precipitation events, tropical cyclones and extra-tropical cyclones. The observed trends after Hartmann et al. (2013) include:

Heavy rainfall: Since the mid-20th century there have been significant increases in the number of heavy precipitation events in more regions than there have been decreases, but there are strong regional variations in the trends. The most consistent trends towards heavier precipitation events are in central North America and Europe.

Hail and thunderstorms: There is low confidence in observed trends in these types of extreme weather events because of inadequacies in historical data and in monitoring systems.

Tropical cyclones: In the North Atlantic basin, where consistent, long-term observations are available, there has been an increase in the frequency and intensity of the strongest tropical cyclones since the 1970s. Globally, long-term trends are difficult to establish because of changes in observing capabilities and data quality concerns.

Figure 10: Hurricane Gonzalo one day before it struck Bermuda in 2014 as a powerful Category 2 storm with winds in excess of 170 km/h. The strongest tropical cyclones in the North Atlantic have increased in frequency and intensity since the 1970s.

Extra-tropical cyclones: Due to a lack of, and inconsistencies in, long-term data, it is difficult to discern any trends in the frequency or intensity of extra-tropical cyclones over the past century. Despite these observational challenges, studies tend to agree on a trend towards more intense extra-tropical cyclones in the southern hemisphere. Wang et al. (2012) found through data reanalysis that cyclonic activity has substantially increased from 1871-2010 in the southern hemisphere, while smaller increases have been identified for the northern hemisphere for this period.

In summary, there is considerable evidence globally that climate change is driving more intense, severe storms with heavier rainfall, despite the challenges in accessing long-term, consistent, reliable global observational datasets and the regional variation in the data that do exist. There is some evidence that the same trends are occurring in Australia, although the data in our region are not yet as conclusive as those at the global level.

There is considerable evidence globally that climate change is driving more intense, severe storms with heavier rainfall.

3.3 Attribution Studies Show Increased Likelihood of Severe Storms Due to Climate Change

Model-based attribution studies for extreme events is a very recent development in the field of climate science and the studies have so far concentrated on high annual and seasonal temperatures, extreme heat and drought. Those attribution studies that have been carried out on specific storms are focused primarily on heavy precipitation events. We note here, that just because an attribution study may not have been carried out on an extreme weather event, it does not mean that climate change did not play a role in influencing the event or increasing the chances of its occurrence.

AUSTRALIA

Most of the attribution studies in Australia have so far been based on heat-related events, such as heatwaves; record hot months, seasons and years; and surface ocean extreme heat events like the one that led to extensive bleaching of the Great Barrier Reef in early 2016. Nevertheless, there have been a few attribution studies that have explored the link between extreme rainfall and climate change. For example, the warming trend in sea surface temperatures (SSTs) to the north of Australia may have contributed, by up to 20%, to the magnitude of the heavy rainfall of 2010-11 in eastern Australia (Hendon et al. 2014). Another study (Christidis et al. 2013) found that the high SSTs increased the probability of above average rainfall in eastern Australia in March 2012 by 5-15%. However, the results differ between different regions and for different extreme rainfall definitions (Lewis and Karoly 2014).

GLOBAL

Although high intrinsic variability in storm frequency and intensity has made it difficult to establish a link between storm behaviour and climate change, a few studies have pointed to climate change as a factor in worsening extreme storms. For example, a modelling study suggested that anthropogenic greenhouse gas emissions contributed to increasing the flood risk in the UK in autumn 2000 (Pall et al. 2011). In more recent times, the UK experienced an extremely stormy and wet winter in 2013/14, resulting in widespread flooding and coastal erosion, costing the UK government around $1 billion in recovery schemes. A study by Christidis and Stott (2015) found that rainfall increases as a result of an atmosphere holding more water were difficult to detect, but they did find some evidence for human-driven climate change causing increases in extreme winter rainfall in the UK for events with time scales of 10 days.

Another study (Singh et al. 2014) focused on an extremely heavy precipitation event that occurred in mountainous northern India during 14-17 June 2013, triggering landslides, debris flows and extensive flooding (Figure 11). The storm resulted in more than 5,800 deaths, affected more than 100,000 people and caused catastrophic damage to housing and infrastructure. An attribution study of the causes of the devastating storm, which was assessed to be at least a 1-in-100 year event, provided evidence that human-driven climate change increased the likelihood of such an event (Singh et al. 2014).

Some evidence is beginning to emerge from the United States linking climate change to the increased likelihood of extreme weather events. For example, one study examined a number of record or near-record precipitation events at a regional level, and found that they were at least partly attributable to climate change (Knutson et al. 2014). The study found that climate change helped to increase the likelihood of these precipitation extremes by a factor of 1.6 to 2.5 beyond natural variability alone.

Figure 11: Floods in Uttakashi, India in 2013 caused by intense rainfall in the mountainous regions of Northern India.

4. How Much Worse Will Storms Become?

Storms are very likely to become more intense and destructive over the next couple of decades because of the climate change that is already locked in from past greenhouse gas emissions. But the severity of storms that our children and grandchildren will face later this century depends on how fast and how deeply we can reduce greenhouse gas emissions now, next year and over the next couple of decades.

Projections for Australia (and globally) of changes in temperature, and in turn extreme weather events in the future generally show little difference among greenhouse gas concentration pathways out to 2040 or 2050. But, there are significant differences in the second half of the 21st century depending on the concentration pathway (Figure 12). More pronounced changes in extremes are predicted for the higher concentration pathways.

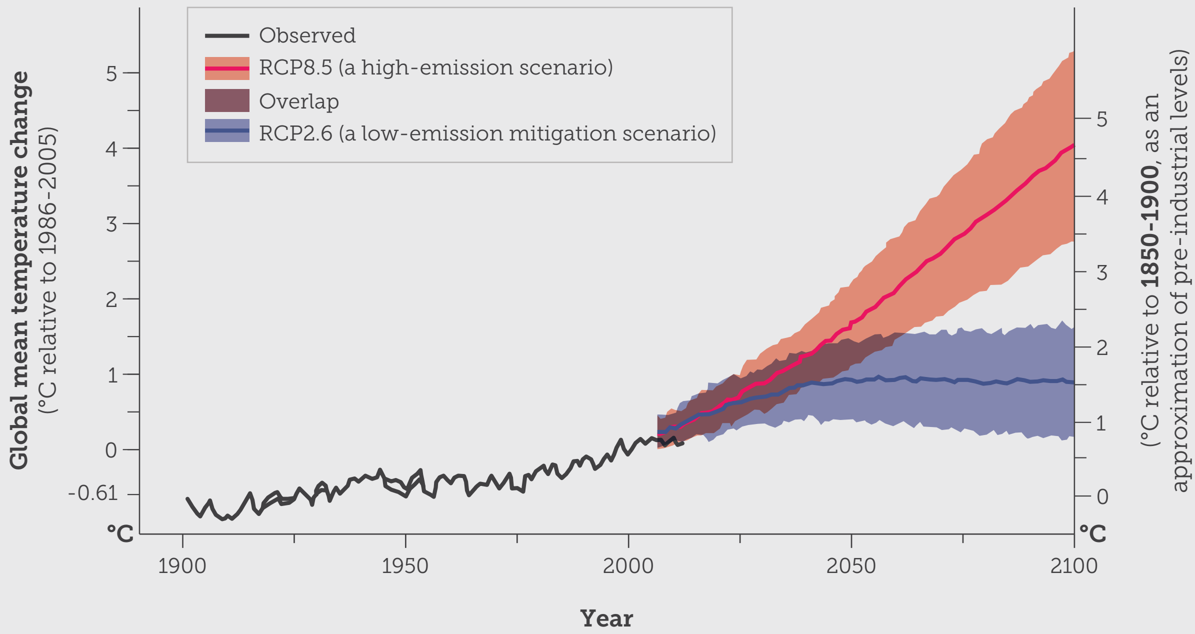

Figure 12: RCP emissions scenarios for different concentrations of carbon dioxide (CO_2) (IPCC 2014a). The upper bound (red, RCP8.5) is a business as usual CO_2 emissions pathway, while the lower bound (blue, RCP2.6) is a very swift reduction in CO_2 emissions, equivalent to a 1.5°C increase in temperature from pre-industrial levels. We are locked in to temperature rises until about 2050, but these paths diverge significantly depending on the climate action we take now. More pronounced extreme weather, including storms is predicted for the higher concentration CO_2 pathways.

AUSTRALIAN PROJECTIONS

Heavy rainfall: Extreme rainfall events are projected, with high confidence, to increase in intensity, where extreme events are defined as the wettest day of the year and the wettest day in 20 years. This projected trend may be less prominent in southwest Western Australia, where large reductions in mean rainfall are projected. However, England et al. (2006) note that an increase in sea surface temperatures will drive more extreme anomalies in the Indian Ocean Dipole (temperature difference between western and eastern Indian Ocean). This could result in more extreme and periodic rainfall events in southwest Western Australia.

Hail and thunderstorms: Climate models do not yet simulate the dynamics of the climate system well enough at small scales to predict changes in hail, thunderstorms and tornadoes. Thus, projections of changes in these types of storms are not yet feasible. However, analysis of the larger-scale environments conducive to severe thunderstorms in Australia indicates significant increases in the frequency of these environments in southern and eastern areas (Allen et al. 2014). The analysis of Allen et al. (2016) projects that the annual frequency of potential severe thunderstorm days is likely to rise by 14% for Brisbane, 22% for Melbourne, and 30% for Sydney by the end of the century

Tropical cyclones: Consistent with observed trends and projections globally (see below), tropical cyclones are projected to become less frequent but with a higher fraction of high intensity storms, as measured by stronger winds and greater rainfall. A higher proportion of tropical cyclones may reach their observed southern-most extent, approximately at a latitude of 25 degrees south (equivalent of central Western Australia and Queensland).

Extra-tropical cyclones: Storm systems originating in the Southern Ocean and their associated cold fronts are projected to shift south in the winter, consistent with the observed expansion of the tropics (intensification of the subtropical ridge and expansion of the Hadley Cell circulation). In addition to a southward shift, the westerly wind flow is projected to strengthen. These projections imply a decrease in the number of deep lows affecting southwest Western Australia and in the number of fronts affecting southern Australia in the cooler months of the year, that is, a decrease in storminess and rainfall. Projections for the warmer months are less clear, with one projection finding that towards the end of the century southeast Australia will experience a significant increase in intense frontal systems that bring extreme winds and dangerous fire conditions (Hasson et al. 2009). Projections for east coast lows suggest a reduction in the number of them by up to 30% towards the end of the century, essentially a continuation of the observed trend. However, there is some indication that the intensity of the most severe East Coast Lows could increase (Grose et al. 2012).

The severity of future storms in Australia depends on how fast and deeply we reduce our greenhouse gas emissions now.

GLOBAL PROJECTIONS

Heavy rainfall: A shift to more intense individual storms and fewer weak storms is likely as the climate warms further. Over most of the mid-latitude land masses and over wet tropical regions, extreme precipitation events will very likely become more intense and more frequent in a warmer world (Collins et al. 2013).

Tropical cyclones: Future projections based on theory and high-resolution modelling indicate that climate change will cause stronger storms, increasing in intensity by 2-11% (Knutson et al. 2010). While modelling consistently projects decreases in the frequency of tropical cyclones, the number of intense cyclones will likely increase in frequency. The likely increase in rainfall rates within 100 km of the storm centre are on the order of 20% (Knutson et al. 2010). More extreme precipitation near the centres of tropical cyclones making landfall is projected for many coastal regions around the world, including Australia and many Pacific Islands (IPCC 2014b).

Associated with tropical cyclones is coastal flooding, the impacts of which are becoming increasingly compounded by sea level rise. Recent research by Lin et al. (2016) indicates that the frequency of extreme coastal flooding that affected New York City when Hurricane Sandy struck in 2012 is very likely to increase over the 21st century (Figure 13). This trend is consistent with projections of increased flooding as sea levels continue to rise.

Extra-tropical cyclones: As for tropical cyclones, most analyses find that the frequency of extra-tropical cyclones is projected to decrease, although the occurrence of strong storms may increase in some regions. As noted above, extra-tropical cyclone storm tracks in the Southern Hemisphere are likely to shift southwards by a few degrees in latitude by the end of the 21st century (Collins et al. 2013).

Figure 13: Aftermath of extensive flooding and coastal inundation along the New Jersey shore in November 2012 resulting from a storm surge driven by Hurricane Sandy.

5. Tackling Climate Change is Critical for Protecting Australians

The risk of more severe and damaging storms is increasing across Australia as temperatures continue to rise as a result of climate change.

As sea levels increase, there is a higher risk of coastal flooding associated with the storm surges resulting from tropical cyclones and extra-tropical cyclones, including east coast lows. The economic impacts of recent storms in Australia to houses, property and critical infrastructure, which have already exceeded $1 billion on multiple occasions since 2010, will continue to escalate. The social consequences of more intense storms, including damage to personal property, injury, loss of of life and post-disaster trauma, will only worsen as storms become more damaging.

If we are to reduce the escalating risks from storms and meet the goal of limiting global temperature rise to less than 2°C, the long-term trend of increasing global emissions must be slowed and halted in the next few years. Emissions must be trending sharply downwards by 2020 at the latest. Investments in and installations of renewable energy such as wind turbines and solar must therefore increase rapidly.

The only approach to halting the escalating risks from storms is to reduce global emissions of greenhouse gases deeply and rapidly.

Australia must do its fair share of meeting the global emissions reduction challenge. Australia's very weak target of a 26-28% reduction in emissions by 2030 compared to 2005 levels – and we are on track to miss this target – leaves Australia lagging well behind other OECD countries. At present, Australia is ranked by Climate Transparency (2016) as the worst of all G20 nations on climate change action and is the only country to receive a rating of 'very poor' in a majority of categories. This lack of action is not consistent with the action required to tackle climate change effectively.

This is the critical decade to get on with the job of protecting Australians from the dangerous impacts of climate change. We are now well into the second half of the decade, and Australia is falling further behind in the level of action required to meet the climate change challenge. The window in which we can act to avoid the most damaging effects of climate change is almost closed. Australia urgently needs a plan to close our ageing and polluting coal-fired power plants and replace them with modern, clean renewables and to become a leader, not a laggard, in the worldwide effort to tackle climate change.

Figure 14: Wind turbines at Brown Hill Range, South Australia.

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