Climate change influences on natural hazards

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Abstract

Many of the most significant and earliest effects of anthropogenic climate change are being experienced through changes to extreme weather and ocean conditions. This includes relatively common extremes that occur a few times a year on average, as well as rarer extremes with multi-year return periods. The influence of anthropogenic climate change on these natural hazards is reviewed here for the Australian region, presenting a synthesis of existing scientific knowledge based on observations for changes that have already occurred, as well as model projections for future scenarios. General summaries are:

- More frequent and intense extreme heat events throughout Australia.
- More dangerous bushfire risk factors including weather conditions in southern and eastern Australia.
- More intense extreme rain events in many parts of Australia, with larger uncertainties for flood risk.
- Sea levels will continue to rise throughout Australia, increasing storm surge risk.
- Fewer but potentially more intense cyclones in some regions of Australia.

Improved preparedness for these hazards will help disaster risk reduction and climate adaptation activities, with benefits for a wide range of sectors such as natural resource management, energy, agriculture, finance, insurance, defence, tourism, transport and health. However, unconstrained future warming this century (i.e. without stabilisation) will lead to large changes that will see communities and sectors experience conditions well beyond current experience.

Extreme Heat

Single- and multi-day extreme heat events pose significant risks to human health, the environment and the economy (Coates et al. 2014). Average temperatures across Australia have increased by about 1°C since 1900 due to anthropogenic greenhouse gas emissions (IPCC2013; Reisinger et al. 2014; CSIRO-BoM 2015). This warming includes both day- and night-time temperatures, and has increased the number of extreme heat events that have occurred on a range of timescales.

Multi-day heat wave events have increased in frequency and duration across many regions (Perkins-Kirkpatrick et al. 2016) with attribution studies clearly demonstrating anthropogenic influences (Black et al. 2015; Dittus et al. 2016). Single-day extreme heat records in Australia have outnumbered extreme cool records by about 3-to-1 for daytime maximum temperatures and 5-to-1 for night-time minimum temperatures since 2001 (CSIRO-BoM 2015).

It is virtually certain that climate change will continue to worsen the impacts of extreme heat events, with longer heat waves and more frequent extremely hot days (and fewer extreme cold days), as well as temperatures above anything in the historical record for many regions. Although continued warming in the next couple of decades is now practically inevitable, greenhouse gas emissions during these decades will help determine the magnitude and rate of future warming towards the end of this century, with higher emission scenarios causing faster rates of warming than lower emission scenarios. For mid-range emission scenarios later this century, some areas of Australia could experience 2-3 times the average number of days above 35°C (CSIRO-BoM 2015). Additionally, heat stress on people in urban areas is likely to be greater than in rural areas, particularly overnight, due to urban heat island effects that can add to the broader regional-scale warming trend (Fischer et al. 2012; Argüeso et al. 2015).

Bushfires

Anthropogenic climate change is influencing the frequency and severity of dangerous fire conditions in Australia and other regions of the world (CSIRO-BoM 2015; Abatzoglou & Williams, 2016; Boer et al. 2016; Dowdy 2018). Weather conditions have become more dangerous for bushfire risk in many regions throughout southern and eastern Australia, and the fire season has lengthened (particularly during spring). Northern Australia, which sees significant fire activity during the dry season, has experienced increased monsoonal rainfall that has increased fuel growth in recent decades, as a key factor influencing fire danger in that region (McKeon et al. 2009).

Bushfire risk factors are projected to increase in severity for many regions of Australia, including due to more extreme heat, with high confidence in this for southern and eastern Australia (CSIRO-BoM 2015). Projected changes in northern and central Australia are less certain (with fire activity strongly related to fuel availability in these regions). Additionally, there have been a number of devastating fire events in Australia associated with extreme pyroconvection (including thunderstorm development in fire plumes) (Mills & McCaw 2010; McRae et al. 2015; Dowdy et al. 2017), with some indication of an increasing risk of pyroconvection in some regions (Dowdy & Pepler 2018).

Extreme Rainfall and Flooding

Extreme rainfall and associated flooding events can cause extensive damages to built and natural environments, as well as loss of life and productivity. Extreme rainfall can be caused by significant weather systems such as cyclones, thunderstorms and frontal systems in most regions of Australia (Dowdy & Catto 2017), while snowmelt can also exacerbate flooding downstream from alpine regions. In Australia, although the range of natural variability in extreme rainfall is large, making trends in rainfall intensity both difficult to detect and sensitive to analysis methodology, there is some evidence that a higher proportion of total annual rainfall in recent decades has come from heavy rainfall events (BoM-CSIRO 2016).

Atmospheric moisture capacity increases by about 7% per degree of warming (this physics law is known as the Clausius–Clapeyron relation), with global analyses showing increased absolute humidity broadly consistent with the observed global warming trends (Trenberth et al. 2007). Some large-scale studies indicate that extreme rainfall intensity is increasing at about 7% per degree of warming, while noting that short-duration events (e.g., hourly extremes) as produced by thunderstorms or tropical cyclones could increase by about double that rate due to the additional effect of potentially stronger convective processes (Lenderink et al. 2008).

Extreme rain events in the future are likely to become more intense across most of Australia (CSIRO-BoM 2015). Despite difficulties associated with characterising current trends, there is relatively high confidence in this projected change (noting the physics underlying the change is well established). Model projections show future increases in rainfall intensity for the wettest day of the year throughout most of Australia, as well as in the likelihood of extreme rainfall events that are currently rare (e.g., 1-in-20 year events), while in some areas where mean rainfall is projected to decrease strongly there is more uncertainty around future changes (e.g., parts of southern Australia).

The extent and severity of flooding is influenced by a range of factors, including the timing, spatial distribution, intensity and duration of rainfall, as well as the antecedent and background climate conditions (such as soil moisture and storage levels). The complex interaction of these factors, coupled with the short length of comprehensive flood records and large interannual variability, make it difficult to confidently assess significant trends in the frequency or magnitude of observed flood events (Johnston et al. 2016). There is also considerable uncertainty based on modelling as to how flood severity and frequency could change in the future at a catchment level, while noting some increased risk factors associated with increased rainfall intensity. In regions where overall drying is projected to occur (e.g., parts of southern Australia), increases in heavy rainfall intensity may be partly offset by an overall drying of catchments at some times of the year. Increases in flash-flood risk are also plausible, due to potential changes as discussed above in short-duration convective rainfall events. Additionally, when combined with increasing sea levels, projected increases in extreme rainfall events suggest that flood risk may increase in some coastal and estuarine regions.

Sea Level Rise and Storm Surge

Elevated sea levels are related to various factors including tides and storms, as well as rising sea levels due to anthropogenic global warming. Intense low pressure systems (e.g., tropical or extratropical cyclones) and periods of prolonged strong winds can also contribute to extreme sea level and storm surge events, with large waves also associated with hazards such as coastal erosion and inundation (Dowdy et al. 2014; McInnes et al. 2016).

Anthropogenic global warming is causing sea levels to rise due to the combined effects of melting glaciers and thermal expansion of the oceans, with a global average rise of about 20 cm since the late-19^{th} century (IPCC 2013). Globally, sea level rose at about 1.7 mm/year during the 20^{th} Century, with similar trends in Australia (CSIRO-BoM 2015). Sea level rise has accelerated in recent decades, with a global increase of 2.6-2.9 mm/year from 1993 to mid-2014 (Watson et al. 2015).

The likely global sea level rise by 2081-2100 relative to 1986-2005 is 32-63 cm for mid-range emission scenarios, and 45-82 cm for high emissions scenarios. These projections do not fully capture the potential contribution to sea level rise from the large ice sheets (Greenland and Antarctica), whose response to global warming is uncertain and possibly underestimated (Vermeer & Rahmstorf 2009; DeConto & Pollard 2016), with rises exceeding 2.4 m being physically possible later this century (USGCRP 2017).

Due to rising sea levels, the frequency and magnitude of coastal flooding is expected to increase significantly this century, regardless of changes in storm characteristics. Sea level rise will also increase the intensity of riverine floods, by slowing the drainage of water from low-lying areas and increasing tidal-zone water heights in rivers and drains. Rising sea levels combined with high astronomical can cause 'nuisance tidal flooding' in the absence of a major weather event (Sweet & Marra 2016). For Australia, to maintain the current level of exposure of coastal assets to extreme sea levels, protective barriers would need to be raised at least 0.7-1.0 m by 2100 for a high emissions scenario (CSIRO-BoM 2015).

Cyclones

Cyclones are intense low-pressure systems, including tropical cyclones (TCs), as well as extratropical cyclones in the more temperate regions of Australia (CSIRO-BoM 2015). They can cause extreme rainfall and winds, as well as various coastal hazards (e.g., destructive waves, storm surge and coastal erosion). Cyclones that occur along central and southern regions of Australia's east coast, known as East Coast Lows (ECLs), often cause severe coastal impacts. Climate change is likely to affect cyclone activity in a number of ways, with these changes being variable between the different types of cyclones described below.

TC activity around Australia has large variability from year to year and can be influenced by the El Niño-Southern Oscillation. Observations show that when that variability is accounted for there is a significant downward trend in TCs in recent decades (Dowdy 2014), potentially due to a combination of natural and anthropogenic sources. The statistical significance of any observed trend in the intensity of TCs is overshadowed by uncertainties due to their high degree of variability and relatively short period of high-quality observations from satellites. Fewer TCs are generally projected in the future for Australia with a greater proportion of severe TCs, as well as potentially reaching further south associated with warmer oceans, while noting medium to low confidence in regional aspects of these projections due to challenges associated with modelling TCs (CSIRO-BoM 2015; Walsh et al. 2016).

ECLs have large interannual variability in their occurrence frequency, overshadowing any observed trends in their characteristics. Studies from reanalysis data show no clear trend in the frequency of ECLs over recent decades (Dowdy et al. 2014; Browning & Goodwin 2016; Pepler et al. 2016a). Projections suggest that fewer ECLs are likely to occur in the future, particularly during the cooler months of the year (Dowdy et al. 2014; Pepler et al. 2016b), while noting that rising sea levels and potential changes to their intensity can also influence future impacts (e.g., from rainfall extremes).

There is some indication in recent decades of a southward shift in the average latitude of extratropical cyclones in the Australian region, leading to fewer cyclones in parts of southern Australia (Hope et al. 2017). Model projections for the future climate indicate a southward shift in the mean latitude of extratropical cyclones in the Southern Hemisphere, potentially associated with tropical expansion and a contraction of the Antarctic polar vortex (CSIRO-BoM 2015). This suggests a future trend towards fewer extratropical cyclones near southern Australia, with some indication that the intensity of strong extratropical cyclones might increase (particularly around 45-60°S) leading to more frequent strong wind events in Tasmania (CSIRO-BoM 2015; Chang 2017).

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