CLIMATE CHANGE IN VICTORIA: TRENDS, PREDICTIONS AND IMPACTS

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Australia's climate is changing, consistent with global trends. Continental average temperatures have increased nearly 1°C since the early 20th century, with warming accelerating since the 1950s. The number of extreme hot days is increasing, whereas the number of cold days and frosts is decreasing. With an average temperature over 1.0°C above the long-term mean, 2005 was Australia's warmest year on record; 2009 was the second warmest year on record. The decade 2000–2009 was Australia's warmest. Rainfall has been decreasing in the south-west and south-east of Australia, but increasing in the north-west. The ocean is warming and sea levels are rising, consistent with global averages. Consistent with global and national trends, Victoria's climate is already changing and will continue to do so, posing significant risks to the State. Over the past few decades Victoria has become hotter and drier, and these trends are likely to continue, together with an increasing intensity and/or frequency of extreme events, such as heatwaves, droughts, bushfires and floods, posing significant risks to the State's infrastructure, coasts, ecosystems, agriculture and health.

Key words: climate change, rainfall, sea level, Victoria, warming.

OBSERVED AND PROJECTED TRENDS IN CLIMATE AND EXTREME EVENTS

Temperature

MAXIMUM and minimum temperatures in south-east Australia have increased 1.1°C and 0.9°C, respectively, since 1960 (Ashcroft et al. 2012). The average number of record hot days per year has also increased; in Melbourne, the long-term average number of days per year above 35°C was 10 (Bureau of Meterology (BoM) 2012a) but, during the decade 2000–2009, the average number of days >35°C increased to 13 (BoM 2010). The January–February 2009 Melbourne heatwave event was consistent with the shift to more record hot weather. The summer of 2012–2013 was remarkable in the number of high temperature records set and for the intensity and extent of extreme hot weather (for details, see Climate Commission 2013).

As average temperatures continue to rise across Victoria, the number of hot days (>35°C) is expected to increase. In Melbourne, the number of hot days is projected to increase from the long-term average of 10 (BoM 2012a) to 15–26 days by 2070 (CSIRO & BoM 2007).

Bushfires

The Forest Fire Danger Index, the measure used to gauge bushfire threat, has increased at 16 of 38 weather stations across Australia over the period 1973–2010, with none of the stations recording a significant decrease (Clarke et al. 2011). The increase has been more prominent in south-east Australia. The conditions for large and intense fires (i.e. low humidity, high winds and extreme temperatures) are likely to become more common in the future. The amount and condition of vegetation available to fuel fires is also likely to change, although the extent of these changes is uncertain (Williams et al. 2009). One of the largest uncertainties is related to the change in rainfall patterns, which influences both the amount of vegetation that is available to burn and its condition. The number of 'very high' and 'extreme' fire danger days is projected to increase as the average temperature increases further by 4%–25% by 2020 and by 15%–70% by 2050 (Lucas et al. 2007).

Black Saturday bushfires

Victoria's worst ever bushfire, which claimed 173 lives, destroyed more than 2000 properties, burnt nearly 400 000 ha and affected 78 communities, occurred during one of the hottest and driest summers on record (Commissioner for Environmental Sustainability (CES) 2012).

On Saturday 7 February 2009, the temperature in Melbourne peaked at 46.4°C. Melbourne had recorded no rainfall from 4 January to 7 February. This, combined with high wind speeds and low humidity, created perfect conditions for an unprecedented natural disaster. The estimated cost of the Black Saturday bushfires to Victoria was approximately Au$4.4 billion (Parliament of Victoria (PoV) 2010). A new level of the fire danger scale has since been added to recognise the significant increase in severe bushfire conditions over the past decade. The 'Code Red' level signals that the safest option for residents is to leave rather than stay to protect their homes (Country Fire Authority (CFA) 2009). If this system been operational at the time, the weather conditions of 7 February 2009 would have resulted in a 'Code Red' alert being issued for most of Victoria (CFA 2009).

Although several of the worst fires on Black Saturday were ignited by sparks from falling power lines, a CSIRO submission to the Victorian Bushfires Royal Commission suggested that the extreme heat and dryness that contributed to the extent and severity of bushfires was influenced by climate change (Hennessy 2009).

Rainfall, drought and floods

Despite the heavy rains in 2010 and 2011, south-east Australia is experiencing a long-term drying trend, particularly evident in the past two decades (BoM 2013). For example, the Big Dry of 1997–2009 in Victoria was the driest period on record, surpassing previous droughts that extended from 1936 to 1945 (the World War II drought) and from 1896 to 1905 (the Federation drought; CSIRO 2010). In the last two decades, Victoria has experienced both a 10–20% reduction in rainfall during the late autumn/winter season and a reduced frequency of very wet years. The observed decreases in rainfall have been much larger than model projections for the next few decades (CSIRO 2010).

Embedded in the overall drying trend are changes in the nature of rainfall when it does occur. Frequent heavy rainfall events throughout 2010 and 2011 resulted in Australia's wettest 2-year period on record (BoM 2012b), with the period from late 2010 to early 2011 bringing Victoria's wettest January on record.

The record rainfall of 2010–2011 effectively brought the Big Dry to an end. However, comparing measurements of rainfall over the past 15 years with the historical average show that large areas of below-average and very much below-average rainfall remain over much of south-east Australia (Timball et al. 2010). Rainfall over half of Victoria in the past 15 years was far below average (see http://www.bom.gov.au/climate/current/statements/scs38.pdf, accessed August 2013).

The exceptional rainfall of 2010–2011, resulting in the Victorian floods, was influenced by strong La Niña conditions and by record warm ocean temperatures around Australia (BoM 2012b). This heavy rainfall resulted in flooding over one-third of Victoria and caused widespread damage to residential and rural property, townships, agriculture and essential services (Comrie 2011).

Climate models suggest that dry conditions will continue across southern Australia (CSIRO 2012). In particular, the models project decreases in average rainfall during winter and spring over the next century. Projections of future rainfall (and therefore water availability) across south-east Australia indicate that water availability will likely continue to be reduced, particularly in winter, compared with that in the 20th century (CSIRO 2010). Because most of the streamflow in Victoria occurs in winter, this translates to a continuing significant reduction in winter, and therefore annual, streamflow.

It is likely that heavy rainfall events will become more frequent across southern Australia (CSIRO & BoM 2007). A heavy rainfall event that currently occurs once every 20 years is projected to become slightly more frequent by mid-century, perhaps occurring once every 15 years, and more frequent again by the end of the 21st century (occuring approximately once in every 10–15 years; Intergovernmental Panel on Climate Change (IPCC) 2012).

Sea level

Global sea levels have risen on average approximately 20 cm since the late 1800s and the rate of change has increased over the past two decades (IPCC 2007; Church and White 2011). The projections for increases in sea levels for this century range from 20 cm to over 100 cm (IPCC 2007; Rahmstorf 2007; Rahmstorf et al. 2012). Most experts agree that a rise of 50–100 cm is likely this century, depending on the stability of the major ice sheets in Greenland and Antarctica (Steffen & Hughes 2013). The observed sea level is tracking close to the upper range of the model projections, suggesting that a global average increase in sea level of 100 cm this century is a serious risk. Even at the lower end of estimates, a 50-cm increase in sea level by the end of the century would contribute to a significant increase in the frequency of coastal flooding. The influence of sea level rises can also be estimated by considering storm tide height, which is the combination of the storm surge height and the height of the tide that results from gravitational effects. For example, a one-in-100-year storm tide height in Geelong is likely to rise from 110 to 220 cm by the end of the century (McInnes et al. 2009).

IMPACTS

Infrastructure

Much of Victoria's critical infrastructure, such as roads, railways and power lines, is vulnerable to very hot temperatures. During very hot weather, bitumen road surfaces can melt, railway lines can buckle and power can be cut when transponders, power lines and power stations fail or are shut down. For example, during the 2009 Melbourne heatwave, when temperatures exceeded 43°C for 3 consecutive days, railway lines buckled from heat stress and, across the 3 days, over one-third of train services were cancelled (Queensland University of Technology (QUT) 2010). In addition, the Basslink connection to Tasmania, which provides 6% of Victoria's electricity, was shut down at various times over 29 and 30 January due to the heat. Faults in major transformers caused outages of main transmission lines across the two days (QUT 2010) and more than half a million Melbourne residents lost power on the evening of 30 January 2009 (QUT 2010). Electricity outages during heatwaves are critical because they occur at the time when power is most needed for cooling systems. An inability to use air-conditioning on very hot days may exacerbate the risk of heat-related illness and death (CES 2012).

Although much of the interest in long-term rainfall changes in Victoria is centred on the drying trend and droughts, wet years with very heavy rainfall can still occur, as 2010 and 2011 demonstrate. Heavy rainfall events, and associated flooding, pose significant risks for health, infrastructure and agriculture. During flood events, immediate impacts can include road closures, power loss and evacuations. Floods can result in the loss of roads and bridges, the contamination of water supplies and damage to personal property. Flooding in 2010 and 2011 resulted in over Au$800 million in insurance claims, damage to more than 100 000 ha of grazing pasture, more than 300 000 livestock deaths and over 200 school closures (CES 2012).

Water security

The observed and projected drying trend has important consequences for urban water supplies. The Big Dry of 1997–2009 had significant impacts on runoff into urban water catchments and on river flows (Chiew et al. 2011). The relationship between rainfall and runoff is not linear: for a given change in rainfall (either increase or decrease), the consequent change in runoff is typically amplified two- or threefold. However, the streamflow decline in Melbourne's catchments, Victoria and the southern Murray–Darling Basin has been disproportionately greater, with, for example, a drop of 50% in the amount of water flowing into the River Murray system during the recent drought (CSIRO 2010). Although rainfall varies greatly from year to year, the overall trend over the past 50 years has been a decline. Annual inflow into Melbourne's four major reservoirs was lower by almost 40% in the period 1997–2011 compared with the previous 80 years. The inflow in 2006 was the lowest in recorded history (Melbourne Water 2012; see http://www.melbournewater.com.au/waterdata/waterstorages/Pages/Inflow-over-the-years.aspx, accessed 5 September 2013).

Agriculture

Australian farmers have shown considerable adaptive capacity in dealing with present-day climate variability (Stokes & Howden 2010). For some farmers there may be limited advantages of a warming climate, such as longer growing seasons and the ability of some crops to use less soil water during their growth phase as a result of higher carbon dioxide concentrations in the atmosphere (Stokes & Howden 2010). However, the adaptive capacity of farmers and the beneficial aspects of climate change can easily be overwhelmed by the negative impacts of climate-related events. For example, in the Wimmera Southern Mallee region, one of Australia's main broadacre cropping and grazing zones, the Big Dry resulted in an 80% reduction in grain production and a 40% reduction in livestock production (Birchip Cropping Group (BCG) 2008). The drought had physical, financial and personal costs for many farming families in the region (BCG 2008). Overall, climate change is expected to reduce crop yields, increase heat stress on livestock, reduce chilling periods for stone fruit and reduce the availability of irrigation, with uncertain impacts on the distribution of pests and diseases (CES 2012; Potgieter et al. 2013).

Coasts

The impacts of increases in sea levels are most acutely felt during extreme weather events, such as storms, which can drive a surge of seawater onto vulnerable coastal areas. These storm surges, when combined with a high tide and sea level rise, will increase the risk of flooding to property, infrastructure and beaches in Victoria (McInnes et al. 2013). Consistent with the upper levels of projected sea level rises, the Australian Government has assessed the risk to Australia's coast from a 110 cm rise in sea level (Department of Climate Change (DCC) 2009): up to 2000 commercial buildings in Victoria, the second highest number for any state in Australia, would be threatened by a 110 cm increase in sea levels. In 2011, this represented a replacement value of Au$8–12 billion (Department of Climate Change and Energy Efficiency (DCCEE) 2011). An estimated 27 600–44 600 residential buildings in Victoria may also be at risk of flooding through the combined effects of sea level rises and a storm surge from a one-in-100-year storm (DCC 2009). Local government areas at particular risk of a 110 cm sea level rise and a one-in-100-year storm tide include Kingston, Hobsons Bay, Greater Geelong, Wellington and Port Phillip (DCC 2009). Storm-related flooding may affect up to 30% of residential buildings in the Kingston local government area by 2100 (DCC 2009).

Higher sea levels can contribute to the erosion of coastlines and eventual coastal retreat. Erosion can cause the loss of iconic beaches and damage property and infrastructure. There are approximately 4700 residential buildings within 110 m of erodible coastline in Victoria (DCC 2009). Particular areas of risk include the Mornington Peninsula and Greater Geelong, with 1140 and 750 residential buildings located near erodible coastline, respectively (DCC 2009).

Impacts in Gippsland Lakes and Lakes Entrance

Within 50 years, parts of the Gippsland coast may be inundated to such an extent that they require protection (e.g. sea walls or relocation of assets, including residential and commercial buildings; Gippsland Coastal Board 2008). This region is already vulnerable to flooding, but rising sea levels could exacerbate this vulnerability. During high tides and heavy rainfall events, water is less able to escape from the Gippsland Lakes. This has resulted in extensive flooding of low-lying towns and infrastructure, such as in the Lakes Entrance township (DCC 2009). The highest recorded flood level in Lakes Entrance was 180 cm above sea level. Rising sea levels, coupled with storm surges and barrier dune erosion, could intensify this existing flooding risk, affecting roads, bridges, buildings and utilities (such as powerlines). Rising sea levels also pose risks to the biodiversity and ecosystems of the Gippsland Lakes, a Ramsar wetland site of national and international importance.

Species and ecosystems

Climate change is expected to have substantial impacts on the geographic ranges, life cycles and population sizes of species. These changes could include reduced population sizes and breeding opportunities for wetland birds; loss of fire- and drought-sensitive habitats; saltwater intrusion into coastal freshwater wetlands; advances in life cycles; loss of groundwater-dependent ecosystems; changed distributions of pests; and increased extinction rates, with some changes already observable in Victoria (Mac Nally et al. 2009; Steffen et al. 2009; CES 2012). Large-scale changes in the distribution of present-day ecosystems are also expected. Modelling by CSIRO for Victoria projects the potential south-ward movement of climates currently associated with Temperate and Grassland vegetation, and a movement of the Desert climate into the north-west and also south-ward into the Mallee by 2050 (CES 2012).

The Victorian Alps

Victoria's alpine environment is extremely vulnerable to climate change. The Australian Alps, extending across south-east New South Wales and eastern Victoria, warmed at a rate of approximately 0.2°C per decade between 1962 and 2001 (Hennessy et al. 2003). Spring snow depth at Spencers Creek on the NSW side of the Alps has decreased by approximately 40% since the 1960s (Nicholls 2005).

Declines in snow cover are expected to continue. Under a best-case scenario (least warming and most precipitation), modelling suggests that areas with an average annual snow cover of at least 30 days per year could decline 14% by 2020 and 30% by 2050 relative to 1990 (Hennessy et al. 2008). Using a higher-impact scenario (greatest warming and least precipitation), these losses could be as high as 54%

by 2020 and 93% by 2050. The worst-case scenario is the complete loss of the alpine zone during this century.

Some changes to the alpine ecosystem have already been observed. For example, snow gums have already started to establish in frost hollows where they have not occurred previously (Wearne & Morgan 2001), and there have been increased sightings of feral and native mammals at higher altitudes than historically recorded (Pickering et al. 2004).

Ongoing losses of snow cover will seriously affect alpine species, many of which are already considered rare and threatened. Small native mammals, such as the mountain pygmy possum and the broad-toothed rat, are experiencing habitat loss due to the reduction of protective snow cover and may become increasingly vulnerable to introduced predators, such as foxes (Pickering et al. 2004). Habitats such as alpine bogs are threatened by the potential increase in the frequency of fires. Food webs, such as those that rely on the yearly arrival of Bogong moths, may be disrupted because warming is affecting the timing of species' life cycles (Green 2010).

Reduced snow cover and increasing uncertainty about suitable conditions for recreational activities is also affecting alpine tourism (Pickering 2011). Ski-field operators have been at the forefront of climate change adaptation (Bicknell & McManus 2006), most notably through their investment in artificial snowmaking to compensate for reduced snow availability. However, snowmaking will be limited in many places in Australia by water availability and costs. For example, an estimated 700 snow guns will be required to maintain skiing conditions in Australia's six main resorts until 2020, requiring Au$100 million in capital investment and 2500–3300 million litres of water per month (Pickering & Buckley 2010).

Human health

More record hot days and associated heatwaves increase the risk of heat-related illnesses and mortality, particularly in the elderly (Loughnan et al. 2010). In January 2009, south-east Australia experienced a record-breaking heatwave and Melbourne recorded its highest temperature of 46.4°C (BoM 2010). During this period, heat-related hospital admissions increased eightfold, with almost half the admissions being of people aged 75 years and older. There was a 46% increase in ambulance call outs, including a 34-fold increase in direct heat-related cases (over 60% aged 75 years or older; Department of Human Services (DHS) 2009). There were an estimated 374 deaths above what would normally be expected during the period, a 62% increase in mortality (DHS 2009).

Heatwaves can also put pressure on hospital morgues. During the 2009 heatwave, the Victorian Coroner mortuary took in 50 bodies a day, more than three times the usual average (16 per day).

Without effective responses to extreme weather events, heat-related deaths in Melbourne are projected to increase 10% by 2020 (based on the Year 2000) and 40% by 2050 (McMichael et al. 2003). One study using a mid-range warming scenario coupled with expected demographic changes estimated that deaths in Melbourne could reach 1000 in a severe heatwave event by 2050 (Pricewaterhouse Coopers 2011); by comparison, there were 374 excess deaths in the 2009 heatwave. However, it should be noted that increases in temperature could also result in a modest reduction in cold-related deaths for several decades (Bambrick et al. 2008).

Other types of extreme events also pose significant risks to human health. For example, bushfires can cause injuries and deaths, and can also exacerbate existing respiratory conditions. During heavy rainfall events, contact with contaminated floodwater and soil can cause diarrhoea and other bacterial infections, and pose risks to drinking water supplies (Climate Commission 2011).

People at most risk are those already vulnerable in our community, including children, the aged, those with existing medical conditions and people living in remote Indigenous and rural communities (Bennett et al. 2011). For more information on the impacts of climate change on human health, readers are referred to the Climate Commission's report *The Critical Decade: Climate Change and Health* (Climate Commission 2011).

To minimise the risks that climate change poses to human health, healthcare organisations are already taking action. Victorian hospitals had prepared for the anticipated increase in burns patients experienced during the 2009 Black Saturday bushfires (Cameron et al. 2009). For example, the specialised referral centre for burns at The Alfred Hospital transferred stable patients to increase ward capacity and additional staff and operating theatres were placed on standby (Cameron et al. 2009). This type of coordinated response allowed the hospital to respond to the emergency and could be required more frequently into the future.

Fig. 1. Risks and impacts of climate change on Victoria. Reproduced with permission from Steffen and Hughes (2013).

CONCLUSIONS

Victoria is already feeling the impacts of human-induced climate change and these impacts will continue to accelerate for decades to come (Fig. 1). Without strong and rapid action, there is a significant risk that climate change will undermine our society's prosperity, health, environment, stability and way of life. To minimise this risk, we must decarbonise our economy and move to clean energy sources by 2050. That means carbon emissions must peak within the next few years and then strongly decline. The longer we wait to start reducing carbon emissions, the more difficult and costly those reductions become. This decade is critical. Unless effective action is taken, the global climate may be so irreversibly altered that we will struggle to maintain our present way of life. The choices we make this decade will shape our long-term climate future.

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