3. Important features of Victoria's climate

This chapter gives a brief general introduction to the climate features relevant to Victoria, where features refers to the atmospheric circulation, weather systems and global processes such as the El Niño Southern Oscillation that affect our weather, seasonal climate and drive much of the longer-term changes to the climate. These features have changed in the past and are projected to continue changing in the future, in turn driving the weather and climate that is experienced in Victoria. For a more thorough coverage, please see work such as the *Victorian Climate Initiative* (VicCI), synthesised in Hope et al. (2017). Another useful introduction to some important climate features is the Victorian Government's *Climate Dogs*[2].

Much of Victoria's climate has a temperate maritime classification, meaning that the moderating effect of the ocean gives generally mild temperatures with more rainfall in winter than in summer. Particularly during the cool season (May to October) Victoria is influenced by the mid-latitude westerlies. The western part of the state receives most of its rainfall from systems such as troughs and fronts embedded in this westerly flow, which are in turn are influenced by features of the general circulation such as the Southern Annular Mode (Figure 6). However, some regions of Victoria, particularly in the east, lack this distinct seasonal cycle of rainfall. The climate in the eastern part of Victoria is more like that of the eastern seaboard of Australia, with a significant proportion of rainfall from weather systems such as cut-off lows, which are low pressure systems that are cut off from the westerly flow. Intense cut-off lows include east coast lows, which can bring some of the most notable extreme rainfalls to the eastern regions of Australia.

In the Victorian region, changes to the atmospheric circulation and incidence of rain-bearing weather systems are likely to be the dominant drivers of changes to rainfall in a warming climate. In general, recent assessments of global climate processes and analysis of climate modelling (IPCC 2013b; Hope et al. 2017), indicate that in the cool season, southeast Australia is expected to see a shift in the dominant circulation and weather systems due to a warming of the climate and changes to the dynamics of the atmosphere. The change can be broken down into changes to the circulation that then manifests in changes in the weather systems and the rainfall they bring. The cool and warm seasons can be influenced in different ways.

The important changes include:

- a southerly shift in the 'storm track', the band where weather systems tend to travel in the southern hemisphere, to the south of Australia. This shift can reduce the influence of the synoptic-scale weather systems that bring rain to Victoria.
- an intensification of the subtropical ridge, the high-pressure belt that generally sits on or to the north of Victoria and is a result of the number and intensity of high-pressure systems that occur (highs are generally linked to drier conditions) (see Grose et al. 2015c).
- an expansion of the Hadley Circulation, the major north–south circulation of the atmosphere over the hemispheres, that determines the edge of the tropics, resulting in a southward extension of the tropics, particularly in summer.
- a weakening of the subtropical jet stream in winter over the Australian region. This is the westerly middle to upper troposphere air current that flows over southern Australia that sits at about 25–30°S in winter (Grose et al. 2017a).

Factors directly related to a warmer climate (the thermodynamic aspects) are also likely to affect not only temperature and evaporation, but some processes driving rainfall. For example, convective rainfall can increase in a warmer climate, and extreme rainfall events have been associated with the combination of thunderstorms with other weather systems over Victoria (Dowdy and Catto 2017), and greater atmospheric moisture is available to fall in extreme rainfall events.

2 http://agriculture.vic.gov.au/agriculture/weather-and-climate/understanding-weather-and-climate/climatedogs

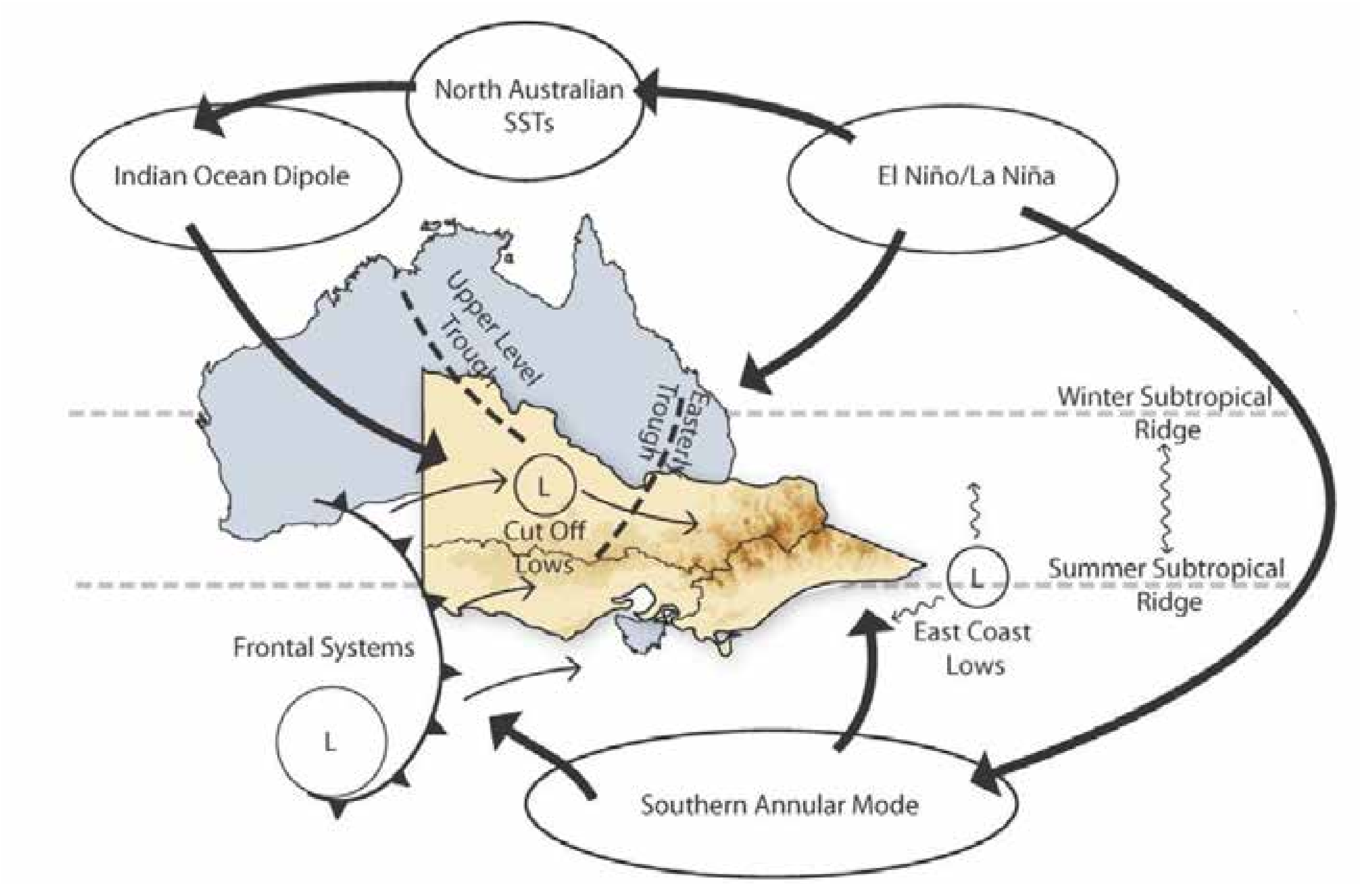

Figure 6. A schematic representation of the main circulation features and drivers of rainfall variability in the Victorian region. Weather systems include fronts, cut-off lows, troughs and east coast lows, that are in part determined by circulation features such as the subtropical ridge and the gradient of sea surface temperatures (SSTs) from north to south. Drivers of variability include the El Niño Southern Oscillation (ENSO) bringing El Niño and La Niña events, the Indian Ocean Dipole (IOD), the Southern Annular Model (SAM), and blocking highs in the Tasman Sea (not shown). Source: VicCI

Along with the changes to the average circulation (the mean state) of the atmosphere, and factors related to a warmer atmosphere, the rainfall variability and averages may also be affected by changes to the drivers of climate variability from year to year. Victoria's climate is influenced by various processes that create climate ups and downs (sometimes called modes of variability), that then have flow-on effects to Australia. On year-to-year time scales, these include the El Niño Southern Oscillation and Indian Ocean Dipole. While the Southern Annular Mode, the north-south shift of the jet to the south of Australia, varies on both shorter (~10 days) and longer (global warming) time scales. The frequency of blocking highs (or simply 'blocking') can also be thought of as one of these modes. For any given phenomenon, there is considerable noise around the relationship between the cycle and the seasonal climate on the ground, and each event has its' own character. Therefore, an index of each phenomenon – such as the Southern Oscillation Index (SOI) for the El Niño Southern Oscillation – is a guide to the likelihood of a particular seasonal climate anomaly but not a predetermination. These modes of variability will continue to exert an influence on Victoria's climate in the future, but climate change may affect their behaviour or their connection to Victoria's climate. The effects of each feature varies somewhat across Victoria.

3.1 El Niño Southern Oscillation

El Niño Southern Oscillation (ENSO) is an irregular cycle in the tropical Pacific Ocean, varying between El Niño, neutral and La Niña events, that has flow-on effects to Australia and many places in the world. Over the entire period 1886–2006, ENSO shows a correlation with rainfall in all or part of Victoria in winter and spring: warmer and drier on average during El Niño conditions, and cooler and wetter during La Niña (Risbey et al. 2009).

El Niño and La Niña events are difficult to predict before autumn of the year they commence; however, the predictability varies from event to event and some are hard to predict even after autumn. Also, the nature of ENSO, and the relationship between ENSO and Victoria's climate, can change over time. Some of these changes are described by a phenomenon termed the Inter-decadal Pacific Oscillation (Timmermann et al. 2018). Climate change due to human emissions may also drive changes to ENSO and its relationship to Victoria's climate, including the possibility of more extreme El Niño and La Niña events (Cai et al. 2015), and a change to the influence on Victorian rainfall (Power et al. 2013); however, there is uncertainty about the future of ENSO due in part to deficiencies of climate models to simulate it with fidelity.

3.2 Southern Annular Mode

The Southern Annular Mode (SAM) is a variation in the atmospheric circulation around the southern hemisphere between around 30°S and 60°S. A positive SAM means higher-than-average pressure over the latitudes near Victoria, and a negative SAM indicates the opposite. SAM has the strongest correlation to Victorian rainfall in winter, where a positive SAM indicates typically lower rainfall than average. There is a connection between SAM and some locations in the mid-latitudes in summer, including typically higher than average rainfall in some places but this effect is not marked in most of Victoria. SAM varies from day to day and week to week but can be persistently high or low for a season, affecting the seasonal climate. In addition, trends have been detected in SAM over time. In recent decades there has been a trend towards positive SAM during summer affected by the ozone depletion over Antarctica as well as the increase in greenhouse gases, and trends in other seasons are less clear (e.g. Marshall 2003). The SAM is projected to continue moving towards a more positive mean state, especially under a high emissions scenario, contributing to the rainfall decline in the mid-latitudes including Victoria (e.g. CAWCR 2016; Lim et al. 2016).

3.3 Indian Ocean Dipole

The Indian Ocean Dipole (IOD) is an ocean–atmosphere phenomenon in the tropical Indian Ocean to the northwest of Australia that has flow on effects to Victoria's climate. The effect typically peaks in spring but can be seen in May to November. A positive IOD is generally linked to below average rainfall in Victoria, and a negative IOD typically is linked to above average rainfall (Ashok et al. 2003). The effect of IOD can be as large as or even override ENSO (Pepler et al. 2014), and when occurring concurrently the two can reinforce each other – an El Niño and positive IOD contributed to some of the driest June to October periods in Victoria. Strong IOD events are linked to heatwaves and pre-conditioning the environment for damaging bushfires (Cai et al. 2009). In the future, the Indian Ocean is projected to warm, and the IOD may change in nature or the influence Victoria's rainfall may change. Currently, the balance of evidence points towards a shift towards a more positive IOD mean state and more positive IOD events (Cai et al. 2013), meaning an influence towards a drier climate.

3.4 Blocking highs

Atmospheric blocking refers to persistent high-pressure systems in a particular location that block the usual atmospheric flow. The frequency and intensity of blocking highs is not the same thing as the average mean sea-level pressure (MSLP) band around the atmosphere, so changes to blocking need to be considered separately from the projected increase of pressure in the mid-latitudes mentioned above. An important centre of blocking is the Tasman Sea. Blocking tends to peak near southeast Australia in winter. Blocking affects Victorian rainfall, particularly in the east, in all seasons (Pook et al. 2013b). The correlation is positive, where more blocking means more rainfall, as blocks are associated with cut-off lows that can bring significant rainfall (Pook et al. 2013a). In future, fewer blocking highs in the Tasman in winter are projected along with a movement in the longitude where most blocks form (e.g. Grose et al. 2017a). The projection of blocking in summer is less clear.