Phase 2 - Physical Climate Risk Assessment – Summary for Policymakers

Clarence Valley Council

October 2021

Risk Frontiers Disclaimer

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Table 1: Acronyms and meanings

Acronym	Meaning
AR6	Sixth Assessment Report of the IPCC
BOM	Australian Bureau of Meteorology
CMIP	Coupled Model Intercomparison Project
CVC	Clarence Valley Council
ECL	East Coast Low
ECMWF	European Centre for Medium Range Weather Forecasting
ENSO	El Niño Southern Oscillation
FFDI	Forest Fire Danger Index
GHG	Greenhouse Gas
GMT	Global Mean Temperature
IPCC	Intergovernmental Panel on Climate Change
IPO	Interdecadal Pacific Oscillation
KBDI	Ketch-Bryam Drought Index
NARCliM	NSW and ACT Regional Climate Model
RCM	Regional Climate Model
RCP	Representative Concentration Pathways
SPM	Summary for Policymakers
TC	Tropical Cyclone
WCRP	World Climate Research Program

Introduction

This Summary for Policymakers (SPM) presents the key findings from the Clarence Valley Council Climate Change Impact Assessment. The SPM provides a high-level summary of the current state of the climate, how it is changing, and how it is expected to change through the 21st century as it relates to Clarence Valley Council (CVC). This report is structured around the primary climate-related impacts affecting Clarence Valley:

1. Flood and extreme rainfall
2. Sea-level rise and coastal flooding
3. Storms
4. Bushfire
5. Heatwave and temperature extremes
6. Drought.

The scientific basis for each key finding is provided in the Technical Summary Report and individual technical reports for each of the primary climate-related impacts (Supplementary Reports S1-7).

This is primarily a modelling study; modelling of present-day and especially future climate entails a range of uncertainties outlined in the Technical Summary and Supplementary reports.

Context

The recently published Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) reiterates that warming of Earth's climate system over recent decades is unequivocal. It is almost certain that this warming has been caused by human activity, including emissions of greenhouse gases, and that this warming will continue throughout the 21st century (Figure 1). The magnitude of warming and its impact on other components of the climate system, such as rainfall patterns, varies significantly between different regions. This report provides a Climate Change Impact Assessment for CVC where historical climate is represented primarily by gridded reanalyses data (Box 1), and information about future climate scenarios (Box 2) is from the latest generation of NSW and ACT Regional Climate Model (NARCliM) simulations (Box 3).

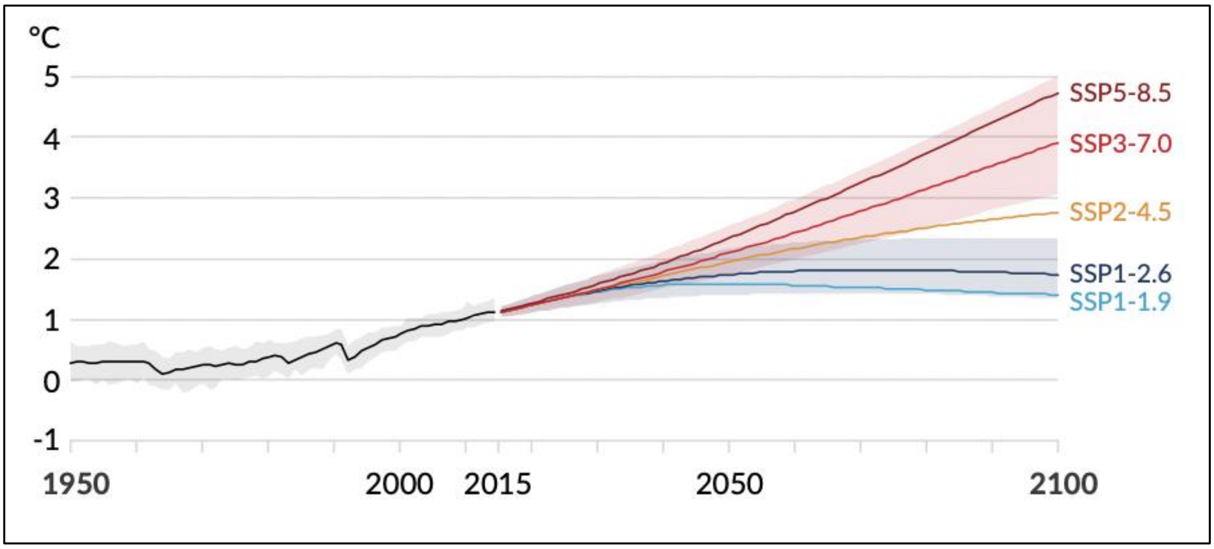

Figure 1: Global surface temperature change from observations and climate model projections from the latest IPCC report. The projections for each of five scenarios are shown in colour: Shared Socioeconomic Pathways (SSP) shown here are comparable to the Representative Concentration Pathways (RCP) used in this report (See Box 2). Shading represents uncertainty ranges from different climate models.

The Current State of the Climate

According to the latest IPCC report, *It is unequivocal that human influence has warmed the atmosphere, ocean, and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere, and biosphere have occurred* (AR6 IPCC 2021). This section describes observed changes for CVC in each of the primary climate-related impacts. Historical and present-day climate is interpreted primarily from reanalyses data, which are the only observation-based datasets with full coverage of the Clarence Valley (See Box 1). A summary of present-day climate and trends since 1980 is shown in Figure 2.

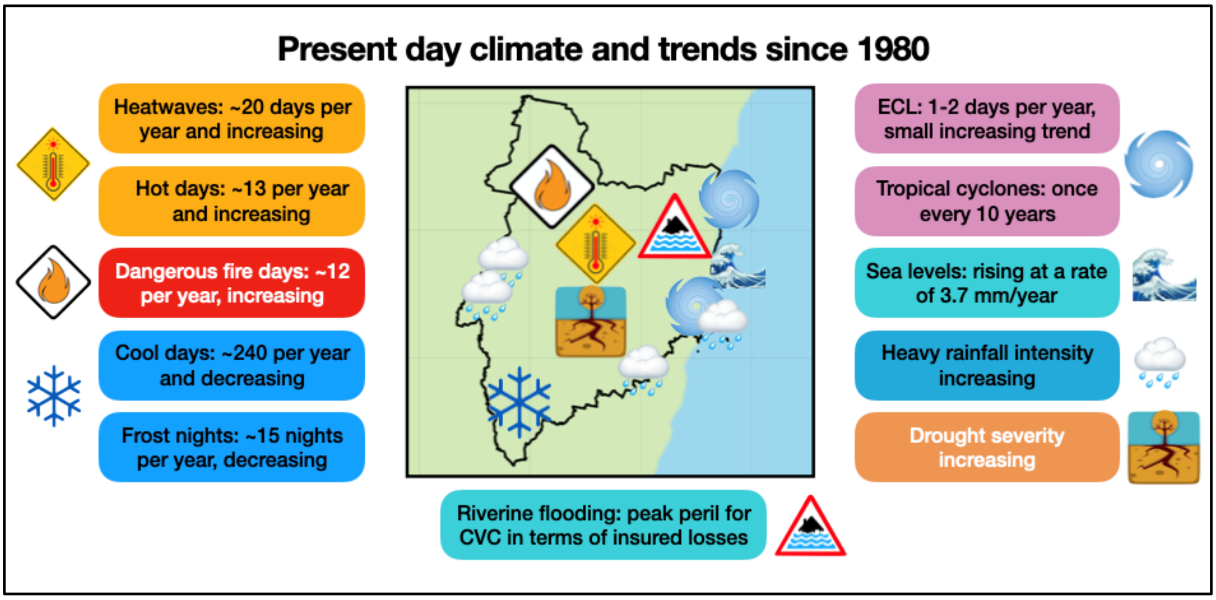

Figure 2: Summary of present-day climate and trends since 1980 for perils of interest. Centre map shows generalised area where peril is of most concern

Flood and extreme rainfall

Flood is the primary climate-related hazard of concern for CVC in terms of losses to residential, commercial, and industrial property. The main climatological driver of flooding is extreme rainfall. At present, heavy rainfall days are most frequent and extreme at coastal locations including Yamba and Iluka, and higher elevation locations including Ewingar. Over the past 39 years there has been a small increasing trend in the intensity of heavy rainfall events (Figure 3), but no consistent trend in the frequency of very heavy rain days or very heavy runoff days. Much of the annual and decadal variability in rainfall is driven by ocean and atmospheric changes in the tropical Pacific associated with El Niño Southern Oscillation (ENSO) and the Interdecadal Pacific Oscillation (IPO), as describe in Box 4.

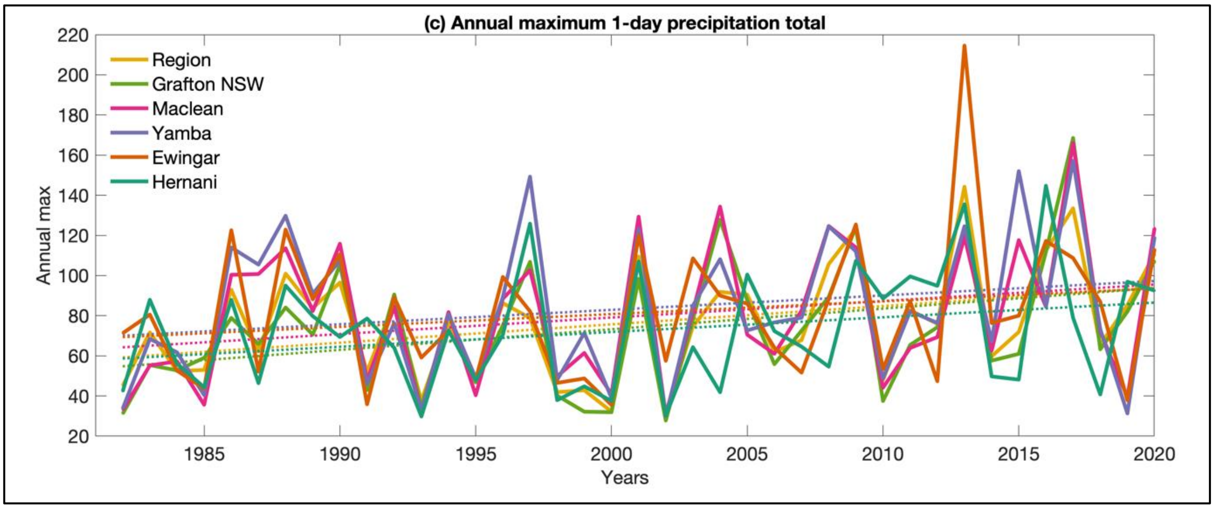

Figure 3: Annual maximum 1-day rainfall totals in mm from the ERA5-Land reanalysis for various locations across Clarence Valley. Regional mean is also shown. Increasing trends are seen at all locations.

Sea-level rise and coastal flooding

Global mean sea level has risen faster since 1900 than over any preceding century in the past 3000 years (IPCC AR6). Around the Australian coastline, sea levels are currently rising at a rate of ~3.7mm/year. Figure 4 illustrates historical and projected global sea level rise. Clarence Valley's coastline is exposed to sea level rise. Sea level rise impacts can be experienced during extreme events such as increased magnitude of storm tide flooding or increased coastal erosion during extreme wave events. They can also impact over longer timescales such as such as ecosystems changes and contamination of aquifers.

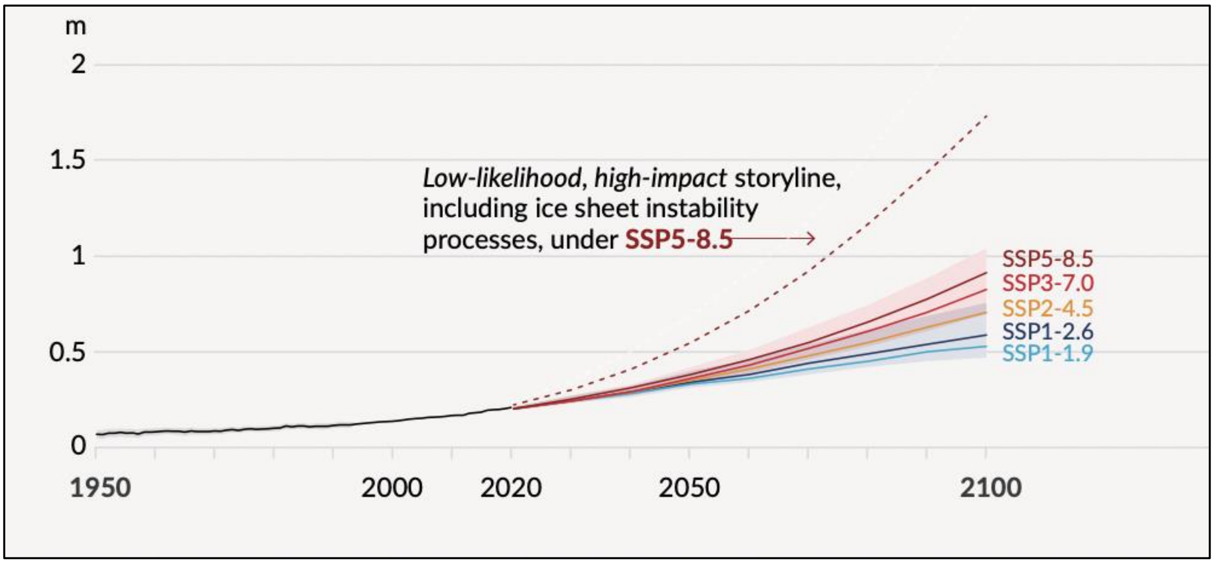

Figure 4: Historical and projected sea level rise from observations and climate model projections from the latest IPCC report. The projections for each of five scenarios are shown in colour. Shades represent uncertainty ranges.

Storms

Under present day climate, CVC is exposed to several types of storms, including east coast lows (ECL), thunderstorms and hailstorms, tropical lows and, occasionally, tropical cyclones (TC). ECL directly impact CVC on average 1-2 days per year and can cause significant damage, especially to coastal locations. TCs are rare, occurring only about once every ten years; however, tropical lows and ex-tropical cyclones can bring heavy rainfall and flooding. There is large year-to-year variability in storm activity (Figure 5), which is modulated by Pacific climate drivers (Box 4): storms tend to be more frequent during La Niña and less frequent during El Niño. Since 1981 there has been an increasing trend in the frequency of ECL impacting coastal locations.

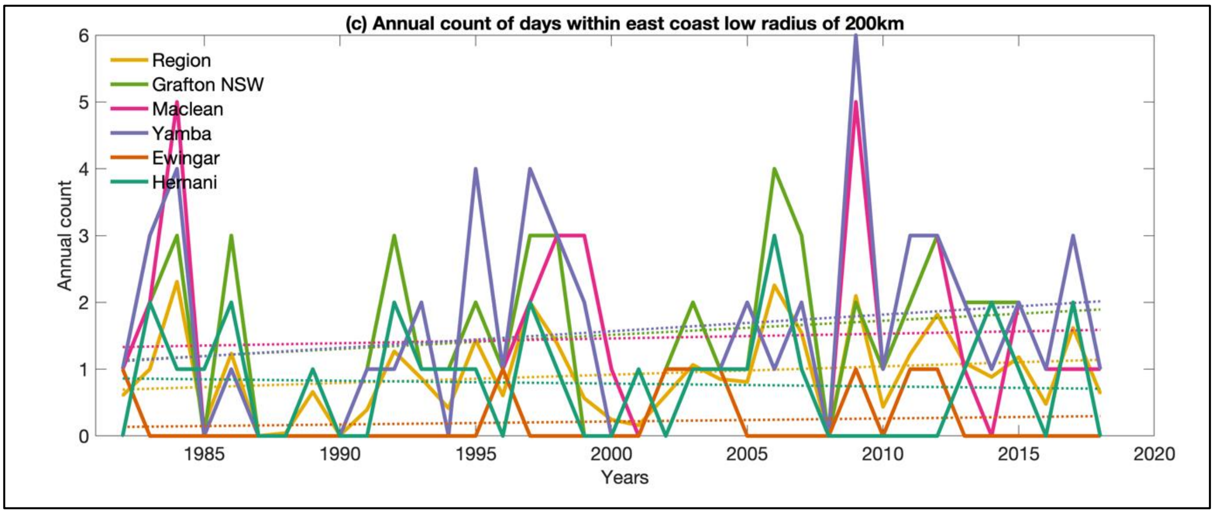

Figure 5: Annual frequency of days when an ECL event was centred within 200km of various locations around Clarence Valley as determined from the ERA5 reanalysis. Regional mean is also shown. Increasing trends are seen at some locations including Maclean, Yamba, and Grafton. Due to high year-to-year variability, these trends are not statistically significant.

Bushfire

Under present day climate, bushfire is the third most expensive climate-related impact, accounting for approximately 6% of all average annual losses to residential, commercial, and industrial properties. Since 1990, the frequency of dangerous fire days, where the Forest Fire Danger Index (FFDI) exceeds 25, has increased from an average of approximately six per year to more than 12 per year (Figure 6). Across CVC, the highest number of dangerous fire days are observed in the inland northwest areas, with the lowest number in the southwest and coastal areas.

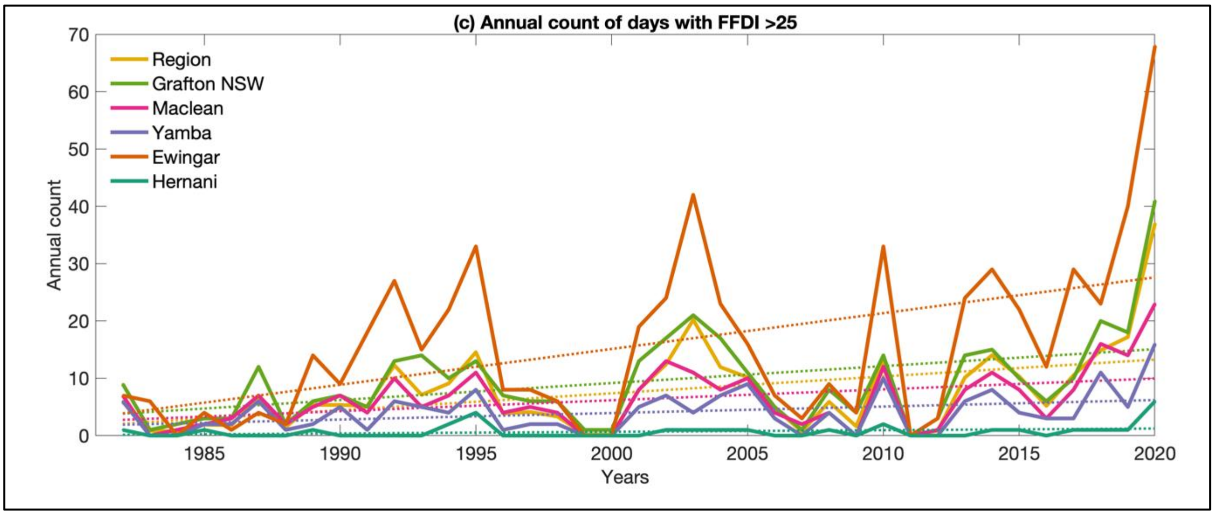

Figure 6: Annual frequency of dangerous bushfire weather days (FFDI > 25) at various locations around Clarence Valley as determined from the BOM FFDI dataset. Regional mean is also shown. Increasing trends are seen at most locations.

Heatwave and temperature extremes

Over recent decades, observed temperature extremes have become more frequent and severe. Since 1990, average hot day frequency has increased from approximately eight days per year to more than 13 days per year; in 2020 there were over 40 days with temperature greater than 35°C (Figure 7). Heatwaves have also increased in frequency from approximately five days per year to more than 20 days per year. During 2019-2020, most parts of CVC experienced over 40 heatwave days. Across CVC, hot days are most frequent at northwest and inland locations, and less frequent in the southwest and coastal regions. In conjunction increasing high temperature extremes, there has been a decrease in the frequency of cool days (temperatures <25°C), and frost nights.

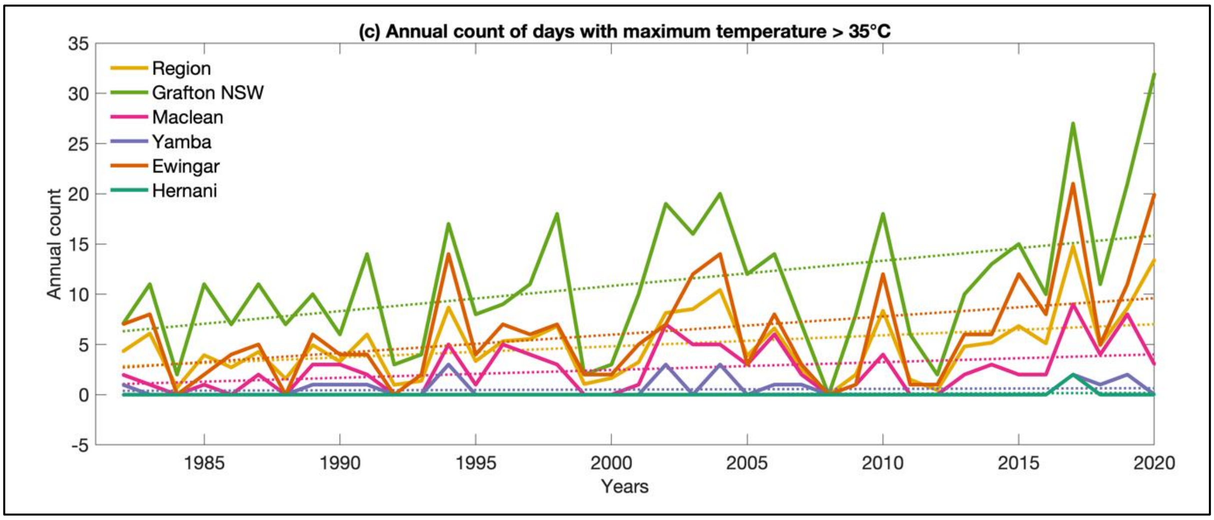

Figure 7: Annual frequency of hot days (with maximum temperature > 35ºC) at various locations around Clarence Valley as determined from the ERA5-Land Reanalysis. Regional mean is also shown. Increasing trends are seen at most locations.

Drought

Over the past 30 years there has been a small increasing trend in the frequency and intensity of drought across CVC (Figure 8). The spatial patterns of drought are comparable to temperature extremes: drought conditions are more severe in the northwest and inland locations, and less severe in the southwest and coastal regions. As with storms and rainfall extremes, there is large year-to-year variability in drought severity which is modulated by Pacific climate drivers (Box 4): droughts tend to be more severe during El Niño and less severe during La Niña.

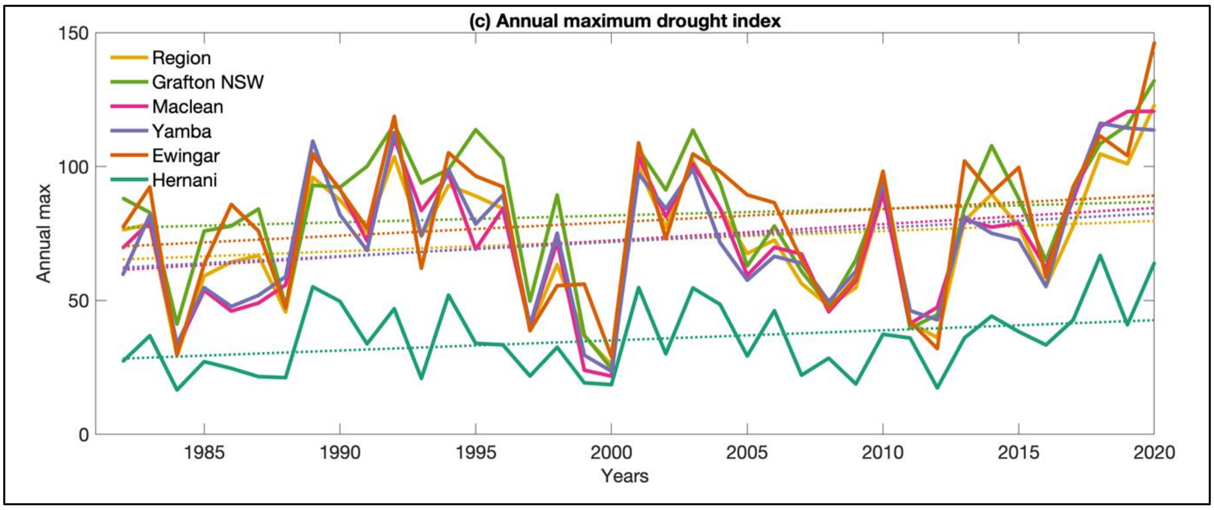

Figure 8 Annual maximum Ketch-Bryam Drought Index (KBDI) from the ERA5-Land reanalysis for various locations across Clarence Valley. Regional mean is also shown. Increasing trends are seen at all locations

Possible Climate Futures

This report uses latest generation regional climate model simulations to assesses the climate response across two possible future scenarios. The climate scenarios are based on the IPCC representative concentration pathways (RCPs) and are designed to explore a range of possible futures in terms of greenhouse gas (GHG) emissions, land use and air pollution (Box 2). The highest GHG scenario is RCP8.5 and represents a worst-case scenario where GHG emissions continue to increase, and global mean temperature increase exceeds 4°C (Figure 1). RCP4.5 is a middle-of-the-road GHG emission scenario where some mitigation of GHG emissions occurs, and global mean temperature increase is between 2-3°C. RCP8.5 is currently considered to be less likely than RCP4.5; however, it is important for decision making to understand the implications of a 'worst' case scenario. Box 3 provides more details on the NSW and ACT Regional Climate Model (NARCliM) simulations use in this analysis.

According to the latest IPCC report, *Global surface temperature will continue to increase until at least the mid-century under all emissions scenarios considered. Global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in CO2 and other greenhouse gas emissions occur in the coming decades.* This section describes implications of projected changes for CVC in each of the primary climate-related impacts as summarised in Figure 9.

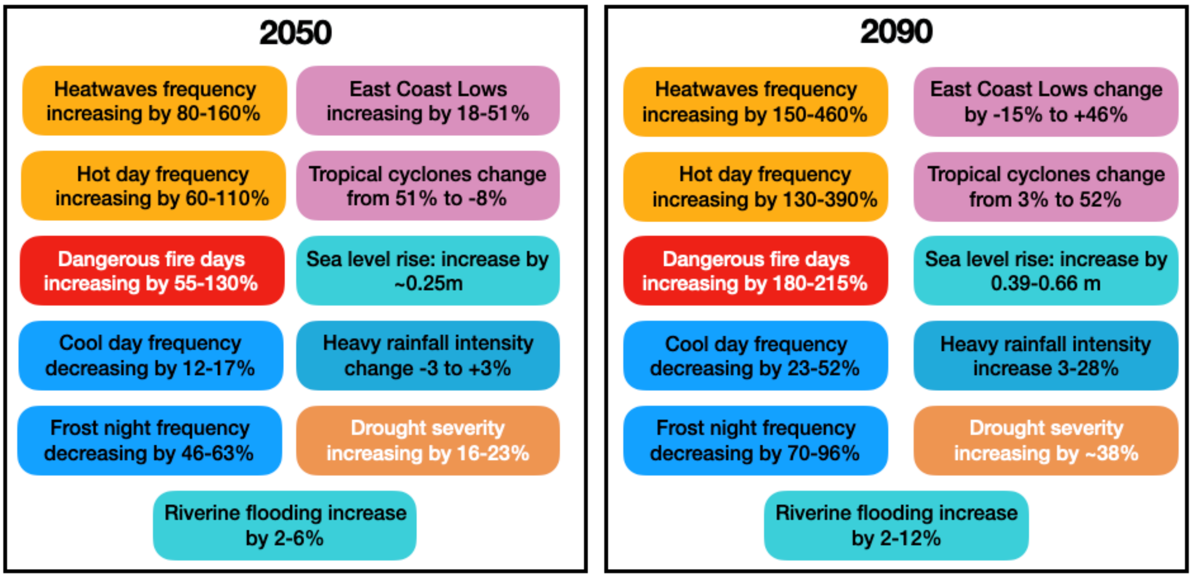

Figure 9: Summary of projected changes in climate parameters of interest from regional climate models for 2050 and 2090. Where are range of values are present this represents differences between climate change scenarios: in most cases smaller magnitude changes are associated with RCP4.5, and larger changes are associated with RCP8.5.

Flood and extreme rainfall

Projections for extreme rainfall indicate no significant trend in frequency, but a small increasing trend in the magnitude of extreme rainfall events (Figure 10). During the 21st century, the primary driver of year-to-year variability in rainfall will continue to be the Pacific climate drivers of ENSO and the IPO (Box 4). Projections for Pacific climate are indicating an increase in ENSO amplitude, meaning both El Niño and La Niña events will be stronger. Extreme rainfall events will produce higher rainfall totals due to the physical relationship between a warmer temperatures and higher atmospheric moisture capacity. Higher rainfall totals may lead to higher flood levels during flooding events, but the frequency of these events will not differ significantly from present. Changes will be similar across CVC, meaning areas of concern at present will continue to be of concern in the future.

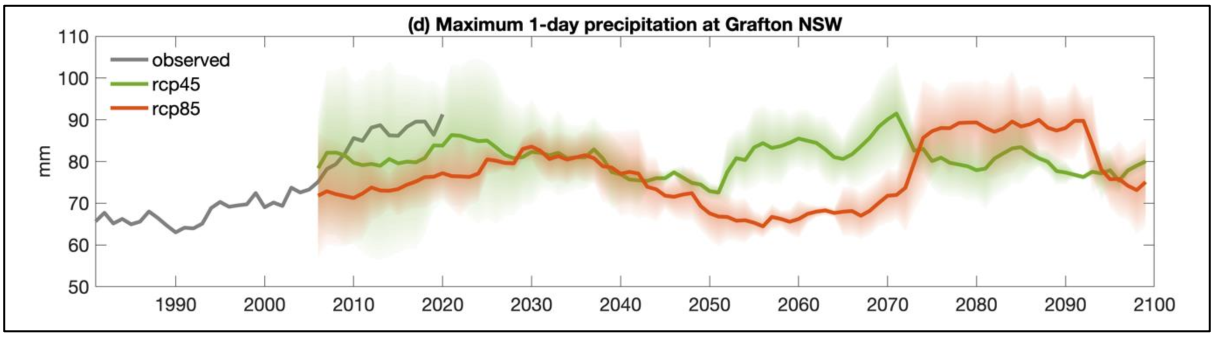

Figure 10: Historical and projected 20-year mean annual maximum 1-day rainfall at Grafton from ERA5-Land (observed) and NARCliM scenario projections (RCP4.5 and RCP 8.5).

Sea-level rise and coastal flooding

Global sea levels are projected to continue rising throughout, and beyond, the 21st century under all scenarios. Projections are for up to 1m sea level rise by 2100 under RCP8.5 (Figure 4); however, uncertainty about ice sheet response means this could be a significant underestimation. For context, global sea levels have risen over 120m since the peak of the last ice age at approximately 20kya, therefore a rise of more than 1m in the coming century would not be unusual.

Storms

Year-to-year storm activity will continue to be driven by changes in Pacific climate described by ENSO and the PDO (Box 4). Projections for Pacific climate are indicating an increase in ENSO amplitude, meaning both El Niño and La Niña events will be stronger. Significant trends in storm frequency are not expected under RCP4.5 or RCP8.5 (Figure 11). However, it is possible that a southward shift in TC storm tracks may occur which, will increase the exposure of CVC to TC events—this situation is not well represented in the current generation of regional climate simulations.

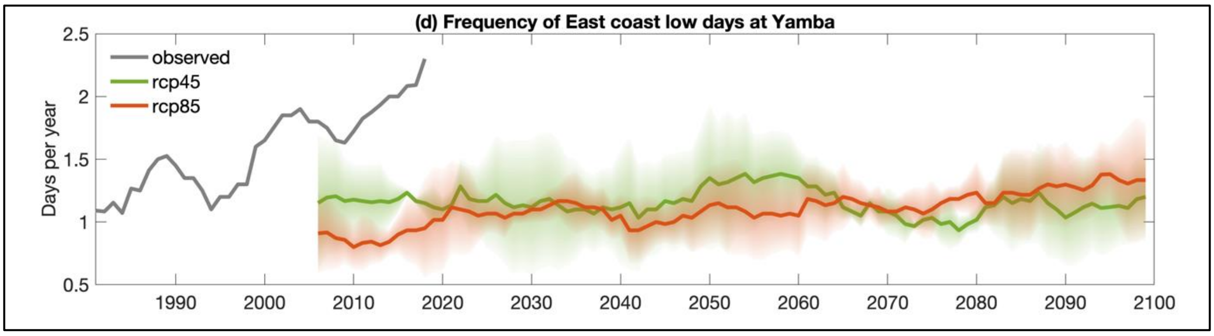

Figure 11: Historical and projected 20-year mean frequency of ECL days per year at Yamba from ERA5 (observed) and NARCliM scenario projections (RCP4.5 and RCP 8.5).

Bushfire

The frequency and severity of dangerous bushfire weather days are projected to continue to increase across all of Clarence Valley during the 21st century under all climate scenarios, with a larger increase under RCP8.5 (Figure 12). Maximum FFDI values will continue to be highest across inland locations and will likely be in the range of 100-150 by 2050, and 150-200 by 2090. The average frequency of very high fire danger days across most parts of CVC will increase by approximately 55% under RCP4.5 and approximately 130% under RCP8.5: for Grafton this means an increase from approximately 9 to up to 21 days per year. By 2090 most locations will have experienced an approximately 200% increase. Note that this is likely an underestimate, as Grafton has already experienced 41 very high fire danger days in 2019. Average annual losses to residential, commercial and industrial property from bushfires are expected to increase by up to 10% by 2050, and up to 16% by 2090. Exposure to dangerous bushfire weather will continue to increase throughout the 21st century, driven primarily by increasing temperatures.

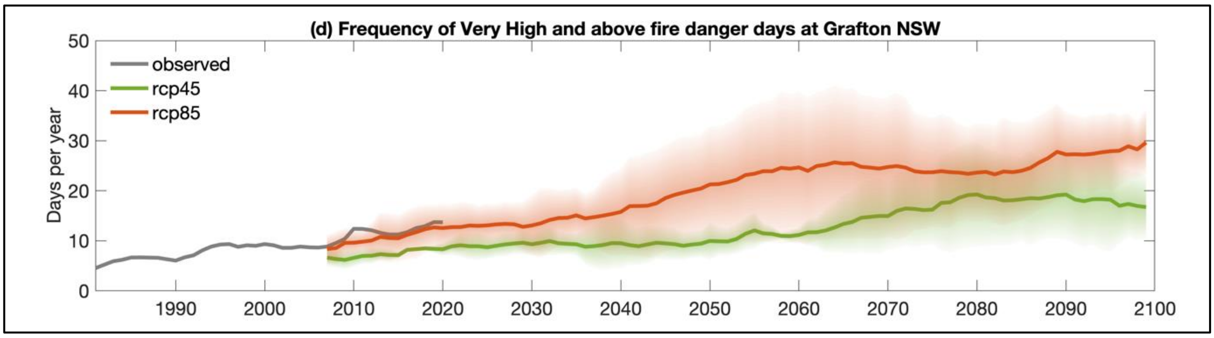

Figure 12: Historical and projected 20-year mean frequency of dangerous bushfire weather days (FFDI > 25) per year at Grafton from BOM FFDI (observed) and NARCliM scenario projections (RCP4.5 and RCP 8.5).

Heatwave and temperature extremes

Heatwaves and hot days will increase in frequency and magnitude under all climate scenarios, with larger increases towards the end of century under RCP8.5 (Figure 13). According to the NARCliM1.5 projections, by 2050, hot day frequency will have approximately doubled to approximately 15 days per year under RCP4.5, and by 2090 this could increase to 40 days per year under RCP8.5. Model simulations of the past decade have underestimated the increase in hot day frequency, suggesting future increases could significantly exceed modelled projections. Grafton has already experienced more than 30 hot days during the summer of 2019/20: models indicate this will be normal by 2070 under RCP8.5. Very hot days (>40°C) are currently uncommon in Clarence Valley but are likely to occur several days per summer by 2050. Heatwave frequency will increase under both RCP4.5 and RCP8.5 scenarios. By 2050 heatwave frequency will have approximately doubled to approximately 35 days per year under RCP4.5, and by 2090 this could increase to over 100 days per year under RCP8.5. In conjunction with increasing heat-related extremes, there will continue to be a decrease in the frequency of cool days and frost nights. In the southern inland parts of CVC, the frequency of frost nights will decrease from 15-20 nights per year at present to approximately 10 nights per year by 2050 (RCP4.5), and as few as 1-2 nights per year by 2090 (RCP8.5).

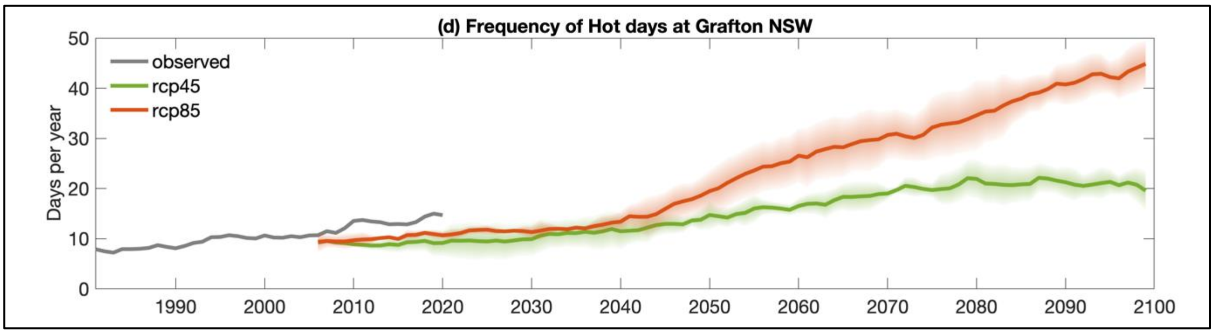

Figure 13: Historical and projected 20-year mean frequency of hot days (temperature >35°C) per year at Grafton from ERA5-Land (observed) and NARCliM scenario projections (RCP4.5 and RCP 8.5).

Drought

There will likely be a continuing increasing trend in drought intensity across most of CVC under both RCP4.5 and RCP8.5 scenarios, with the largest increases seen under RCP8.5 by the end of this century (Figure 14). A steady increasing trend is expected in the frequency of dry days, combined with a small decreasing trend in total annual rainfall. In conjunction with long-term trends, year-to-year drought severity will continue to be driven by changes in Pacific climate described by ENSO and the PDO (Box 4).

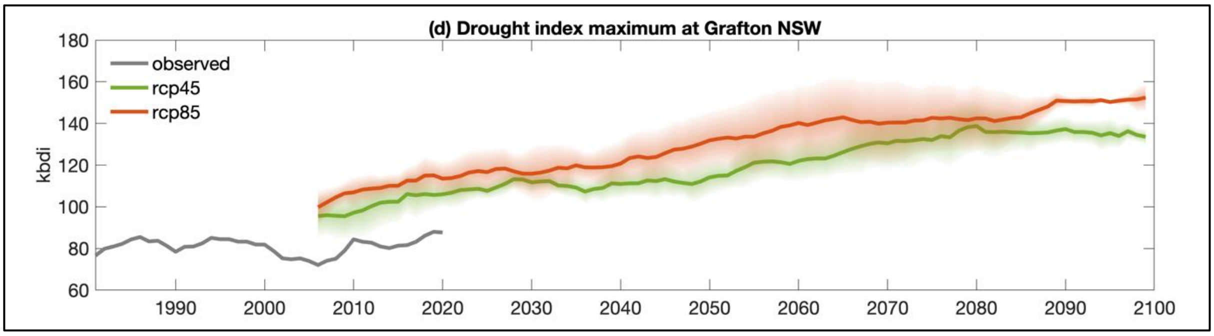

Figure 14: Historical and projected 20-year mean annual maximum Ketch-Bryam Drought Index (KBDI) from the ERA5-Land (observed) and NARCliM scenario projections (RCP4.5 and RCP 8.5).

Climate Impacts for Clarence Valley Council

Impacts to council assets and responsibilities

The implications of climate variability and change for Clarence Valley are described in terms of social, biophysical and economic impacts. Impacts as they relate to council responsibilities are summarised in Figure 15, and discussed in more detail below.

COUNCIL ASSETS AND RESPONSIBILITIES IMPACTED BY EXTREME WEATHER

ASSET/ RESPONSIBILITY	FLOOD	STORM	BUSHFIRE	HEAT	DROUGHT	SEA LEVEL RISE
COUNCIL FACILITIES	✓	✓	✓	✓	✓	✓
COUNCIL OPERATIONS	✓	✓	✓	✓		✓
COST OF INSURANCE	✓	✓	✓			✓
PLANNING	✓	✓	✓	✓	✓	✓
ECONOMY	✓	✓	✓	✓	✓	✓
LANDFILL WASTE	✓	✓	✓			
FLOOD LEVEES	✓	✓		✓	✓	✓
STORMWATER	✓	✓	✓			✓
SEWER NETWORK	✓	✓			✓	✓
WATER SUPPLY	✓	✓	✓	✓	✓	✓
ROADS & BRIDGES	✓	✓	✓	✓	✓	✓
PARKS & PUBLIC FACILITIES	✓	✓	✓	✓	✓	✓
COASTAL ZONE		✓	✓	✓		✓
NATURAL RESOURCES & ENVIRONMENT	✓		✓	✓	✓	✓

Figure 15: Summary of impacts as they relate to council responsibilities for each of the main weather- and climate-related perils

Flood and extreme rainfall

Flooding has been identified as the primary natural hazard facing Clarence Valley in terms of risk to assets and infrastructure. During heavy rainfall events, flooding can create emergency situations and threaten property and infrastructure including roads, power and water utilities.

Increased runoff and saturated soils can cause landslips and treefall. Opportunities exist through increased rainfall replenishing terrestrial water storages and reducing bushfire risk.

Sea-level rise and coastal flooding

Sea level rise and coastal erosion will continue to create a range of issues and challenges for Clarence Valley. These include more frequent repair and maintenance of exposed roads, and community expectations for road raising; increased flood mitigation costs; increased frequency of flooding leading to greater demands on waste management capacity; more frequent emergency operations; damage and disruptions to water and sewer infrastructure; beach erosion and loss of public amenities and restrictions to development in at-risk areas. Coastal erosion is currently of concern for some areas including include Wooli, Brooms Head and Yamba, and will be exacerbated under sea level rise.

For CVC there are currently over 500 properties at risk of a one in 100-year storm tide coastal flooding event. Most of these properties are in the Yamba to Angourie coastal area and are concentrated around the Clarence River. Increases in exposure to storm tide flooding—resulting from sea level rise—only emerges post-2050, when storm tide heights begin to exceed 2 m. By 2090 there will be approximately 65-300 additional properties exposed, depending on the climate change scenario.

Storms

Exposure to storm activity will not increase consistently though the 21st century; however, it is probable that during future La Niña and IPO negative phases, coastal storm activity could exceed the range of natural variability observed in the past 30-years (Box 4).

Some of the main issues and challenges associated with storms include beach erosion; possible disruptions to power and water supplies; disruption and damage to roads through treefall; downed power lines; landslips, washouts, and erosion; more frequent emergency operations; greater demand on waste management; damage to council assets and additional impacts associated with strong winds, extreme rainfall and flooding. Potential for increased periods of storm activity combined with projected sea level rise will place addition stresses on coastal development and infrastructure. Storms such as ECL are also one of the main contributors to rainfall, and so can be beneficial in terms of recharging water supplies.

Bushfire

Projections for increasing bushfire weather extremes will create a range of issues and adaptation challenges for CVC including more frequent emergency operations; restrictions on development in bushfire zones; risk to natural capital including heritage sites, parks and recreation areas and direct damage to council infrastructure.

Heatwave and temperature extremes

Projections for increases in hot days and heatwave days will create a range of issues and adaptation challenges for CVC, including increased maintenance costs for roads and public spaces, increased municipal water demands coupled with increased pathogen risk, serious disruptions to council productivity through work health and safety issues, energy usage, demands on emergency services and increased visitation to the coastal zones. The threat to human health from extreme temperature events will increase the need for adaptation measures to be included in town planning decision-making.

The biophysical impacts of increased temperature will place additional stresses on ecosystem health in council-managed parks and reserves. Increasing temperatures also contribute to increasing risk from bushfire weather and drought. The increasing frequency of warm days and decreasing frequency of cool days could also increase risk from *Naegleria fowleri* in water supplies and increasing risk of zoonotic diseases.

Drought

Projections for increases in drought intensity will create a range of issues and adaptation challenges for CVC, including decreased flow into catchments, reducing water availability while increasing demand for municipal, industrial and irrigation requirements. Severe and protracted drought also increases the risk of soil compaction and damage to subsurface infrastructure such as sewer and water mains and contributes to socioeconomic stressors, especially to the agricultural sector.

Landscape-wide drought threatens ecological systems and is a leading factor in forest dieback. Dry landscapes are also more susceptible to bushfire. Much of the Clarence Valley cultural heritage is connected to the biophysical environment; drought and increased risk for forest dieback and bushfire may threaten important cultural heritage, including scar trees.

Summary

This CCIA has assessed present and future risk to CVC from a range of weather- and climate-related hazards. In terms of modelled losses to property, present day risk in CVC is highest from flood, followed by hail, bushfire and tropical cyclone. CVC also experiences impacts from ECL, coastal flooding, heavy rainfall events, drought and temperature extremes.

Global temperatures have increased in recent decades in conjunction with a range of climatic changes affecting Clarence Valley. The most significant of these changes relate to temperature sensitive impacts: CVC has experienced increasing trends in the frequency of heatwaves and hot days, dangerous bushfire weather and drought severity. There has also been increasing trends in the frequency of ECL and intensity of heavy rainfall events. Increasing temperatures have also caused sea levels to rise, amplifying the risk of coastal erosion and storm tide inundation.

As the climate system warms during the 21st century, many of the present-day trends will continue. Strongest trends will be observed in temperature-sensitive risks, especially heatwaves, hot days and bushfire weather. Changes in rainfall and storms will be more variable, with small increases expected in the intensity of heavy rainfall events and the severity of drought. ECL may increase in frequency during some decades, but storms and rainfall will continue to be influenced by Pacific climate drivers of ENSO and IPO. Sea levels will continue to rise throughout the 21st century.

For CVC, the greatest impacts will continue to be associated with heavy rainfall, flooding and storms. Over the next 30 years, flood risk is expected to increase by 2-6%. However, the greatest change will be associated with temperature related risks—including heatwaves and bushfire weather—which will increase significantly through the 21st century under all climate scenarios. The substantial socioeconomic and biophysical impacts of heat related stressors mean adaptation measures will be required across many aspects of council responsibilities. The impacts of sea level rise will become substantial after 2050, and so should be considered in long term coastal planning.

Box 1: Historical climate from reanalyses

For this study, historical weather data were mostly obtained from the European Centre for Medium Range Weather Forecasting (ECMWF) ERA5-Land reanalysis (Muñoz-Sabater et al 2019). ERA5-Land provides hourly weather variables on a 0.1x0.1 degree grid, which is approximately 9km spatial resolution. Reanalyses are a combination of weather model simulations and observations from satellites and weather stations. Reanalyses are used extensively in weather and climate research (https://reanalyses.org); although they have limitations, these are well understood. The type of analysis presented here would not be possible without reanalyses. Reanalyses are used instead of weather station data for several important reasons, including:

- Weather station data coverage is not spatially continuous across Clarence Valley (or anywhere), whereas reanalyses provide modelled values (with assimilation) for all of Clarence Valley
- Reanalyses provide a more complete set of variables (windspeed, humidity, atmospheric pressure, etc) than are usually available from weather stations
- Weather observations often have biases, missing data and quality issues; the Australian Bureau of Meteorology (BOM) carefully correct data for a limited number of high-quality stations (http://www.bom.gov.au/climate/data/acorn-sat/). The only one of these stations in Clarence Valley is Yamba. The Yamba station provides an excellent historical climate record with a wide range of variables, but unfortunately it is only one point location and therefore not suitable for this type of analysis. Prior to assimilation in reanalyses, weather observations are rigorously quality controlled, and bias adjusted.

Box 2: Modelling future change scenarios

The only evidence-based climate projections available are those produced by global climate models which incorporate a physical based understanding of how the climate system works. Climate model simulations are produced by a range of research institutes around the world, and most are developed within the framework of the United Nations World Climate Research Program (WCRP) Coupled Model Intercomparison Project (CMIP). CMIP simulations are designed to contribute to the Intergovernmental Panel on Climate Change (IPCC) reports. Because the future is unknown, CMIP simulations are designed explore a range of possible future scenarios based on anthropogenic drivers of climate change and levels of global mean temperature (GMT) increase. For CMIP5 these are called Representative Concentration Pathways (RCP) (Figure 17) and range from low levels of warming under RCP2.6 (GMT increase of ~1.5C), to medium levels of warming under RCP4.5 (GMT increase of 2-3C) and high levels of warming under RCP8.5 (GMT increase of >4C).

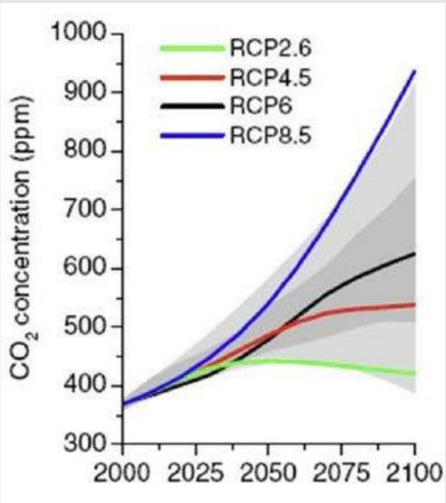

Figure 16: RCP scenarios for the 21st Century. IPCC (2014)

Box 3: Regional Climate Models

Global climate models used in CMIP attempt to simulate a wide range of earth system processes and are therefore very computationally expensive. To manage the computational costs, model grid resolutions are typically coarse; around 50km to 100km. At these resolutions, large-scale processes, such as global temperature change, and synoptic weather systems are reasonably well-simulated, but locally relevant processes, such as orographic rainfall, are not. To produce more locally relevant information, Regional Climate Models (RCM) are used. These models take the output from global climate models and then re-run simulations at much finer spatial resolutions, typically 10km to 20km. Due to the high computation demands, RCM are usually only run over regional domains.

In this study, future climate is represented by the NSW and ACT Regional Climate Model (NARCliM) climate model simulations version 1.5. NARCliM1.5 data are produced as part of a NSW government-led project providing high resolution climate change projections across NSW. NARCliM1.5 uses a regional climate model to dynamically downscale projections from three Coupled Model Intercomparison Project Phase 5 (CMIP5) models: CAN-ESM2, ACCESS1.0 and ACCESS1.3. These projections cover the 2006 to 2099 period at a spatial resolution of approximately 9km. Projections have been downscaled for two scenarios—RCP4.5 and RCP8.5.

BOX 4: El Niño Southern Oscillation (ENSO) and the Inter-decadal Pacific Oscillation (IPO)

ENSO is the leading global model of coupled ocean atmosphere variability. This means that changes in ocean temperatures and atmospheric circulation in the central tropical Pacific can influence climate in many parts of the world, including Australia. Rainfall and storm activity affecting CVC is strongly modulated by ENSO. During El Niño years, when SST in the central Pacific is warmer than usual, CVC experiences less rainfall than usual; tropical cyclones (TC) and East Coast Lows (ECL) are also less frequent. During La Niña events, CVC experiences higher rainfall than usual; TC and ECL are more frequent. For example, 2010-11 was one of the strongest La Niña years on record, resulting in widespread flooding along Australia's eastern seaboard. Conversely, the extended dry period preceding the 2019-2020 bushfire season was characterised by El Niño-like conditions; central pacific SSTs were above average but did not quite reach the threshold required to declare an El Niño event.

ENSO typically operates on a cycle of 3-7 years. Over longer time periods, on timescales of 10-20 years, the strength and frequency of El Niño and La Niña events are modulated by the IPO. During IPO positive phases, El Niño events tend to be stronger and more frequent. During IPO negative phases, La Niña events tend to be stronger and more frequent. The IPO influences Tasman Sea storm activity in a similar fashion to ENSO.

ENSO is closely linked to global mean temperature; during El Niño events, heat is released from the ocean, and GMT is higher than normal; during La Niña events, GMT is lower than normal. Under a warming climate, the amplitude of ENSO events is expected to increase. This means that both El Niño and La Niña will be stronger. Because ENSO is a primary driver of rainfall and storm variability at CVC, the implications are that conditions will become more extreme; dry years will be dryer and wet years will be wetter.