Climate Change and Variability - Tasman District

August 2015

Prepared for Tasman District Council

August 2015

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Executive summary

This report describes changes which may occur over the coming century in the climate of the region administered by the Tasman District Council, and outlines some possible impacts of these changes.

To set the context, we summarise key findings of the recent (2013-2014) global climate change assessment undertaken by the Intergovernmental Panel on Climate Change.

- Warming of the climate system is 'unequivocal', and most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the increase in greenhouse gas concentrations caused by human activities.

- The IPCC updates projections for global and regional changes in temperature, sea level, and precipitation for the coming century, and points to an expected increase in the frequency of heavy rainfall events.

- Recent global warming is already having physical and biological effects in many parts of the world.

- Work assessed by the IPCC indicates that limiting future global warming to targets which are currently being discussed internationally would require substantial reductions in global greenhouse gas emissions from human activities.

- Continued emissions of greenhouse gases will cause further warming and changes in all parts of the climate system. There are four scenarios named RCPs (Representative Concentration Pathways) by the IPCC. These RCPs represent different climate change mitigation scenarios – one (RCP2.6) leading to a very low emissions level (requiring removal of CO_2 from the atmosphere), two stabilisation scenarios (RCPs 4.5 and 6.0), and one (RCP8.5) with very high greenhouse gas concentrations. Therefore, the RCPs represent a range of 21st century climate policies.

Next, information is summarised about expected New Zealand national and regional impacts of climate change, from the IPCC chapter on Australia and New Zealand.

- New Zealand has warmed by 0.09 ± 0.03°C per decade since 1909, with more heat waves, fewer frosts, more rain in the south and west of New Zealand, less rain in the north and east of the North and South Islands, and a rise in sea level since 1900 of 1.7 ± 0.1 mm/yr.

- Ongoing vulnerability in New Zealand to extreme events is demonstrated by substantial economic losses caused by droughts, floods, fire, tropical cyclones, and hail. During the 21st century, New Zealand's climate is virtually certain to warm further, with noticeable changes in extreme events.

- Heat waves and fire risk are virtually certain to increase in intensity and frequency. Floods, landslides, droughts and storm surges are likely to become more frequent and intense, and snow and frost to become less frequent.

- Precipitation changes are projected to lead to increased runoff in the west and south of the South Island and reduced runoff in the northeast of the South Island, and the east and north of the North Island.

- The potential impacts of climate change on industry are likely to be substantial. New Zealand's predominantly hydroelectric power generation is vulnerable to precipitation variability, changes in snow cover are likely to have a significant impact on the ski industry, and pasture production may be impacted by warming and elevated CO_2.

Tasman District's present climate is then described.

- An upward trend in mean temperature, consistent with the overall New Zealand warming through the 20th century, is apparent at the long-term climate monitoring site at Nelson and Appleby. There are substantial year to year fluctuations in temperature superimposed on this long-term trend, with some years being nearly 2°C different from others.

- There is also substantial year to year variation in rainfall. Appleby exhibits annual rainfall totals ranging from around 600 mm up to more than 1400 mm.

- Three natural fluctuations leading to year-to-year variations are the El Niño-Southern Oscillation (ENSO), the Interdecadal Pacific Oscillation (IPO), and the Southern Annular Mode (SAM). These factors also lead to fluctuations in sea level.

Projections for Tasman District's future climate are then covered:

- Future temperature scenarios for 2040 (2031-2050 relative to 1986-2005) show that annual average temperatures are projected to increase by between 0.7°C (RCP2.6) and 1.0°C (RCP8.5). By 2090 (2081-2100 relative to 1986-2005) annual average temperatures are projected to increase by between 0.6°C (RCP2.6) and 3.0°C (RCP8.5). The greatest warming is projected for summer or autumn (depending on the RCP) and the least warming is projected for spring. A slight acceleration in warming is projected for the second 50 years of the 21st century compared to the first 50 years under the higher emission scenarios. There are only modest spatial gradients in the warming relative to the mean increase. By 2090 for RCP4.5, the greatest warming in spring is expected to occur in the east and north of Tasman District in spring, and in winter in the south and west of the District. For RCP8.5 by 2090, more warming is expected for the west of the region in summer and for the south of the region in winter.

- Future precipitation projections indicate slightly more rainfall in most seasons except spring for much of the area of coastal plains adjacent to Tasman Bay (i.e. Motueka, Waimea Plains) to 2040. By 2090 for RCP4.5, more rainfall is projected for the plains in summer, autumn, and especially winter. By 2090 under RCP8.5, the western part of Tasman District is projected to receive less rainfall (by less than 5%) in summer and autumn, but significantly more rainfall in winter (up to 40% in some parts).

- For Appleby, there is no clear precipitation signal, even at 2090 under RCP 8.5. The ensemble-average is often less than ±5%, with the model range (the 5th and 95th percentile values) varying between quite large (>10%) increases and decreases. By 2040 (2031-2050, relative to 1986-2005), winter is the season with the most precipitation change, with a small increase in the ensemble-average (3-5% across the different RCPs). By 2090 (2081-2100, relative to 1986-2005), winter is still the season with the most precipitation change, with increases in the ensemble-average ranging from 4 to 11% depending on the RCP.
- For Takaka, there is a clearer precipitation signal than for Appleby, especially for winter. At both 2040 and 2090 under all RCPs, winter precipitation is projected to increase. The winter ensemble-average for RCP8.5 at 2090 at an increase of 26%, with the 95th percentile value at 58% increase. For the other seasons, the ensemble-average is often less than 5%, with the model range (5th and 95th percentiles) varying between small decreases to large increases in precipitation. However, the direction of change overall is for an increase in precipitation across all seasons at Takaka.
- Projections for Tasman for the coming century also include a substantial decrease in cold nights, an increase in the number of hot days, and an increase in the frequency of very heavy rainfall.
- For engineering purposes some scenarios for changes in rainfall depth/duration/frequency statistics are provided for Richmond.
- An increase in drought frequency is projected for the plains adjacent to Tasman Bay of about 5% for 2030-2050 and 10% for 2070-2090, compared to 1980-1999 levels. These projections were calculated from the IPCC Fourth Assessment Report emissions scenarios and will be updated in due course.
- The frequency of extreme winds (99th percentile) over the 21st century is likely to increase in winter and decrease in summer.
- New guidance on planning for sea level is expected in due course from the Ministry for the Environment (the last update was published in 2008). In the interim we suggest using a minimum sea-level rise scenario of 0.5 metres by the 2090s (2090 to 2099) relative to the 1980-1999 average for coastal planning, plus an assessment of sensitivity to possible higher mean sea levels. For longer-term considerations an allowance for further sea-level rise of 10 mm/year beyond 2100 is recommended.
- The height of waves and storm surges are expected to increase due to climate change, by 6.4% for storm surge and 1.8% for significant wave heights, for 2070-2100. This translates to about a 10 cm increase in significant wave height for a 5 m high wave.
- The pH of the oceans around New Zealand is projected to decrease, consistent with global trends. The variability and rate of change in pH will differ in coastal waters as these are also influenced by terrestrial factors and run-off. Changes in ocean pH may have significant impacts on New Zealand fisheries and aquaculture into the future.

The Council is referred to material published by the Ministry for the Environment for guidance on assessing likely vulnerability and impacts for the Tasman District of these projected climate changes, and for considering adaptation options. Relevant issues could include:

- Implications of sea-level rise and coastal change for planning and development in coastal areas
- Implications of potential changes in rainfall and of drought frequency for water demand, availability, and allocation
- Implications for roading and stormwater drainage, lifelines planning, and civil defence and emergency management of changes in extreme rainfall, erosion risk, and coastal hazards
- Opportunities which climate change may bring for new horticultural crops
- Implications for land use planning of potential changes including floods and coastal hazards
- Implications for aquaculture and fisheries
- Implications for natural ecosystems (both terrestrial and marine) and their management

1 Introduction

Tasman District Council applied for and received funding (Advice No. 1552-TSDC109) from the Envirolink Fund (Ministry of Business, Innovation, and Employment) for NIWA to undertake a review of updated climate change projections and potential impacts for the Tasman District, since the publication of the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report in 2013 and 2014.

This report, which is an update of the report published for Tasman District Council in 2008 (Wratt et al., 2008), describes climate changes which may occur over the coming century for the region administered by the Tasman District Council, and outlines some possible impacts of these changes. The report does not address the issue of mitigation (reducing greenhouse gas emissions, or increasing "sinks" such as areas of growing forest), apart from a brief summary of recent findings of the Intergovernmental Panel on Climate Change.

Consideration is given to both possible natural variations in the climate, and to changes which may result from increasing global concentrations of greenhouse gases caused by human activities. Climatic factors discussed include temperature, rainfall, wind, evaporation, and soil moisture.

Possible changes along the coast in sea level, storm surge, and wave climate are also considered. Figure 1-1 shows the Tasman District Council area of administration.

Preparation of the report has been supported through an Envirolink medium advice grant. This did not fund any new data analysis, but enabled us to draw on information which is already available from various sources. Much of this information is very new, resulting from the latest assessments of the Intergovernmental Panel on Climate Change (IPCC, 2013, IPCC, 2014a, IPCC, 2014b), and scenarios for New Zealand generated by NIWA scientists based on downscaling from global climate model runs undertaken for these IPCC assessments (undertaken through NIWA's core-funded Regional Modelling Programme). The climate change information presented in this report is entirely consistent with recently-updated climate change guidance produced for the Ministry of the Environment (Mullan et al., 2015).

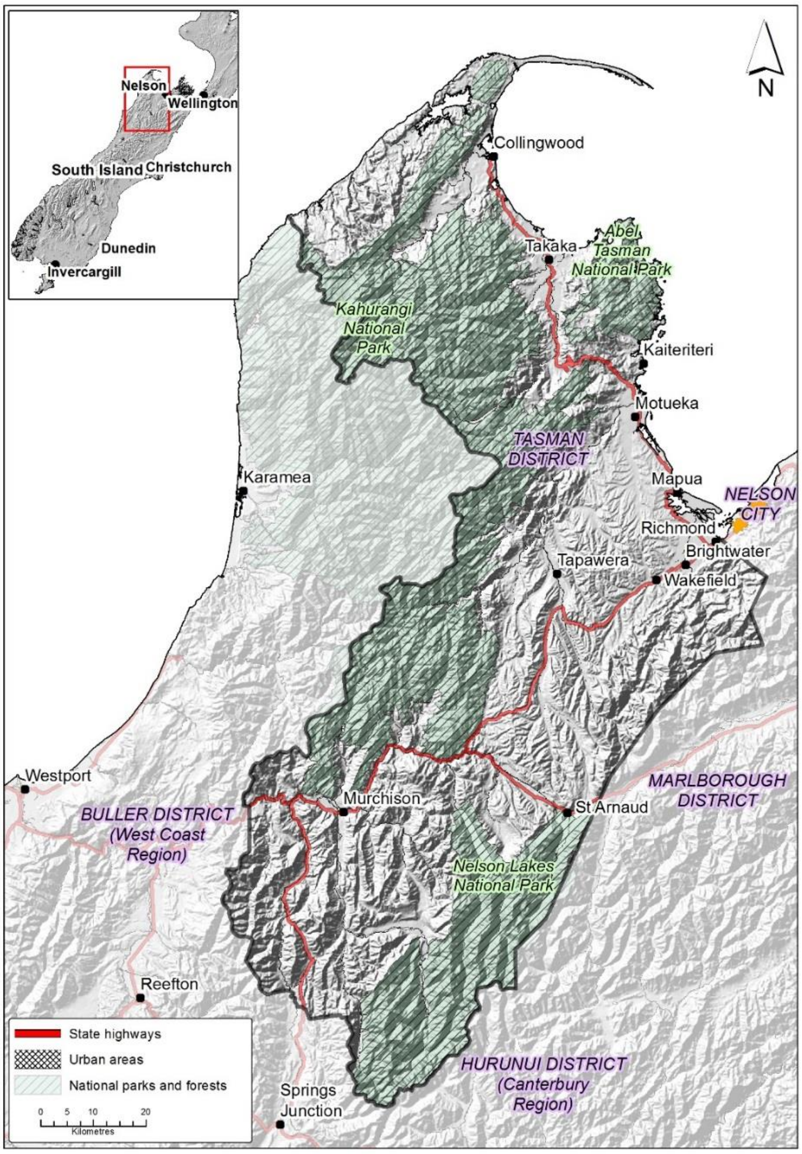


Figure 1-1: The Tasman District Council area. The region administered by the Council is outlined.

2 Background: Global Climate Change – Science and Impacts

This section summarises some key findings from the 2013 and 2014 IPCC Fifth Assessment Reports (AR5) as contextual information for the discussion of past and future climate changes in Tasman District to follow in this report.

2.1 The Physical Science Basis (IPCC Working Group I)

The Summary for Policymakers of the IPCC AR5 Working Group I Report (IPCC, 2013) emphasises the following points regarding changes to the climate system:

- Warming of the climate system is 'unequivocal', and since the 1950s, many of the observed climate changes are unprecedented over short and long timescales (decades to millennia). These changes include warming of the atmosphere and ocean, diminishing of ice and snow, sea-level rise, and increases in the concentration of greenhouse gases.

- The atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased to levels unprecedented in at least the last 800,000 years. Carbon dioxide concentrations have increased by 40% since pre-industrial times, primarily from fossil fuel emissions and secondarily from net land use change emissions. The ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide, causing ocean acidification.
- Climate change is already influencing the intensity and frequency of many extreme weather and climate events globally.
- It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century.

Continued emissions of greenhouse gases will cause further warming and changes in all parts of the climate system. There are four scenarios named RCPs (Representative Concentration Pathways) by the IPCC. These RCPs represent different climate change mitigation scenarios – one (RCP2.6) leading to a very low emissions level (requiring removal of CO_2 from the atmosphere), two stabilisation scenarios (RCPs 4.5 and 6.0), and one (RCP8.5) with very high greenhouse gas concentrations. Therefore, the RCPs represent a range of 21st century climate policies.

By the middle of the 21st century, the magnitudes of the projected climate changes are substantially affected by the choice of scenario. **Global surface temperature change for the end of the 21st century is likely to exceed 1.5°C relative to 1850-1900** for all scenarios except for the lowest emissions scenario (RCP 2.6).

In contrast to the Fourth IPCC Assessment Report which concentrated on projections for the end of the 21st century, the Fifth Assessment Report projects climate changes for earlier in the 21st century as well in its Summary for Policymakers. As such, **the global mean surface temperature change for the period 2016-2035 (relative to 1986-2005) will likely be in the range of 0.3 to 0.7°C.** This assumes that there will be no major volcanic eruptions (which may cause global cooling) and that total solar irradiance remains similar. Temperature increases are expected to be larger in the tropics and subtropics than in the southern mid-latitudes (i.e. New Zealand).

The full range of projected globally averaged temperature increases for all scenarios for 2081-2100 (relative to 1986-2005) is 0.3 to 4.8°C (Figure 2-1). As global temperatures increase, it is virtually certain that there will be more hot and fewer cold temperature extremes over most land areas. It is very likely that heat waves will occur with a higher frequency and duration. Furthermore, in general, the contrast in precipitation between wet and dry regions and wet and dry seasons will increase. With increases in global mean temperature, mid-latitude and wet tropical regions will experience more intense and more frequent extreme precipitation events by the end of the 21st century.

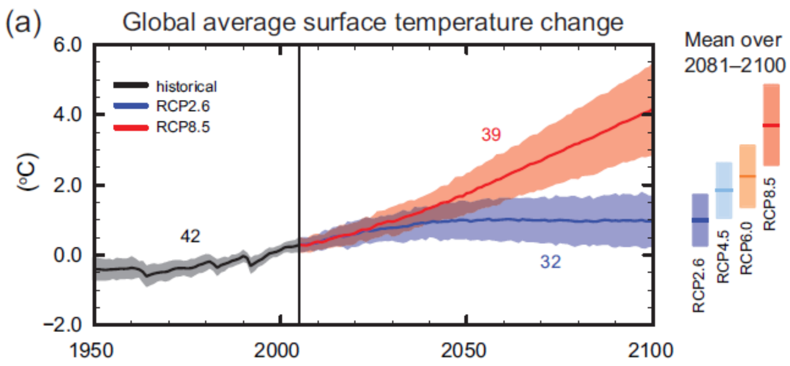


Figure 2-1: CMIP5 multi-model simulated time series from 1950-2100 for change in global annual mean surface temperature relative to 1986-2005. Time series of projections and a measure of uncertainty (shading) are shown for scenarios RCP2.6 (blue) and RCP8.5 (red). Black (grey shading) is the modelled historical evolution using historical reconstructed forcings. The mean and associated uncertainties averaged over 2081−2100 are given for all RCP scenarios as coloured vertical bars. The numbers of CMIP5 models used to calculate the multi-model mean is indicated. After IPCC (2013).

The global ocean will continue to warm during the 21st century. Eventually, heat will penetrate into the deep ocean and affect ocean circulation. Sea ice is projected to shrink and thin in the Arctic. Some scenarios project that late summer Arctic sea ice extent could almost completely disappear by the end of the 21st century, and a nearly ice-free Arctic Ocean in late summer before mid-century is likely under the most extreme scenario. Northern Hemisphere spring snow cover will decrease as global mean surface temperature increases. The global glacier volume (excluding glaciers on the periphery of Antarctica) is projected to decrease by 15-85% by the end of the 21st century under different scenarios.

Global mean sea level will continue to rise during the 21st century. All scenarios project that the rate of sea level rise will very likely exceed that observed during 1971-2010 due to increased ocean warming and higher loss of mass from glaciers and ice sheets. For all scenarios, **the total range of projected sea level rise for 2081-2100 (relative to 1986-2005) is 0.26-0.82m.** It is virtually certain that global mean sea level rise will continue beyond 2100, with sea level rise due to thermal expansion expected to continue for many centuries. The range for mean sea level rise beyond 2100 for different scenarios is from less than 1 m to more than 3 m, but sustained mass loss by ice sheets would cause larger sea level rise. Sustained warming greater than a critical threshold could lead to the near complete loss of the Greenland ice sheet over a millennium or more, causing a global mean sea level rise of up to 7 m. Current estimates place this threshold between 1 and 4°C global mean warming with respect to pre-industrial mean temperatures.

Cumulative CO_2 emissions largely determine global mean surface warming by the late 21st century and further into the future. Even if emissions are stopped, most aspects of global climate change will persist for many centuries.

2.2 Impacts, Adaptation, and Vulnerability (IPCC Working Group II)

The IPCC AR5 Working Group II Summary for Policymakers (IPCC, 2014a) concludes that in recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Specifically, these include impacts to hydrological systems with regards to snow and ice melt, changing precipitation patterns and resulting river flow and drought, as well as terrestrial and marine ecosystems, the incidence of wildfire, food production, livelihoods, and economies.

Changes in precipitation and melting snow and ice are altering hydrological systems and are driving changes to water resources in terms of quantity and quality. The flow-on effects from this include impacts to agricultural systems, in particular crop yields, which have experienced more negative impacts than positive due to recent climate change. In response to changes in climate, many species have shifted their geographical ranges, migration patterns, and abundances. Some unique and threatened systems, including ecosystems and cultures, are already at risk from climate change. With increased warming around 1°C, the number of such systems at risk of severe consequences is higher, and many species with limited adaptive capacity (e.g. coral reefs and Arctic sea ice) are subject to very high risks with additional warming of 2°C. In addition, climate change-related risks from extreme events, such as heat waves, extreme precipitation, and coastal flooding, are already moderate/high with 1°C additional warming. Risks associated with some types of extreme events (e.g. heat waves) increase further with higher temperatures.

There is also the risk of physical systems or ecosystems undergoing abrupt and irreversible changes under increased warming. At present, warm-water coral reef and Arctic ecosystems are showing warning signs of irreversible regime shifts. With additional warming of 1-2°C, risks increase disproportionately and become high under additional warming of 3°C due to the threat of global sea level rise from ice sheet loss.

Global climate change risks are significant with global mean temperature increase of 4°C or more above pre-industrial levels and include severe and widespread impacts on unique or threatened systems, substantial species extinction, large risks to global and regional food security, and the combination of high temperature and humidity compromising normal human activities, including growing food or working outdoors in some areas for parts of the year.

Impacts of climate change vary regionally, and impacts are exacerbated by uneven development processes. Marginalised people are especially vulnerable to climate change and also to some adaptation and mitigation responses. This has been observed during recent climate-related extremes, such as heat waves, droughts, floods, cyclones, and wildfires, where different ecosystems and human systems are significantly vulnerable and exposed to climate variability. In addition, aggregate economic damages accelerate with increasing temperature.

In many regions, climate change adaptation experience is accumulating across the public and private sector and within communities. Adaptation is becoming embedded in governmental planning and development processes, but at this stage there has been only limited implementation of responses to climate change.

The overall risks of climate change impacts can be reduced by limiting the rate and magnitude of climate change.

2.3 Mitigation of Climate Change (IPCC Working Group III)

The IPCC AR5 Working Group III Summary for Policymakers (IPCC, 2014b) notes that total anthropogenic greenhouse gas emissions have continued to increase over 1970 to 2010 with larger absolute decadal increases toward the end of this period. Despite a growing number of climate change mitigation policies, annual emissions grew on average 2.2% per year from 2000 to 2010 compared with 1.3% per year from 1970 to 2000. Total anthropogenic greenhouse gas emissions were the highest in human history from 2000 to 2010. Globally, economic and population growth continue to be the most important drivers of increases in CO_2 emissions from fossil fuel combustion.

Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions. The IPCC report considers multiple mitigation scenarios with a range of technological and behavioural options, with different characteristics and implications for sustainable development. These scenarios are consistent with different levels of mitigation.

The IPCC report examines mitigation scenarios that would eventually stabilise greenhouse gases in the atmosphere at various concentration levels, and the expected corresponding changes in global temperatures. Mitigation scenarios where temperature change caused by anthropogenic greenhouse gas emissions can be kept to less than 2°C relative to pre-industrial levels involve stabilising atmospheric concentrations of carbon dioxide equivalent (CO_2-eq) at about 450 ppm in 2100. If concentration levels are not limited to 500 ppm CO_2-eq or less, temperature increases are unlikely to remain below 2°C relative to pre-industrial levels.

Without additional efforts to reduce emissions beyond those in place at present, scenarios project that global mean surface temperature increases in 2100 will be from 3.7 to 4.8°C compared to pre-industrial levels. This range is based on the median climate response, but when climate uncertainty is included the range becomes broader from 2.5 to 7.8°C.

In order to reach atmospheric greenhouse gas concentration levels of about 450 ppm CO_2-eq by 2100 (in order to have a likely chance to keep temperature change below 2°C relative to pre-industrial levels), anthropogenic greenhouse gas emissions would need to be cut by 40-70% globally by 2050 (compared with levels in 2010). Emissions levels would need to be near zero in 2100. The scenarios describe a wide range of changes to achieve this reduction in emissions, including large-scale changes in energy systems and land use.

Estimates of the cost of mitigation vary widely. Under scenarios in which all countries begin mitigation immediately, there is a single carbon price, and all key technologies are available, there will be losses of global consumption of 1-4% in 2030, 2-6% in 2050, and 3-11% in 2100.

Delaying mitigation efforts beyond those in place today through 2030 is estimated to substantially increase the difficulty in obtaining a longer term low level of greenhouse gas emissions, as well as narrowing the range of options available to maintain temperature change below 2°C relative to pre-industrial levels.

3 Background: New Zealand Climate Change – Science and Impacts

Published information about the expected impacts of climate change on New Zealand is summarised and assessed in the Australasia chapter of the IPCC Working Group II assessment report (Reisinger et al., 2014). Key findings from this chapter include:

The regional climate is changing. The Australasia region continues to demonstrate long-term trends toward higher surface air and sea surface temperatures, more hot extremes and fewer cold extremes, and changed rainfall patterns. Over the past 50 years, increasing greenhouse gas concentrations have contributed to rising average temperatures in New Zealand. Changing precipitation patterns have resulted in increases in rainfall for the south and west of the South Island and west of the North Island, and decreases in the northeast of the South Island and the east and north of the North Island. Cold extremes have become rarer and hot extremes have become more common.

The region has exhibited warming to the present and is virtually certain to continue to do so. New Zealand mean annual temperature has increased by 0.09°C (± 0.03°C) per decade since 1909.

Warming is projected to continue through the 21st century along with other changes in climate. Warming is expected to be associated with rising snow lines, more frequent hot extremes, less frequent cold extremes, and increasing extreme rainfall related to flood risk in many locations. Annual average rainfall is expected to decrease in the northeast South Island and north and east of the North Island, and to increase in other parts of New Zealand. Fire weather is projected to increase in many parts of New Zealand. Regional sea level rise will very likely exceed the historical rate, consistent with global mean trends.

Uncertainty in projected rainfall changes remains large for many parts of New Zealand, which creates significant challenges for adaptation.

Impacts and vulnerability: Without adaptation, further climate-related changes are projected to have substantial impacts on water resources, coastal ecosystems, infrastructure, health, agriculture, and biodiversity. However, uncertainty in projected rainfall changes and other climate-related changes remains large for many parts of New Zealand, which creates significant challenges for adaptation.

3.1 Sectoral Impacts

Some New Zealand sectors have the potential to benefit from projected changes in climate and increasing CO_2, including reduced winter mortality, reduced energy demand for winter heating, and forest and pasture growth in currently cooler regions.

Freshwater resources: In New Zealand, precipitation changes are projected to lead to increased runoff in the west and south of the South Island and reduced runoff in the northeast of the South Island, and the east and north of the North Island. Annual flows of eastward-flowing rivers with headwaters in the Southern Alps are projected to increase by 5-10% by 2040 in response to higher alpine precipitation. Most of the increases occur in winter and spring, as more precipitation falls as rain and snow melts earlier. Climate change will affect groundwater through changes in recharge rates and the relationship between surface waters and aquifers.

Natural ecosystems: Existing environmental stresses will interact with, and in many cases be exacerbated by, shifts in mean climatic conditions and associated changes in the frequency or intensity of extreme events, especially fire, drought, and floods. Ongoing impacts of invasive species and habitat loss will dominate climate change signals in the short to medium term. The rich biota of the alpine zone is at risk through increasing shrubby growth and loss of herbs, especially if combined with increased establishment of native species. Some cold water-adapted freshwater fish and invertebrates are vulnerable to warming and increased spring flooding may increase risks for braided river bird species.

Coastal and ocean ecosystems: The increasing density of coastal populations and stressors such as pollution and sedimentation from settlements and agriculture will intensify non-climate stressors in coastal areas. Coastal habitats provide many ecosystem services including coastal protection and carbon storage, which could become increasingly important for mitigation. Variability in ocean circulation and temperature plays an important role in local fish abundance, and this could change with climate-related oceanic changes. A strengthening East Auckland Current in northern New Zealand is expected to promote establishment of tropical or subtropical species that currently occur as vagrants, potentially changing the production and profit of both wild fisheries and aquaculture. Estuarine habitats will be affected by changing rainfall or sediment discharges, as well as connectivity to the ocean. Loss of coastal habitats and declines in iconic species will result in substantial impacts on coastal settlements and infrastructure from direct impacts such as storm surge, and will effect tourism. Changes in temperature and rainfall, and sea level rise, are expected to lead to secondary effects, including erosion, landslips, and flooding, affecting coastal habitats and their dependent species, for example loss of habitat for nesting birds.

Forestry: Warming is expected to increase *Pinus radiata* growth in the cooler south, whereas in the warmer north, temperature increases can reduce productivity, but CO_2 fertilisation may offset this. *Dothistroma* blight, a pine disease, has a temperature optimum that coincides with New Zealand's warmer, but not warmest, pine growing regions; under climate change, its severity is, therefore, expected to reduce in the warm central North Island but increase in the cooler South Island where it could offset temperature-driven improved plantation growth.

Agriculture: Projected changes in national pasture production for dairy, sheep, and beef pastures range from an average reduction of 4% across climate scenarios for the 2030s, to increases of up to 4% for two scenarios in the 2050s. Studies modelling seasonal changes in fodder supply show greater sensitivity in animal production to climate change and elevated CO_2 than models using annual average production, with some impacts expected even under modest warming. New Zealand agro-ecosystems are subject to erosion processes strongly driven by climate - greater certainty in projections of rainfall, particularly storm frequency, are needed to better understand climate change impacts on erosion and consequent changes in the ecosystem services provided by soils.

Energy supply, demand, and transmission: New Zealand's predominantly hydroelectric power generation is vulnerable to precipitation variability. Increasing winter precipitation and snow melt, and a shift from snowfall to rainfall will reduce this vulnerability as winter/spring inflows to main hydro lakes are projected to increase by 5-10% over the next few decades. Further reductions in seasonal snow and glacial melt as glaciers diminish, however, would compromise this benefit. Increasing wind power generation would benefit from projected increases in mean westerly winds but face increased risk of damages and shutdown during extreme winds. Climate warming would reduce annual average peak electricity demands by 1-2% per degree Celsius across New Zealand.

Tourism: Changes in snow cover are likely to have a significant impact on the ski industry, but tourist numbers from Australia to New Zealand may increase due to the rapid reduction in snow cover in Australia, and the greater perceived scenic attractiveness of New Zealand. Warmer and drier conditions mostly benefit tourism but wetter conditions and extreme climate events undermine tourism.

4 Present Climate

The plains of the Tasman District are sheltered both from the prevailing westerly winds and from winds from an easterly quarter, providing a sunny, mild climate, less windy than most other areas in New Zealand but prone to frost in sheltered positions (De Lisle and Kerr, 1965). The rainfall, which is adequate for spring pasture growth, is liable to be insufficient in summer and early autumn when long dry spells can occur.

4.1 Spatial Patterns in Tasman's Climate

Figure 4-1 shows the spatial variation in annual average temperature over the Tasman region. Figure 4-2 shows the spatial pattern of annual total rainfall, and also the median seasonal total rainfalls. Temperature varies with elevation, with the coolest mean annual temperatures of the Tasman District experienced in the high elevation mountain ranges in the south of the District. Mean annual temperatures are highest near the coast. Annual rainfall varies significantly throughout the Tasman District. The Tasman Mountains in the northwest of the District receive the most rain, due to their exposure to the prevailing westerly airflow. These mountains receive over 6000 mm of rainfall per year, on average. The driest part of the District is the low-elevation plains to the south of Motueka and Tasman Bay, which receive less than 1500 mm of rainfall per year, on average. This is because these plains are sheltered from the prevailing moisture-laden airflows from the south and east by the Southern Alps, as well as the Kaikoura and Richmond Ranges, and to the west by the Tasman Mountains and multiple ranges to the southwest.

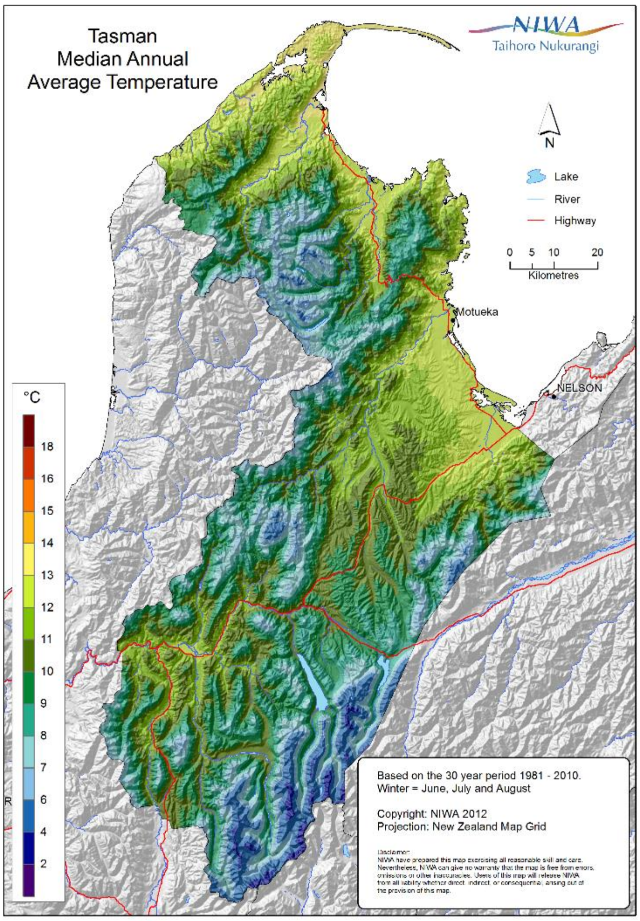


Figure 4-1: Annual average temperature for the Tasman region (median for 1981-2010). ©NIWA.

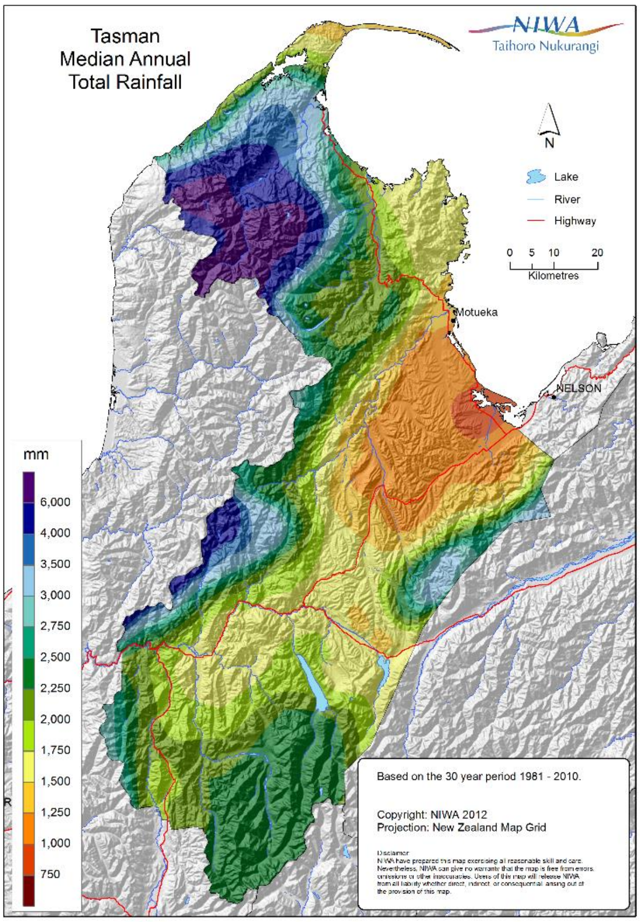


Figure 4-2: **Annual rainfall for the Tasman District (median for 1981-2010). ©NIWA.**

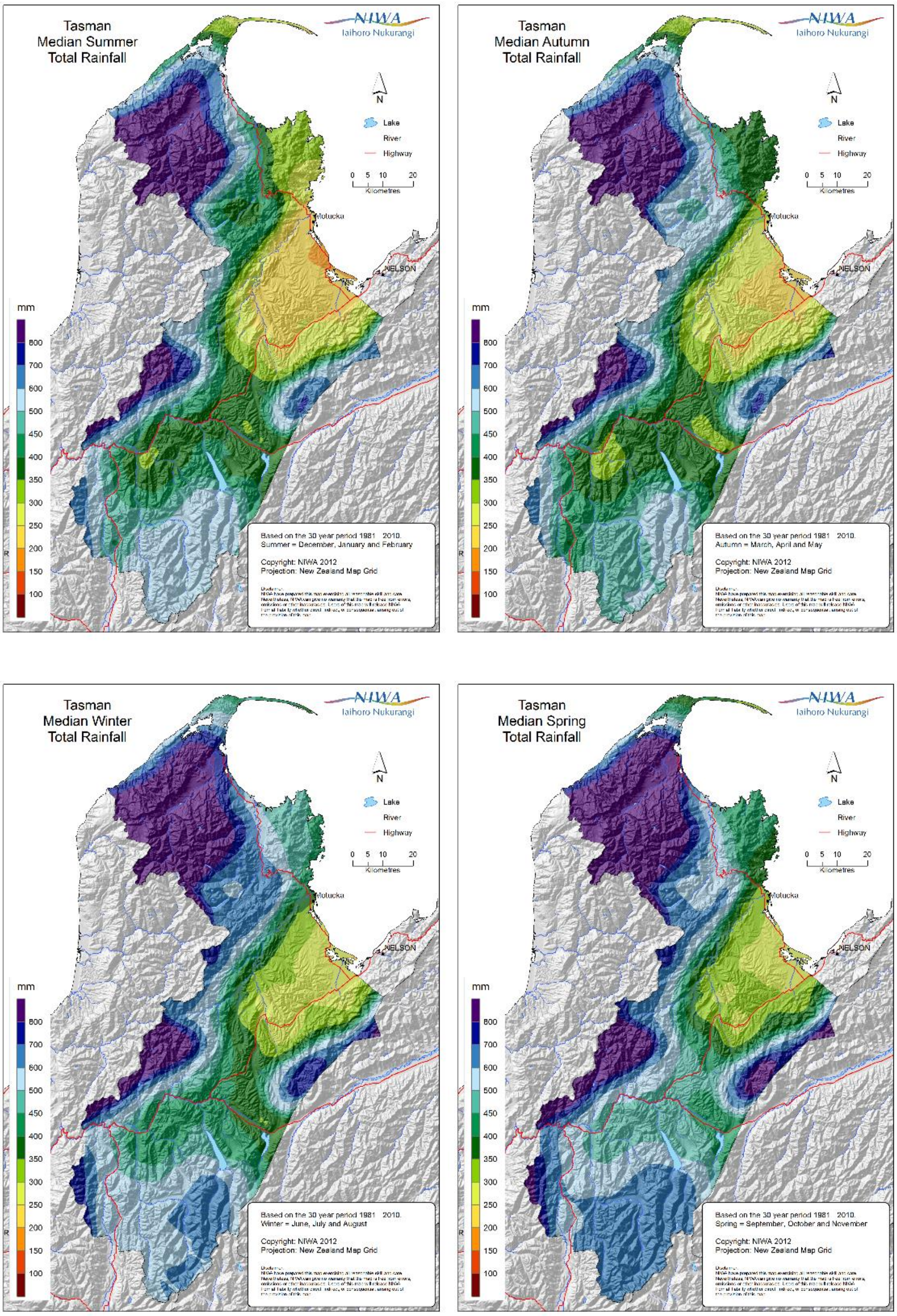


Figure 4-2 continued: Seasonal rainfall totals (medians for spring, summer, autumn, and winter). ©NIWA.

4.2 Temporal Variability in Tasman's Climate

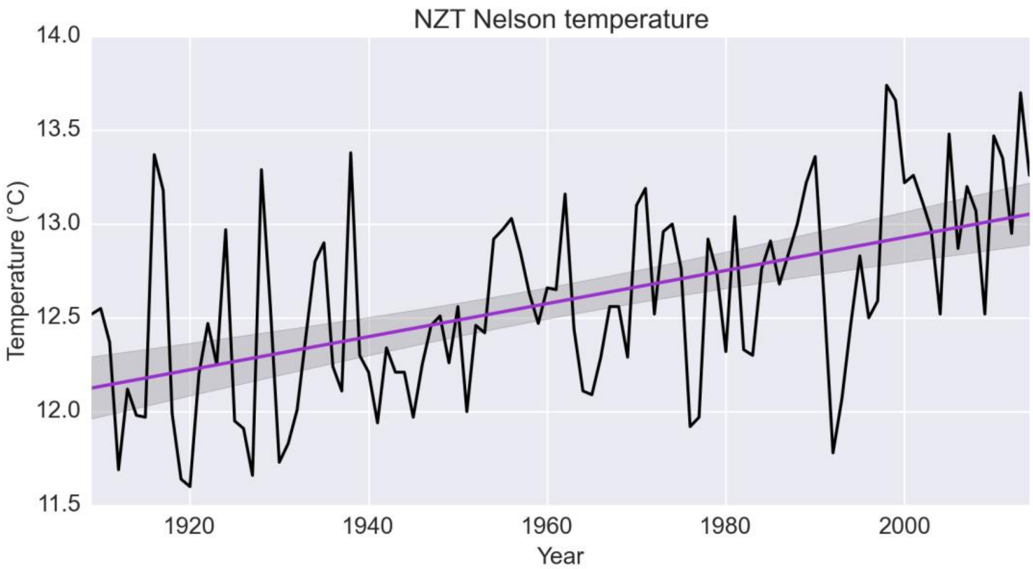


Figure 4-3: Homogenised annual temperature time series for Nelson from 1909 to 2014. A number of climate stations surrounding Nelson (including Appleby) are compiled into this long-term series. For more information see https://www.niwa.co.nz/our-science/climate/information-and-resources/nz-temp-record/seven-station-series-temperature-data. The purple line removes the year-to-year variability and shows an upward long-term trend.

There is significant year-to-year variability in Tasman's climate. For example, Figure 4-3 shows the average annual temperature for Nelson (and surrounding sites, including Appleby) from 1909 to 2013. There are substantial differences between years, with some years having temperatures almost 2°C different to others.

The temperature trend at Nelson from 1909 to 2014 (shown on Figure 4-3), is 0.88 ± 0.27 °C/century. This is similar to the trend in New Zealand average temperatures for the 1910-2010 period, 0.92 ± 0.27 °C/century (data sourced from NIWA's Seven Station Temperature Series, website in caption above). A likely explanation for the overall increase in average temperatures over this period is due to increasing concentrations of anthropogenic greenhouse gases, whereas the short-term variability is due to natural causes, such as the El Niño-Southern Oscillation, together with random year-to-year fluctuations ("climate noise").

As shown in Figure 4-4, there is also substantial variability in annual rainfall totals. At Appleby, rainfall varies from around 600 mm per year to over 1400 mm, but there is no long term trend observed.

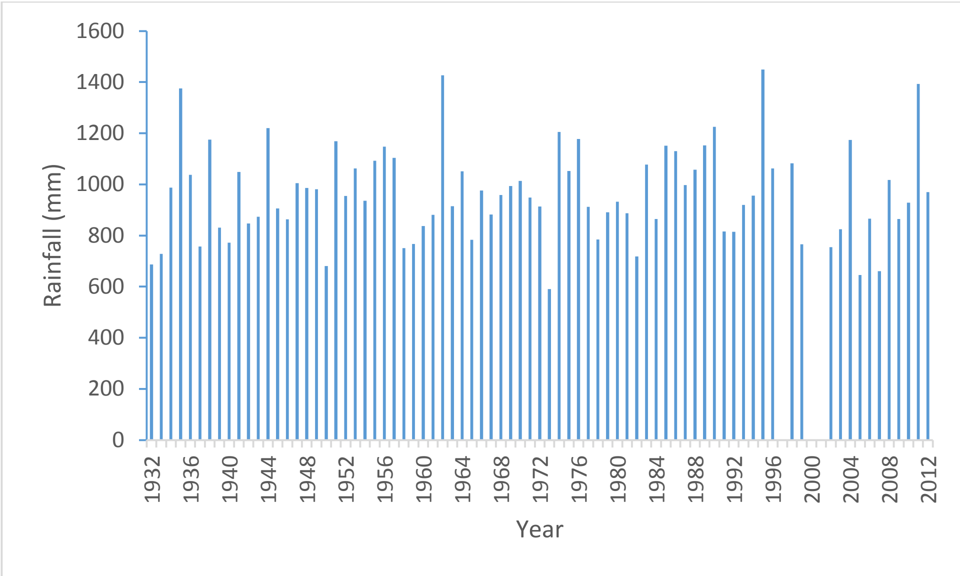


Figure 4-4: Annual rainfall total (mm) at Appleby from 1932 to 2012. There is missing data for both 2013 and 2014, hence the series ends with 2012.

4.3 Natural factors causing fluctuation in climate patterns over New Zealand

Much of the variation in New Zealand's climate is random and lasts for only a short period, but longer term, quasi-cyclic variations in climate can be attributed to different factors. Three large-scale oscillations that influence climate in New Zealand are the El Niño-Southern Oscillation, the Interdecadal Pacific Oscillation, and the Southern Annular Mode (Ministry for the Environment, 2008a).

4.3.1 The effect of El Niño and La Niña

The El Niño-Southern Oscillation (ENSO) is a natural oscillation that has wide-ranging impacts around the Pacific basin (Ministry for the Environment, 2008a). The oscillation involves a movement of warm ocean water from one side of the Pacific to the other, and the movement of rainfall across the Pacific associated with this warm water.

In an El Niño event, easterly trade winds weaken and warm water 'spills' across the Pacific towards the east, accompanied by higher rainfall than normal in the central-east Pacific. A La Niña event is essentially the opposite of this and is an intensification of 'normal' conditions, where the warm ocean waters remain over the western Pacific and the trade winds strengthen.

El Niño events occur on average 3 to 7 years apart, typically becoming established in April or May and persisting for about a year thereafter. The Southern Oscillation Index, or SOI, uses the pressure difference between Tahiti and Darwin to determine the state and intensity of ENSO. Persistence of about -1 signifies El Niño events, whereas +1 signifies La Niña (Figure 4-5).

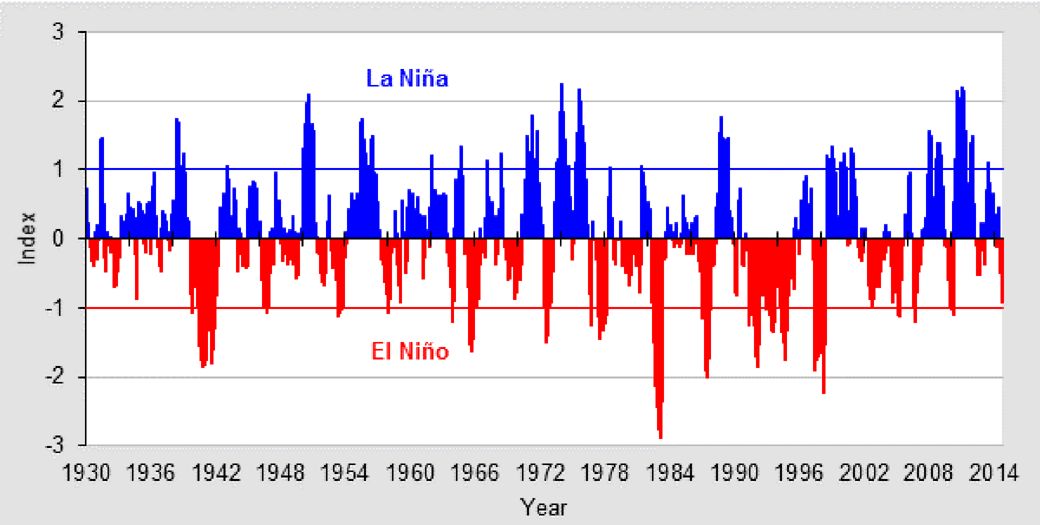


Figure 4-5: Time series of the Southern Oscillation Index from 1930 to present.

The effects of El Niño and La Niña are most clearly observed in the tropics, but impacts are well-recognised in New Zealand also. In El Niño events, the weakened trade winds cause New Zealand to experience a stronger than normal south-westerly airflow. This generally brings lower seasonal temperatures to the country and drier than normal conditions to the north and east of New Zealand.

In La Niña conditions, the strengthened trade winds cause New Zealand to experience more north-easterly airflow than normal, higher temperatures, and wetter conditions in the north and east of the North Island. In the South Island higher pressures are often dominant, which can cause drought conditions there. Therefore, drought conditions can persist in either El Niño or La Niña phases in the South Island. Figure 4-6 shows average summer rainfall anomalies in New Zealand associated with El Niño and La Niña conditions. However, individual ENSO events may have significantly different rainfall patterns to those pictured.

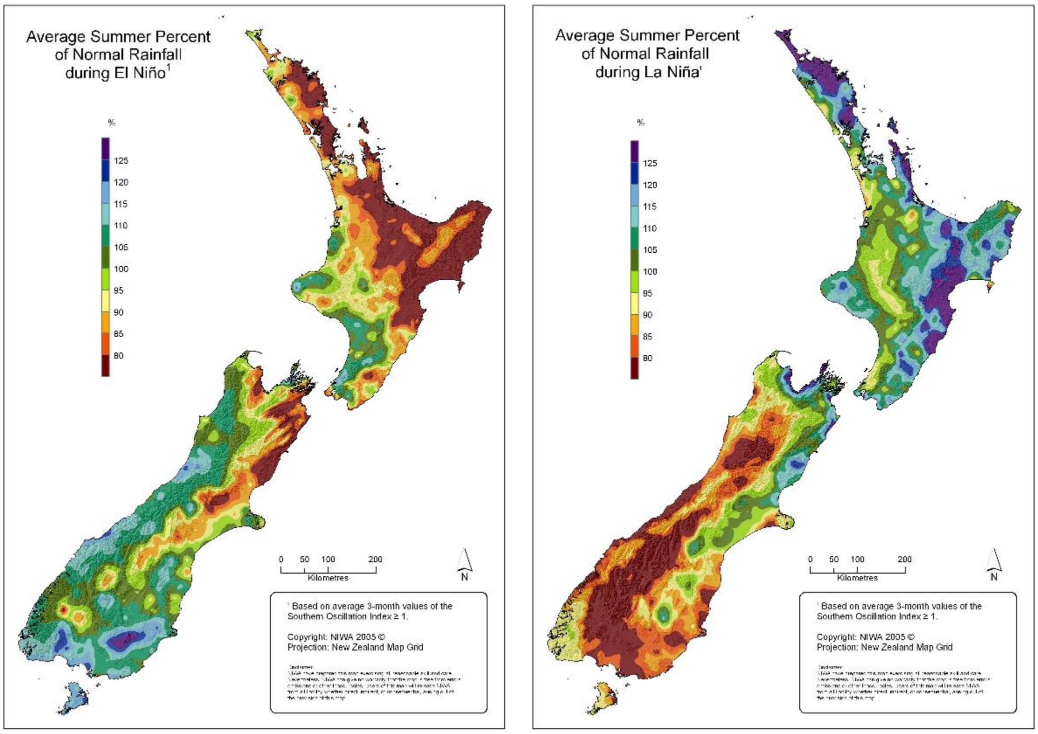


Figure 4-6: Average summer percentage of normal rainfall during El Niño (left) and La Niña (right).

From Figure 4-6 it is evident that on average summer rainfall for most of the plains adjacent to Tasman Bay (e.g. Motueka, Waimea) is below normal during El Niño periods and above normal during La Niña periods.

According to the IPCC Assessment Report from Working Group I (IPCC, 2013), precipitation variability relating to ENSO will likely intensify due to increased moisture availability in the atmosphere. However, variations in the amplitude and spatial pattern of ENSO are large and therefore any specific projected changes in ENSO remain uncertain at this stage.

4.3.2 The effect of the Interdecadal Pacific Oscillation

The Interdecadal Pacific Oscillation, or IPO, is a large-scale, long period oscillation that influences climate variability over the Pacific Basin including New Zealand (Salinger et al., 2001). The IPO operates at a multi-decadal scale, with phases lasting around 20 to 30 years (Figure 4-7). During the positive phase of the IPO, sea surface temperatures around New Zealand tend to be lower, and westerly winds stronger, with the opposite occurring in the negative phase.

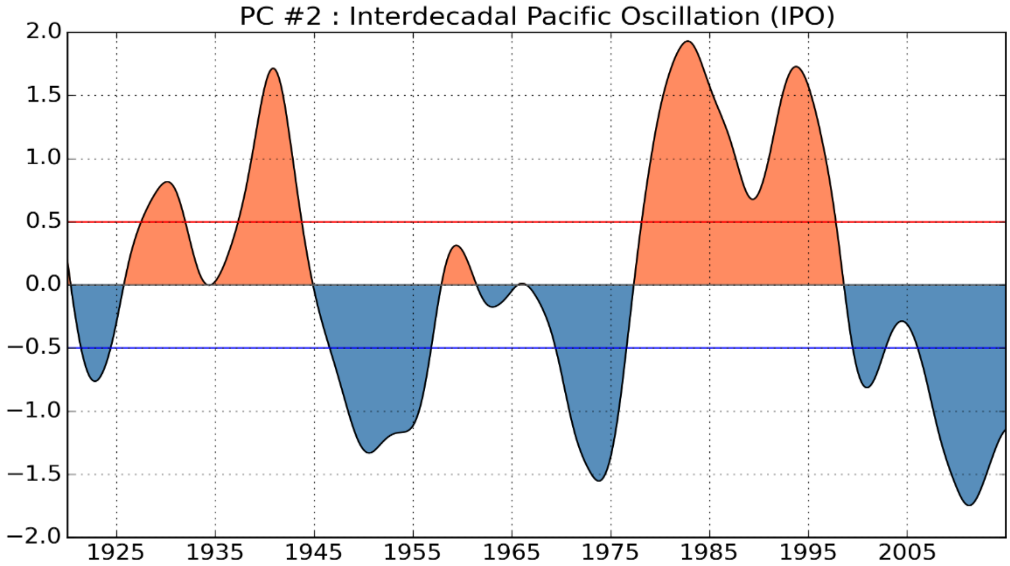


Figure 4-7: The Interdecadal Pacific Oscillation (IPO) index. Positive values indicate periods when stronger-than-normal westerlies occur over New Zealand, with more anticyclones than usual over northern New Zealand. Negative values indicate periods with more northeasterlies than normal over northern regions of the country. Vertical axis is the IPO index, and horizontal axis is the year.

New Zealand's climate appears to be affected by the long-term IPO cycle. The increase in New Zealand-wide temperatures around 1950 occurred shortly after the change from positive to negative phase of the IPO. In addition, the switch from negative to positive phase in 1977-78 coincided with significant rainfall changes (Ministry for the Environment, 2008a).

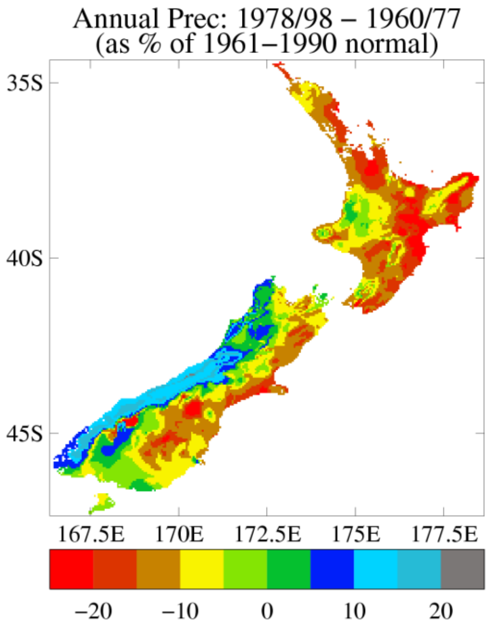


Figure 4-8: Percentage change in average annual rainfall, for the 1978-1998 period compared to the 1960-1977 period. (Note: From 1978-98 the IPO was in its positive phase, compared to the previous 18 years when the IPO was negative. Any local rainfall response due to global warming would also be contained within this pattern of rainfall trends). ©NIWA.

Figure 4-8 suggests that periods of positive IPO (which generally coincide with increased El Niño activity) tend to be a little drier, on average, for most of the plains adjacent to Tasman Bay. During the period 1930-2004, a trend to decreases in mean and extreme 1-day rainfall, and increasing dry spell duration, was generally observed in the north and east of both the North Island and South Island[1] (Griffiths, 2006). Griffiths suggests this results from a trend to increased westerly circulation across New Zealand between 1950 and 2004. This trend is consistent with enhanced warming since 1950 (as predicted by climate change modelling); the stronger IPO westerly phase since 1977; the increased frequency of El Niño events since 1977; or a mixture of all these considerations.

4.3.3 The effect of the Southern Annular Mode

The Southern Annular Mode (SAM) is a hemispheric atmospheric wave centred on the South Pole that affects New Zealand's climate in terms of westerly wind strength and storm occurrence (Kidston et al., 2009). In its positive phase, the SAM is associated with relatively light winds and more settled weather over New Zealand, with stronger westerly winds further south towards the pole. In contrast, the negative phase of the SAM is associated with unsettled weather over New Zealand and stronger westerly winds, whereas wind and storms decrease towards Antarctica.

In contrast to the longer-lived oscillations of ENSO and the IPO, each phase of the SAM may only last for a number of weeks before switching to the opposite phase. The phase and strength of the SAM is influenced by the size of the ozone hole, with the past increase in ozone depleting substances giving rise to a positive trend in the phase of the SAM (Thompson et al., 2011). However, with the recovery of the ozone hole and reduction of ozone-depleting substances projected into the future, the trend of summertime SAM phases is expected to become more negative and stabilise slightly above zero (i.e., it is expected that there will be slightly more positive SAM phases than negative phases. However, increasing concentration of greenhouse gases in the atmosphere will have the opposite effect, of an increasing positive trend in summer and winter SAM phases, i.e. there will be more positive phases than negative phases into the future (Figure 4-9). The net result for SAM behaviour, as a consequence of both ozone recovery and greenhouse gas increases, is therefore likely to be relatively little change from present by 2100.

[1] The opposite behaviour – i.e. a trend to increases in mean and extreme rainfall – was observed to the west of a line from Westport to Invercargill.

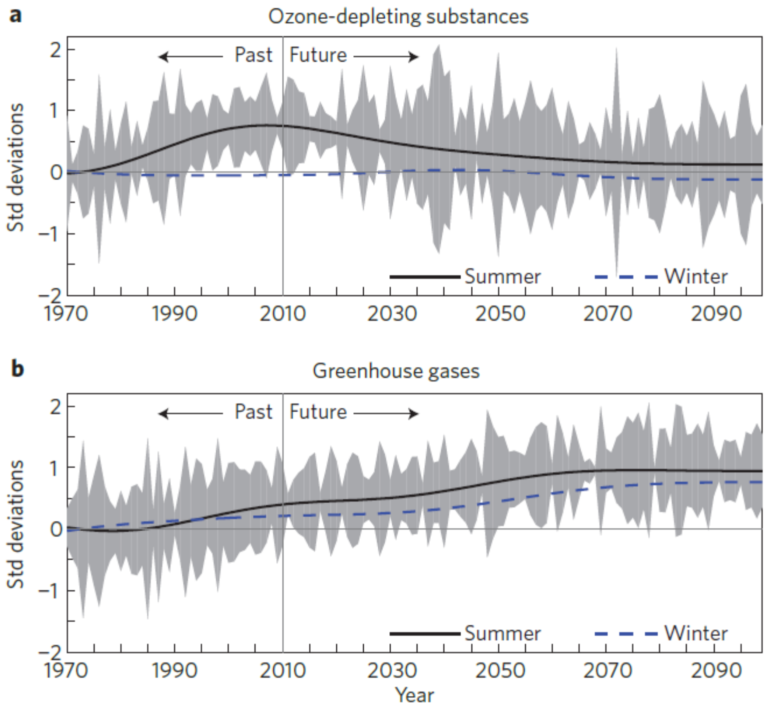


Figure 4-9: Time series of the Southern Annular Mode from transient experiments forced with time-varying ozone-depleting substances and greenhouse gases. a. Forcing with ozone-depleting substances; b. forcing with greenhouse gases. The SAM index is defined as the leading principal component time series of 850-hpa Z anomalies 20-90°S; positive values of the index correspond to anomalously low Z over the polar cap, and vice versa. Lines denote the 50-year low-pass ensemble mean response for summer (DJF, solid black) and winter (JJA, dashed blue). Grey shading denotes +/- one standard deviation of the three ensemble members about the ensemble mean. The long-term means of the time series are arbitrary and are set to zero for the period 1970-1975. Past forcings are based on observational estimates; future forcings are based on predictions. After Thompson et al. (2011).

4.4 New Zealand Sea Level Trends and Variability

According to the IPCC AR5 Working Group I, global mean sea level rose by 0.19 ± 0.02 m from 1901 to 2010 (IPCC, 2013). Sea level rise around New Zealand is comparable to the global average, being approximately 0.19 m for the 20th century (Reisinger et al., 2014).

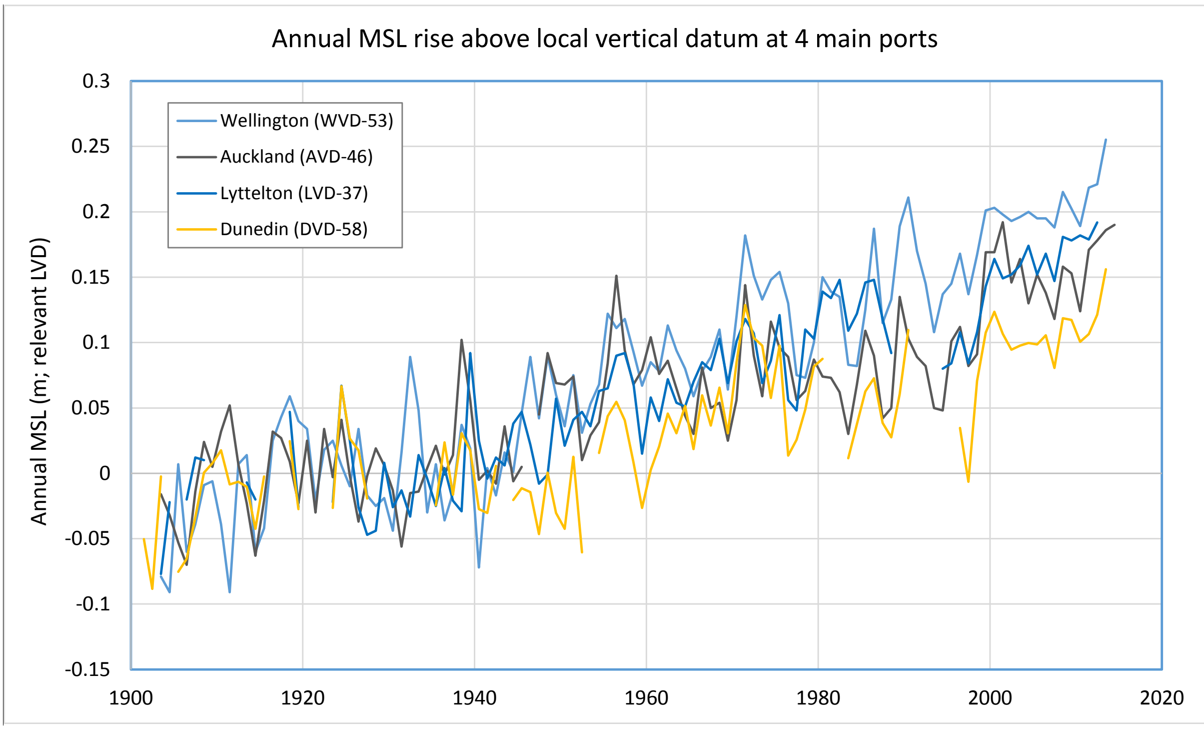


Figure 4-10: Relative sea-level rise at four main New Zealand ports, 1900-2007. Modified after Hannah and Bell (2012). Annual MSL quality assurance undertaken by Prof. John Hannah and NIWA – data sourced originally from the port companies and obtained from the Land Information NZ archives. Each local vertical datum (LVD) was established from tide-gauge measurements in the earlier part of last century for years listed in Table 1 of Hannah & Bell (2012). Note: the plot shows the increase in annual MSL since the zero MSL datums were established from measurements in the earlier part of the 1900s, where the average passes through the zero line.

Table 4-1: Historical relative sea-level rise rates. Source: Hannah and Bell (2012). The SLR rates are relative to the local landmass at the sea-level gauge locations (and implicitly include vertical landmass movement).

Location	Historical rate of sea-level rise (mm yr^{-1})
Auckland	1.5 ± 0.1
Wellington	2.0 ± 0.2
Lyttelton	1.9 ± 0.1
Dunedin	1.3 ± 0.1

Figure 4-10 and Table 4-1 show that along with the long-term positive trend in sea level, there are short-term variations as well. Seasonal (annual), El Nino-Southern Oscillation (ENSO, 3-7 year), and Interdecadal Pacific Oscillation (IPO, 20-30 year) variations can cause fluctuations of up to about ±0.25 m in background sea levels for short periods. For example during El Niño phases, sea levels around New Zealand tend to be depressed, and during La Niña phases sea levels around the country tend to be higher. The IPO in its negative phase tends to increase sea levels around the North Island by around 0.06 m above the background sea level rise.

Storm surge can also temporarily increase sea level over 1-3 days. Storm surge occurs due to a reduction in atmospheric pressure (inverse barometer effect) and the influence of the wind on the sea surface. In a New Zealand context, maximum storm surge on the open coast is unlikely to be more than 1 m, but can be higher in estuarine and harbour settings. Wave conditions also affect localised water levels where inshore of the wave breaker zone, water levels are set-up. This is a localised phenomenon and can be highly variable along even a short stretch of coastline, being dependent on the wave conditions and configurations of offshore sandbars and beach slope.

5 Projections of Tasman's Future Climate

Tasman District's future climate will be influenced by a combination of the effects of anthropogenic climate change (increasing global concentrations of greenhouse gases, Section 2) plus the natural year-to-year and decade-to-decade variability resulting from "climate noise" and features such as the El Nino-Southern Oscillation (ENSO), the Interdecadal Pacific Oscillation (IPO), and the Southern Annular Mode (SAM), discussed in Section 4. This section first outlines the projected changes due to anthropogenic climate change in Tasman District, and then returns to the issue of natural variability. Note that the projected changes use 20-year averages, which will not entirely remove effects of natural variability.

Predicting future changes in climate due to anthropogenic activity is made difficult because (a) predictions depend on future greenhouse gas concentrations, which in turn depend on global greenhouse gas emissions driven by factors such as economic activity, population changes, technological advances and policies for sustainable resource use, and (b) even for a specific future trajectory of global greenhouse gas emissions, different climate models predict somewhat different amounts of climate change.

This has been dealt with by the Intergovernmental Panel on Climate Change through consideration of 'scenarios' describing concentrations of greenhouse gases in the atmosphere associated with a range of possible economic, political, and social developments during the 21st century, and by considering results from several different climate models for a given scenario. In the 2013 IPCC Fifth Assessment Report, these scenarios are called Representative Concentrations Pathways (RCPs).

In Sections 5.1 and 5.2, global climate model output based on two RCPs has been downscaled to produce future projections for temperature and precipitation for the Tasman District. The RCPs are based on 21st century climate policies, and thus differ from the previous IPCC SRES emissions scenarios and their 'no-climate policy' (IPCC, 2013). RCP4.5 is a low-mid-range emissions scenario, which is also called a 'stabilisation' scenario where radiative forcing stabilises by 2100. RCP8.5 is a scenario with very high greenhouse gas emissions, and radiative forcing continues to increase beyond 2100. Each RCP provides spatially-resolved data sets of land use change and sector-based emissions of air pollutants, and it specifies annual greenhouse gas concentrations and anthropogenic emissions up to 2500 (although this report only considers changes to 2100). RCPs are based on a combination of integrated assessment models, simple climate models, atmospheric chemistry and global carbon cycle models.

NIWA has used climate model data from the IPCC Fifth Assessment (IPCC, 2013) to update climate change scenarios for New Zealand, through both a regional and statistical downscaling process. The regional downscaling process is described in detail in an updated climate guidance manual prepared for the Ministry for the Environment (Mullan et al., 2015). This report is currently under review, and the final report is due in late 2015.The statistical downscaling for up to 41 Global Climate Models (GCMs) uses essentially the same methodology used in the Ministry for the Environment (2008a) report and the previous climate change report for Tasman District Council (Wratt et al., 2008).

5.1 Tasman Climate Change Temperature Projections

The magnitude of the temperature change projections varies with the RCP and also with the climate models used. In this report, downscaling of two RCPs has been carried out to show the differences in temperature and precipitation projections for a stabilisation emissions scenario (RCP4.5) and a high emissions scenario (RCP8.5).

Figure 5-1 shows the seasonal patterns of projected temperature increase over the Tasman District and surrounding areas for 2040 for the RCP4.5 scenario, where the temperature changes of 37 climate models have been averaged together. Figure 5-2 shows corresponding patterns for 2090. Figure 5-3 shows the seasonal patterns of projected temperature increase for 2040 for the RCP8.5 scenario, where the temperature changes of 41 climate models have been averaged together, and Figure 5-4 shows the corresponding patterns for 2090. These nominal years represent the mid-points of bi-decadal periods: 2040 is the average over 2031-2050, and 2090 the average over 2081-2100. All maps show changes relative to the baseline climate of 1986-2005.

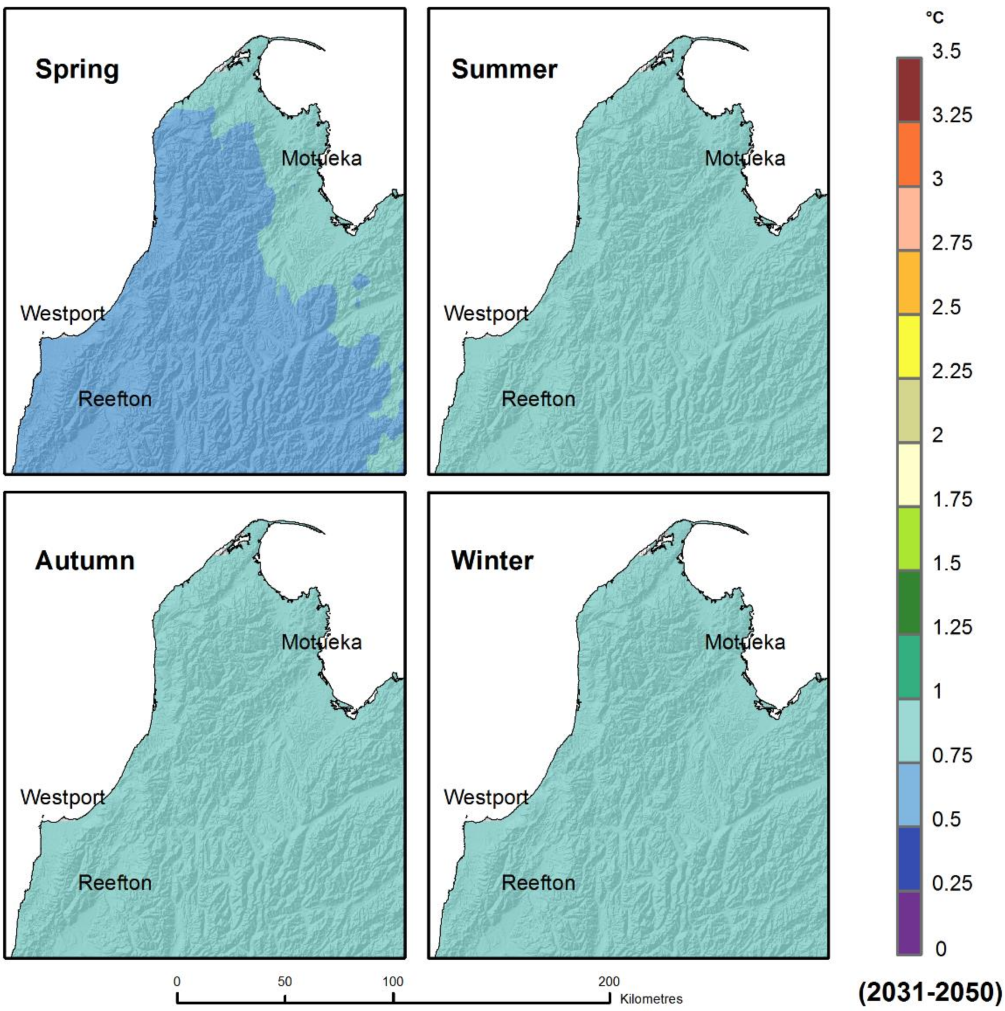


Figure 5-1: Projected seasonal temperature changes at 2040 (2031-2050 average). Relative to 1986-2005 average, for the IPCC RCP4.5 scenario, averaged over 37 climate models. ©NIWA.

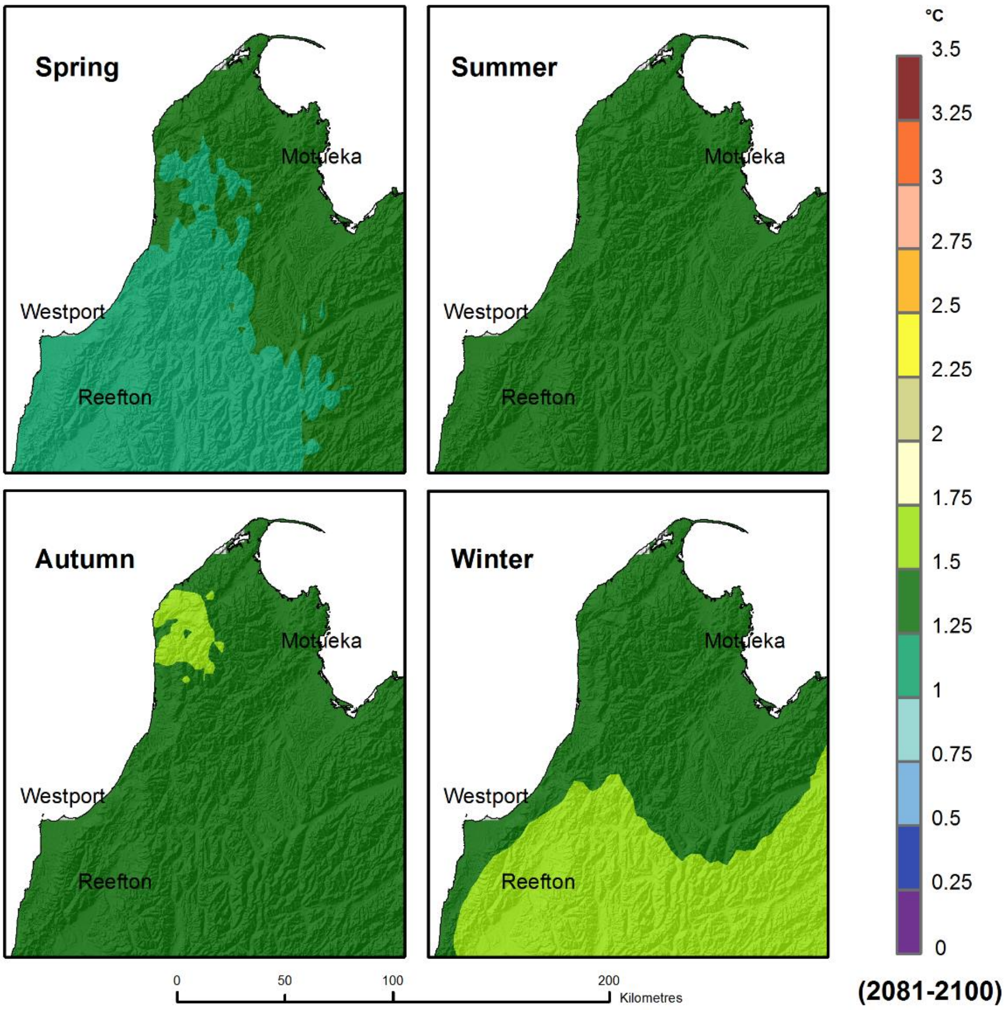


Figure 5-2: Projected seasonal temperature changes at 2090 (2081-2100 average). Relative to 1986-2005 average, for the IPCC RCP4.5 scenario, averaged over 37 climate models. ©NIWA.

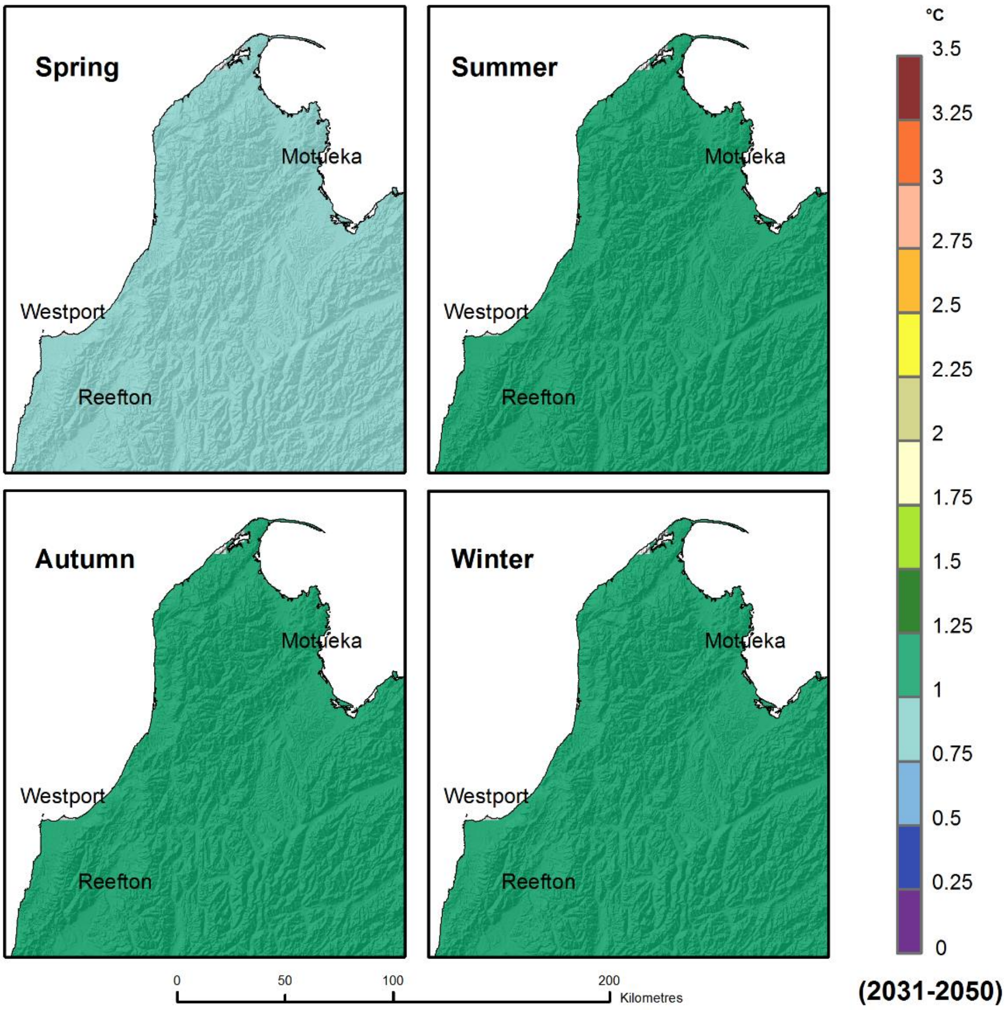


Figure 5-3: Projected seasonal temperature changes at 2040 (2031-2050 average). Relative to 1986-2005 average, for the IPCC RCP8.5 scenario, averaged over 41 climate models. ©NIWA.

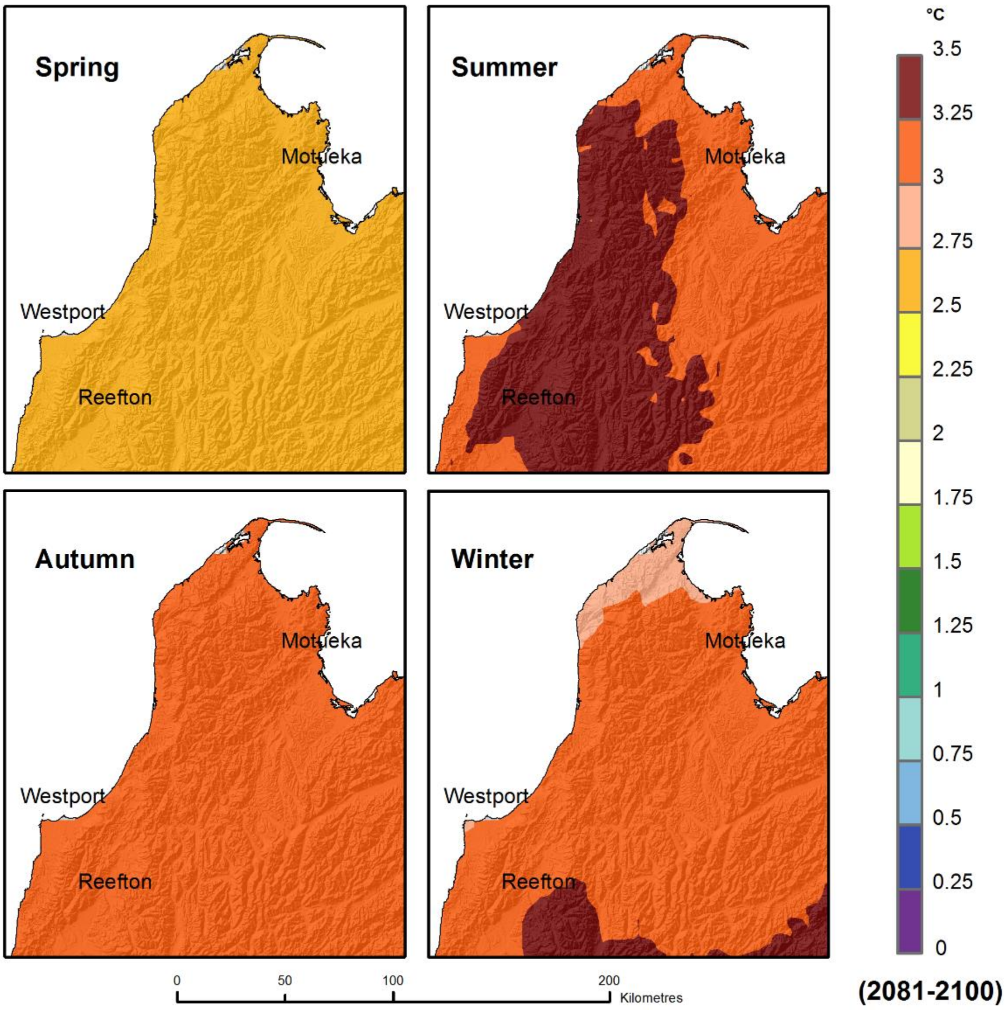


Figure 5-4: Projected seasonal temperature changes at 2090 (2081-2100 average). Relative to 1986-2005 average, for the IPCC RCP8.5 scenario, averaged over 41 climate models. ©NIWA.

Figures 5-1 and 5-2 show projected future warming in the Tasman District of approximately 0.2°C per decade for the RCP4.5 scenario, when averaged over the 37 climate models analysed by NIWA. Figures 5-3 and 5-4 show projected future warming of approximately 0.3°C per decade for the RCP8.5 scenario, when averaged over 41 climate models. A slight acceleration in warming is projected for the second 50 years of the 21st century compared to the first 50 years. Some models give less warming and others give a faster rate of warming (IPCC, 2013). The full range of model-projected warming is given in Table 5-1. The temperature ranges are relative to the baseline period 1986-2005 (as used by IPCC). Hence the projected changes at 2040 and 2090 should be thought of as 50-year and 100-year trends.

Table 5-1: Projected changes in seasonal and annual mean temperature (in °C) for the Tasman District for 2040 and 2090. The changes are given for all four RCPs (2.6, 4.5, 6.0, 8.5), where the ensemble-average is taken over (23, 37, 18, 41) models, respectively. The first number is the ensemble average, with the bracketed numbers giving the range (5th and 95th percentile). ©NIWA.

Period	RCP	Summer	Autumn	Winter	Spring	Annual
2040	**RCP 2.6**	0.7 (0.2, 1.3)	0.8 (0.3, 1.2)	0.7 (0.3, 1.1)	0.6 (0.2, 1.0)	0.7 (0.3, 1.1)
	RCP 4.5	0.9 (0.4, 1.6)	0.9 (0.4, 1.4)	0.9 (0.6, 1.3)	0.7 (0.3, 1.2)	0.9 (0.5, 1.3)
	RCP 6.0	0.9 (0.3, 1.7)	0.9 (0.3, 1.2)	0.8 (0.3, 1.2)	0.7 (0.1, 1.2)	0.8 (0.2, 1.2)
	RCP 8.5	1.0 (0.3, 1.7)	1.1 (0.7, 1.6)	1.1 (0.7, 1.5)	0.9 (0.4, 1.4)	1.0 (0.6, 1.6)
2090	**RCP 2.6**	0.6 (0.2, 1.4)	0.7 (0.1, 1.5)	0.7 (0.3, 1.2)	0.6 (0.1, 1.1)	0.6 (0.3, 1.3)
	RCP 4.5	1.4 (0.7, 2.7)	1.5 (0.8, 2.3)	1.5 (0.8, 2.1)	1.3 (0.7, 1.8)	1.4 (0.9, 2.2)
	RCP 6.0	1.8 (0.8, 4.1)	1.9 (1.0, 3.1)	1.8 (1.1, 2.6)	1.5 (0.9, 2.3)	1.8 (1.0, 3.0)
	RCP 8.5	3.2 (2.1, 5.4)	3.2 (2.3, 4.7)	3.1 (2.3, 4.1)	2.6 (1.9, 3.5)	3.0 (2.3, 4.5)

The seasonal and annual ensemble average projection (the number outside the brackets) in Table 5-1 is the temperature increase averaged over all 23 models for RCP 2.6, 37 models for RCP 4.5, 18 models for RCP 6.0, and 41 models for RCP 8.5 analysed by NIWA. The bracketed numbers give the range (5th and 95th percentile) for each RCP for each season and the annual projection.

By 2040 (2031-2050, relative to 1986-2005), annual average temperatures are projected to increase by between 0.7°C (RCP 2.6) and 1.0°C (RCP 8.5). The greatest warming is projected for summer or autumn (depending on the RCP) and the least warming is projected for spring. By 2090 (2081-2100, relative to 1986-2005), annual average temperatures are projected to increase by between 0.6°C for RCP 2.6 and 3.0°C for RCP 8.5. The greatest warming is projected for summer or autumn (depending on the RCP) and the least warming is projected for spring. Note that the mitigation scenario (RCP 2.6) temperature change for 2090 is less than the change for 2040, whereas all other emissions scenarios show increased warming at 2090 relative to 2040.

5.2 Projections for Frosts and Hot Days under Climate Change

As the seasonal mean temperature increases over time, we also expect to see changes in temperature extremes. In general, an increase in high temperature extremes, and a decrease in low temperature extremes is expected. Natural variability, of course, will continue to influence the climate of particular years, and the specific time variation of this variability cannot be predicted by the climate models due to the chaotic interactions that affect development of individual weather systems and larger-scale climate modes (such as El Niño events) (Mullan et al., 2015).

For this report, high temperature extremes (i.e. 'hot days') are considered as the number of days per year of 25°C or above, and low temperature extremes (i.e. 'cold nights' or frosts) are considered as the number of nights per year of 0°C or below. These extremes were determined by adding the monthly statistically downscaled temperature offsets to the daily VCSN[2] maximum temperature (for 'hot days') and to daily VCSN minimum temperature (for 'cold nights') for each model; then counting the exceedances (greater than or equal to 25°C, or less than or equal to 0°C, for hot days and cold nights, respectively) for the selected RCP and time period. Finally the changes were averaged over the number of years (20) and the number of models (37 for RCP4.5 and 41 for RCP8.5).

Figure 5-5 shows the projected increase in the number of hot days per year at 2040 (2031-2050) and 2090 (2081-2100) relative to 1986-2005, for RCP4.5 and RCP8.5. At 2040 there is projected to be only a small increase in the number of hot days in higher elevations, with the lowlands (Motueka and Waimea Plains) receiving the largest projected increase (an increase of 10-15 days under RCP8.5 compared to 1986-2005). By 2090, the projected change in hot days is much larger, with an expected increase of 50-60 days under RCP8.5 compared to 1986-2005 in the Motueka and Waimea Plains.

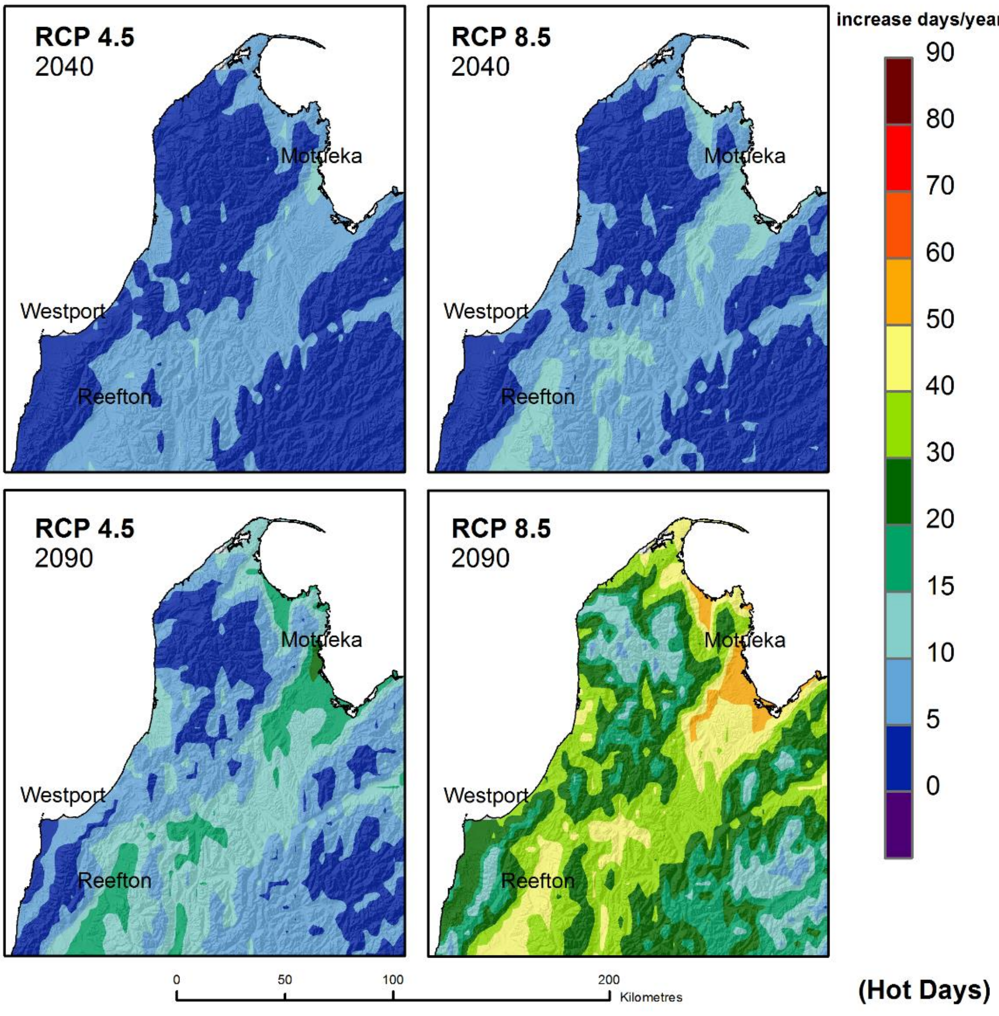


Figure 5-5: Projected increase in number of hot days per year (Tmax >25°C) at 2040 and 2090 for RCP4.5 (left panels) and RCP8.5 (right panels), for Tasman District. Projected change in hot days is relative to 1986-2005. The numbers on the scale refer to the *increase* in the number of hot days, e.g., the coast adjacent to Tasman Bay is projected to experience an increase in the number of hot days by 50-60 days by 2090 under RCP8.5 (lower right panel).

[2] Virtual Climate Station Network, a set of New Zealand climate data based on a 5 km by 5 km grid across the country. Data has been interpolated from 'real' climate station records (TAIT, A., HENDERSON, R., TURNER, R. & ZHENG, X. G. 2006. Thin plate smoothing spline interpolation of daily rainfall for New Zealand using a climatological rainfall surface. *International Journal of Climatology,* 26**,** 2097-2115.)

Figure 5-6 shows the projected decrease in the number of cold nights (or frosts) per year by 2040 (2031-2050) and 2090 (2081-2100) for RCP4.5 and RCP8.5. The projected decrease in the number of cold nights at both 2040 and 2090 for both RCPs is most significant in the southeast of the Tasman District (at higher elevations). By 2090 under RCP8.5, the number of cold nights in the southeast part of the District is expected decrease by more than 90 nights per year compared to 1986-2005. By 2090 under RCP8.5 along the coast and inland between Motueka and Nelson, the number of cold nights is projected to decrease by 20-30 nights per year compared to 1986-2005.

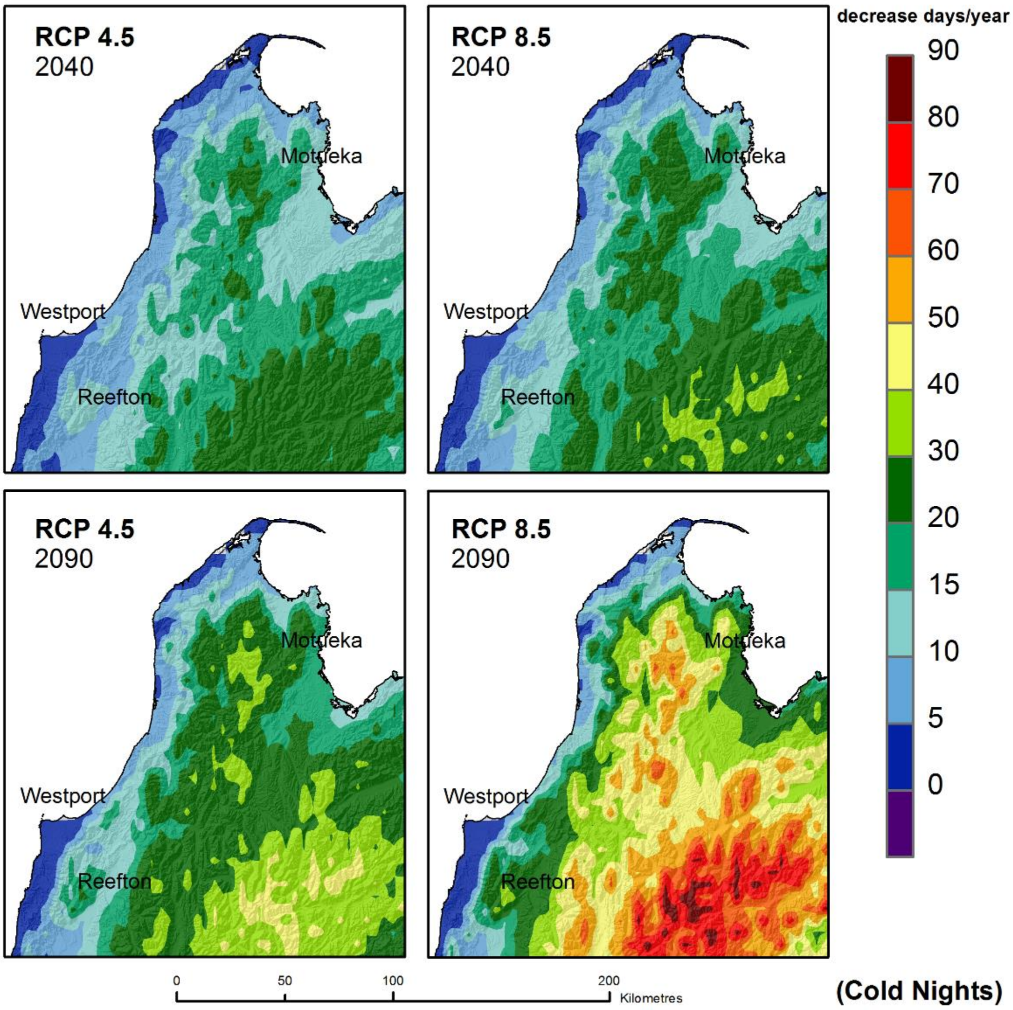


Figure 5-6: Projected decrease in number of cold nights per year (Tmin <0°C) at 2040 and 2090 for RCP4.5 (left panels) and RCP8.5 (right panels), for Tasman District. Projected change in cold nights is relative to 1986-2005. The numbers on the scale refer to the *decrease* in the number of cold nights, e.g., the coast adjacent to Tasman Bay is projected to experience a decrease in the number of cold nights by 10-15 days by 2040 under RCP8.5 (top right panel).

Table 5-2 shows that projections suggest a substantial decrease in the annual number of cold nights (or frosts) in Tasman District, with perhaps 28 fewer cold nights by 2090 under RCP8.5 (a decrease from 36 days per year during 1986-2005 to 8 days per year during 2081-2100 under RCP8.5). The number of hot days is projected to increase significantly, with perhaps 43 more hot days by 2090 under RCP8.5 (an increase from 11 days per year during 1986-2005 to 54 days per year during 2081-2100 under RCP8.5). The values in Table 5-2 are a calculated average over the Tasman District for all

VCSN points below 500m altitude; hence the projected changes are lower (or higher) than some of the local-scale changes in Figures 5-5 and 5-6.

Table 5-2: Projected changes in the number of hot days and cold nights (frosts) at 2040 and 2090 for Tasman District, with RCP4.5 and RCP8.5 compared to the historical period (1986-2005). The projected changes were averaged over all VCSN points across the Tasman District below 500 m elevation.

		Historical period days	2040 number of days	2040 change	2090 number of days	2090 change
Hot days	**RCP 4.5**	11	19	+8 days	25	+14 days
	RCP 8.5		20	+9 days	54	+43 days
Cold nights	**RCP 4.5**	36	25	-11 days	19	-17 days
	RCP 8.5		23	-13 days	8	-28 days

5.3 Tasman Climate Change Precipitation Projections

Precipitation (rain + snow) projections show much more spatial variation than the temperature projections. Again, the magnitude of the projected change will scale up or down with the different RCPs, and will also differ between climate models. Figures 5-7 and 5-8 show the projected seasonal patterns of precipitation change over the Tasman District and surrounding areas at 2040 and 2090 for RCP4.5 (averaging 37 climate models), and Figures 5-9 and 5-10 show the same for RCP8.5 (averaging 41 climate models).

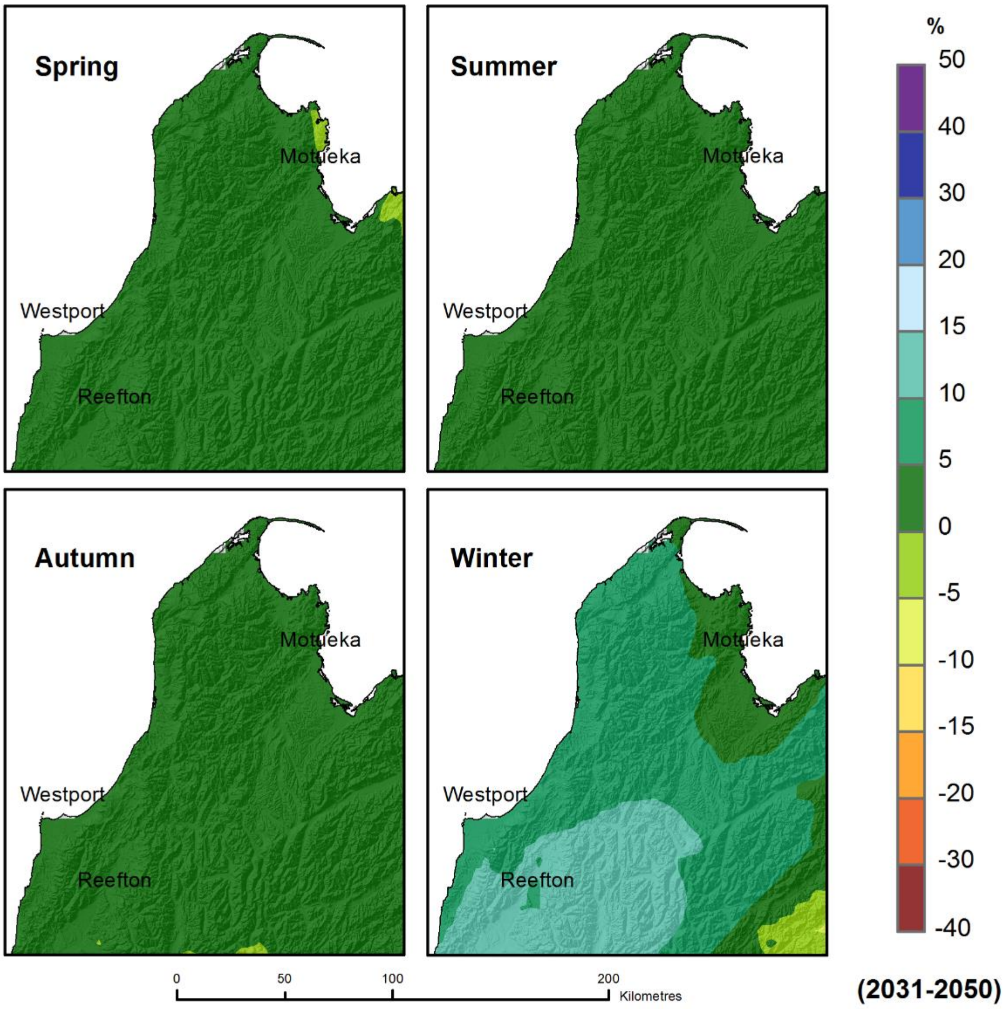


Figure 5-7: Projected seasonal precipitation changes (in %) at 2040 (2031-2050 average). Relative to 1986-2005 average, for the IPCC RCP4.5 scenario, averaged over 37 climate models. ©NIWA.

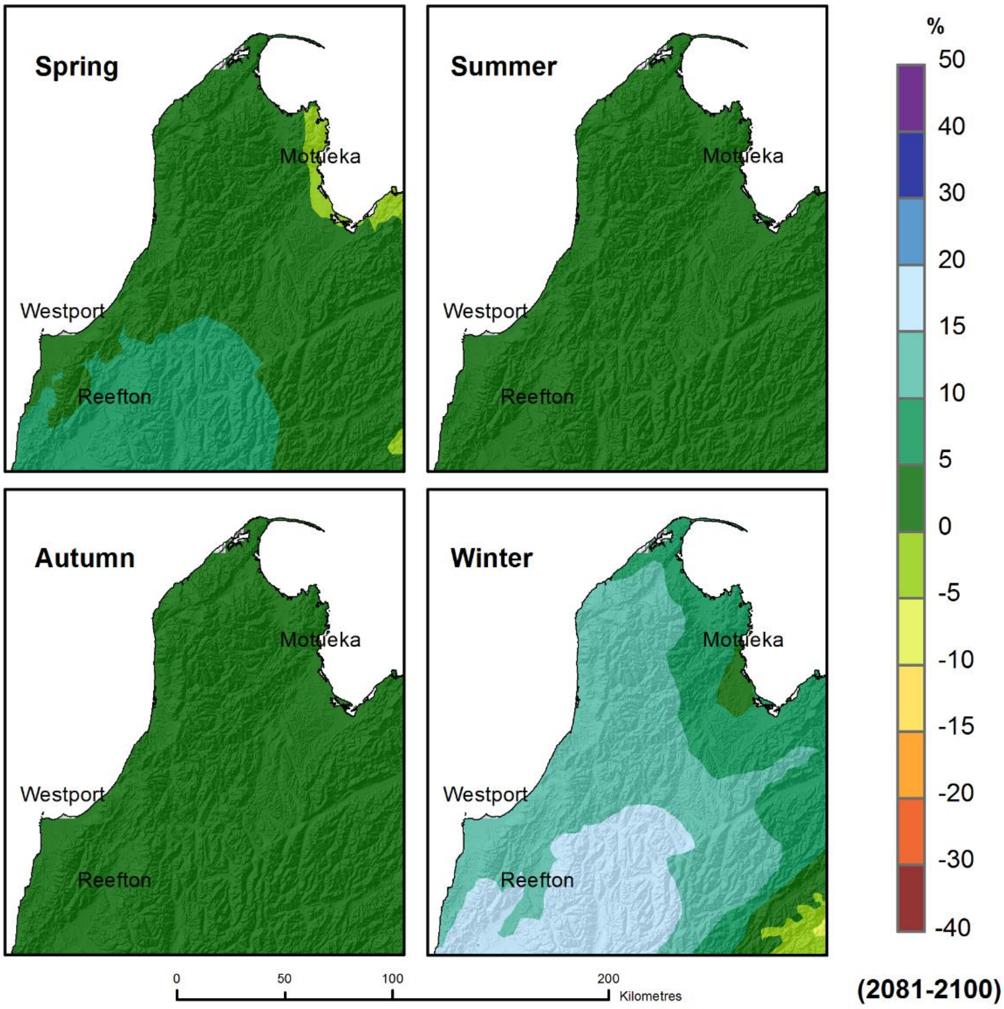


Figure 5-8: Projected seasonal precipitation changes (in %) at 2090 (2081-2100 average). Relative to 1986-2005 average, for the IPCC RCP4.5 scenario, averaged over 37 climate models. ©NIWA.

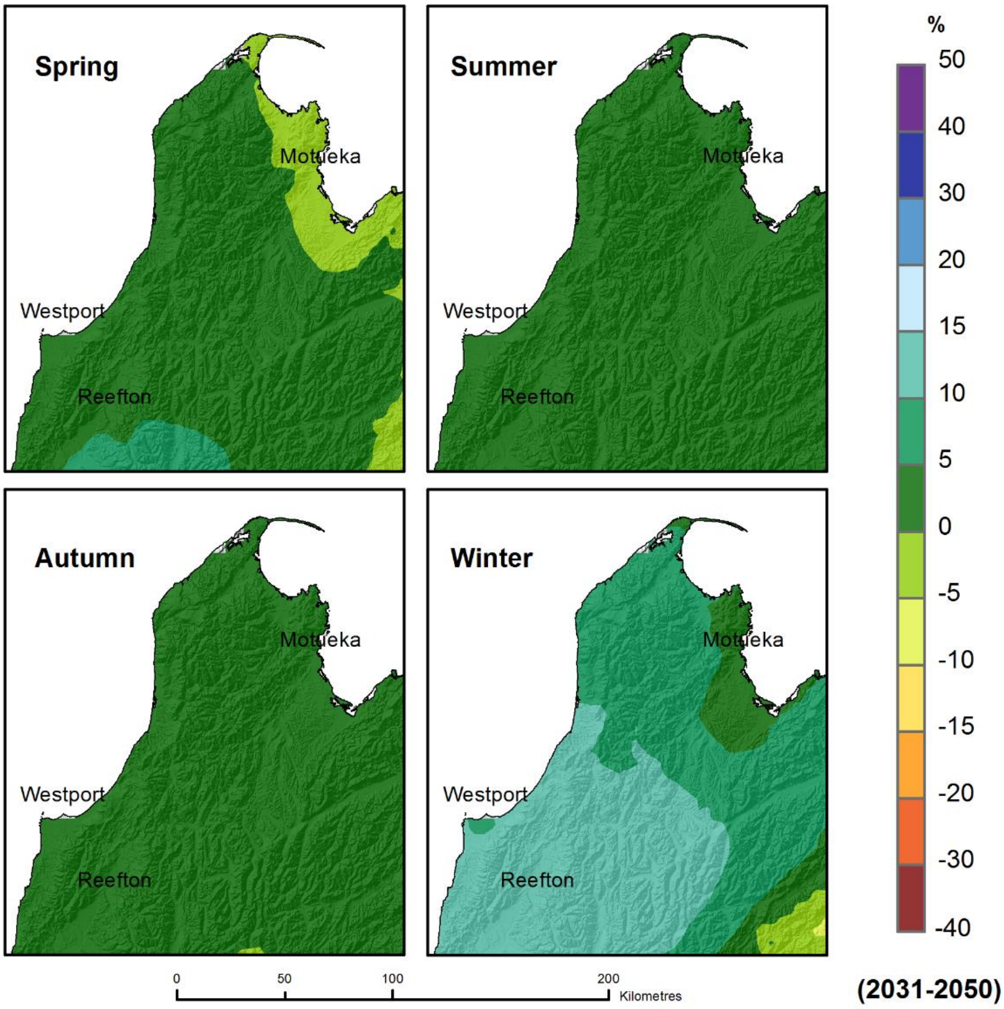


Figure 5-9: Projected seasonal precipitation changes (in %) at 2040 (2031-2050 average). Relative to 1986-2005 average, for the IPCC RCP8.5 scenario, averaged over 41 climate models. ©NIWA.

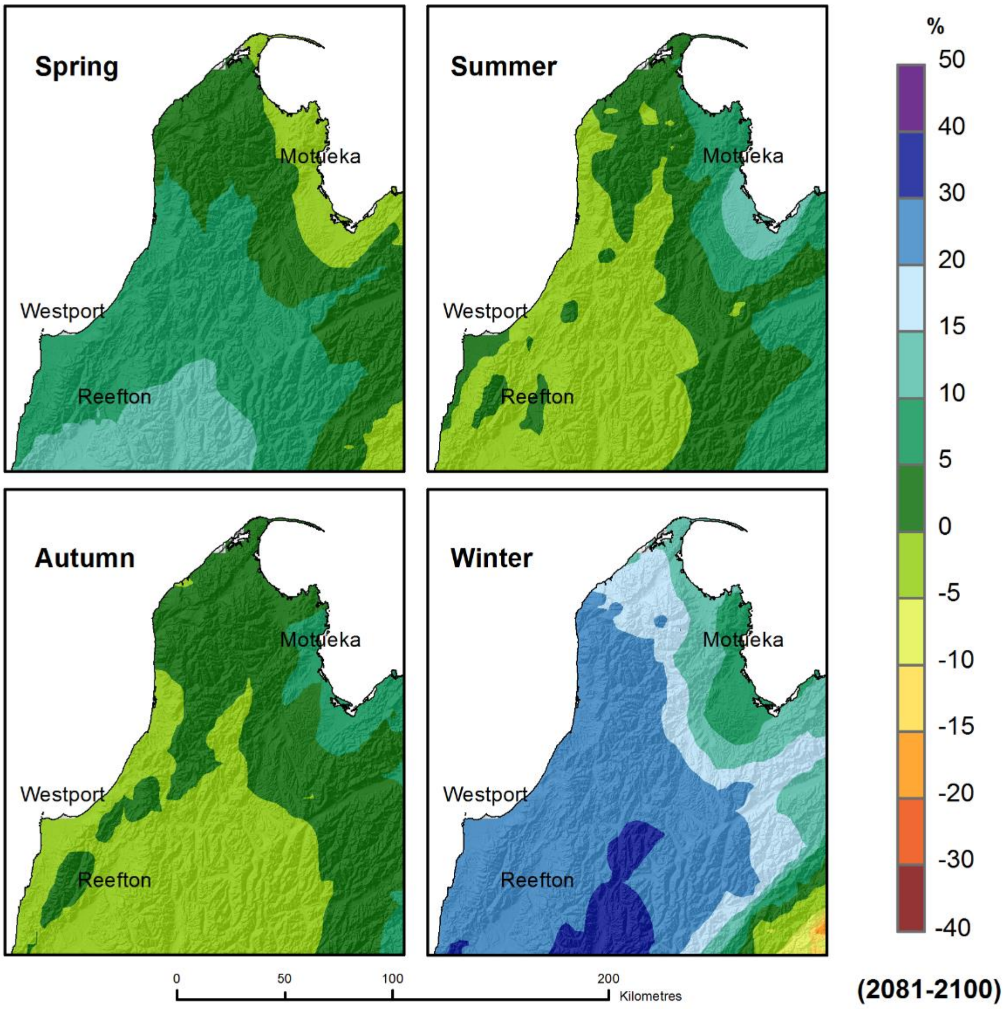


Figure 5-10: Projected seasonal precipitation changes (in %) at 2090 (2081-2100 average). Relative to 1986-2005 average, for the IPCC RCP8.5 scenario, averaged over 41 climate models. ©NIWA.

The RCP4.5 and RCP8.5 projections indicate slightly more rainfall in most seasons except spring for much of the area of coastal plains adjacent to Tasman Bay (i.e. Motueka, Waimea plains) to 2040. By 2090 for RCP8.5, more rainfall is projected for the plains in summer, autumn, and especially winter. By 2090 under RCP8.5, the western part of Tasman District is projected to receive less rainfall (by less than 5%) in summer and autumn, but significantly more rainfall in winter (up to 40% in some parts).

The full range of model-projected precipitation change (in %) is given in

Table 5-3 for Appleby and Table 5-4 for Takaka. The precipitation changes are relative to the baseline period 1986-2005. Hence the projected changes at 2040 and 2090 should be thought of as 45-year and 95-year trends.

Table 5-3: Projected changes in seasonal and annual mean rainfall (in %) for the Appleby grid point for 2040 and 2090. The changes are given for all four RCPs (2.6, 4.5, 6.0, 8.5), where the ensemble-average is taken over (23, 37, 18, 41) models, respectively. The first number is the ensemble average, with the bracketed numbers giving the range (5th and 95th percentile). ©NIWA.

Period	RCP	Summer	Autumn	Winter	Spring	Annual
2040	**RCP 2.6**	2 (-7, 9)	3 (-5, 8)	3 (-2, 9)	0 (-10, 6)	2 (-3, 5)
	RCP 4.5	1 (-4, 9)	3 (-6, 12)	4 (-7, 13)	0 (-7, 9)	2 (-3, 7)
	RCP 6.0	2 (-6, 18)	3 (-5, 11)	4 (-11, 17)	0 (-9, 11)	2 (-2, 8)
	RCP 8.5	1 (-10, 10)	3 (-5, 9)	4 (-5, 15)	-1 (-10, 7)	2 (-3, 7)
2090	**RCP 2.6**	0 (-14, 8)	3 (-7, 13)	3 (-4, 11)	1 (-7, 7)	2 (-4, 7)
	RCP 4.5	3 (-6, 13)	4 (-8, 11)	6 (-8, 15)	0 (-7, 7)	3 (-2, 9)
	RCP 6.0	5 (-10, 22)	5 (-6, 15)	7 (-8, 25)	0 (-8, 9)	4 (-2, 15)
	RCP 8.5	11 (-1, 27)	6 (-5, 16)	9 (-8, 26)	-2 (-17, 9)	6 (-2, 14)

Table 5-4: Projected changes in seasonal and annual mean rainfall (in %) for the Takaka grid point for 2040 and 2090. The changes are given for all four RCPs (2.6, 4.5, 6.0, 8.5), where the ensemble-average is taken over (23, 37, 18, 41) models, respectively. The first number is the ensemble average, with the bracketed numbers giving the range (5th and 95th percentile). ©NIWA.

Period	RCP	Summer	Autumn	Winter	Spring	Annual
2040	**RCP 2.6**	0 (-8, 9)	2 (-7, 12)	6 (-16, 20)	3 (-9, 16)	3 (-4, 12)
	RCP 4.5	1 (-8, 9)	1 (-9, 13)	10 (-6, 22)	3 (-12, 17)	4 (-3, 11)
	RCP 6.0	-1 (-9, 12)	1 (-11, 10)	10 (-7, 29)	1 (-13, 15)	3 (-4, 13)
	RCP 8.5	1 (-9, 10)	1 (-12, 10)	11 (-5, 30)	3 (-12, 17)	4 (-2, 14)
2090	**RCP 2.6**	3 (-7, 18)	3 (-7, 15)	8 (-7, 28)	5 (-4, 18)	5 (-2, 16)
	RCP 4.5	2 (-8, 14)	2 (-8, 11)	14 (-9, 37)	5 (-6, 18)	6 (-4, 13)
	RCP 6.0	0 (-25, 12)	0 (-17, 20)	18 (-4, 50)	7 (-15, 19)	7 (-10, 18)
	RCP 8.5	1 (-26, 22)	-2 (-18, 11)	26 (-5, 58)	9 (-15, 28)	9 (-10, 19)

The seasonal and annual ensemble average projection (the number outside the brackets) in

Table 5-3 and Table 5-4 is the precipitation increase or decrease (in %) for Appleby and Takaka, respectively, averaged over all 23 models for RCP 2.6, 37 models for RCP 4.5, 18 models for RCP 6.0, and 41 models for RCP 8.5 analysed by NIWA. The bracketed numbers give the range (5th and 95th percentile) for each RCP for each season and the annual projection.

For Appleby, there is no clear precipitation signal, even at 2090 under RCP 8.5. The ensemble-average is often less than ±5%, with the model range (the 5th and 95th percentile values) varying between quite large (>10%) increases and decreases. By 2040 (2031-2050, relative to 1986-2005), winter is the season with the most precipitation change, with a small increase in the ensemble-average (3-5% across the different RCPs). By 2090 (2081-2100, relative to 1986-2005), winter is still the season with the most precipitation change, with increases in the ensemble-average ranging from 4 to 11% depending on the RCP.

For Takaka, there is a clearer precipitation signal than for Appleby, especially for winter. At both 2040 and 2090 under all RCPs, winter precipitation is projected to increase. The winter ensemble-average for RCP8.5 at 2090 at an increase of 26%, with the 95th percentile value at 58% increase. For the other seasons, the ensemble-average is often less than 5%, with the model range (5th and 95th percentiles) varying between small decreases to large increases in precipitation. However, the direction of change overall is for an increase in precipitation across all seasons at Takaka.

The average picture of projected temperature and rainfall changes in the tables and maps in Sections 5.1 to 5.3 obscures significant variations between individual models on the projected seasonal changes. Figure 5-11 and Figure 5-12 show seasonal temperature projections from all the models individually averaged over the Tasman District for 2040 and 2090, respectively. For 2040 (Figure 5-11), all four RCPs project quite similar changes on average (model-average warming is within about 0.5°C). The models for RCP8.5 have the greatest spread, particularly in summer. However, the models all agree on the direction of change (i.e. warming). For 2090 (Figure 5-12) the model spread is much larger, with the models for summer for RCP8.5 spread across more than 4°C of warming (from ~2.0°C to ~6.2°C). Most of the models agree on the direction of change (i.e. warming), but a small number from RCP2.6 project cooling by 2090.

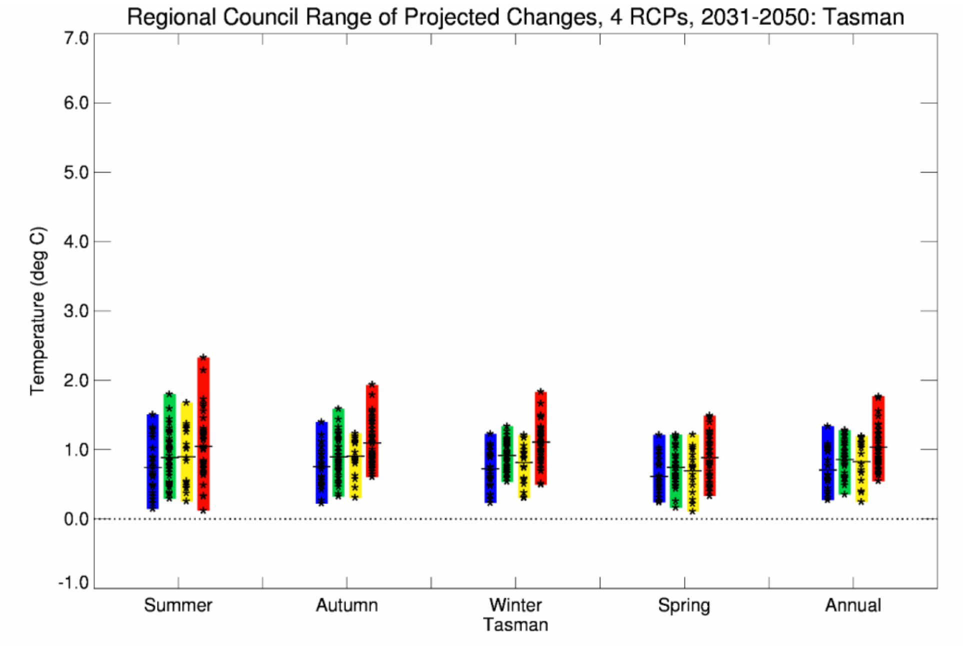


Figure 5-11: Projected seasonal temperature changes by 2040 (2031-2050) averaged over the Tasman District, for the four RCPs. The vertical coloured bars show the range over all climate models used, and stars the projected changes for each model individually. The short horizontal line is the model-average warming. Blue = RCP2.6, 23 models; green = RCP4.5, 37 models; yellow = RCP6.0, 18 models; red = RCP8.5, 41 models.

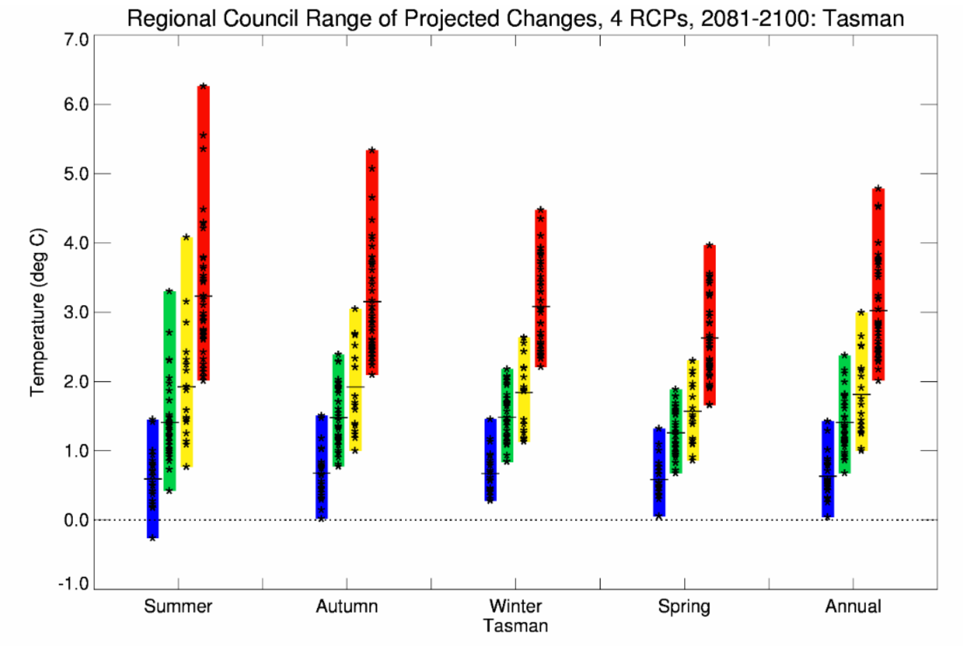


Figure 5-12: Projected seasonal temperature changes by 2090 (2081-2100) averaged over the Tasman District, for the four RCPs. The vertical coloured bars show the range over all climate models used, and stars the projected changes for each model individually. The short horizontal line is the model-average warming. Blue = RCP2.6, 23 models; green = RCP4.5, 37 models; yellow = RCP6.0, 18 models; red = RCP8.5, 41 models.

Figure 5-13 and Figure 5-14 show seasonal rainfall projections from all the models individually for the Appleby grid point only for 2040 and 2090, respectively. There is disagreement between the models as to the direction of projected rainfall changes, as identified in Table 5-3 for the different RCPs. However, for 2040 in Figure 5-13, the model-average rainfall projections are quite similar for all seasons (with summer being the most variable), even though the spread of the models under each RCP is quite large (spread across approximately -10% to +20% precipitation change). For 2090 (Figure 5-14), the model spread under each RCP is much larger than in Figure 5-13 (spread across approximately -15% to +25%) and the model-averages between each RCP are quite varied.

Note that Figures 5-13 to 5-16 show the model variability at two grid points only (Appleby and Takaka), rather than a regional average (as was done for temperature). This is because the projected changes to rainfall vary greatly over the region. These figures can be replicated for any grid point in the Tasman District, upon request.

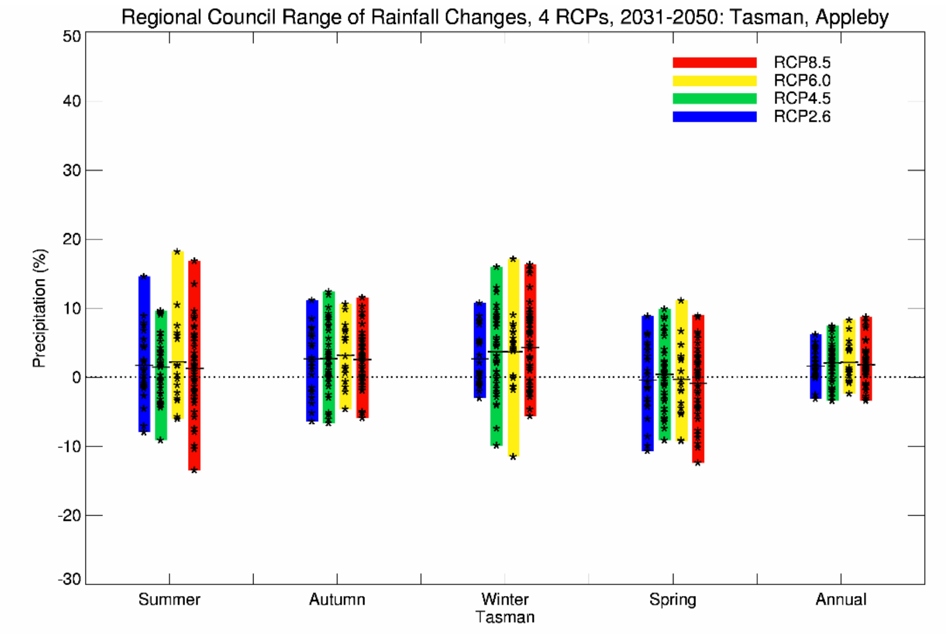


Figure 5-13 Projected seasonal rainfall changes by 2040 (2081-2100) for Appleby, for the four RCPs. The vertical coloured bars show the range over all climate models used, and stars the projected changes for each model individually. The short horizontal line is the model-average rainfall. Blue = RCP2.6, 23 models; green = RCP4.5, 37 models; yellow = RCP6.0, 18 models; red = RCP8.5, 41 models.

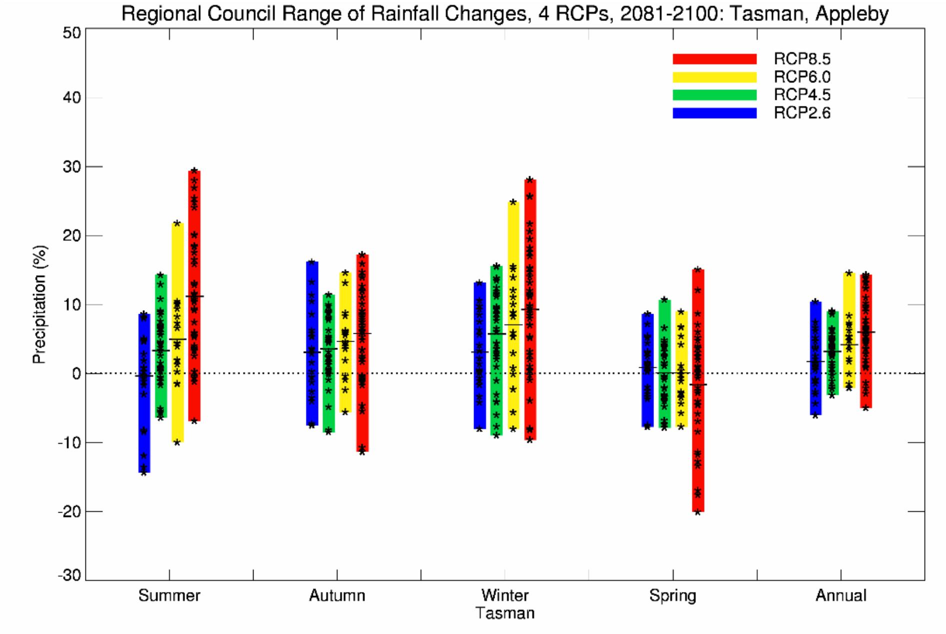


Figure 5-14 Projected seasonal rainfall changes by 2090 (2081-2100) for Appleby, for the four RCPs. The vertical coloured bars show the range over all climate models used, and stars the projected changes for each model individually. The short horizontal line is the model-average rainfall. Blue = RCP2.6, 23 models; green = RCP4.5, 37 models; yellow = RCP6.0, 18 models; red = RCP8.5, 41 models.

Figure 5-15 and Figure 5-16 show seasonal rainfall projections from all the models individually for the Takaka grid point only for 2040 and 2090, respectively. Although the ensemble-averages show an increase in precipitation, there is some disagreement between the individual models as to the direction and magnitude of projected rainfall changes – the spread within each RCP coloured bar is quite large, for example, ranging from a 20% decrease to more than a 50% increase in rainfall during winter for under RCP8.5 at 2090 (Figure 5-16). The model spread is much larger for Takaka than for Appleby for all RCPs at both 2040 and 2090.

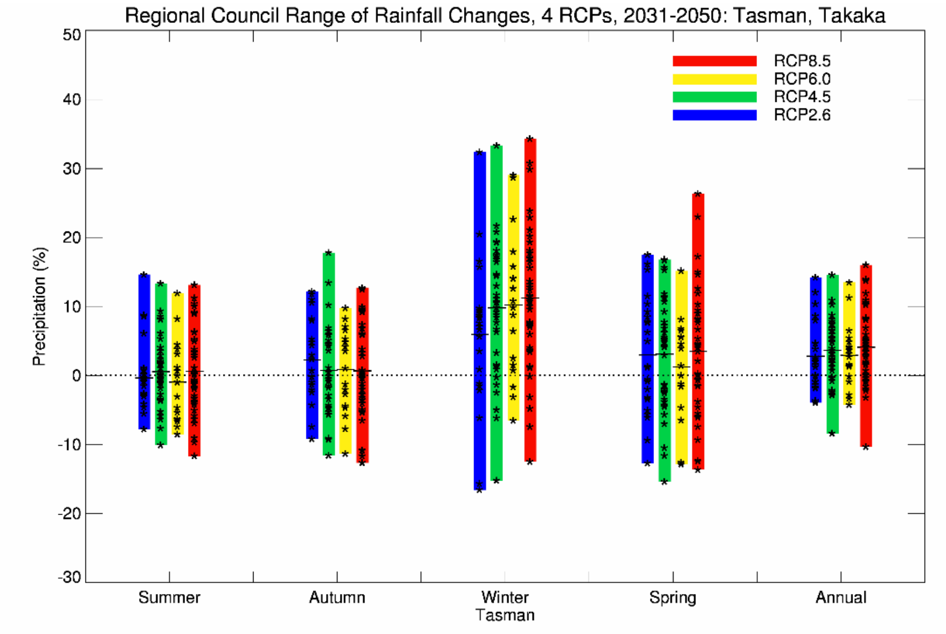


Figure 5-15: Projected seasonal rainfall changes by 2040 (2081-2100) for Takaka, for the four RCPs. The vertical coloured bars show the range over all climate models used, and stars the projected changes for each model individually. The short horizontal line is the model-average rainfall. Blue = RCP2.6, 23 models; green = RCP4.5, 37 models; yellow = RCP6.0, 18 models; red = RCP8.5, 41 models.

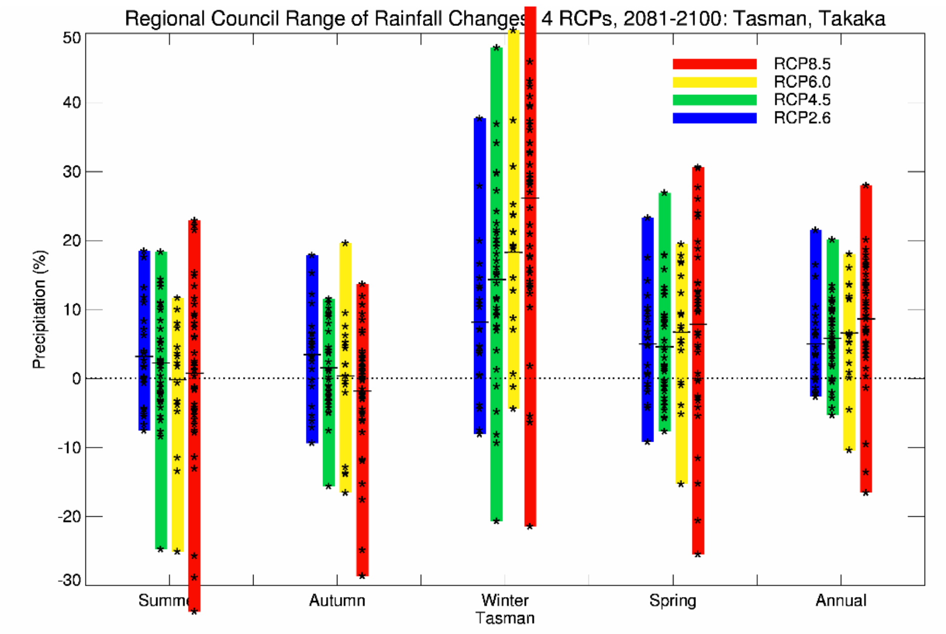


Figure 5-16: Projected seasonal rainfall changes by 2090 (2081-2100) for Takaka for the four RCPs. The vertical coloured bars show the range over all climate models used, and stars the projected changes for each model individually. The short horizontal line is the model-average rainfall. Blue = RCP2.6, 23 models; green = RCP4.5, 37 models; yellow = RCP6.0, 18 models; red = RCP8.5, 41 models.

5.4 Scenarios for Changes in Extreme Rainfall

A warmer atmosphere can hold more moisture (about 8% more for every 1°C increase in temperature), so there is potential for heavier extreme rainfall with global increases in temperatures under climate change. In its Fifth Assessment Report, the IPCC concluded that the frequency of heavy precipitation events is “very likely” to increase over most mid-latitude land areas (this includes New Zealand) (IPCC, 2013, Table SPM.1). Given the mountainous nature of New Zealand, spatial patterns of changes in rainfall extremes are expected to depend on changes in atmospheric circulation and storm tracks.

NIWA produced some updated guidance on changes in heavy rainfall to be used for “screening assessments”[3] in New Zealand, for the 2008 update to the Local Government Guidance manual (Ministry for the Environment, 2008a). An overview of the process for producing heavy rainfall statistics for screening analyses, with a detailed example of its application for Richmond, is provided in the appendix to the present report. The recommendation in the Local Government Guidance manual is that if a screening analysis using statistics produced through this process indicates changes in heavy rainfall could lead to problems for a particular asset or activity, then further guidance should be sought from a science provider for a more detailed risk analysis. Rainfall depth-duration-frequency statistics for Richmond under current conditions are provided in Table 5-5. Statistics for screening studies under mid-range and high-end temperature scenarios for 2100 are provided in Table 5-6, Table 5-7, and Table 5-8.

Table 5-5: Current rainfall depth-duration-frequency statistics for Richmond from HIRDS V3. Numbers in the body of the table are in mm.

ARI (years)	Duration									
	10m	**20m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	7.9	11.8	14.9	22.3	29.5	45.8	60.4	79.8	94.9	105.1
5	10.2	15.3	19.3	28.9	38.0	58.4	76.7	100.6	119.7	132.6
10	12.1	18.1	22.9	34.3	44.9	68.7	89.8	117.4	139.7	154.6
20	14.3	21.4	27.0	40.5	52.7	80.2	104.4	136.1	161.9	179.2
30	15.7	23.5	29.7	44.5	57.8	87.6	113.9	148.1	176.3	195.1
50	17.7	26.4	33.4	50.0	64.9	98.0	127.0	164.7	196.0	217.0
100	20.7	31.0	39.2	58.7	75.8	113.8	147.1	190.1	226.2	250.4

Table 5-6: Projected rainfall depth-duration-frequency statistics for Richmond in 2100, for a low-range temperature scenario (1°C warming).

ARI (years)	Duration									
	10m	**20m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	8.5	12.7	16.0	23.8	31.3	48.2	63.3	83.2	98.5	108.8
5	11.0	16.5	20.7	31.0	40.5	62.0	81.1	106.0	125.7	139.0
10	13.1	19.5	24.6	36.8	48.1	73.4	95.6	124.8	148.2	163.7
20	15.4	23.1	29.1	43.6	56.7	86.1	112.0	145.9	173.4	191.7
30	17.0	25.4	32.1	48.1	62.4	94.6	123.0	159.9	190.1	210.1
50	19.1	28.5	36.1	54.0	70.1	105.8	137.2	177.9	211.7	234.4
100	22.4	33.5	42.3	63.4	81.9	122.9	158.9	205.3	244.3	270.4

[3] “Screening” describes an initial assessment step to consider whether potential impacts of climate change on a particular function or item of infrastructure are likely to be material.

Table 5-7: Projected rainfall depth-duration-frequency statistics for Richmond in 2100 for a mid-range temperature scenario (2°C warming).

ARI (years)	Duration									
	10m	**20m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	9.2	13.6	17.0	25.3	33.2	50.7	66.2	86.7	102.1	112.5
5	11.8	17.7	22.2	33.0	43.1	65.5	85.6	111.5	131.7	145.3
10	14.0	20.9	26.4	39.4	51.4	78.0	101.5	132.2	156.7	172.8
20	16.6	24.8	31.2	46.7	60.7	92.1	119.6	155.7	184.9	204.3
30	18.2	27.3	34.5	51.6	67.0	101.6	132.1	171.8	203.8	225.1
50	20.5	30.6	38.7	58.0	75.3	113.7	147.3	191.1	227.4	251.7
100	24.0	36.0	45.5	68.1	87.9	132.0	170.6	220.5	262.4	290.5

Table 5-8: Projected rainfall depth-duration-frequency statistics for Richmond in 2100, for a higher-end temperature scenario (3°C warming).

ARI (years)	Duration									
	10m	**20m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	9.8	14.5	18.1	26.8	35.0	53.1	69.1	90.1	105.7	116.1
5	12.6	18.8	23.6	35.1	45.6	69.1	90.0	116.9	137.7	151.7
10	15.0	22.3	28.1	41.9	54.6	82.7	107.3	139.6	165.3	182.0
20	17.7	26.5	33.3	49.9	64.7	98.0	127.3	165.5	196.4	216.8
40	20.8	31.1	39.4	58.9	76.5	115.7	150.2	195.1	231.4	256.0
50	21.9	32.7	41.4	62.0	80.5	121.5	157.5	204.2	243.0	269.1
100	25.7	38.4	48.6	72.8	94.0	141.1	182.4	235.7	280.5	310.5

Projected rainfall depth-duration-frequency tables for other locations in Tasman District can be produced using HIRDS software package and the process illustrated in the Appendix and described in the revised Local Government Guidance Manual (Ministry for the Environment, 2008a).

5.5 Evaporation, Soil Moisture, and Drought

A NIWA study published in 2011 (Clark et al., 2011) used downscaled climate model results from the IPCC Fourth Assessment Report to examine how the frequency of very dry conditions could change over the 21st century. Three major global greenhouse gas emissions scenarios were used (B1, A1B, and A2), and the final estimates of drought probability were derived from a nationally comprehensive soil moisture indicator.

The study established distinct regional differences across New Zealand in changes to drought vulnerability projected under future climate change, with an increase in drought on the east coast of the North and South Islands being the most plausible and consistent outcome. This is consistent with previous studies on climate change impacts on drought in a New Zealand context (e.g. Mullan et al., 2005). The study concluded that drought risk is expected to increase during this century in all areas that are currently drought prone, under both the 'low-medium' and 'medium-high' scenarios. The 'drought risk' was analysed in terms of soil moisture levels – drought initiation occurs when soil moisture falls below the historically established 10th percentile for the given time of year for a period greater than one month, and drought termination occurs when soil moisture is above the 10th percentile for one month.

Under the most likely mid-range emissions scenario the projected increase in percentage of time spent in drought from 1980-99 levels is about 5% for 2030-2050 and 10% for 2070-2090 for the low-lying plains adjacent to Tasman Bay (e.g. Motueka and Waimea plains). This can be interpreted as: for a site that is currently in drought 5% of the time in the plains, in 2030-2050 it is likely that this same location will be in drought 10% of the time (i.e. an additional 5%), and in 2070-2090 that location is likely to be in drought 15% of the time (an additional 10%). Other parts of Tasman District are unlikely to be as affected as the plains by climate-change-induced drought.

5.6 Wind

Some broad scale analyses have been undertaken (Mullan et al., 2011) of how the seasonal and annual components of the flow across New Zealand could change by the end of the 21st century, based on GCM model results using the A1B mid-range emissions scenario from the IPCC Fourth Assessment Report. In all seasons there is an increasing easterly tendency over or north of the North Island. In the summer and autumn seasons, there is an increase in easterly (or more commonly it will be a decrease in westerly) over the entire country with the exception of Otago and Southland. In winter and spring, the easterly tendency is confined to the north of the North Island from about Coromandel Peninsula northwards, with the remainder of New Zealand experiencing an increasing westerly tendency.

An increase in the mean westerly component of the wind does not in itself necessarily imply an increase in total wind speed, or in wind speed extremes. However Mullan et al. (2011) undertook analyses to understand how extreme (99th percentile) winds may change across regions of New Zealand with climate change, based on climate model results from the IPCC Fourth Assessment Report. The frequency of extreme winds over the 21st century is likely to increase in almost all regions of New Zealand in winter, and decrease in summer, especially for Wellington and the South Island. However, the magnitude of the increase in extreme wind speed is not large – only a few per cent by the end of the century under the middle-of-the-range A1B emissions scenario.

In addition, Mullan et al. (2011) found that it is likely that there will also be an increase in cyclone activity in the Tasman Sea in summer and a decrease in activity south of New Zealand ('cyclone' in this context refers to a sub-tropical or mid-latitude low pressure centre and not to a tropical cyclone).

5.7 Climate Change and Sea Level

Sea levels will continue to rise over the 21st century and beyond, primarily because of thermal expansion within the oceans and loss of ice sheets and glaciers on land. The basic range of projected global sea-level rise estimated in the IPCC's Fifth Assessment Report (IPCC, 2013) is for a rise of 0.26 m-0.82 m for 2081-2100 (2080s and 2090s) relative to the average sea level over the period 1986-2005, as shown in Figure 5-17. This is based on projections from IPCC AR5 climate model projections in combination with process-based models of glacier and ice sheet surface mass balance for the four different RCP emissions scenarios. Global mean sea level rise for the scenarios will likely be in the 5 to 95% ranges characterising the spread of the model results (bars on the right hand side of Figure 5-17).

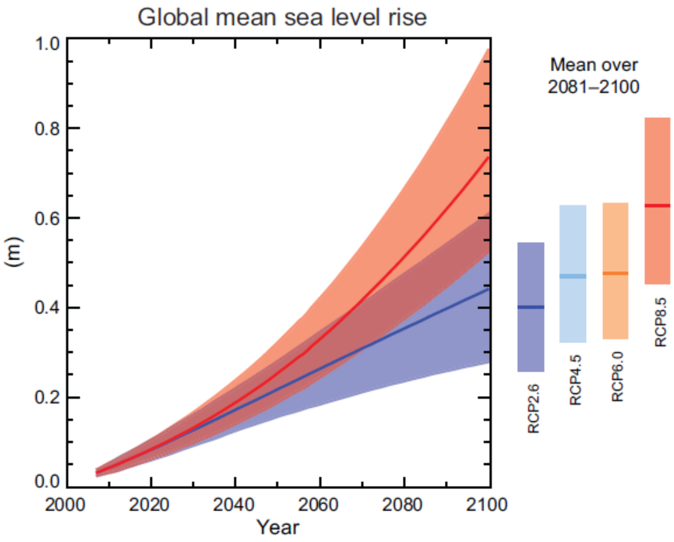


Figure 5-17: Projections of global mean sea level rise over the 21st century relative to 1986-2005. Projections are from the combination of the Coupled Model Intercomparison Project (CMIP5) ensemble with process-based models, for RCP2.6 and RCP8.5. The assessed likely range is shown as a shaded band. The assessed likely ranges for the mean over the period 2081-2100 for all RCP scenarios are given as coloured vertical bars, with the corresponding median value given as a horizontal line. After IPCC (2013).

In all emissions scenarios, thermal expansion is the largest contribution to global mean sea-level rise, accounting for about 30-55% of the total. Glaciers are the next largest, accounting for 15-35% of total sea level rise. By 2100, 15-55% of the present glacier volume is projected to be eliminated under the lowest emissions scenario, and 35-85% under the highest emissions scenario. The increase in surface melting in Greenland is projected to exceed the increase in accumulation, and there is high confidence that the surface mass balance changes on the Greenland ice sheet will make a positive contribution to sea-level rise over the 21st century. On the Antarctic ice sheet, surface melting is projected to remain small.

Figure 5-18 shows Wellington and Auckland annual mean sea level measurements spliced with global-mean sea-level rise projections for two of the RCPs (RCP2.6 and RCP8.5) from IPCC (2013). Note that IPCC provided a caveat that further collapse of Antarctica ice sheets could cause global sea level to rise substantially above the *likely* ranges by 2100 (shown as dashed lines in Figure 5-18), with medium confidence that the additional contribution would not exceed several decimetres of sea-level rise by 2100. The RCP projections from IPCC have been extended out from 2100 to 2120, to assist with the application of the NZ Coastal Policy Statement that requires coastal hazards and climate change effects be assessed over “at least 100 years”. Both measurements from the two ports and the projections are relative to a baseline averaged from 1986–2005 (centred on 1996).

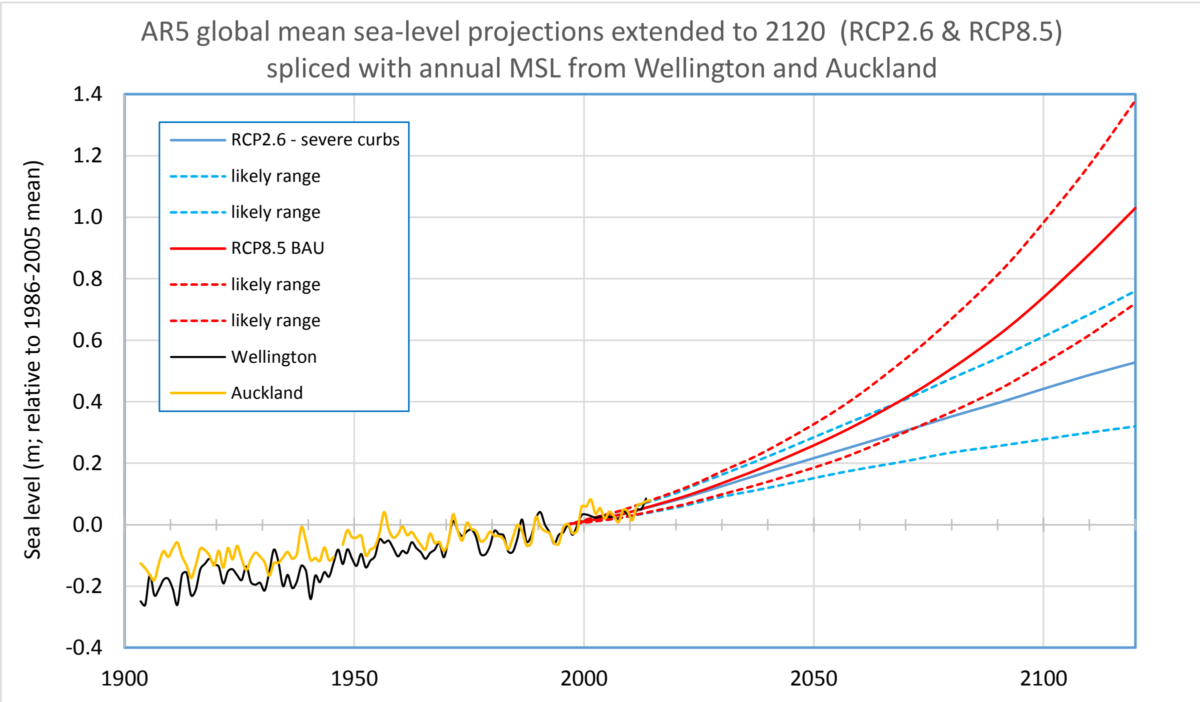


Figure 5-18: AR5 global mean sea-level projections extended to 2120 spliced with annual MSL from Wellington and Auckland. Dashed lines show the upper and lower bounds of the *likely* range for each RCP shown, which in the calibrated language of IPCC means there is a 33% change the SLR could lie outside those bounds (Church et al., 2013a). Source: QA for annual MSL for historic NZ ports undertaken by Prof. John Hannah and NIWA – data sourced originally from the port companies and obtained from the Land Information NZ archives. The global-mean SLR projections were interpolated by data from Table 13.5 (Church et al., 2013b) and from Figure SPM.9 in the IPCC AR5 Summary for Policymakers (IPCC, 2013).

Since the 2008 climate change report for Tasman District Council was prepared, a revised manual for local government on coastal hazards and climate change has been published (Ministry for the Environment, 2008b). This guidance manual uses projections based on the IPCC's Fourth Assessment Report. In time, it is expected an updated report will be published using projections based on the IPCC Fifth Assessment Report projections, but in this report the 2008 report will be referenced.

The coastal hazards and climate change guidance report includes guidance on changes in mean sea-level for use in future planning and decisions. Numbers for use in such guidance depend on risk management considerations as well as scientific assessment. The guidance manual advocates the use of a risk assessment process to assist incorporating sea-level rise and the associated uncertainties, within local government planning and decision-making. This requires a broader consideration of the potential impacts or consequences of sea-level rise on a specific decision or issue. Rather than define a specific climate change scenario or sea-level rise value to be accommodated, it is recommended in the manual that the magnitude of sea-level rise accommodated is based on the acceptability of the potential risk.

To aid this risk assessment process, the manual recommends that allowance for sea-level rise is based on the IPCC Fourth Assessment Report, and that consideration be given to the potential consequences from higher sea-levels due to factors not included in current global climate models[4].

[4] Such factors relate to uncertainties associated with increased contribution from the Greenland and Antarctica ice sheets, carbon cycle feedbacks, and possible differences in mean sea level when comparing the New Zealand region with the global average.

For planning and decision timeframes out to the 2090s (2090-2099):

a. A base value sea level rise of 0.5 m relative to the 1980-1999 average should be used, along with:

b. An assessment of the potential consequences from a range of possible higher sea-level rises (particularly where impacts are likely to have high consequence or where additional future adaptation options are limited). At the very least, all assessments should consider the consequences of a mean sea-level rise of at least 0.8 m relative to the 1980-1999 average.

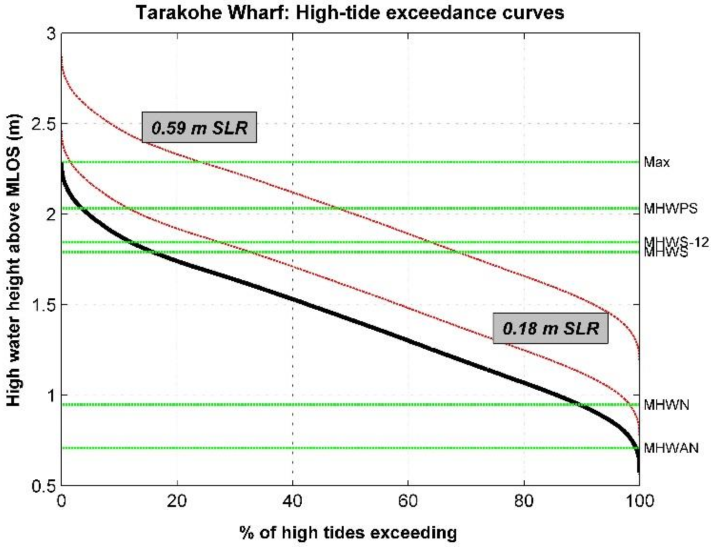
For planning and decision timeframes beyond 2100 where, as a result of the particular decision, future adaptation options will be limited, an allowance of sea-level rise of 10 mm per year beyond 2100 is recommended (in addition to the above recommendation).

Climate change will also impact on other coastal hazard drivers, such as tides, storm surge, waves, swell, and coastal sediment supply. The potential changes and their impacts are at present much less well understood, but the manual provides pragmatic guidance informed by expert judgement and the current state of scientific knowledge.

5.7.1 Effect of Sea-Level Rise on High Tide Exceedance Frequency

A NIWA study for Nelson City Council (Stephens and Bell, 2009) considered climate change effects on high tide exceedances for Tasman Bay. On the open coast of Tasman Bay, sea-level rise will not significantly alter the tidal range. However, up the Waimea Inlet the tidal range may change somewhat, depending on the net effect of sediment deposition on the seabed versus sea-level rise. What will change substantially as sea-level rise accelerates are the occurrences when high tides exceed a specific elevation (above present Mean Level Of the Sea) (Figure 5-19).

The Coastal Hazards and Climate Change guidance manual (Ministry for the Environment, 2008b) provides information on tide ranges and frequency of high tides. The present Mean High Water Spring level will be exceeded much more frequently by high tides in the future, particularly on sections of the coast where the tide range is relatively small (compared with those sections of the coast where the tide range is relatively large). Sea-level rise will have a greater influence on storm inundation and rates of coastal erosion on the central parts of the east coast and Cook Strait/Wellington areas than on coastal regions with larger tidal ranges (e.g. west coast).



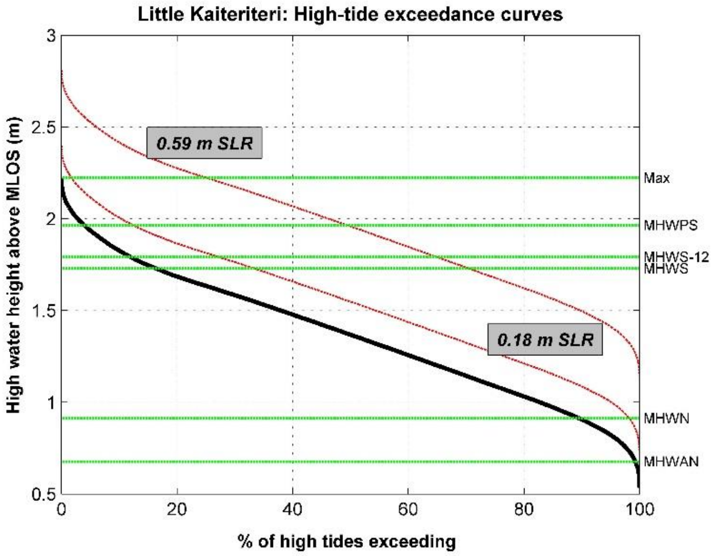


Figure 5-19: The frequency of occurrence of high tides exceeding different present day tide marks. The tide marks for the present is shown by the heavy line, 0.18m of sea level rise (lower red line) and 0.59 m of sea level rise (upper red line) for Tarakohe (top) and Little Kaiteriteri (bottom). ©NIWA.

Terminology used in Figure 5-19 includes:
MLOS: Mean Level of the Sea
Max: Maximum expected in 100 years (2000-2099) excluding climate and meteorological effects. (Also called Highest Astronomical Tide)
MHWPS: Mean High Water at Perigean Spring
MHWS: Mean High Water Spring
MHWS-12: A definition of MHWS based on 12% of high tides exceeding this level
MHWN: Mean High Water Neap
MHWAN: Mean High Water at Apogean Neap
Definitions of most of these terms are provided on the Proudman Oceanographic Laboratory web page at http://www.pol.ac.uk/ntslf/tgi/definitions.html. Terms not explained there include:
Perigean Spring Tides: These occur when a full or new moon coincides with *perigee*, the point of closest approach of the moon to the earth. Likewise, *apogee* is when the moon is at its furthest point from the earth.

An example of the effect that future sea-level rise has on the frequency of high tides at Tarakohe and Little Kaiteriteri is shown in Figure 5-19. For each plot the black line shows the percentage of high tides that exceed certain levels above the mean level of the sea for present day sea-levels. If we consider the Mean High Water Perigean Spring (MHWPS) level, at Tarakohe this is exceeded by about 3.5% of high tides. The coloured lines show this occurrence with different future sea level rises (0.18 m and 0.59 m). For a sea-level rise of 0.18 m, a present day MHWPS level would be exceeded by 12% of the high tides at Tarakohe and by 48% with a sea-level rise of 0.59 m.

5.8 Climate Change Impacts on Other Coastal Hazard Drivers

While it is expected that the intensity of tropical cyclones and extratropical cyclones will increase (i.e. wind speed and rain rates), it is likely that their frequency will either decrease or remain essentially unchanged (IPCC, 2013). These storms affect the coastal zone through impacts on waves, storm surge, and swell.

Some high-resolution atmospheric models have realistically simulated tracks and counts of tropical cyclones and models are able to capture the general characteristics of storm tracks and extratropical cyclones with evidence of improvement since the IPCC Fourth Assessment Report. However, uncertainties in projections of cyclone frequency and tracks make it difficult to project how future changes will impact particular regions.

In addition, the projections of storm surges (increase in sea level caused by the inverse barometer effect from large storms such as tropical cyclones) have low confidence, in part due to the high uncertainty surrounding future storminess. Changes in storm surge will depend on changes in the frequency, intensity, and/or tracking of low-pressure systems, and the occurrence of stronger winds associated with these systems (IPCC, 2013).

5.8.1 Climate change impacts on waves

Expected changes in wind and atmospheric patterns, storms and cyclones around New Zealand and the wider southwest Pacific and Southern Ocean regions also have the potential to change the wave climate experienced around New Zealand in the future. In turn, this will influence patterns or coastal erosion and the movements of beach and nearshore sediments within coastal zones.

At a large scale, it is likely that the mean significant wave heights will increase in the Southern Ocean as a result of enhanced westerly wind speeds, especially in the austral winter months (5-10% higher at the end of the 21st century than the present-day mean). In addition, Southern Ocean-generated swells are likely to affect heights, periods, and directions of waves in adjacent basins (IPCC, 2013).

A NIWA study prepared for Nelson City Council (Goodhue et al., 2012) considered the effects of climate change on waves and storm surges by 2100, over and above sea-level rise. The WASP project (Wave And Storm surge Projections) used the SRES emissions scenarios provided by the IPCC to run simulations of storm surge, storm tide height, and significant wave height under climate change to 2100.

WASP future-casts for the A2 (high) and B2 (low) emissions scenarios were simulated for a 30-year period at the end of the 21st century (2070-2100). To quantify climate change effects on storm tides and waves, these were compared to WASP predictions forced by a global climate prediction of the 30-year period 1970-2000.

Waves and storm-surge time series were output at a location within Tasman Bay, which enabled the climate change scenarios to be averaged together relative to the present-day scenario. The 99th exceedance percentile wave heights and storm surges were determined for the present-day and each of the climate change scenarios, enabling an approximate scaling factor to be calculated for large (99th percentile) events. These values are shown in Table 5-9.

Table 5-9: Predicted increase in storm surge and wave height within the Tasman Bay as a result of climate change averaged over 2070-2100, using the WASP output. Values based on the percentage change from present-day WASP simulations and the average of the future cast WASP climate change predictions, at the 99% exceedance level. The changes were calculated for one location in Tasman Bay, assuming such large-scale changes would be ubiquitous to the entire Bay. After Goodhue et al. (2012).

Variable	Increase by 2070-2100 (%)
Storm surge at 99th percentile	6.4
Storm-tide height (change in storm surge with no change in coastal tide heights	1.3
Significant wave height at 99th percentile	1.8

Storm surge is only one component of the total storm tide height. To determine the change in storm tide height the Monte Carlo joint-probability technique, which was used to determine the marginal storm tide heights, was re-run with the 6.4% scale factor (Table 5-9) applied to the storm surge component. Because the astronomical tide forms a bigger proportion of the total storm height than the weather-induced storm surge, the 6.4% increase in storm surge resulted in a 1.3% increase in storm tide levels, due to climate change.

To summarise, the WASP climate change scenarios indicate that climate change will cause approximately a 2% rise in both extreme storm tide height and extreme significant wave height, by the end of the 21st century. This translates to about a 10 cm increase for a 5 m high wave, or a 6 cm increase for a 2.8 m storm tide.

Robinson et al. (2014) from NIWA completed a study for Tasman District Council which included the development of a 'Coastal Calculator' for assessing coastal inundation. This calculator can be used to estimate storm-tides, wave setup and wave run-up under current conditions and also with the addition of a sea-level rise variable, for the open coast of Tasman and Golden Bays (excluding sheltered harbours and estuaries).

Wave setup is seen to be a relatively small component of the total sea-level elevation on the Tasman and Golden Bay coastline due to large tidal range and limited-fetch wind waves with only a limited window for swell waves to propagate to the sites; however wave run-up is considerably larger.

The reader is directed to Robinson et al. (2014) for more information on how to use the Coastal Calculator with regard to sea-level rise. Note that Table 5-9 and this discussion do not include any allowance for rise in mean sea-level.

5.9 Ocean acidification

Since the beginning of the industrial era, the pH of global ocean surface water has decreased by 0.1, corresponding to a 26% increase in hydrogen ion concentration (IPCC, 2013). It is virtually certain that the increased storage of carbon by the ocean will increase acidification in the future, continuing the observed trends of the past decades. Ocean acidification in the surface ocean will follow atmospheric CO_2 and it will also increase in the deep ocean as CO_2 continues to penetrate the abyss (Figure 5-20).

A global increase in ocean acidification is projected under all RCP scenarios, due to the increasing uptake of carbon by the ocean. The corresponding decrease in surface ocean pH by the end of the 21st century is in the range of 0.06-0.07 for RCP2.6, 0.14-0.15 for RCP4.5, 0.20-0.21 for RCP6.0, and 0.30-0.32 for RCP8.5.

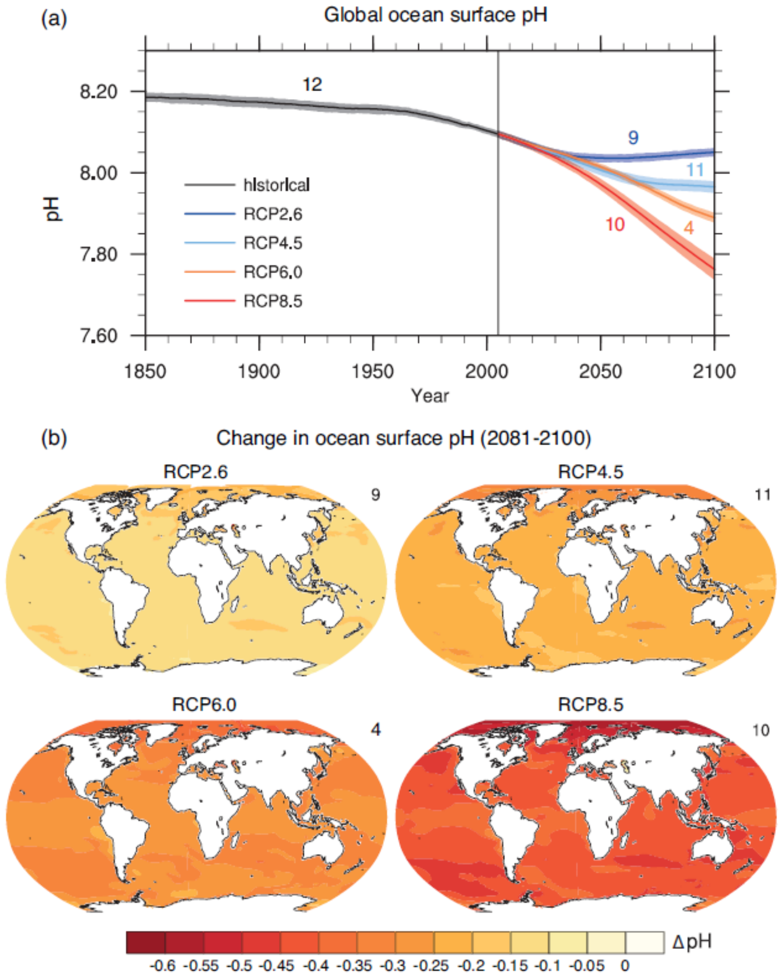


Figure 5-20: Change in ocean surface pH. Time series (model averages and minimum to maximum ranges and (b) maps of multi-model surface ocean pH for the scenarios RCP2.6, RCP4.5, RCP6.0 and RCP8.5 in 2081-2100. The maps in (b) show change in global ocean surface pH in 2081-2100 relative to 1986-2005. The number of CMIP5 movels to calculate the multi-model mean is indicated in the upper right corner of each panel. Figure after (IPCC, 2013).

Figure 5-21 shows the projected pH decrease to 2100, using RCP8.5, in New Zealand's Exclusive Economic Zone (EEZ). The pH decrease, from current values of ~8.08 to 7.95 by mid-century and 7.75 by 2100, is consistent with global trends of a decline by 0.3-0.4 by the end of the century. The sinusoidal pattern reflects the seasonal shift within each year of higher pH in summer (when phytoplankton growth removes CO_2) and lower pH in winter (when growth is low and mixing raises surface water CO_2).

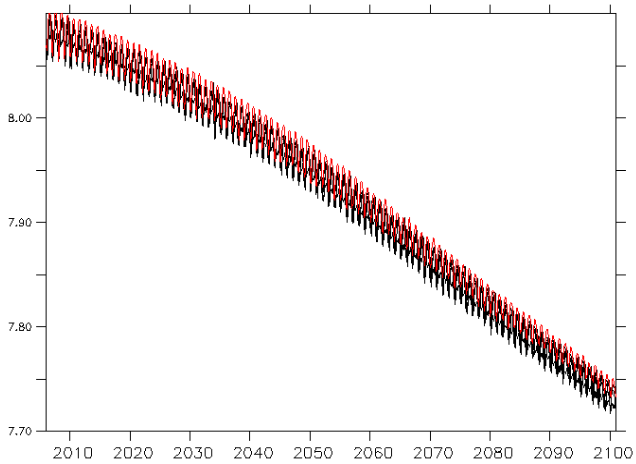


Figure 5-21: Projected mean surface pH for the NZ EEZ open ocean from a suite of six CMIP5 models, using the RCP8.5 scenario. The outputs from the models that show the closest fit to carbonate observations in the NZ EEZ during the present period are highlighted in red (S. Mikaloff-Fletcher, NIWA).

The 15-year Munida time-series in Figure 5-22 shows that ocean acidification of NZ waters is already evident, with an increase in dissolved surface CO_2 and associated decreases in surface pH and carbonate saturation state. The increase in dissolved CO_2 is consistent with the regional increase in atmospheric CO_2 recorded at the NIWA Baring Head Atmospheric Station. The observed decline in pH and carbonate saturation are consistent with observations at 6 other time-series stations in the global ocean, although the rate of change of pH at the Munida station is the lowest.

The variability and rate of change in pH will differ in coastal waters as these are also influenced by terrestrial factors and run-off. The rate and magnitude of acidification in coastal waters is being monitored by the recently initiated New Zealand Ocean Acidification Observing Network (NZOA-ON) of 14 stations around the coast.

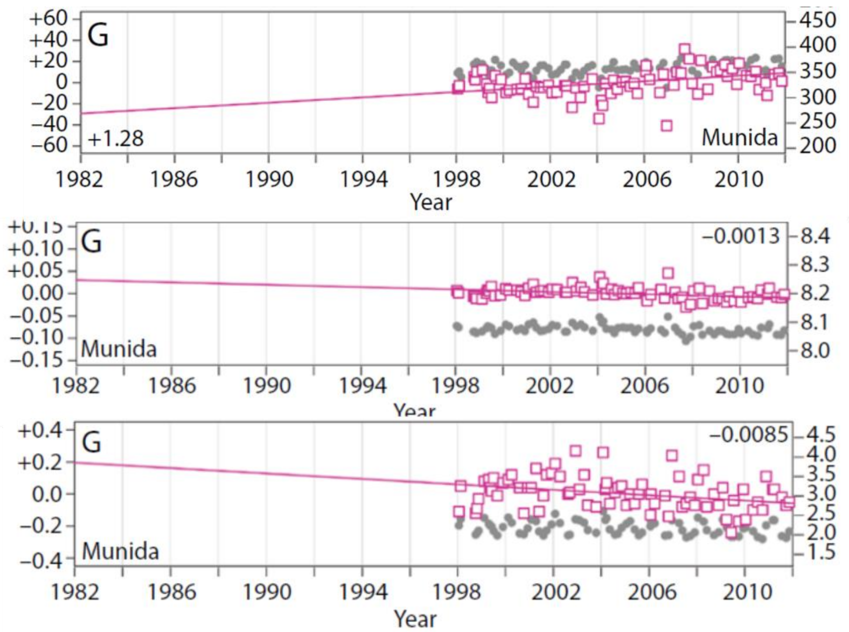


Figure 5-22: Time series of Surface seawater pCO2 (µatm, top panel), pH (middle panel), and saturation state of the carbonate mineral, aragonite (lower panel). This time series is from Sub-Antarctica water at the Munida site (Otago shelf). Coloured symbols are the anomalies and the grey symbols the observed data, with the annual trends (yr-1) shown (Bates et al., 2014).

5.9.1 New Zealand-specific impacts of ocean acidification

- There is evidence of an increase in bacterial enzyme activity under increased dissolved CO_2, which increase oxygen removal and decrease carbon uptake in the ocean (Burrell, 2015, Maas et al., 2015).

- Time series studies show no discernible impact of current increases in dissolved carbon dioxide on phytoplankton or zooplankton with carbonate shells in NZ waters currently (S. Nodder & C. Law, pers. comm.), although decreased carbonate production under conditions projected for 2100 in comparative species from other regions suggest they may be detrimentally impacted by the end of the century.

- Nitrogen fixers that live in nutrient-depleted regions are predicted to be “winners” from ocean acidification; however no significant effect of increased dissolved CO_2 was observed in experiments carried out on mixed plankton communities in NZ subtropical waters (Law et al, 2012).

- Macroalgae community structure in coastal regions may be altered in response to ocean acidification with a decline in encrusting coralline algae that use carbonate, while red algae found in deeper waters may benefit from an increase in dissolved CO_2 (Hepburn et al., 2011, Tait, 2014). Changes in the biomineralisation or species distribution of Coralline red algae may occur in response to ocean acidification, particularly in species producing high-Mg calcite (James et al., 2014, Smith et al., 2013).

- Sponges may benefit from ocean acidification (Bell et al., 2013) although those that produce calcite of high magnesium content, or aragonite may be vulnerable to dissolution (Smith et al., 2013).

- The projected decrease of carbonate saturation in the deep ocean may cause a decline in the abundance and distribution of cold water corals, which support important ecosystems in regions such as the Chatham Rise (Bostock et al., 2015). It is suggested that seamounts and topographic features may be important future refugia for cold water corals (Thresher, 2015, Tittensor et al., 2010).
- There is clear evidence of malformation of Sea Urchin larvae, in tropical to Antarctic species including from NZ, under higher dissolved CO_2. This may result in smaller larvae and an increased duration in the planktonic phase, reducing the chances of survival to the adult stage (Byrne et al., 2013, Clark et al., 2009).
- Experimental work on the impacts of acidification in New Zealand waters on juvenile paua has shown that while survival was not affected, growth was significantly reduced, and dissolution of the shell surface was evident (Cunningham, 2013). Similar effects were found for growth and shell surfaces of flat oysters (Cummings et al., 2013, Cummings et al., 2015). This is consistent with observed negative effects of ocean acidification on the function and metabolism of Antarctic bivalves (Bylenga et al., in press, Cummings et al., 2011).
- The behaviour of Australian reef fish is affected by ocean acidification, with olfaction, hearing, visual risk assessment and activity altered due to the impact on neurotransmitter function (Munday et al., 2014). MPI funding has supported studies of the impacts of ocean acidification on Kingfish, and this work will be extended to Snapper.

5.10 Considering both Anthropogenic and Natural Changes

Much of the material in Sections 5.1 to 5.8 focuses on the projected impact on the climate of Tasman District over the coming century of increases in global anthropogenic greenhouse gas concentrations. But natural variations, such as those described in Section 4.3 (associated with for example El Niño, La Niña, the Interdecadal Pacific Oscillation, the Southern Annular Mode, and “climate noise”), will also continue to occur. As noted at the beginning of Section 5, those involved in (or planning for) climate-sensitive activities in the Tasman District will need to cope with the sum of both anthropogenic change and natural variability.

An example of this for temperature (from an overall New Zealand perspective) is shown in Figure 5-23. This figure shows annual temperature anomalies relative to the 1986-2005 base period used throughout this report. The solid black line on the left-hand side represents NIWA’s 7-station temperature anomalies (i.e., the average over Auckland, Masterton, Wellington, Nelson, Hokitika, Lincoln, and Dunedin), and the dotted black line represents the 1909-2014 trend of 0.92°C/century extrapolated to 2100. All the other line plots and shading refer to the air temperature averaged over the region 33-48°S, 160-190°W, and thus encompasses air temperature over the surrounding seas as well as land air temperatures over New Zealand. Post-2014, the two line plots show the annual temperature changes (for the ‘box’ average) under RCP8.5 (orange) and RCP26 (blue); a single model (the Japanese ‘*miroc5*’ model, see Mullan et al. 2015) is selected to illustrate the interannual variability. (Note that a single illustrative model (*miroc5*) has been used in Figure 5-23 rather than the model-ensemble, which would suppress most of the interannual variability). The shading shows the range across <u>all</u> AR5 models for both historical (41 models) and future periods (23 for RCP2.6, 41 for RCP8.5).

Over the 1900-2014 historical period, the 7-station curve lies within the 41-model ensemble, in spite of the model temperatures including air temperature over the sea, which is expected to warm somewhat slower than over land (Mullan et al., 2015). For the future 2015-2100 period, the RCP2.6 ensemble shows very little warming trend after about 2030, whereas the RCP8.5 ensemble 'takes off' to be anywhere between +2°C and +5°C by 2100. The *miroc5* model is deliberately chosen to sit in the middle of the ensemble, and illustrates well how interannual variability dominates in individual years: the *miroc5* model under RCP8.5 is the warmest of all models in the year 2036 and the coldest of all models in the year 2059, but nonetheless has a long-term trend that sits approximately in the middle of the ensemble.

Figure 5-23 should not be interpreted as a set of specific predictions for individual years. But it illustrates that although we expect a long term overall upward trend in temperatures (at least for RCP8.5), there will still be some relatively cool years. However for this particular example, a year which is unusually warm under our present climate could become the norm by about 2050, and an "unusually warm" year in 30-50 years' time (under the higher emission scenarios) is likely to be warmer than anything we currently experience.

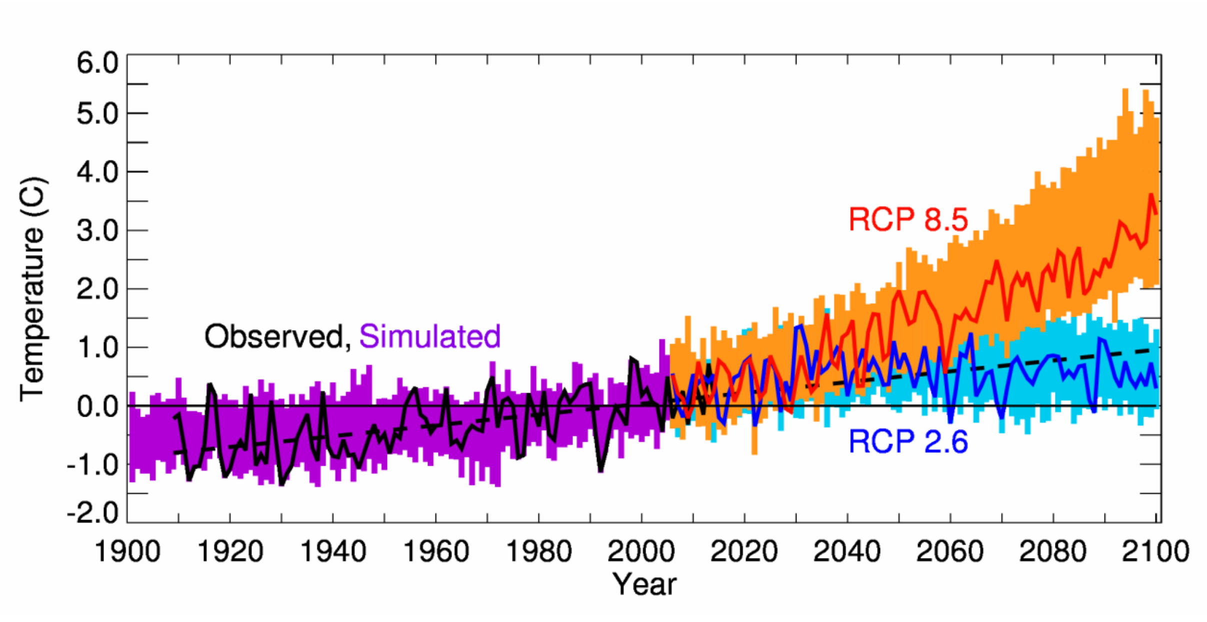


Figure 5-23: New Zealand Temperature - historical record and an illustrative schematic projection illustrating future year-to-year variability. (See text for full explanation).

For rainfall, the fact that we have recently moved into a negative phase of the Interdecadal Pacific Oscillation (Figure 4-7) may be just as important for the Tasman region over the next 2-3 decades as the effects of anthropogenic climate change. From Section 4.3.1, it can be seen that periods of negative SOI may on average experience slightly above normal rainfall in the coastal plains areas fringing Tasman Bay, pushing rainfall in these directions in the same direction as expected from anthropogenic factors (Section 5.3). A subsequent further reversal of the IPO in 20-30 years' time could have the opposite effect, offsetting part of the anthropogenic trend in rainfall for a few decades.

As discussed in Section 4.3, the IPO and the El Niño/La Niña cycle have an effect on New Zealand sea level. So the sea levels we experience over the coming century will also result from the sum of anthropogenic trend and natural variability.

The message from the section is *not* that anthropogenic trends in climate can be ignored because of natural variability. In the projections we have discussed these anthropogenic trends become the dominant factor locally as the century progresses. Nevertheless, we need to bear in mind that at some times natural variability will be adding to the human-induced trends, while at others it may be offsetting part of the anthropogenic effect.

6 Tasman District – Impacts, Vulnerability, and Adaptation

The main purpose of this report has been to draw together existing information on how Tasman District's climate may change in the future. The resourcing did not extend to undertaking a detailed evaluation of the likely impacts of these changes, of the vulnerability of the Tasman District to these impacts, or of investigating options for adapting to them.

Ways in which councils can investigate some of these issues are outlined in the guidance manual published by the Ministry for the Environment (Ministry for the Environment, 2008a). The report on coastal hazards and climate change is also useful (Ministry for the Environment, 2008b).

The Ministry for the Environment climate change guidance manuals recommend that councils should build consideration of climate change into their planning activities rather than considering them in isolation, and should take a risk management approach. Issues surrounding climate change impacts, especially related to local government as well as Maori communities, are covered by Manning et al. (2014). As illustrated by Figure 6-1, consideration of climate change becomes particularly important for designing climate-sensitive infrastructure or assets which are likely to be around for many decades, and for resource use and land development planning over similar timescales.

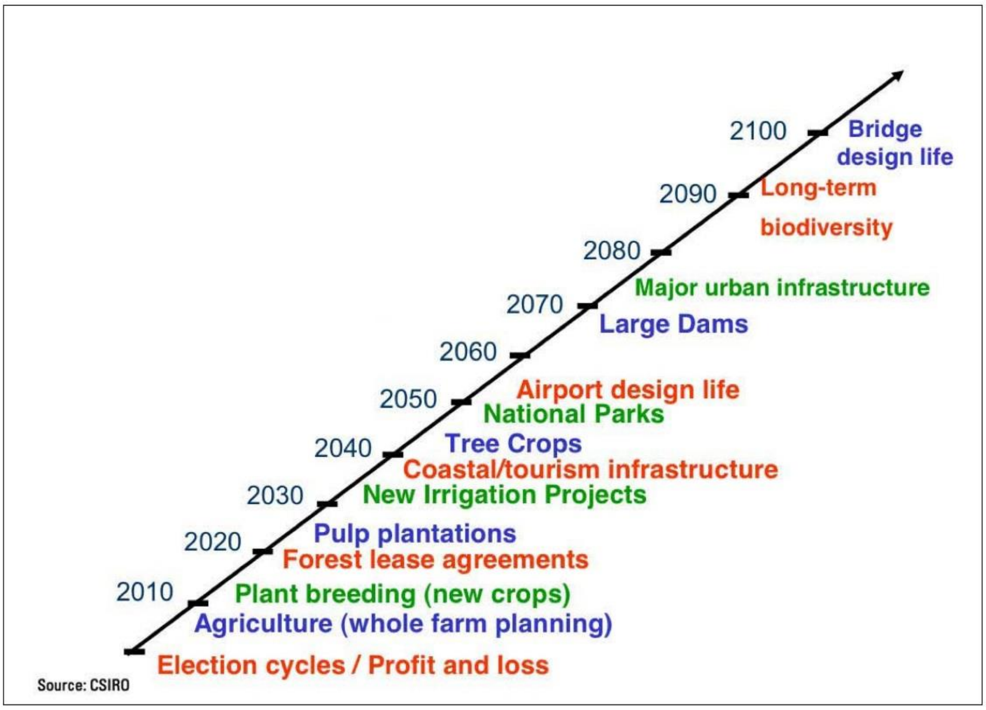


Figure 6-1: Time scales and adaptation. Planning for human-induced climate change becomes increasingly important as one moves right along this line.

Some particular impact, vulnerability, and adaptation issues to which Tasman District Council may wish to give consideration include:

- Implications of sea-level rise and coastal change for planning and development in coastal areas.
- Implications of potential changes in rainfall and of drought frequency for water demand, availability and allocation (including planning for irrigation schemes and storage).
- Implications of projected changes in extreme rainfall, erosion risk and coastal hazards for council roading and stormwater drainage infrastructure, lifelines planning, and civil defence and emergency management.
- Opportunities which climate change may bring for new horticultural crops – and infrastructure and land-use issues that might arise.
- Implications of climate change (including potential changes in flood frequency and in coastal hazards) for land-use planning.
- Implications for aquaculture and fisheries. Not a lot is known about this, but Willis et al. (2007) provides a useful starting point.
- Implications for natural ecosystems and their management, both terrestrial and marine. This is especially relevant given the three National Parks in the region. Reisinger (2014) gives information on the projected impacts on natural ecosystems for New Zealand as a whole.

- Building consideration of climate change impacts and adaptation into council planning as outlined in MfE guidance. Also important is consultation and discussion with stakeholders (e.g. groups of farmers, iwi) to help them identify climate-related risks and ways of building resilience (e.g. King et al. (2013)).

7 Acknowledgements

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Appendix A Rainfall depth-duration-frequency statistics and scenarios

Because the comprehensive modelling studies to identify and justify the numbers for regionally varying changes in extreme rainfall have not yet been undertaken, the revised Local Government Guidance Manual (Ministry for the Environment, 2008a) presently recommends use of a geographically uniform relationship between projected changes in temperature and changes in extreme rainfall return period statistics. The procedure outlined in the revised manual has been used in this report to derive changes in extreme rainfall at one site in Tasman District (Richmond) for preliminary scenario studies ("screening" studies). This method uses augmentation amounts for various rainfall return intervals and durations set out in Table A1, which is a reproduction of Table 5.2 of the revised Guidance Manual (Ministry for the Environment, 2008a)

	ARI						
Duration	**2 yrs**	**5 yrs**	**10 yrs**	**20 yrs**	**30 yrs**	**50 yrs**	**100 yrs**
< 10 minutes	8.0	8.0	8.0	8.0	8.0	8.0	8.0
10 minutes	8.0	8.0	8.0	8.0	8.0	8.0	8.0
30 minutes	7.2	7.4	7.6	7.8	8.0	8.0	8.0
60 minutes	6.7	7.1	7.4	7.7	8.0	8.0	8.0
2 hours	6.2	6.7	7.2	7.6	8.0	8.0	8.0
3 hours	5.9	6.5	7.0	7.5	8.0	8.0	8.0
6 hours	5.3	6.1	6.8	7.4	8.0	8.0	8.0
12 hours	4.8	5.8	6.5	7.3	8.0	8.0	8.0
24 hours	4.3	5.4	6.3	7.2	8.0	8.0	8.0
48 hours	3.8	5.0	6.1	7.1	7.8	8.0	8.0
72 hours	3.5	4.8	5.9	7.0	7.7	8.0	8.0

Table A-1: Augmentation factors (percentage increases per degree of warming) used in deriving changes in extreme rainfall for preliminary scenario studies. [Note: In preparing this table, all reasonable skill and care was exercised, using best available methods and data. Nevertheless, NIWA does not accept any liability, whether direct, indirect, or consequential, arising out of its use].

Note that the Guidance Manual recommends that if a screening analysis using statistics produced through this process indicates changes in heavy rainfall could lead to problems for a particular asset or activity, then further guidance should be sought from a science provider for a more detailed risk analysis.

This appendix first provides current rainfall depth-duration-frequency analysis statistics for Richmond obtained from the NIWA HIRDS V3.0 software package (Thompson, 2011), and "scenario" depth-duration-frequency tables for 2040 and 2090.

Current statistics, Richmond: Rainfall depth-duration-frequency statistics for Richmond (173.184 °S, 41.338 °E) from HIRDS V3.0. Numbers in the body of the table are in millimetres.

	Duration									
ARI (y)	**10m**	**20m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	7.9	11.8	14.9	22.3	29.5	45.8	60.4	79.8	94.9	105.1
5	10.2	15.3	19.3	28.9	38	58.4	76.7	100.6	119.7	132.6
10	12.1	18.1	22.9	34.3	44.9	68.7	89.8	117.4	139.7	154.6
20	14.3	21.4	27	40.5	52.7	80.2	104.4	136.1	161.9	179.2
30	15.7	23.5	29.7	44.5	57.8	87.6	113.9	148.1	176.3	195.1
50	17.7	26.4	33.4	50	64.9	98	127	164.7	196	217
100	20.7	31	39.2	58.7	75.8	113.8	147.1	190.1	226.2	250.4

Projected future temperature changes are then used with Table A1 to provide factors by which to multiply the entries in the current rainfall depth-duration-frequency table for Richmond, to produce depth-duration-frequency tables for 2040 and 2090. The temperature changes used are the annual changes from Table 5-1 of the main report, i.e.:

For 2040: Low range +0.3°C; Mid-range +1.0°C; High range +1.6°C

For 2090: Low range +0.3°C; Mid-range +2.4°C; High range +4.5°C

Tables for 2040 and 2090 for all three scenarios (low, medium, high) of warming to follow.

Richmond, 2040 Low Range (0.3°C warming)

	Duration									
ARI (y)	**10m**	**20m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	8.1	12.1	15.2	22.7	30	46.5	61.3	80.8	96	106.2
5	10.4	15.7	19.7	29.5	38.8	59.5	78	102.2	121.5	134.5
10	12.4	18.5	23.4	35.1	45.9	70.1	91.6	119.6	142.3	157.3
20	14.6	21.9	27.6	41.4	53.9	82	106.7	139	165.3	183
30	16.1	24.1	30.4	45.6	59.2	89.7	116.6	151.7	180.4	199.6
50	18.1	27	34.2	51.2	66.5	100.4	130	168.7	200.7	222.2
100	21.2	31.7	40.1	60.1	77.6	116.5	150.6	194.7	231.6	256.4

Richmond, 2040 Mid Range (1.0°C warming)

	Duration									
ARI (y)	**10m**	**20m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	8.5	12.7	15.9	23.7	31.2	48.1	63.2	83.1	98.3	108.6
5	11	16.4	20.7	30.8	40.4	61.8	80.9	105.8	125.4	138.6
10	13	19.4	24.6	36.7	48	73.1	95.3	124.4	147.8	163.3
20	15.4	23	29	43.5	56.5	85.8	111.6	145.4	172.8	191.1
30	16.9	25.3	32	47.9	62.2	94.3	122.6	159.4	189.4	209.4
50	19	28.4	35.9	53.8	69.8	105.4	136.7	177.2	210.9	233.5
100	22.3	33.4	42.2	63.2	81.6	122.4	158.3	204.5	243.4	269.4

Richmond, 2040 High Range (1.6°C warming)

	Duration									
ARI (y)	**10m**	**20m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	8.9	13.3	16.6	24.7	32.4	49.7	65	85.3	100.7	111
5	11.5	17.2	21.6	32.2	42.1	64.1	83.8	109.3	129.3	142.8
10	13.6	20.4	25.7	38.4	50.1	76.2	99.1	129.2	153.3	169.2
20	16.1	24.1	30.4	45.5	59.1	89.7	116.6	151.8	180.3	199.3
30	17.7	26.5	33.5	50.2	65.2	98.8	128.5	167.1	198.3	219.1
50	20	29.8	37.7	56.4	73.2	110.5	143.3	185.8	221.1	244.8
100	23.3	35	44.2	66.2	85.5	128.4	165.9	214.4	255.2	282.5

Richmond, 2090 Mid Range (2.4°C warming)

	Duration									
ARI (y)	**10m**	**20m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	9.4	14	17.5	25.9	33.9	51.6	67.4	88	103.6	113.9
5	12.2	18.1	22.7	33.8	44.1	66.9	87.4	113.6	134.1	147.9
10	14.4	21.5	27.1	40.4	52.7	79.9	103.8	135.2	160.2	176.5
20	17	25.5	32.1	48	62.3	94.4	122.7	159.6	189.5	209.3
30	18.7	28	35.4	53	68.9	104.4	135.8	176.5	209.3	231.2
50	21.1	31.5	39.8	59.6	77.4	116.8	151.4	196.3	233.6	258.7
100	24.7	37	46.7	70	90.4	135.6	175.3	226.6	269.6	298.5

Richmond, 2090 High Range (4.5°C warming)

	Duration									
ARI (y)	**10m**	**20m**	**30m**	**60m**	**2h**	**6h**	**12h**	**24h**	**48h**	**72h**
2	10.7	15.9	19.7	29	37.7	56.7	73.4	95.2	111.1	121.7
5	13.9	20.6	25.7	38.1	49.5	74.4	96.7	125	146.6	161.2
10	16.5	24.5	30.7	45.7	59.4	89.7	116.1	150.7	178	195.6
20	19.4	29.1	36.5	54.5	70.7	106.9	138.7	180.2	213.6	235.6
30	21.4	32	40.4	60.5	78.6	119.1	154.9	201.4	238.2	262.7
50	24.1	35.9	45.4	68	88.3	133.3	172.7	224	266.6	295.1
100	28.2	42.2	53.3	79.8	103.1	154.8	200.1	258.5	307.6	340.5