



Earth Sciences
New Zealand

Auckland climate change

CMIP6 projections for the Auckland Region

Prepared for Auckland Council

July 2025

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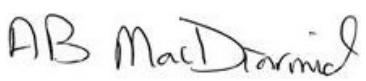
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Executive summary

Human-caused greenhouse gas emissions are the dominant cause of recent global climate change. In Auckland, the current average annual temperature is about 1.7°C higher than 100 years ago.

Earth Sciences New Zealand has generated bespoke climate change projections for New Zealand by downscaling and bias-correcting an updated suite of global climate model projections. Auckland Council requested a refreshed climate change and variability report focussing on the Auckland region, utilising these updated climate projections.

This report addresses the projected changes for 24 different variables out to the end of the century (2100). The results of the projections for four scenarios of atmospheric greenhouse gas concentrations (SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5) are included in tables, while a collection of maps illustrate the projections under SSP2-4.5 and SSP3-7.0. SSP2-4.5 is an intermediate concentration scenario that could be a realistic outcome if moderate global action is taken towards reducing greenhouse gas emissions. SSP3-7.0 is a high concentration scenario where little global action is taken towards reducing greenhouse gas emissions.

Key findings of this report (focussing on SSP2-4.5 and SSP3-7.0) include:

- Continued temperature increases are projected for Auckland. Both heatwave frequency and duration are projected to increase, with 16 more days of heatwave by 2050 under SSP2-4.5, and 80 more days of heatwave by 2090 under SSP3-7.0.
- Projected changes to annual and seasonal total rainfall mostly fall within the range of $\pm 10\%$. There is uncertainty as to whether future increases or decreases in annual and seasonal rainfall will be observed. Spring is an exception, where total rainfall is projected to decrease between 7% (by 2050 under SSP2-4.5) and 17% (by 2090 under SSP3-7.0).
- Heavy rainfalls are projected to become more intense for Auckland. A heavy rainfall (99th percentile) event in summer historically brings 69 mm of daily rainfall. By 2050 under SSP2-4.5, this could increase by 16% to 80 mm. By 2090 under SSP3-7.0, this could increase by 31% to 90 mm. Extreme rainfalls of sub-daily duration were not assessed directly in this report.
- Increased drought frequency, duration, and severity are projected for Auckland. The annual number of days of meteorological drought is projected to increase by 10 days by 2050 under SSP2-4.5, and by 53 days by 2090 under SSP3-7.0.
- Fewer windy days (daily wind speed $> 10 \text{ m s}^{-1}$) are projected. Auckland historically records 55 windy days per year. This decreases by between 6 days (by 2050 under SSP2-4.5) and 15 days (by 2090 under SSP3-7.0).

Auckland's future climate is expected to become increasingly extreme. Combined with ongoing sea-level rise, the region will become increasingly impacted by climate change. However, the extent and severity of future climate changes and associated impacts depends on future greenhouse gas concentrations. Understanding these projected changes can allow Auckland to prepare, find opportunities, adapt, and continue to prosper.

1 Purpose of this report

In 2020, NIWA delivered Auckland Council and other stakeholders a climate change and variability report for the Auckland region (Pearce et al., 2020). This report presented climate change projections that were downscaled and bias-corrected for New Zealand from Global Climate Models (GCMs) available via the Fifth Coupled Model Intercomparison Project (CMIP5). An updated suite of global climate model projections was subsequently developed via the Sixth Coupled Model Intercomparison Project (CMIP6), and these now represent the most relevant GCM data for assessing future climate change. Earth Sciences New Zealand¹ have downscaled and bias-corrected a selection of the CMIP6 GCM data to create bespoke projections for New Zealand (Gibson et al., 2024a; Campbell et al., 2024). These data are publicly available via the Ministry for the Environment (MfE, 2025).

In 2024, NIWA produced a report comparing the CMIP5 and CMIP6 projections for a selection of temperature and rainfall variables, tailored to the Auckland region (Macara et al., 2024). Notable results of the comparison include that projected increases to mean temperature, annual hot days, and heavy rainfall are consistently higher under CMIP6 scenarios compared to the corresponding CMIP5 scenarios.

Auckland Council have commissioned Earth Sciences New Zealand to produce a refreshed climate change and variability report focussing on the Auckland region, utilising New Zealand's updated CMIP6 climate projections.

This report is structured as follows:

- Section 2 presents a description of the data and methods used.
- Section 3 illustrates the observed temperature changes for Auckland and compares these to the corresponding modelled temperature changes projected under a moderate emissions scenario.
- Section 4 presents the climate change projections for 24 variables to the end of the 21st-century.
- Section 5 examines the climate model agreement and spread for the projections of mean temperature and total rainfall. The purpose of this section is to demonstrate that projection results should be interpreted carefully, and that the multi-model (ensemble) mean projections presented often obscure the variability between different models.
- Auckland Council requested data for the projected mean temperature change by 2130. This required additional modelling efforts, and the results are presented in Section 6.
- Section 7 highlights some of the key results of the CMIP6 projections. A high-level summary of the impacts associated with the projections is included, as well as addressing contemporary sea-level rise projections as they apply to Auckland.
- An overall summary and recommendations are described in Section 8.

¹ On 1 July 2025, NIWA and GNS Science merged to create Earth Sciences New Zealand.

2 Data and methods

2.1 Global climate modelling

Coupled global atmosphere-ocean general circulation models are used to generate climate change projections for prescribed scenarios of future greenhouse gas concentrations. The CMIP6 project (Eyring et al., 2016) comprises model results from approximately 100 climate models across 49 different modelling groups (Hausfather 2019; WCRP 2021). Some of the notable improvements to CMIP6 models, compared with CMIP5 models, include higher atmosphere and ocean resolution, and the inclusion of new and more complex processes such as interactive chemistry, active land processes, ice sheets and permafrost (Simpkins 2017).

2.2 Downscaling of global climate model data

In regions characterised by complex and coastal terrain, such as New Zealand, the raw output from GCMs can contain large biases. This generally means that GCMs should not be used directly in downstream climate impact studies, especially for local and regional applications. Well-known issues include that GCMs struggle to capture orographic precipitation and extremes over New Zealand, the intensity of extreme events such as tropical cyclones, as well as the impact of elevation and coastal processes on temperature variability (Gibson et al., 2024b).

Due to these issues, downscaling² is a valuable tool for better capturing smaller scale processes that impact climate while enhancing the spatial resolution of projections. The Conformal Cubic Atmospheric Model (CCAM) is used as the primary model for dynamical downscaling of selected CMIP6 GCMs over New Zealand. CCAM has been extensively used for downscaling over Australia in CMIP3 (Perkins et al., 2014), CMIP5 (Evans et al., 2021), and CMIP6 (Chapman et al., 2023; Grose et al., 2023) climate projections.

When compared to NIWA's previous CMIP5 downscaling (MfE, 2018), the current CMIP6 downscaling has been driven by updated CMIP6 GCMs and scenarios, different regional models run at higher resolution, and a modified bias correction methodology has been applied. Gibson et al. (2023; 2024b) extensively documents the CCAM model, grid configuration, physics settings, and experiment design utilised for the CMIP6 downscaling effort. Considering the improvements outlined above, CMIP6 data are more suitable for use than corresponding CMIP5 data.

2.3 Climate change scenarios

Assessing possible changes for our future climate due to human activity is challenging because climate projections strongly depend on estimates for future greenhouse gas concentrations. In turn, those concentrations depend on global greenhouse gas emissions that are driven by factors such as economic activity, population changes, technological advances and policies for mitigation and sustainable resource use. This range of uncertainty has been dealt with by the Intergovernmental Panel on Climate Change (IPCC) through consideration of 'scenarios' that describe concentrations of greenhouse gases in the atmosphere. The range of scenarios are associated with possible economic, political, and social developments during the twenty-first century.

² Deriving local climate information from larger-scale model or observational data. See Glossary for further details.

In the IPCC Sixth Assessment Report, which is based on CMIP6 models, the scenarios are called Shared Socioeconomic Pathways (SSPs). This is a new range of pathways compared to the IPCC Fifth Assessment Report, which used Representative Concentration Pathways (RCPs). In contrast to RCPs – which focus only on changes in atmospheric composition – SSP emission scenarios originate from a wide array of socioeconomic drivers (Bodeker et al., 2022). These include economic, political, and technological developments, as well as population growth.

The updated projections for New Zealand use SSP scenarios. These SSP scenarios start in 2015, and are abbreviated as SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5, in order of increasing greenhouse gas emissions. These SSPs represent narratives characterised as ‘sustainability’ (SSP1), ‘middle of the road’ (SSP2), ‘regional rivalry’ (SSP3) and ‘fossil-fuel intensive development’ (SSP5). SSPs also specify the end-of-21st-century radiative forcing reached; e.g. the ‘4.5’ in SSP2-4.5 assumes a radiative forcing of 4.5 W m² in 2100. The following definition of each SSP is adapted from IPCC (2021):

- SSP1-1.9 and SSP1-2.6 are scenarios with very low and low greenhouse gas emissions, with CO₂ emissions declining to net zero around or after 2050, followed by varying levels of net negative CO₂ emissions.
- SSP2-4.5 is an intermediate greenhouse gas emissions scenario, with CO₂ emissions remaining around current levels until the middle of the century.
- SSP3-7.0 and SSP5-8.5 are high and very high greenhouse gas emissions scenarios, with CO₂ emissions that roughly double from current levels by 2100 and 2050, respectively.

Bodeker et al. (2022) note that while some of the RCP and SSP scenarios reach the same radiative forcing by 2100 (e.g. RCP4.5 and SSP2-4.5), the greenhouse gas emissions and concentration pathways taken to reach that radiative forcing are not necessarily the same (Figure 2-1 and Figure 2-2). However, the premise of both RCPs and SSPs is the same; they present scenarios that cover the range of possible future development of anthropogenic drivers of climate change (IPCC, 2021). Note, neither the IPCC nor scenario developers have placed likelihoods on any scenario.

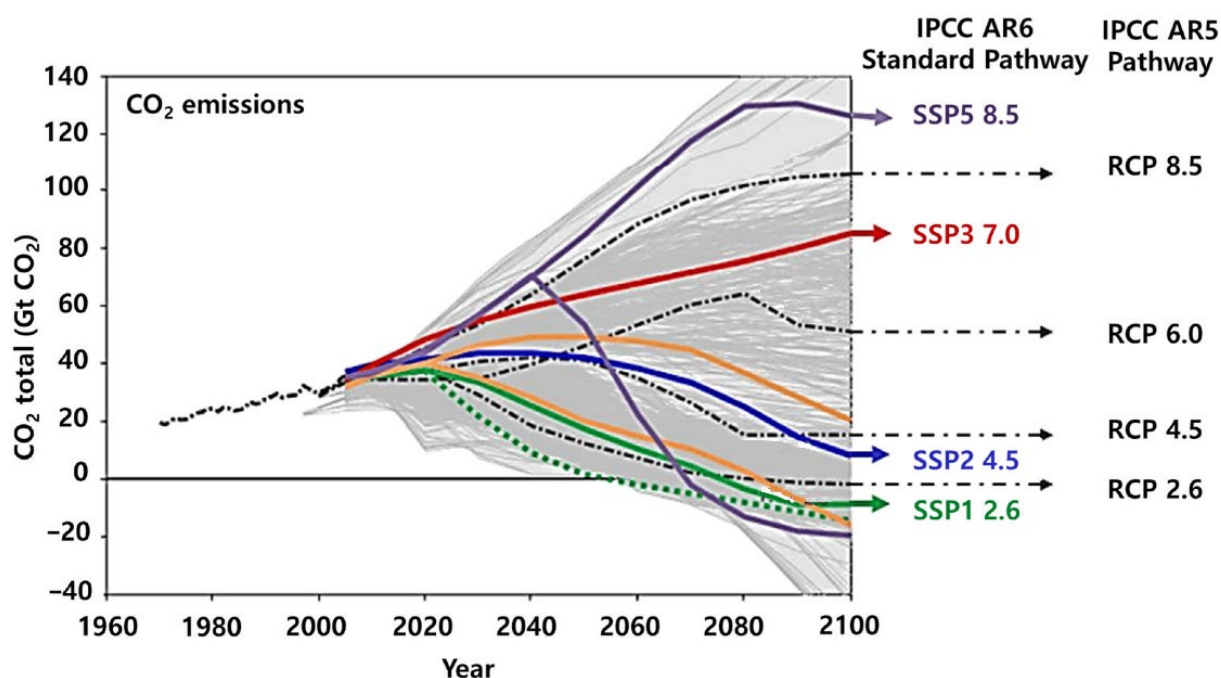


Figure 2-1: Global CO₂ emissions for the 21st century scenarios. Sourced from An et al. (2022).

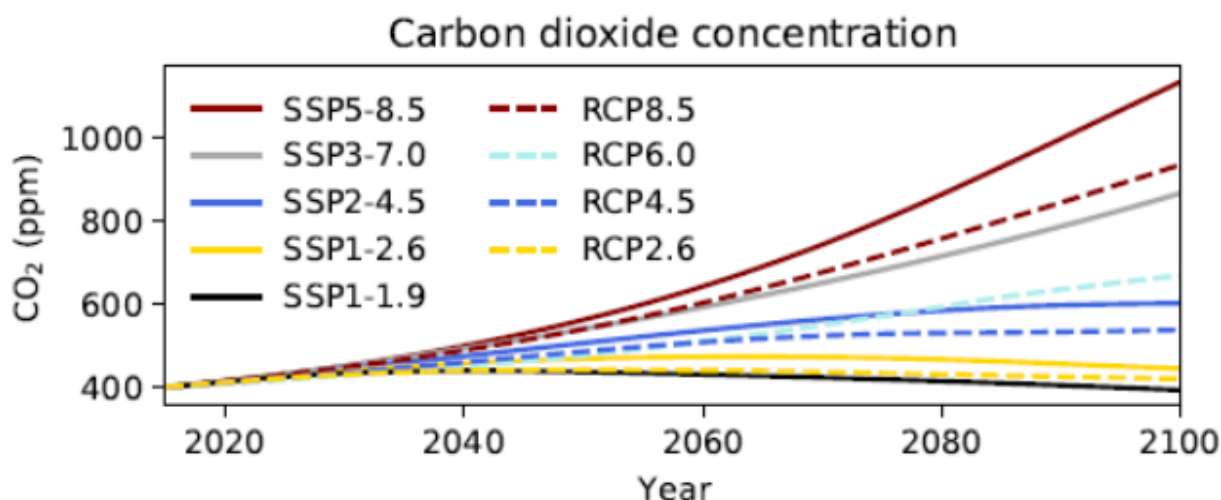


Figure 2-2: Global annual mean CO₂ concentrations for the 21st century scenarios. Sourced from Bodeker et al. (2022).

2.4 Calculation of observed temperature changes

New Zealand's seven-station temperature series is a homogenised temperature record derived from seven locations³ (Mullan et al., 2010). One of these locations is Auckland, which provides an opportunity to examine how temperatures have changed for a low-elevation location representative of the region. Observed Auckland temperature data were compared with projected temperature data to assess contemporary temperature changes. Three timeseries are presented for the period 1995-2024:

³ For further details on New Zealand's seven-station temperature series: <https://niwa.co.nz/climate-and-weather/nz-temperature-record/seven-station-series-temperature-data>

1. *Tmean*: Auckland's homogenised annual average temperature;
2. *Tmean (20-yr avg)*: Auckland's 20-year moving average annual temperature. The series begins in 1995 and ends in 2014 i.e. the 2004 *Tmean (20-yr avg)* is the average annual temperature from 1995-2014, whilst the 2014 *Tmean (20-yr avg)* is the average annual temperature from 2005-2024;
3. *SSP2-4.5 & SSP3-7.0*: Projected temperature change from 2004 (1995-2014) to 2050 (2041-2060) under SSP2-4.5 (SSP3-7.0). Data were calculated as follows:
 - Using Auckland's regionally averaged projected annual temperature change of 1.1°C (1.3°C); see Figure 4-2. Averaged over the 46-year period from 2004-2050, this equals an average increase of 0.024°C (0.028°C) per year. This average increase was applied iteratively to Auckland's 2004 *Tmean (20-yr avg)* (15.7°C) to generate the *SSP2-4.5 (SSP3-7.0)* timeseries.

Note:

- The SSP2-4.5 rate of change calculated above is only relevant for the period 2004-2050. Different periods may result in different rates of change.
- By calculating average annual projected temperature increases from 2004-2050 (using the rates of change), the interannual variability of projected temperature data is removed. Interannual variability is present in modelled temperature projections, and it will remain a feature of Auckland's future climate.

2.5 Variables selected for assessment

The CMIP6 projections for the Auckland region encompass 24 climate variables, listed in Table 2-1 below. Four scenarios were selected for the CMIP6 projections: SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5. Two future time periods are presented – 2050 (2041-2060) and 2090 (2080-2099). In all cases, projections are calculated as a difference from the historic average. The 20-year periods of 1986-2005 (1995) and 1995-2014 (2004) were selected for the historic averages. The 1995 historic period was chosen as it matches the historic period used in the previous climate change and variability report for the Auckland region (Pearce et al., 2020). The 2004 historic period is chosen as it is the most recent historic period available in the CMIP6 projections. Note, all scenarios and both historic average periods are presented in the tabular data of Section 4.

At the request of Auckland Council, the maps included in Section 4 comprise:

- i. SSP2-4.5 and SSP3-7.0 scenarios, relative to the 1995-2014 (2004) historic average.
- ii. The spatial extent of Auckland's regional boundary, plus a 10 km buffer along the southern boundary of the region. This is to ensure the entire Hunua Ranges are included, as this area is important for Auckland's water supply.

Note, there are inherent challenges and uncertainty associated with modelling climate variables at high spatial resolution. This is apparent in Auckland where coastal land and associated features such as Te Korowai-o-Te-Tonga Peninsula are not resolved by GCMs, nor the CCAM model used for downscaling. Readers are therefore encouraged to place greater emphasis on the overall patterns of region-wide modelled data, rather than overinterpret localised values.

NIWA supplied Auckland Council with GeoTIFF and NetCDF files of all the projections included in this report.

Table 2-1: Climate variables included in this report.

Variables	Descriptions
Mean temperature	Annual and seasonal average daily air temperature (°C). The average daily temperature is calculated as the average of the daily maximum and minimum temperature.
Maximum temperature	Annual and seasonal average daily maximum air temperature (°C).
Minimum temperature	Annual and seasonal average daily minimum air temperature (°C).
Daily temperature range	Annual and seasonal difference between the average daily maximum and average daily minimum temperatures (°C).
Hot days	Annual and seasonal number of days where the daily maximum temperature exceeds 25°C.
Very hot days	Annual and seasonal number of days where the daily maximum temperature exceeds 30°C.
Heatwave frequency	Annual number of days spent in heatwave. Following the framework of Perkins and Alexander (2013), a heatwave is defined as a period of at least three consecutive days during which the daily maximum temperature exceeds the 95 th percentile. It is calculated relative to the time of year (using a 15-day moving window) and specific location (i.e., percentiles are computed separately for each grid cell based on historical data). The analysis is restricted to the southern hemisphere extended summer period, from November through March.
Heatwave duration	Length of the longest annual heatwave. Heatwave is defined as described above for <i>Heatwave frequency</i> . The analysis is restricted to the southern hemisphere extended summer period, from November through March.
Total rainfall	Average annual and seasonal total rainfall.
Dry days	Average annual and seasonal number of days where the daily rainfall total is less than 1 mm.
Wet days	Average annual and seasonal number of days where the daily rainfall total is at least 1 mm.
Very wet days	Average annual and seasonal number of days where the daily rainfall total is more than 25 mm.
Heavy rainfall (99 th percentile) amount	Annual and seasonal daily rainfall total that exceeds the 99 th percentile during a given base period. It is based on wet days, i.e. dry days are excluded from the calculation, and equivalent to the magnitude of rainfall on the 1-2 wettest wet days of the year. The historic base periods of 2004 (1995-2014) and 1995 (1986-2005) are applied in this report.
Heavy rainfall (99 th percentile) days	Annual and seasonal number of days where the daily rainfall total exceeds the <i>heavy rainfall (99th percentile) amount</i> during a given base period. The historic base periods of 2004 (1995-2014) and 1995 (1986-2005) are applied in this report.

Variables	Descriptions
Potential evapotranspiration deficit	Average annual potential evapotranspiration deficit (PED) accumulation total (mm/year). PED can be interpreted as a measure of drought severity. It represents the gap between the amount of water that could evaporate and transpire from land, and the actual amount of water that is available. PED is calculated daily, and daily values are added to generate PED accumulation values.
Meteorological drought frequency	Average annual and seasonal number of meteorological drought days. We analyse meteorological drought – defined as rainfall deficits – using the approach outlined in Ukkola et al. (2020). Drought conditions are identified when the 3-month running mean of precipitation falls below the 15 th percentile, calculated for each month and location (i.e., grid cell) based on the historical reference period. A drought event is defined as any continuous period of at least one month during which the running mean remains below this threshold.
Meteorological drought duration	Annual and seasonal length of the longest continuous meteorological drought. Meteorological drought is defined as described above for <i>Meteorological drought frequency</i> .
Average wind speed	Annual and seasonal average daily wind speed.
Windy days	Annual and seasonal number of days where the daily mean wind speed exceeds 10 m s ⁻¹ (36 km/h).
Strong wind (99 th percentile)	Annual and seasonal daily wind speed that exceeds the 99 th percentile during a given base period. The historic base periods of 2004 (1995-2014) and 1995 (1986-2005) are applied in this report.
Relative humidity	Annual and seasonal average daily relative humidity.
Solar radiation	Annual and seasonal average daily incoming shortwave radiation at Earth's surface.
Ex-tropical cyclones and atmospheric rivers	Ex-tropical cyclones (ex-TCs) are low pressure systems in the mid-latitudes that were formerly characterised as a Tropical Cyclone (TC). A TC becomes known as an ex-TC when the TC moves away from the tropics and undergoes extratropical transformation. Atmospheric Rivers (ARs) transport considerable amounts of water vapour in the lower atmosphere from tropical regions to the mid-latitudes. They often produce extreme rainfall events across New Zealand.
Sea-surface temperature	The temperature of the uppermost layer of the ocean, typically measured within the top few millimetres to a depth of 10 metres in CMIP6 models.

2.6 Calculation of temperature change by 2130

Auckland Council requested information on projected mean temperature changes by 2130. Unfortunately, the GCMs produced by international research centres that form the basis of the downscaled national projections presented in this report only produced data to 2100. Therefore, it was not possible to produce downscaled projections post-2100 in the same way that was done pre-2100. It is also problematic to use simple extrapolation methods based on the current downscaled data: considerable continued warming after 2100 is anticipated under the higher emissions scenarios, while extending the 21st-century trend would miss the anticipated results of aggressive emissions reductions for the lower emissions scenarios.

Our solution is to fit a simple, physically-based model of the temperature response to projections of 21st-century greenhouse gas concentrations, and then run the model past 2100 using projections of greenhouse gas concentrations after 2100 (Stone et al., 2007). The simple energy balance model (EBM) has three parameters:

- one parameter representing how much warming would eventually occur, after sufficient time, given doubling of greenhouse gas concentrations;
- one parameter representing the heat capacity of the atmosphere and upper ocean, controlling how quickly they can warm; and
- one parameter representing the speed at which heat is sequestered into the deep ocean.

The EBM is produced by tuning the three parameters to best fit the Auckland Region temperature over the 1960-2099 period. This fitting process is performed separately for each scenario, meaning that the values of the three EBM parameters can differ across scenarios. The reason for doing this is that the EBM assumes that the ocean responds to climate warming as a single block. However, the Southern Ocean's warming substantially lags the rest of the world, because it is efficient at transferring its warming to the deep ocean. This means that the way the Southern Ocean responds in a high-warming scenario (i.e. SSP5-8.5) may differ noticeably from how it warms in a low-warming scenario (i.e. SSP1-2.6). Separate tuning of the EBM parameters provides an ability to account for this effect.

EBMs have been used for decades for rapid estimation of global climate change, but can also be applied locally under certain assumptions. We run the model using projected concentrations of the major greenhouse gases in the 20th-, 21st-, and 22nd-centuries provided by Meinshausen et al. (2020). We apply the model to the six downscaled CMIP6 GCMs as described by Gibson et al. (2023; 2024b). We calculate mean temperature changes by 2130 (2120-2139) under SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5. Changes are calculated relative to two historic base periods: 1995 (1986-2005), and 2004 (1995-2014).

3 Observed temperature changes

The purpose of this analysis is to provide context for contemporary temperature observations (in this case from 1995-2024), and to illustrate that due to ongoing observed warming, a portion of the projected temperature changes have already materialised. Specifically, projected temperature changes presented in maps in this report (Section 4.1) are relative to 2004 (1995-2014). Given we are now at 2025 (at the time of writing), a portion of the projected temperature changes will have already occurred. This section should not be used to assess the accuracy of the projected temperature data because natural random climate variability will be large compared to the anthropogenic climate change signal over this short time period.

Figure 3-1 shows Auckland's mean annual temperature from 1910-2024. There is considerable interannual variability. This is due to a combination of natural causes such as the El Niño Southern Oscillation, together with other random year-to-year fluctuations ("climate noise"), as well as anthropogenic influences (e.g. greenhouse gas emissions). According to these data, Auckland's coldest year occurred in 1919 (13.43°C), and the warmest year occurred in 2022

(16.92°C). Overall, a trend of +0.17°C per decade is observed, which is significant at the 5% level ($p < 0.05$)⁴.

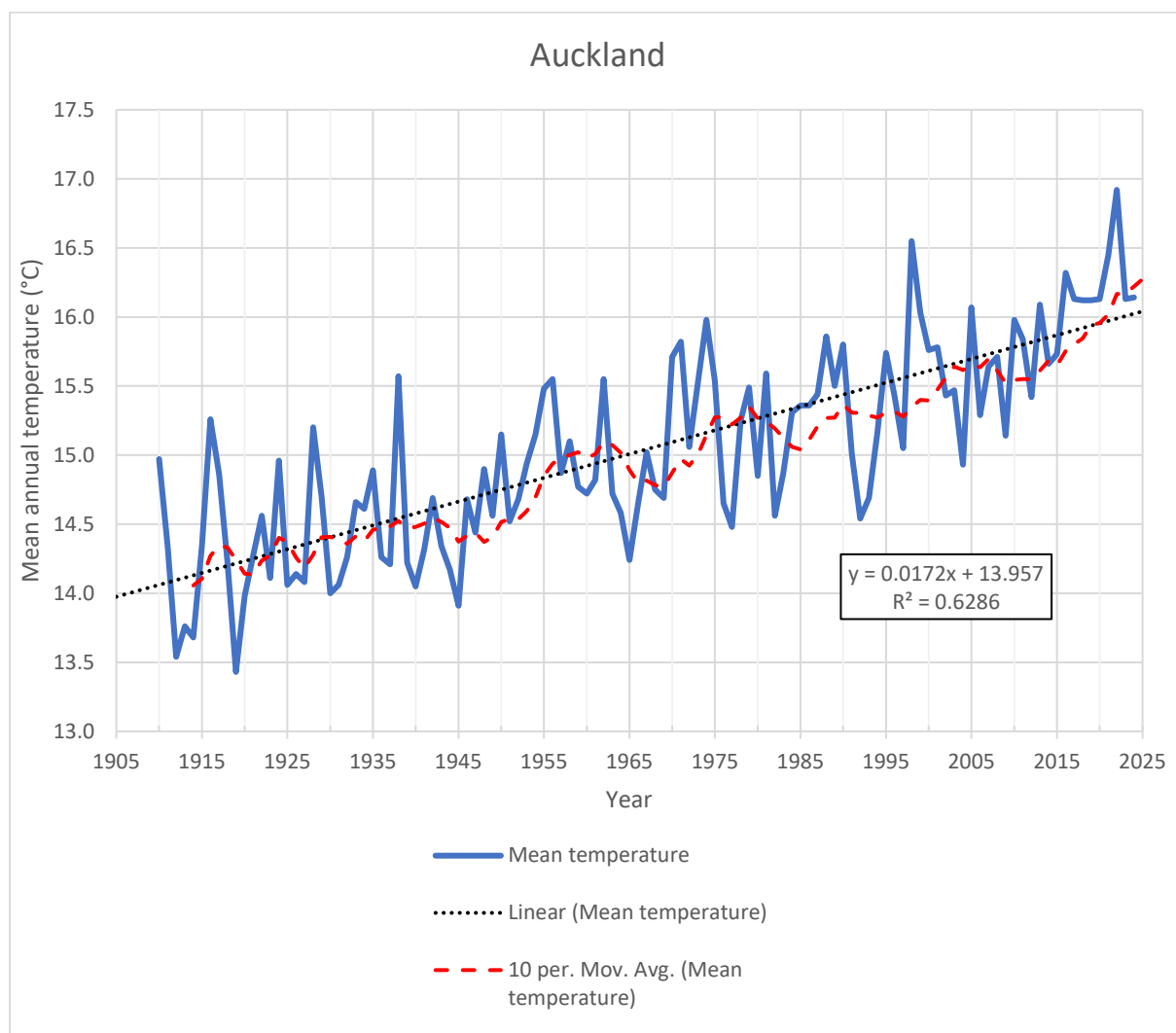


Figure 3-1: Mean annual temperature for Auckland. The linear trend (black dotted line) and associated regression equation indicates an annual mean temperature increase of approximately 0.17°C/decade overall, which is significant at $p < 0.05$. The 10-year period moving average (red dashed line) illustrates the non-linear character of Auckland’s observed increase in annual mean temperature.

Figure 3-2 shows observed and projected temperatures for Auckland. In the 10-year period from 2004-2014, Auckland’s observed 20-year moving average annual temperature increased 0.3°C, from 15.65°C to 15.95°C. Based on these observed temperature data, approximately 27% (23%) of Auckland’s projected warming by 2050 under SSP2-4.5 (SSP3-7.0) has materialised. Note, the rate of projected change for the Auckland region under SSP2-4.5 and SSP3-7.0 (Figure 3-2; dashed lines) is +0.24°C and +0.28°C per decade respectively, which is higher than Auckland’s observed rate of change illustrated in Figure 3-1.

⁴ $p < 0.05$ is a measure of statistical significance, indicating a 5% chance of rejecting the null hypothesis when it is true. In this instance, the null hypothesis - that there has been no trend observed in Auckland’s annual mean temperature - is rejected.

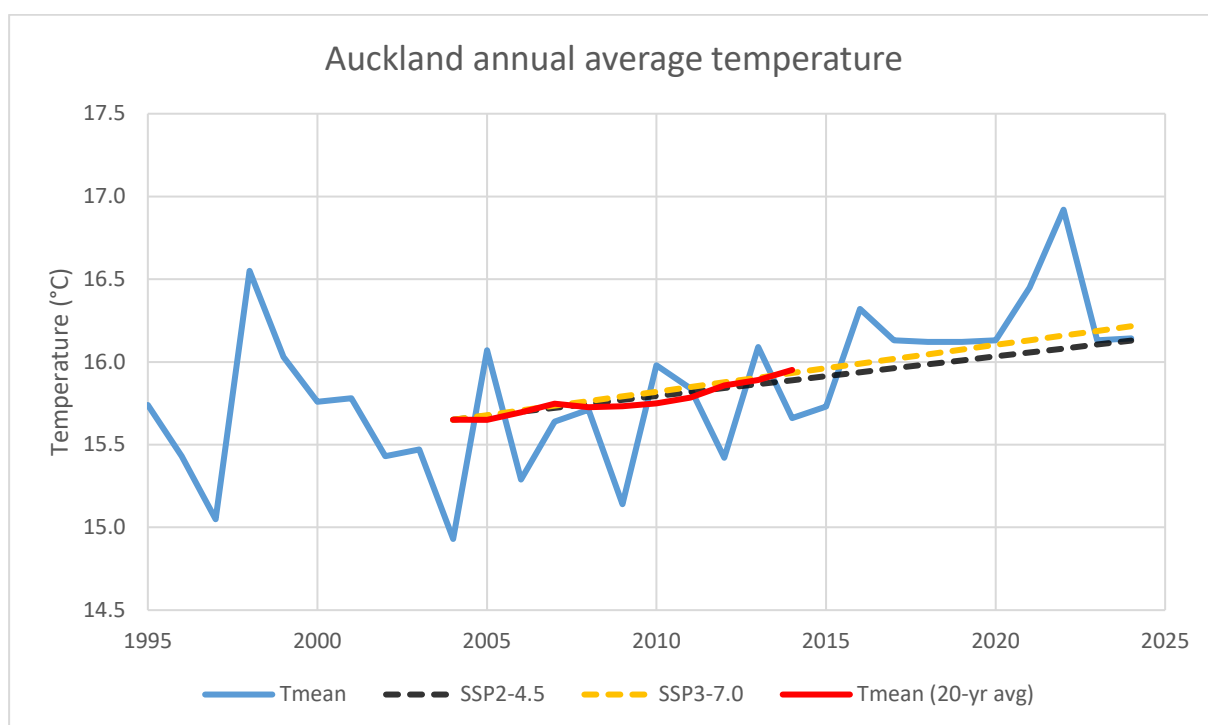


Figure 3-2: Observed and projected temperature change for Auckland. The generation of these data are described in Section 2.1.

4 Climate change projections

4.1 Mean temperature

Mean temperature refers to the annual and seasonal average daily temperature. The average daily temperature is calculated as the average of the daily maximum and minimum temperature. Modelled historic and future projections of annual and seasonal mean temperature are illustrated in Figure 4-1 to Figure 4-10. Region-wide averages are summarised in the two boxes below.

Historic mean temperature and projected changes (°C) Relative to 1995-2014 (2004)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2004	2050	2090	2050	2090	2050	2090	2050	2090
Annual	15.0	+0.8	+0.8	+1.1	+1.9	+1.3	+2.9	+1.4	+3.7
Summer	18.7	+1.0	+0.9	+1.2	+2.2	+1.6	+3.4	+1.6	+4.2
Autumn	16.0	+0.9	+0.9	+1.2	+2.0	+1.4	+3.0	+1.5	+3.8
Winter	11.3	+0.7	+0.7	+0.9	+1.7	+1.1	+2.5	+1.2	+3.3
Spring	14.1	+0.7	+0.7	+0.9	+1.7	+1.1	+2.6	+1.3	+3.3

Historic mean temperature and projected changes (°C) Relative to 1986-2005 (1995)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	1995	2050	2090	2050	2090	2050	2090	2050	2090
Annual	14.8	+1.0	+1.0	+1.2	+2.1	+1.5	+3.1	+1.6	+3.9
Summer	18.5	+1.2	+1.0	+1.4	+2.4	+1.8	+3.6	+1.8	+4.4
Autumn	15.8	+1.0	+1.1	+1.3	+2.2	+1.5	+3.2	+1.7	+4.0
Winter	11.1	+0.9	+0.9	+1.1	+1.9	+1.3	+2.7	+1.4	+3.5
Spring	13.9	+0.9	+0.9	+1.1	+1.9	+1.3	+2.8	+1.5	+3.5

4.1.1 Annual

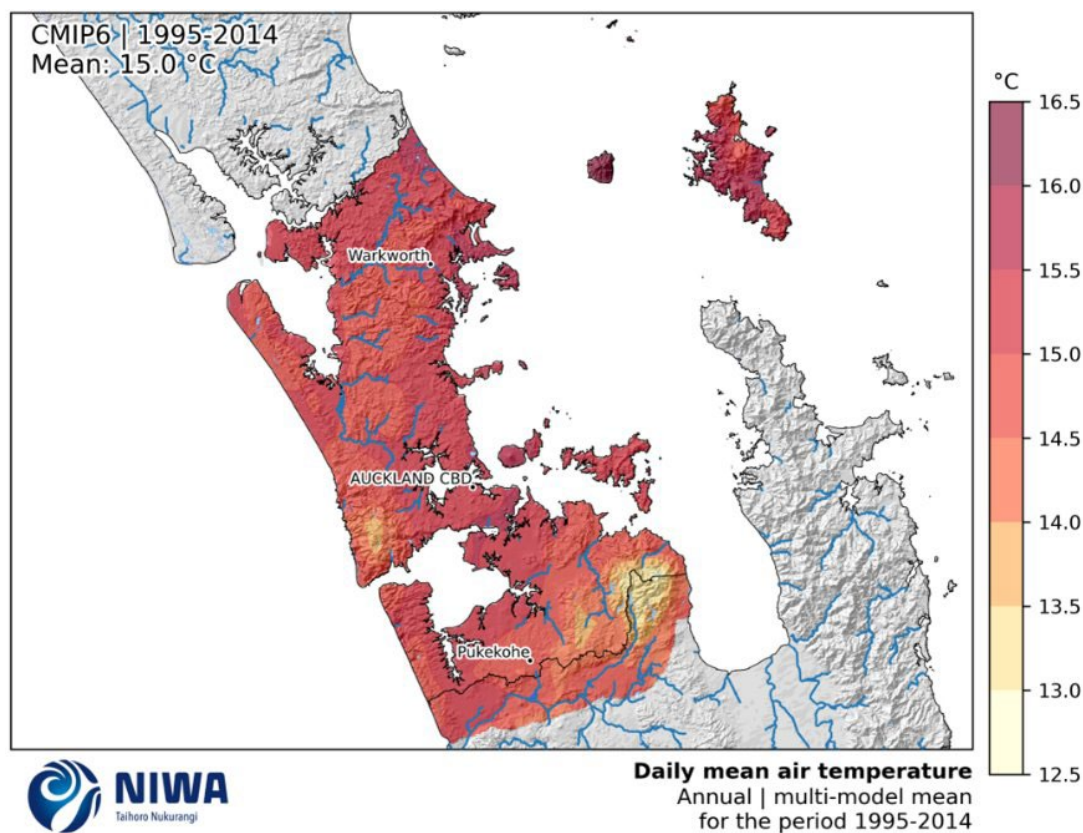


Figure 4-1: Modelled historic annual mean temperature.

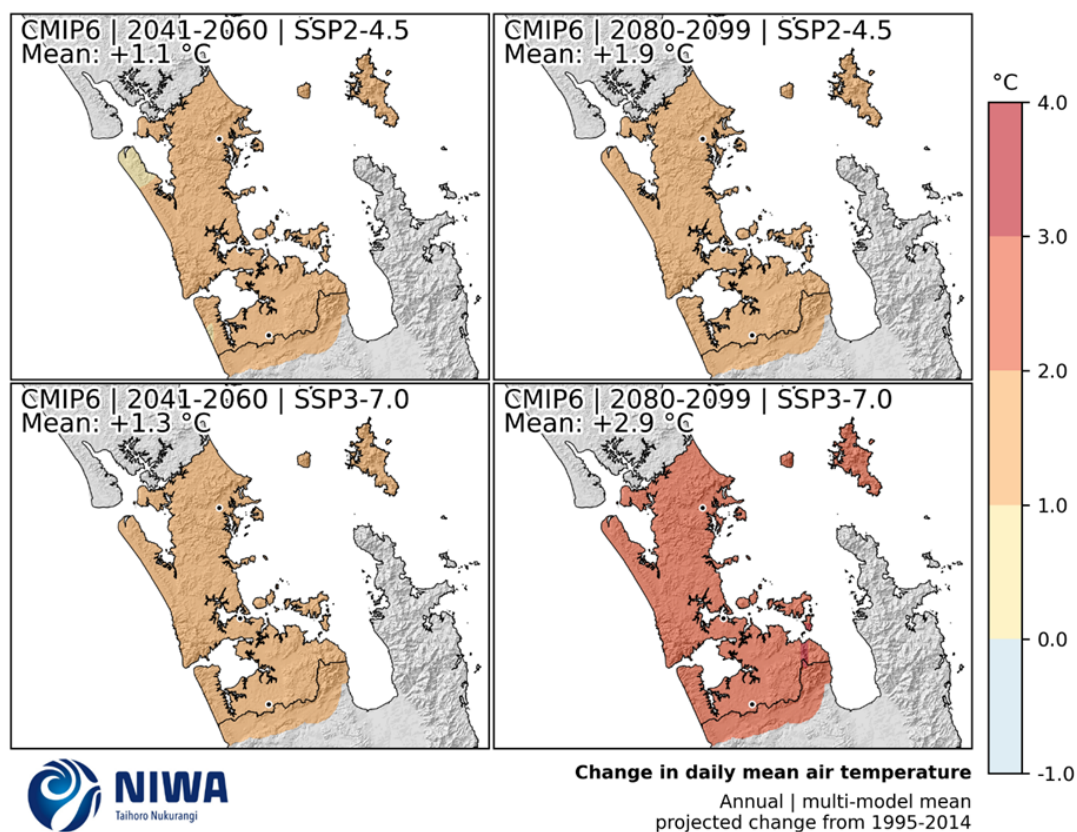


Figure 4-2: Projected annual mean temperature changes.

4.1.2 Seasonal

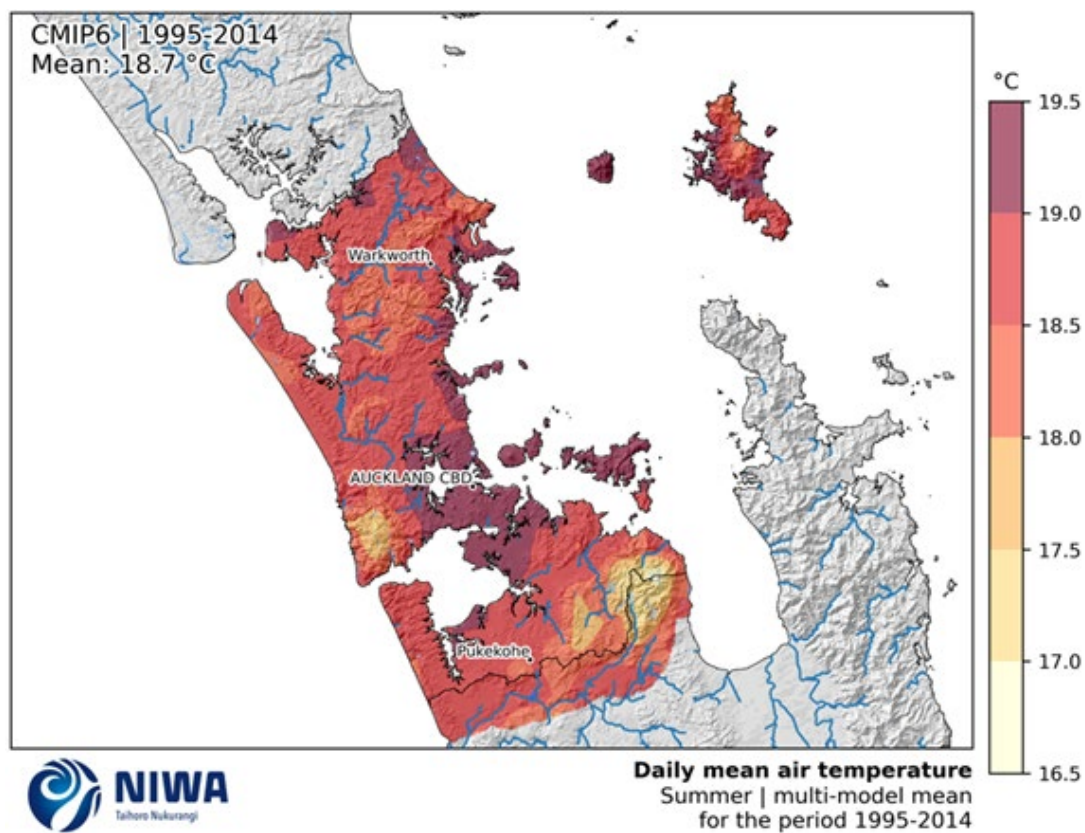


Figure 4-3: Modelled historic summer mean temperature.

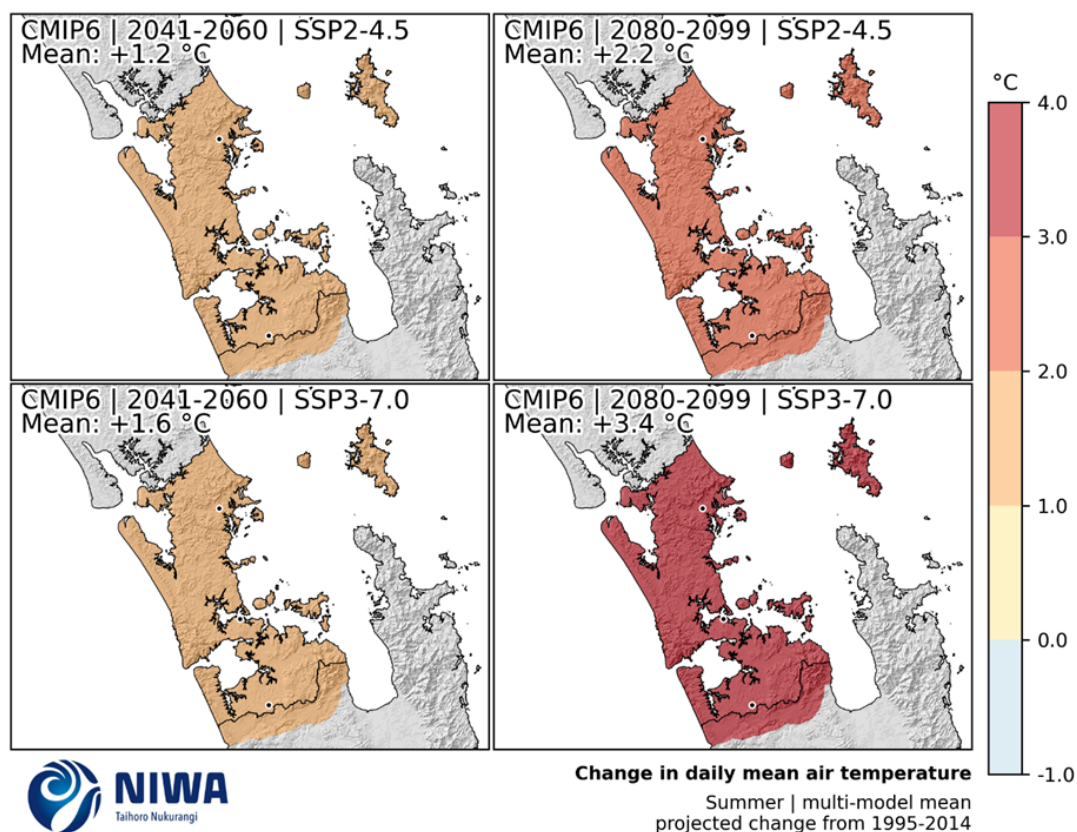


Figure 4-4: Projected summer mean temperature changes.

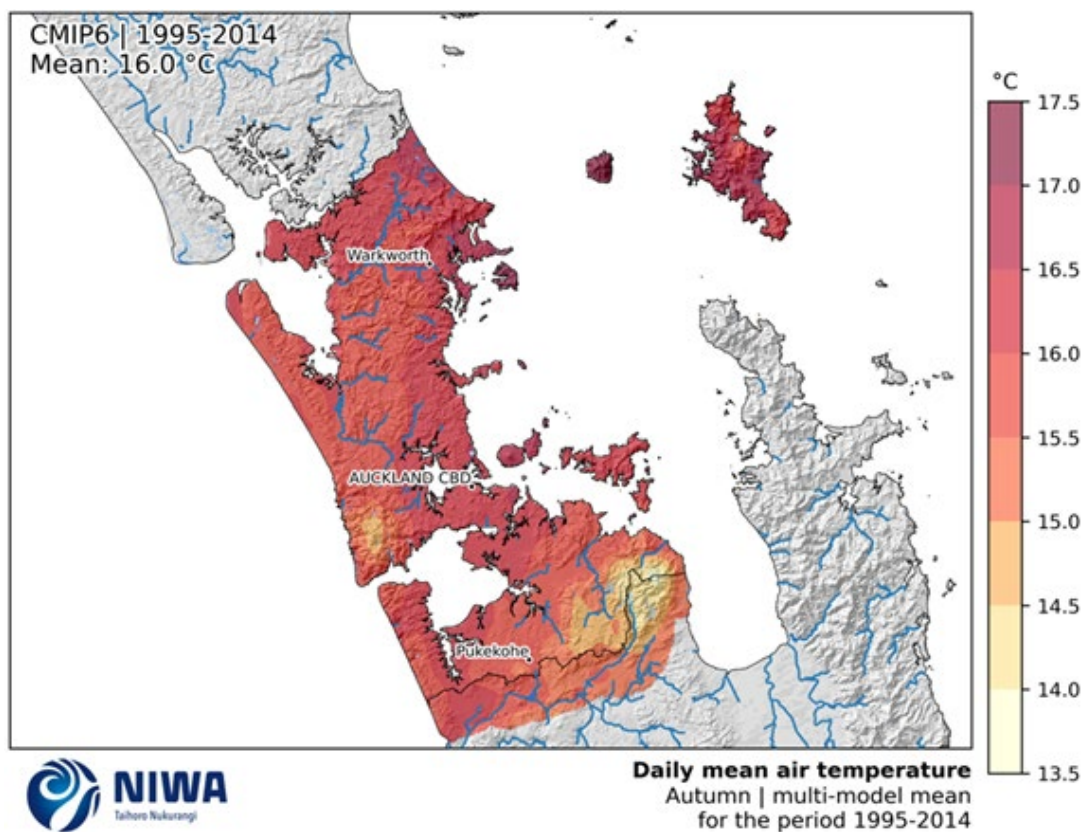


Figure 4-5: Modelled historic autumn mean temperature.

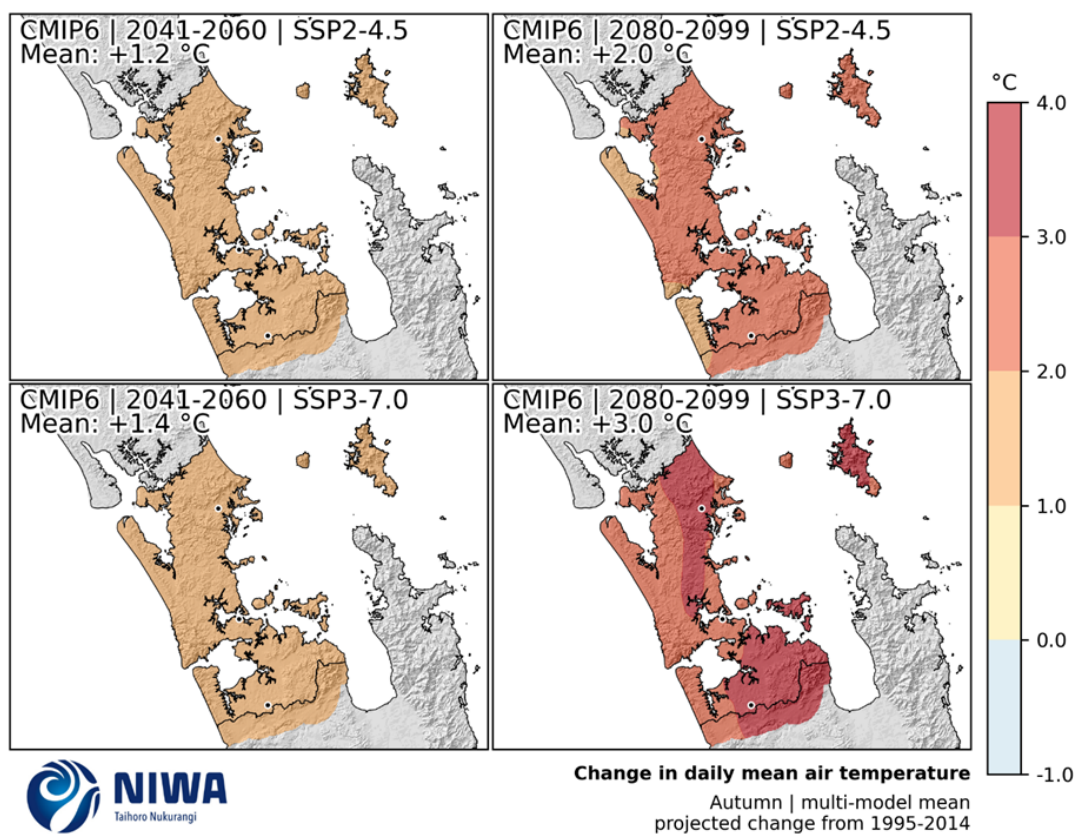


Figure 4-6: Projected autumn mean temperature changes.

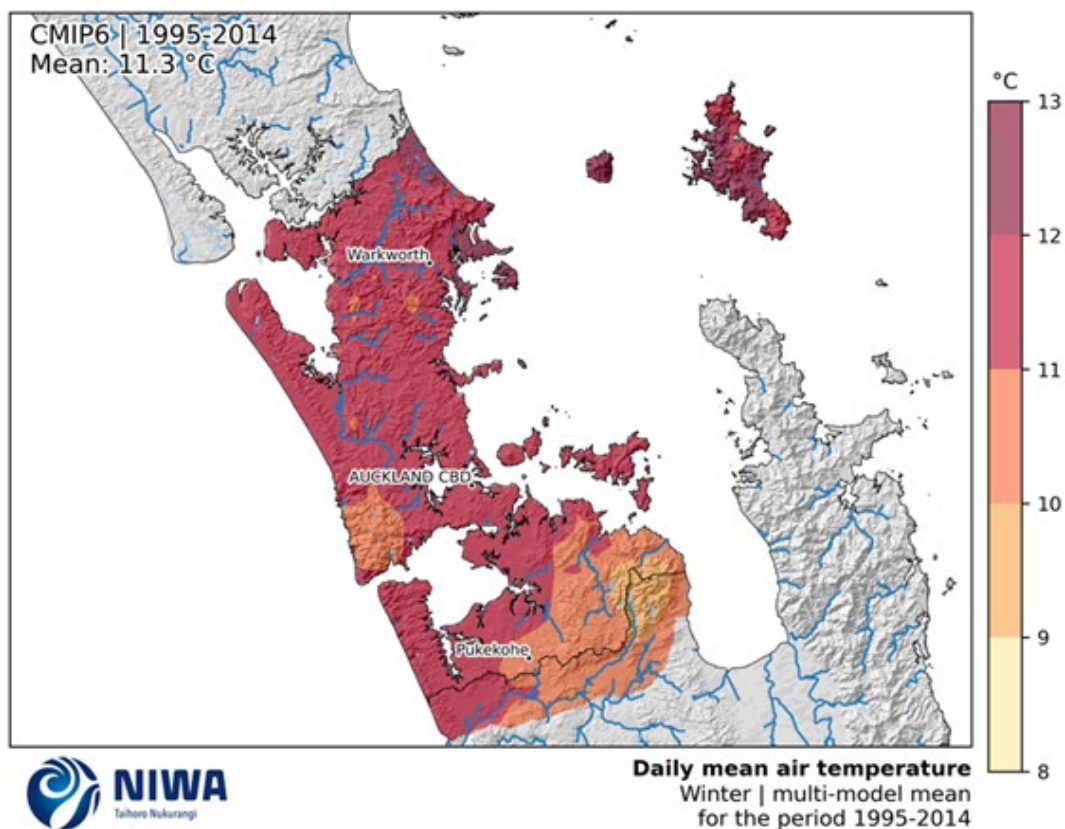


Figure 4-7: Modelled historic winter mean temperature.

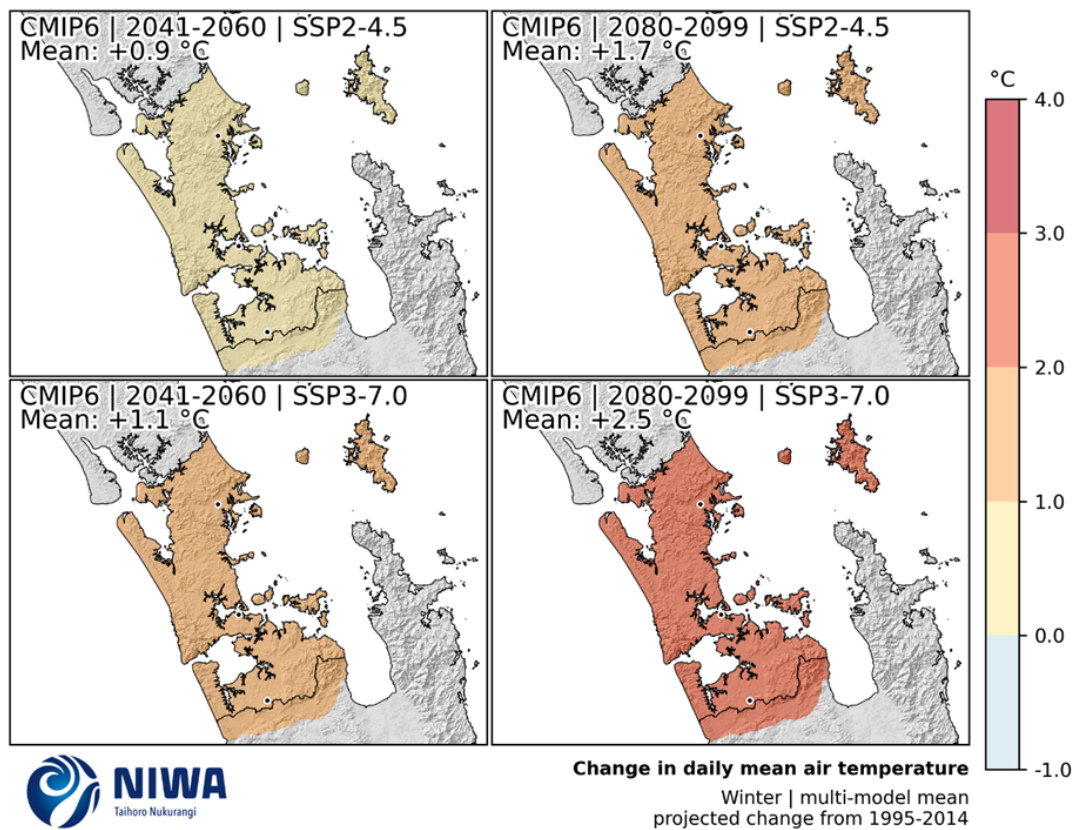


Figure 4-8: Projected winter mean temperature changes.

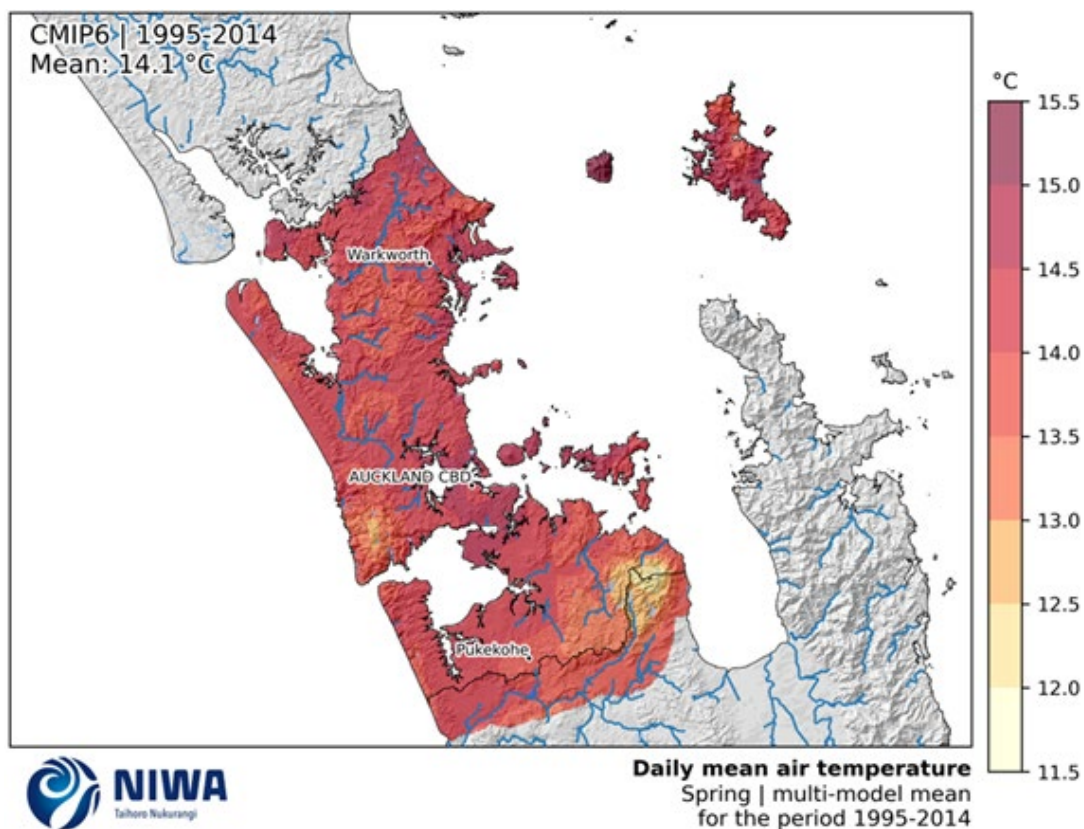


Figure 4-9: Modelled historic spring mean temperature.

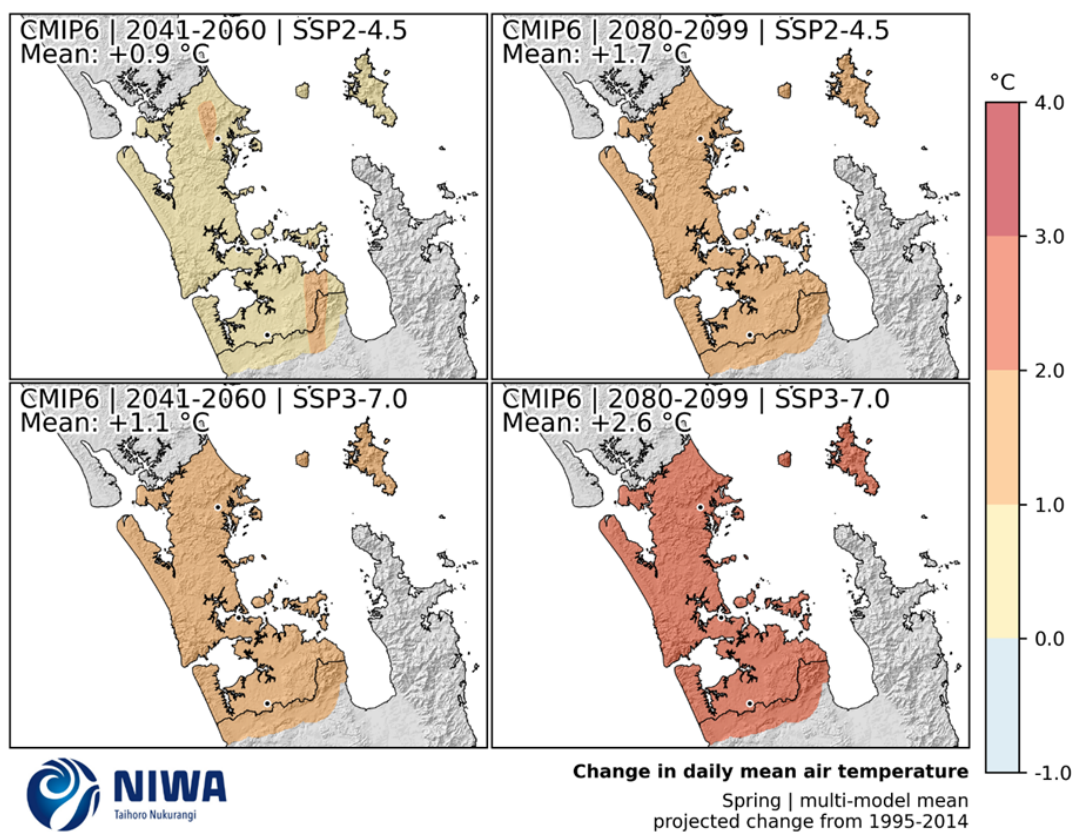


Figure 4-10: Projected spring mean temperature changes.

4.2 Maximum temperature

Maximum temperature refers to the annual and seasonal average daily maximum temperature. Modelled historic and future projections of annual and seasonal maximum temperature are illustrated in Figure 4-11 to Figure 4-20. Region-wide averages are summarised in the two boxes below.

Historic maximum temperature and projected changes (°C) Relative to 1995-2014 (2004)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2004	2050	2090	2050	2090	2050	2090	2050	2090
Annual	19.0	+0.9	+0.9	+1.1	+2.0	+1.3	+3.0	+1.5	+3.8
Summer	23.0	+1.0	+0.9	+1.2	+2.2	+1.6	+3.5	+1.7	+4.3
Autumn	20.1	+0.9	+1.0	+1.2	+2.1	+1.4	+3.1	+1.5	+3.9
Winter	15.1	+0.8	+0.8	+0.9	+1.7	+1.2	+2.6	+1.3	+3.4
Spring	17.9	+0.8	+0.8	+1.0	+1.8	+1.2	+2.7	+1.4	+3.6

Historic maximum temperature and projected changes (°C) Relative to 1986-2005 (1995)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	1995	2050	2090	2050	2090	2050	2090	2050	2090
Annual	18.8	+1.1	+1.0	+1.3	+2.1	+1.5	+3.2	+1.7	+4.0
Summer	22.8	+1.2	+1.1	+1.4	+2.4	+1.8	+3.7	+1.9	+4.5
Autumn	20.0	+1.1	+1.1	+1.3	+2.3	+1.6	+3.2	+1.7	+4.1
Winter	14.9	+1.0	+1.0	+1.1	+1.9	+1.3	+2.8	+1.5	+3.6
Spring	17.7	+1.0	+1.0	+1.2	+2.0	+1.4	+2.9	+1.6	+3.8

4.2.1 Annual

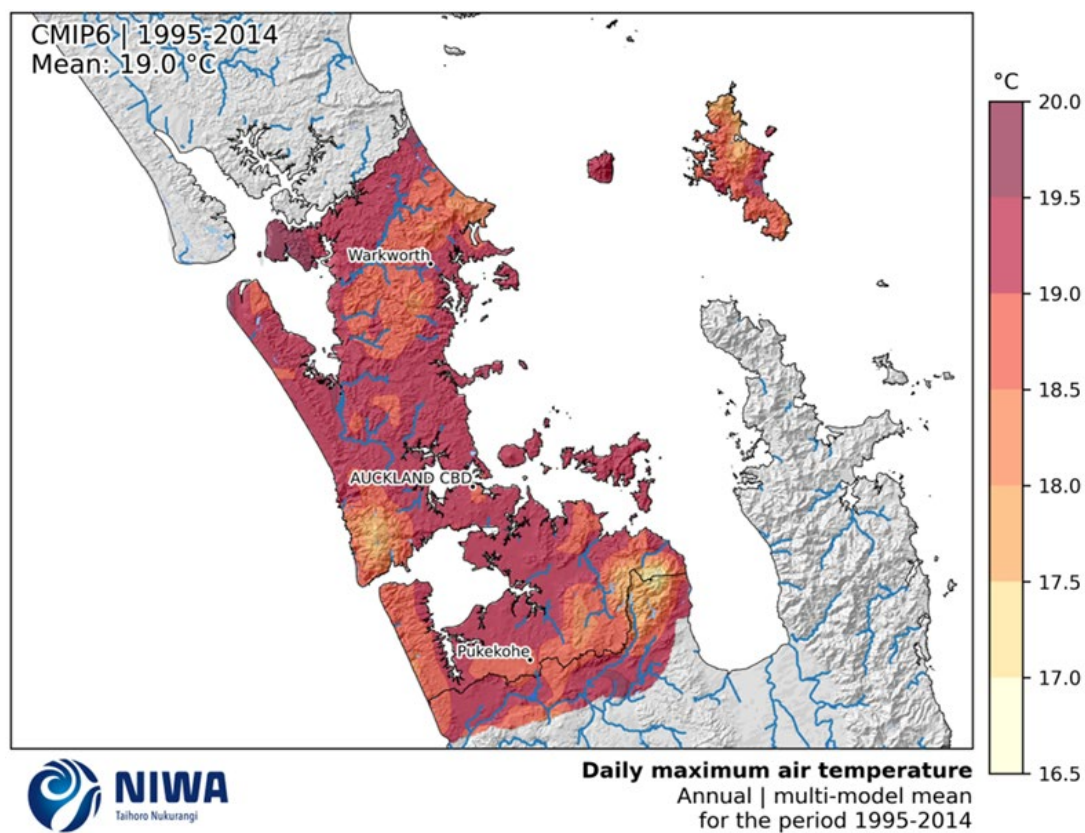


Figure 4-11: Modelled historic annual average daily maximum air temperature.

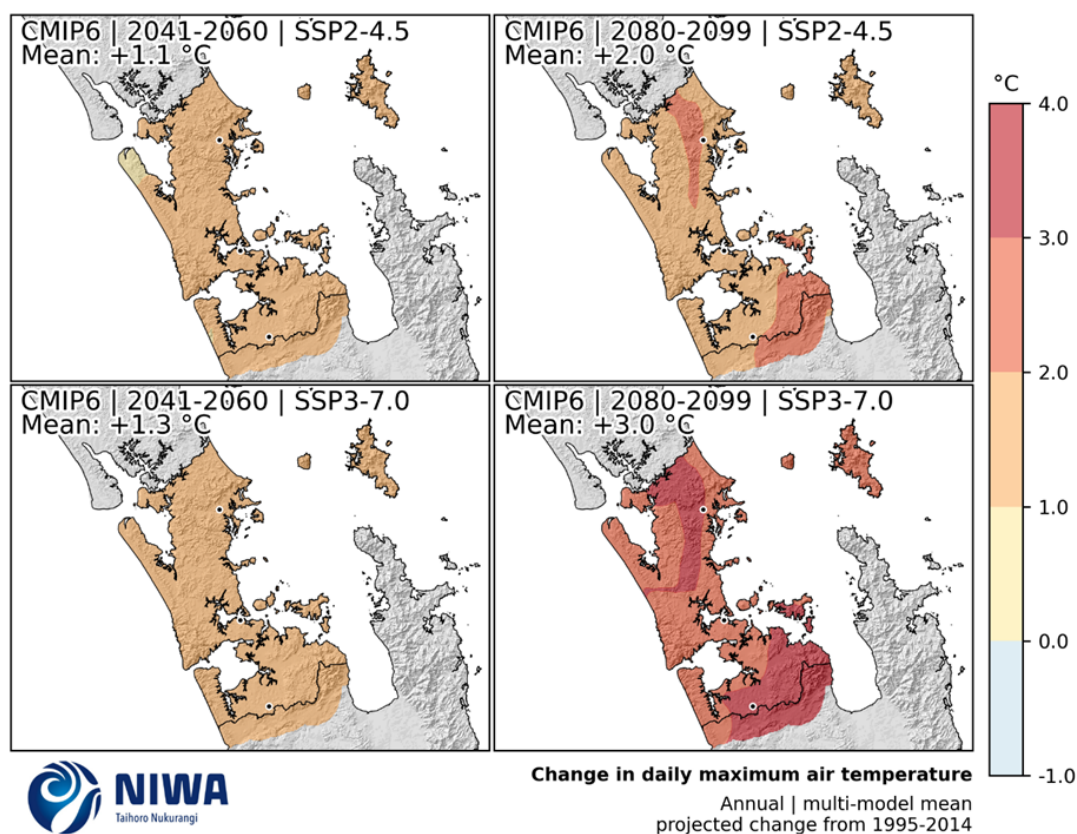


Figure 4-12: Projected annual average daily maximum temperature changes.

4.2.2 Seasonal

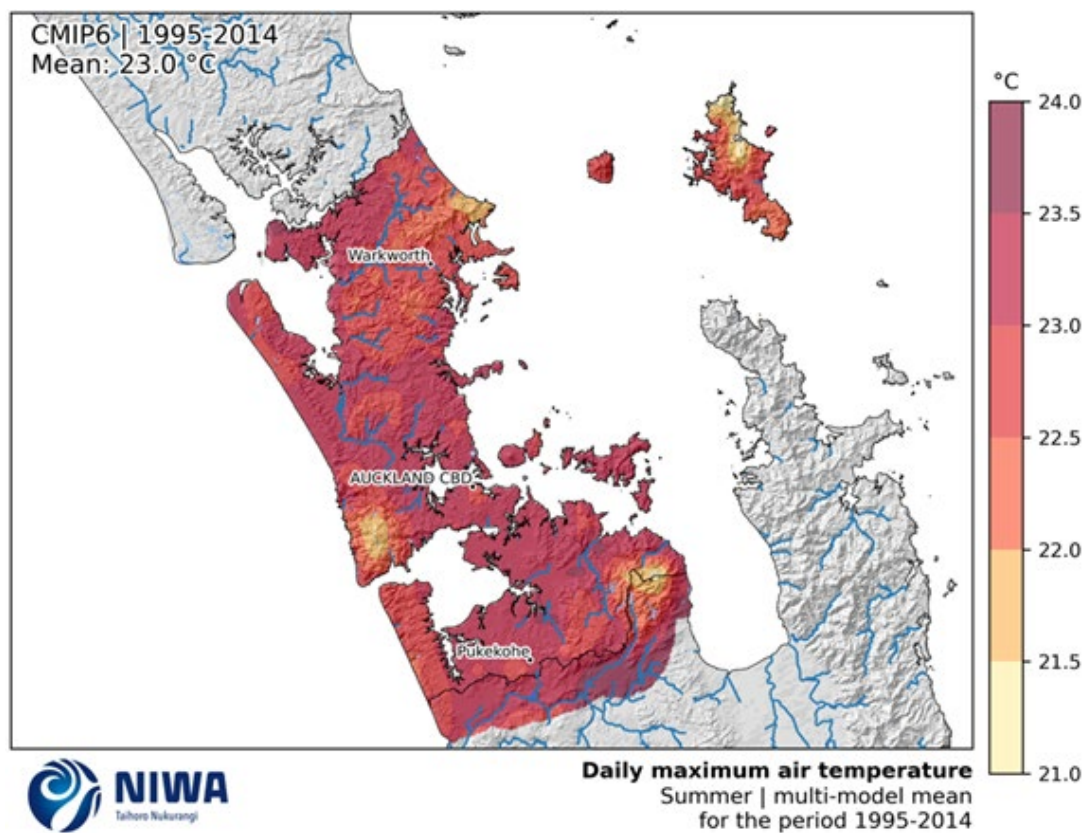


Figure 4-13: Modelled historic summer average daily maximum air temperature.

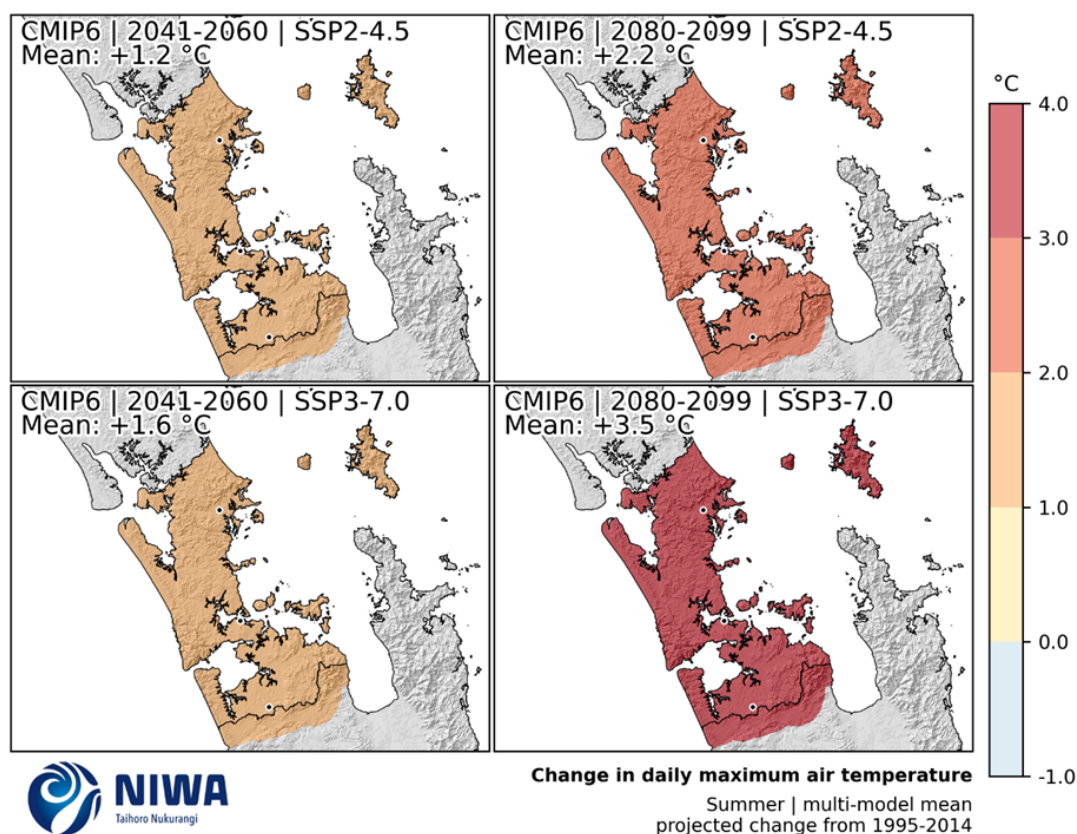


Figure 4-14: Projected summer average daily maximum temperature changes.

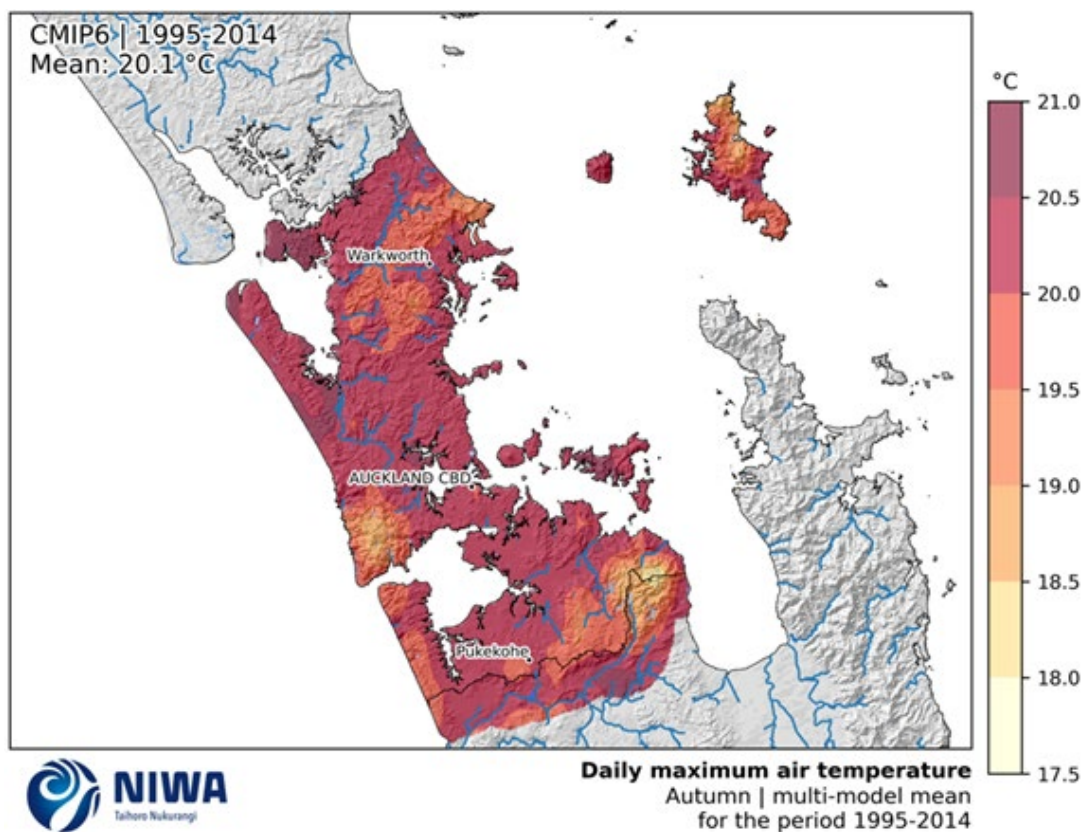


Figure 4-15: Modelled historic autumn average daily maximum air temperature.

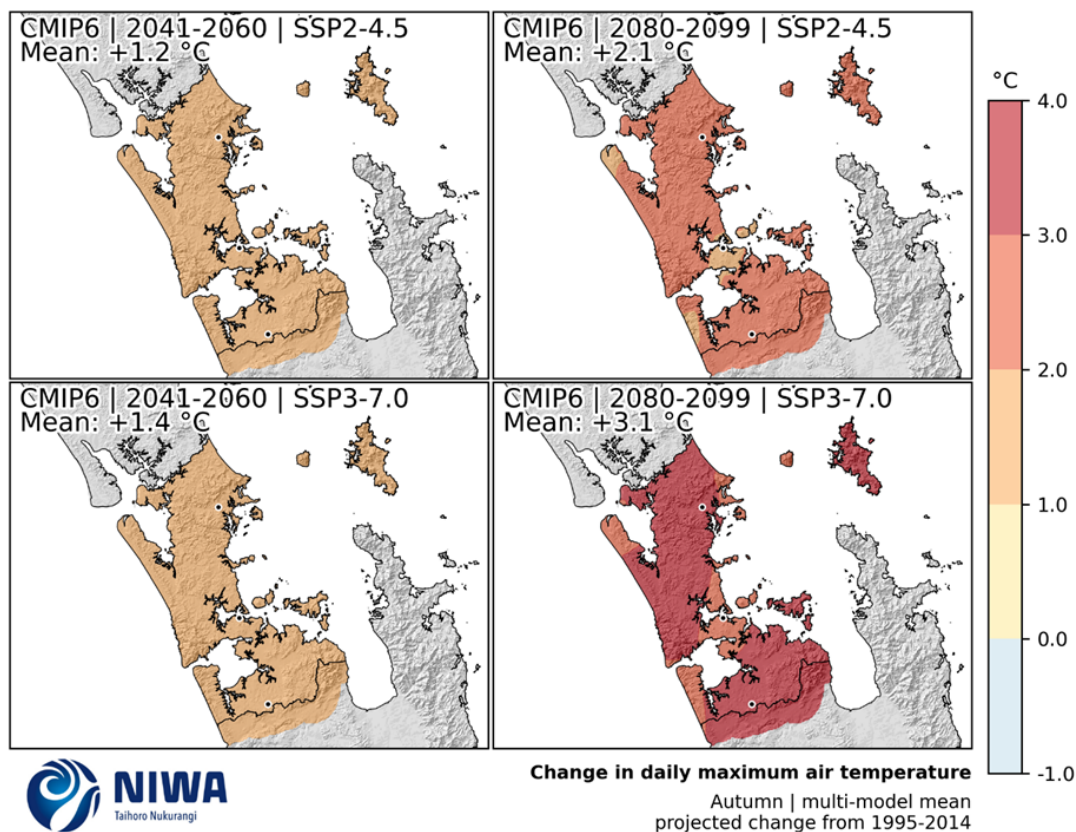


Figure 4-16: Projected autumn average daily maximum temperature changes.

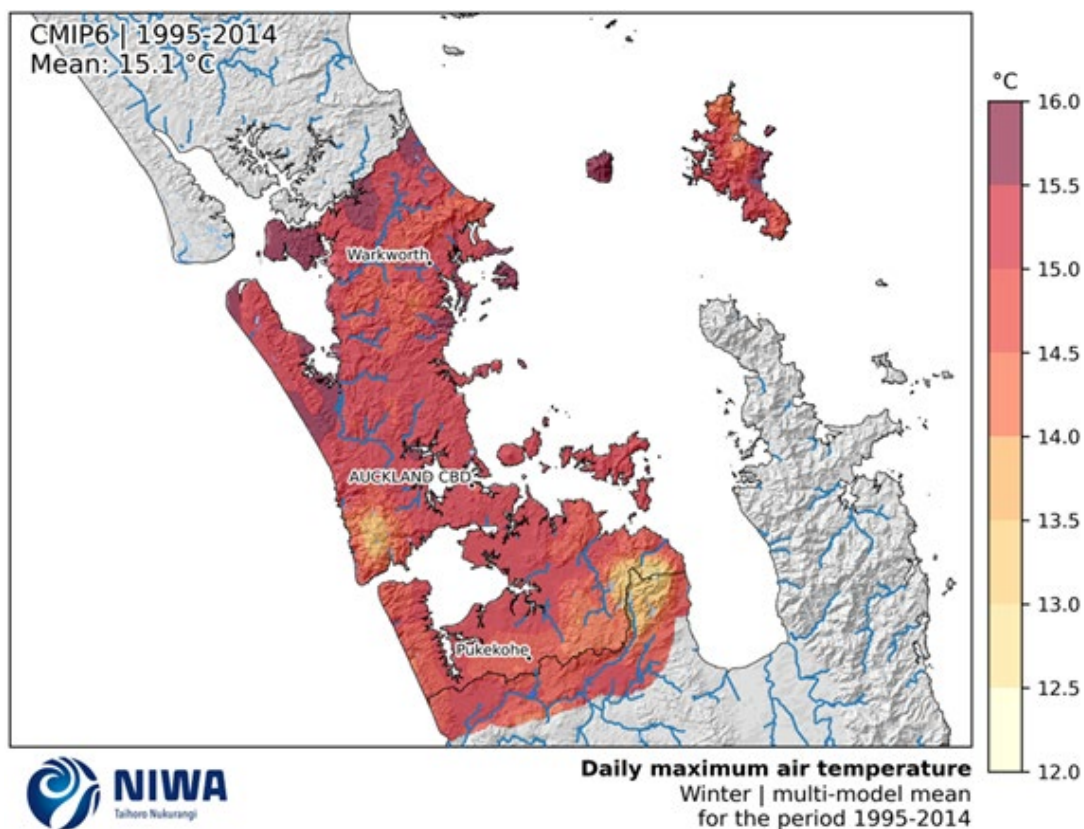


Figure 4-17: Modelled historic winter average daily maximum air temperature.

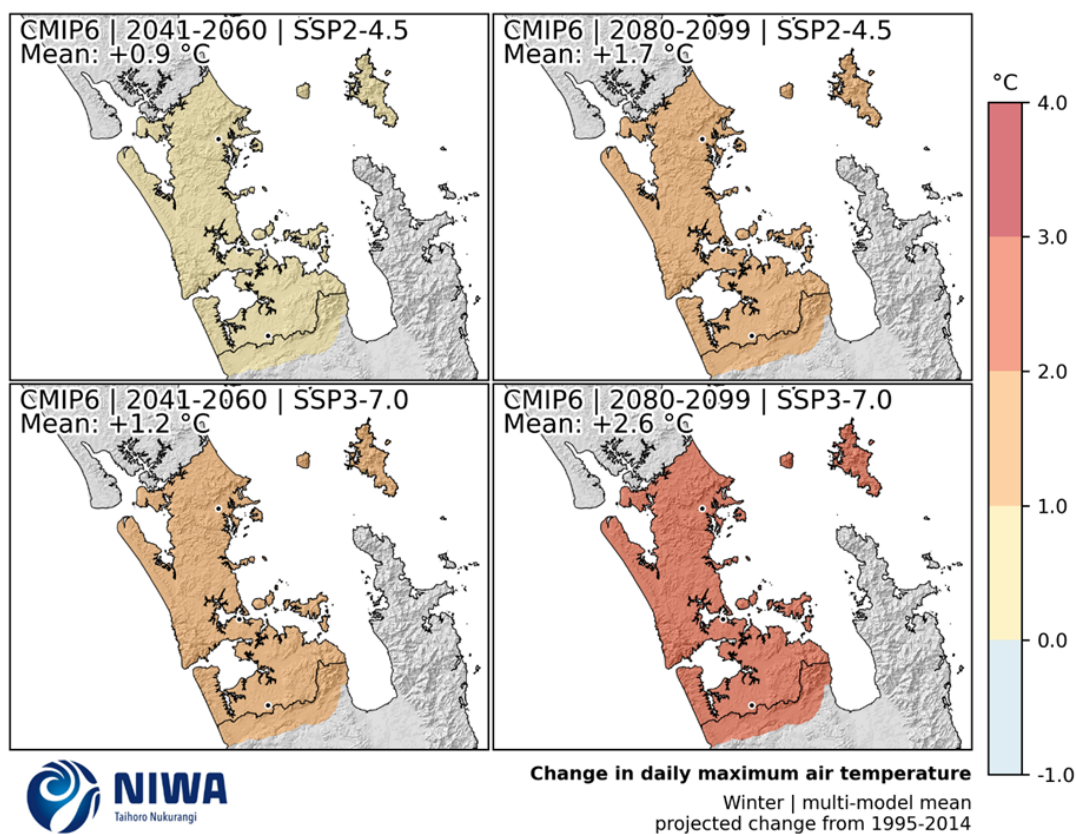


Figure 4-18: Projected winter average daily maximum temperature changes.

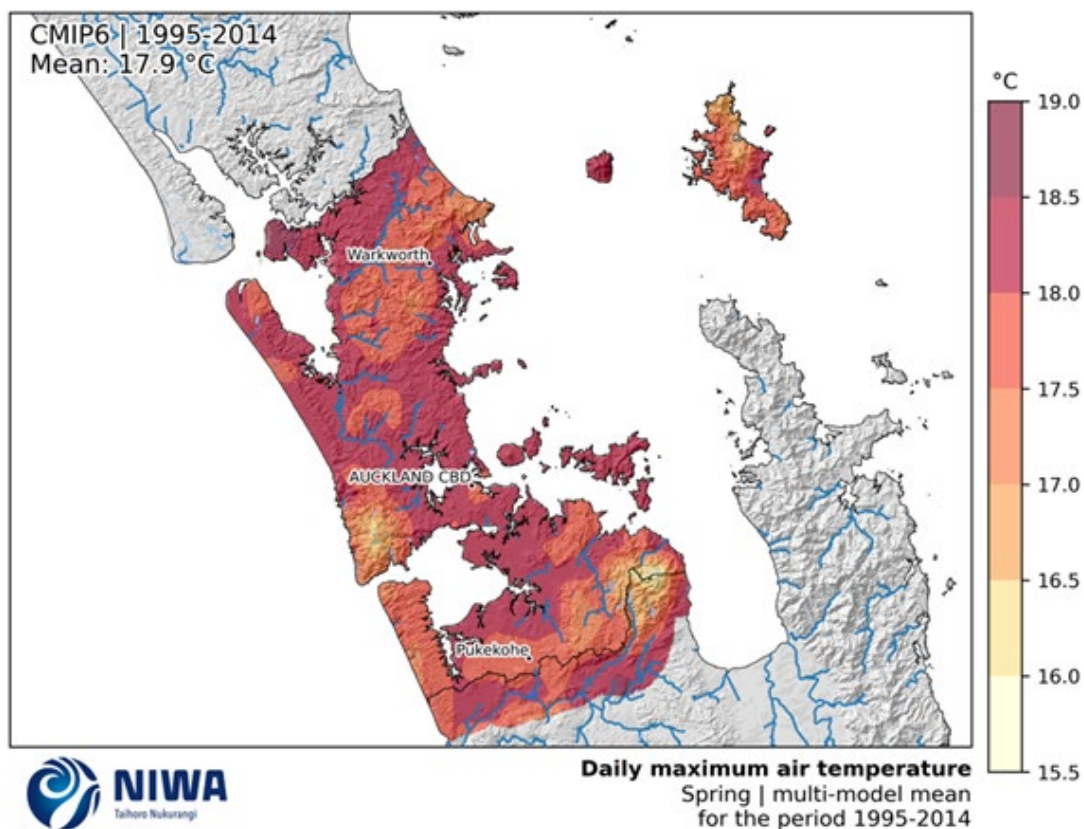


Figure 4-19: Modelled historic spring average daily maximum air temperature.

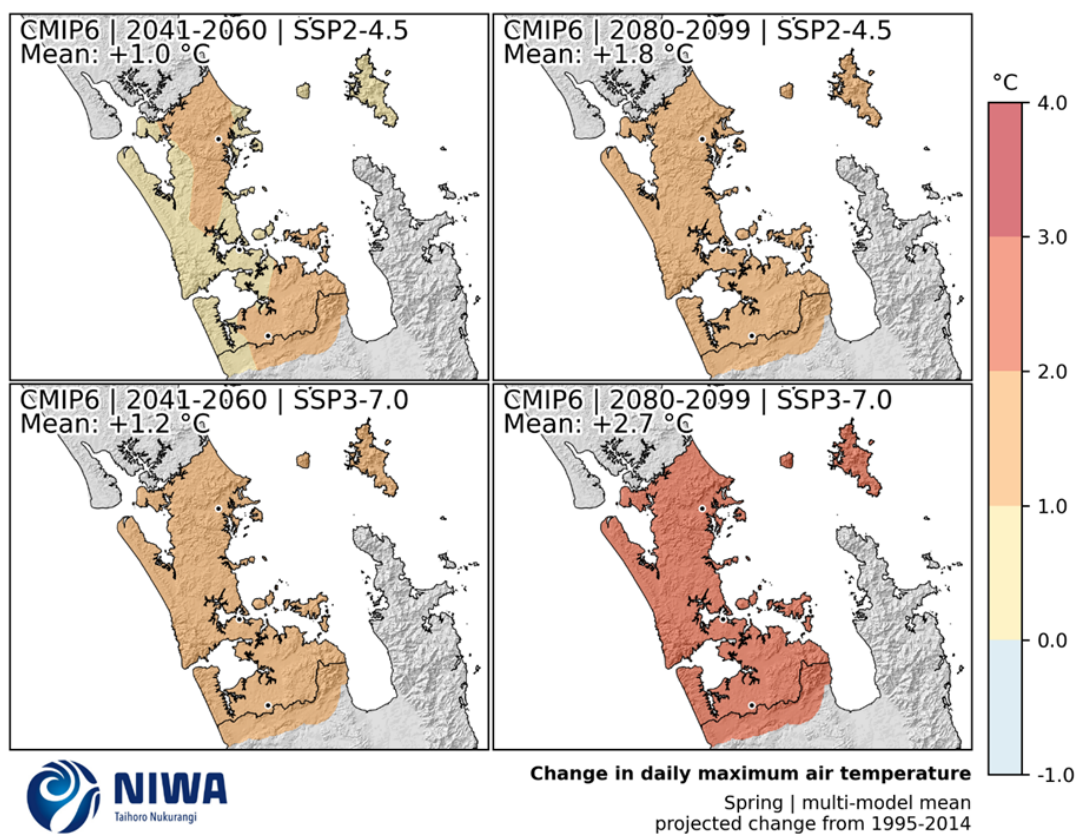


Figure 4-20: Projected spring average daily maximum temperature changes.

4.3 Minimum temperature

Minimum temperature refers to the annual and seasonal average daily minimum temperature. Modelled historic and future projections of annual and seasonal minimum temperature are illustrated in Figure 4-21 to Figure 4-30. Region-wide averages are summarised in the two boxes below.

Historic minimum temperature and projected changes (°C) Relative to 1995-2014 (2004)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2004	2050	2090	2050	2090	2050	2090	2050	2090
Annual	11.0	+0.8	+0.8	+1.0	+1.8	+1.3	+2.8	+1.3	+3.6
Summer	14.5	+1.0	+0.8	+1.2	+2.1	+1.6	+3.4	+1.5	+4.1
Autumn	11.8	+0.8	+0.9	+1.2	+2.0	+1.3	+2.9	+1.4	+3.8
Winter	7.6	+0.7	+0.7	+0.9	+1.6	+1.1	+2.4	+1.2	+3.2
Spring	10.3	+0.7	+0.7	+0.9	+1.6	+1.1	+2.4	+1.2	+3.1

Historic minimum temperature and projected changes (°C) Relative to 1986-2005 (1995)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	1995	2050	2090	2050	2090	2050	2090	2050	2090
Annual	10.8	+1.0	+1.0	+1.2	+2.0	+1.5	+3.0	+1.5	+3.8
Summer	14.3	+1.1	+1.0	+1.4	+2.3	+1.7	+3.6	+1.7	+4.3
Autumn	11.6	+1.0	+1.1	+1.4	+2.2	+1.5	+3.1	+1.6	+4.0
Winter	7.4	+0.9	+0.9	+1.1	+1.9	+1.3	+2.6	+1.4	+3.4
Spring	10.1	+0.8	+0.8	+1.1	+1.8	+1.2	+2.6	+1.4	+3.3

4.3.1 Annual

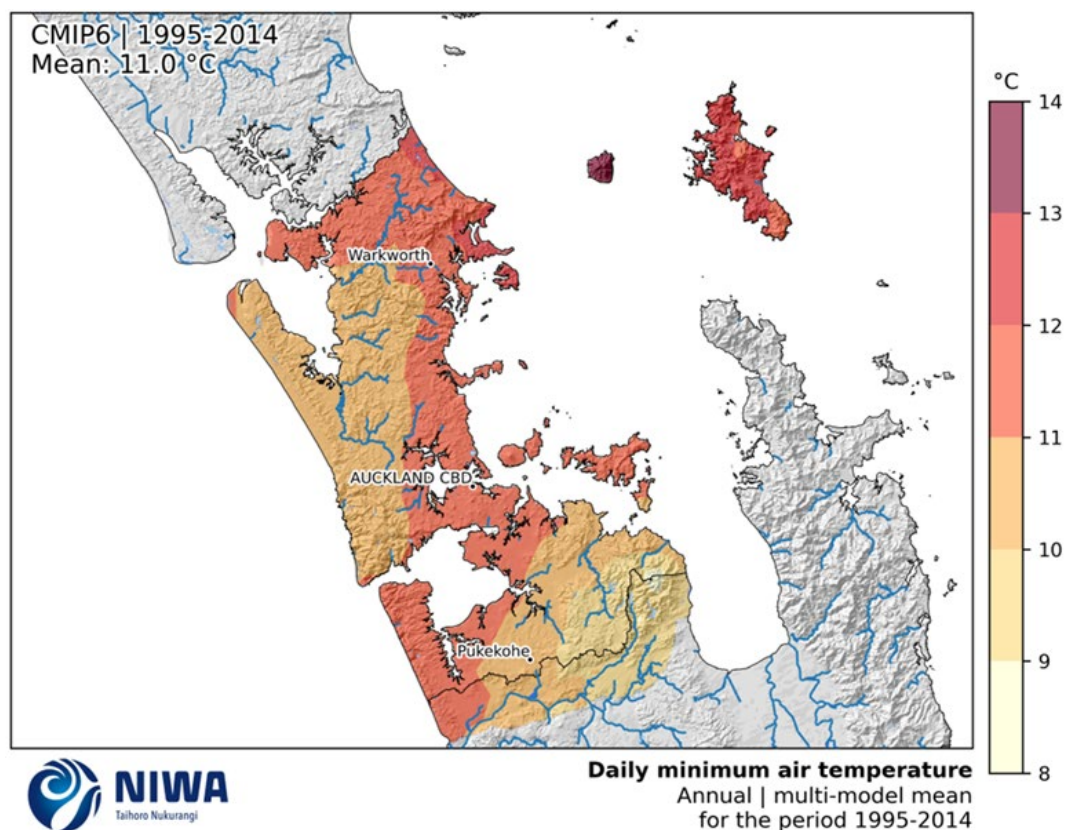


Figure 4-21: Modelled historic annual average daily minimum air temperature.

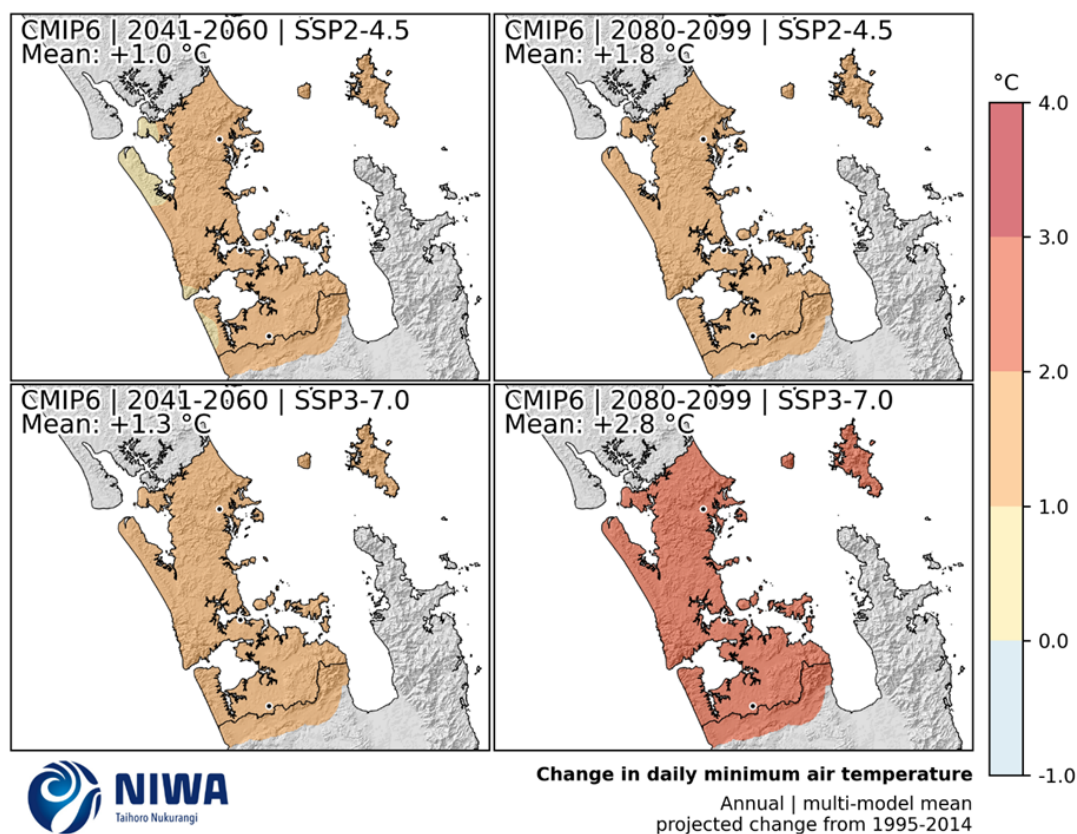


Figure 4-22: Projected annual average daily minimum temperature changes.

4.3.2 Seasonal

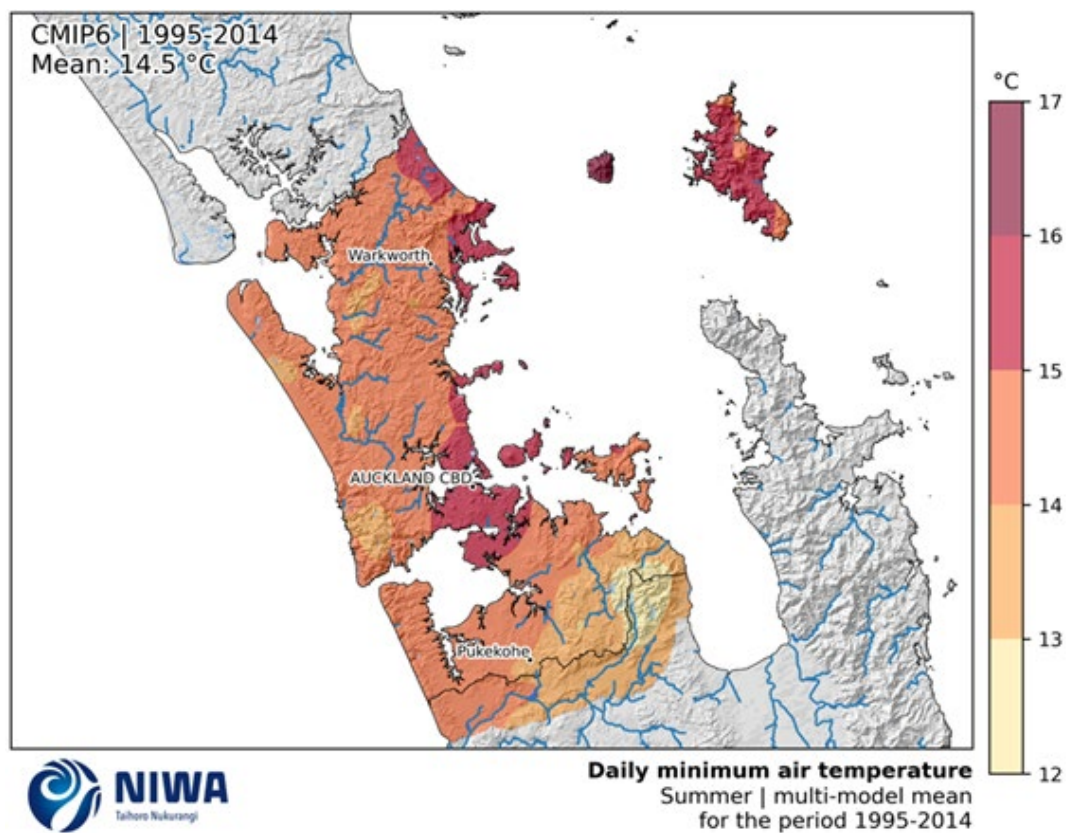


Figure 4-23: Modelled historic summer average daily minimum air temperature.

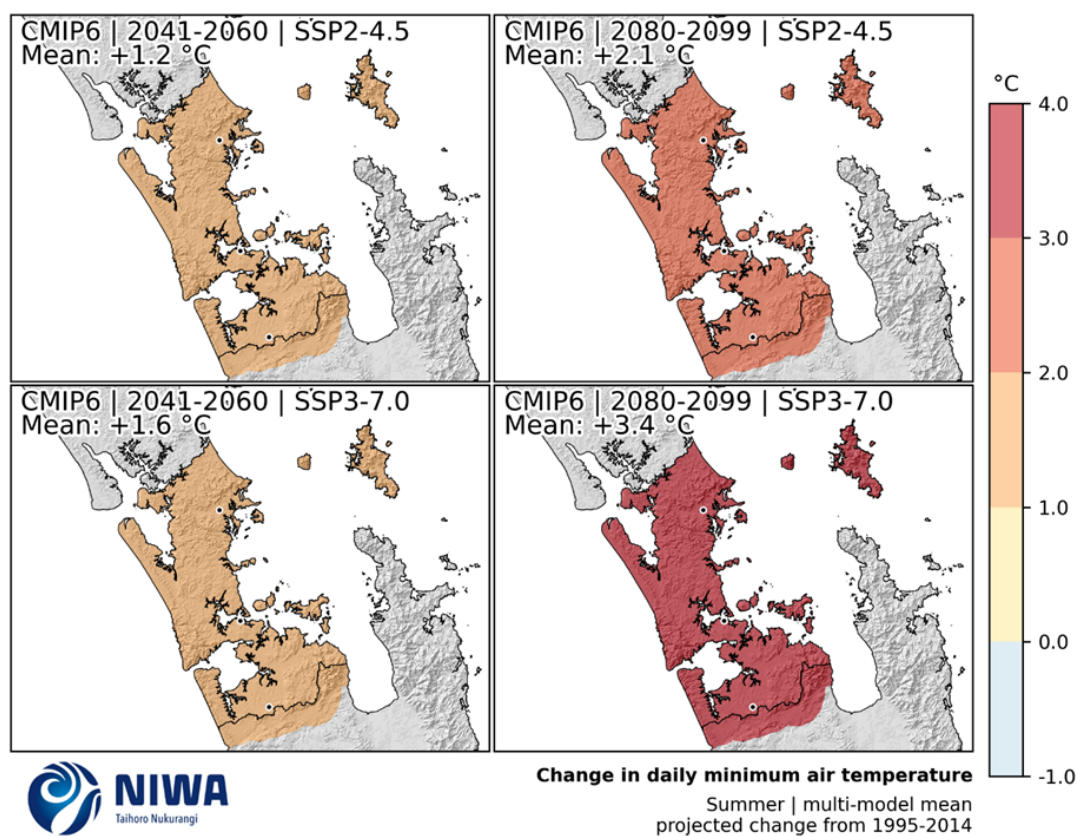


Figure 4-24: Projected summer average daily minimum temperature changes.

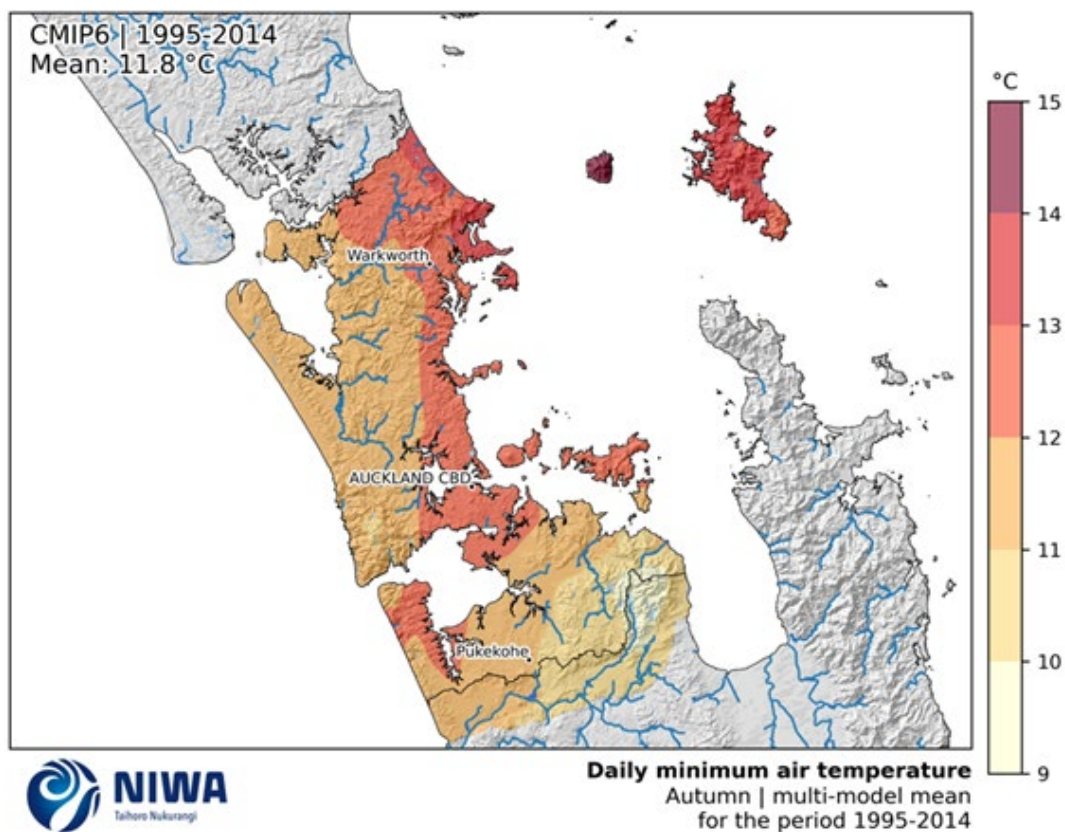


Figure 4-25: Modelled historic autumn average daily minimum air temperature.

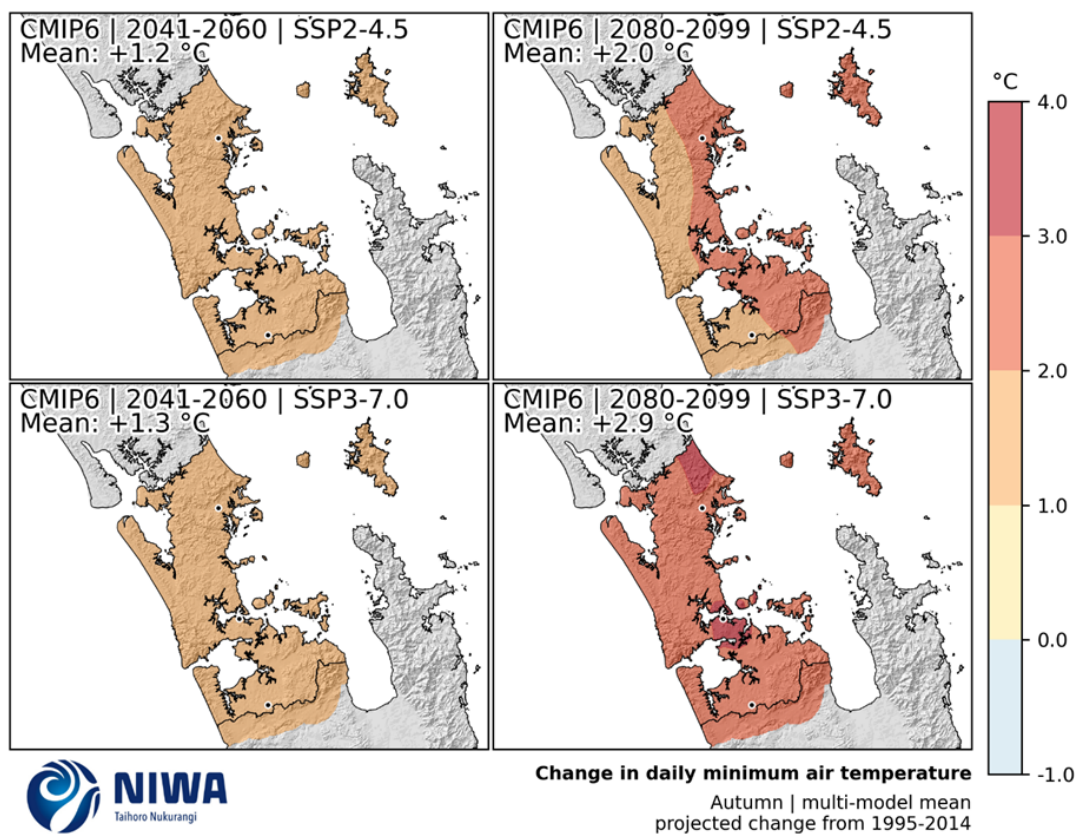


Figure 4-26: Projected autumn average daily minimum temperature changes.

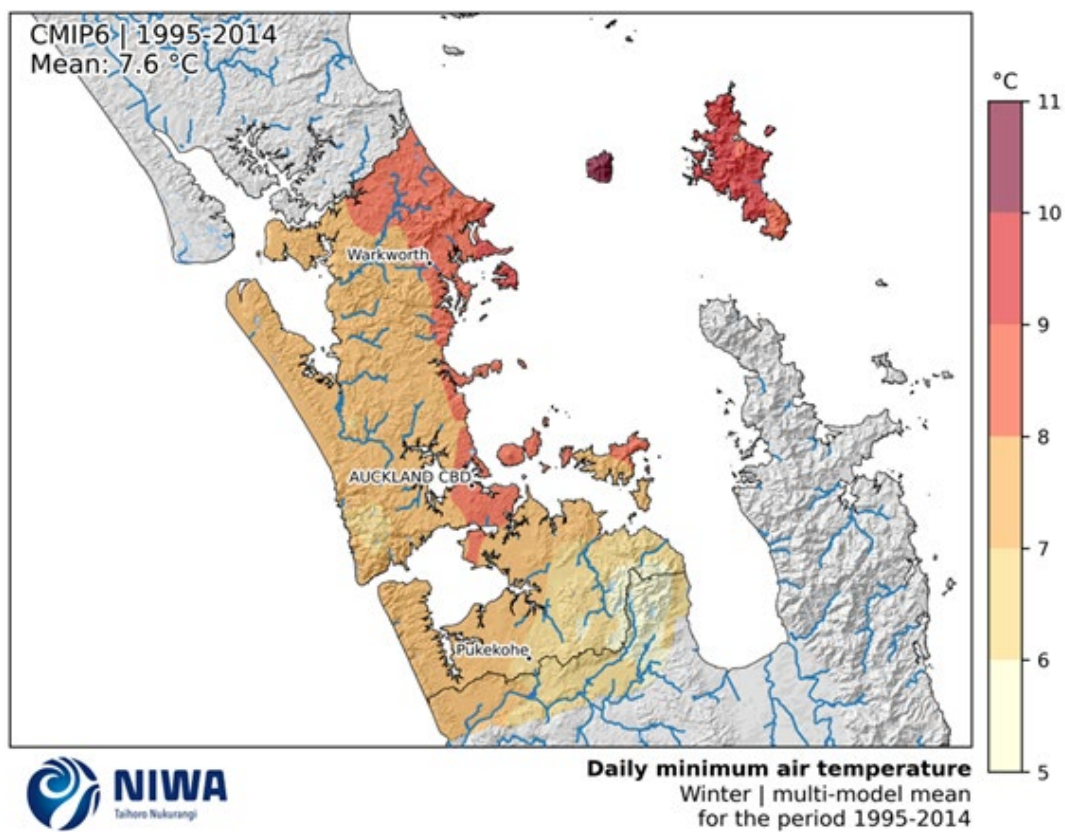


Figure 4-27: Modelled historic winter average daily minimum air temperature.

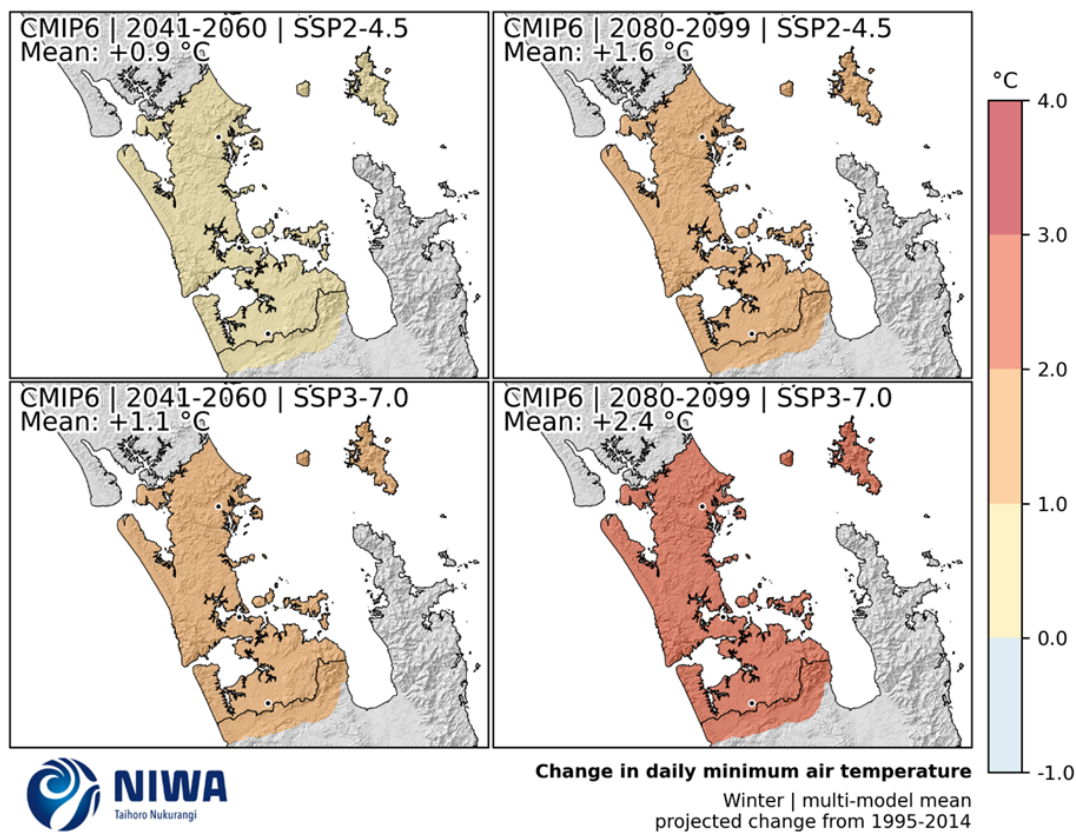


Figure 4-28: Projected winter average daily minimum temperature changes.

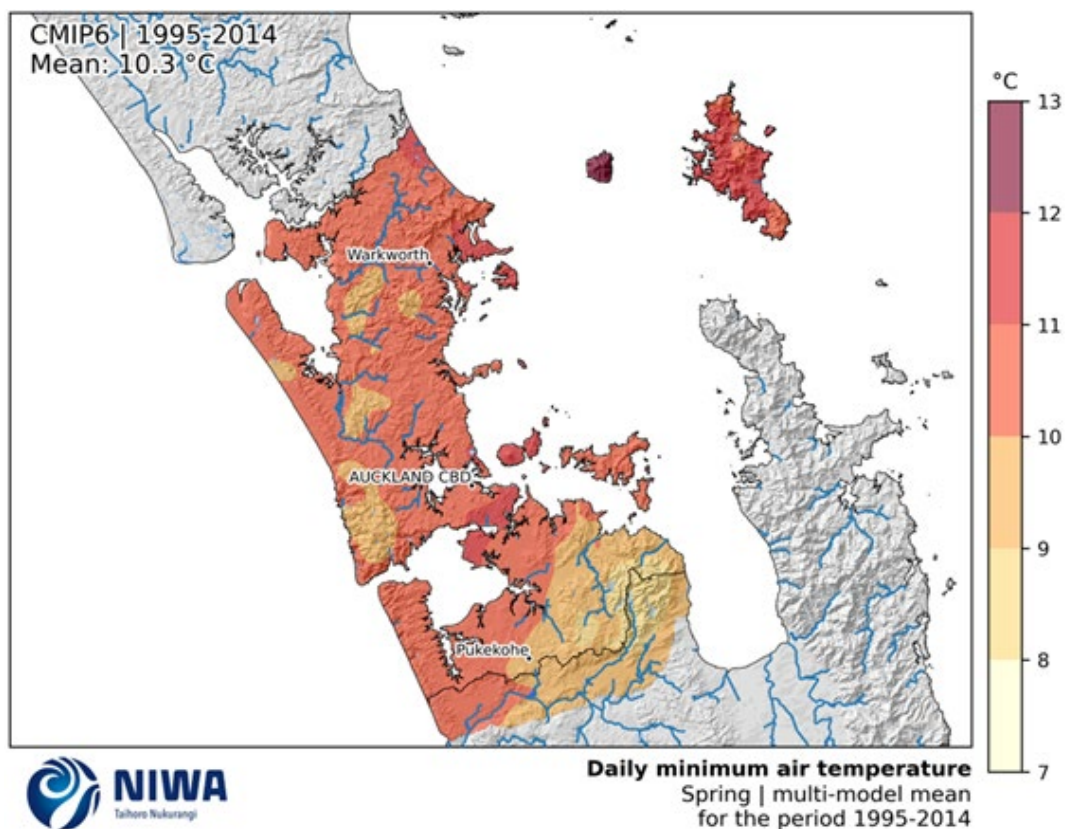


Figure 4-29: Modelled historic spring average daily minimum air temperature.

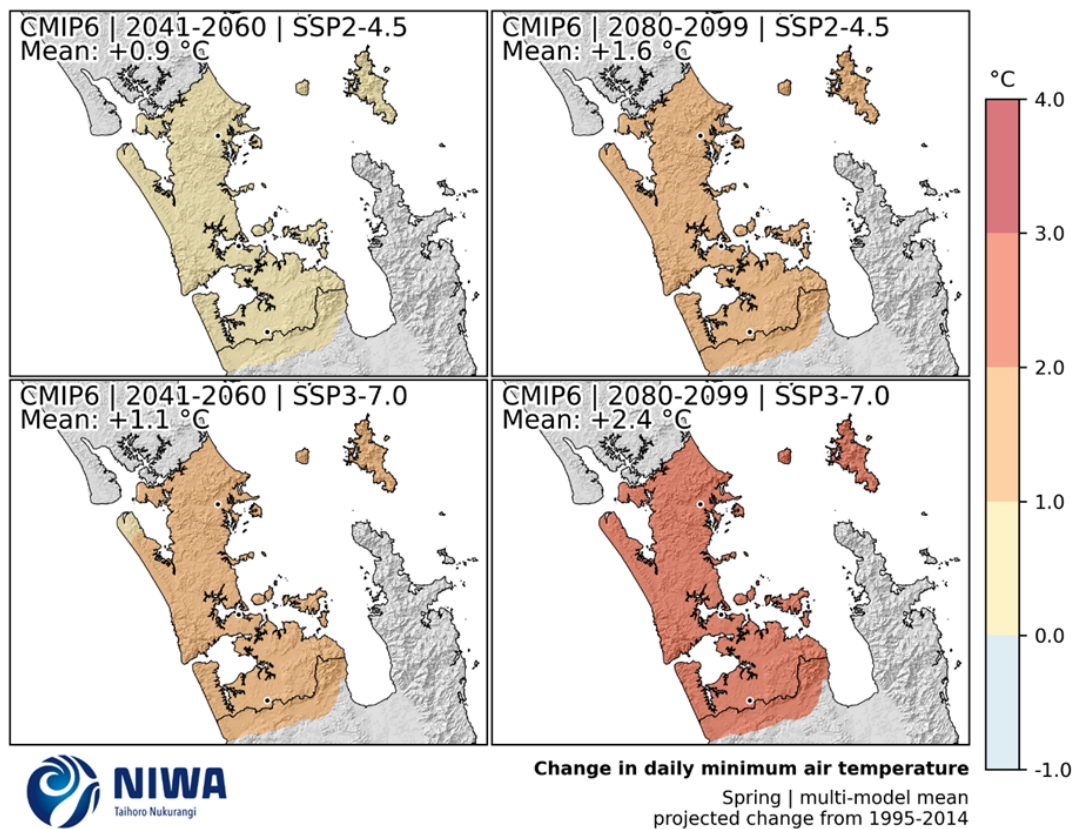


Figure 4-30: Projected spring average daily minimum temperature changes.

4.4 Daily temperature range

Daily temperature range refers to the annual and seasonal average daily temperature range. The daily temperature range is the difference between the daily maximum and minimum temperature. Modelled historic and future projections of annual daily temperature range are illustrated in Figure 4-31 and Figure 4-32. Seasonal maps were generated, but they are not included in this report due to their limited utility. Region-wide averages are summarised in the two boxes below.

Historic daily temperature range and projected changes (°C) Relative to 1995-2014 (2004)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2004	2050	2090	2050	2090	2050	2090	2050	2090
Annual	8.0	+0.1	+0.1	+0.1	+0.1	+0.1	+0.2	+0.1	+0.2
Summer	8.5	0	+0.1	0	+0.1	0	+0.1	+0.2	+0.2
Autumn	8.3	+0.1	+0.1	0	+0.1	+0.1	+0.2	+0.1	+0.2
Winter	7.5	+0.1	+0.1	+0.1	+0.1	+0.1	+0.2	+0.1	+0.2
Spring	7.6	+0.2	+0.1	+0.1	+0.2	+0.1	+0.3	+0.2	+0.4

Historic daily temperature range and projected changes (°C) Relative to 1986-2005 (1995)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	1995	2050	2090	2050	2090	2050	2090	2050	2090
Annual	8.0	+0.1	+0.1	0	+0.1	+0.1	+0.2	+0.1	+0.2
Summer	8.5	+0.1	+0.1	+0.1	+0.1	+0.1	+0.1	+0.2	+0.2
Autumn	8.3	+0.1	0	0	+0.1	+0.1	+0.1	+0.1	+0.1
Winter	7.5	0	0	0	0	0	+0.2	0	+0.1
Spring	7.6	+0.2	+0.1	+0.1	+0.2	+0.2	+0.3	+0.2	+0.4

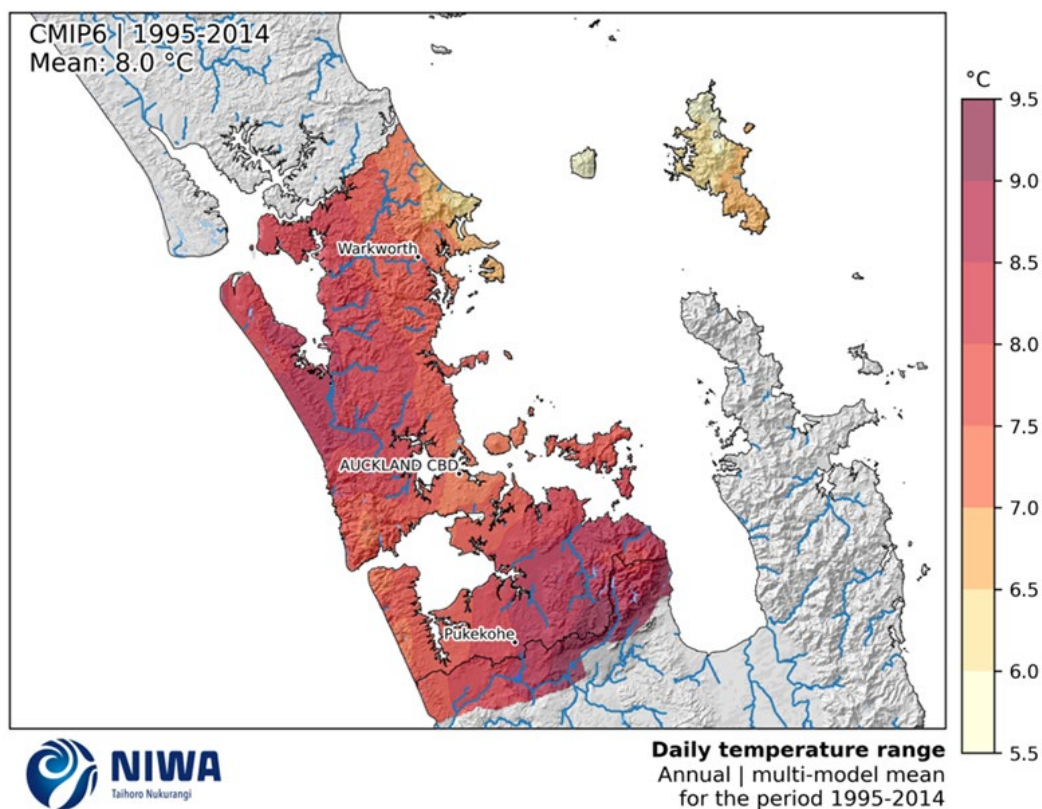


Figure 4-31: Modelled historic annual average daily temperature range.

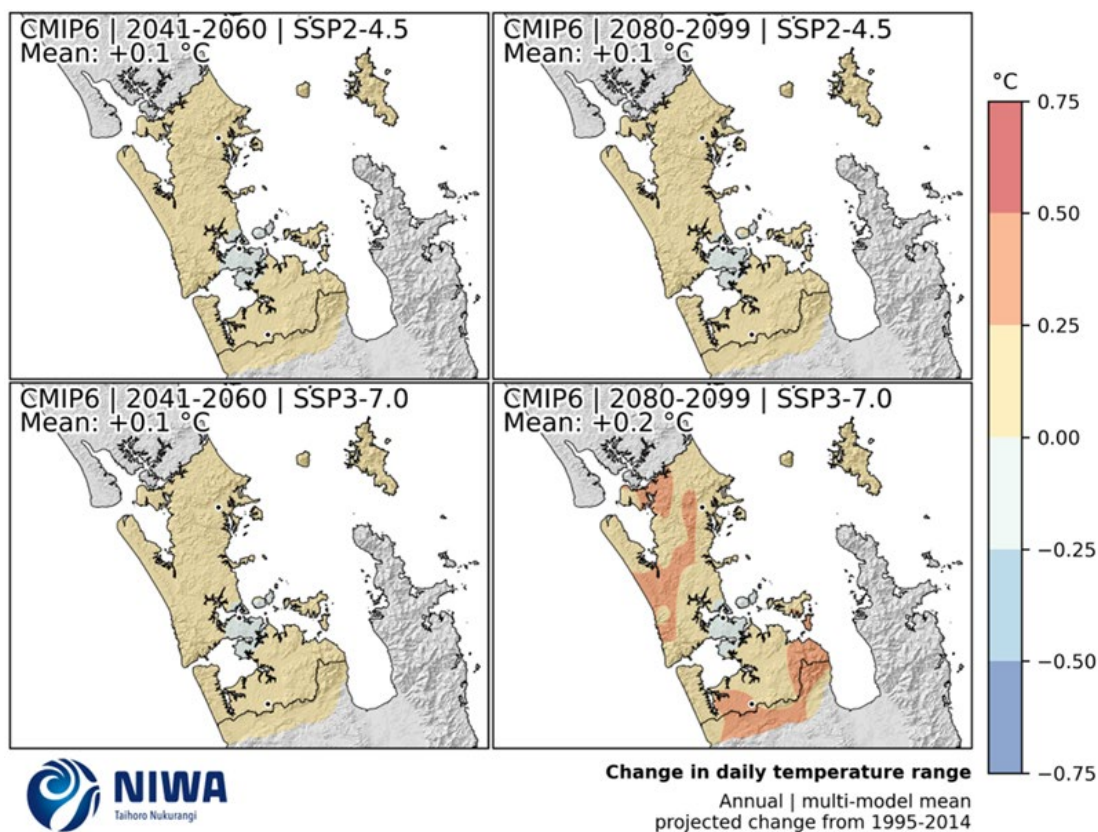


Figure 4-32: Projected annual average daily temperature range changes.

4.5 Hot days (>25°C)

Hot days (>25°C) refers to the annual and seasonal average number of days where the maximum temperature exceeds 25°C. Modelled historic and future projections of annual and seasonal hot days (>25°C) are illustrated in Figure 4-33 to Figure 4-40. Winter maps were generated, but are not included in this report due to their limited utility.

Note, the maps illustrate comparatively high values of historic hot days about South Head of Te Korowai-o-Te-Tonga Peninsula and Ōkahukura Peninsula near Kaipara Harbour. These relatively high values are more pronounced in the models compared to historical climate observations for this region, and illustrate the challenge and uncertainty associated with modelling climate variables at high spatial resolution. In any case, the projected changes are not directly impacted by these localised large modelled historic values. Readers are also encouraged to place greater emphasis on region-wide projections, rather than overinterpret localised values.

Region-wide averages are summarised in the two boxes below.

Historic hot days and projected changes (days) Relative to 1995-2014 (2004)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2004	2050	2090	2050	2090	2050	2090	2050	2090
Annual	19.6	+20.2	+17.9	+25.0	+49.3	+33.6	+77.6	+35.7	+98.9
Summer	16.4	+14.5	+12.6	+17.6	+32.9	+23.9	+49.2	+24.9	+57.5
Autumn	3.0	+5.4	+4.9	+6.7	+14.5	+8.7	+24.2	+9.5	+32.6
Winter	0	0	0	0	0	0	0	0	0
Spring	0.2	+0.4	+0.4	+0.6	+1.7	+0.8	+4.0	+1.0	+8.6

Historic hot days and projected changes (days) Relative to 1986-2005 (1995)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	1995	2050	2090	2050	2090	2050	2090	2050	2090
Annual	16.6	+23.3	+20.9	+28.1	+52.3	+36.6	+80.7	+38.7	+101.9
Summer	14.0	+16.9	+15.0	+20.0	+35.3	+26.3	+51.6	+27.3	+59.9
Autumn	2.4	+6.0	+5.5	+7.3	+15.1	+9.3	+24.8	+10.1	+33.2
Winter	0	0	0	0	0	0	0	0	0
Spring	0.2	+0.4	+0.4	+0.7	+1.7	+0.8	+4.1	+1.0	+8.6

4.5.1 Annual

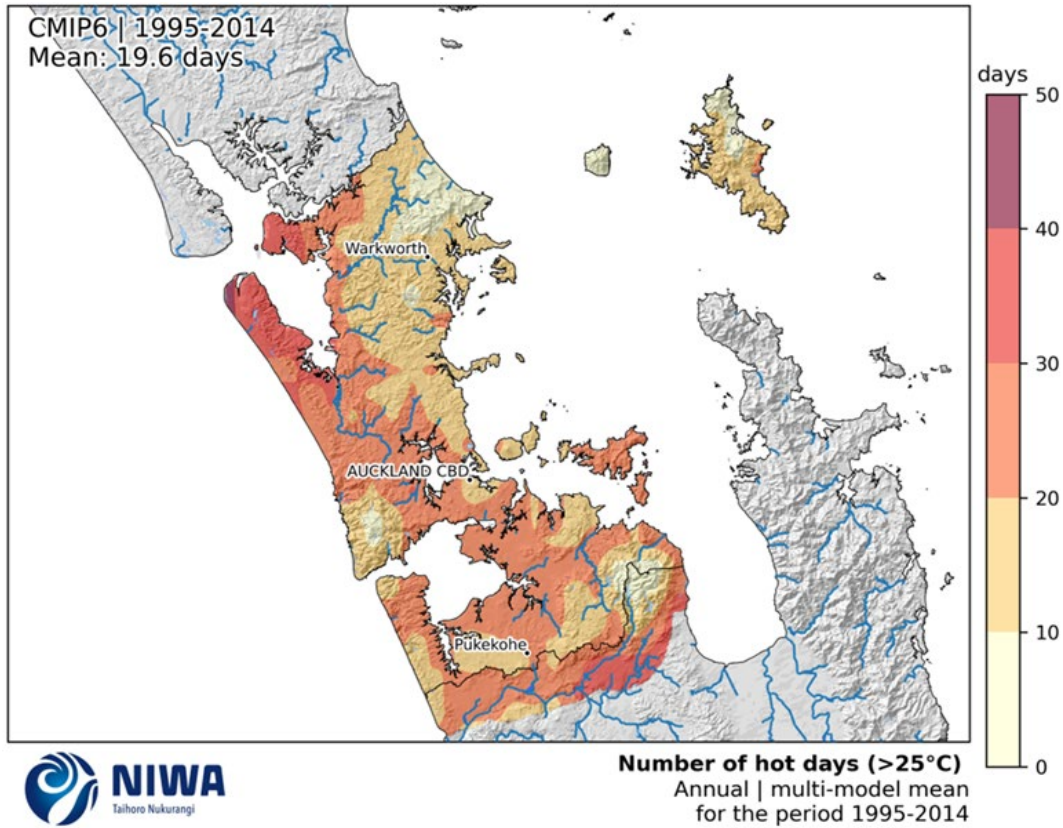


Figure 4-33: Modelled historic average annual number of hot days.

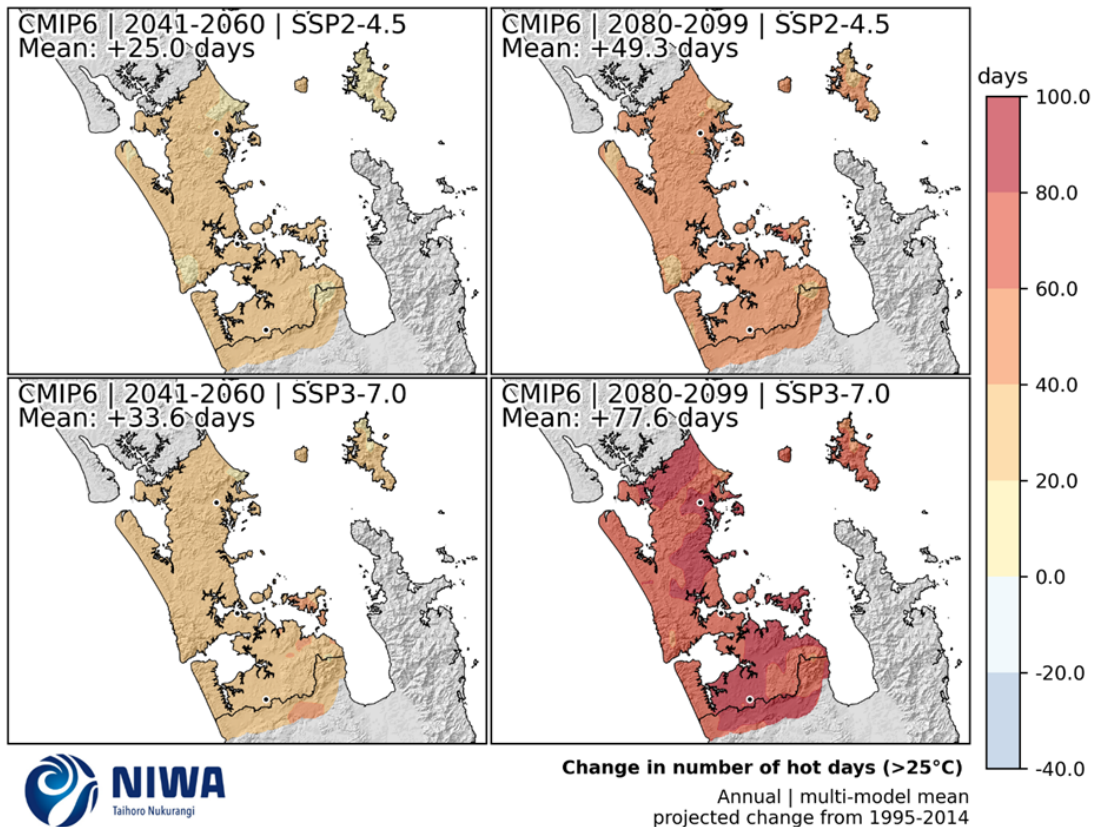


Figure 4-34: Projected annual hot day changes.

4.5.2 Seasonal

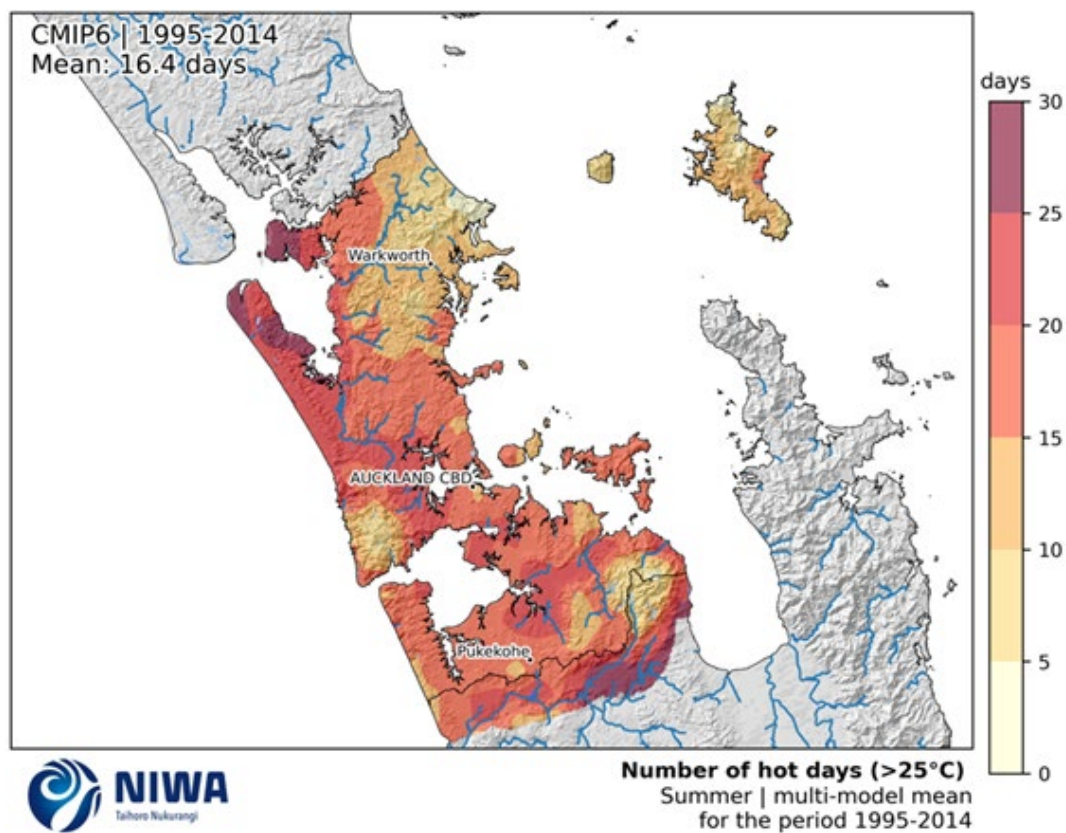


Figure 4-35: Modelled historic average summer number of hot days.

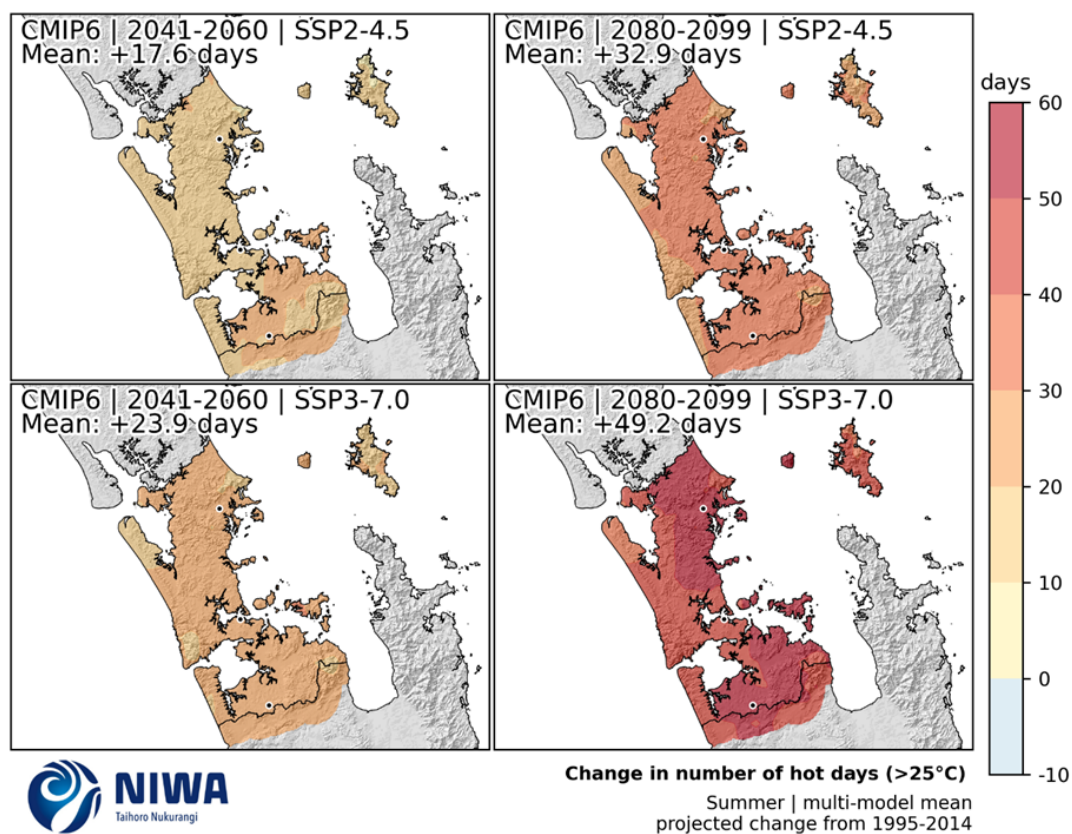


Figure 4-36: Projected summer hot day changes.

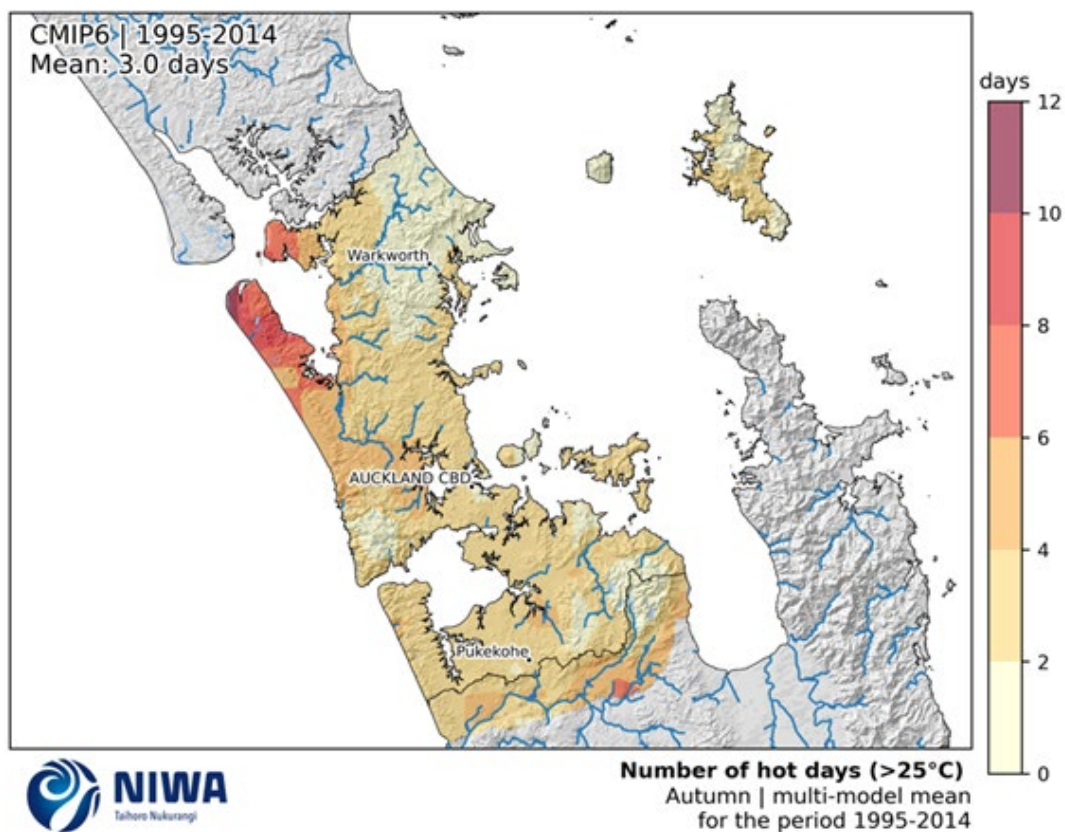


Figure 4-37: Modelled historic average autumn number of hot days.

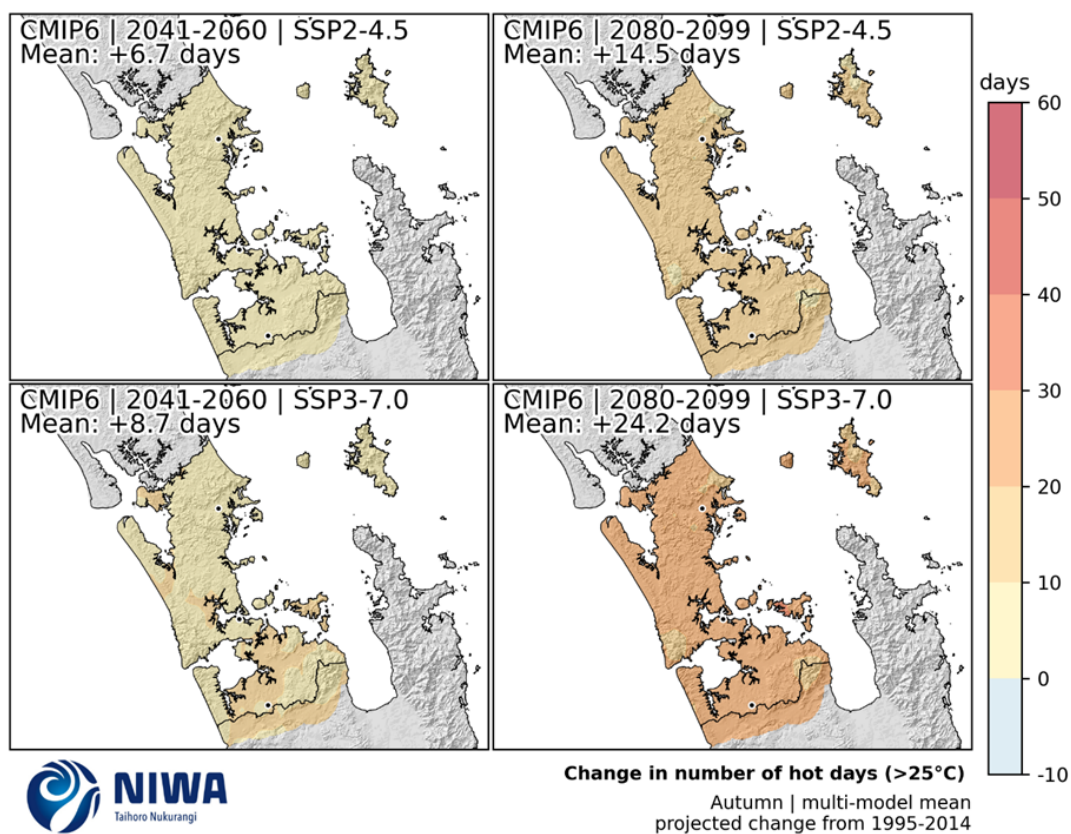


Figure 4-38: Projected autumn hot day changes.

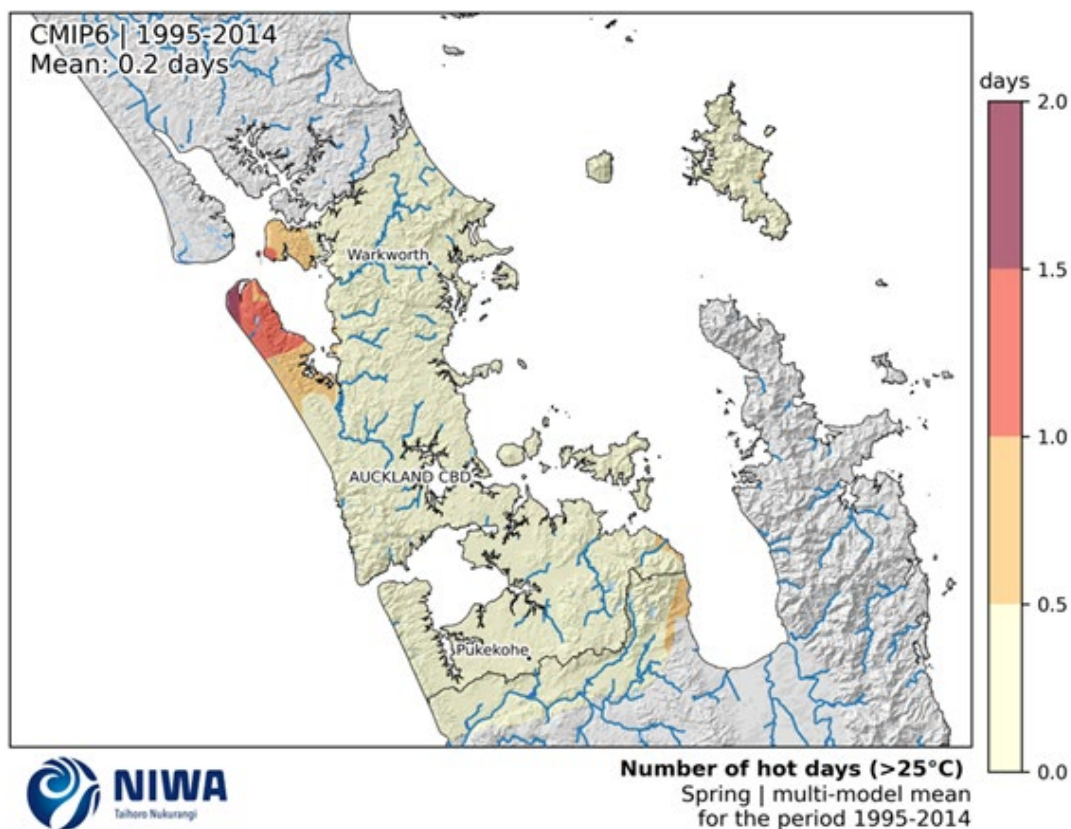


Figure 4-39: Modelled historic average spring number of hot days.

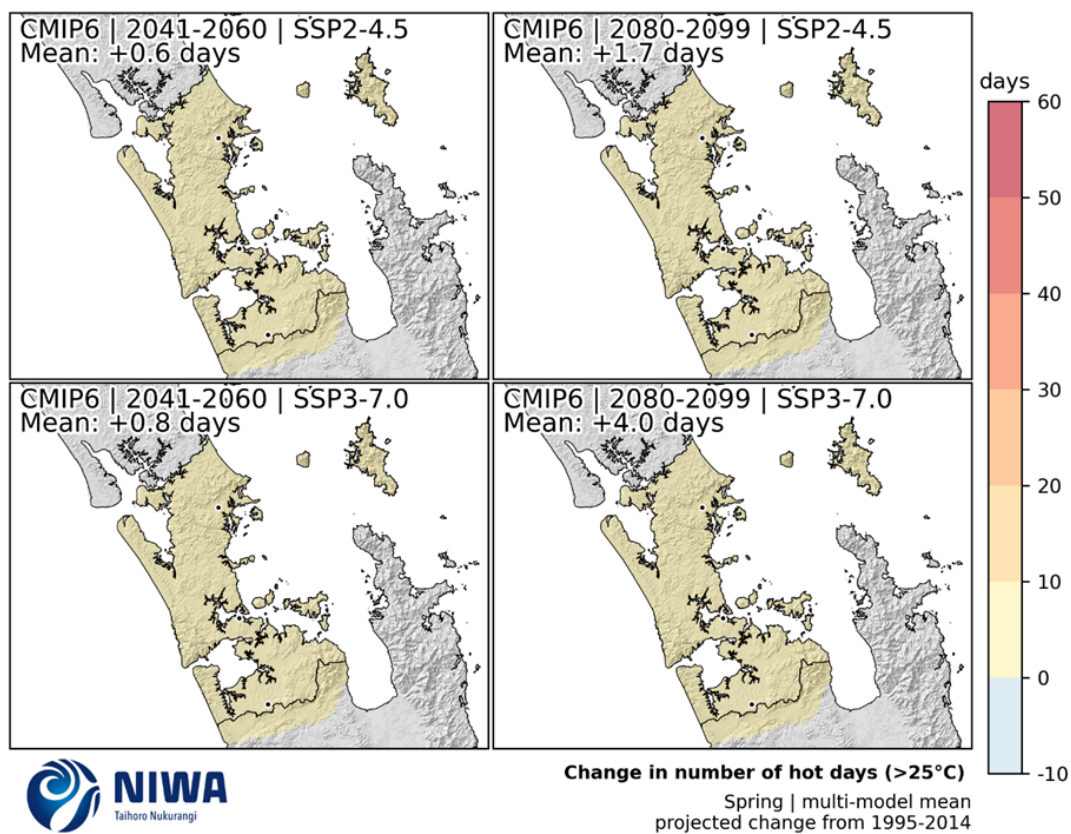


Figure 4-40: Projected spring hot day changes.

4.6 Very hot days (>30°C)

Very hot days (>30°C) refers to the annual and seasonal average number of days where the maximum temperature exceeds 30°C. Modelled historic and future projections of annual and seasonal very hot days (>30°C) are illustrated in Figure 4-41 to Figure 4-46. Winter and spring maps were generated, but are not included in this report due to their limited utility.

Note, the maps illustrate comparatively high values of very hot days about South Head of Te Korowai-o-Te-Tonga Peninsula near Kaipara Harbour. These relatively high values are more pronounced in the models compared to historical climate observations for this region, and illustrate the challenge and uncertainty associated with modelling climate variables at high spatial resolution. In any case, the projected changes are not directly impacted by these localised large modelled historic values. Readers are also encouraged to place greater emphasis on region-wide projections, rather than overinterpret localised values.

Region-wide averages are summarised in the two boxes below.

Historic very hot days and projected changes (days) Relative to 1995-2014 (2004)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2004	2050	2090	2050	2090	2050	2090	2050	2090
Annual	0.1	+0.3	+0.2	+0.5	+1.6	+0.6	+6.8	+0.6	+13.7
Summer	0.1	+0.2	+0.2	+0.4	+1.4	+0.5	+5.8	+0.6	+11.6
Autumn	0	0	0	0	+0.2	0	+0.9	0	+1.9
Winter	0	0	0	0	0	0	0	0	0
Spring	0	0	0	0	0	0	0	0	+0.1

Historic very hot days and projected changes (days) Relative to 1986-2005 (1995)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	1995	2050	2090	2050	2090	2050	2090	2050	2090
Annual	0	+0.3	+0.2	+0.5	+1.6	+0.6	+6.8	+0.7	+13.7
Summer	0	+0.3	+0.2	+0.5	+1.4	+0.5	+5.8	+0.6	+11.6
Autumn	0	0	0	0	+0.2	0	+0.9	0	+1.9
Winter	0	0	0	0	0	0	0	0	0
Spring	0	0	0	0	0	0	0	0	+0.1

4.6.1 Annual

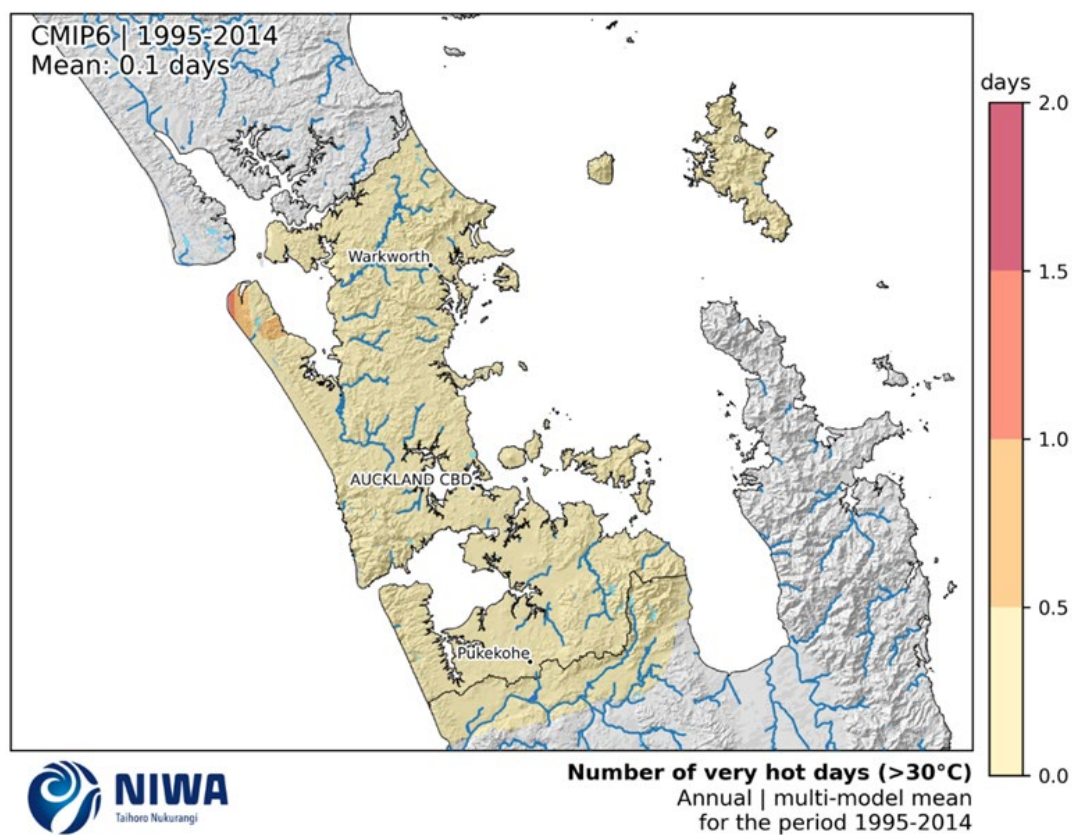


Figure 4-41: Modelled historic average annual number of very hot days.

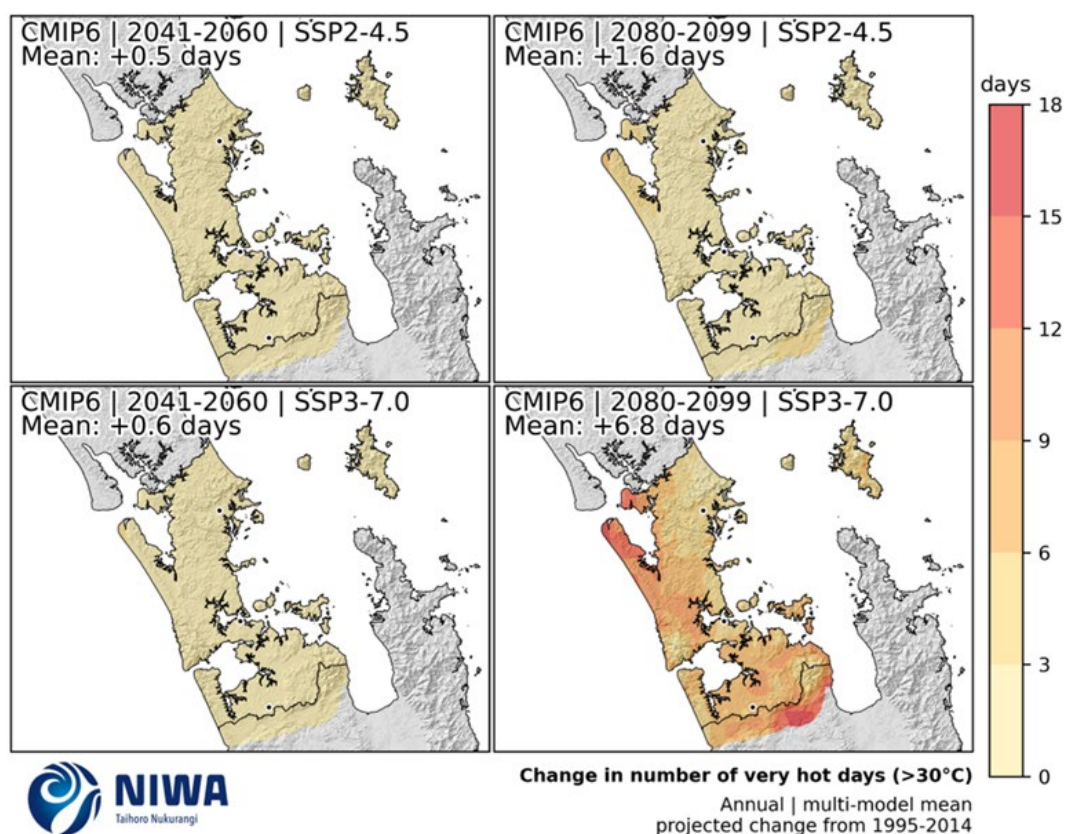


Figure 4-42: Projected annual very hot day changes.

4.6.2 Seasonal

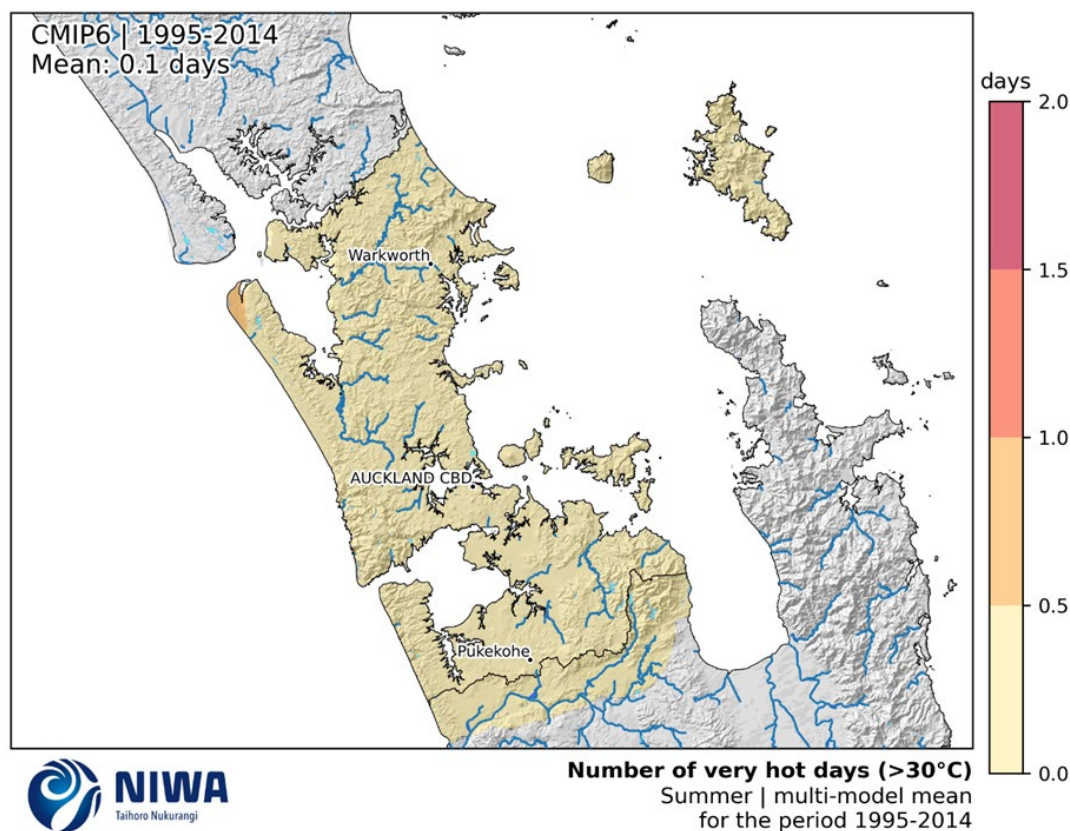


Figure 4-43: Modelled historic average summer number of very hot days.

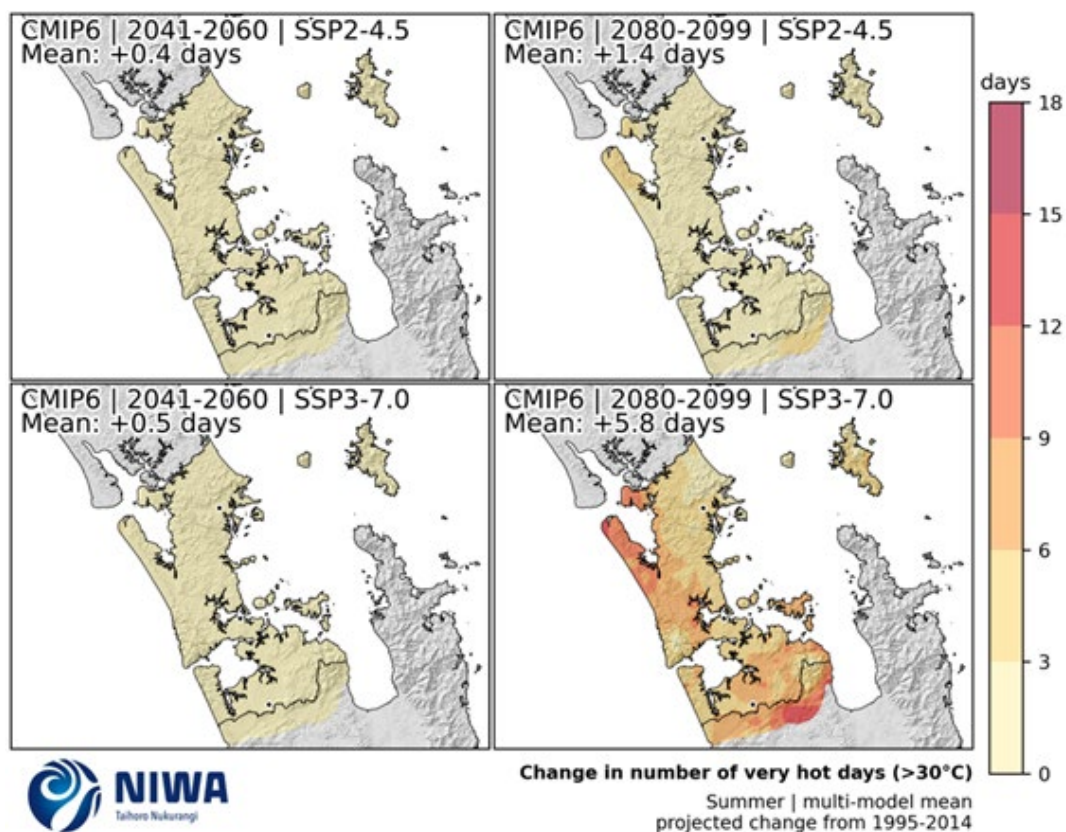


Figure 4-44: Projected summer very hot day changes.

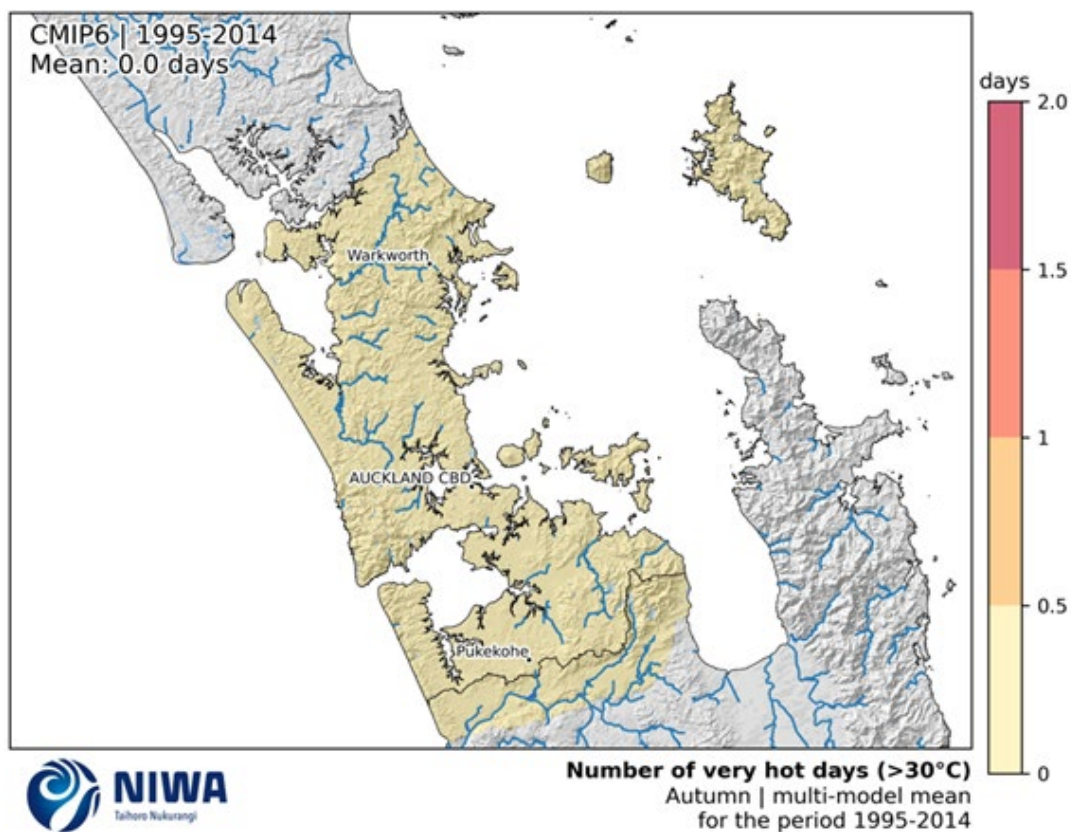


Figure 4-45: Modelled historic average autumn number of very hot days.

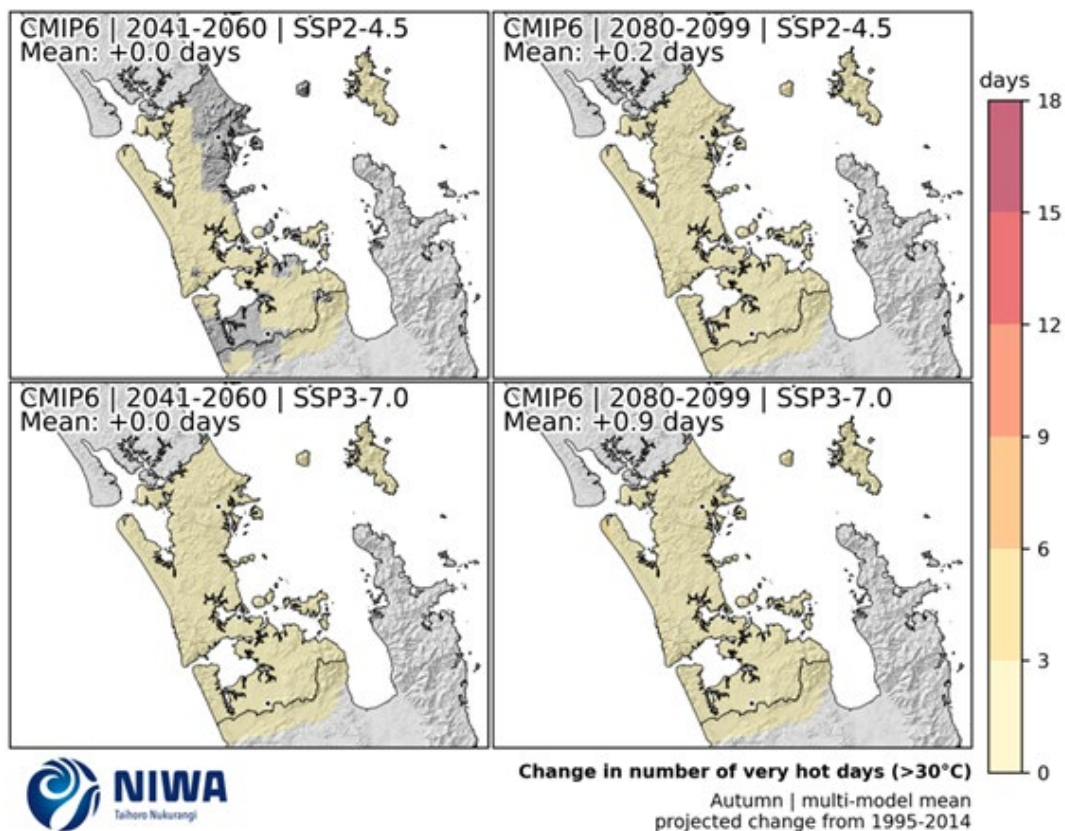


Figure 4-46: Projected autumn very hot day changes.

4.7 Heatwave frequency

A plethora of metrics may be used to measure heatwaves and warm spells. Following the framework of Perkins and Alexander (2013), a heatwave is defined here as a period of at least three consecutive days during which the daily maximum temperature exceeds the 90th percentile. It is calculated relative to the time of year (using a 15-day moving window) and specific location (i.e., percentiles are computed separately for each grid cell based on historical data). The analysis is restricted to the southern hemisphere extended summer period, from November through March.

Heatwave frequency refers to the annual number of days spent in heatwave. Modelled future projections of annual heatwave frequency are illustrated in Figure 4-47. The map of modelled historic annual heatwave frequency is not included here because there was little discernible spatial variability. The historic average (for both historic periods) for the region is 2.3 heatwave days per year; or a total of 46 days of heatwave over the historic 20-year period. Region-wide average projected changes are summarised in the two boxes below.

Projected heatwave frequency changes (days)								
Relative to 1995-2014 (2004)								
	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090	2050	2090
Annual	+11.9	+10.8	+15.9	+39.7	+23.4	+79.7	+24.9	+106.4

Projected heatwave frequency changes (days)								
Relative to 1986-2005 (1995)								
	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090	2050	2090
Annual	+15.6	+14.3	+20.5	+47.3	+28.8	+88.1	+30.6	+113.8

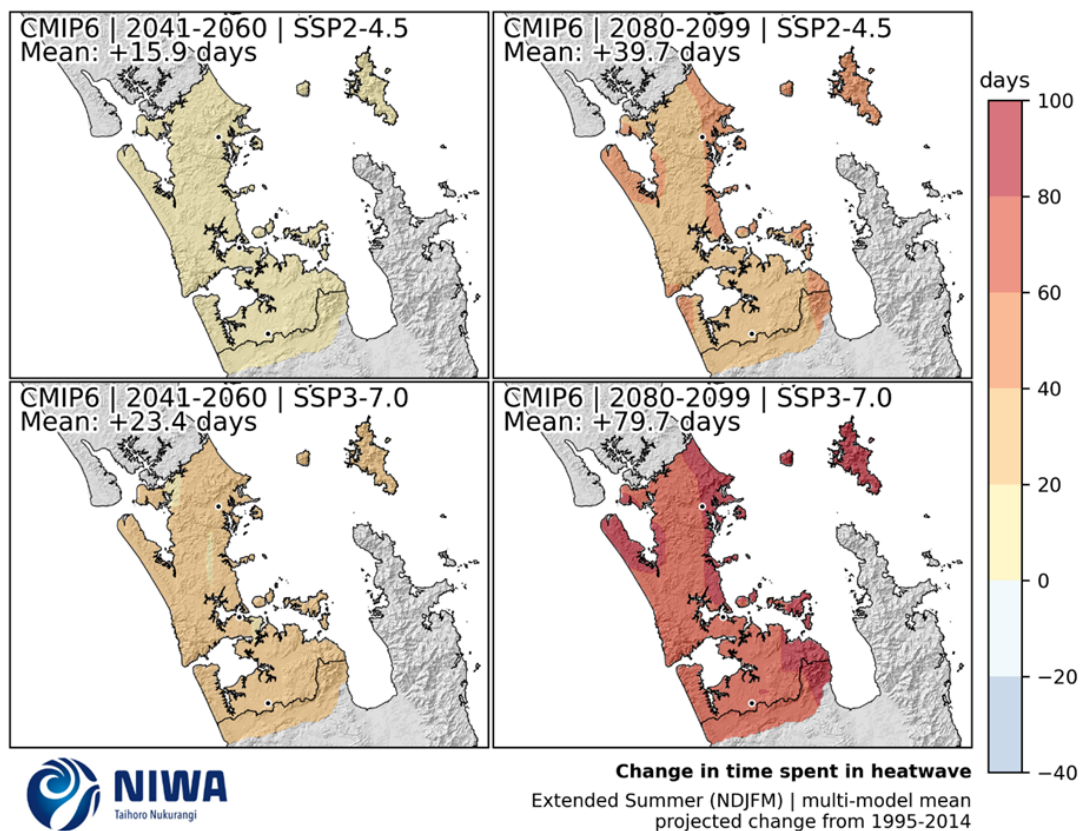


Figure 4-47: Projected annual heatwave frequency changes.

4.8 Heatwave duration

Heatwave duration refers to the length of the longest annual heatwave. A heatwave is defined as described above for *Heatwave frequency* (Section 4.7). The analysis is restricted to the southern hemisphere extended summer period, from November through March.

Modelled future projections of annual heatwave frequency are illustrated in Figure 4-48. The map of modelled historic annual longest heatwave is not included here because there was little discernible spatial variability. The historic annual average (for both historic periods) for the region is 3.8 days. Region-wide average projected changes are summarised in the two boxes below.

Projected heatwave duration changes (days)								
Relative to 1995-2014 (2004)								
	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090	2050	2090
Annual	+2.2	+2.1	+3.3	+8.2	+4.9	+20.7	+4.9	+30.1

Projected heatwave duration changes (days)								
Relative to 1986-2005 (1995)								
	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090	2050	2090
Annual	+2.9	+2.7	+4.1	+9.5	+5.8	+23.5	+5.9	+34.6

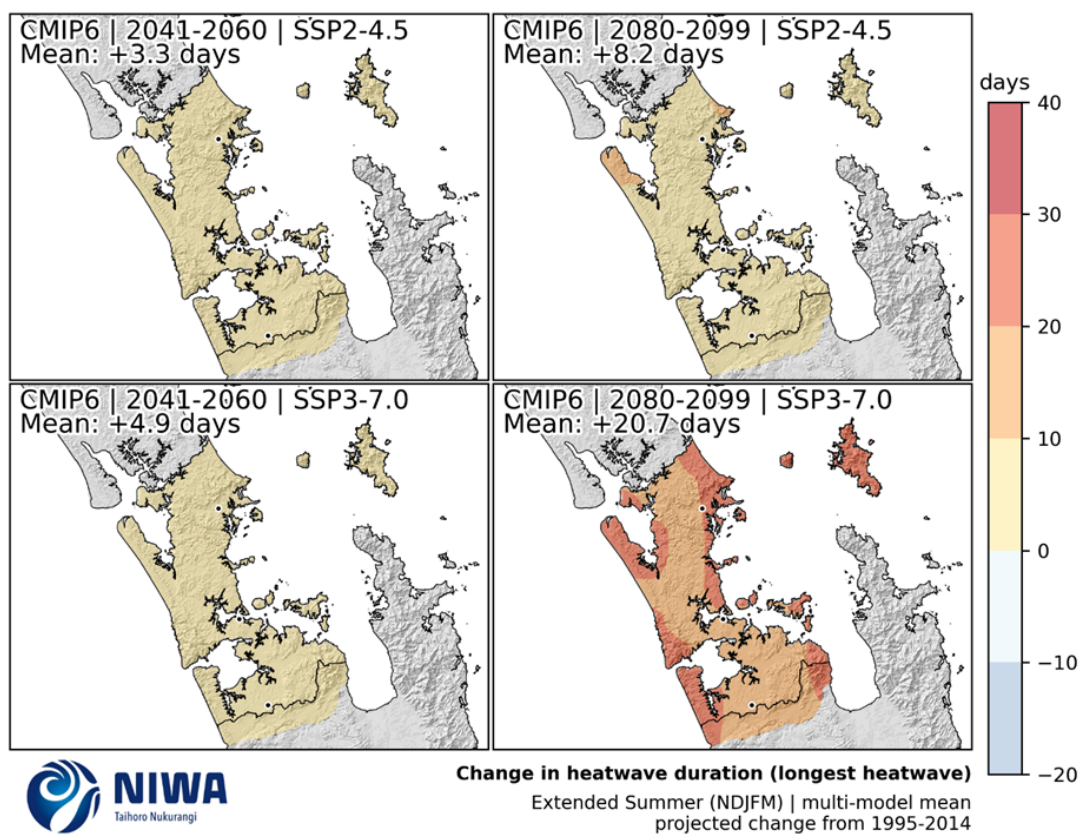


Figure 4-48: Projected annual heatwave duration changes.

4.9 Total rainfall

Total rainfall refers to the average annual and seasonal rainfall amount. Modelled historic and future projections of annual and seasonal total rainfall are illustrated in Figure 4-49 to Figure 4-58. Region-wide averages are summarised in the two boxes below.

Historic total rainfall (mm) and projected changes (%) Relative to 1995-2014 (2004)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2004	2050	2090	2050	2090	2050	2090	2050	2090
Annual	1,340	-1.0	-0.2	-1.3	-3.5	-1.9	-9.2	-5.4	-8.9
Summer	240	+3.8	+2.5	+5.2	-2.9	+3.1	+4.0	-4.8	+8.2
Autumn	323	-5.3	+1.3	+2.6	+0.3	+3.1	-5.9	-3.4	-6.3
Winter	463	+1.7	+1.4	-2.3	-2.2	-1.4	-12.5	-4.1	-13.0
Spring	309	-3.4	-5.6	-7.4	-10.4	-10.6	-16.8	-10.1	-18.5

Historic total rainfall (mm) and projected changes (%) Relative to 1986-2005 (1995)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	1995	2050	2090	2050	2090	2050	2090	2050	2090
Annual	1,350	-1.7	-0.9	-2.0	-4.1	-2.6	-9.8	-6.1	-9.6
Summer	246	+3.1	+1.8	+4.6	-3.5	+2.4	+3.3	-5.4	+7.5
Autumn	320	-4.2	+2.5	+3.8	+1.4	+4.3	-4.8	-2.3	-5.3
Winter	463	+1.7	+1.4	-2.3	-2.2	-1.4	-12.5	-4.1	-13.0
Spring	322	-7.3	-9.4	-11.1	-14.0	-14.2	-20.1	-13.7	-21.8

4.9.1 Annual

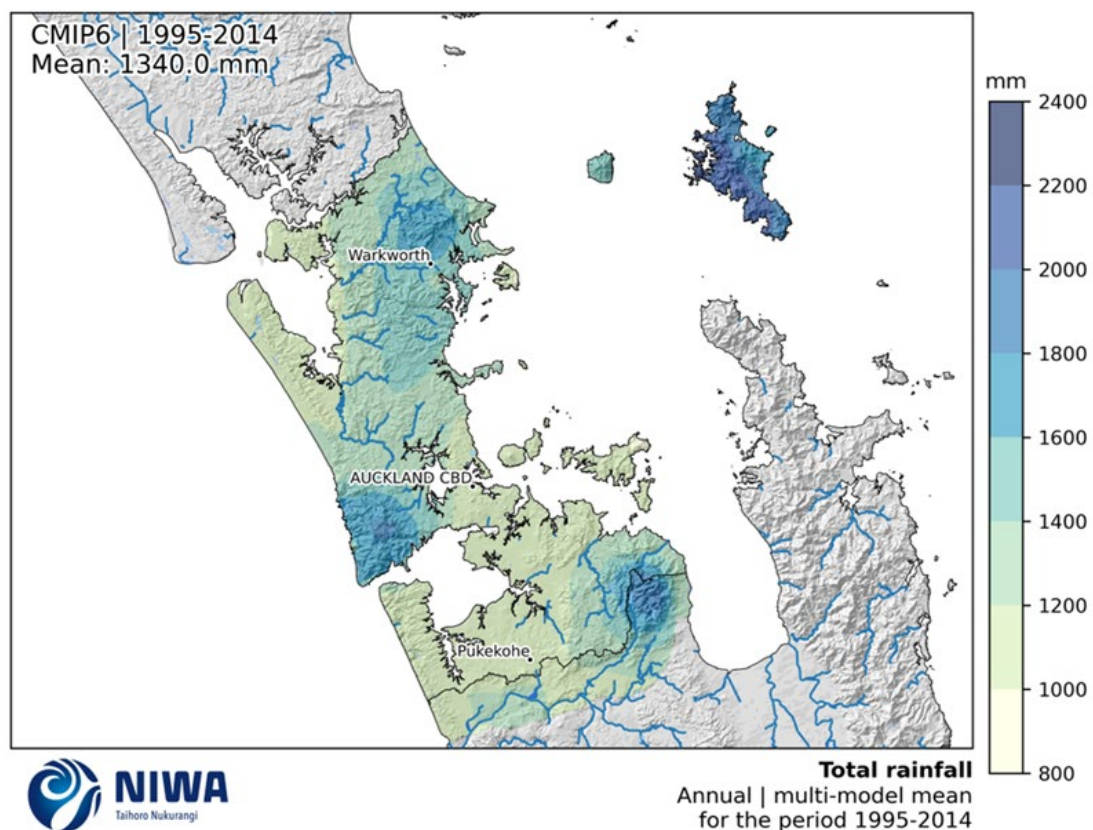


Figure 4-49: Modelled historic average annual total rainfall.

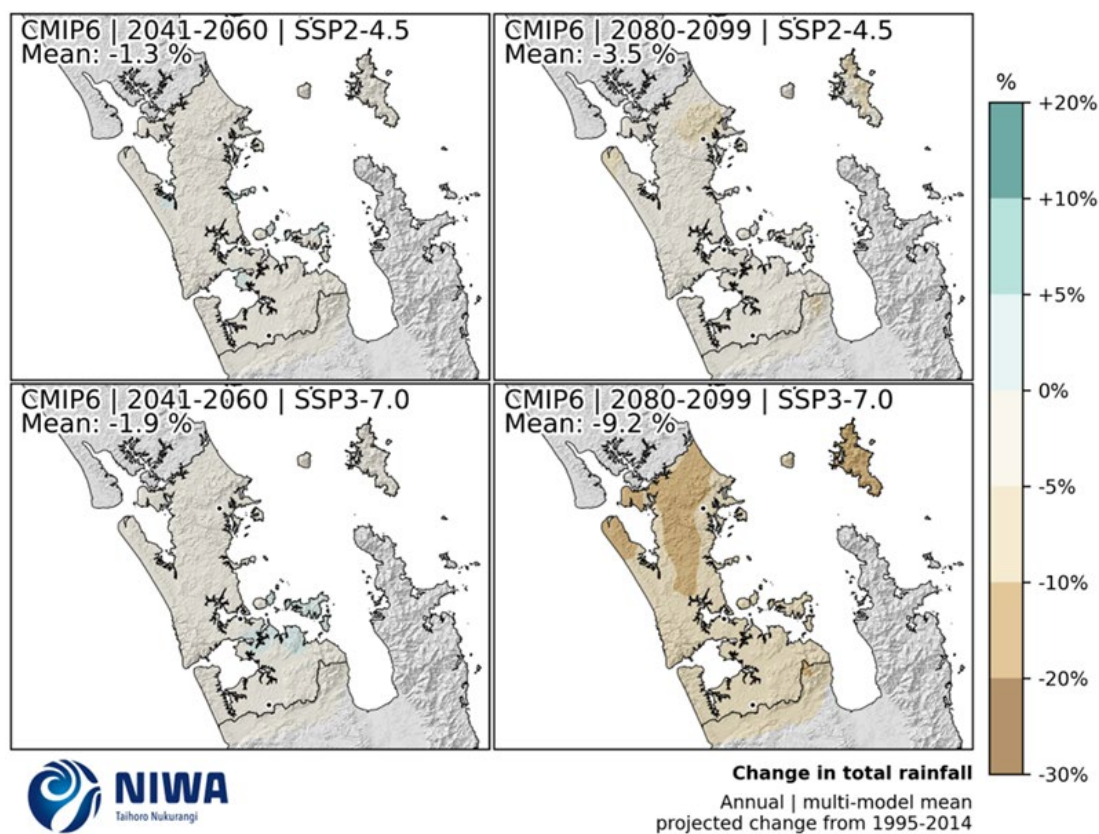


Figure 4-50: Projected annual average total rainfall changes.

4.9.2 Seasonal

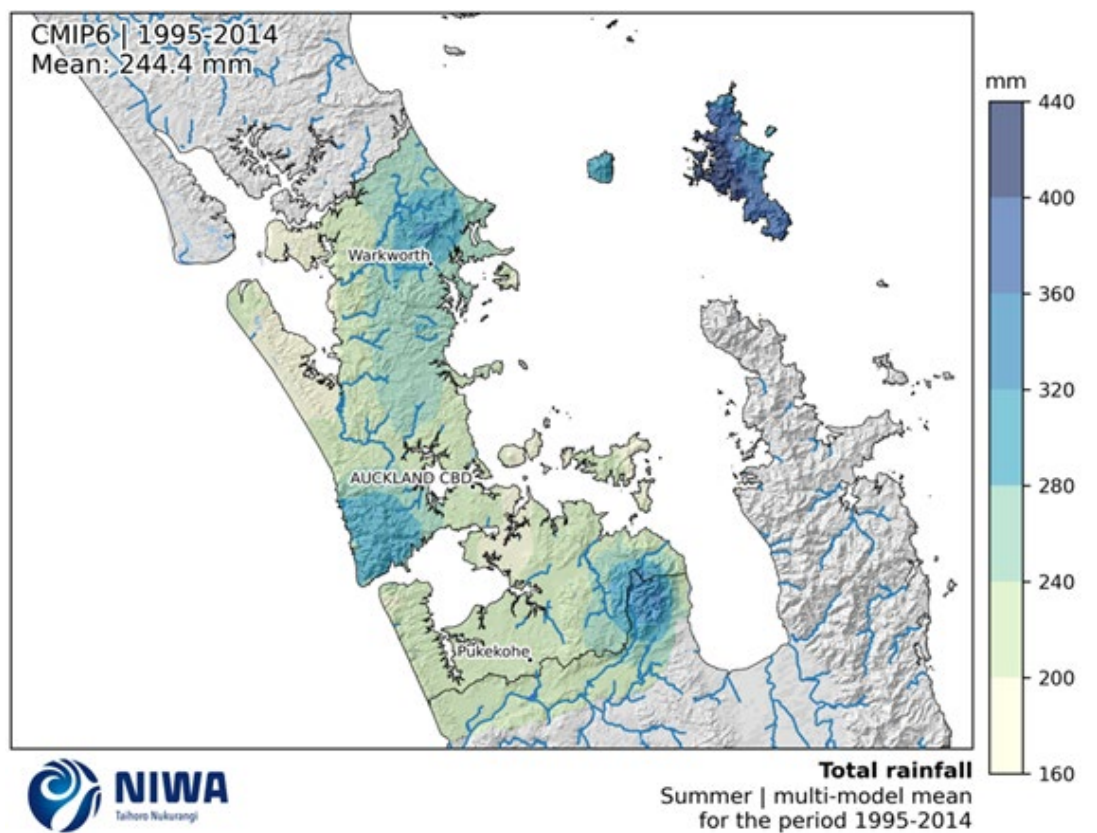


Figure 4-51: Modelled historic average summer total rainfall.

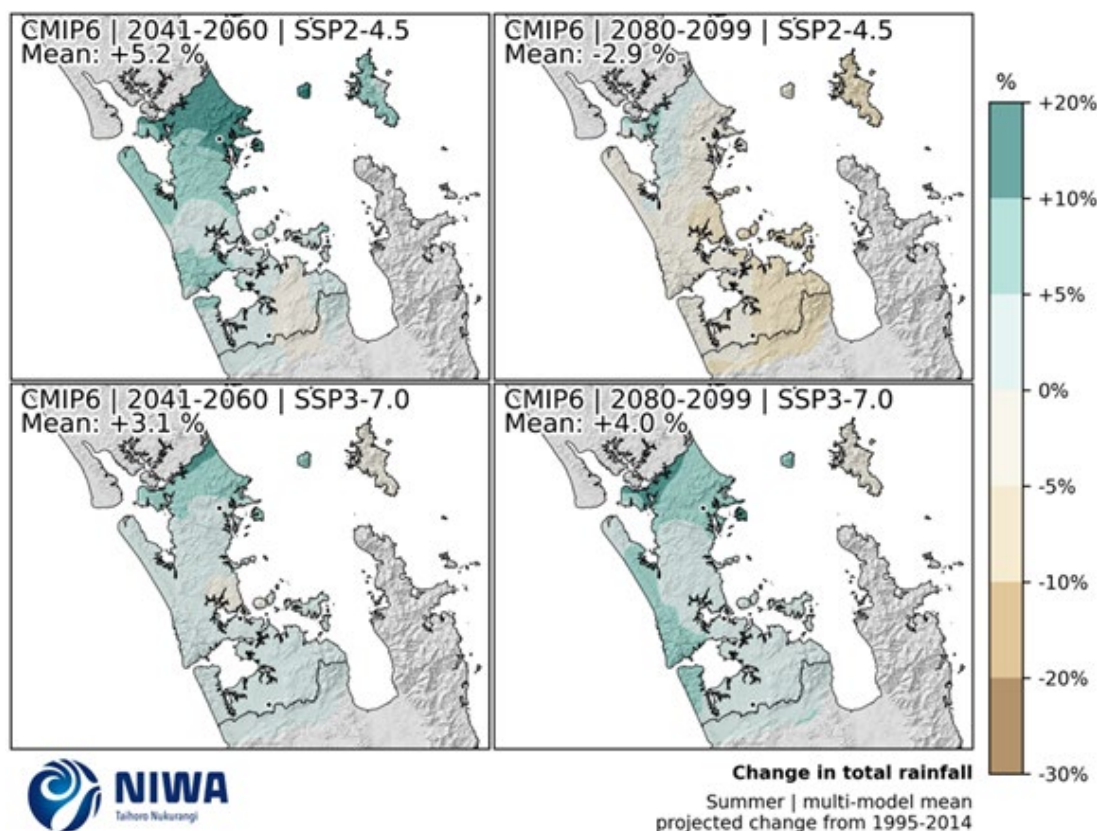


Figure 4-52: Projected summer average total rainfall changes.

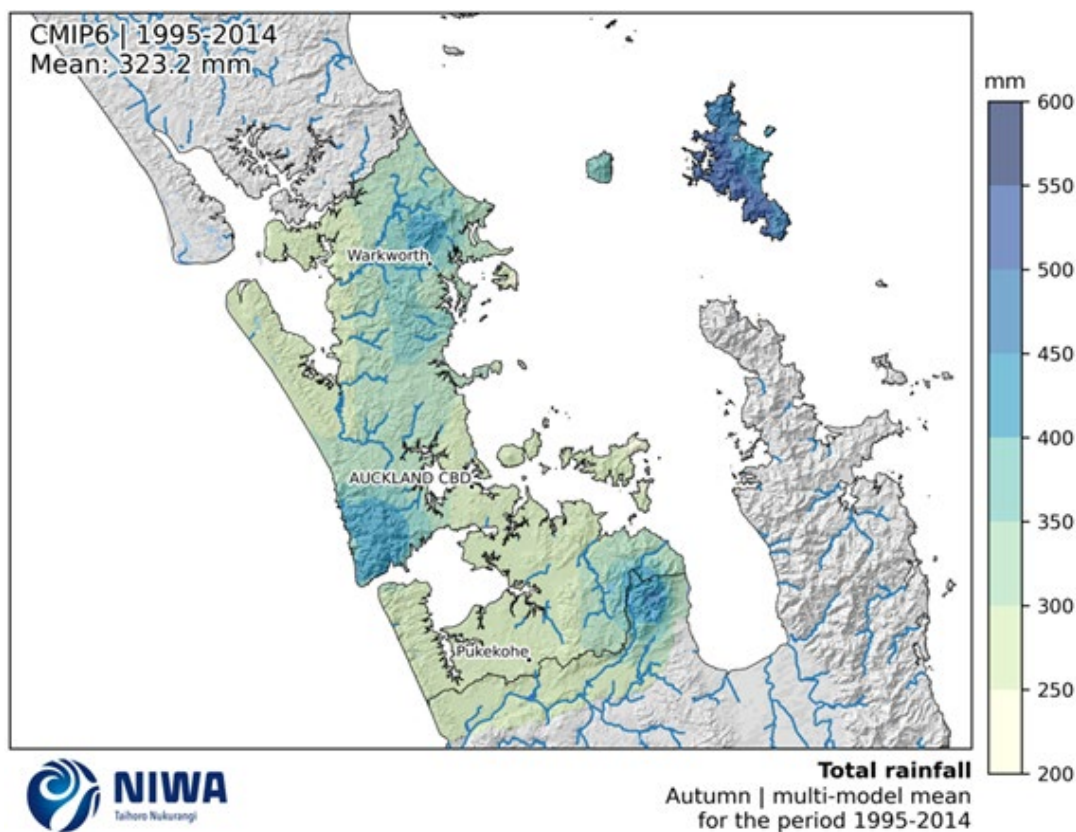


Figure 4-53: Modelled historic average autumn total rainfall.

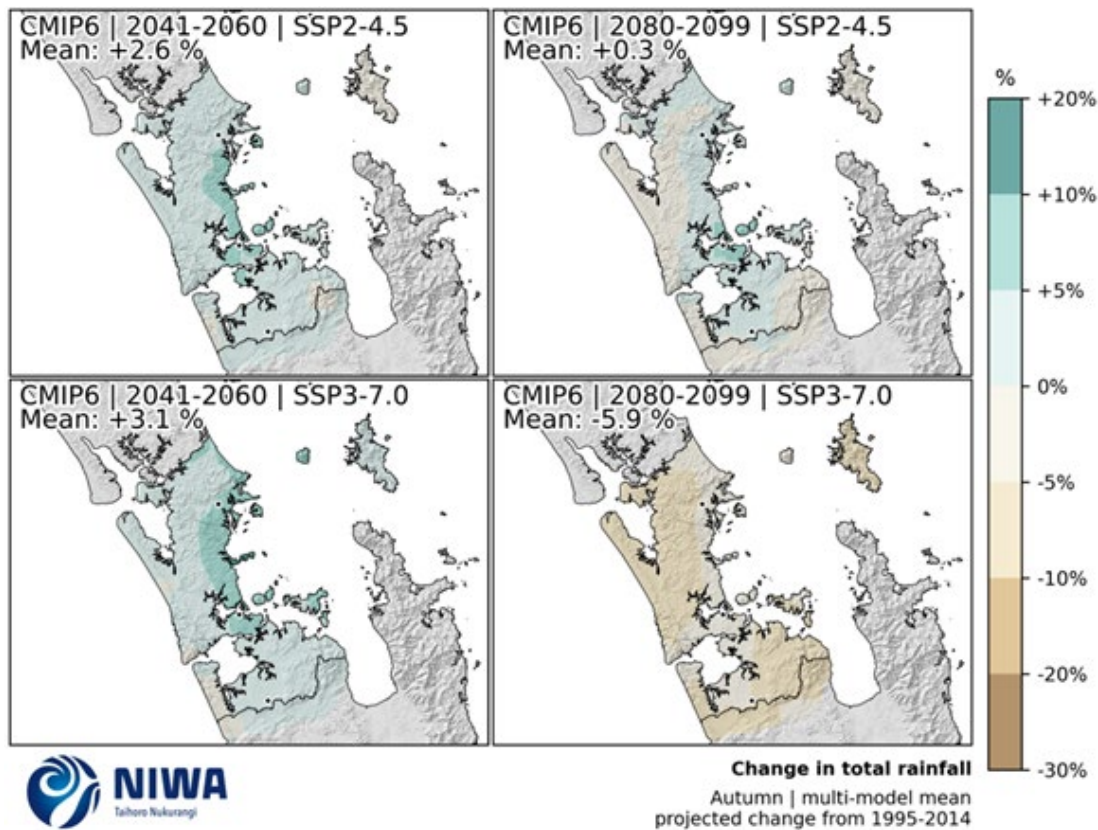


Figure 4-54: Projected autumn average total rainfall changes.

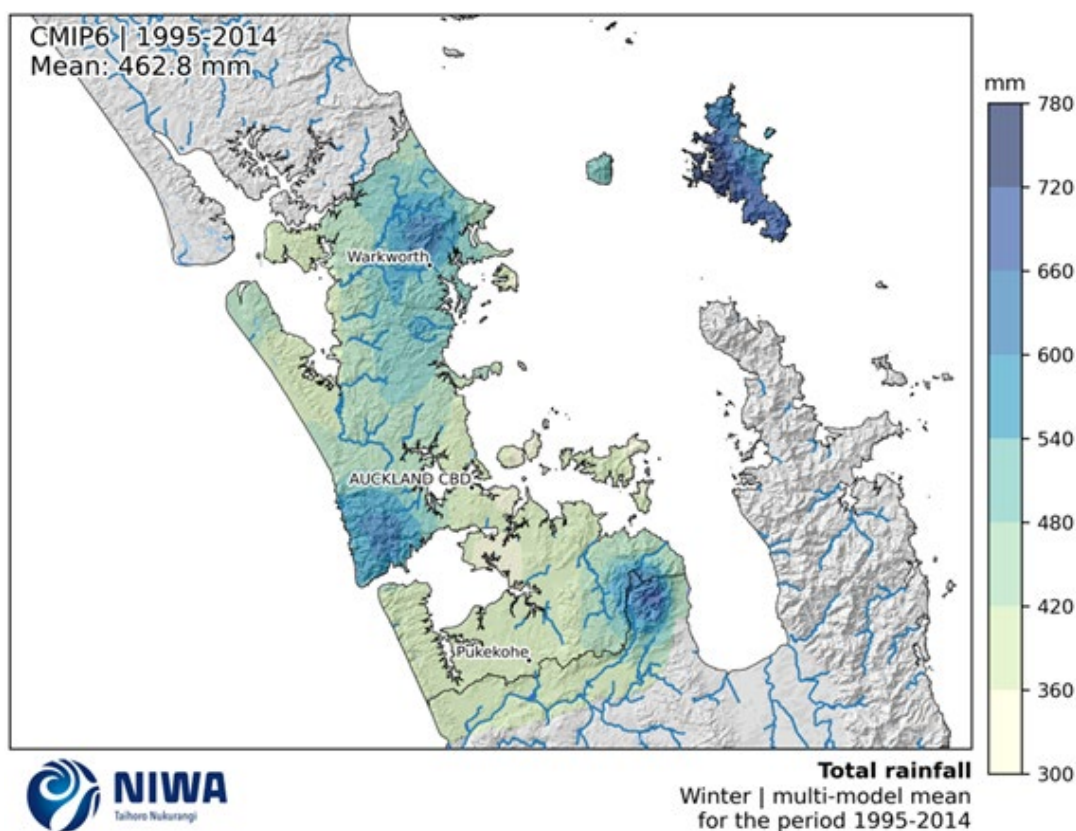


Figure 4-55: Modelled historic average winter total rainfall.

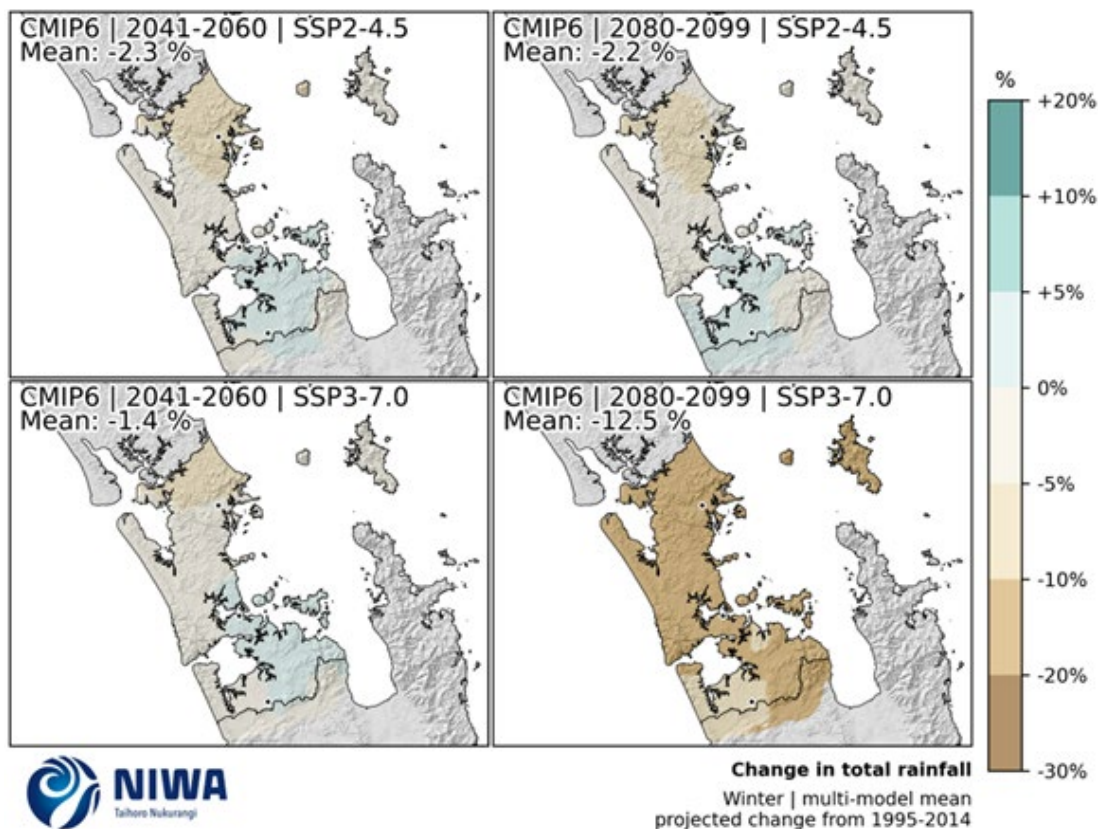


Figure 4-56: Projected winter average total rainfall changes.

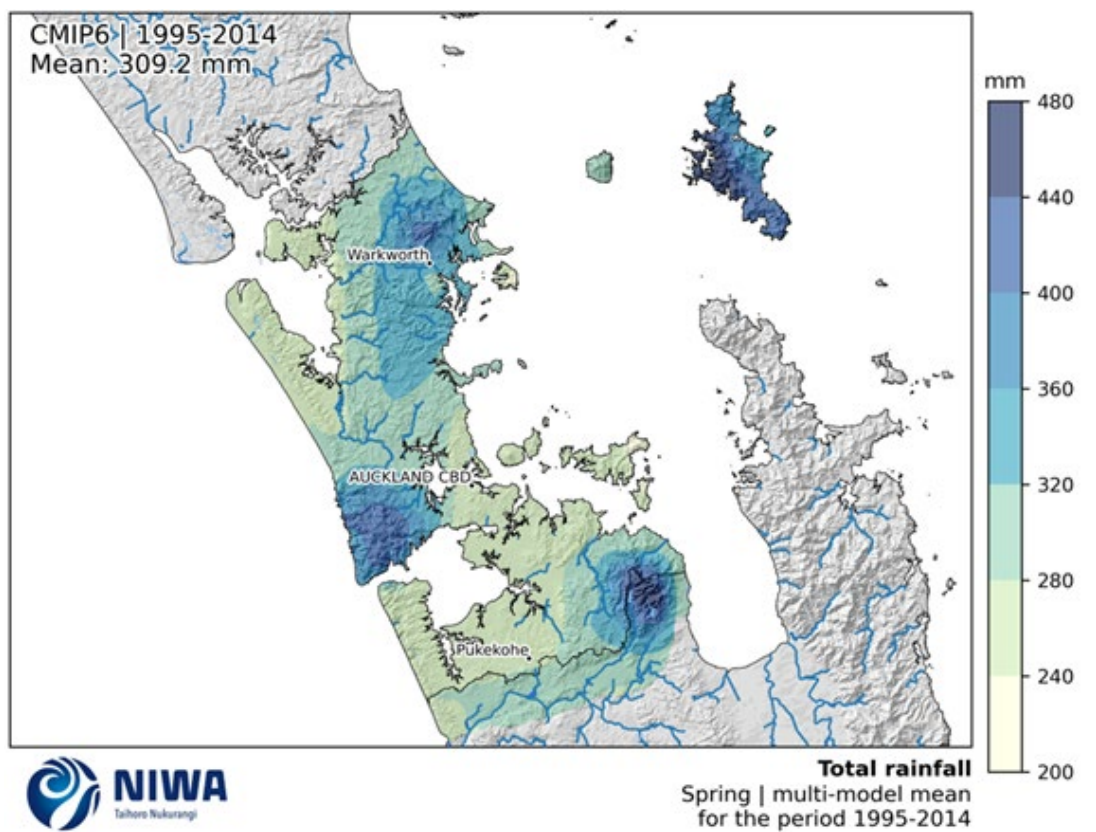


Figure 4-57: Modelled historic average spring total rainfall.

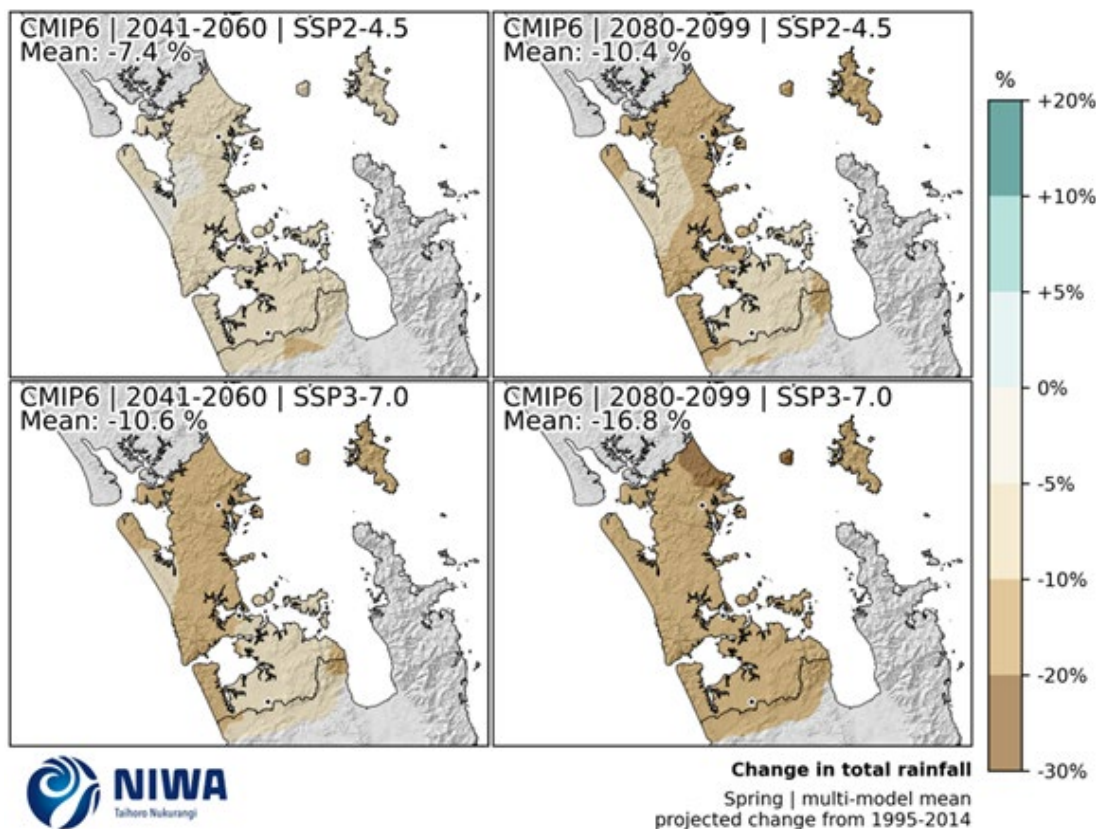


Figure 4-58: Projected spring average total rainfall changes.

4.10 Dry days (< 1 mm)

Dry days (< 1 mm) refers to the annual and seasonal average number of days where the rainfall total is less than 1 mm. Modelled historic and future projections of annual and seasonal dry days (< 1 mm) are illustrated in Figure 4-59 to Figure 4-68. Region-wide averages are summarised in the two boxes below.

Historic dry days and projected changes (days) Relative to 1995-2014 (2004)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2004	2050	2090	2050	2090	2050	2090	2050	2090
Annual	231.1	+0.1	-0.8	-1.1	+2.2	-0.5	+8.3	+0.9	+10.2
Summer	66.1	+0.2	0	-0.2	0	-0.2	+0.3	+0.1	-0.1
Autumn	61.0	+0.4	-0.3	-0.5	+0.5	+0.1	+2.1	+0.9	+2.4
Winter	47.3	-0.4	-0.8	-0.4	+0.7	-1.0	+3.4	+0.2	+4.1
Spring	56.8	-0.2	+0.1	-0.2	+1.1	+0.4	+2.2	-0.3	+3.8

Historic dry days and projected changes (days) Relative to 1986-2005 (1995)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	1995	2050	2090	2050	2090	2050	2090	2050	2090
Annual	230.0	+1.3	+0.4	+0.1	+3.4	+0.7	+9.5	+2.1	+11.4
Summer	65.6	+0.7	+0.4	+0.3	+0.4	+0.3	+0.8	+0.5	+0.4
Autumn	61.3	+0.2	-0.6	-0.8	+0.2	-0.2	+1.8	+0.6	+2.1
Winter	47.4	-0.5	-0.9	-0.5	+0.6	-1.1	+3.3	+0.1	+4.0
Spring	55.5	+1.0	+1.4	+1.0	+2.4	+1.7	+3.4	+1.0	+5.1

4.10.1 Annual

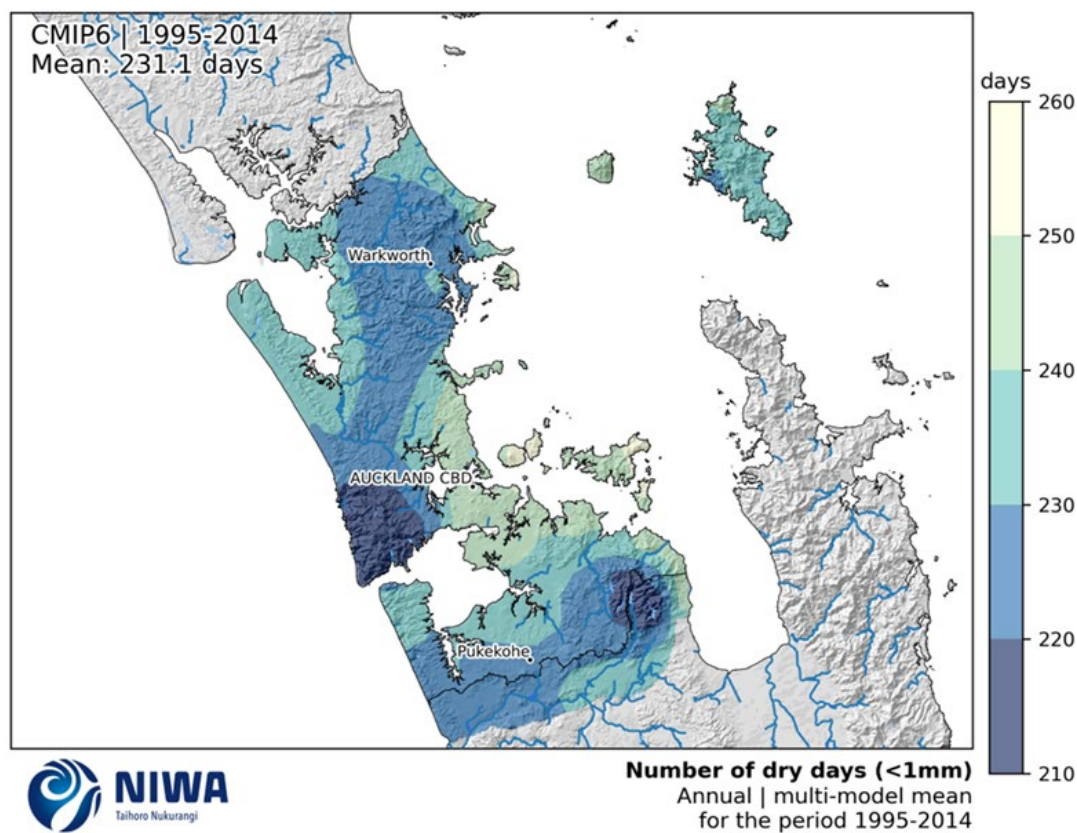


Figure 4-59: Modelled historic average annual number of dry days.

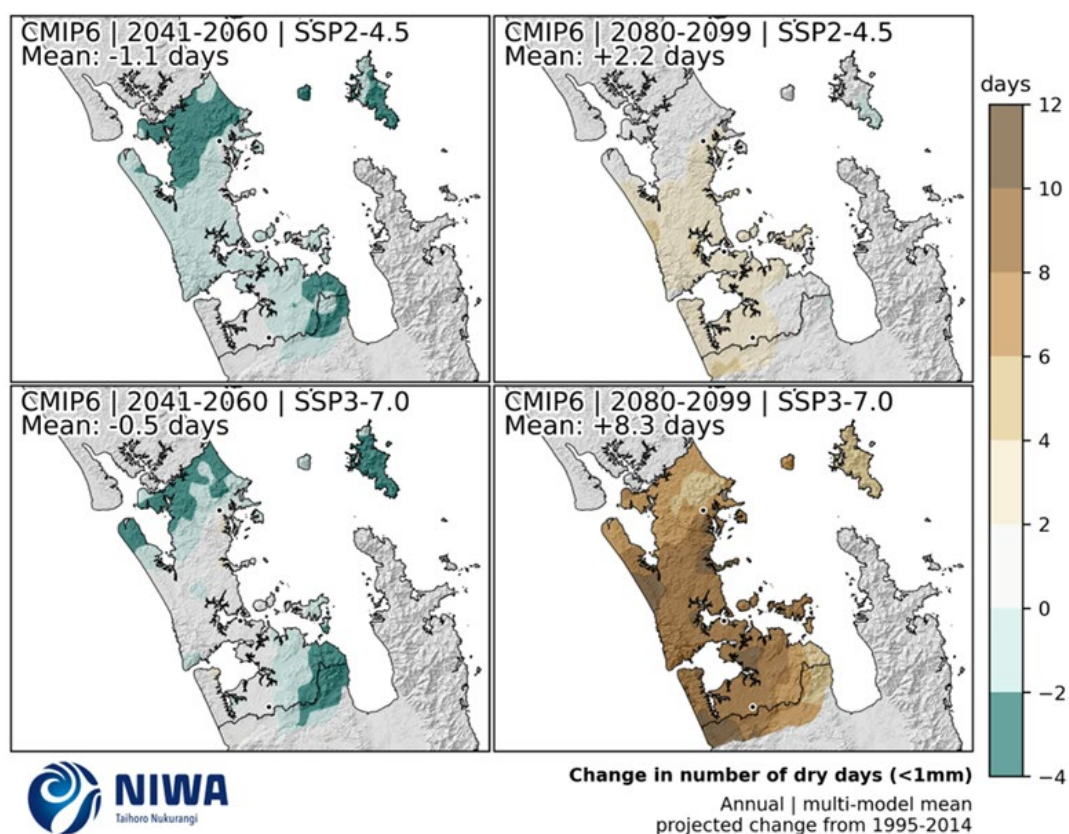


Figure 4-60: Projected annual dry day changes.

4.10.2 Seasonal

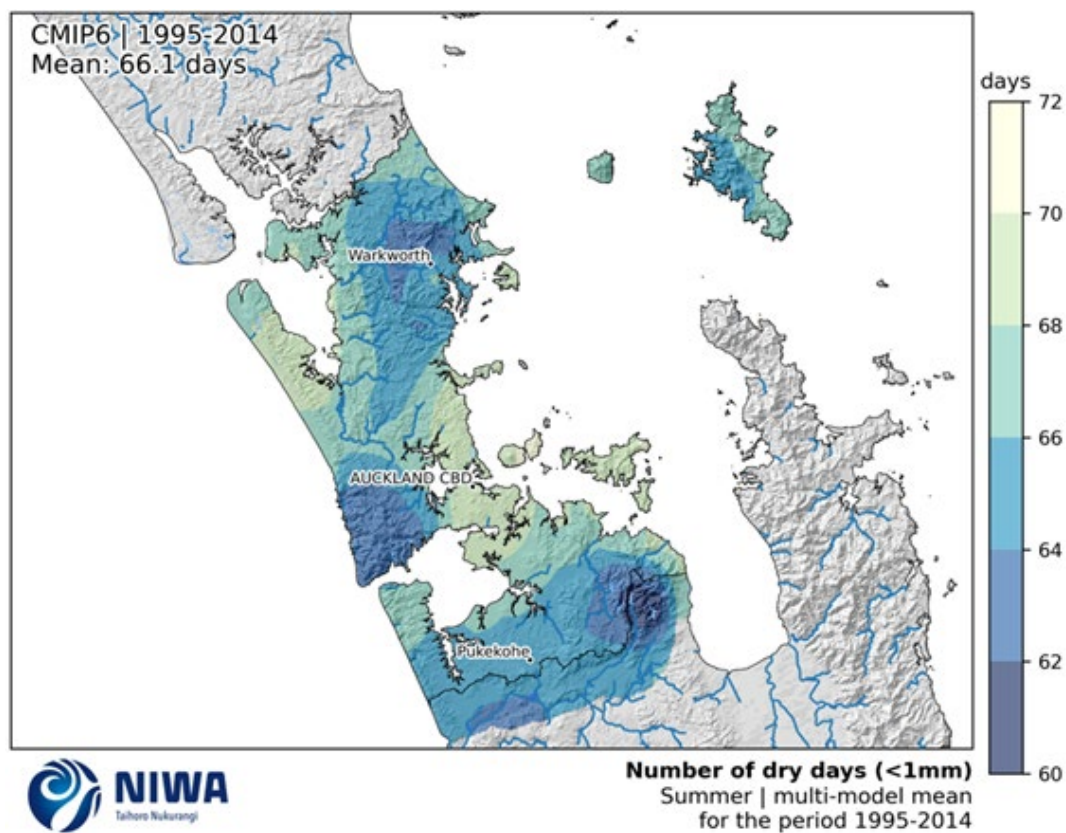


Figure 4-61: Modelled historic average summer number of dry days.

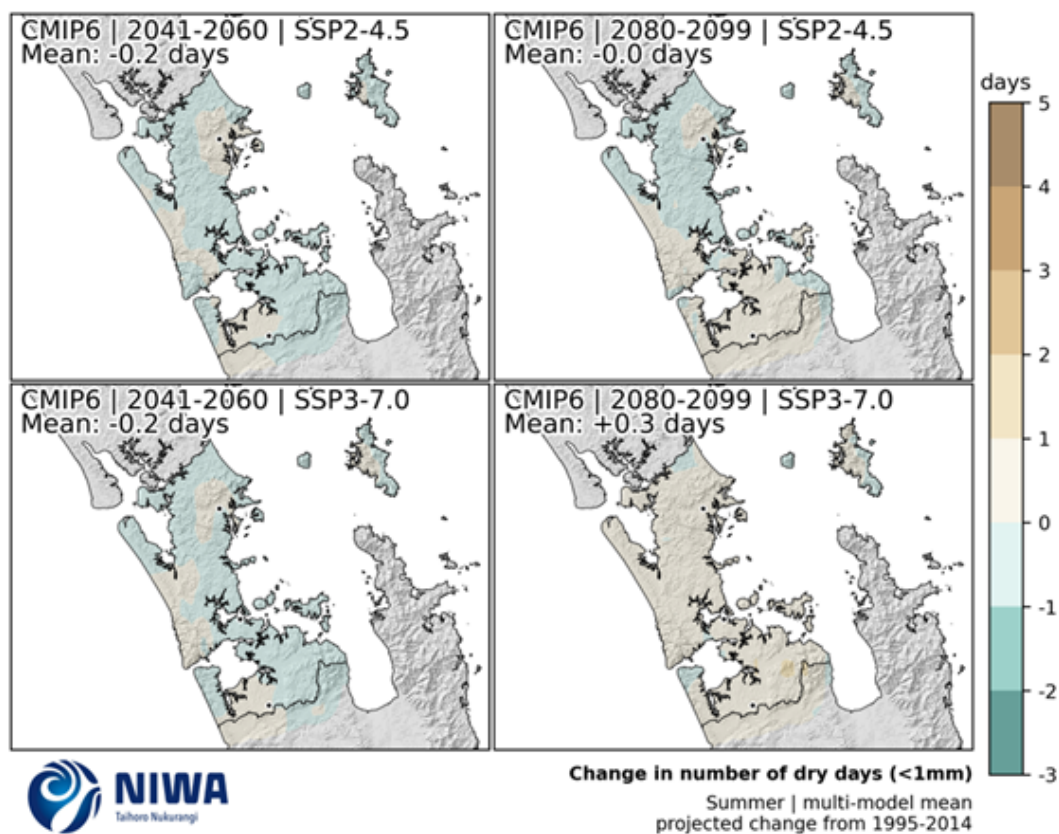


Figure 4-62: Projected summer dry day changes.

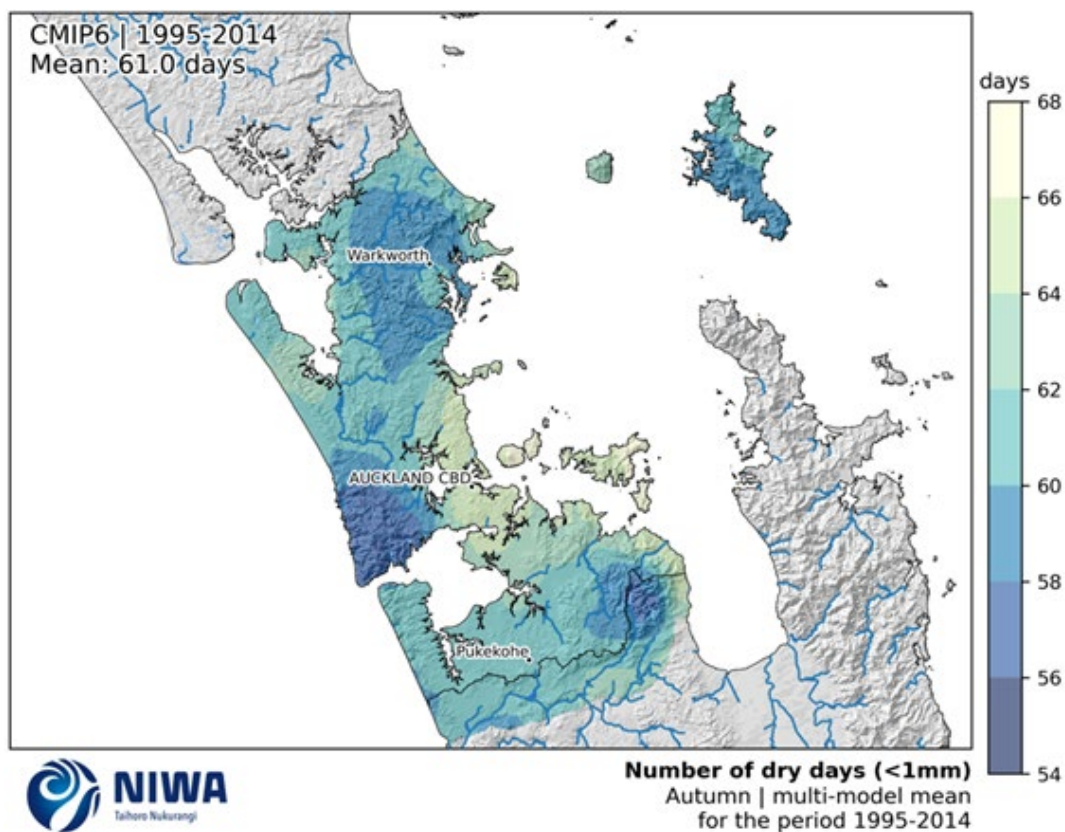


Figure 4-63: Modelled historic average autumn number of dry days.

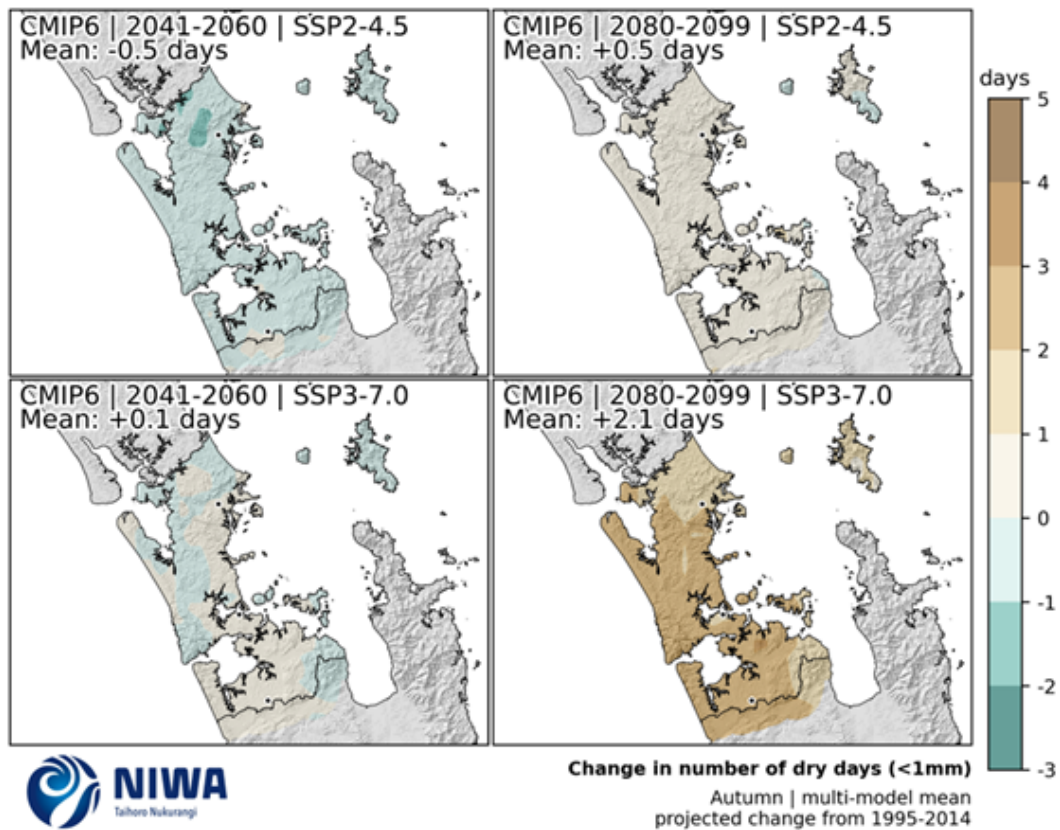


Figure 4-64: Projected autumn dry day changes.

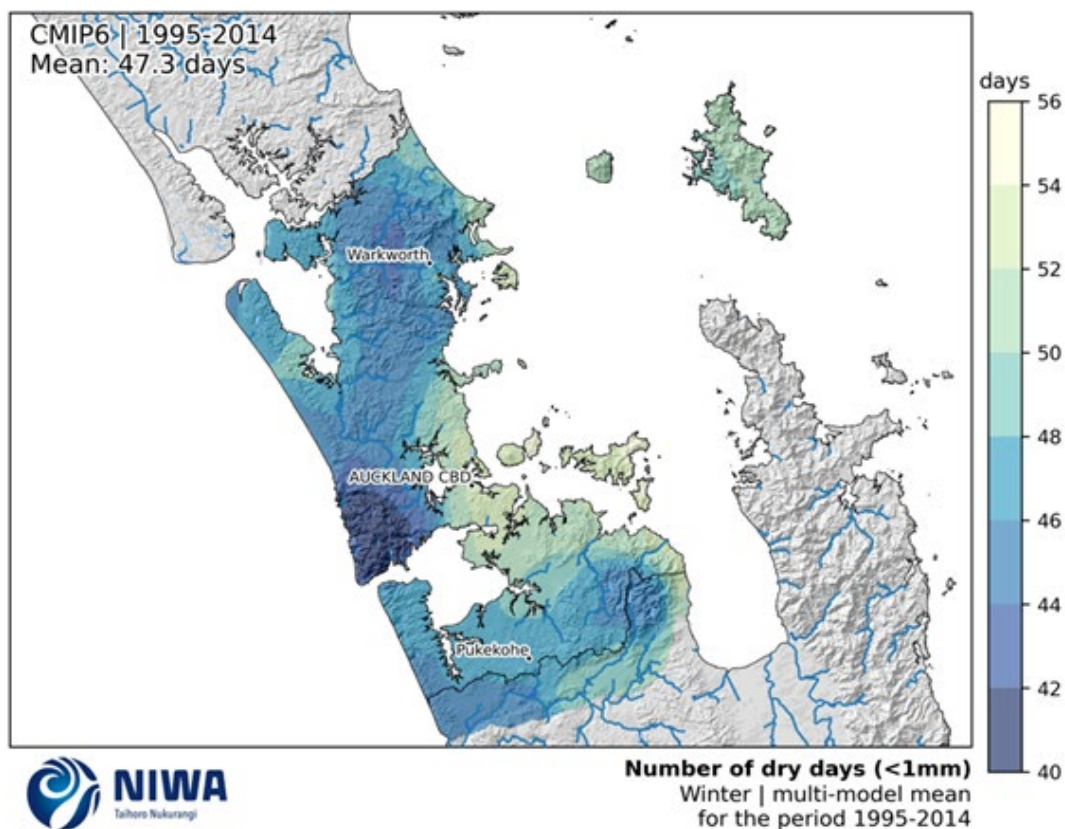


Figure 4-65: Modelled historic average winter number of dry days.

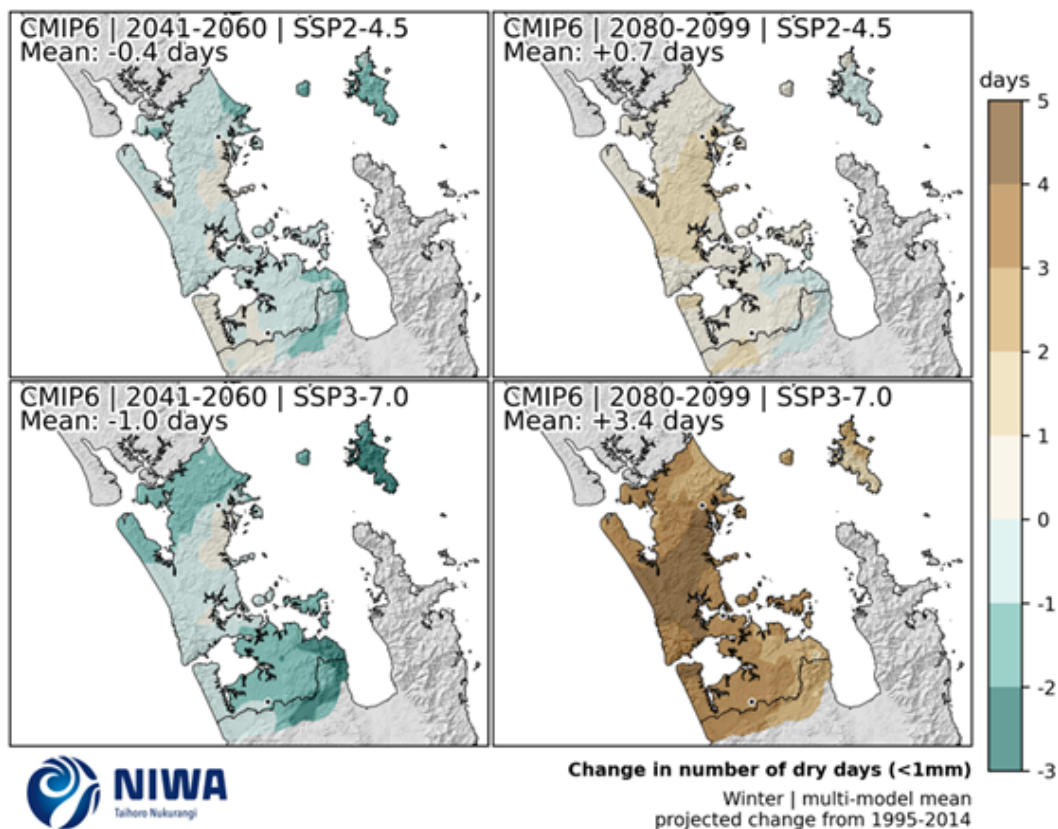


Figure 4-66: Projected winter dry day changes.

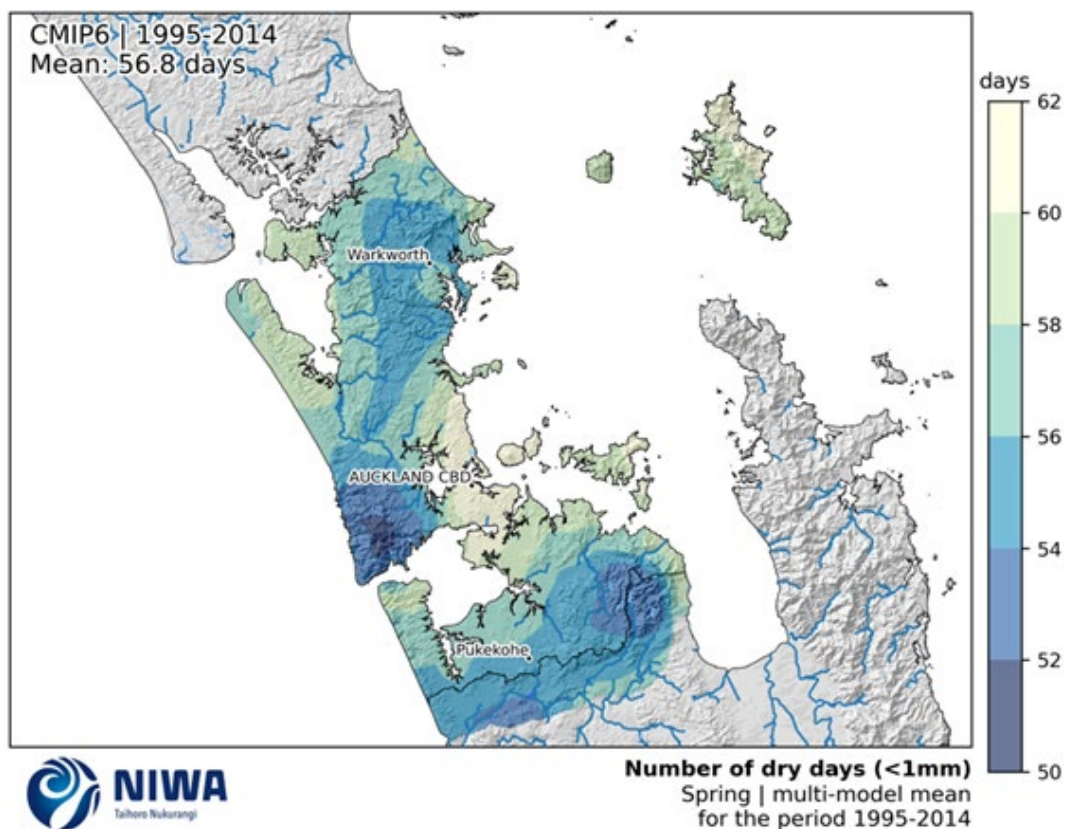


Figure 4-67: Modelled historic average spring number of dry days.

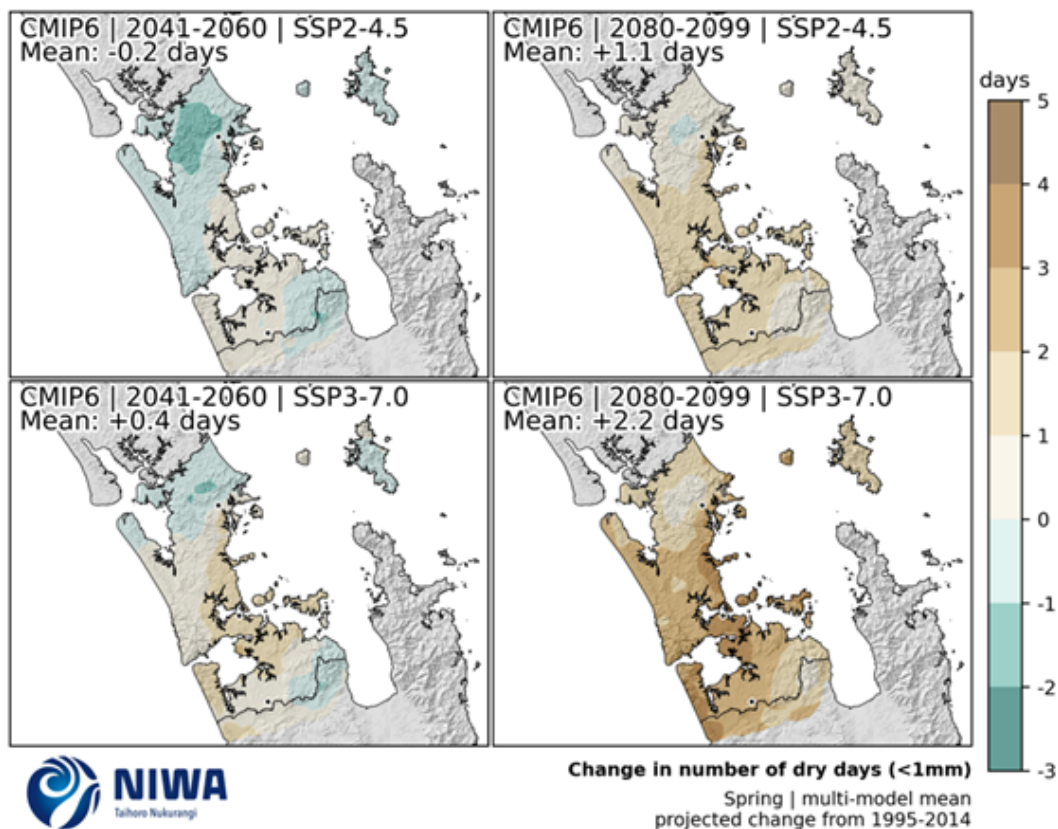


Figure 4-68: Projected spring dry day changes.

4.11 Wet days (≥ 1 mm)

Wet days (≥ 1 mm) refers to the annual and seasonal average number of days where the rainfall total is at least 1 mm. Modelled historic and future projections of annual and seasonal wet days (≥ 1 mm) are illustrated in Figure 4-69 to Figure 4-78. Region-wide averages are summarised in the two boxes below.

Historic wet days and projected changes (days) Relative to 1995-2014 (2004)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2004	2050	2090	2050	2090	2050	2090	2050	2090
Annual	133.9	-0.1	+0.8	+1.1	-2.2	+0.5	-8.3	-0.9	-10.2
Summer	23.9	-0.2	0	+0.2	0	+0.2	-0.3	-0.1	+0.1
Autumn	31.0	-0.4	+0.3	+0.5	-0.5	-0.1	-2.1	-0.9	-2.4
Winter	44.7	+0.4	+0.8	+0.4	-0.7	+1.0	-3.4	-0.2	-4.1
Spring	34.2	+0.2	-0.1	+0.2	-1.1	-0.4	-2.2	+0.3	-3.8

Historic wet days and projected changes (days) Relative to 1986-2005 (1995)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	1995	2050	2090	2050	2090	2050	2090	2050	2090
Annual	135.0	-1.3	-0.4	-0.1	-3.4	-0.7	-9.5	-2.1	-11.4
Summer	24.4	-0.7	-0.4	-0.3	-0.4	-0.3	-0.8	-0.5	-0.4
Autumn	30.7	-0.2	+0.6	+0.8	-0.2	+0.2	-1.8	-0.6	-2.1
Winter	44.6	+0.5	+0.9	+0.5	-0.6	+1.1	-3.3	-0.1	-4.0
Spring	35.5	-1.0	-1.4	-1.0	-2.4	-1.7	-3.4	-1.0	-5.1

4.11.1 Annual

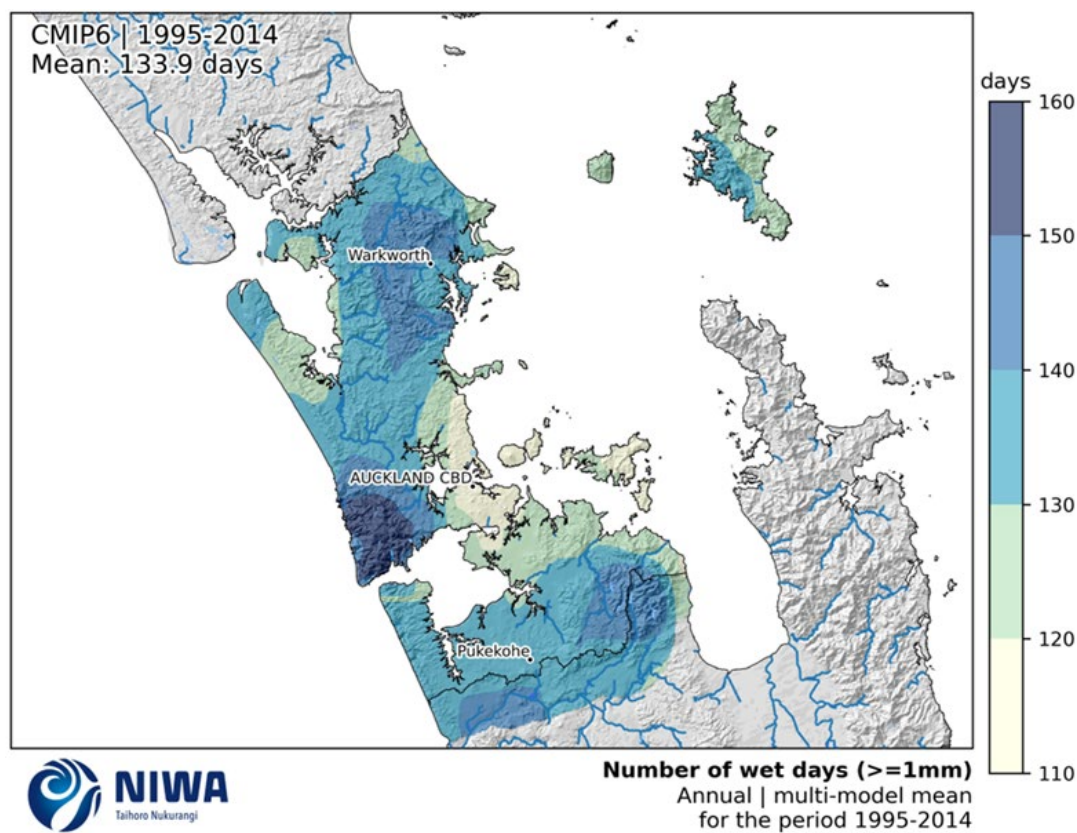


Figure 4-69: Modelled historic average annual number of wet days.

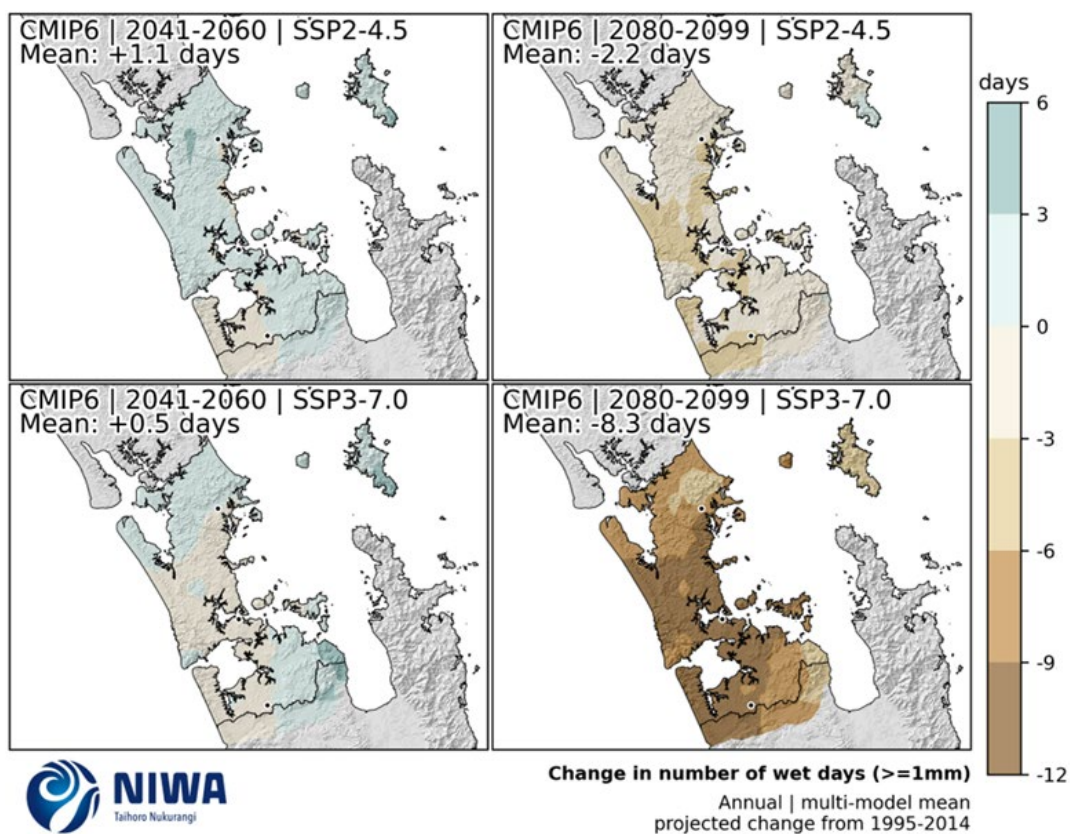


Figure 4-70: Projected annual wet day changes.

4.11.2 Seasonal

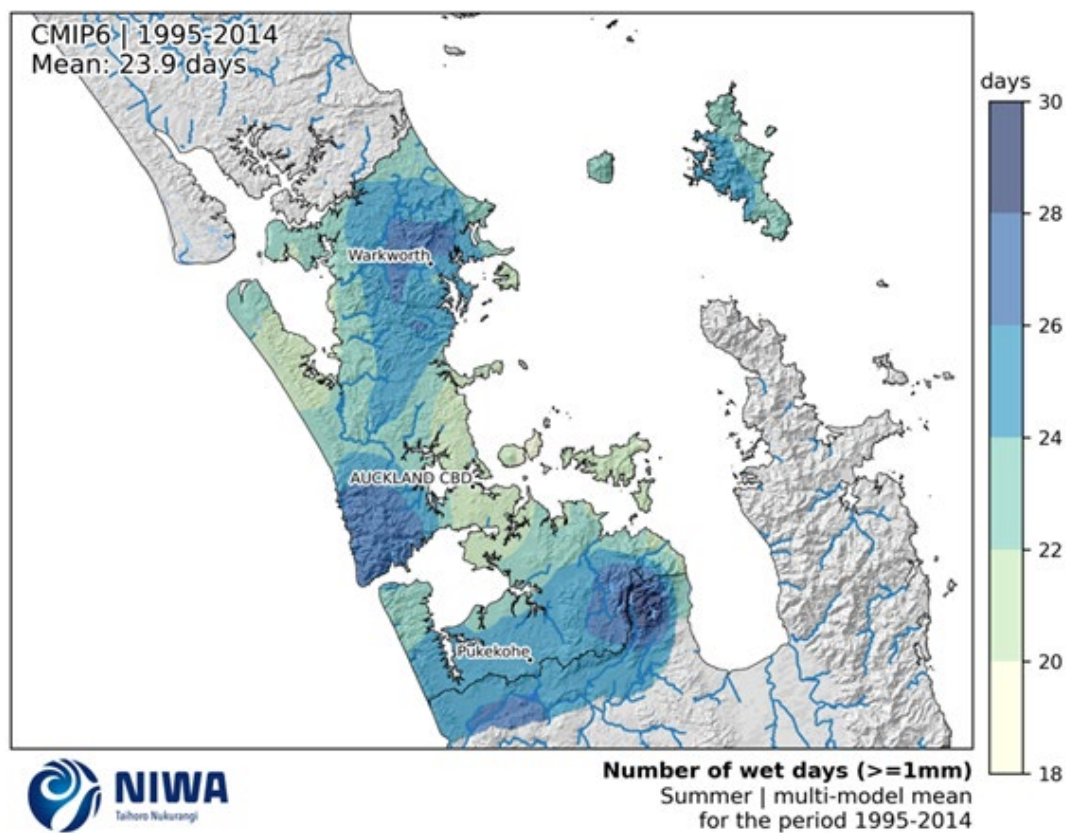


Figure 4-71: Modelled historic average summer number of wet days.

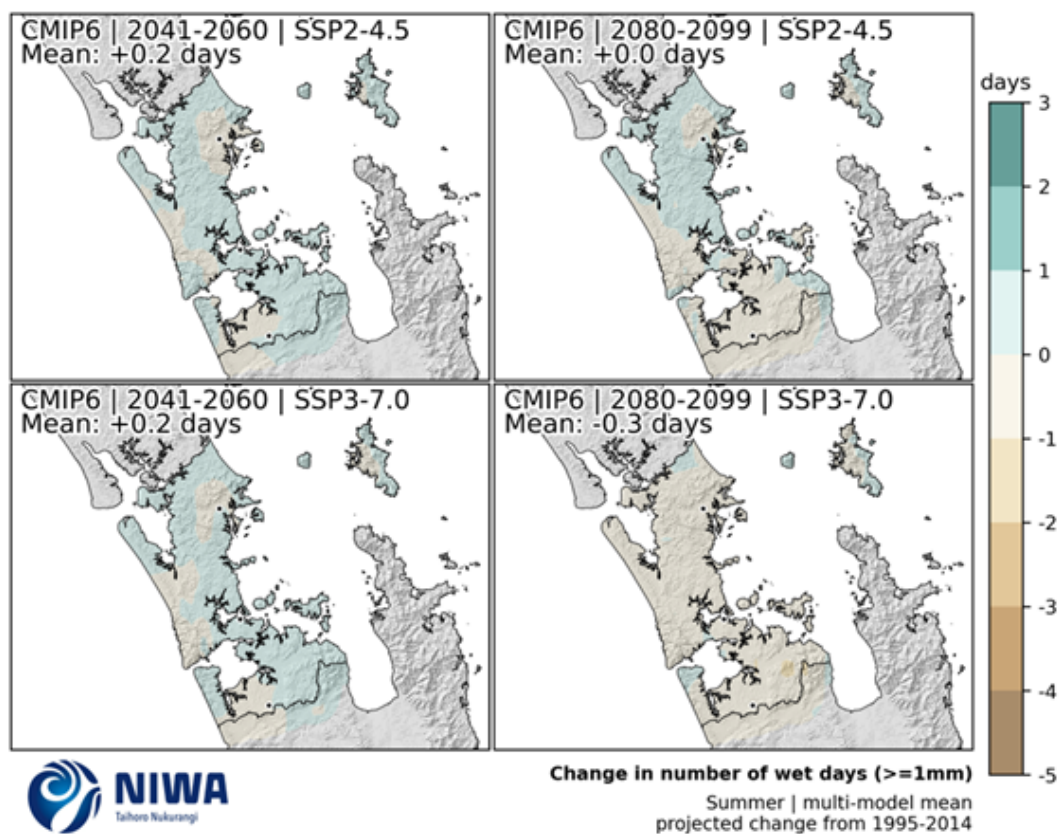


Figure 4-72: Projected summer wet day changes.

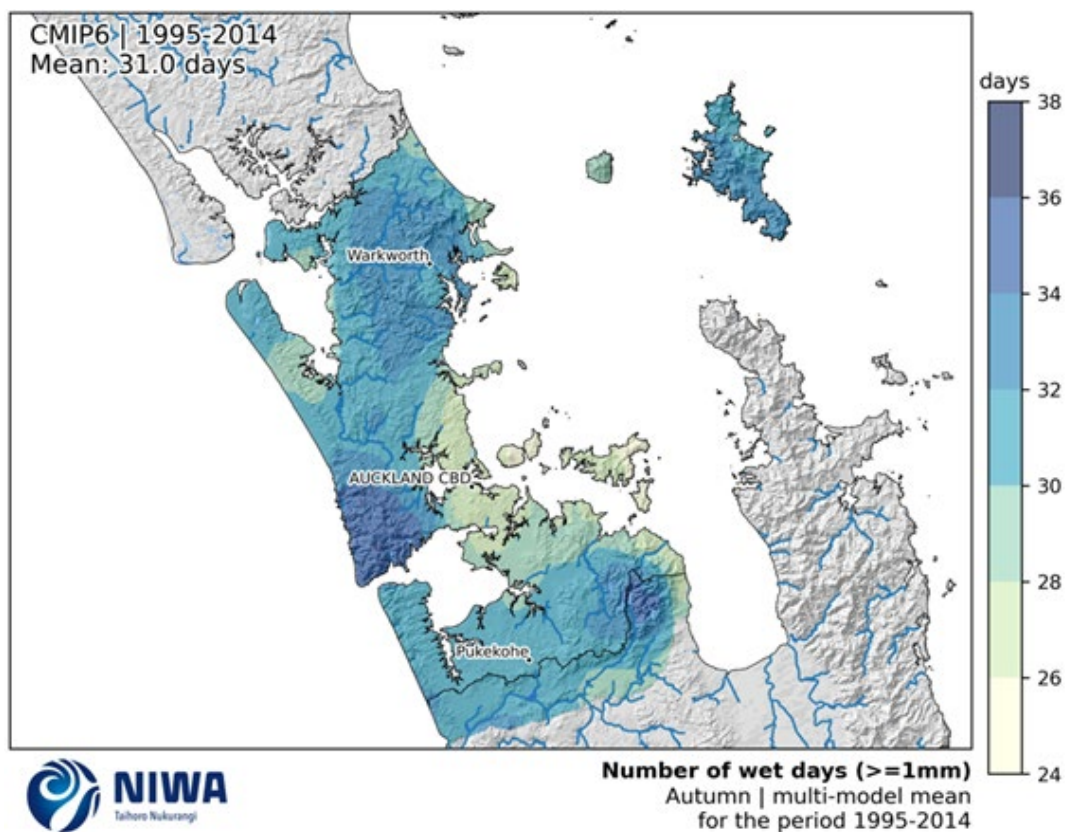


Figure 4-73: Modelled historic average autumn number of wet days.

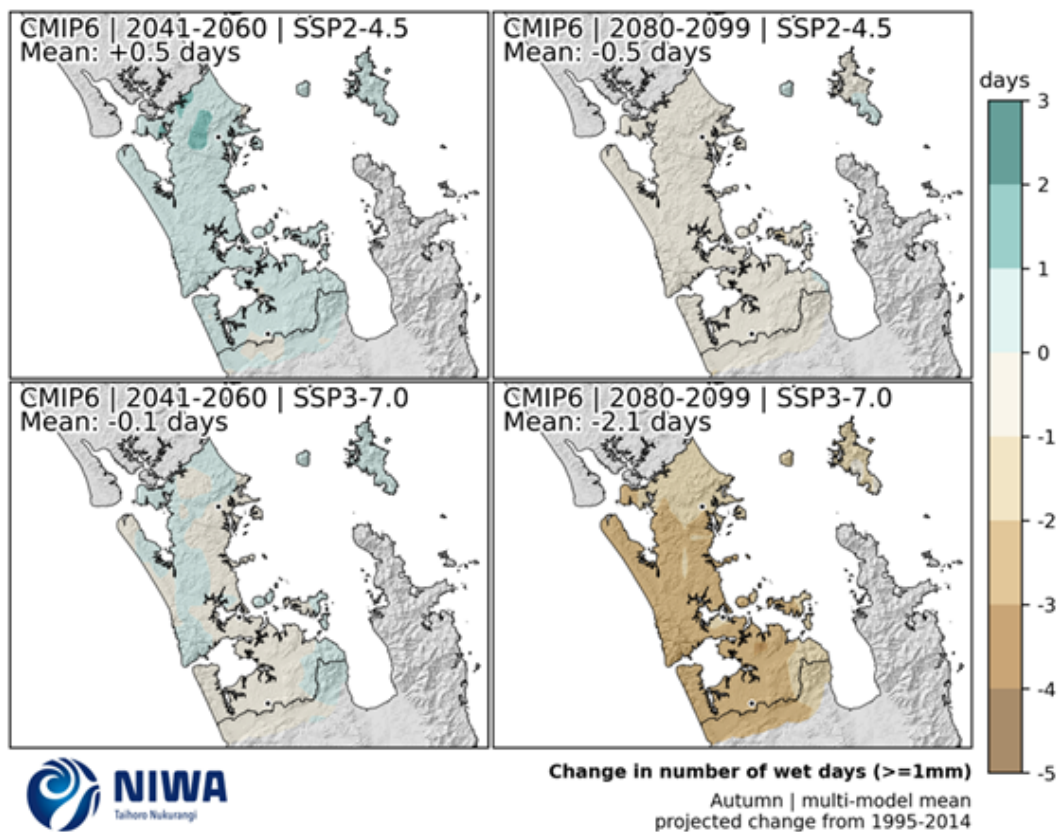


Figure 4-74: Projected autumn wet day changes.

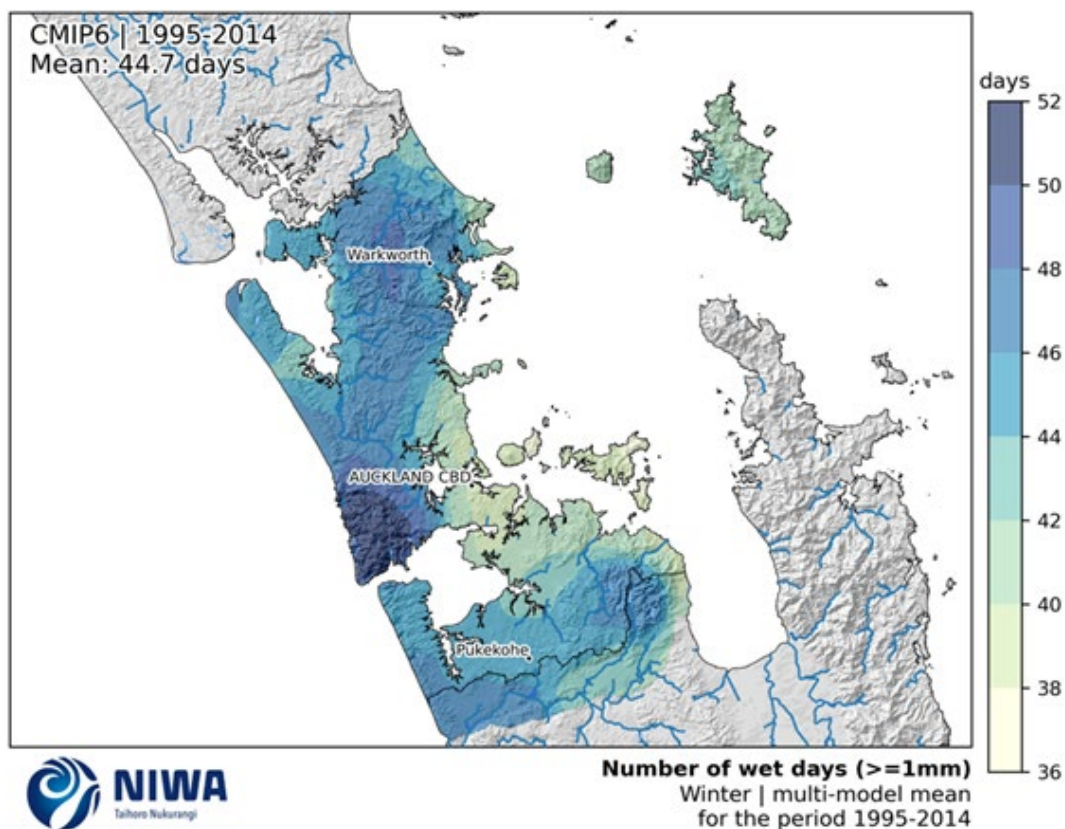


Figure 4-75: Modelled historic average winter number of wet days.

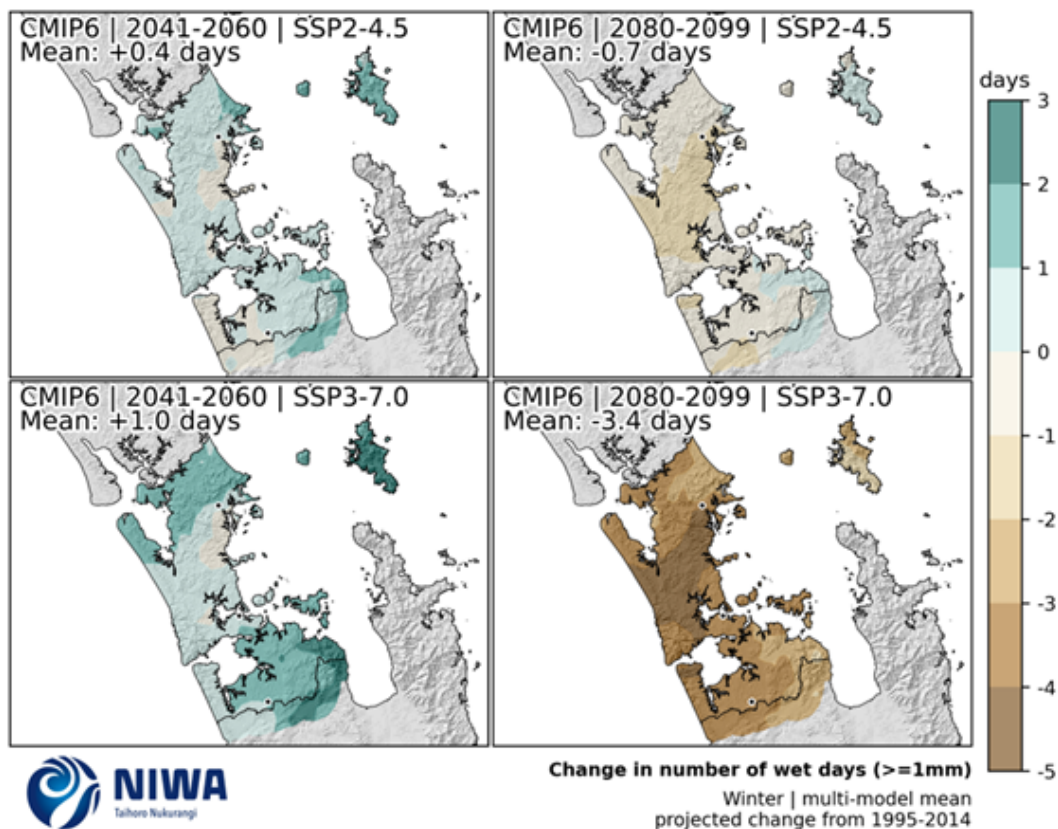


Figure 4-76: Projected winter wet day changes.

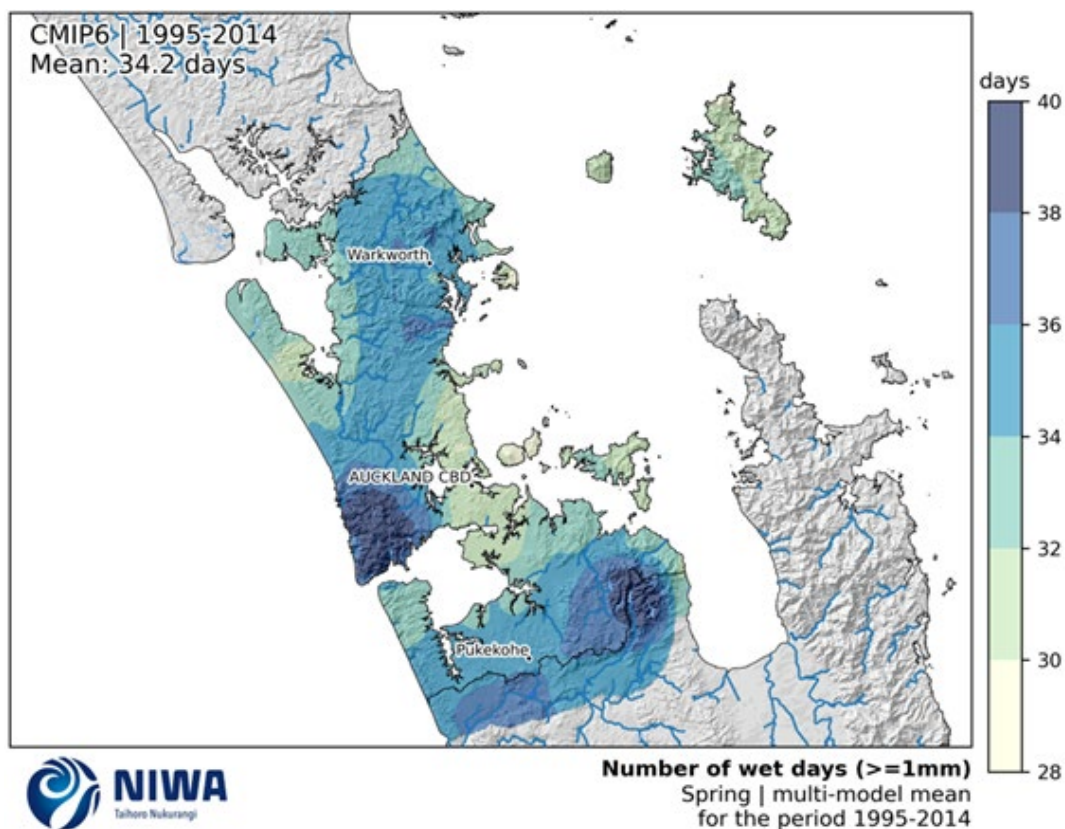


Figure 4-77: Modelled historic average spring number of wet days.

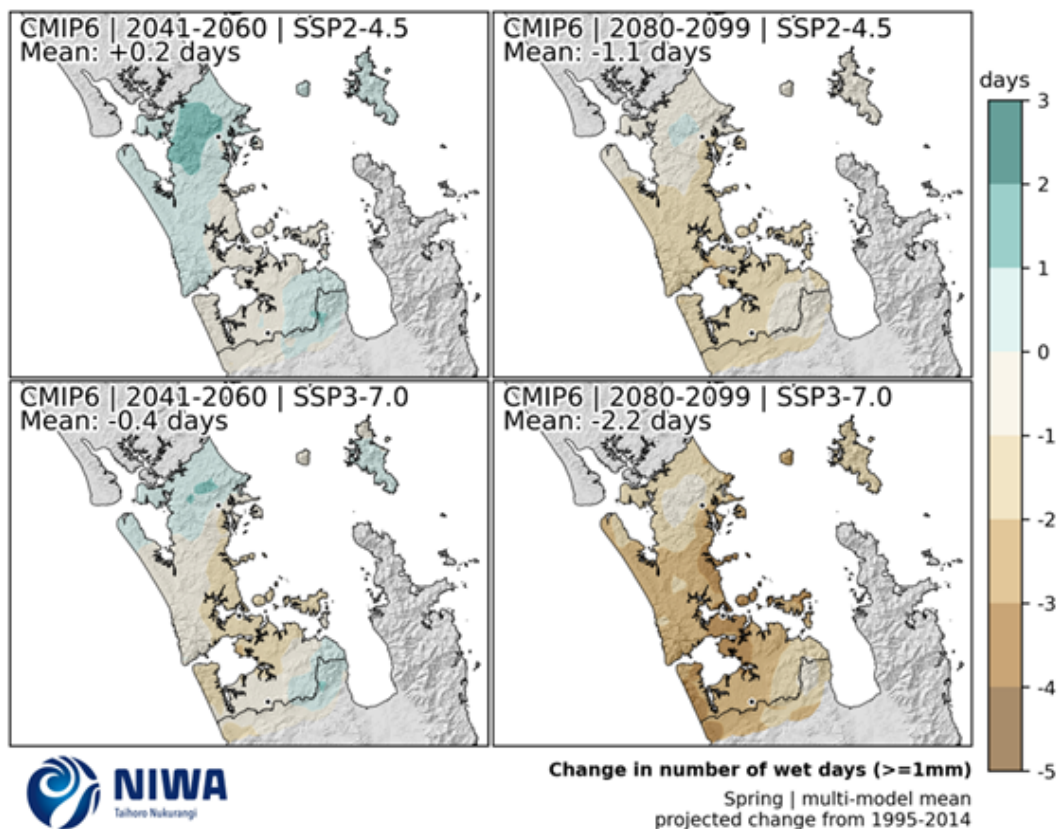


Figure 4-78: Projected spring wet day changes.

4.12 Very wet days (> 25 mm)

Very wet days (> 25 mm) refers to the annual and seasonal average number of days where the rainfall total is more than 25 mm. Modelled historic and future projections of annual and seasonal very wet days (> 25 mm) are illustrated in Figure 4-79 to Figure 4-88. Region-wide averages are summarised in the two boxes below.

Historic very wet days and projected changes (days) Relative to 1995-2014 (2004)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2004	2050	2090	2050	2090	2050	2090	2050	2090
Annual	11.1	+0.2	+0.3	+0.2	+0.2	+0.2	-0.5	-0.2	-0.2
Summer	2.2	+0.2	+0.2	+0.2	-0.1	+0.1	+0.1	-0.1	+0.2
Autumn	2.9	-0.1	+0.1	+0.2	+0.1	+0.2	0	+0.1	-0.1
Winter	3.7	+0.3	+0.2	0	+0.3	+0.1	-0.2	0	-0.1
Spring	2.2	-0.1	-0.2	-0.2	-0.2	-0.2	-0.3	-0.2	-0.2

Historic very wet days and projected changes (days) Relative to 1986-2005 (1995)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	1995	2050	2090	2050	2090	2050	2090	2050	2090
Annual	11.1	+0.2	+0.3	+0.1	+0.1	+0.1	-0.6	-0.3	-0.3
Summer	2.2	+0.2	+0.2	+0.3	-0.1	+0.1	+0.2	-0.1	+0.2
Autumn	2.9	-0.1	+0.2	+0.2	+0.2	+0.2	0	+0.1	-0.1
Winter	3.8	+0.3	+0.2	0	+0.2	+0.1	-0.3	0	-0.2
Spring	2.3	-0.2	-0.2	-0.3	-0.2	-0.3	-0.4	-0.3	-0.3

4.12.1 Annual

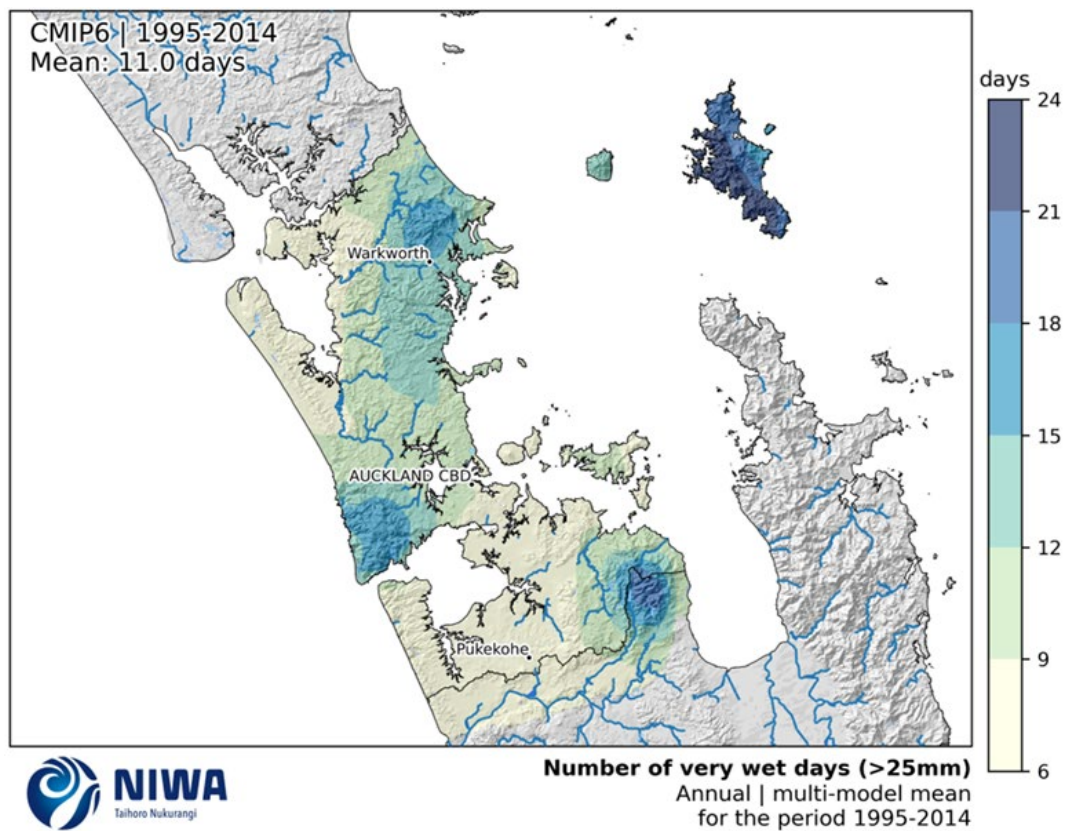


Figure 4-79: Modelled historic average annual number of very wet days.

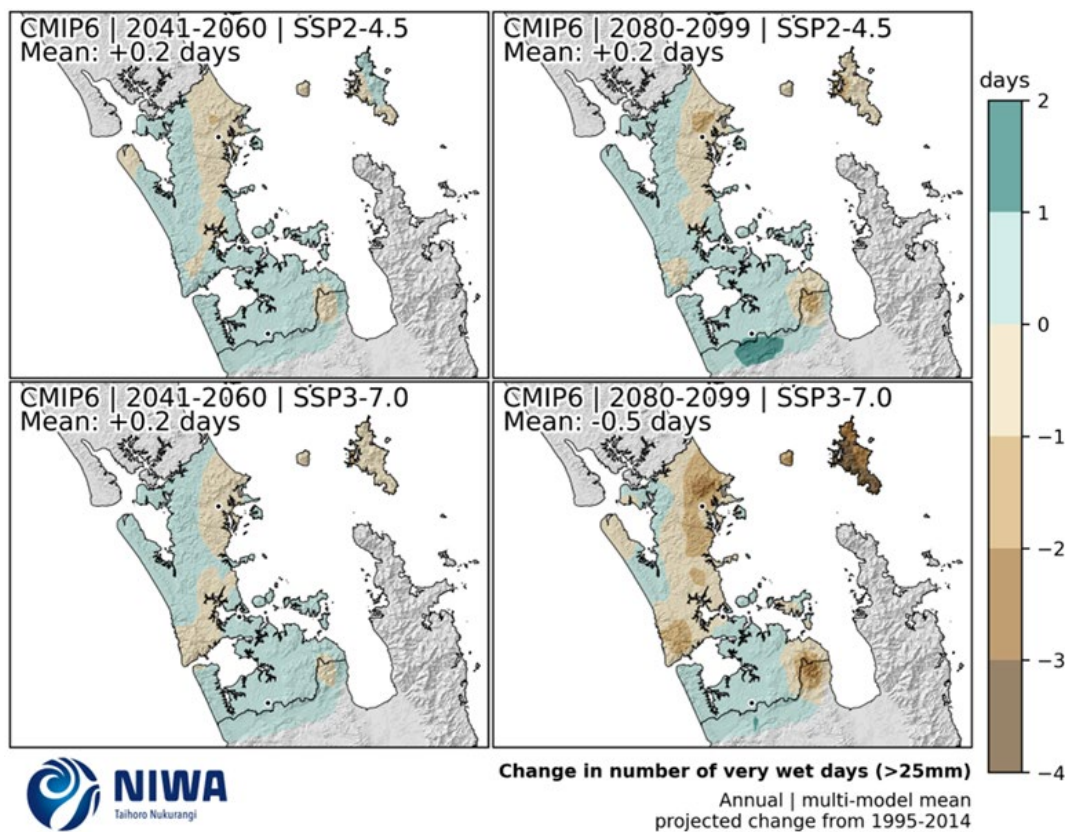


Figure 4-80: Projected annual very wet day changes.

4.12.2 Seasonal

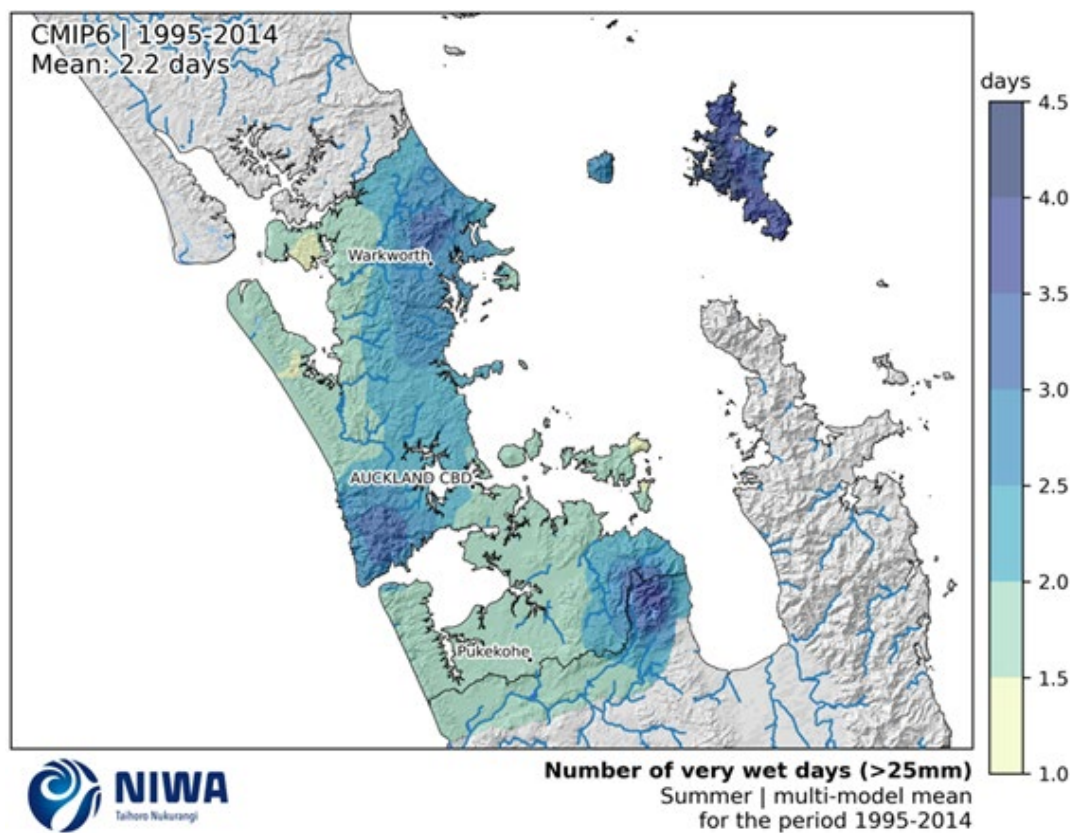


Figure 4-81: Modelled historic average summer number of very wet days.

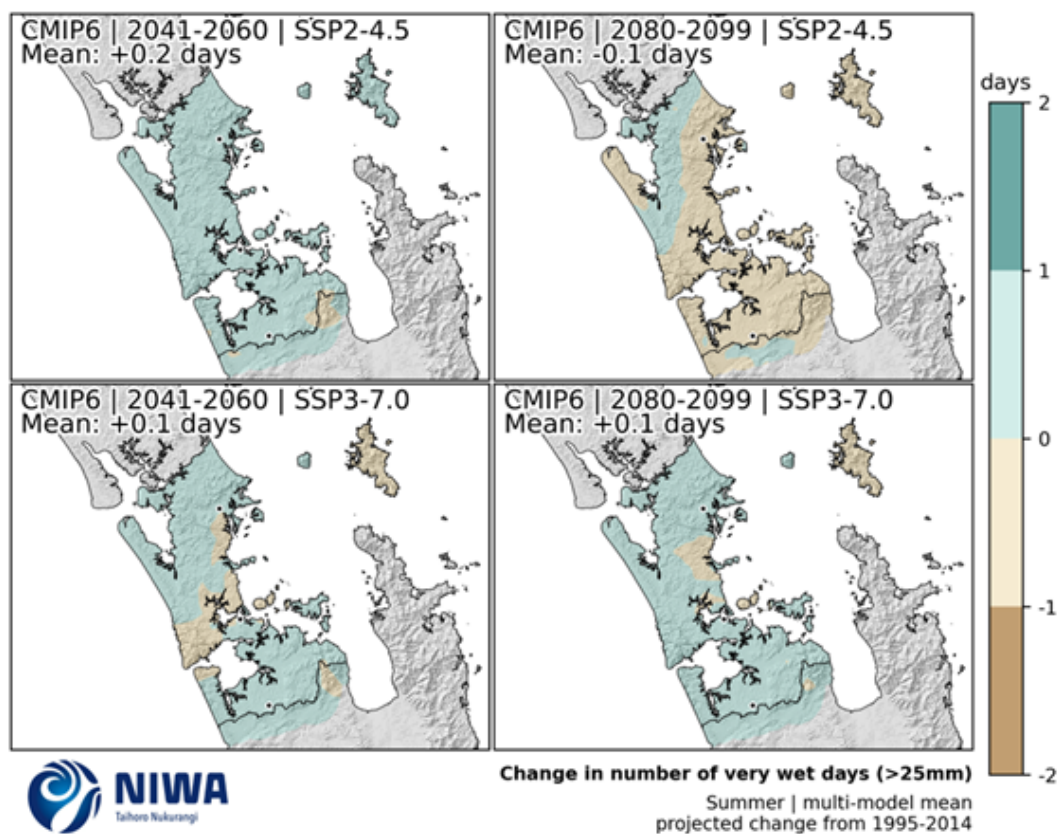


Figure 4-82: Projected summer very wet day changes.

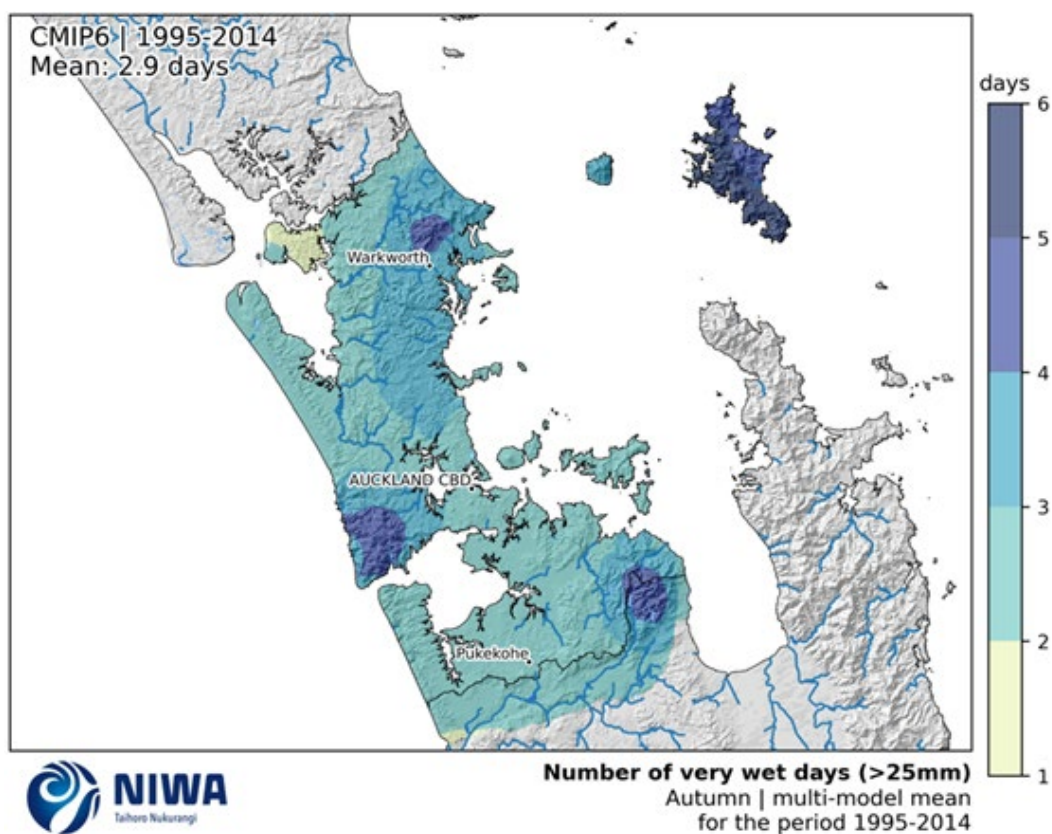


Figure 4-83: Modelled historic average autumn number of very wet days.

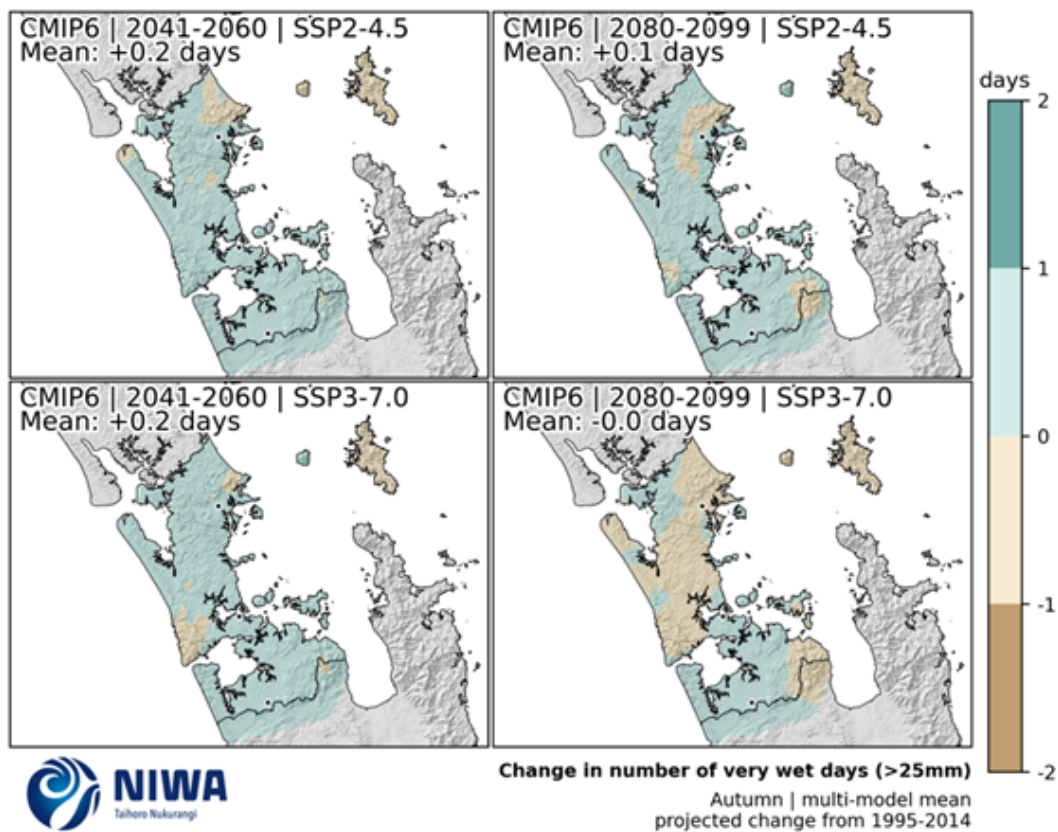


Figure 4-84: Projected autumn very wet day changes.

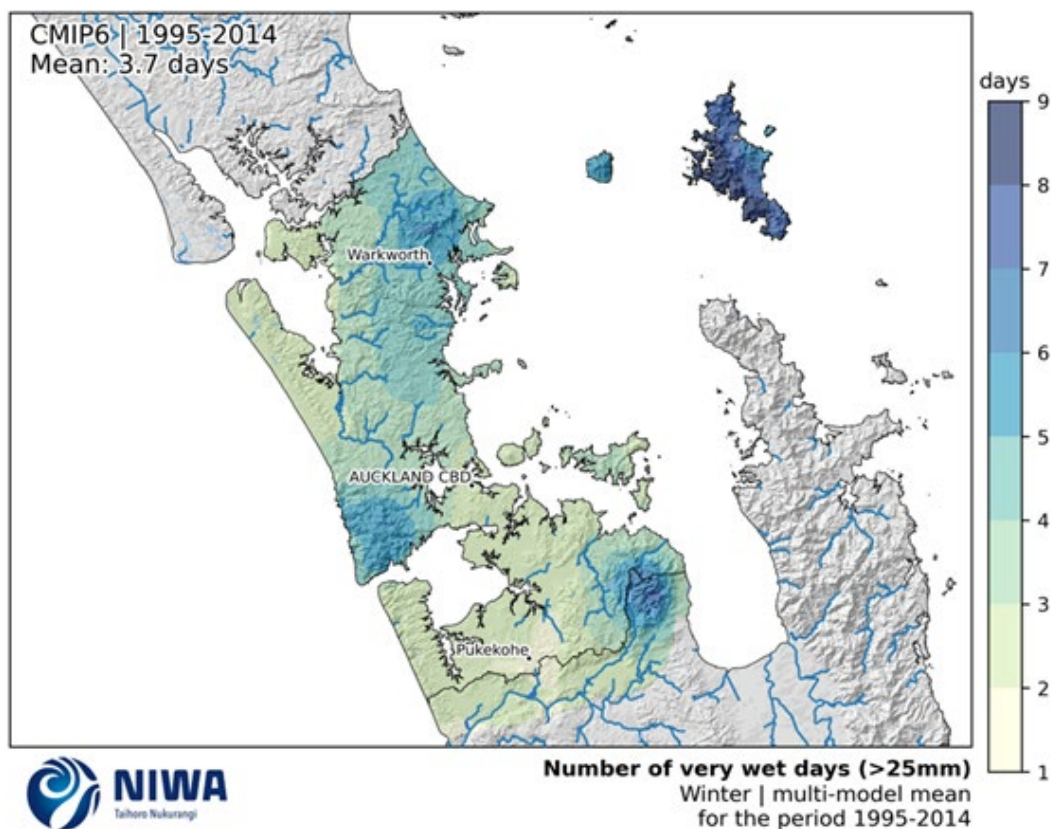


Figure 4-85: Modelled historic average winter number of very wet days.

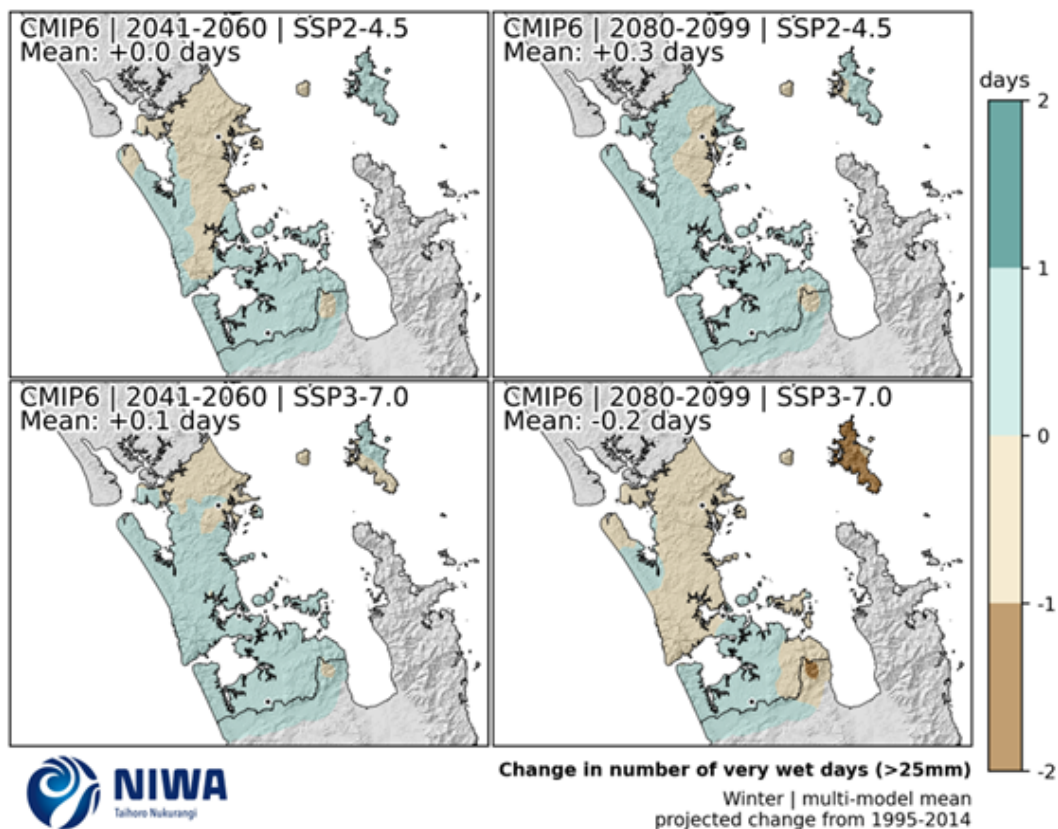


Figure 4-86: Projected winter very wet day changes.

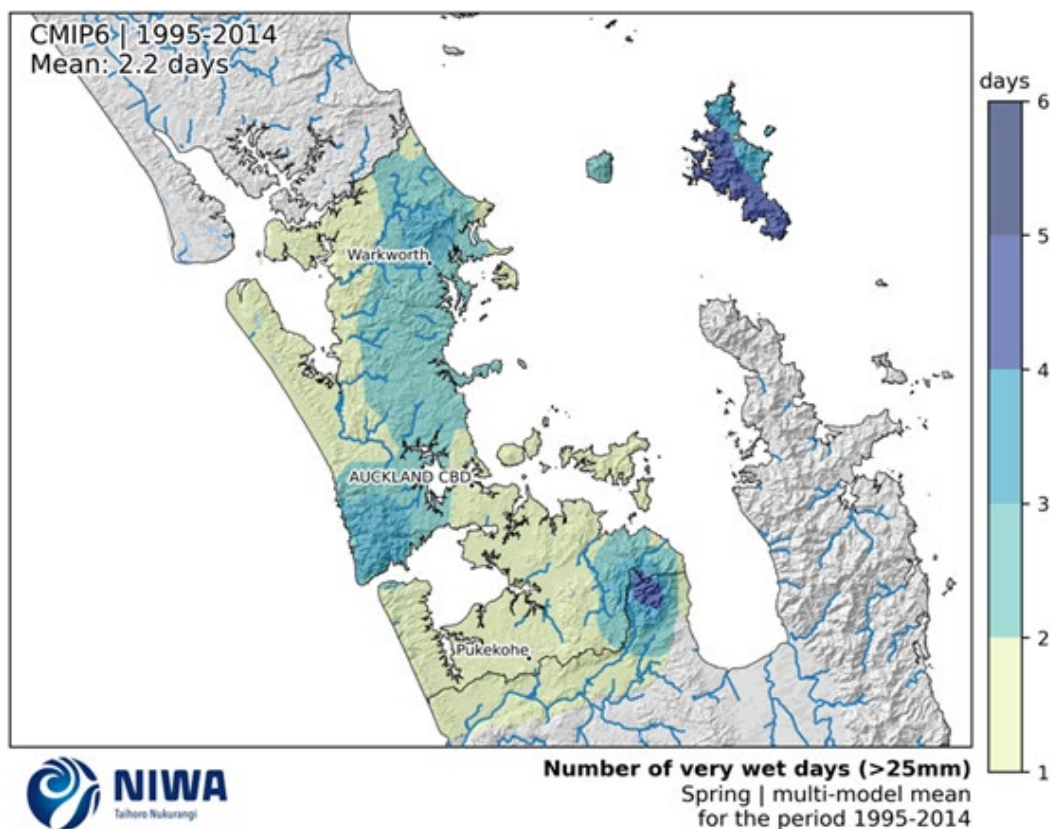


Figure 4-87: Modelled historic average spring number of very wet days.

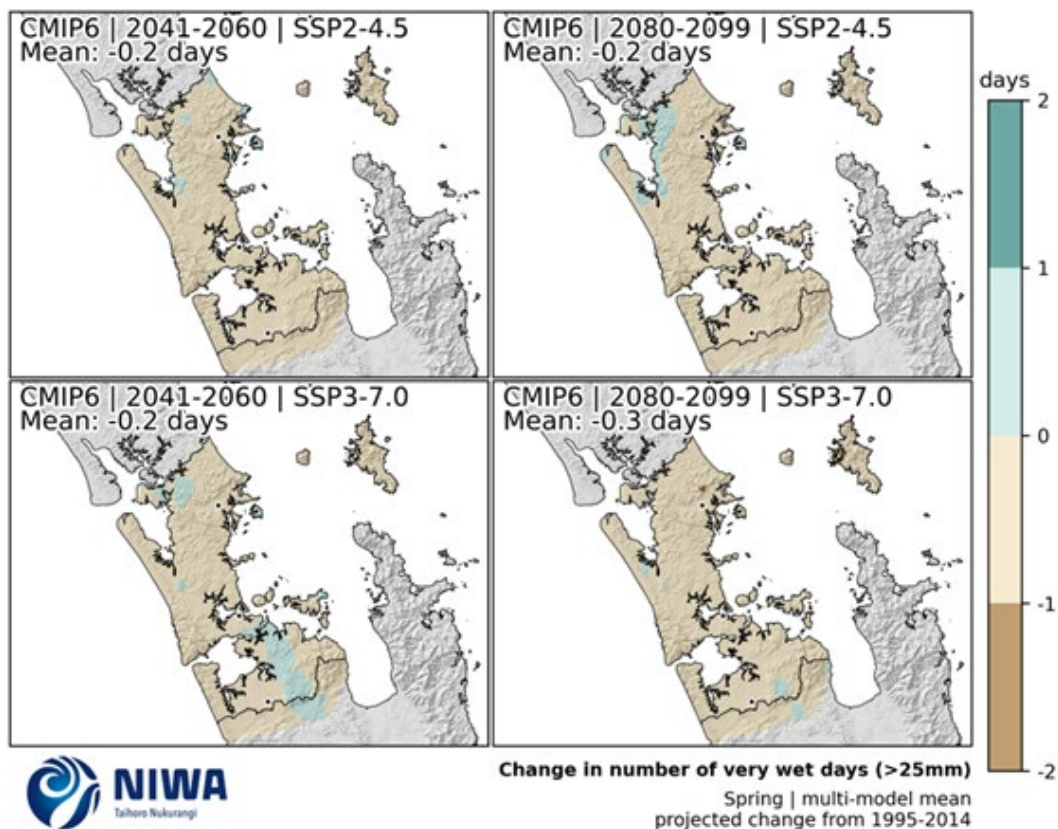


Figure 4-88: Projected spring very wet day changes.

4.13 Heavy rainfall (99th percentile) amount

Heavy rainfall (99th percentile) amount refers to the annual and seasonal daily rainfall total that exceeds the 99th percentile during a given base period. It is equivalent to the magnitude of rainfall on the 1-2 wettest wet days of the year. In this report, the historic base periods of 2004 (1995-2014) and 1995 (1986-2005) have been applied. Modelled historic and future projections of annual and seasonal heavy rainfall (99th percentile) amount are illustrated in Figure 4-89 to Figure 4-98. Note, the units for the historic data are mm, whereas the projections are calculated as a percentage change from the historic period. Region-wide averages are summarised in the two boxes below.

Historic heavy rainfall (99th percentile) (mm) and projected changes (%)									
Relative to 1995-2014 (2004)									
	Historic	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2004	2050	2090	2050	2090	2050	2090	2050	2090
Annual	61.5	+6.0	+7.1	+10.2	+13.4	+12.0	+18.5	+9.3	+22.3
Summer	68.7	+16.8	+7.6	+16.4	+10.0	+14.5	+31.3	+8.6	+41.3
Autumn	67.8	+3.1	+15.0	+14.1	+19.0	+27.0	+30.3	+14.6	+27.4
Winter	61.2	+5.1	+4.4	+4.8	+13.9	+4.4	+12.1	+10.3	+14.9
Spring	49.8	+0.8	-2.0	+2.1	+2.1	+1.2	+2.7	-0.6	+11.6

Historic heavy rainfall (99th percentile) (mm) and projected changes (%)									
Relative to 1986-2005 (1995)									
	Historic	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	1995	2050	2090	2050	2090	2050	2090	2050	2090
Annual	60.5	+7.4	+8.5	+11.7	+14.9	+13.5	+20.1	+10.7	+24.0
Summer	67.6	+17.6	+8.8	+17.6	+11.0	+15.4	+32.3	+9.7	+42.9
Autumn	67.5	+3.0	+14.8	+14.0	+18.9	+26.8	+30.1	+14.6	+27.5
Winter	60.2	+6.6	+5.9	+6.2	+15.5	+5.9	+13.6	+11.8	+16.5
Spring	48.8	+2.7	-0.2	+4.0	+4.1	+3.1	+4.7	+1.4	+13.7

4.13.1 Annual

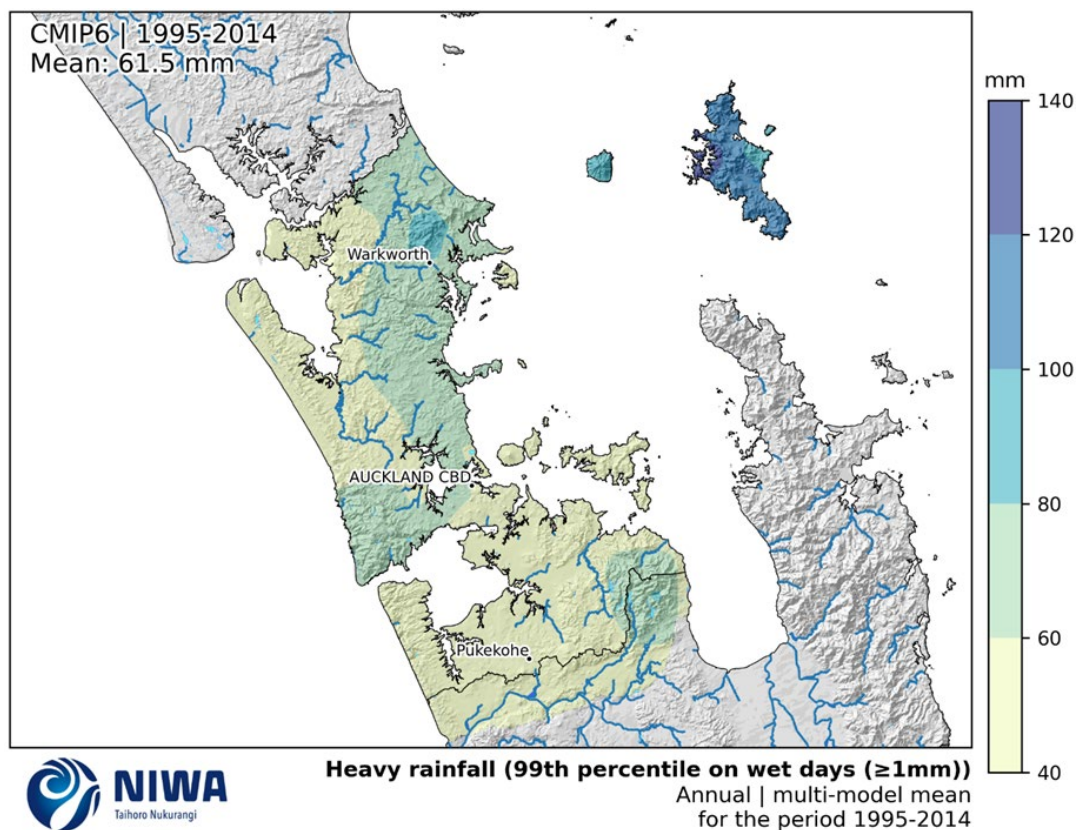


Figure 4-89: Modelled historic average annual heavy rainfall total.

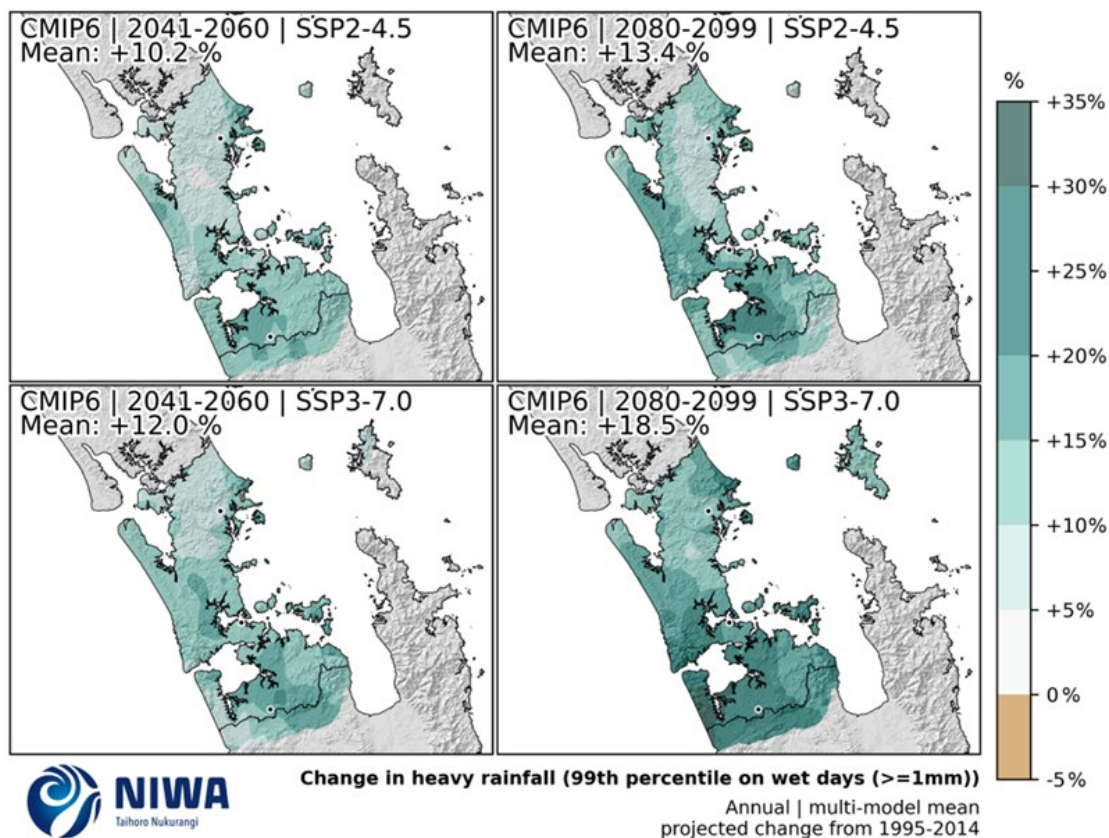


Figure 4-90: Projected annual heavy rainfall changes.

4.13.2 Seasonal

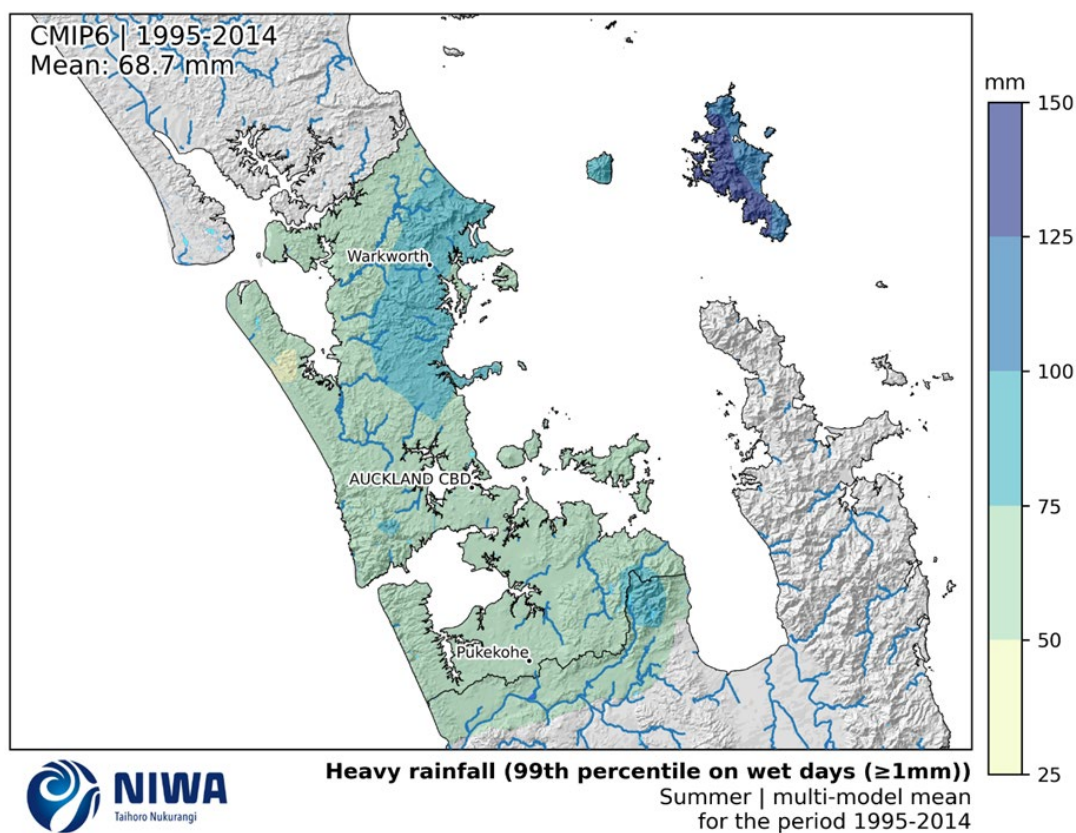


Figure 4-91: Modelled historic average summer heavy rainfall total.

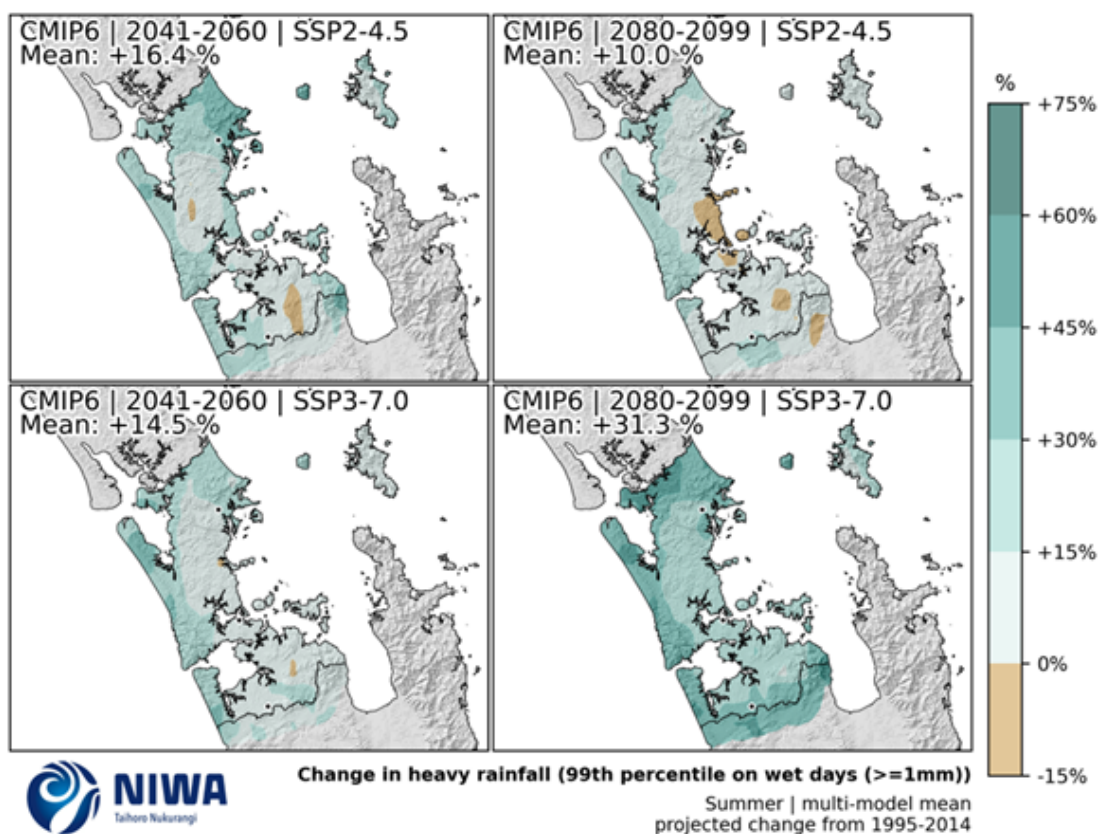


Figure 4-92: Projected summer heavy rainfall changes.

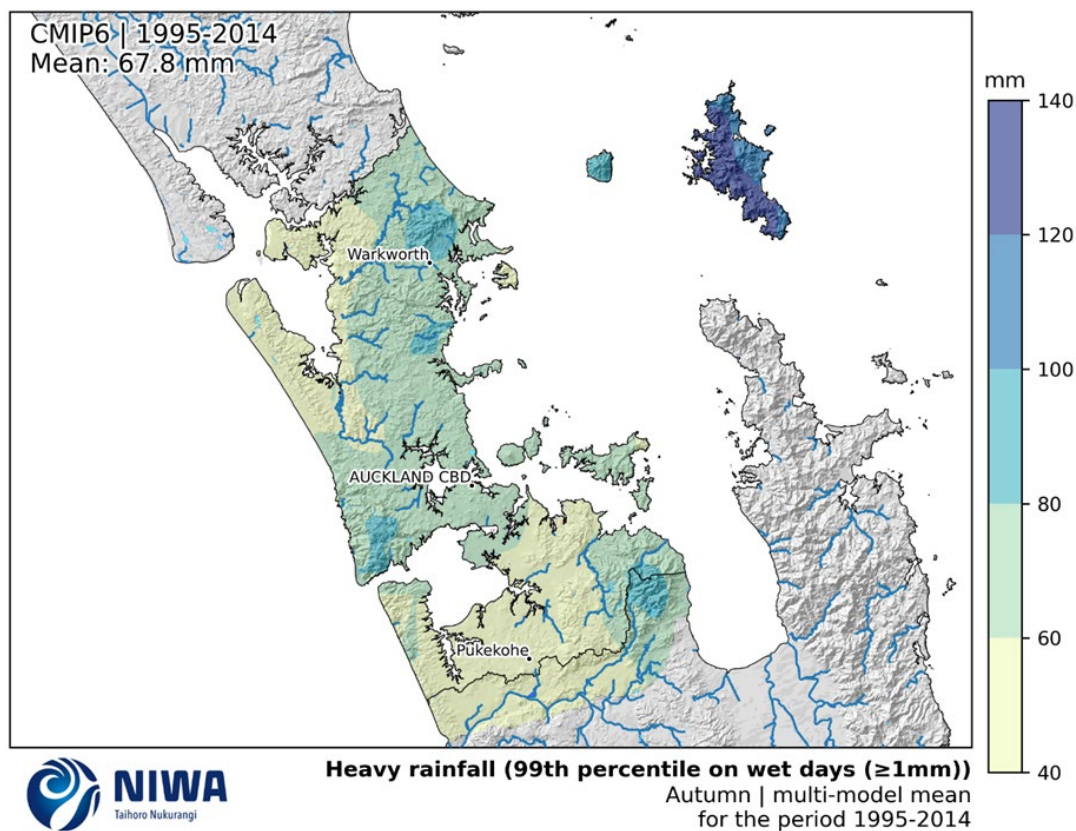


Figure 4-93: Modelled historic average autumn heavy rainfall total.

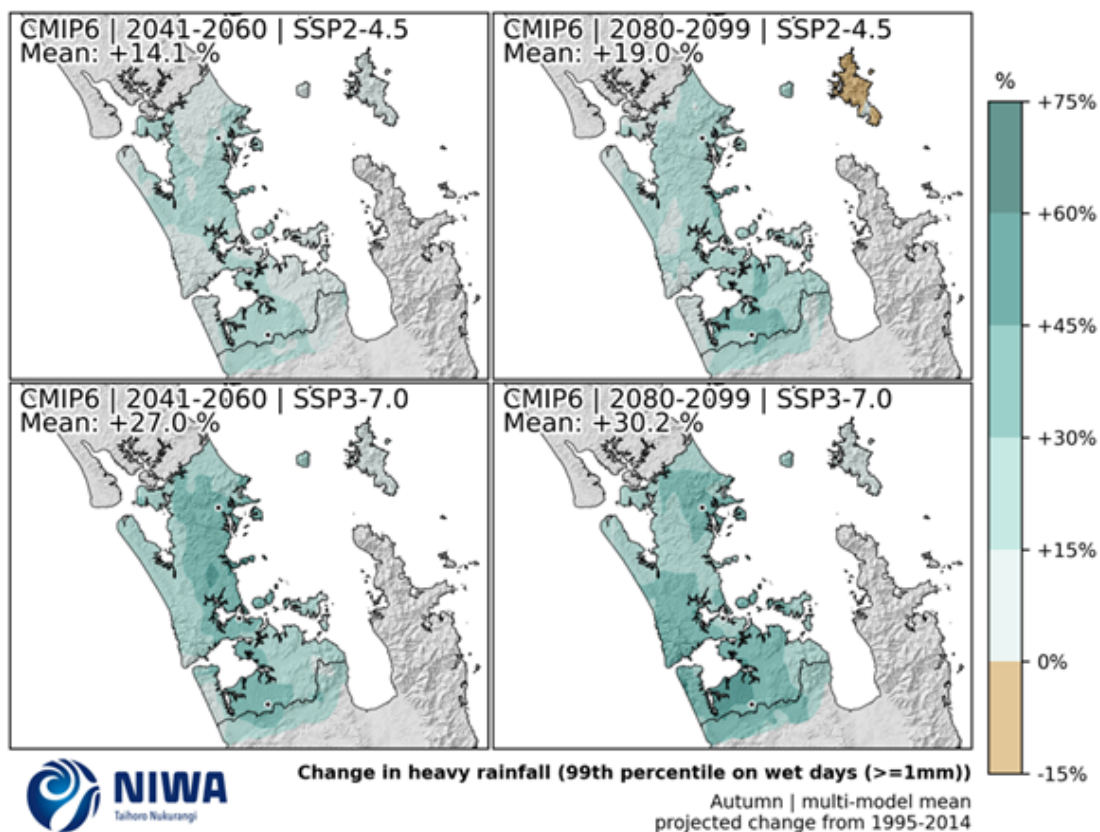


Figure 4-94: Projected autumn heavy rainfall changes.

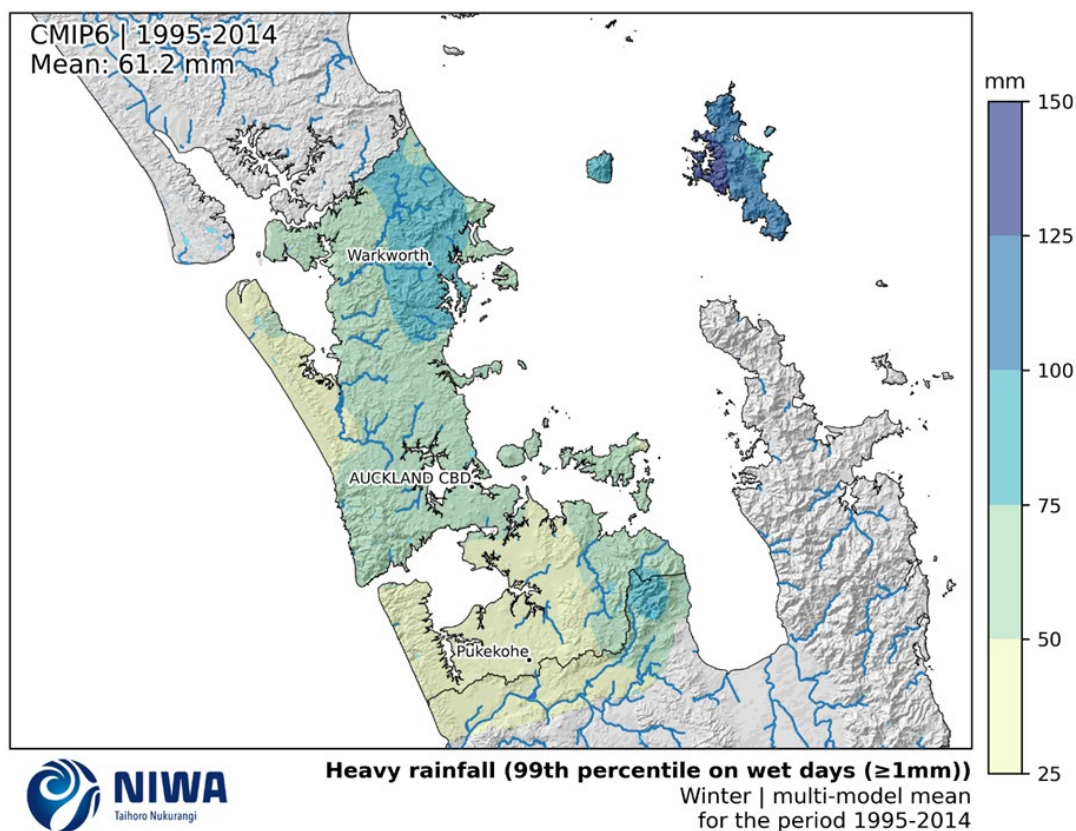


Figure 4-95: Modelled historic average winter heavy rainfall total.

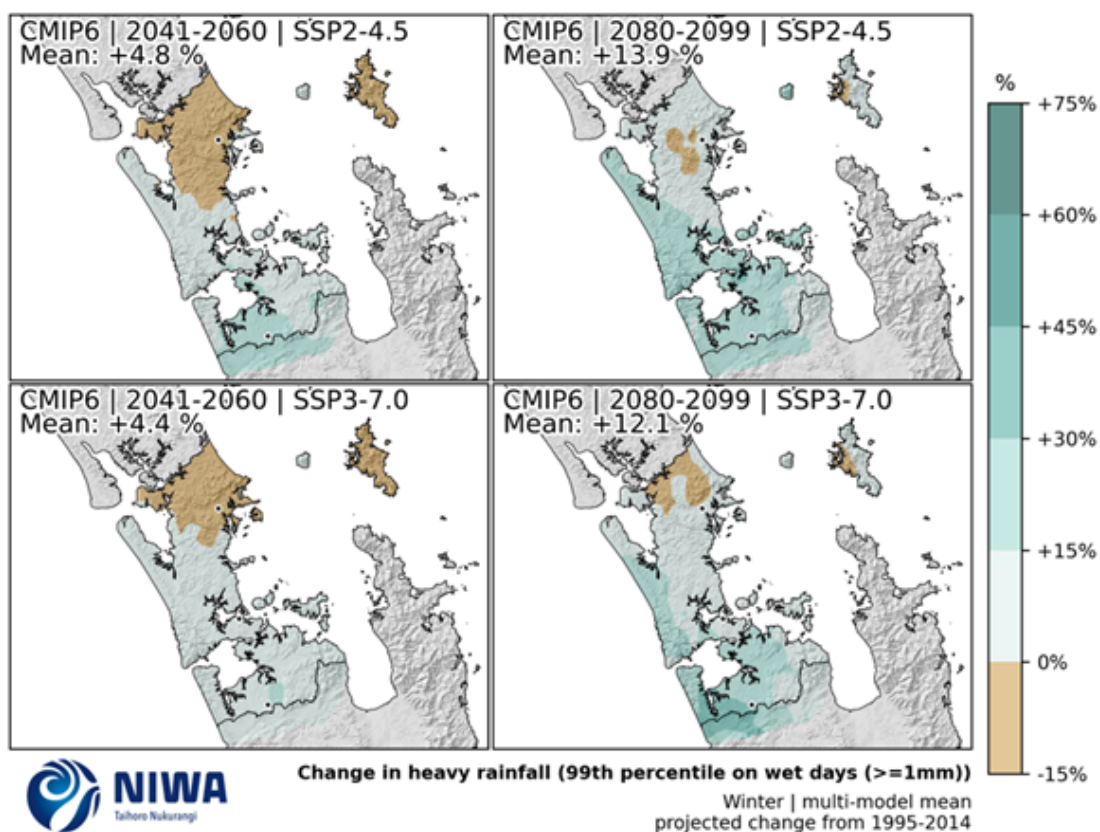


Figure 4-96: Projected winter heavy rainfall changes.

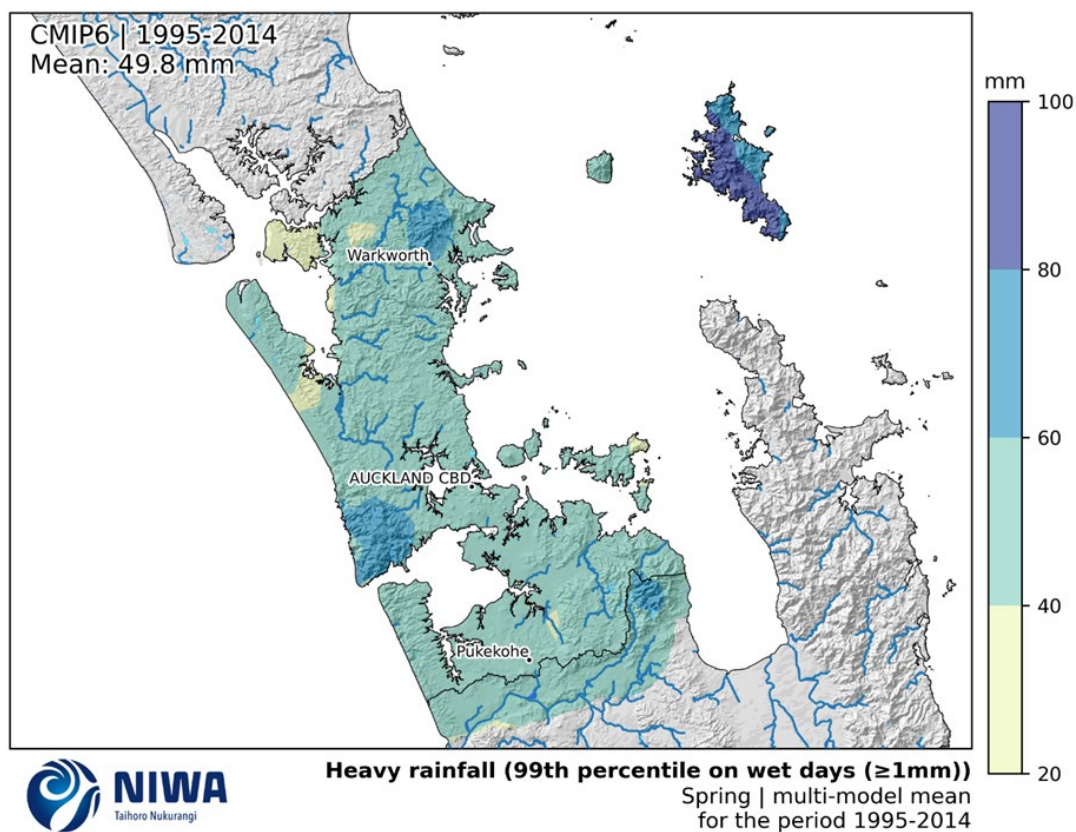


Figure 4-97: Modelled historic average spring heavy rainfall total.

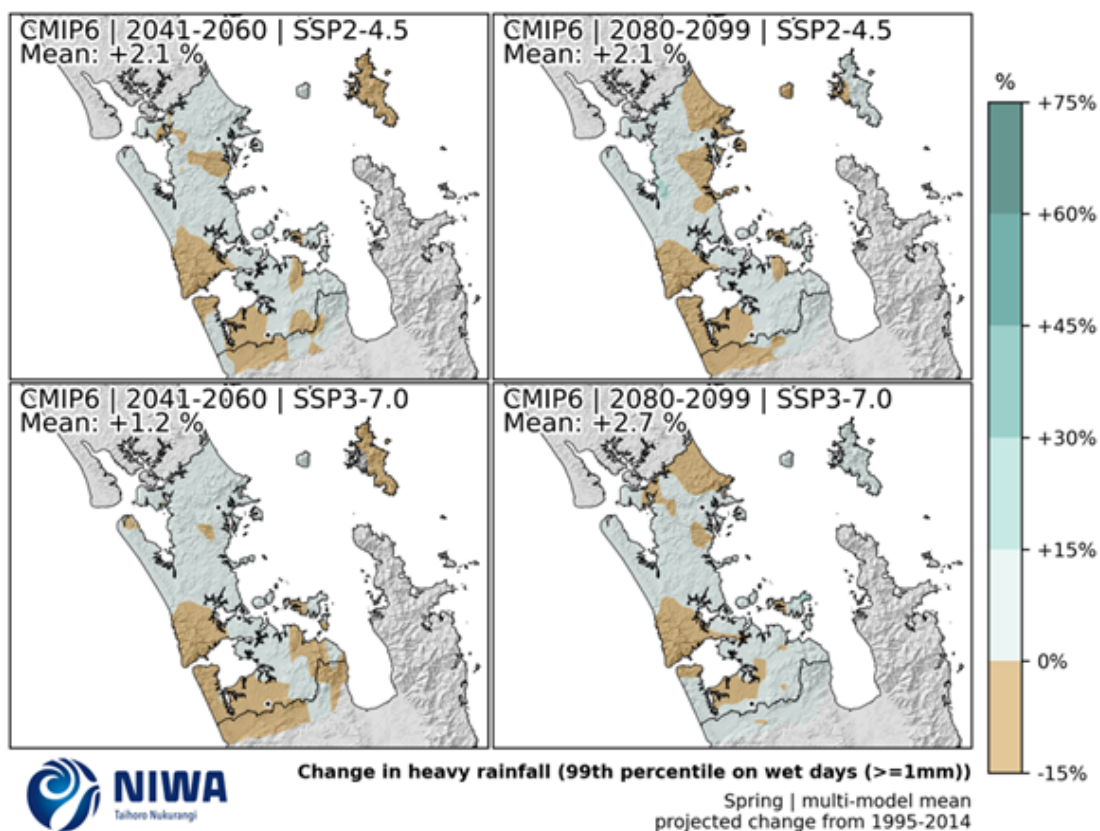


Figure 4-98: Projected spring heavy rainfall changes.

4.14 Heavy rainfall (99th percentile) days

Heavy rainfall (99th percentile) days refers to the annual and seasonal number of days where the daily rainfall total exceeds the *heavy rainfall (99th percentile) amount* during a given base period. In this report, the historic base periods of 2004 (1995-2014) and 1995 (1986-2005) have been applied. Note, historic data are not presented here because the data are not meaningful in their own right; the nature of the calculation means there are approximately 3.6 such days per year, and approximately 0.9 such days per season, irrespective of the base period chosen.

Modelled future projections of annual and seasonal heavy rainfall (99th percentile) days show the change in number of days where the annual or seasonal heavy rainfall (99th percentile) amount is exceeded. These projections are illustrated in Figure 4-99 to Figure 4-103. Region-wide averages are summarised in the two boxes below.

Projected heavy rainfall (99 th percentile) days changes (days)								
Relative to 1995-2014 (2004)								
	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090	2050	2090
Annual	+0.4	+0.4	+0.7	+0.7	+0.7	+0.8	+0.5	+1.0
Summer	+0.2	+0.2	+0.3	+0.1	+0.2	+0.3	0	+0.4
Autumn	+0.1	+0.2	+0.3	+0.3	+0.4	+0.3	+0.3	+0.3
Winter	+0.2	+0.1	+0.1	+0.3	+0.1	+0.2	+0.2	+0.2
Spring	0	0	0	0	0	0	0	+0.1

Projected heavy rainfall (99 th percentile) days changes (days)								
Relative to 1986-2005 (1995)								
	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2050	2090	2050	2090	2050	2090	2050	2090
Annual	+0.4	+0.5	+0.7	+0.7	+0.7	+0.8	+0.5	+1.0
Summer	+0.2	+0.2	+0.3	+0.1	+0.2	+0.3	+0.1	+0.5
Autumn	0	+0.2	+0.3	+0.3	+0.3	+0.3	+0.3	+0.3
Winter	+0.2	+0.2	+0.2	+0.3	+0.2	+0.2	+0.2	+0.2
Spring	0	-0.1	-0.1	0	0	0	0	0

4.14.1 Annual

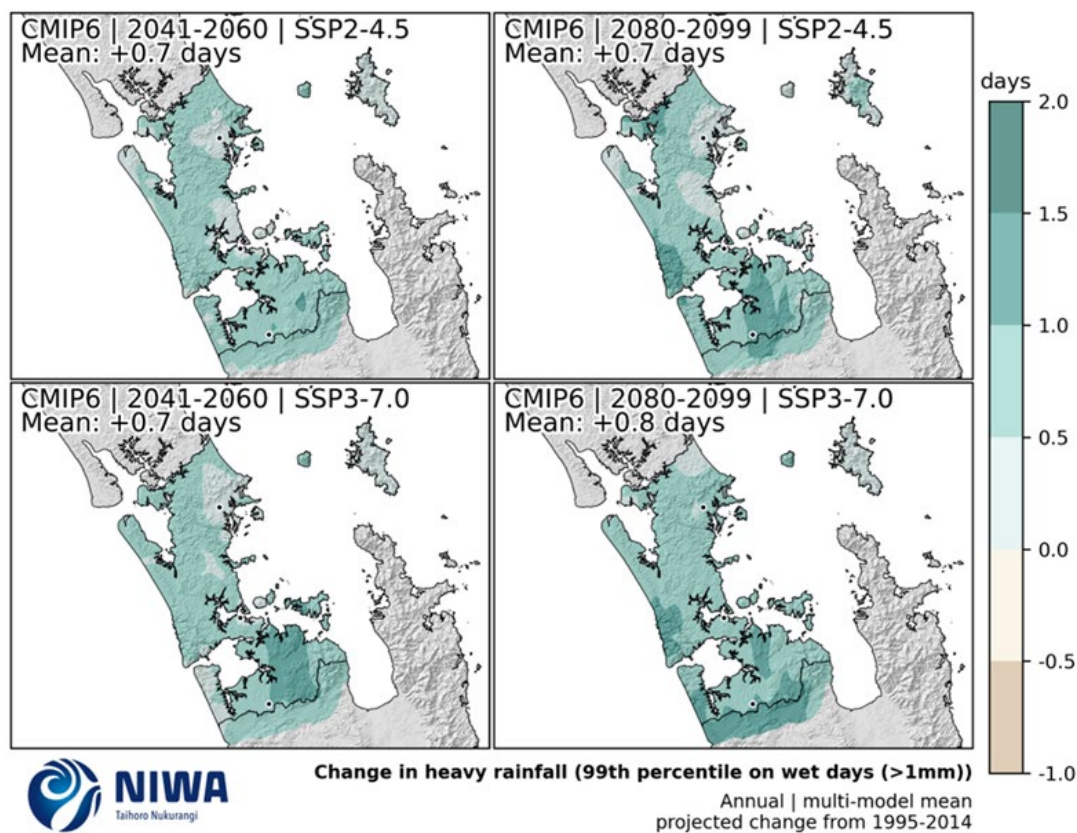


Figure 4-99: Projected annual heavy rainfall day changes.

4.14.2 Seasonal

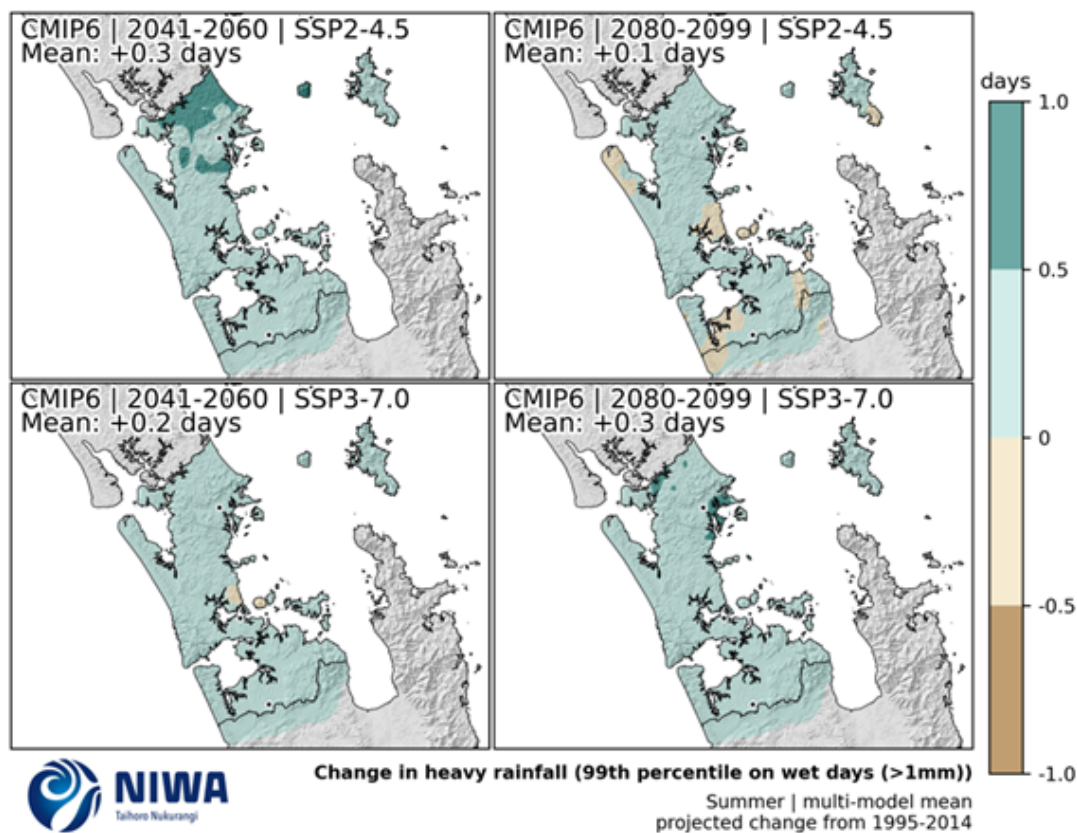


Figure 4-100: Projected summer heavy rainfall day changes.

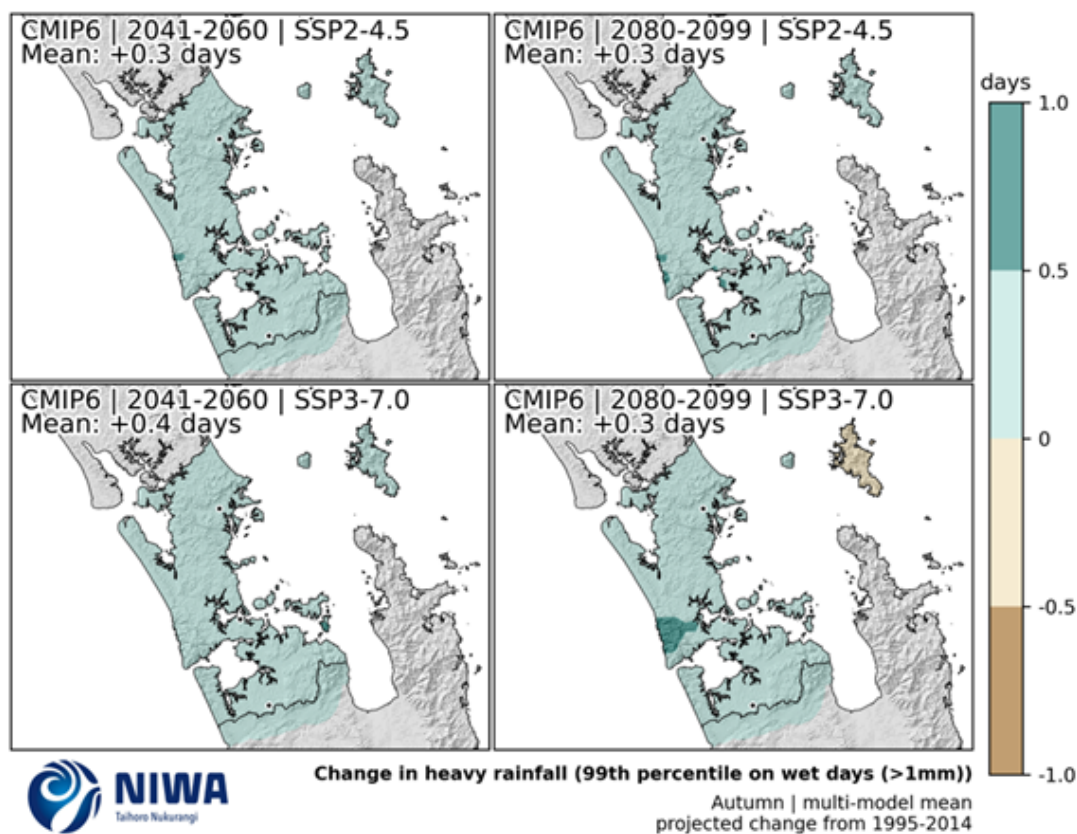


Figure 4-101: Projected autumn heavy rainfall day changes.

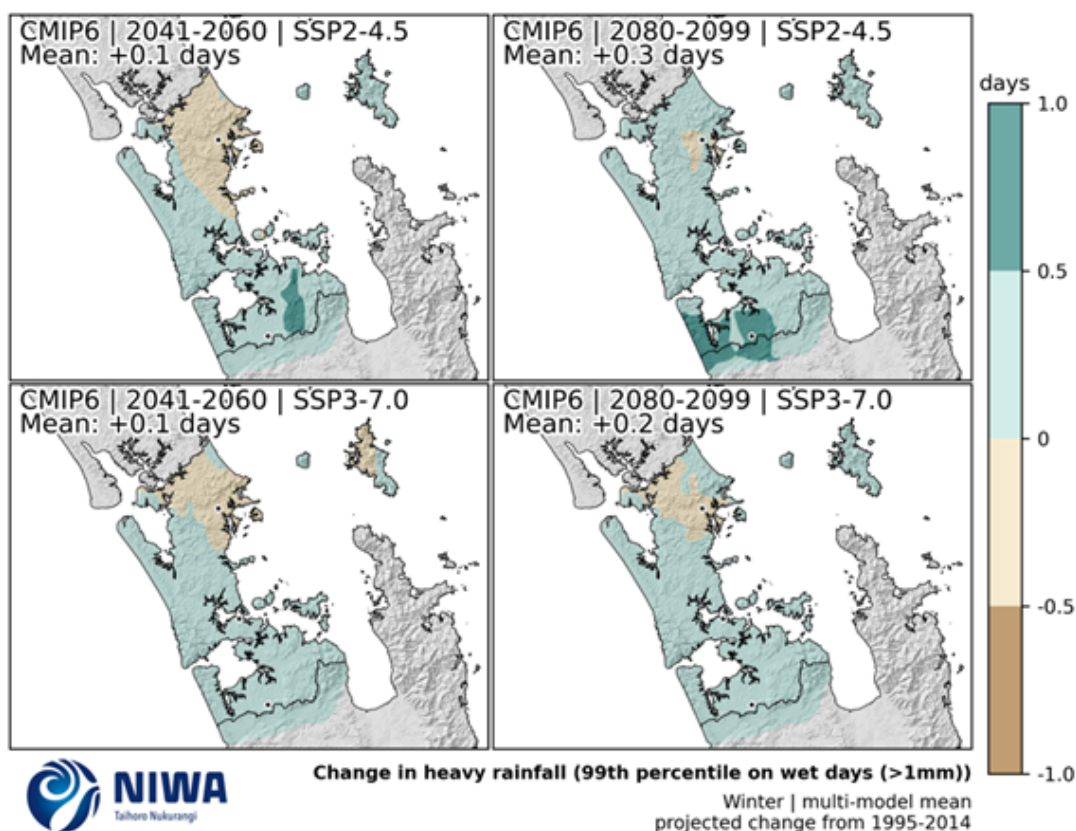


Figure 4-102: Projected winter heavy rainfall day changes.

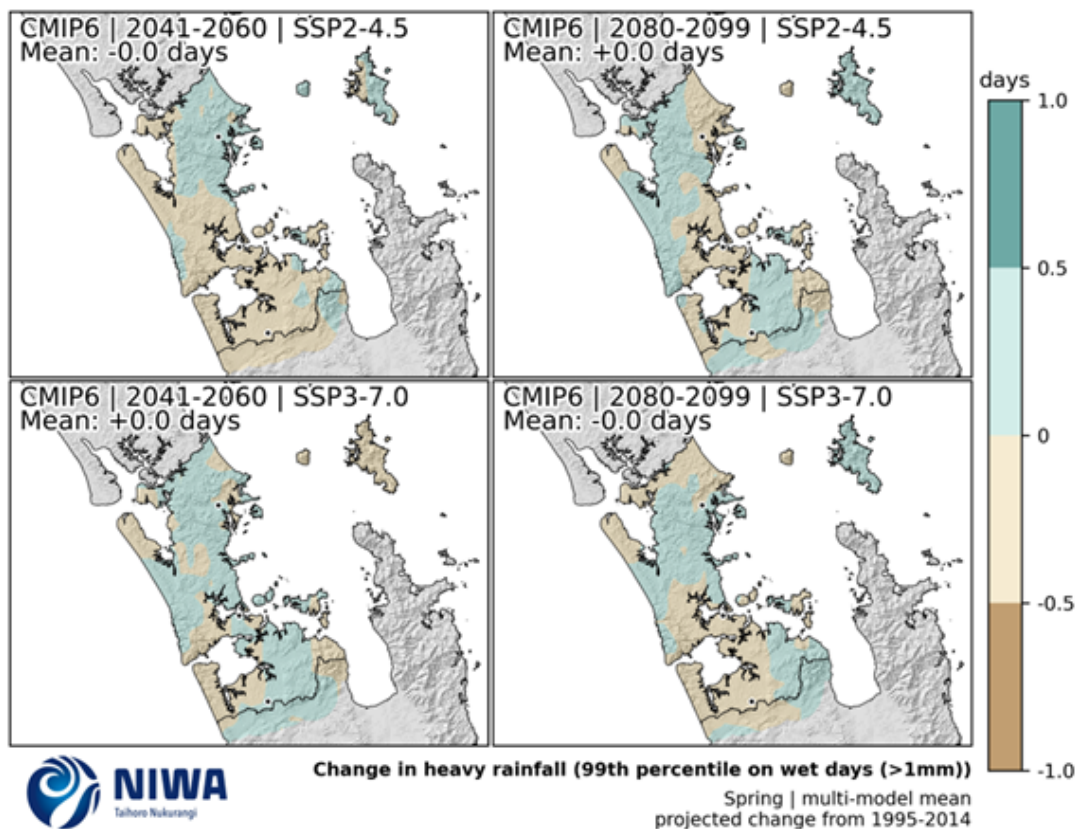


Figure 4-103: Projected spring heavy rainfall day changes.

4.15 Potential evapotranspiration deficit

Potential evapotranspiration deficit (PED) can be interpreted as a measure of drought severity. It represents the gap between the amount of water that could evaporate and transpire from land, and the actual amount of water that is available. PED is a daily calculation, and daily values are added to generate PED accumulation values. Here, PED refers to annual PED accumulation.

Modelled historic and future projections of annual PED are illustrated in Figure 4-104 and Figure 4-105. Region-wide averages are summarised in the two boxes below.

Historic PED accumulation and projected changes (mm) Relative to 1995-2014 (2004)									
	Historic avg. 2004	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
		2050	2090	2050	2090	2050	2090	2050	2090
Annual	166.6	+30.8	+28.4	+30.2	+61.8	+39.9	+88.6	+53.8	+95.3

Historic PED accumulation and projected changes (mm) Relative to 1986-2005 (1995)									
	Historic avg. 1995	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
		2050	2090	2050	2090	2050	2090	2050	2090
Annual	162.6	+34.9	+32.5	+34.3	+65.8	+44.0	+92.6	+57.9	+99.4

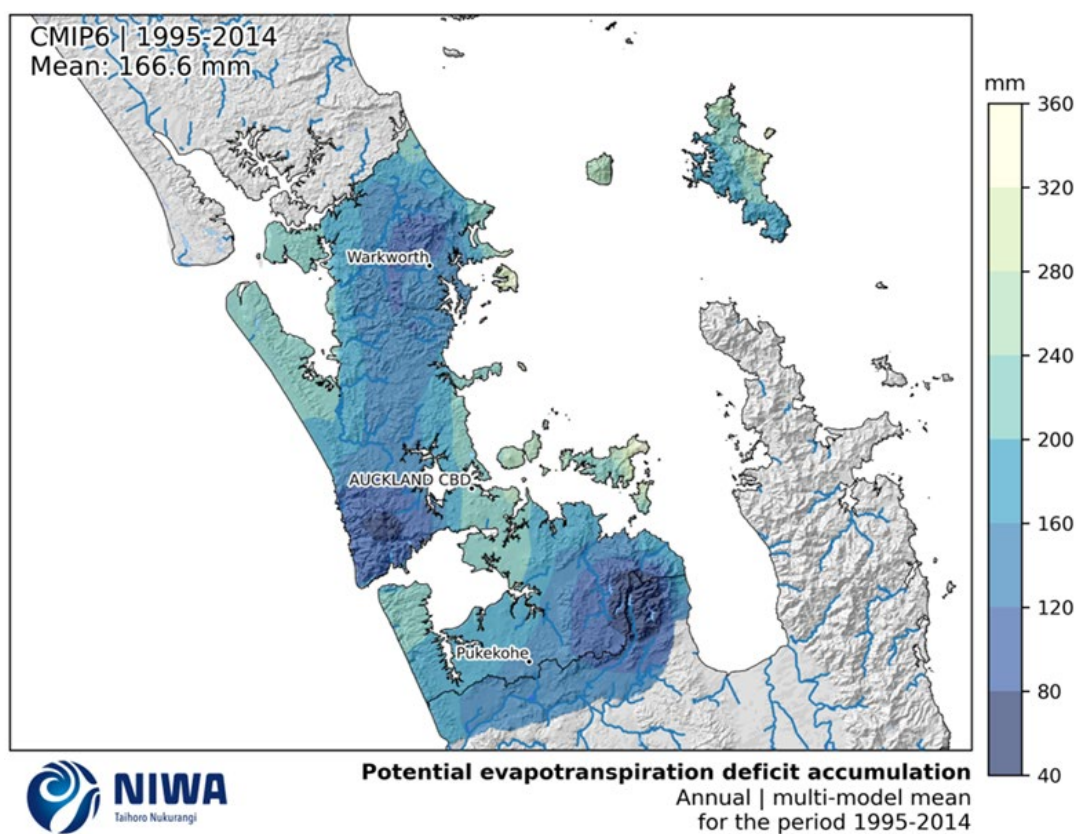


Figure 4-104: Modelled historic average annual potential evapotranspiration deficit accumulation.

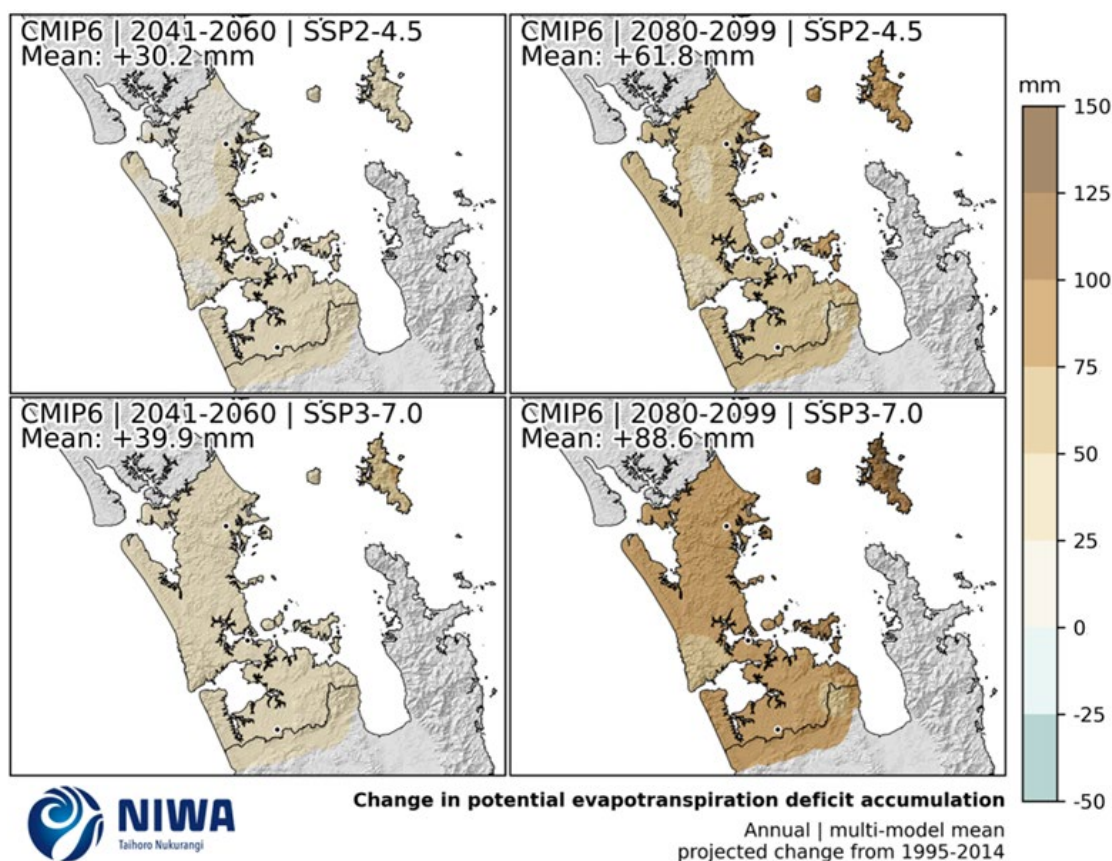


Figure 4-105: Projected annual potential evapotranspiration deficit accumulation changes.

4.16 Meteorological drought frequency

Meteorological drought frequency refers to the annual and seasonal number of meteorological drought days. A meteorological drought is defined here using the approach outlined in Ukkola et al. (2020). Drought conditions are identified when the 3-month running average of precipitation falls below the 15th percentile, calculated for each month and location (i.e., grid cell) based on the historical reference period. A drought event is defined as any continuous period of at least one month during which the running average remains below this threshold.

Modelled historic and future projections of annual and seasonal meteorological drought frequency are illustrated in Figure 4-106 to Figure 4-115. Region-wide averages are summarised in the two boxes below.

Historic meteorological drought frequency and projected changes (days)									
Relative to 1995-2014 (2004)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2004	2050	2090	2050	2090	2050	2090	2050	2090
Annual	66.3	+4.3	+7.4	+9.5	+24.5	+19.4	+53.1	+24.9	+55.1
Summer	15.7	+3.5	+2.9	+4.6	+8.1	+8.8	+11.3	+8.0	+8.8
Autumn	14.2	+4.2	+3.7	-0.1	+4.8	+1.9	+8.7	+4.6	+7.0
Winter	19.5	-3.7	-3.5	+0.5	+3.0	+1.4	+15.7	+2.6	+16.3
Spring	16.6	-0.1	+4.5	+4.4	+9.5	+7.1	+17.8	+9.6	+23.3

Historic meteorological drought frequency and projected changes (days)									
Relative to 1986-2005 (1995)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	1995	2050	2090	2050	2090	2050	2090	2050	2090
Annual	62.4	+8.2	+11.3	+13.4	+28.4	+23.3	+57.0	+28.8	+59.0
Summer	13.2	+6.1	+5.4	+7.1	+10.7	+11.3	+13.9	+10.5	+11.4
Autumn	17.2	+1.2	+0.7	-3.1	+1.9	-1.1	+5.7	+1.6	+4.0
Winter	18.1	-2.3	-2.1	+2.0	+4.5	+2.9	+17.2	+4.1	+17.7
Spring	14.2	+2.3	+7.0	+6.8	+11.9	+9.6	+20.2	+12.1	+25.7

4.16.1 Annual

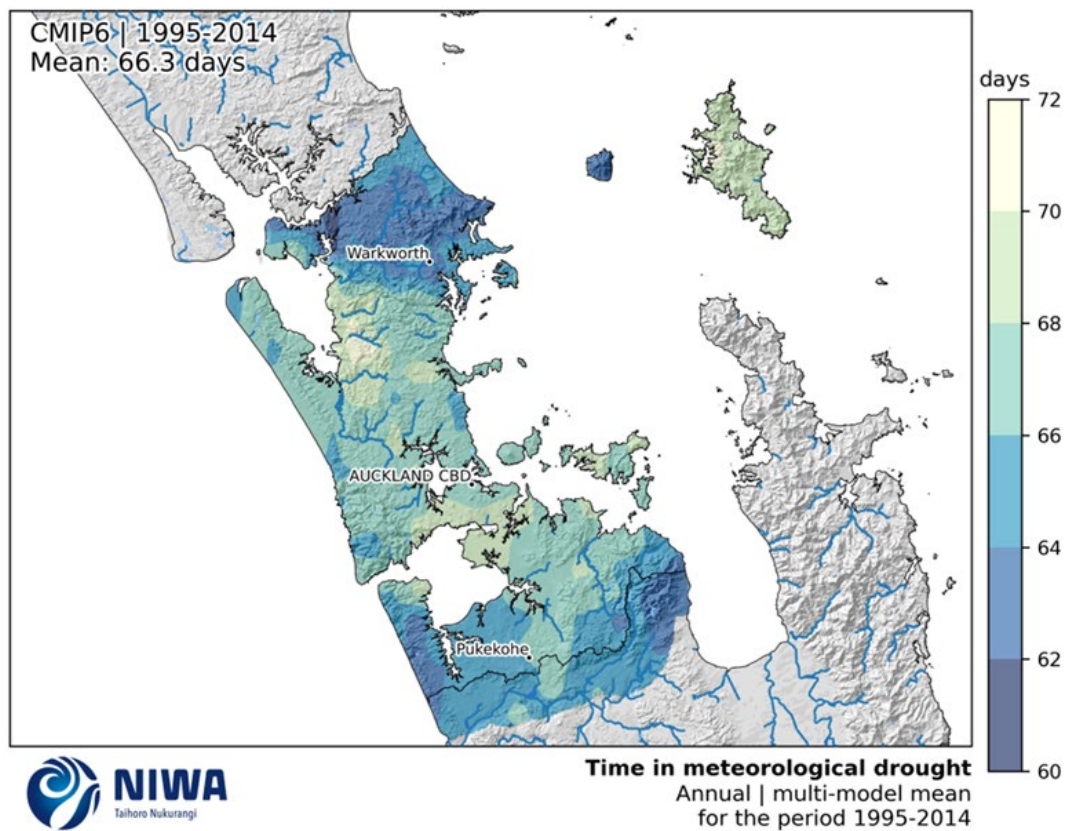


Figure 4-106: Modelled historic average annual meteorological drought frequency.

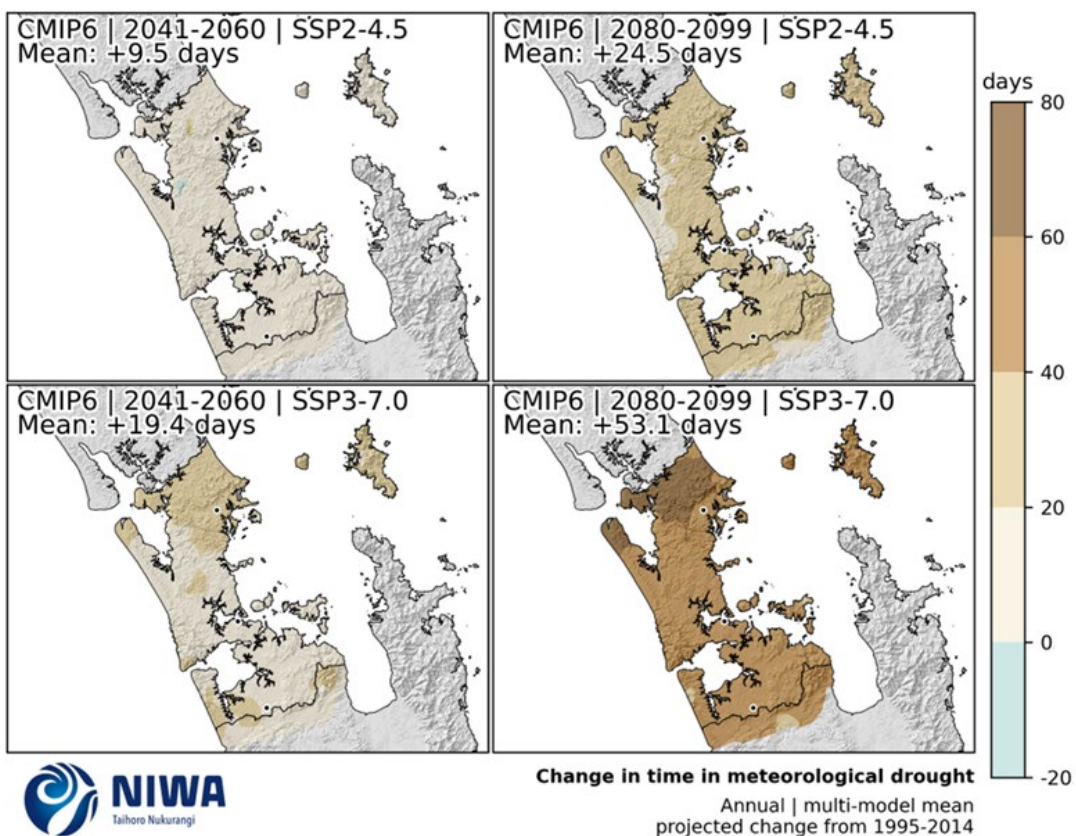


Figure 4-107: Projected annual meteorological drought frequency changes.

4.16.2 Seasonal

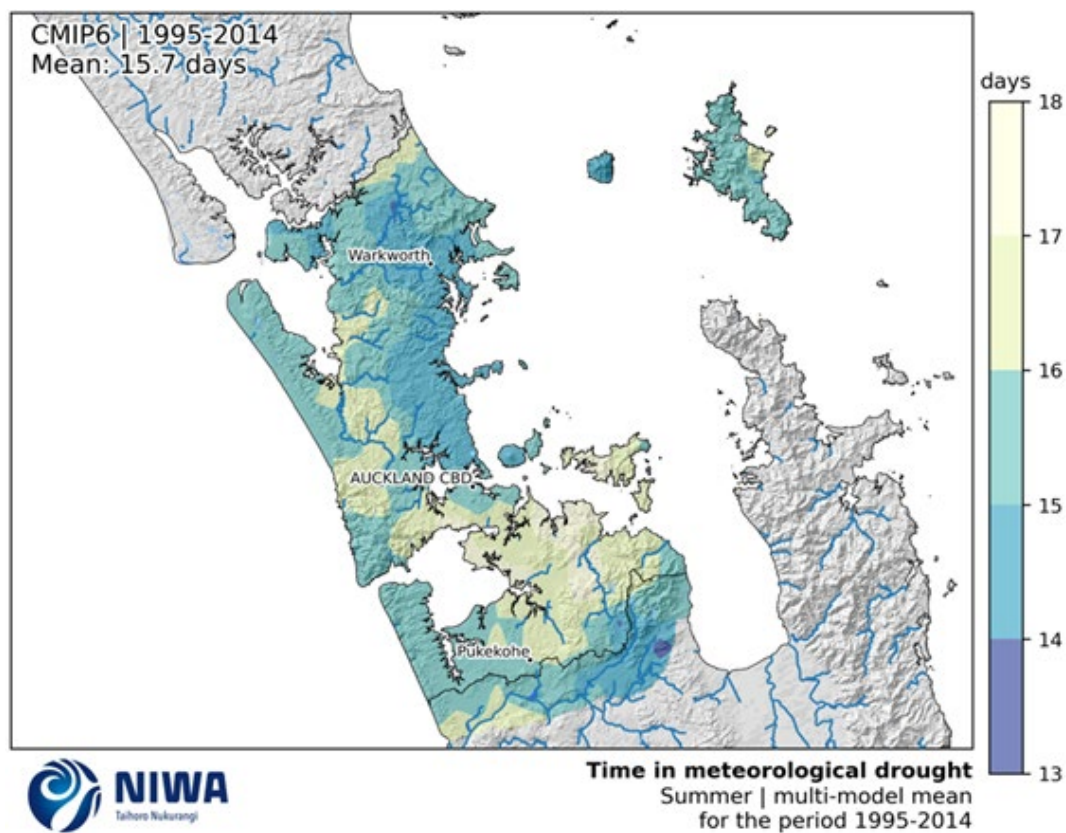


Figure 4-108: Modelled historic average summer meteorological drought frequency.

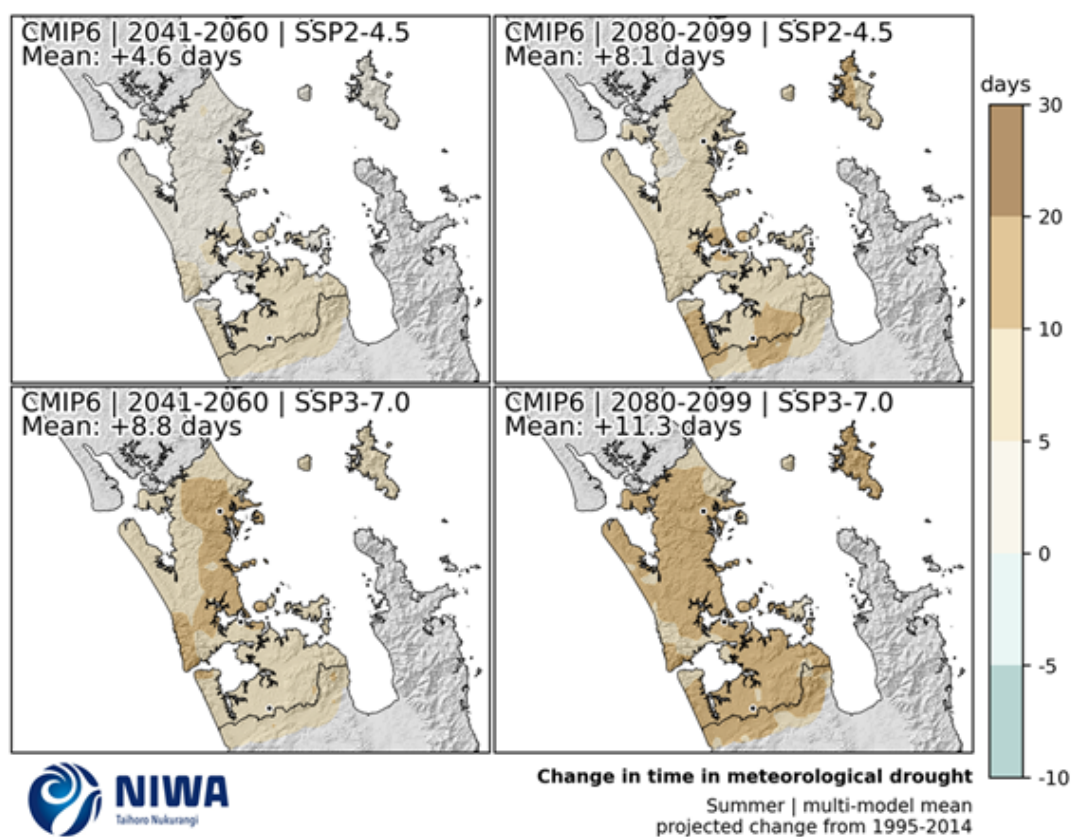


Figure 4-109: Projected summer meteorological drought frequency changes.

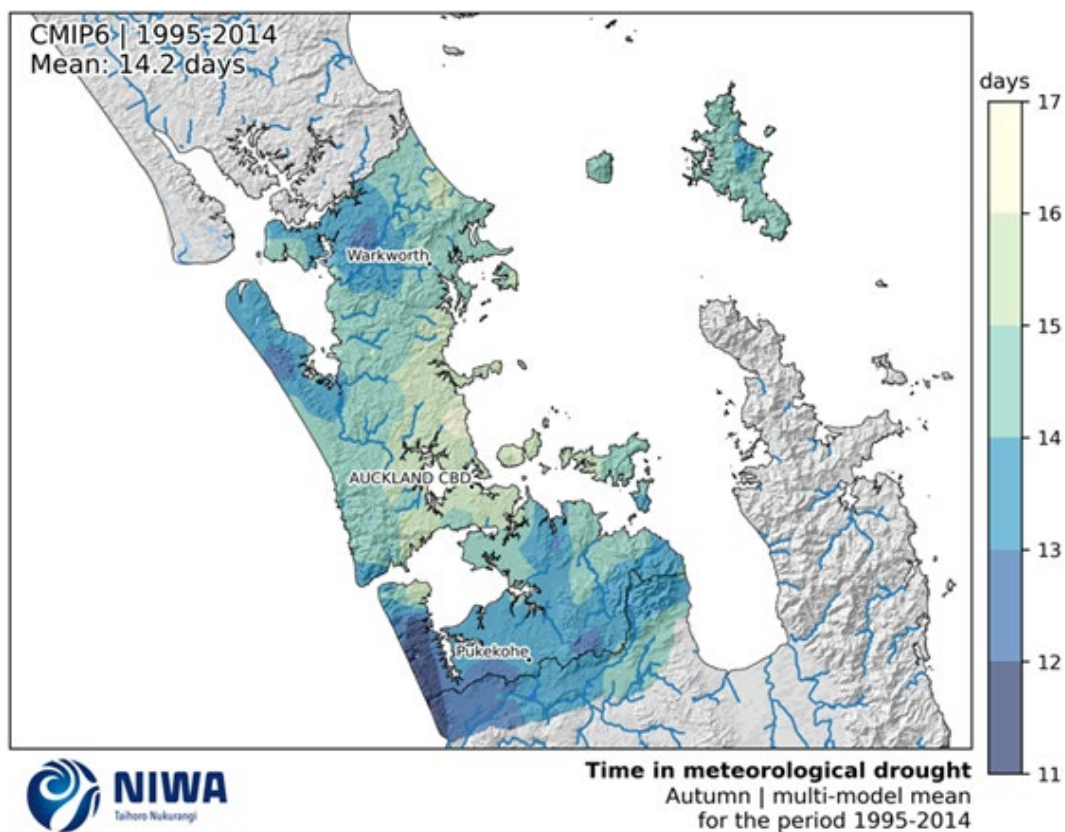


Figure 4-110: Modelled historic average autumn meteorological drought frequency.

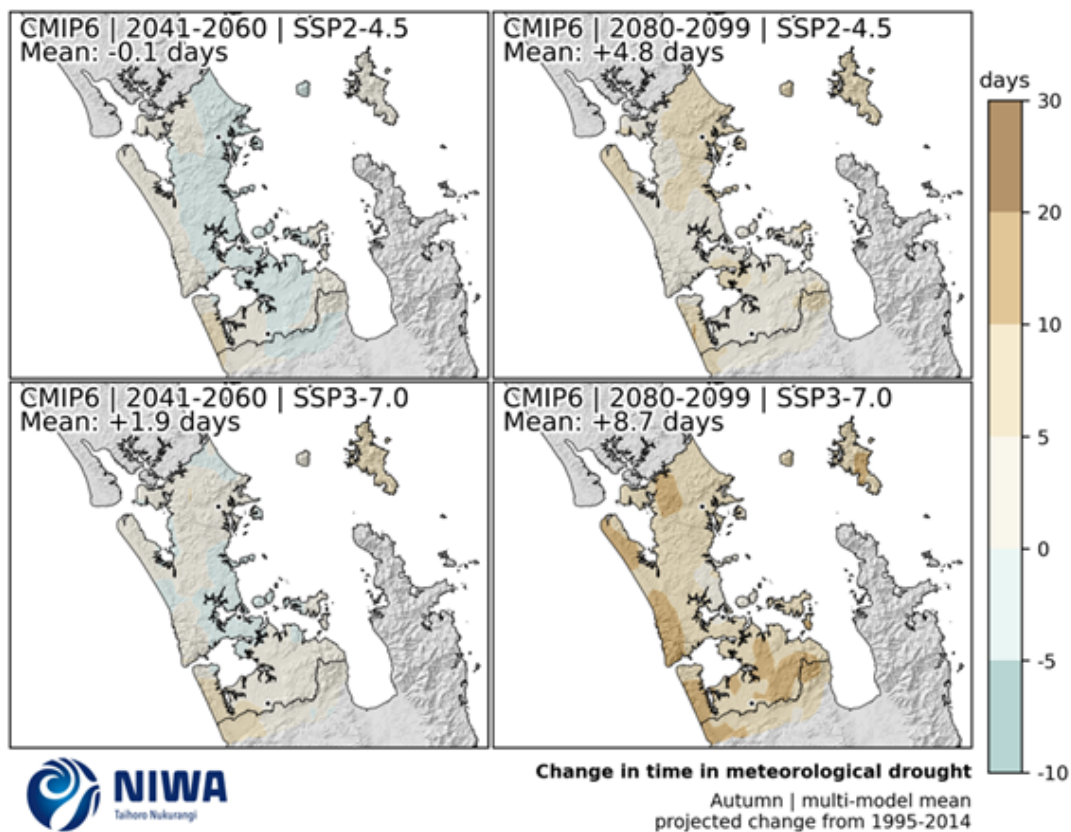


Figure 4-111: Projected autumn meteorological drought frequency changes.

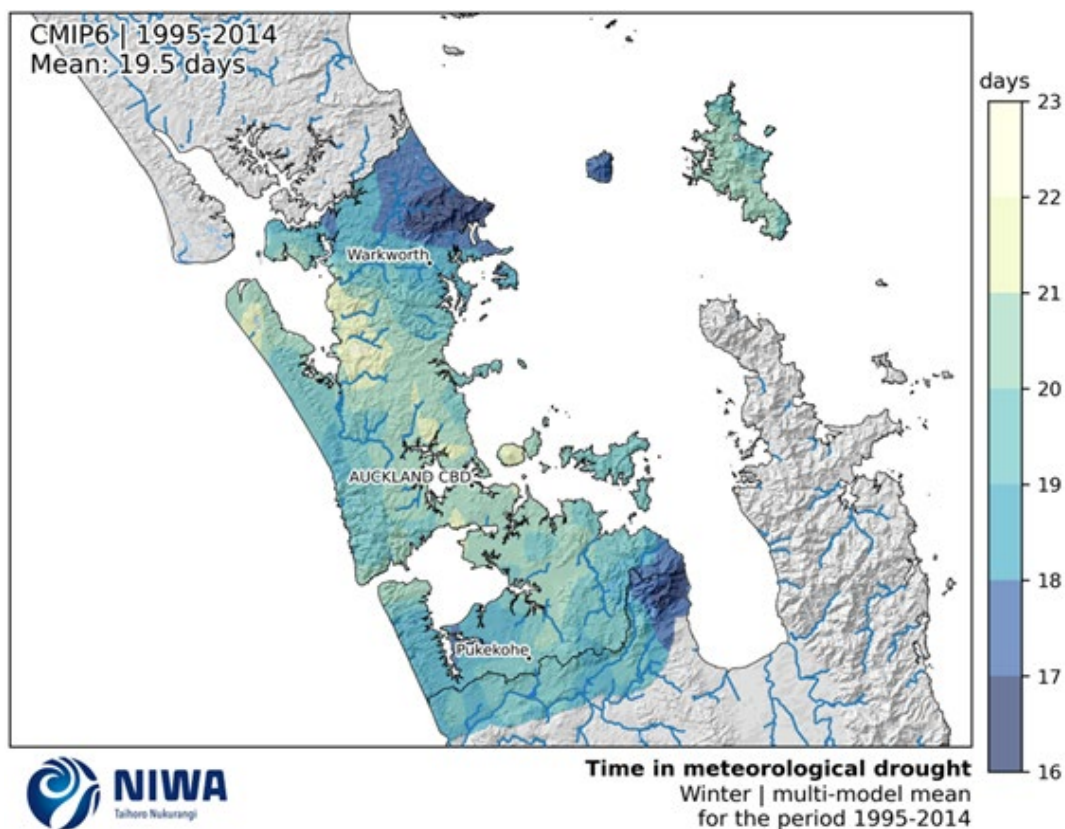


Figure 4-112: Modelled historic average winter meteorological drought frequency.

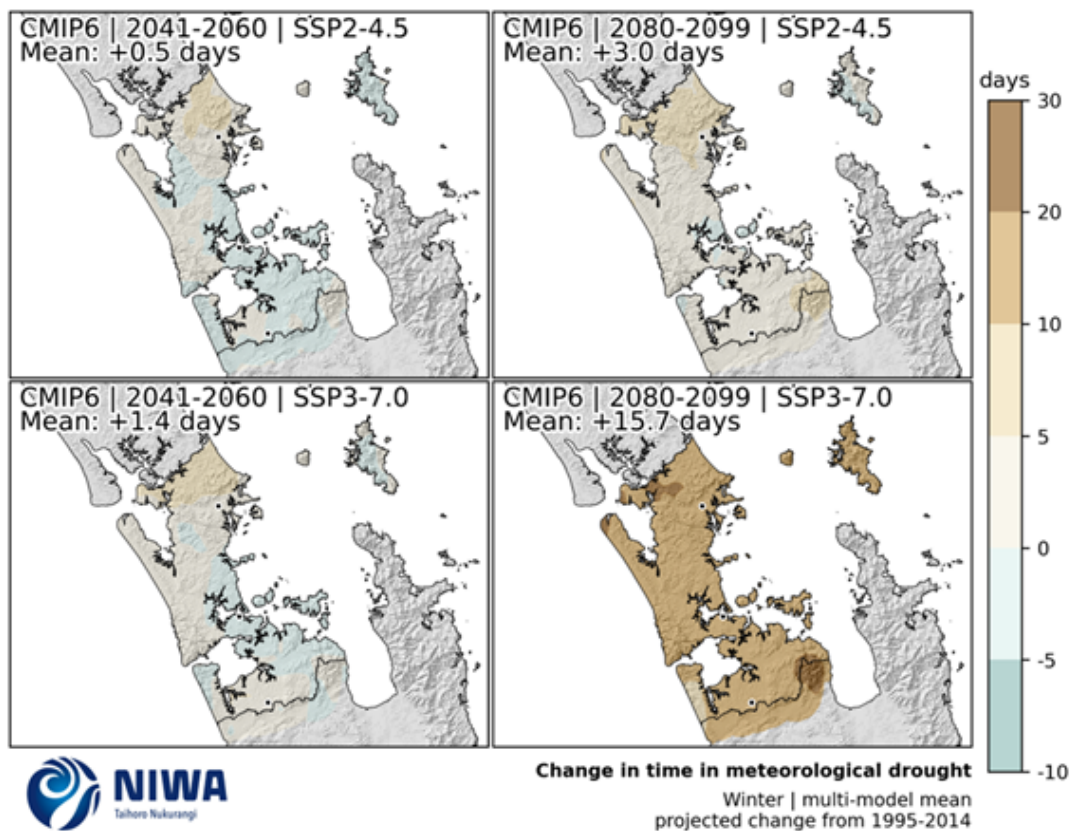


Figure 4-113: Projected winter meteorological drought frequency changes.

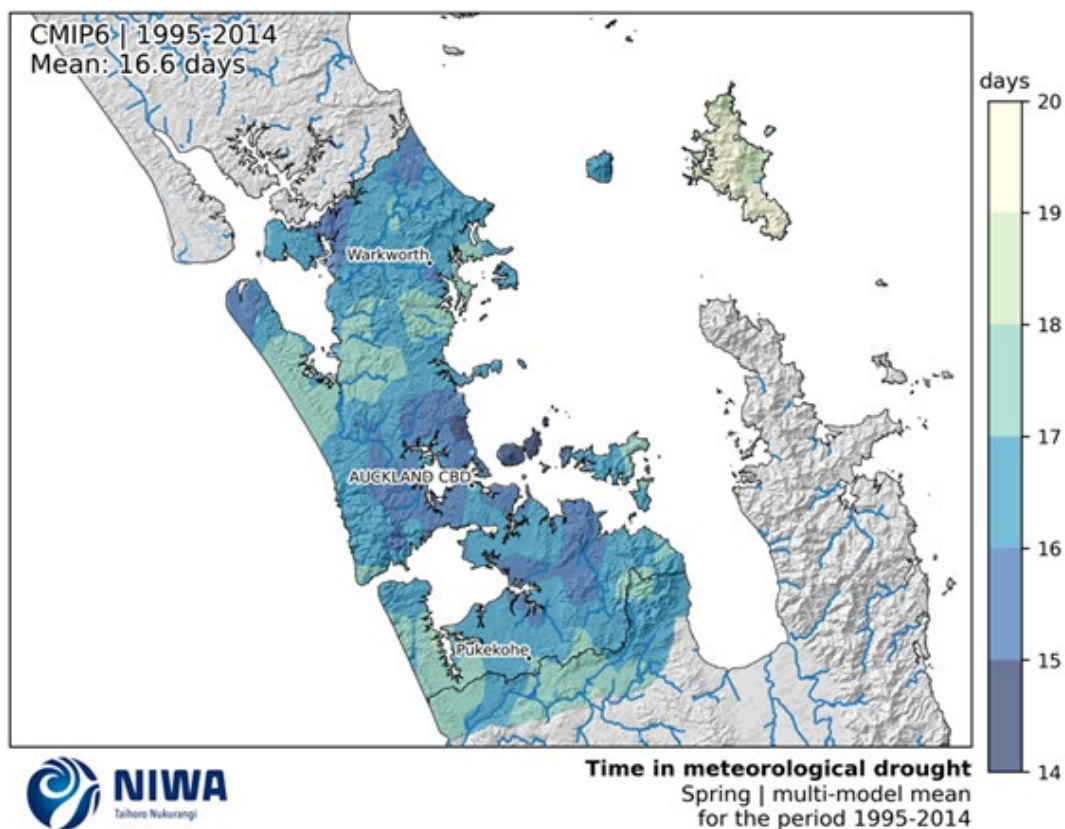


Figure 4-114: Modelled historic average spring meteorological drought frequency.

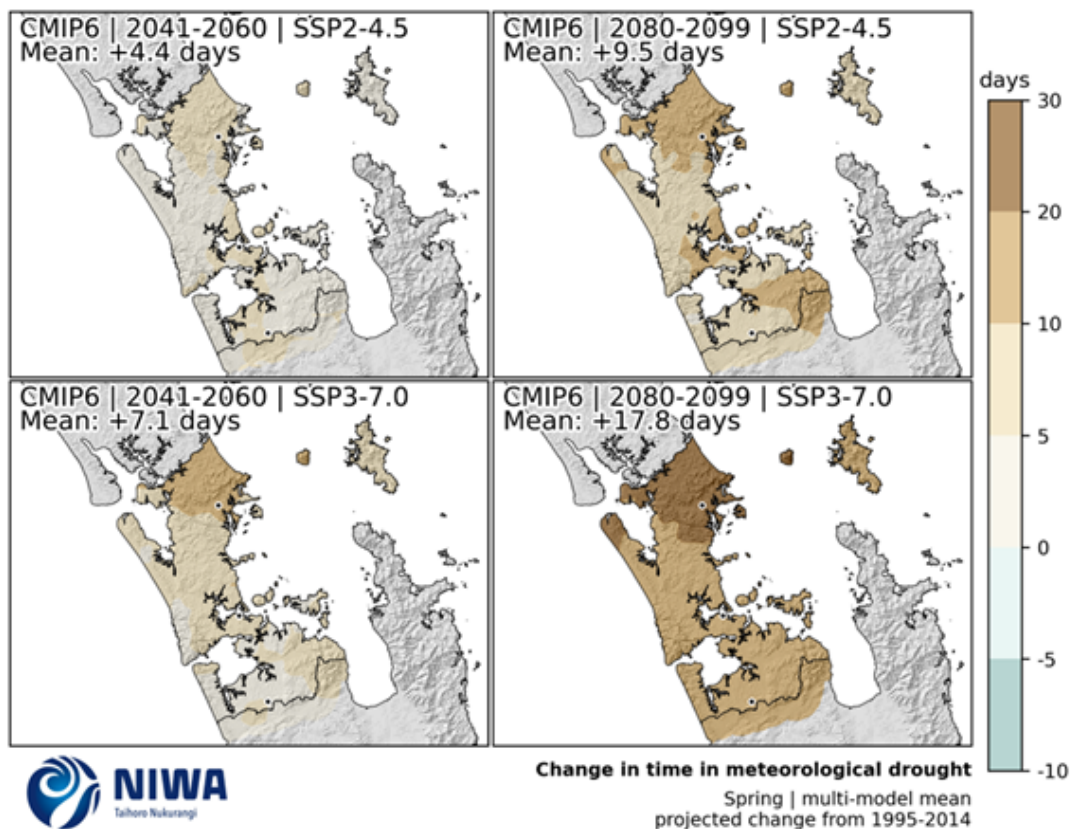


Figure 4-115: Projected spring meteorological drought frequency changes.

4.17 Meteorological drought duration

Meteorological drought duration refers to the annual and seasonal length of the longest continuous meteorological drought. Meteorological drought is defined as described above for *Meteorological drought frequency* (Section 4.16). Modelled historic and future projections of annual and seasonal meteorological drought duration are illustrated in Figure 4-116 to Figure 4-125. Region-wide averages are summarised in the two boxes below.

Historic meteorological drought duration and projected changes (days) Relative to 1995-2014 (2004)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2004	2050	2090	2050	2090	2050	2090	2050	2090
Annual	55.5	+6.6	+8.7	+10.8	+22.2	+20.5	+50.4	+24.3	+52.5
Summer	3.8	+0.9	+0.7	+1.1	+2.0	+2.2	+2.8	+2.0	+2.2
Autumn	3.4	+1.0	+0.9	0	+1.2	+0.5	+2.2	+1.1	+1.7
Winter	4.7	-0.9	-0.8	+0.1	+0.7	+0.4	+3.8	+0.7	+3.9
Spring	4.1	0	+1.1	+1.1	+2.3	+1.7	+4.3	+2.3	+5.7

Historic meteorological drought duration and projected changes (days) Relative to 1986-2005 (1995)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	1995	2050	2090	2050	2090	2050	2090	2050	2090
Annual	51.0	+11.1	+13.2	+15.3	+26.7	+25.0	+54.9	+28.7	+57.0
Summer	3.2	+1.5	+1.3	+1.8	+2.6	+2.8	+3.4	+2.6	+2.8
Autumn	4.2	+0.2	+0.2	-0.8	+0.5	-0.3	+1.4	+0.3	+0.9
Winter	4.4	-0.5	-0.5	+0.5	+1.1	+0.7	+4.2	+1.0	+4.3
Spring	3.5	+0.6	+1.7	+1.7	+2.9	+2.3	+4.9	+2.9	+6.3

4.17.1 Annual

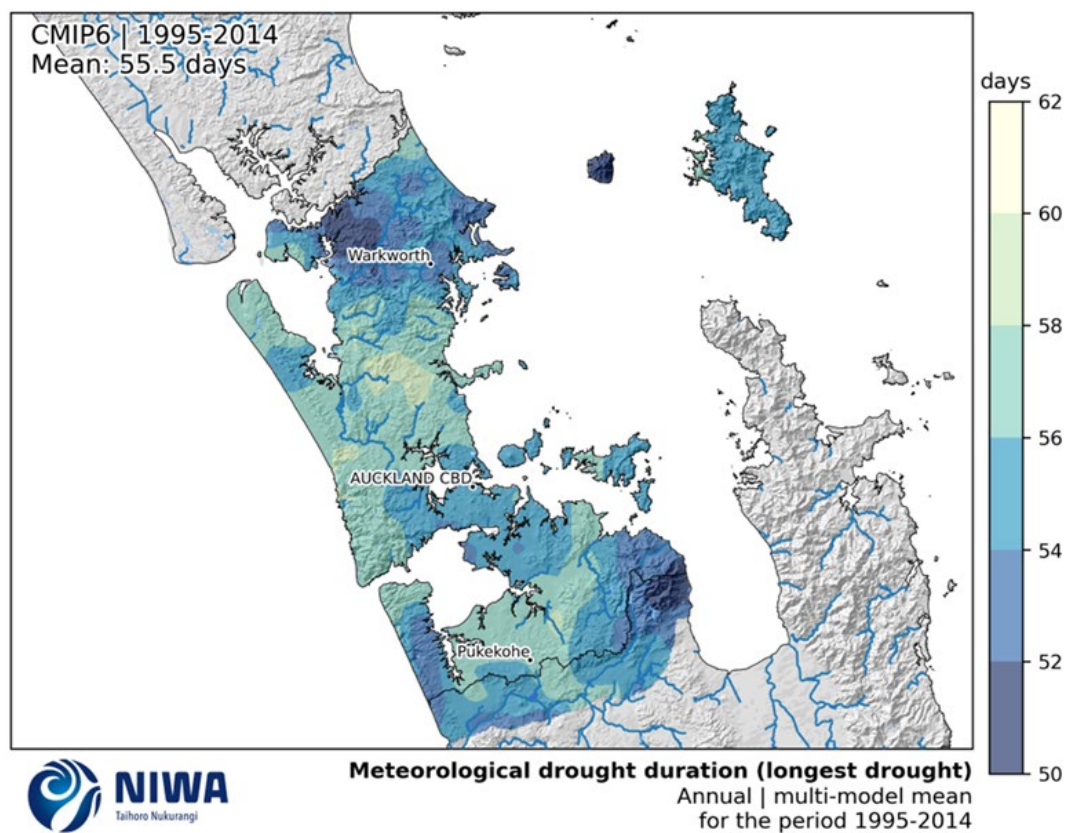


Figure 4-116: Modelled historic average annual meteorological drought duration.

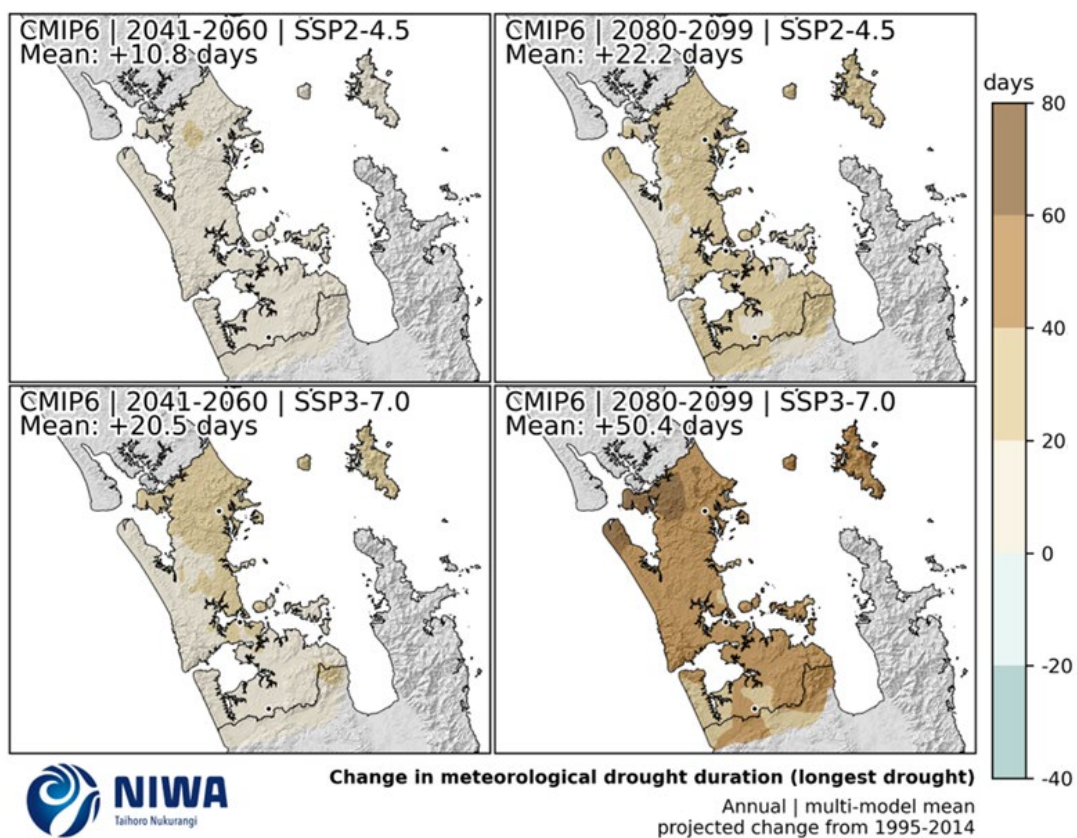


Figure 4-117: Projected annual meteorological drought duration changes.

4.17.2 Seasonal

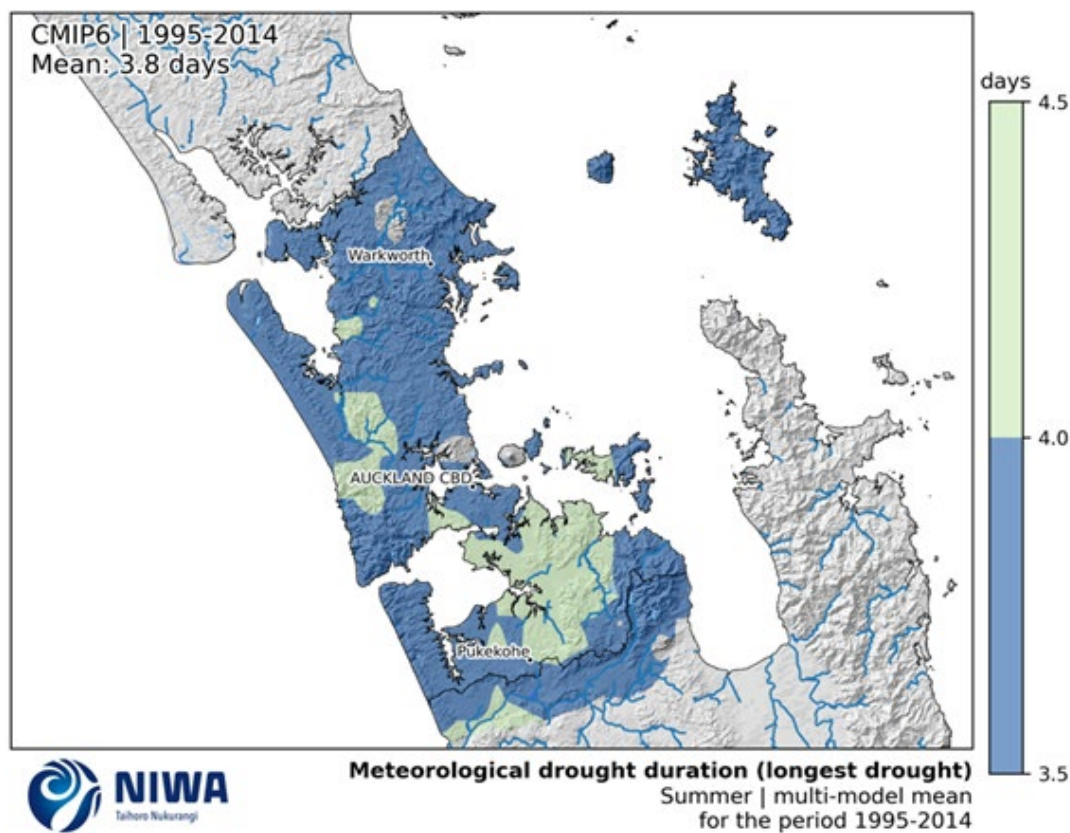


Figure 4-118: Modelled historic average summer meteorological drought duration.

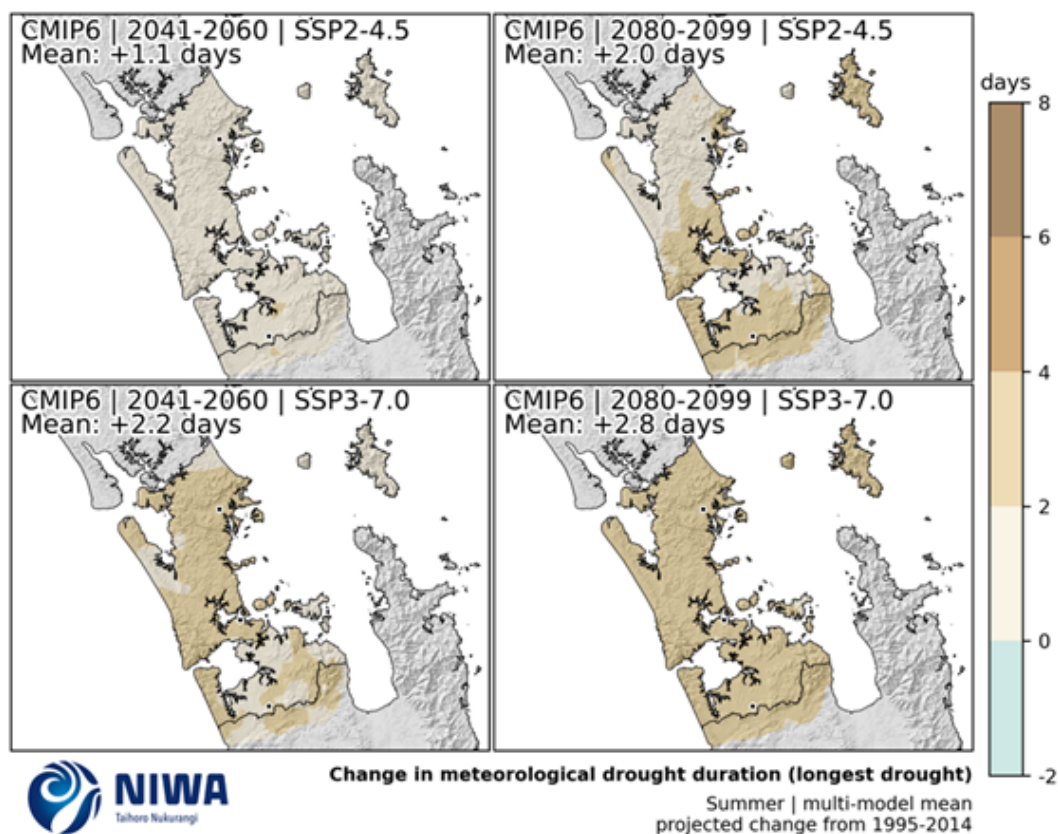


Figure 4-119: Projected summer meteorological drought duration changes.

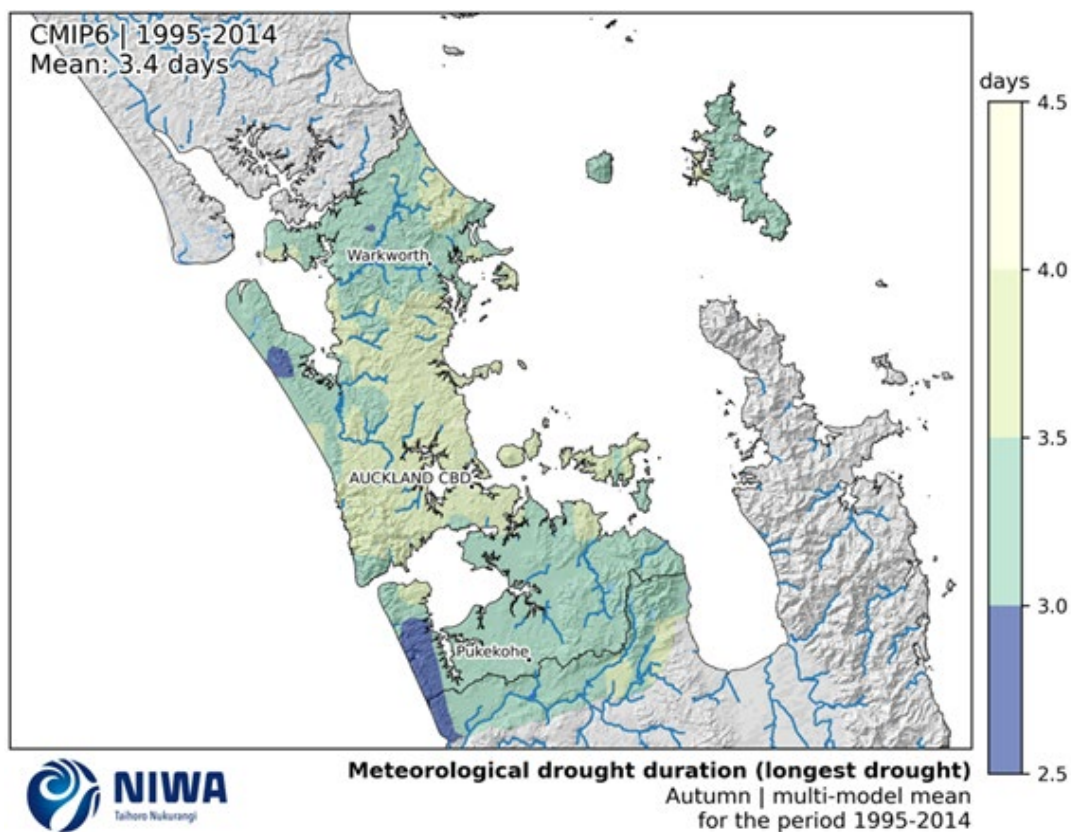


Figure 4-120: Modelled historic average autumn meteorological drought duration.

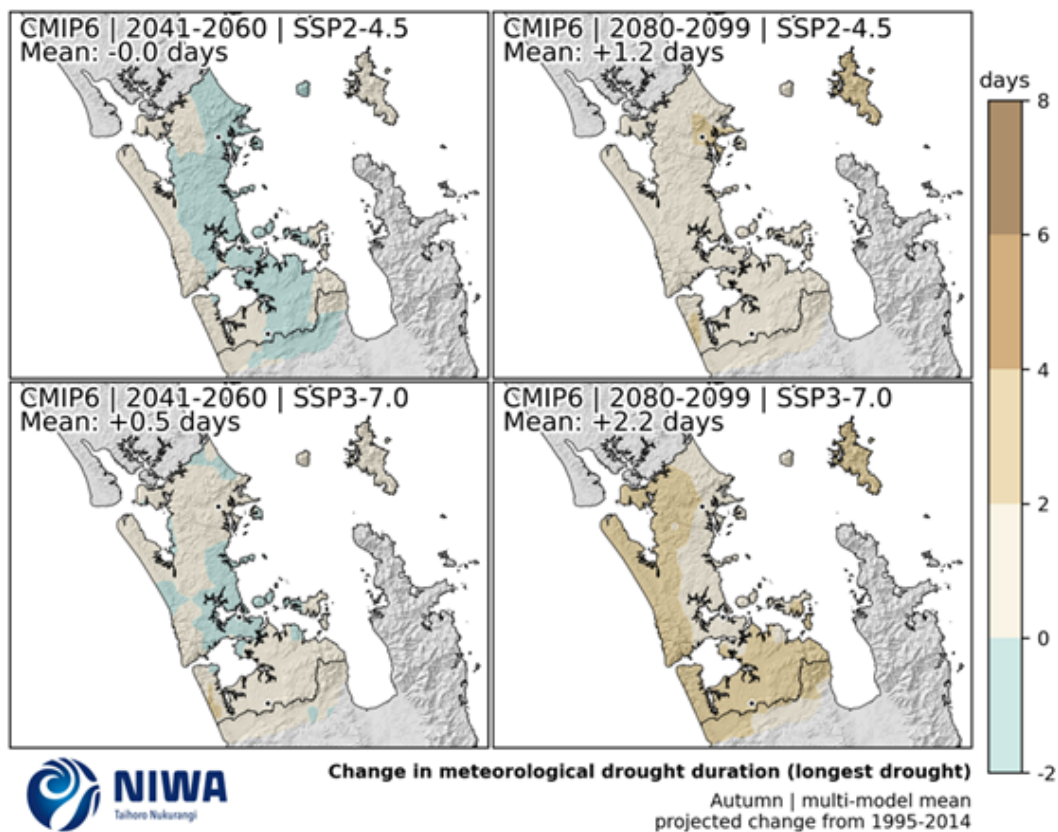


Figure 4-121: Projected autumn meteorological drought duration changes.

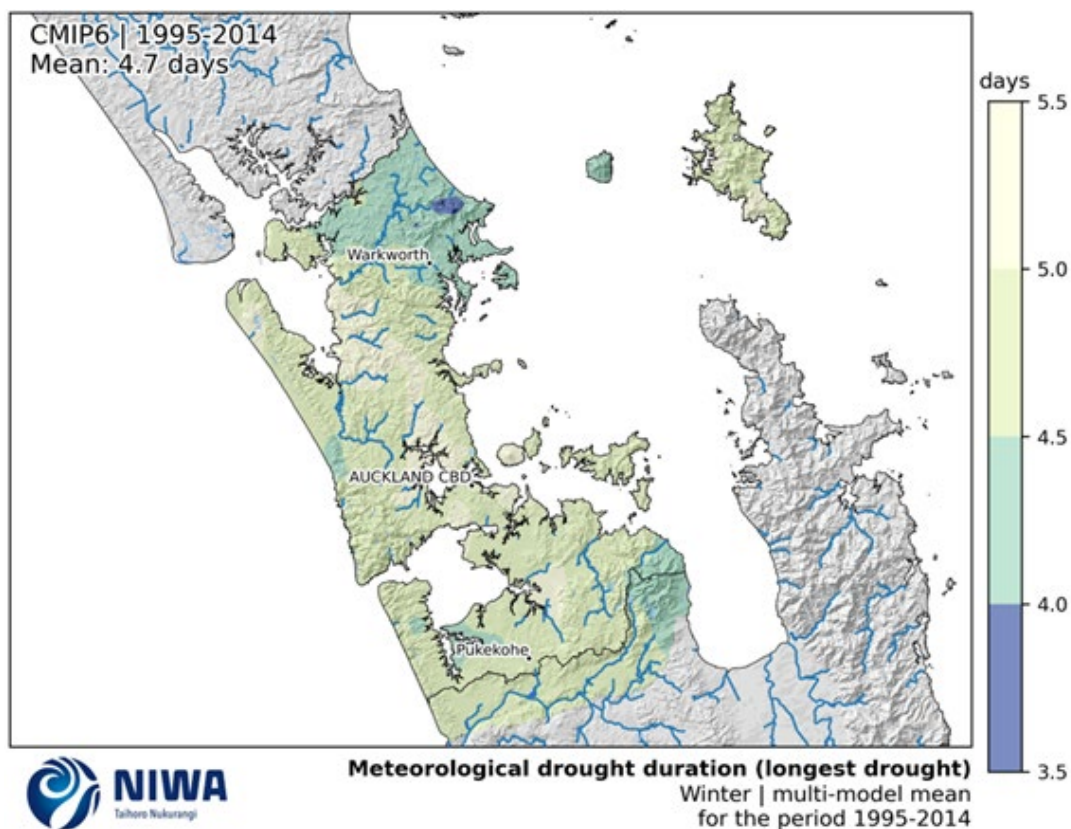


Figure 4-122: Modelled historic average winter meteorological drought duration.

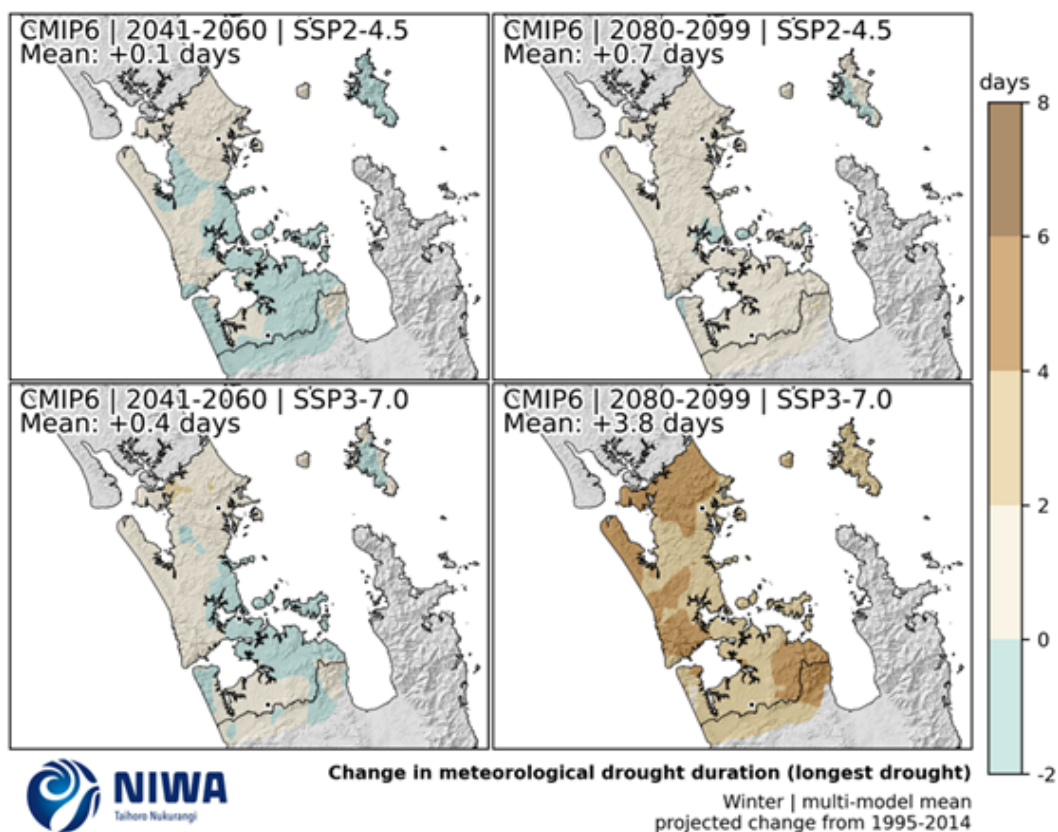


Figure 4-123: Projected winter meteorological drought duration changes.

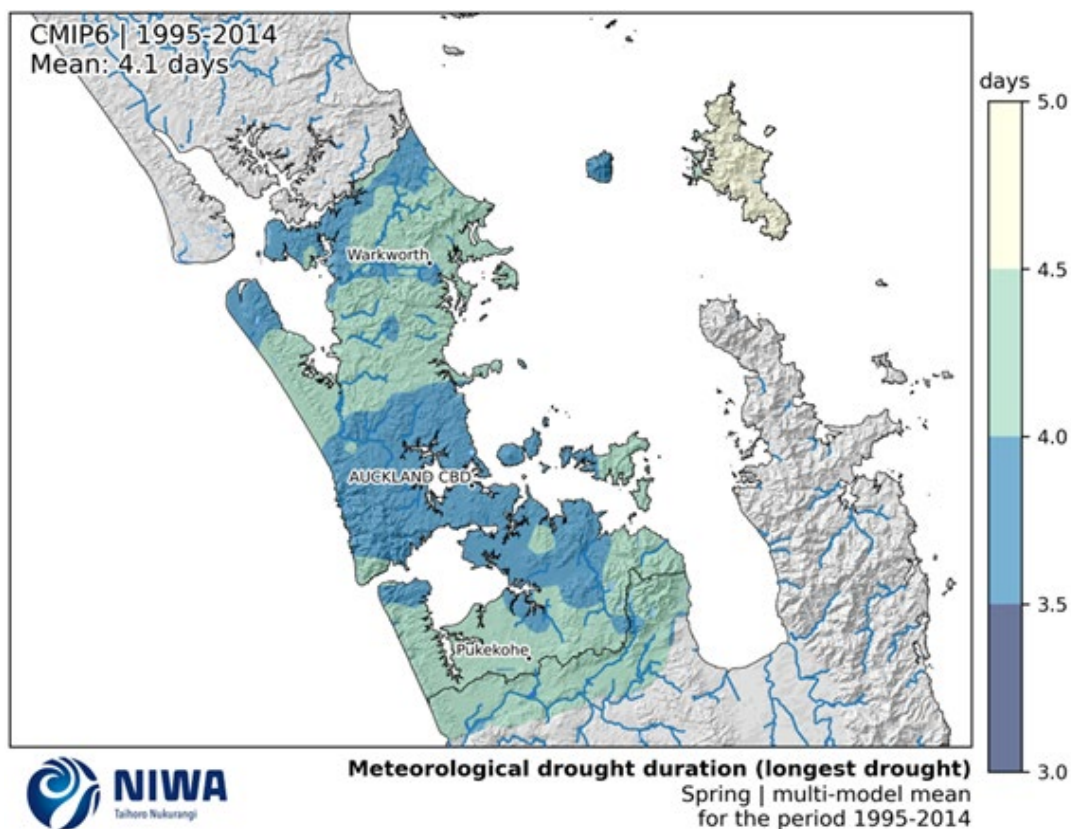


Figure 4-124: Modelled historic average spring meteorological drought duration.

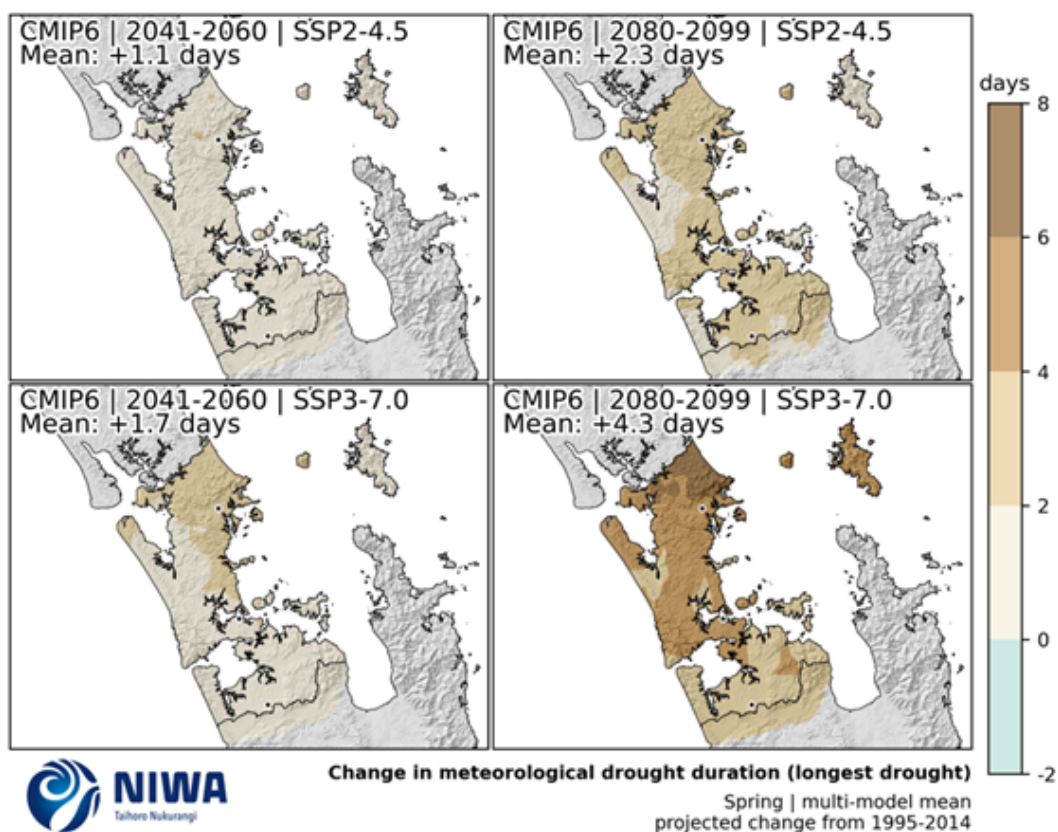


Figure 4-125: Projected spring meteorological drought duration changes.

4.18 Average wind speed

Average wind speed refers to the annual and seasonal average daily wind speed. Modelled historic and future projections of annual and seasonal average wind speed are illustrated in Figure 4-126 to Figure 4-135. Note, the units for historic data are m s^{-1} , whereas future projections are presented as percentage changes from the historic period. Region-wide averages are summarised in the two boxes below.

Historic average wind speed (m s^{-1}) and projected changes (%) Relative to 1995-2014 (2004)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2004	2050	2090	2050	2090	2050	2090	2050	2090
Annual	4.5	-2.2	-1.3	-2.6	-5.1	-3.2	-7.6	-3.5	-7.7
Summer	4.1	-2.2	-1.3	-2.2	-5.8	-3.3	-6.1	-4.1	-4.6
Autumn	4.1	-3.7	-2.4	-3.4	-6.2	-4.4	-9.2	-4.3	-9.4
Winter	4.8	-0.8	-0.3	-2.5	-4.2	-1.4	-8.6	-2.8	-7.8
Spring	5.0	-2.5	-1.5	-2.3	-4.5	-3.8	-6.4	-3.2	-8.7

Historic average wind speed (m s^{-1}) and projected changes (%) Relative to 1986-2005 (1995)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	1995	2050	2090	2050	2090	2050	2090	2050	2090
Annual	4.5	-2.4	-1.4	-2.7	-5.2	-3.4	-7.7	-3.6	-7.8
Summer	4.2	-2.8	-1.8	-2.7	-6.3	-3.8	-6.6	-4.7	-5.1
Autumn	4.1	-4.1	-2.8	-3.8	-6.6	-4.8	-9.6	-4.8	-9.8
Winter	4.8	-0.5	0	-2.1	-3.9	-1.0	-8.3	-2.5	-7.4
Spring	5.0	-2.4	-1.4	-2.2	-4.4	-3.6	-6.2	-3.0	-8.5

4.18.1 Annual

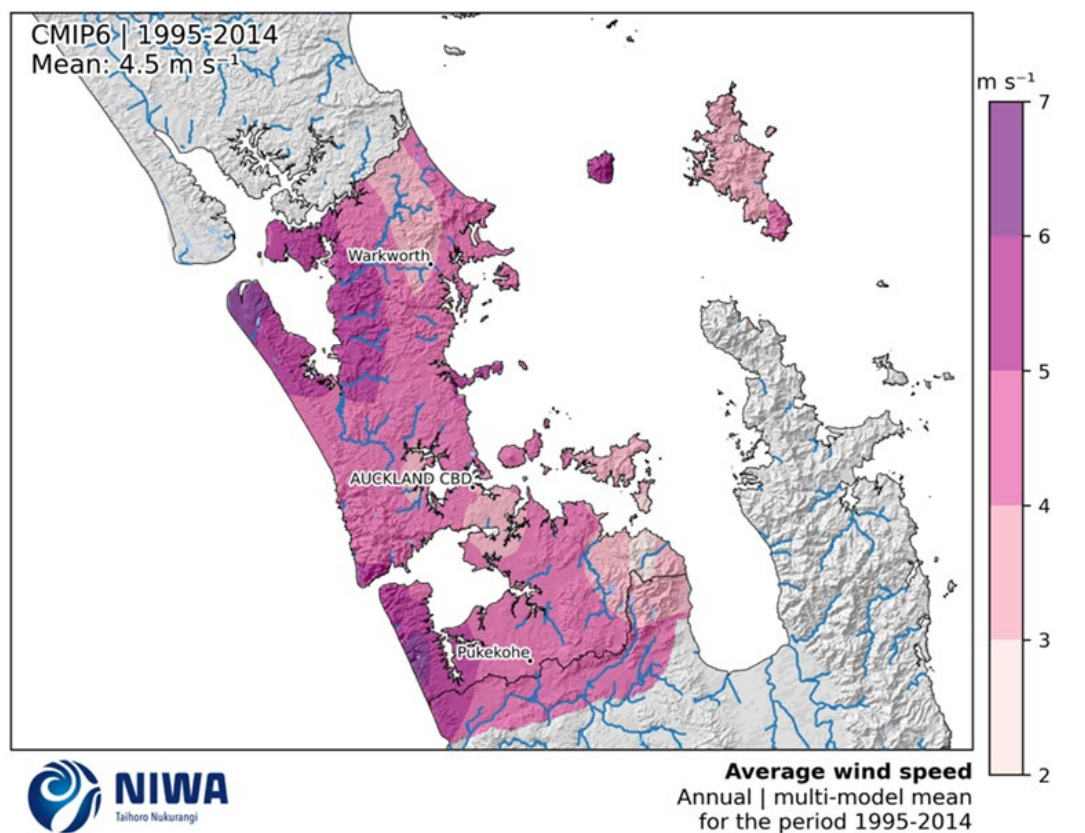


Figure 4-126: Modelled historic annual average wind speed.

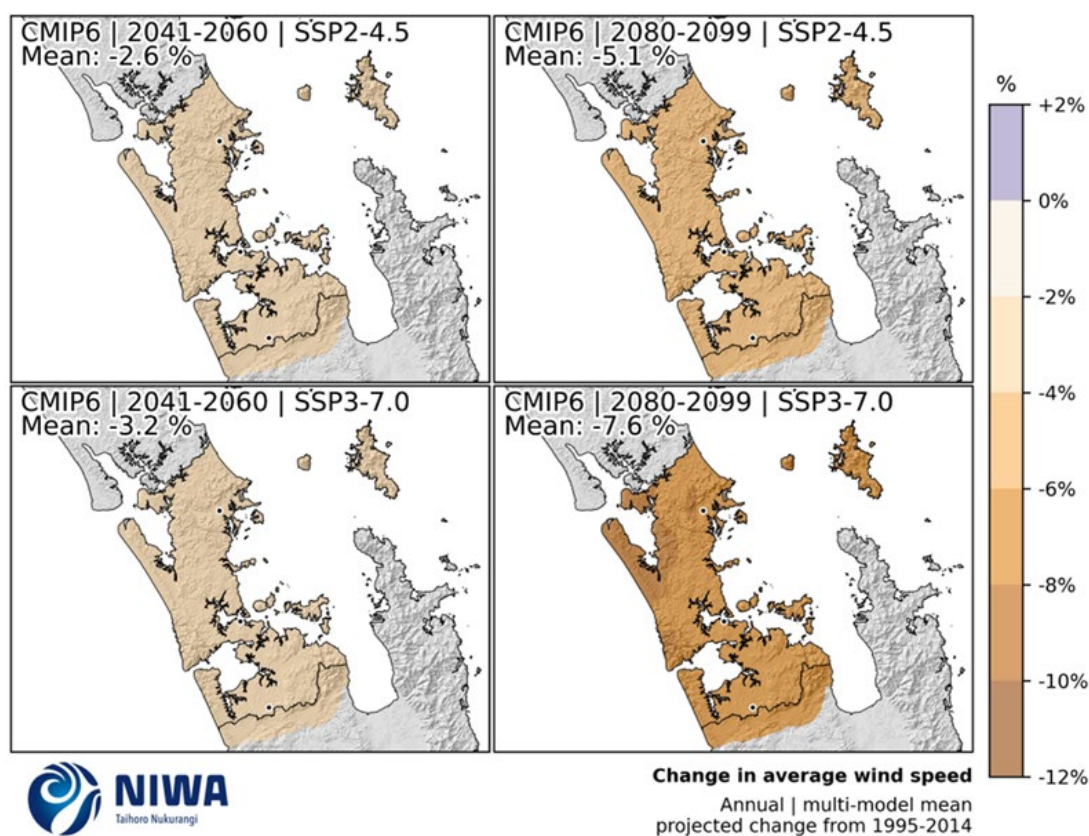


Figure 4-127: Projected annual average wind speed changes.

4.18.2 Seasonal

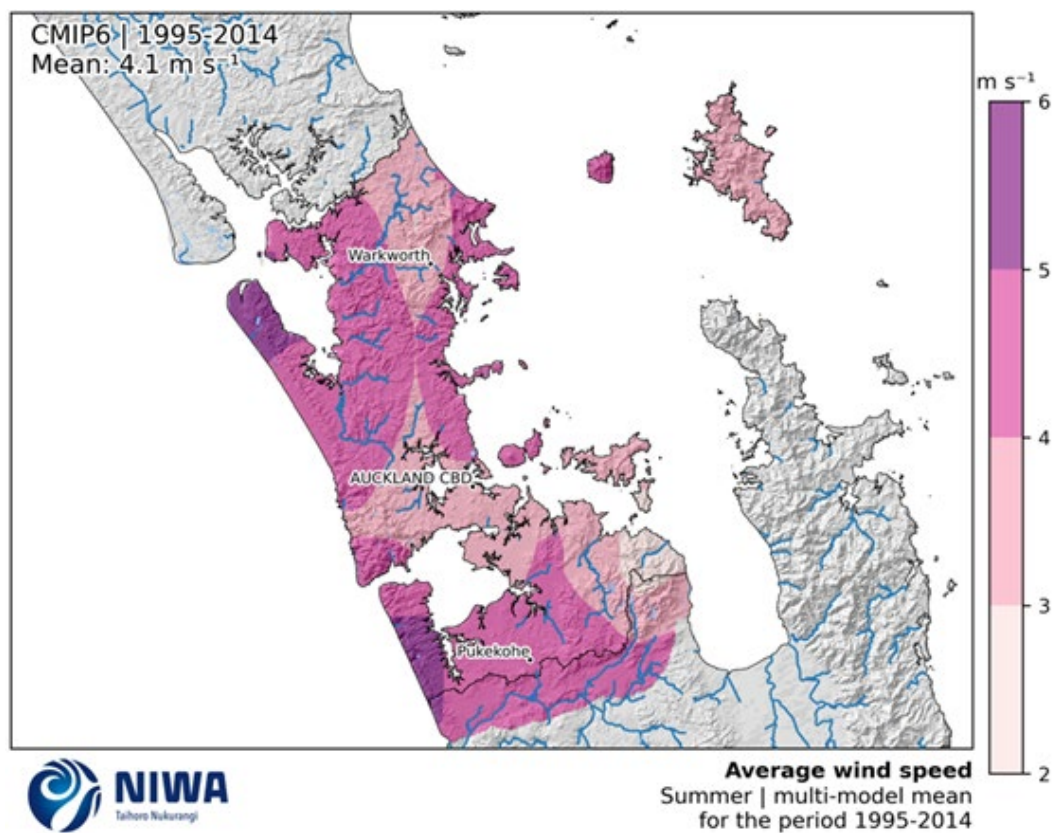


Figure 4-128: Modelled historic summer average wind speed.

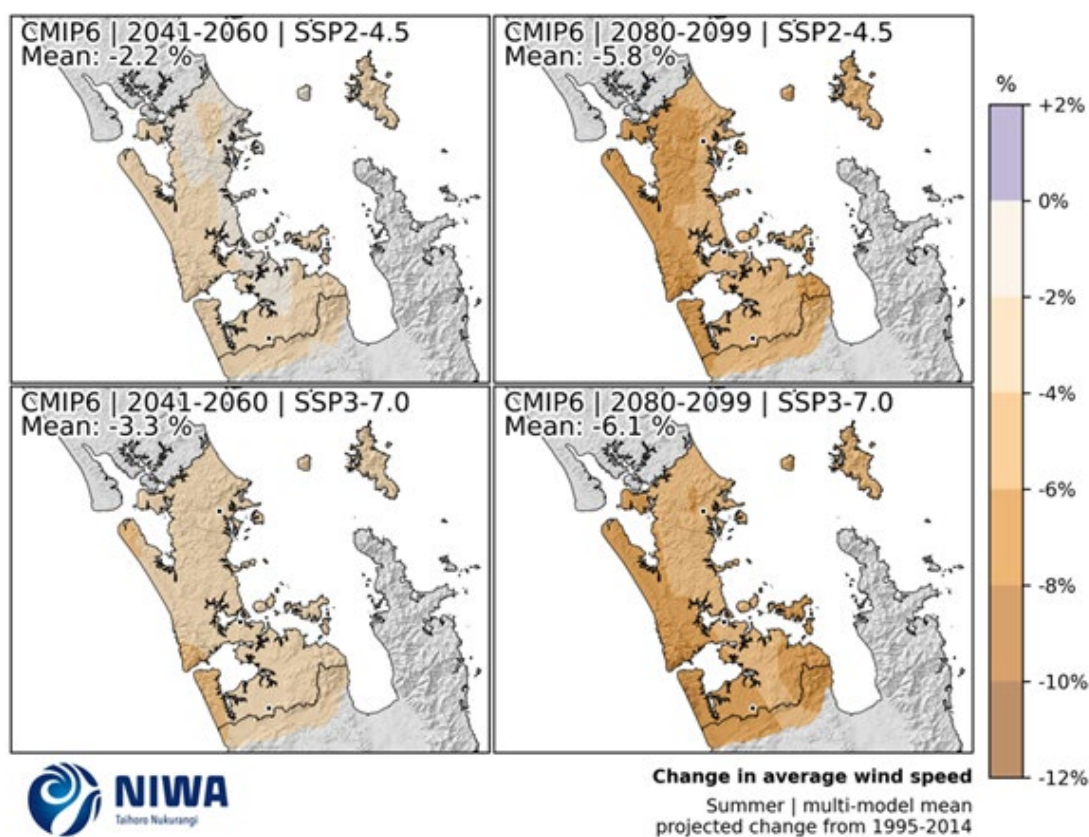


Figure 4-129: Projected summer average wind speed changes.

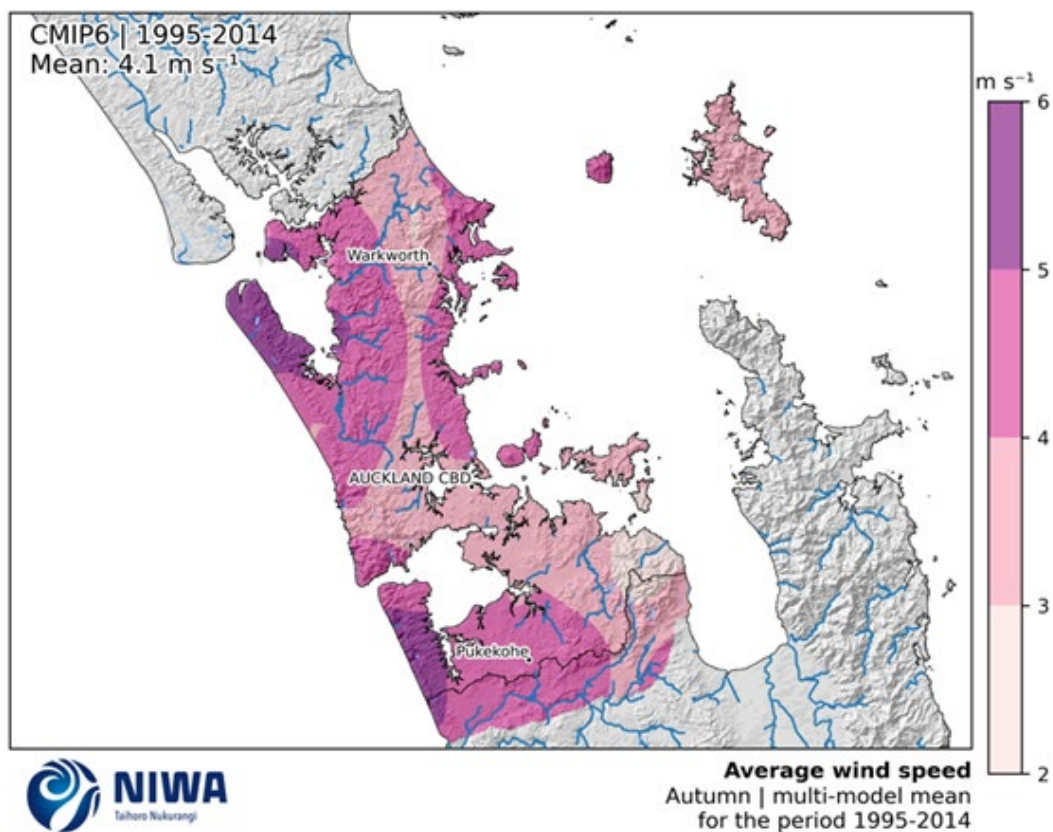


Figure 4-130: Modelled historic autumn average wind speed.

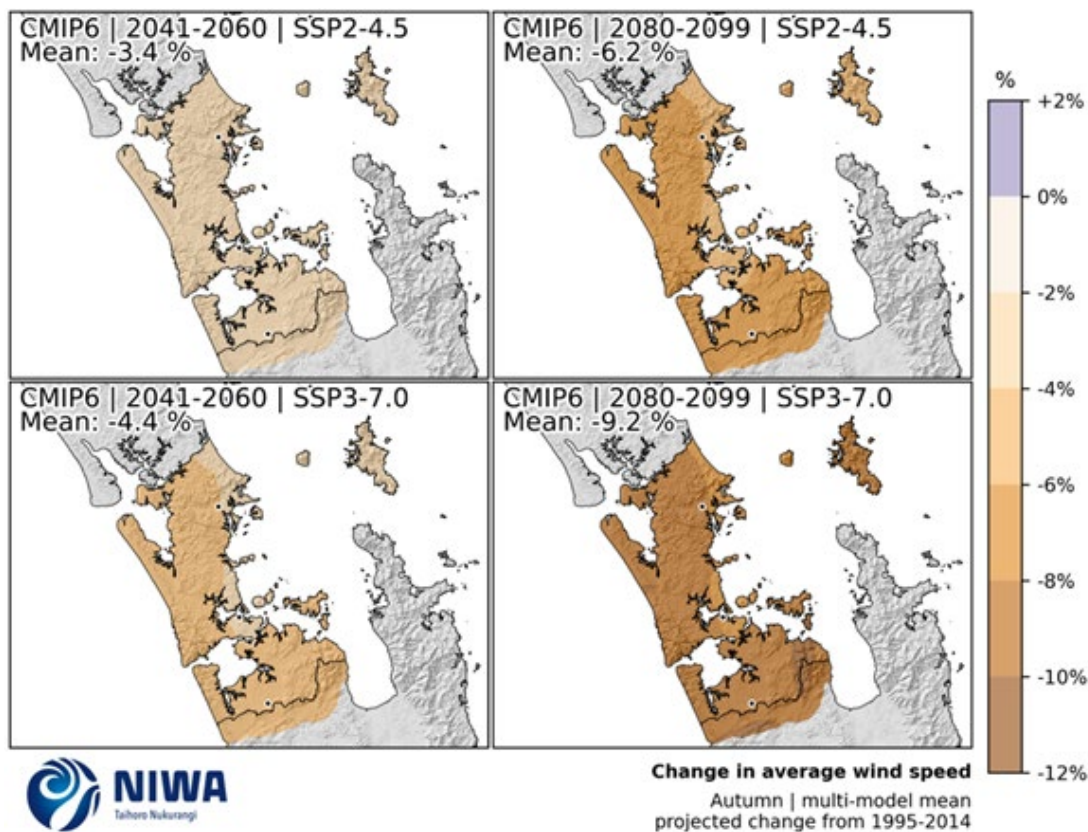


Figure 4-131: Projected autumn average wind speed changes.

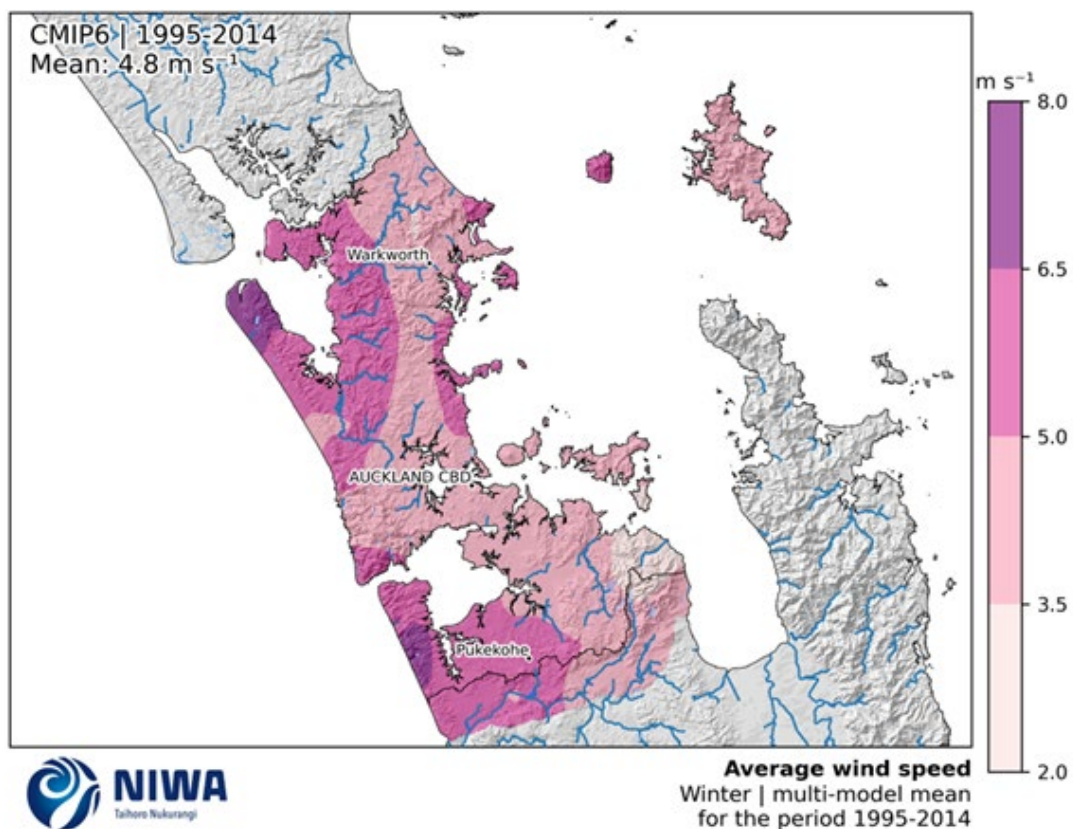


Figure 4-132: Modelled historic winter average wind speed.

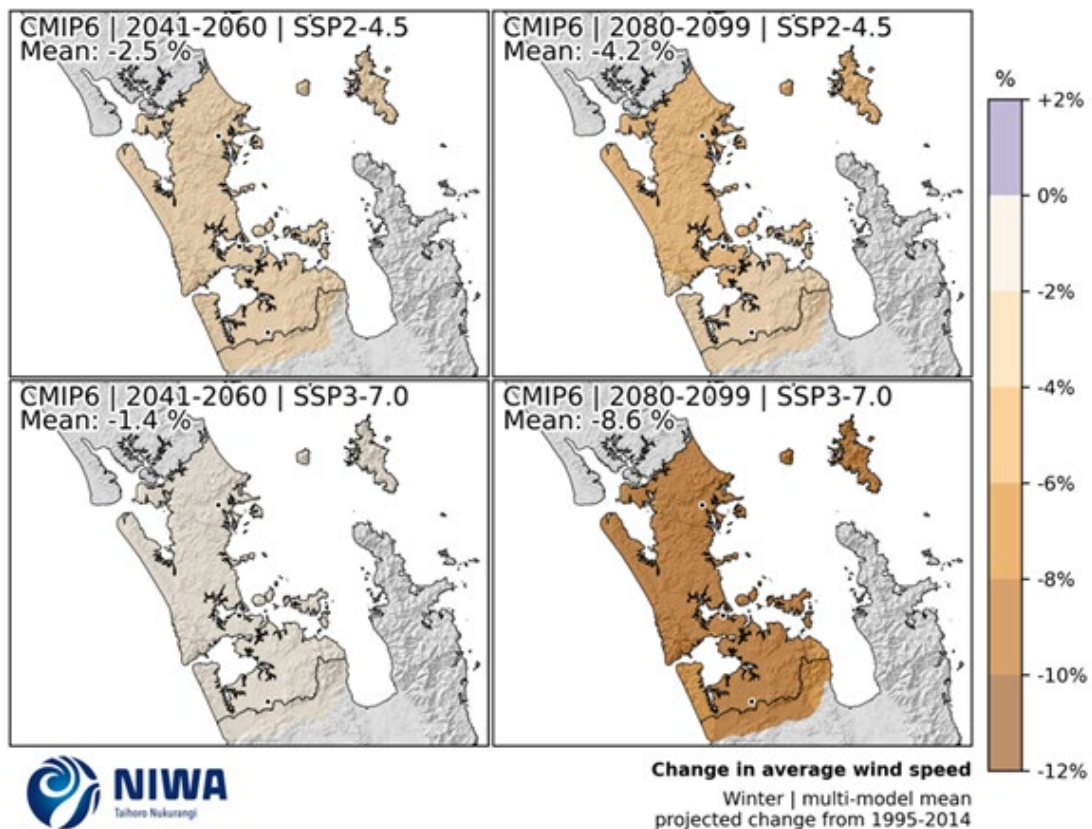


Figure 4-133: Projected winter average wind speed changes.

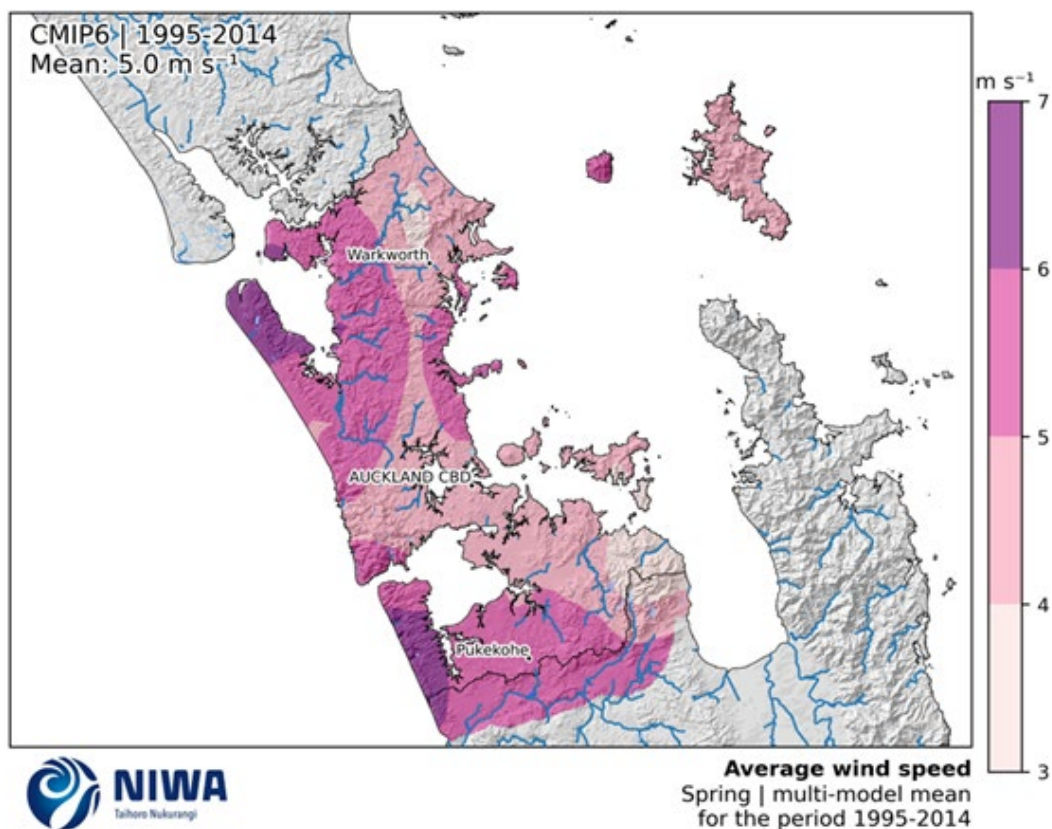


Figure 4-134: Modelled historic spring average wind speed.

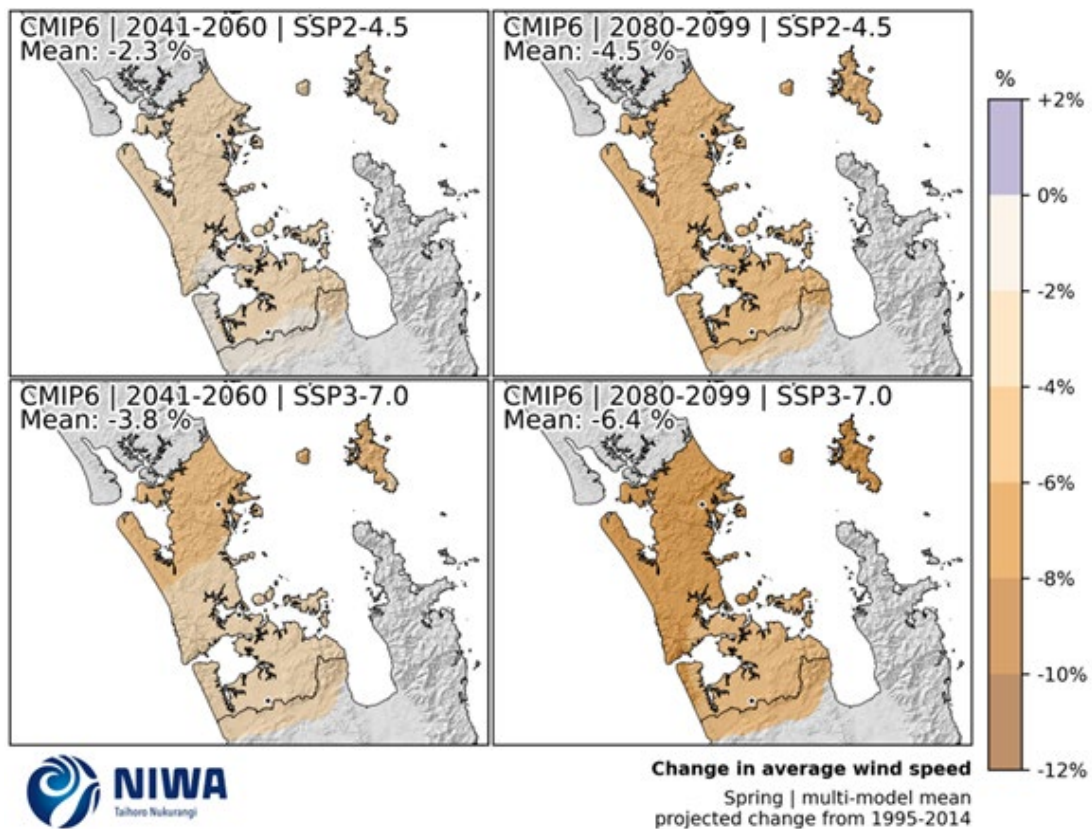


Figure 4-135: Projected spring average wind speed changes.

4.19 Windy days

Windy days refers to the annual and seasonal average number of days where the daily mean wind speed is greater than 10 m s^{-1} . Modelled historic and future projections of annual and seasonal windy days are illustrated in Figure 4-136 to Figure 4-145. Region-wide averages are summarised in the two boxes below.

Historic number of windy days and projected changes (days)									
Relative to 1995-2014 (2004)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2004	2050	2090	2050	2090	2050	2090	2050	2090
Annual	54.5	-4.4	-2.6	-5.8	-9.8	-6.5	-14.8	-7.7	-15.7
Summer	6.1	-0.6	-0.2	-0.6	-1.6	-1.0	-2.1	-1.1	-1.3
Autumn	10.5	-1.6	-1.1	-1.6	-2.5	-1.8	-3.4	-2.1	-3.9
Winter	20.2	-0.5	0	-1.7	-2.4	-0.6	-4.9	-1.7	-4.7
Spring	17.7	-1.8	-1.5	-1.7	-3.4	-2.9	-4.3	-2.9	-5.9

Historic number of windy days and projected changes (days)									
Relative to 1986-2005 (1995)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	1995	2050	2090	2050	2090	2050	2090	2050	2090
Annual	54.6	-4.6	-2.7	-5.9	-9.9	-6.6	-14.9	-7.8	-15.8
Summer	6.3	-0.9	-0.4	-0.9	-1.9	-1.3	-2.4	-1.4	-1.5
Autumn	10.7	-1.9	-1.3	-1.9	-2.7	-2.0	-3.7	-2.4	-4.1
Winter	19.9	-0.1	+0.4	-1.4	-2.1	-0.3	-4.6	-1.3	-4.4
Spring	17.6	-1.7	-1.4	-1.6	-3.3	-2.8	-4.2	-2.7	-5.8

4.19.1 Annual

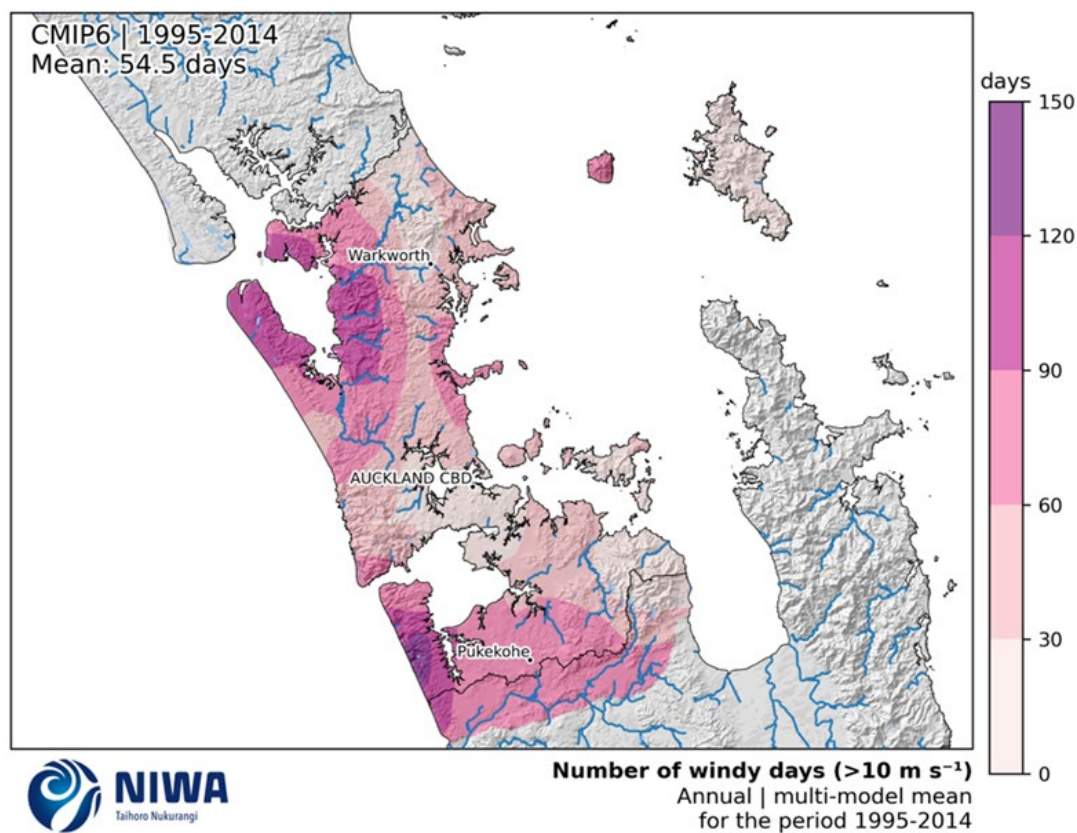


Figure 4-136: Modelled historic average annual number of windy days.

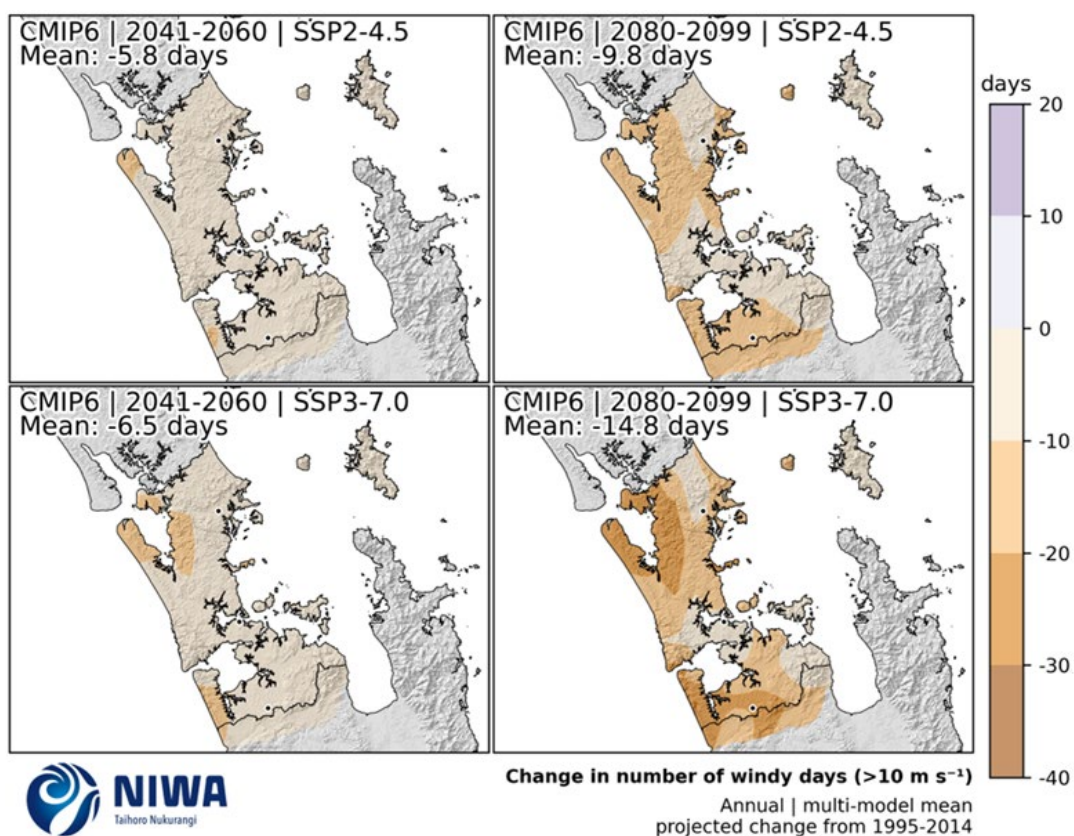


Figure 4-137: Projected annual average windy days changes.

4.19.2 Seasonal

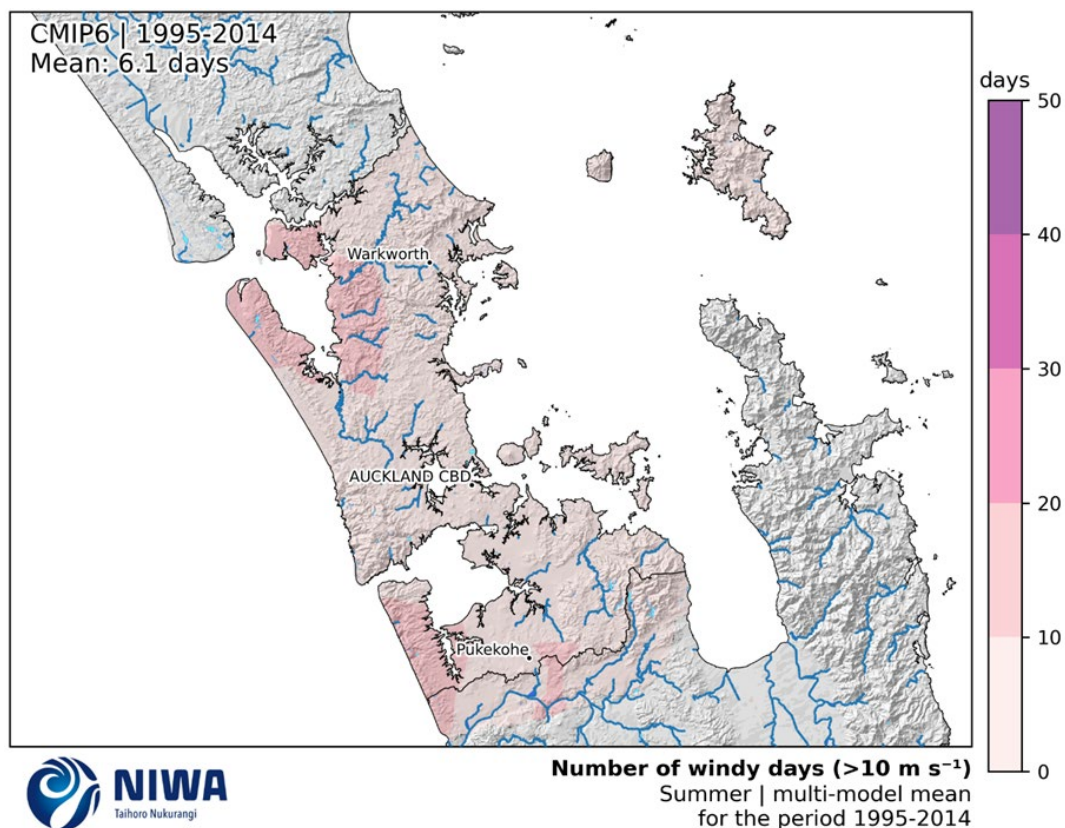


Figure 4-138: Modelled historic average summer number of windy days.

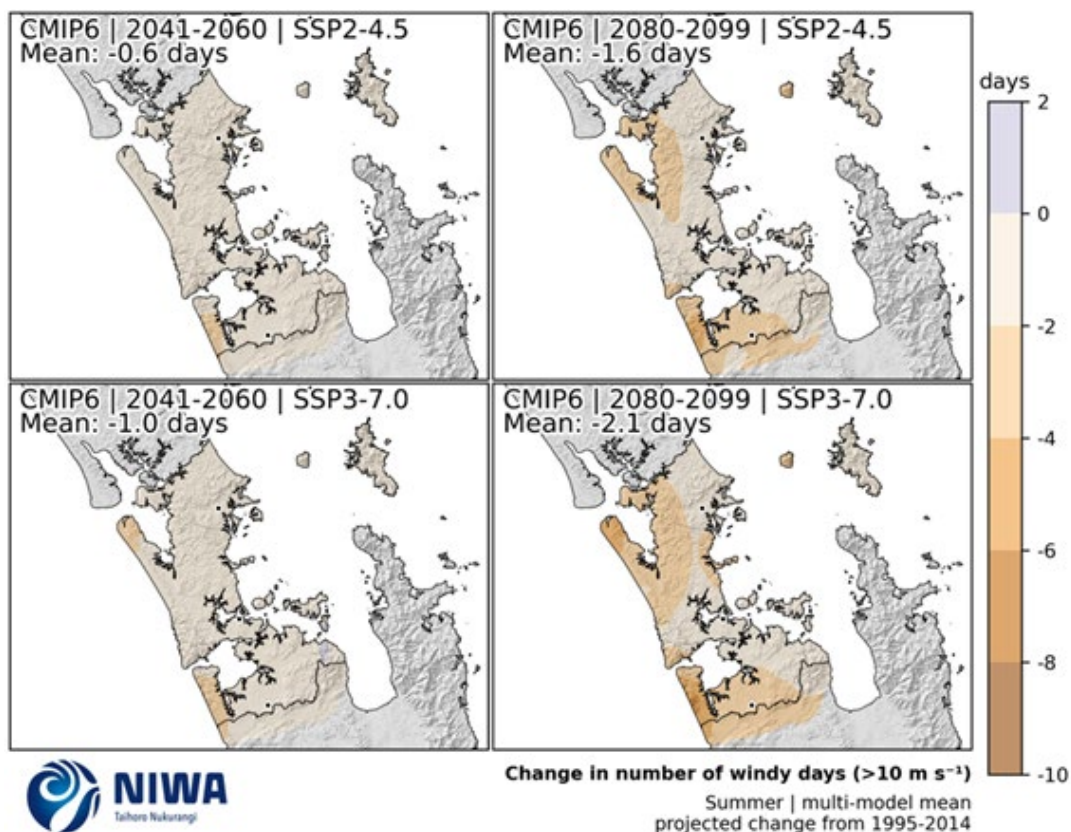


Figure 4-139: Projected summer average windy days changes.

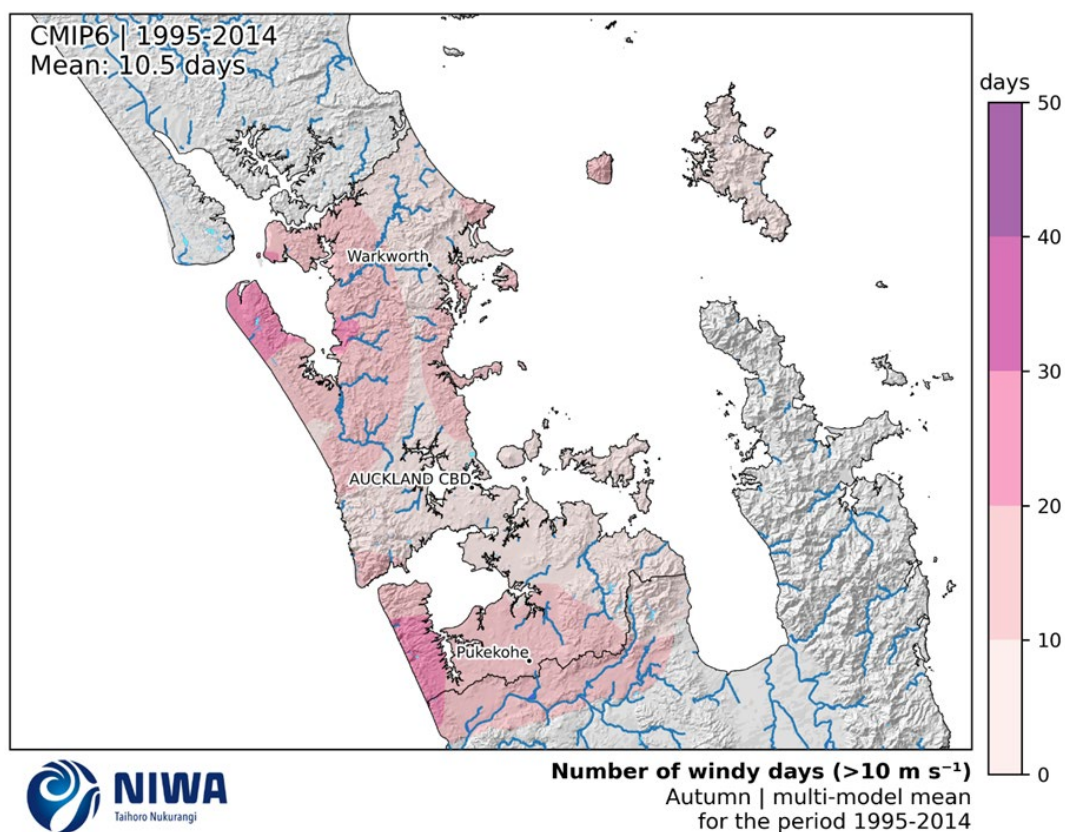


Figure 4-140: Modelled historic average autumn number of windy days.

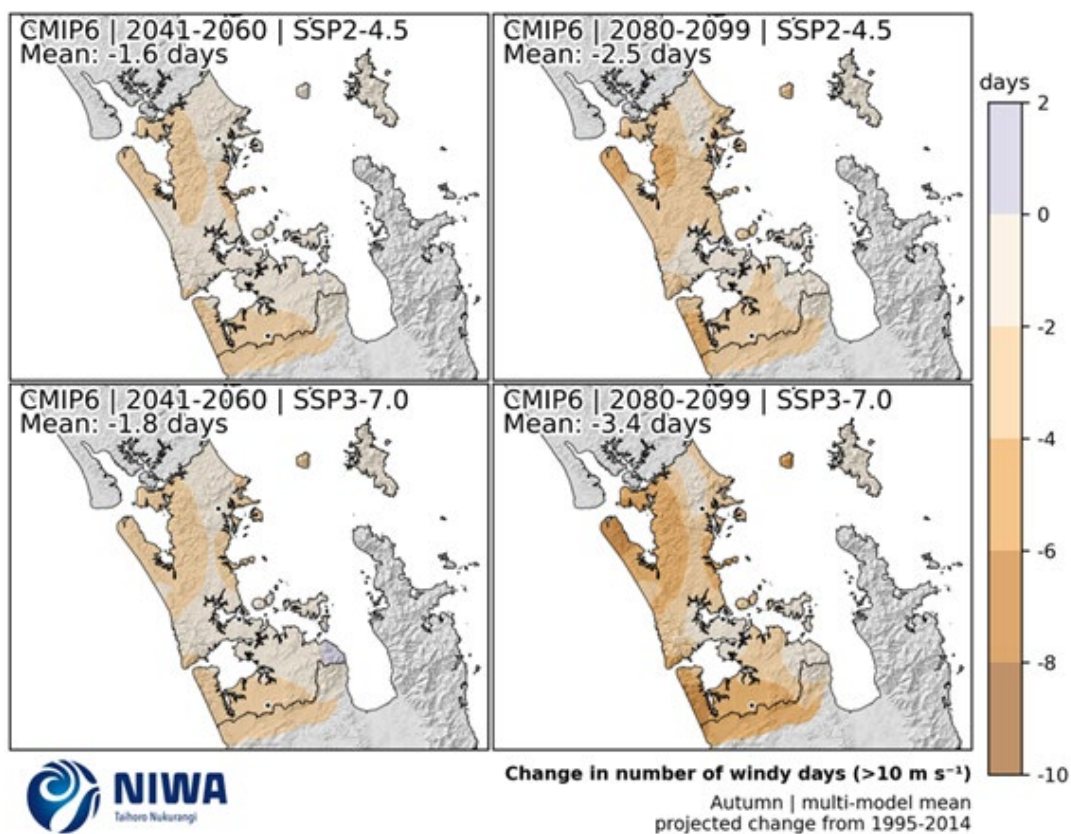


Figure 4-141: Projected autumn average windy days changes.

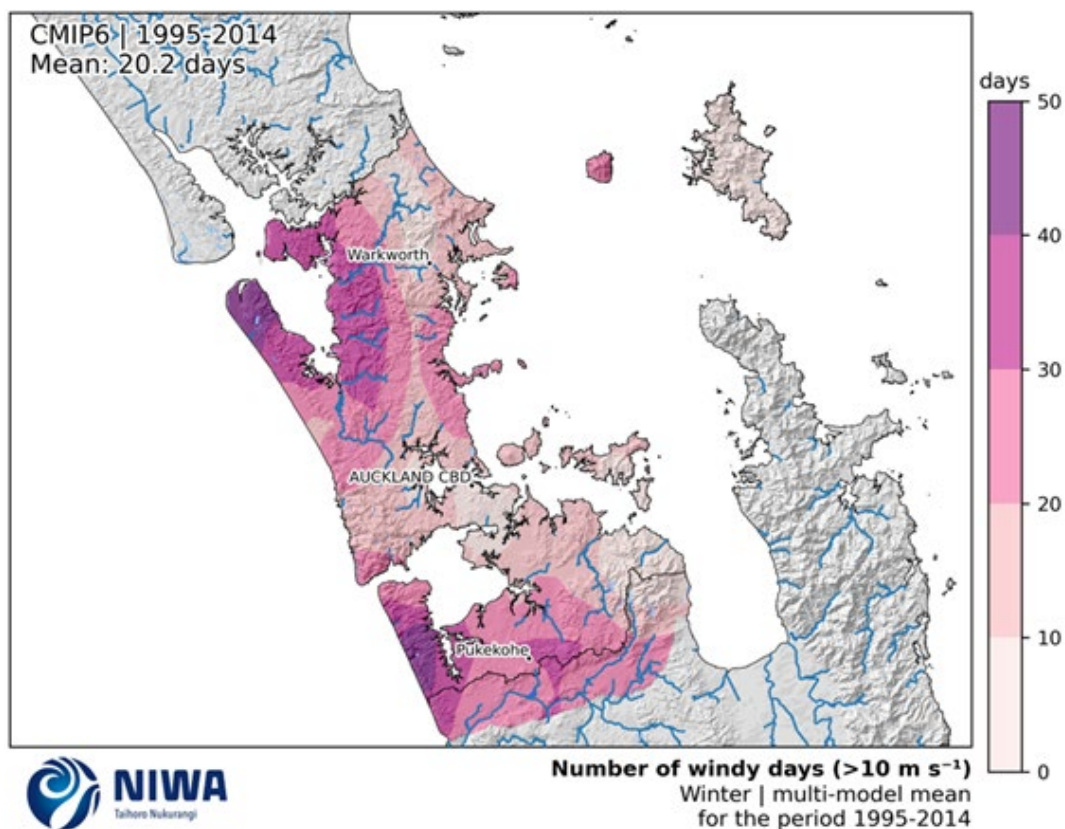


Figure 4-142: Modelled historic average winter number of windy days.

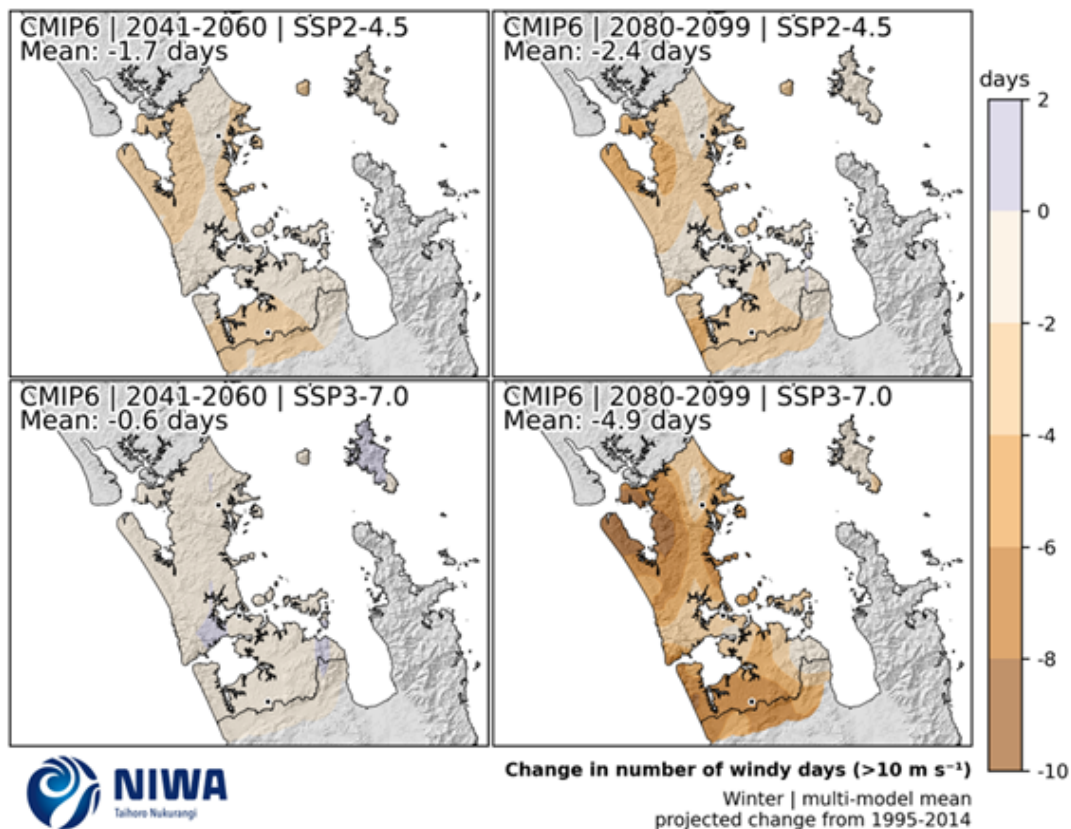


Figure 4-143: Projected winter average windy days changes.

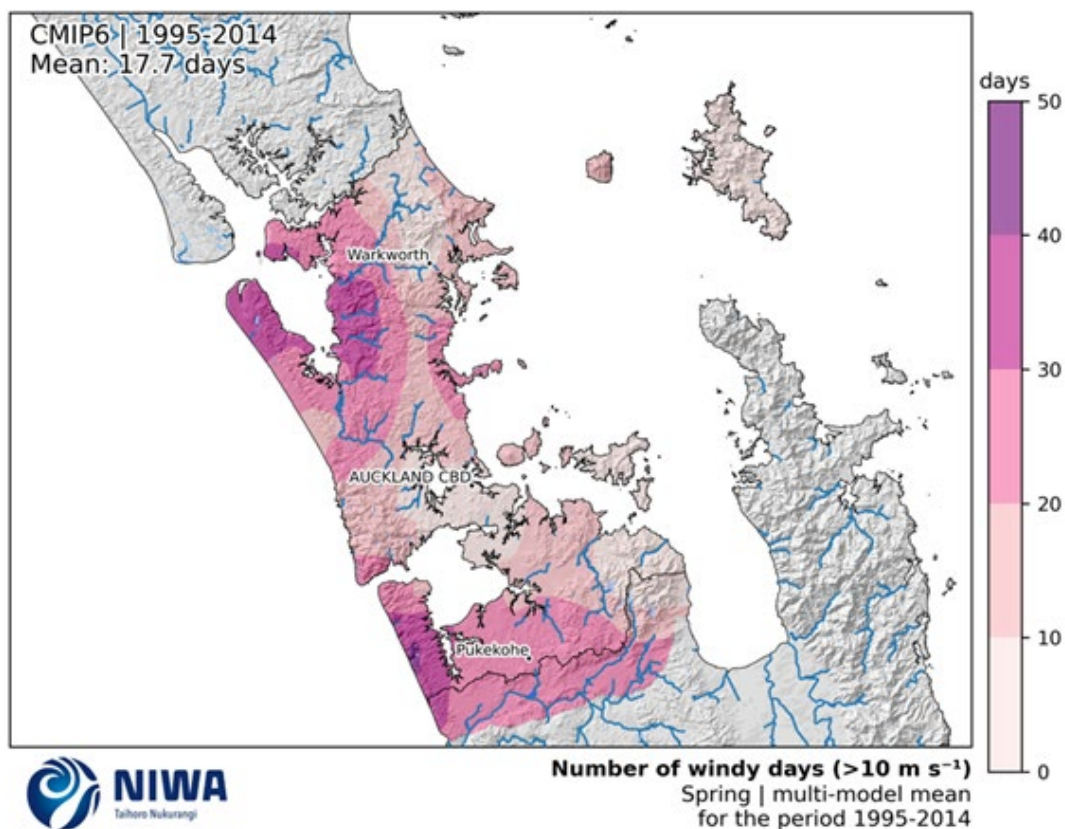


Figure 4-144: Modelled historic average spring number of windy days.

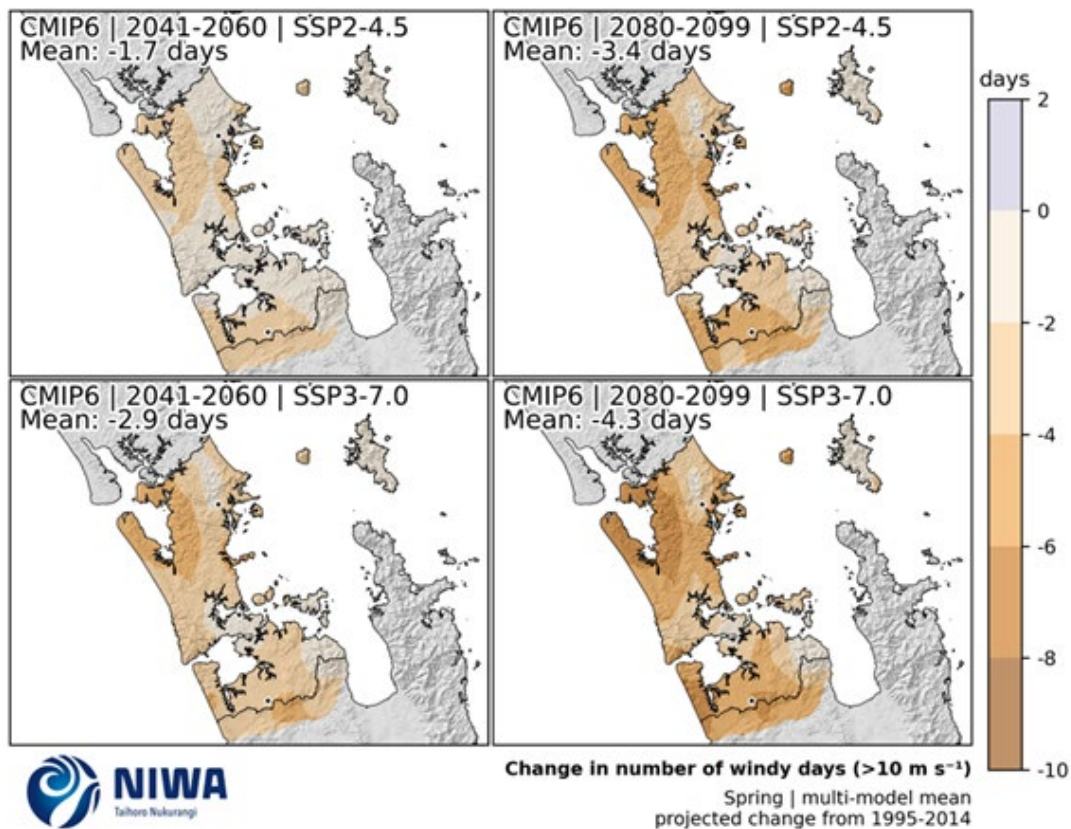


Figure 4-145: Projected spring average windy days changes.

4.20 Strong wind (99th percentile)

Strong wind (99th percentile) refers to the annual and seasonal daily wind speed that exceeds the 99th percentile during a given base period. In this report, the historic base periods of 2004 (1995-2014) and 1995 (1986-2005) have been applied. Modelled historic and future projections of annual and seasonal strong wind (99th percentile) are illustrated in Figure 4-146 to Figure 4-155. Note, the units for the historic data are m s⁻¹, whereas the projections are calculated as a percentage change from the historic period. Region-wide averages are summarised in the two boxes below.

Historic strong wind (99th percentile) speed (m s⁻¹) and projected changes (%) Relative to 1995-2014 (2004)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2004	2050	2090	2050	2090	2050	2090	2050	2090
Annual	14.3	-0.5	-0.6	-2.0	-2.3	-0.5	-3.5	-1.3	-3.5
Summer	12.7	+0.9	+0.5	-3.6	-7.4	-2.3	-4.8	-2.7	+0.3
Autumn	13.9	-2.0	-0.5	-1.2	-3.4	-0.5	-3.9	-1.3	-5.1
Winter	15.0	+0.2	-0.4	-1.9	+0.1	+0.5	-3.6	-1.6	-2.7
Spring	14.4	-2.5	-2.5	-1.5	-4.1	-2.7	-3.3	-1.7	-6.3

Historic strong wind (99th percentile) speed (m s⁻¹) and projected changes (%) Relative to 1986-2005 (1995)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	1995	2050	2090	2050	2090	2050	2090	2050	2090
Annual	14.2	+0.1	0	-1.4	-1.6	+0.1	-2.9	-0.7	-2.9
Summer	12.8	+0.1	-0.3	-4.3	-8.1	-3.1	-5.5	-3.5	-0.4
Autumn	13.9	-2.1	-0.5	-1.2	-3.4	-0.5	-4.0	-1.4	-5.1
Winter	14.8	+2.0	+1.5	-0.2	+2.0	+2.3	-1.9	+0.2	-1.0
Spring	14.4	-2.0	-2.0	-1.1	-3.6	-2.2	-2.8	-1.2	-5.9

4.20.1 Annual

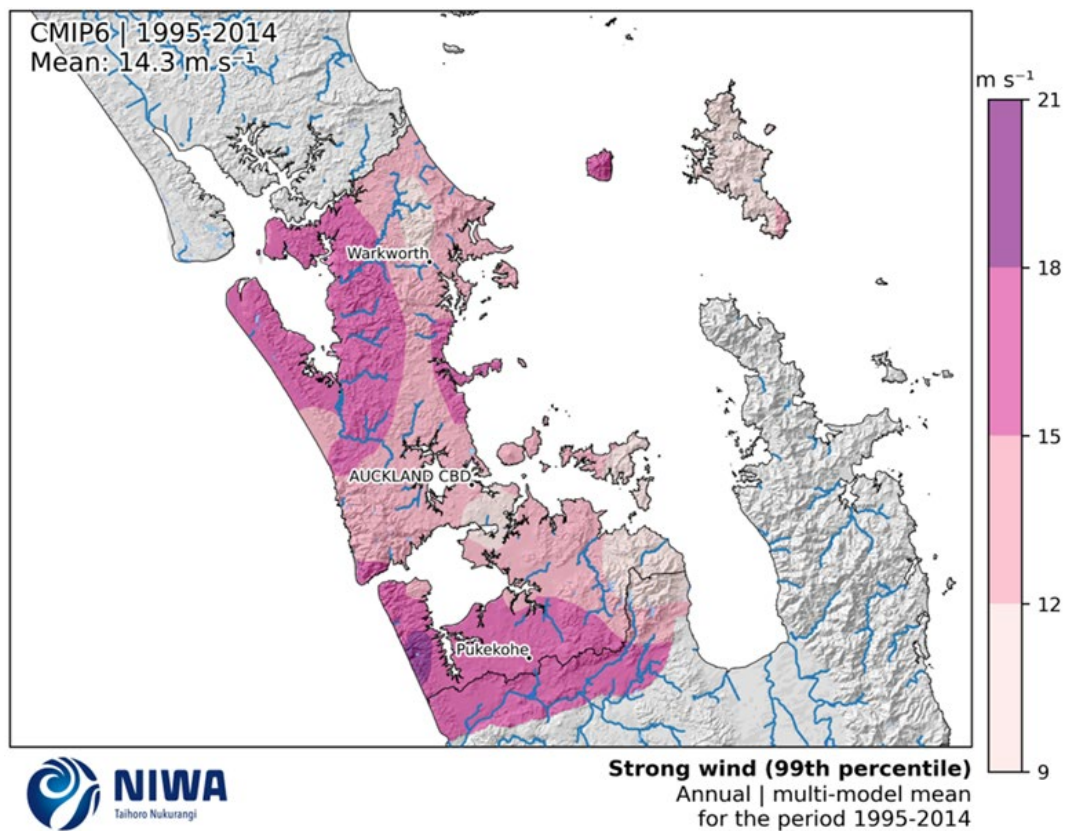


Figure 4-146: Modelled historic average annual strong wind speed.

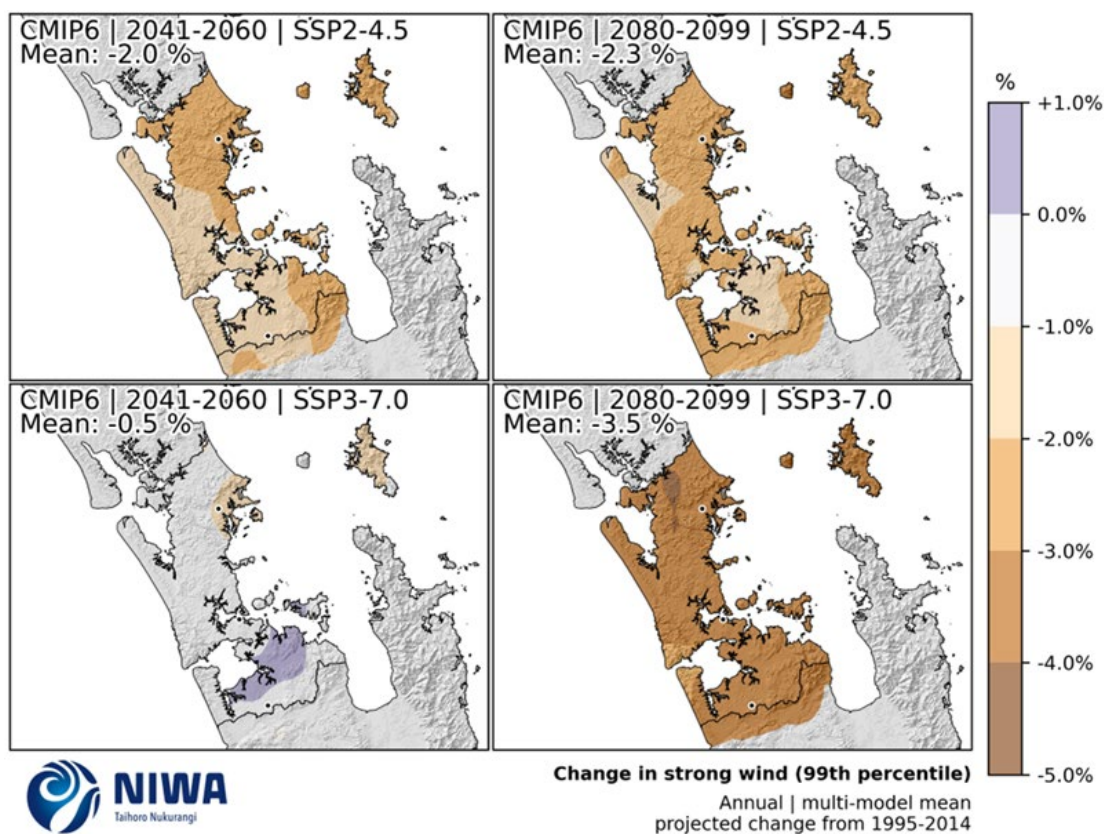


Figure 4-147: Projected annual average strong wind changes.

4.20.2 Seasonal

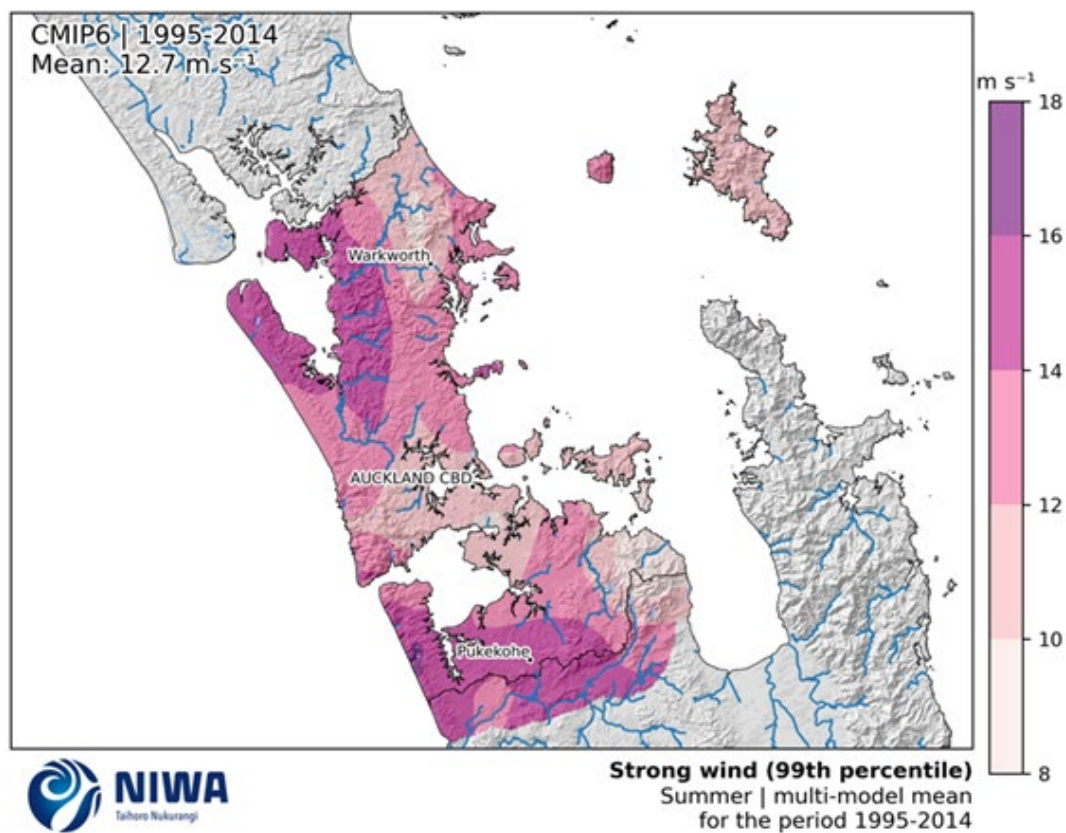


Figure 4-148: Modelled historic average summer strong wind speed.

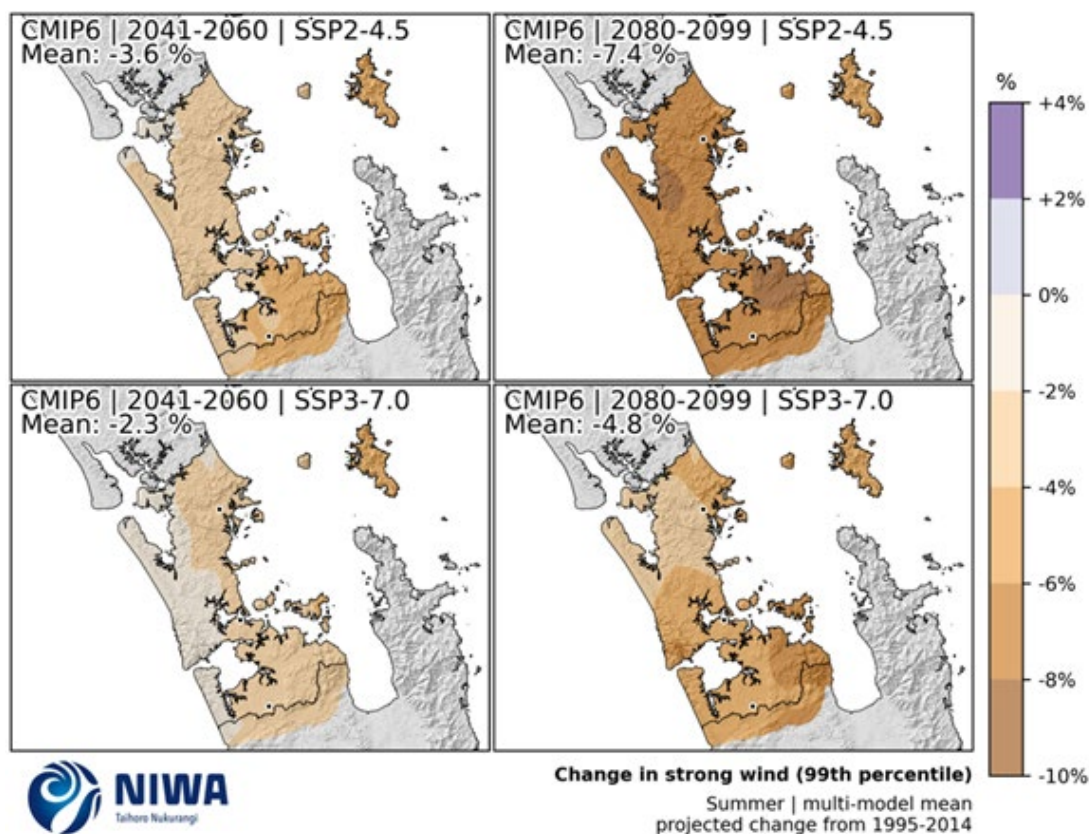


Figure 4-149: Projected summer average strong wind changes.

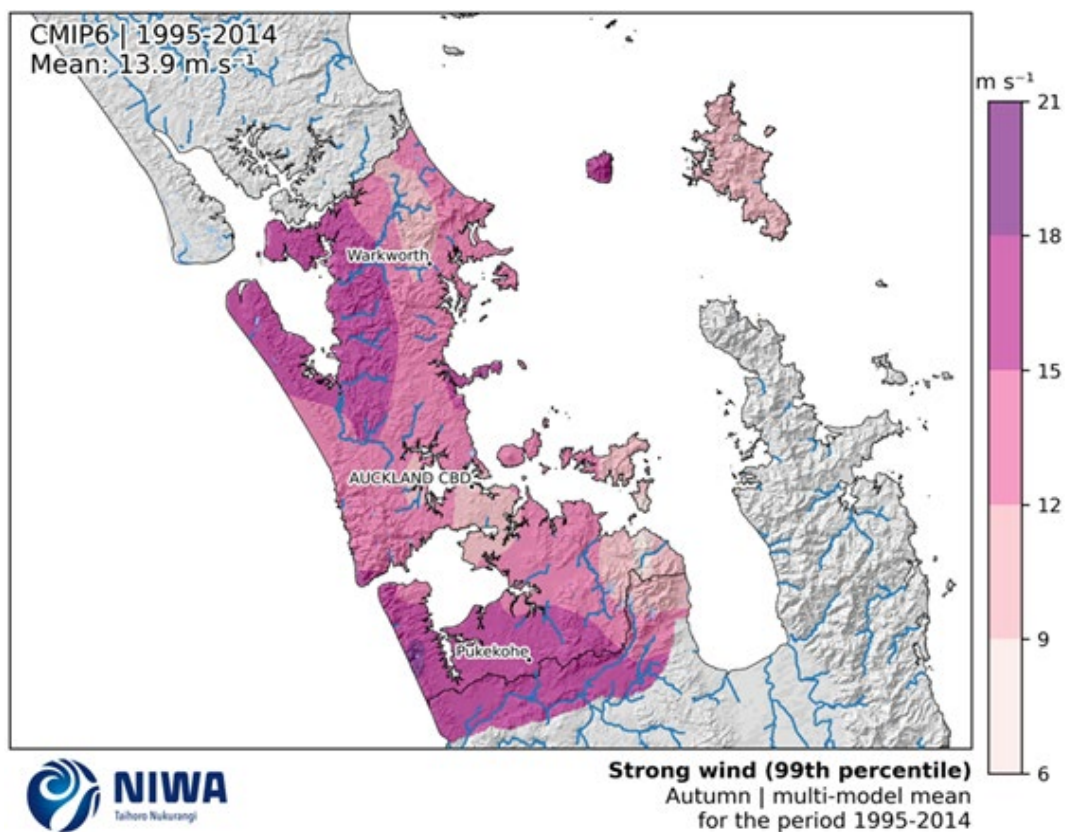


Figure 4-150: Modelled historic average autumn strong wind speed.

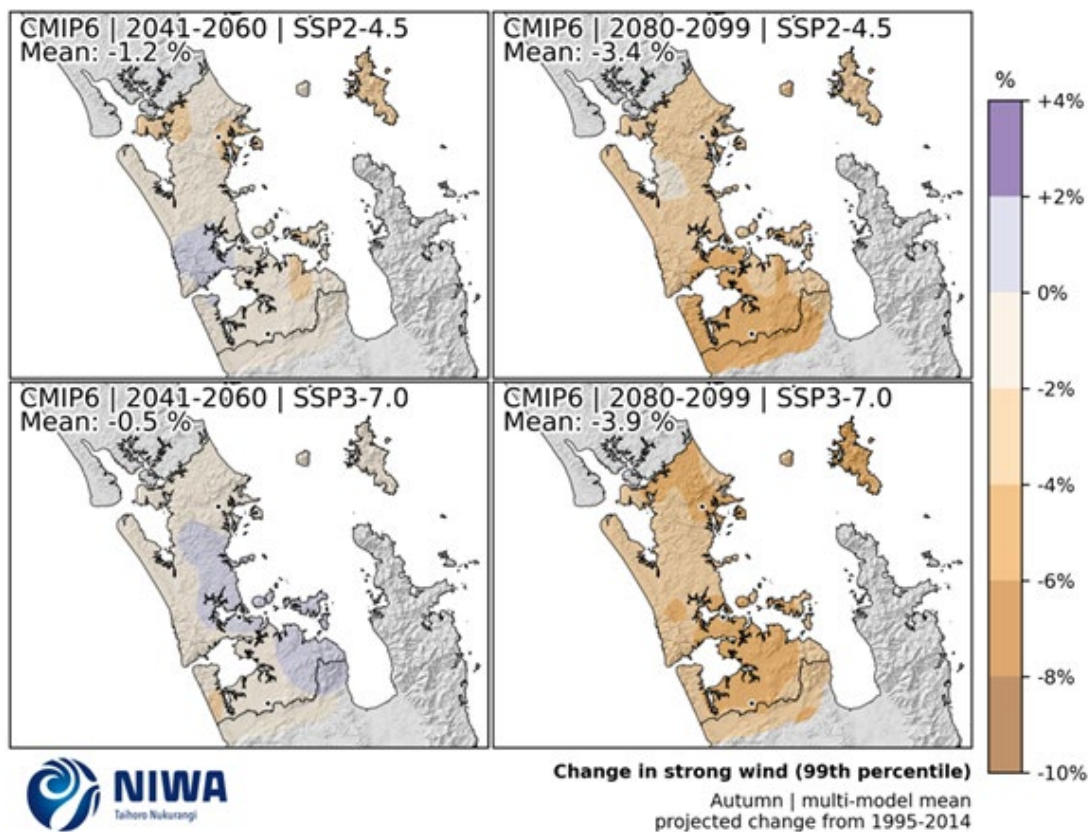


Figure 4-151: Projected autumn average strong wind changes.

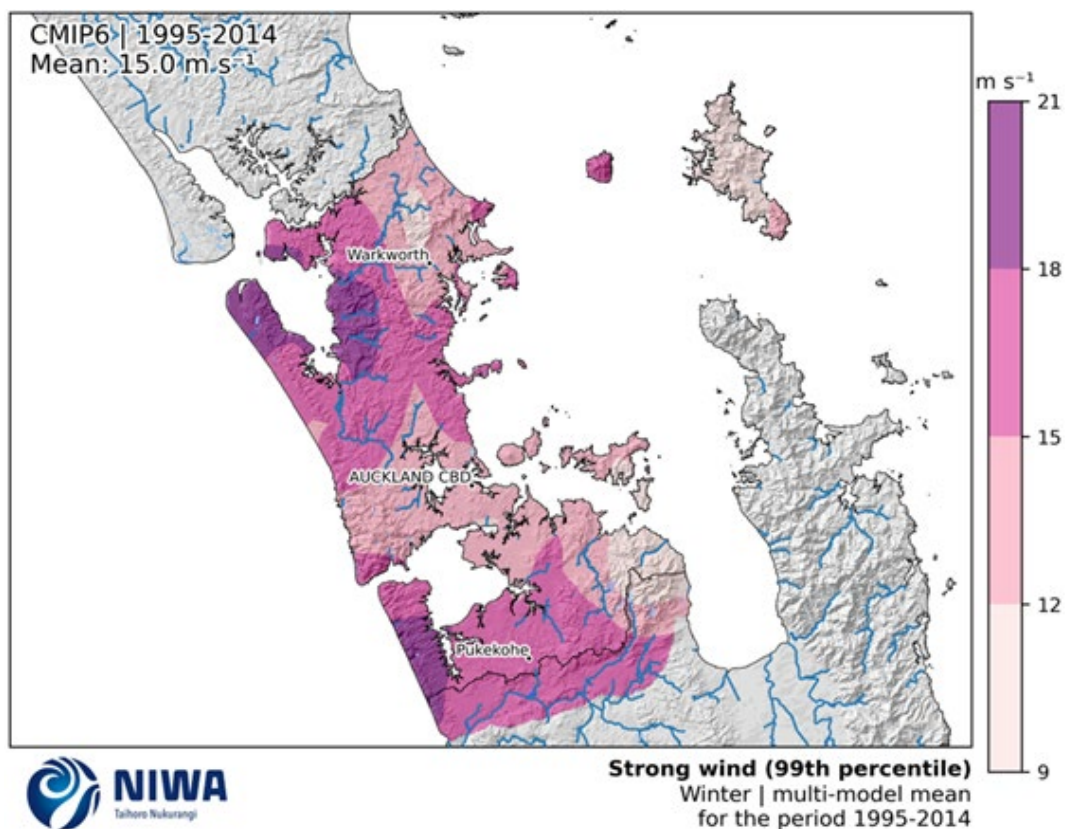


Figure 4-152: Modelled historic average winter strong wind speed.

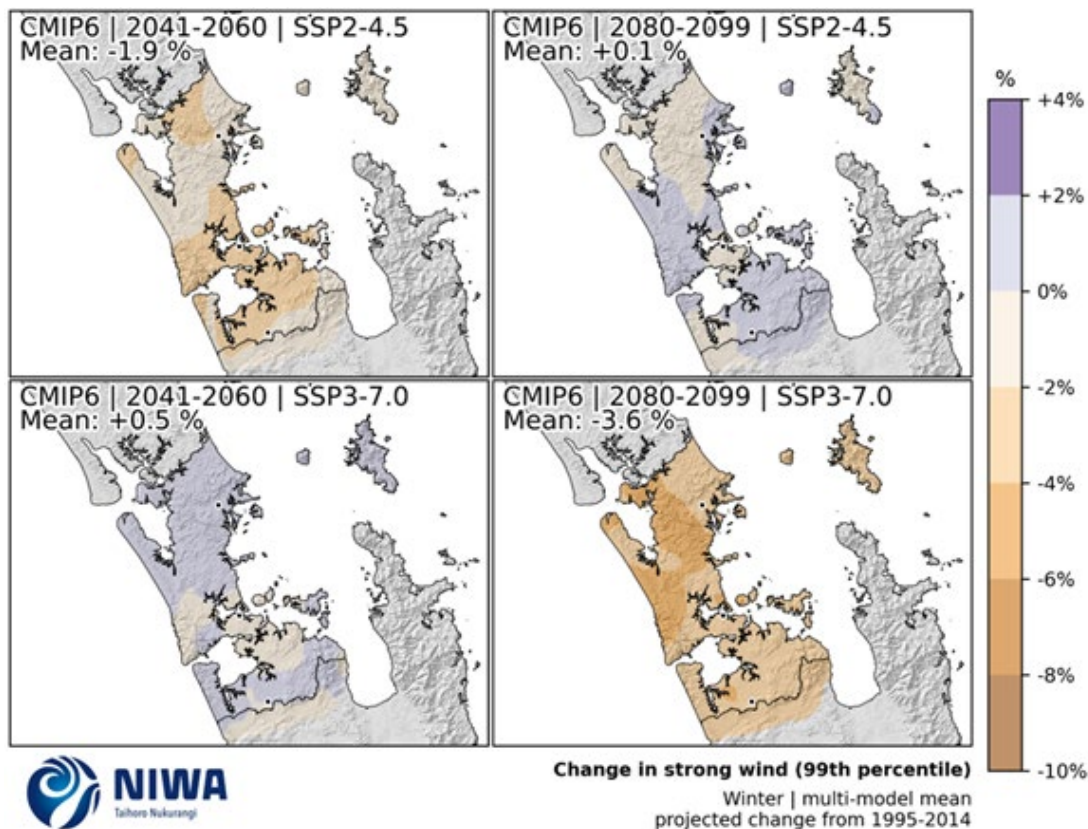


Figure 4-153: Projected winter average strong wind changes.

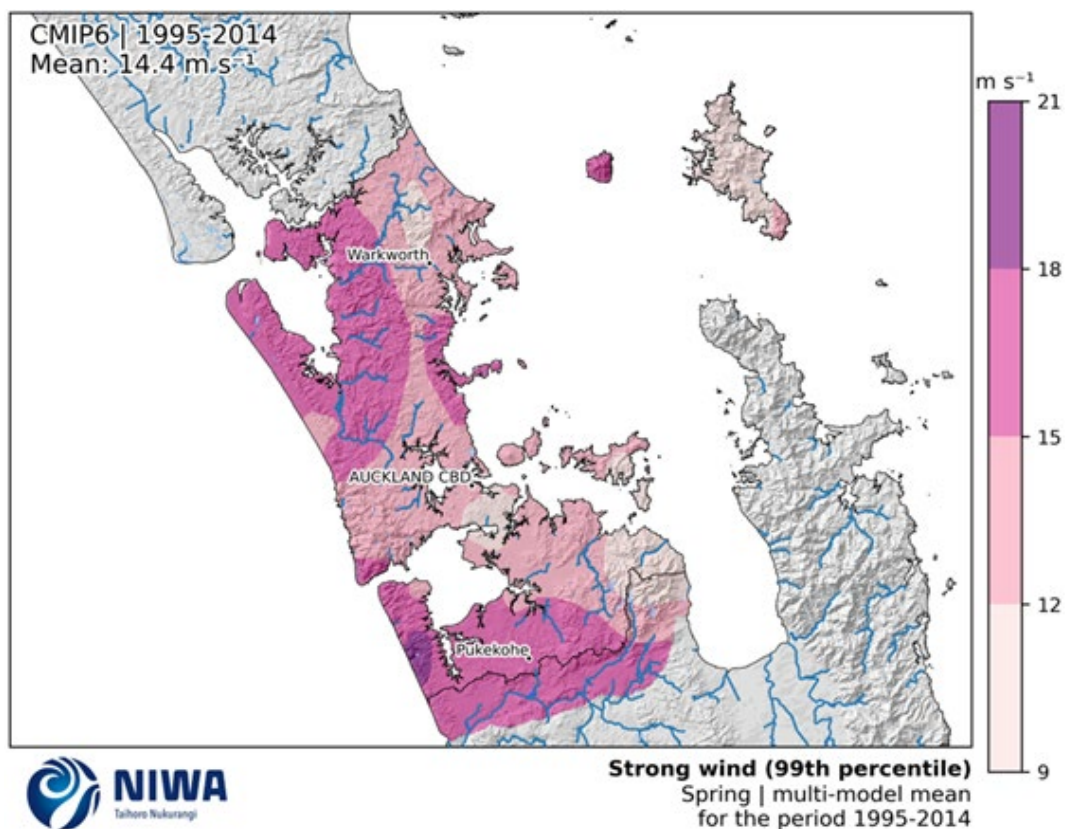


Figure 4-154: Modelled historic average spring strong wind speed.

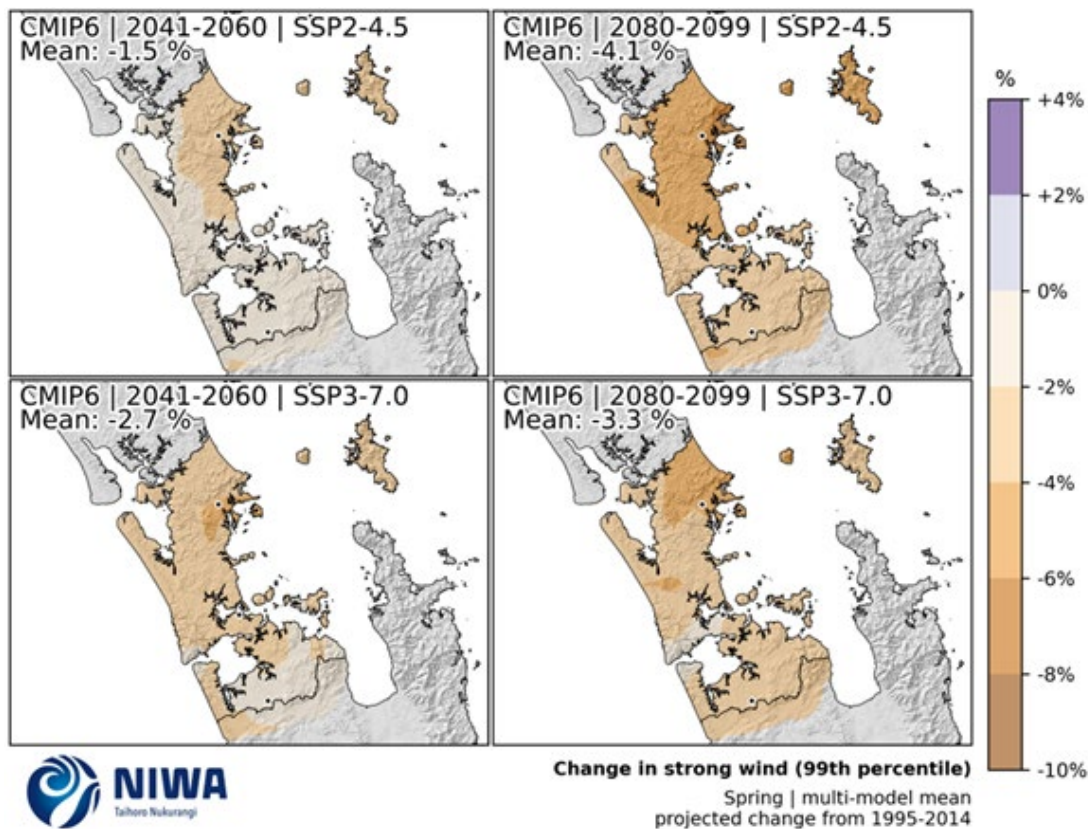


Figure 4-155: Projected spring average strong wind changes.

4.21 Relative humidity

Relative humidity refers to the annual and seasonal average daily relative humidity. Modelled historic and future projections of annual relative humidity are illustrated in Figure 4-156 and Figure 4-157. Seasonal maps were generated, but they are not included in this report due to their limited utility. Region-wide averages are summarised in the two boxes below.

Historic relative humidity and projected changes (%)									
Relative to 1995-2014 (2004)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2004	2050	2090	2050	2090	2050	2090	2050	2090
Annual	83.6	0	0	+0.1	+0.1	0	+0.1	0	+0.1
Summer	82.2	0	0	0	0	+0.1	0	-0.1	-0.1
Autumn	84.1	0	-0.1	+0.2	0	0	0	0	+0.1
Winter	84.6	-0.1	0	+0.2	+0.3	-0.1	+0.4	0	+0.3
Spring	83.6	+0.1	0	+0.2	+0.2	+0.1	+0.2	0	+0.3

Historic relative humidity and projected changes (%)									
Relative to 1986-2005 (1995)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	1995	2050	2090	2050	2090	2050	2090	2050	2090
Annual	83.6	+0.1	0	+0.2	+0.2	+0.1	+0.2	0	+0.2
Summer	82.1	0	0	0	0	+0.1	0	-0.1	-0.1
Autumn	83.9	+0.1	+0.1	+0.3	+0.2	+0.1	+0.1	+0.1	+0.2
Winter	84.5	0	+0.1	+0.3	+0.4	0	+0.5	+0.1	+0.4
Spring	83.5	+0.1	0	+0.2	+0.2	+0.1	+0.2	+0.1	+0.3

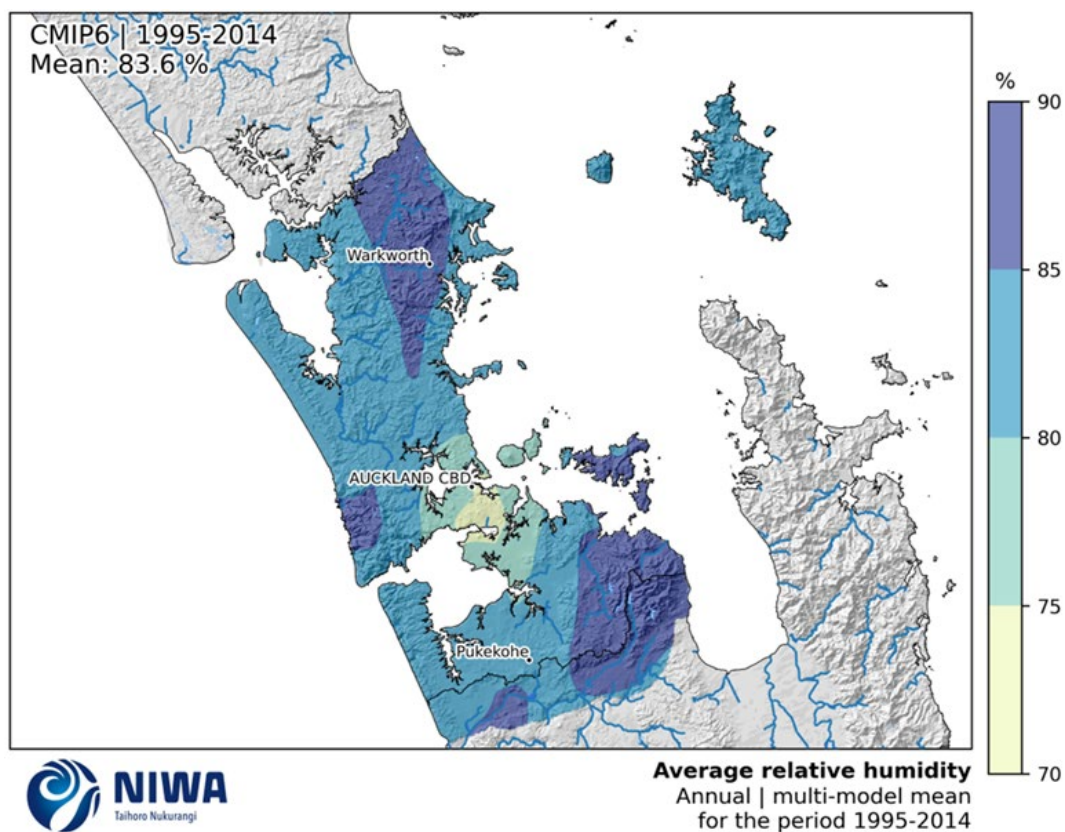


Figure 4-156: Modelled historic annual average relative humidity.

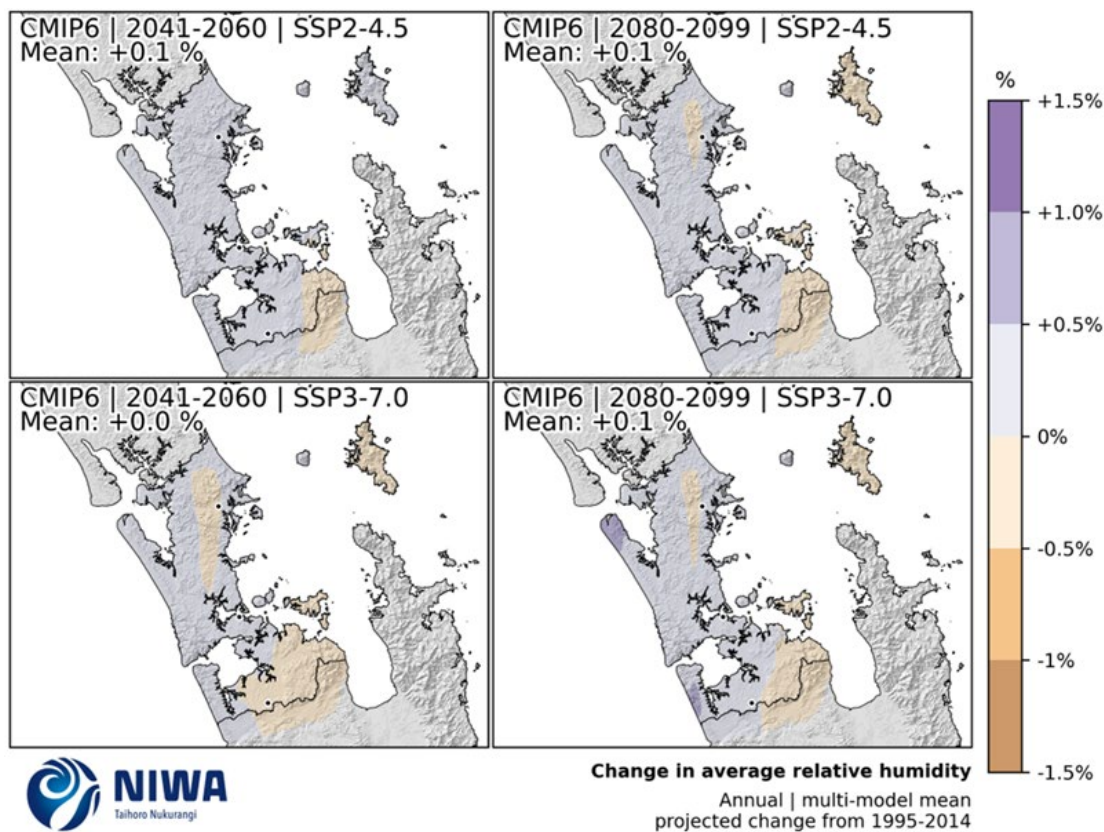


Figure 4-157: Projected annual average relative humidity changes.

4.22 Solar radiation

Solar radiation refers to the annual and seasonal average daily incoming shortwave radiation at Earth's surface. Modelled historic and future projections of annual and seasonal solar radiation are illustrated in Figure 4-158 to Figure 4-167. Note, projected changes in solar radiation at Earth's surface are primarily due to changes in cloudiness (i.e. not due to changes in solar output). Region-wide averages are summarised in the two boxes below.

Historic solar radiation and projected changes (W m⁻²) Relative to 1995-2014 (2004)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	2004	2050	2090	2050	2090	2050	2090	2050	2090
Annual	195.2	+1.4	+1.7	+0.9	+1.5	+1.1	+2.6	+1.8	+2.5
Summer	295.0	-0.8	+0.3	-0.6	-0.7	-1.5	-1.3	+0.3	-1.9
Autumn	156.6	+2.0	+1.7	0	+1.6	+1.0	+2.6	+1.5	+2.1
Winter	101.6	+0.5	+0.3	+0.8	+1.3	+0.6	+2.4	+1.1	+2.4
Spring	230.2	+3.6	+4.1	+2.8	+4.0	+4.0	+6.1	+4.0	+7.4

Historic solar radiation and projected changes (W m⁻²) Relative to 1986-2005 (1995)									
	Historic avg.	SSP1-2.6		SSP2-4.5		SSP3-7.0		SSP5-8.5	
	1995	2050	2090	2050	2090	2050	2090	2050	2090
Annual	195.2	+1.4	+1.7	+0.9	+1.5	+1.1	+2.6	+1.8	+2.5
Summer	294.8	-0.7	+0.5	-0.4	-0.6	-1.4	-1.2	+0.5	-1.8
Autumn	157.4	+1.2	+0.9	-0.7	+0.8	+0.2	+1.8	+0.8	+1.3
Winter	101.9	+0.2	0	+0.5	+1.0	+0.3	+2.1	+0.8	+2.0
Spring	229.1	+4.7	+5.2	+3.9	+5.0	+5.0	+7.2	+5.1	+8.4

4.22.1 Annual

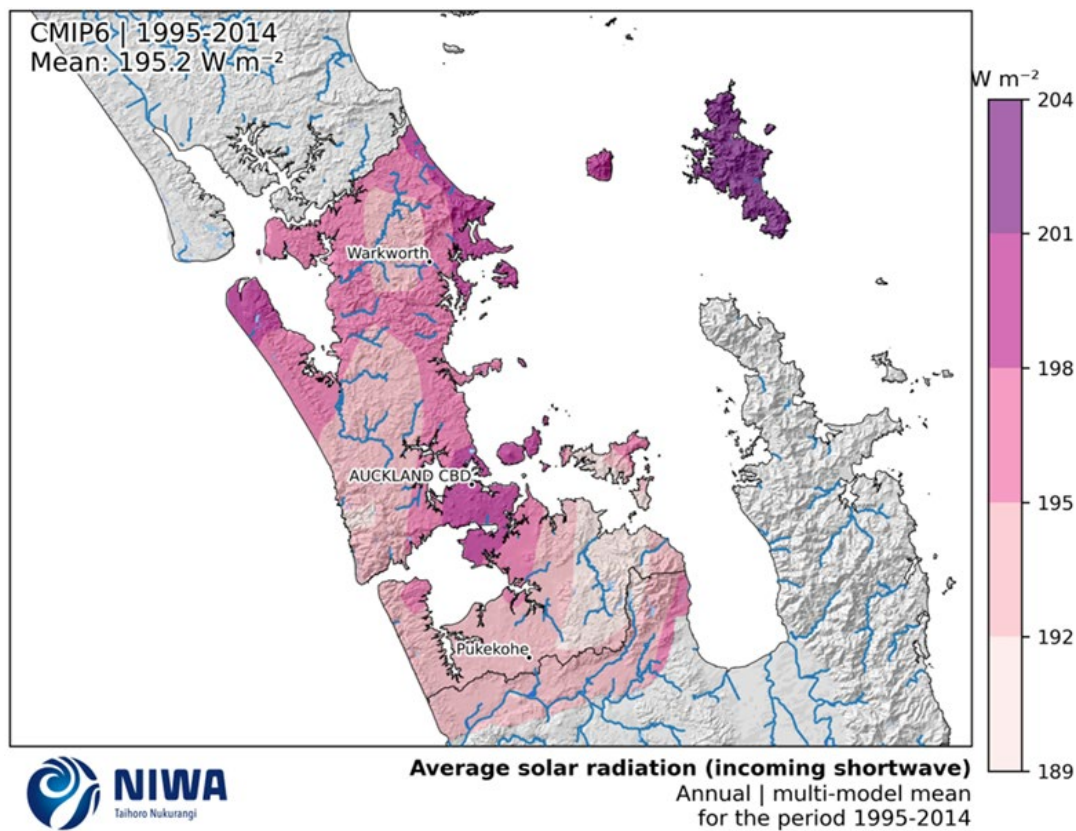


Figure 4-158: Modelled historic annual average solar radiation.

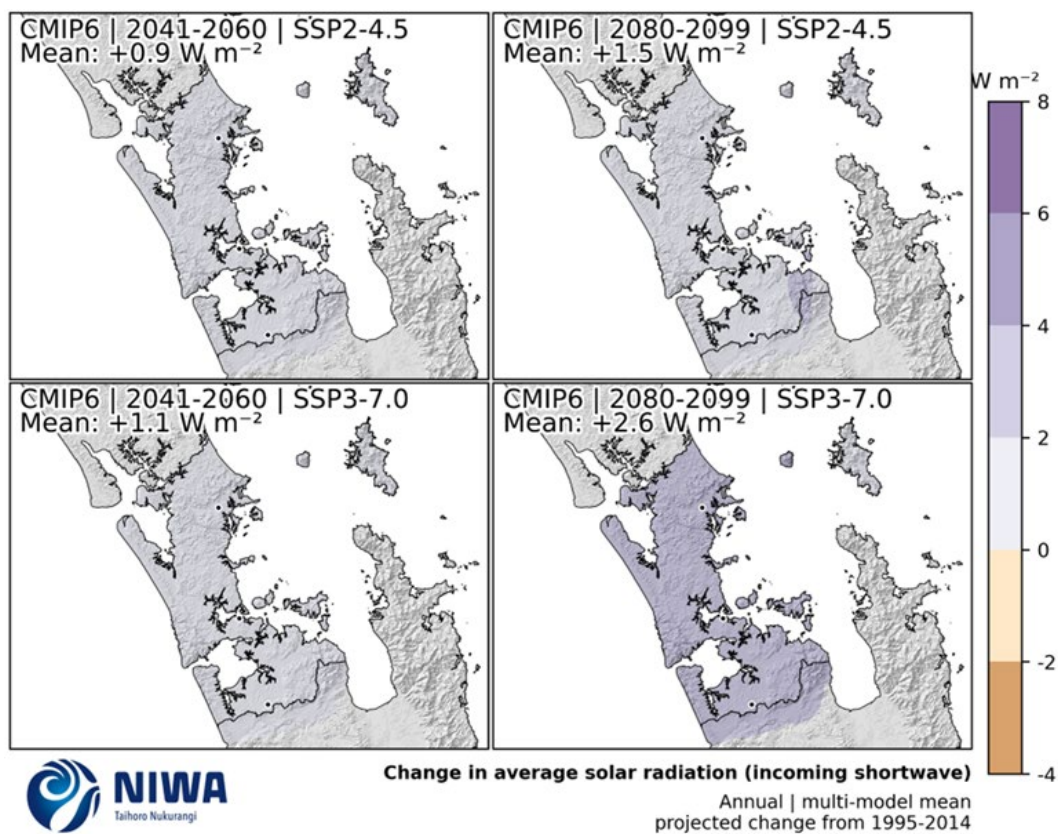


Figure 4-159: Projected annual average solar radiation changes.

4.22.2 Seasonal

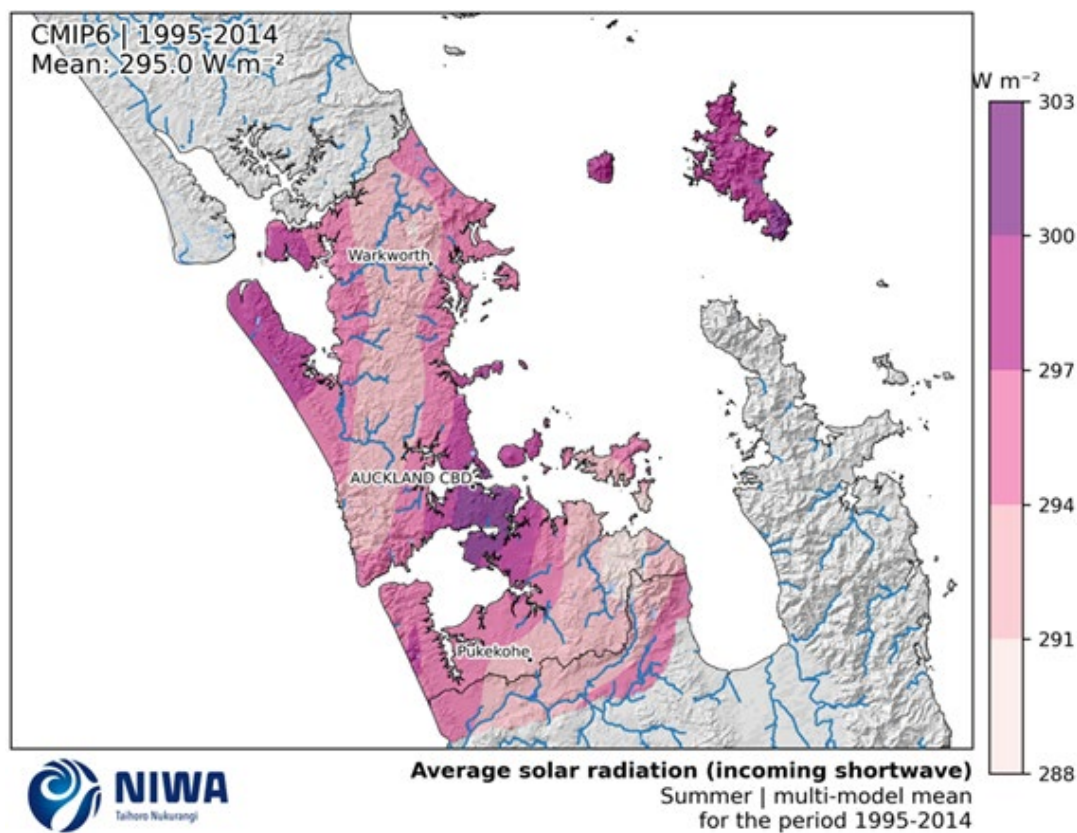


Figure 4-160: Modelled historic summer average solar radiation.

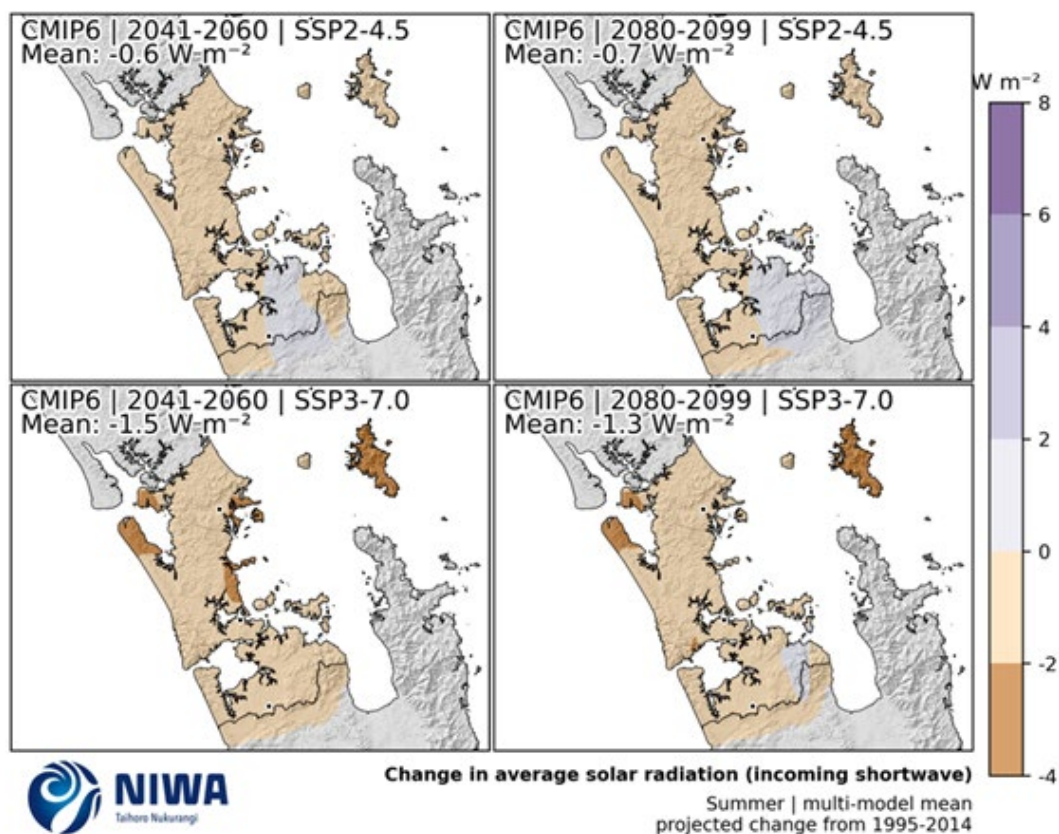


Figure 4-161: Projected summer average solar radiation changes.

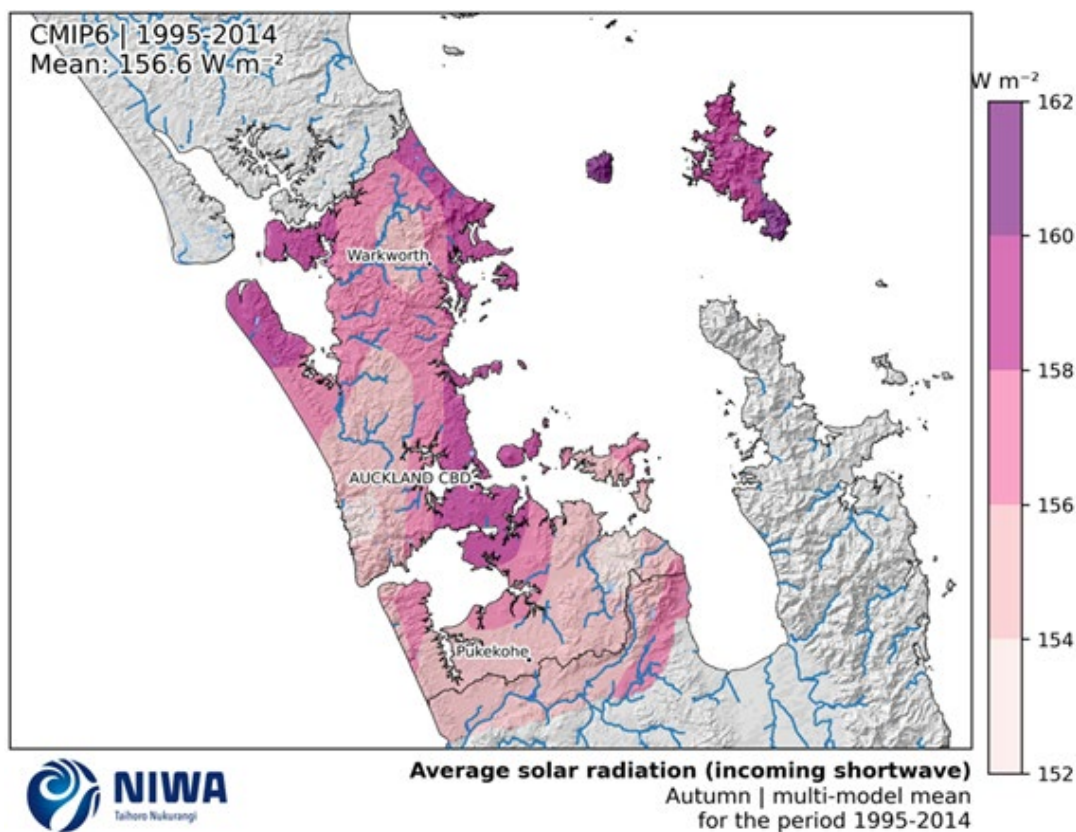


Figure 4-162: Modelled historic autumn average solar radiation.

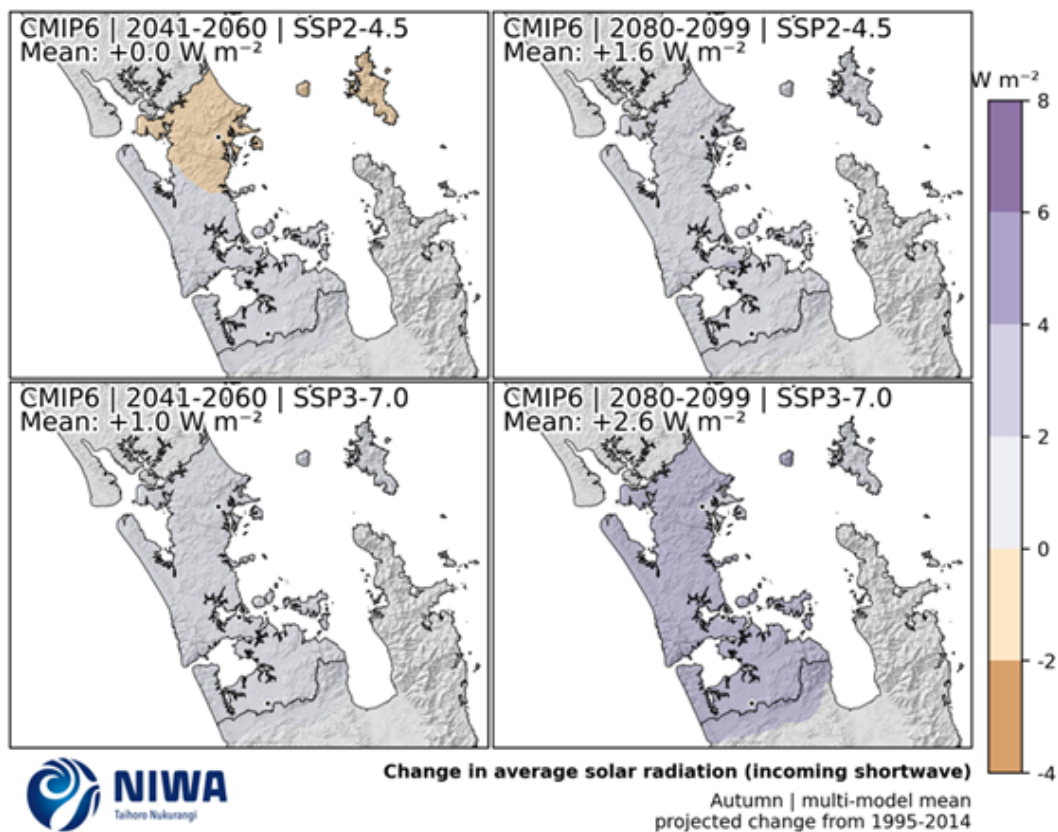


Figure 4-163: Projected autumn average solar radiation changes.

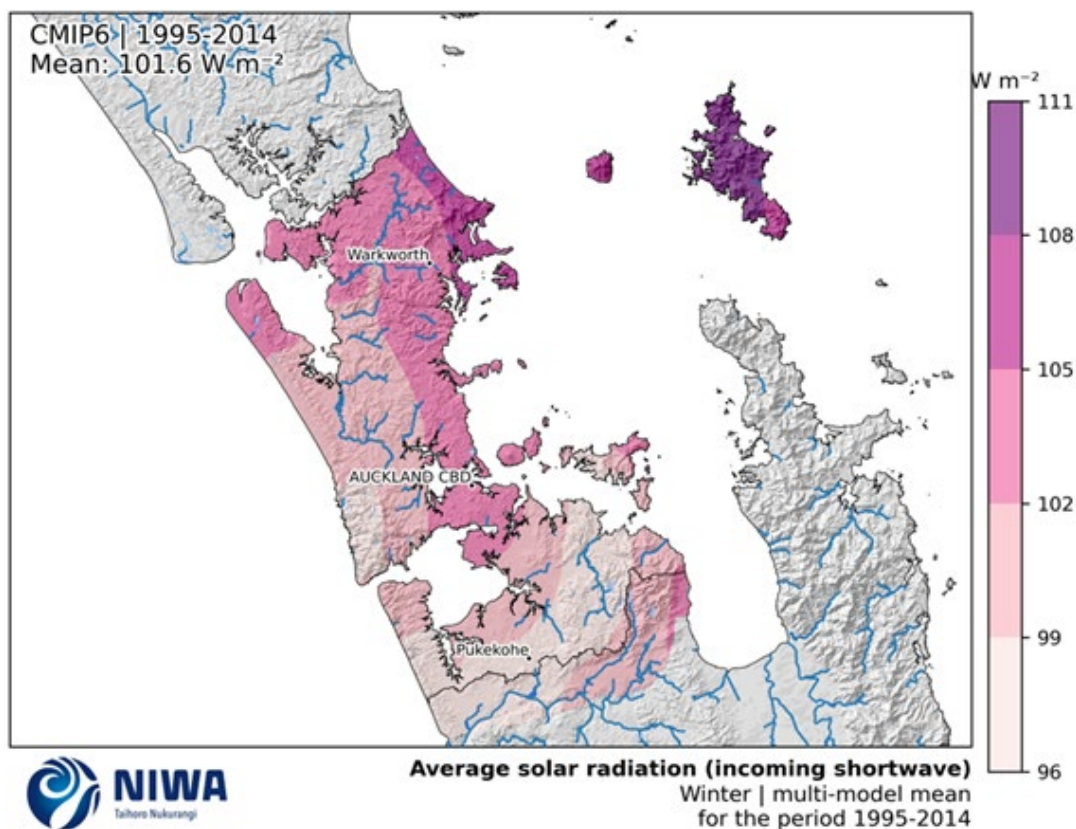


Figure 4-164: Modelled historic winter average solar radiation.

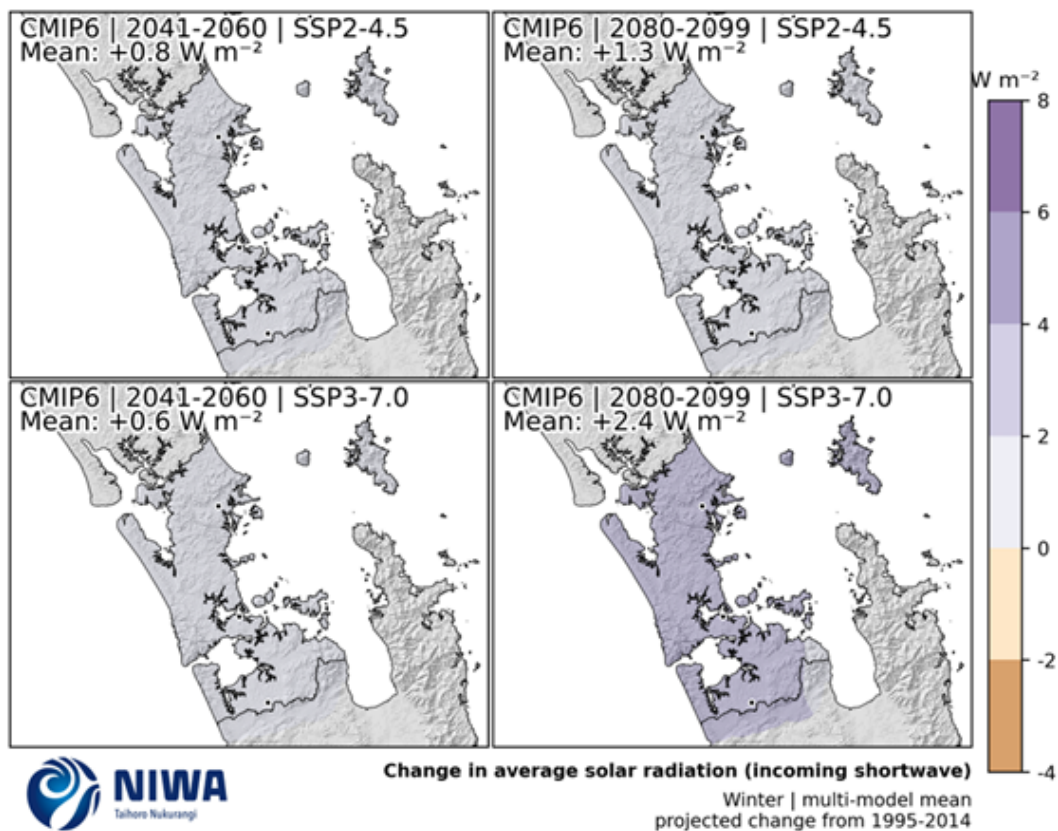


Figure 4-165: Projected winter average solar radiation changes.

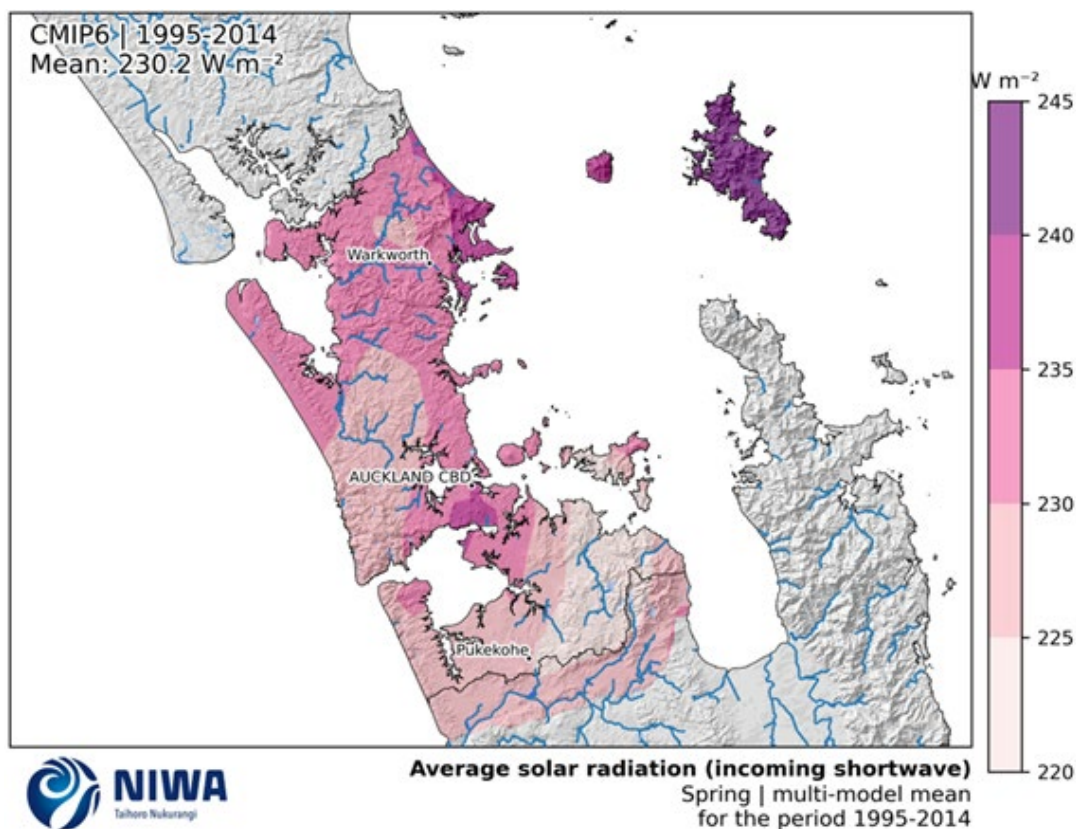


Figure 4-166: Modelled historic spring average solar radiation.

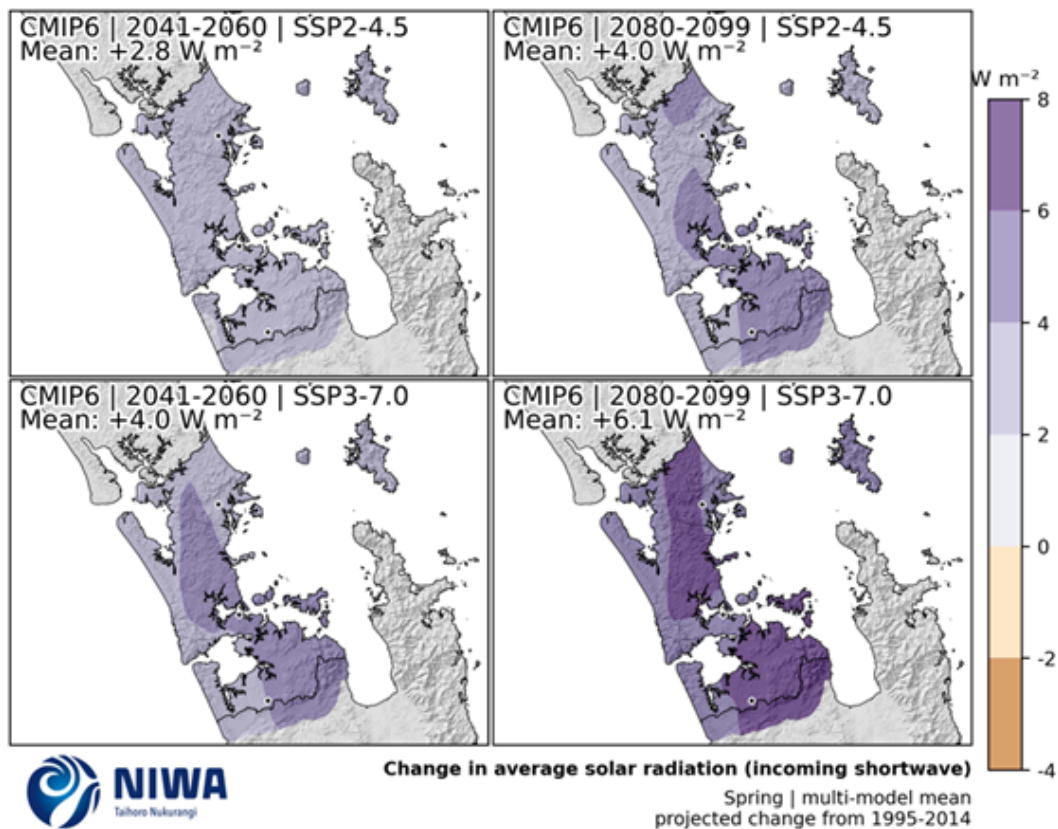


Figure 4-167: Projected spring average solar radiation changes.

4.23 Ex-tropical cyclones and atmospheric rivers

Ex-tropical cyclones (ex-TCs) and atmospheric rivers (ARs) are occasional features of New Zealand's weather, which can cause damaging and costly impacts when their paths intersect with our built and natural environments. Therefore, they are an important component to consider when investigating climate change projections for New Zealand.

Tropical cyclones (TCs) form in tropical regions near the equator. They are fuelled by relatively warm sea-surface temperatures (SSTs), and occur most frequently during November-April in the southwest Pacific region (Diamond et al., 2011). TCs lose structure and strength as they travel away from the relatively warm SSTs of the tropics, and meet the relatively high wind shear environments of the mid-latitudes. Nevertheless, they can re-intensify for periods of time in the mid-latitudes (Sinclair, 2002). In this case, TCs undergo extratropical transformation, as described in Sinclair (2002), and become known as ex-TCs for the time they persist in the mid-latitudes.

Gibson et al. (2025) examined the projections of ex-TCs over the New Zealand domain (32S-48°S, 165°E-181°E):

- The authors found little consensus across the models regarding the frequency of ex-TCs impacting the New Zealand domain. Compared to the long-term average frequency of 1.3 ex-TCs impacting New Zealand per year, the projections showed “no strong robust frequency changes in either direction.”
- However, using the model ensemble mean, by the end of the century (2070-2099) under SSP3-7.0, extreme precipitation associated with ex-TCs impacting New Zealand is projected to increase by approximately 30-35%. Extreme windspeeds are projected to increase by 3%, but the projected magnitude is more variable across the model projections compared to extreme precipitation.

ARs transport considerable amounts of water vapour in the lower atmosphere from tropical and sub-tropical regions to the mid-latitudes. They often produce extreme rainfall events across New Zealand. In Auckland, around 60% of the city's total precipitation occurs during and within 12 hours of a detected AR (Prince et al., 2021). Additionally, around 65% of Auckland's extreme (98th percentile) 6-hourly precipitation occurs within 12 hours of an AR (Prince et al., 2021).

Goddard et al. (2025) examined climate change projections of ARs over the South Pacific and New Zealand. Although these were the highest resolution projections of ARs produced to date for New Zealand, the relatively coarse spatial resolution of the models relative to Auckland's land area mean it is not suitable to determine Auckland-specific results from the publication. However, the regional results offer useful insights into the future changes in ARs that may impact Auckland. By the end of the century (2080-2099) under SSP3-7.0, Goddard et al. (2025) found:

- An increase in AR frequency of up to +5 ARs per year when averaged across the South Pacific. The increase over the upper North Island is projected to be smaller at around +1 ARs per year in the multi-model mean.
- Increased AR intensities of up to +20%, defined as the strength of the water vapour transport in the AR.

- ARs contribute up to 20% more of annual rainfall totals over NZ in the future, highlighting their increased relevance in future.

4.24 Sea-surface temperature

Sea-surface temperature (SST) is the temperature of the uppermost layer of the ocean. The data presented here are derived from those generated and described by Behrens et al. (2022). Note, there is a subtle difference in mid-century period of these data (2040-2059) compared to that applied to other variables in Section 4 (2041-2060). However, there would not be a significant change to the mid-century SST projections if the 2041-2060 were applied. Modelled historic and future projections of annual sea-surface temperature are illustrated in Figure 4-168 and Figure 4-169. Ranges for the grid-box encompassing the Auckland region (36-37°S, 174-176°E) are summarised in the box below.

Historic sea-surface temperature and projected changes (°C)					
Relative to 1995-2014 (2004)					
	Historic avg.	SSP2-4.5		SSP3-7.0	
	2004	2050	2090	2050	2090
Annual	16.5-18.0	+1.25-1.75	+2.00-2.50	+1.50-2.00	+3.25-3.75

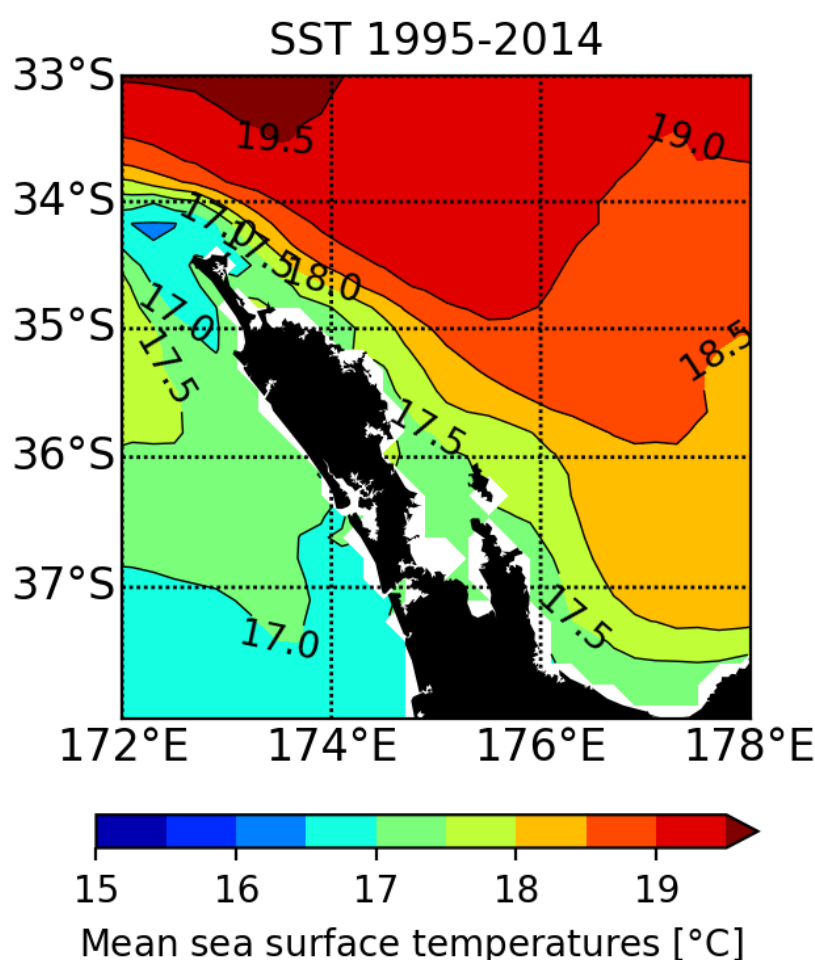


Figure 4-168: Modelled historic annual mean sea-surface temperature (SST).

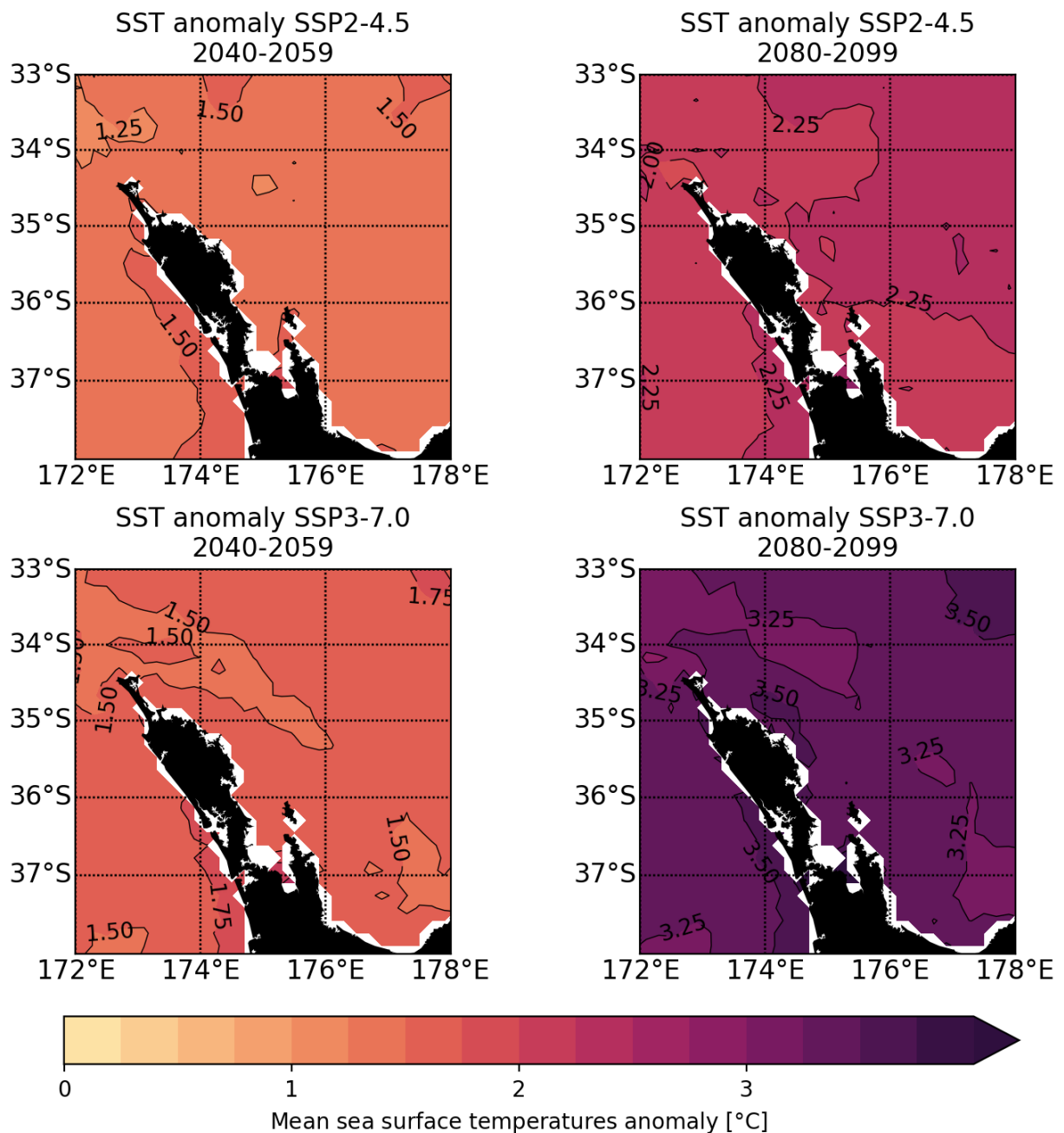


Figure 4-169: Projected annual mean sea-surface temperature (SST) changes. Panels in the left column are for 2050 (2040-2059), panels in the right column are for 2090 (2080-2099). Panels in the top and bottom row are for SSP2-4.5 and SSP3-7.0, respectively.

5 Climate model agreement and spread

5.1 Mean temperature

The multi-model (ensemble) average projected mean temperature changes presented in Section 4.1 obscures variations between the individual models run under each SSP. Figure 5-1 shows the seasonal and annual mean temperature projections from the individual models comprising the multi-model average for the Auckland region. Projections for SSP2-4.5 and SSP3-7.0 are illustrated for both 2050 (2041-2060) and 2090 (2080-2099).

All models project increases to mean temperature for each future period and SSP scenario. This model agreement on the direction of change (i.e. warming) provides greater confidence in the projected change of mean temperature. However, the spread between individual models for a given season and future period means there is uncertainty as to the amount of warming that will occur under each SSP. The models have the greatest spread for 2090, particularly under SSP3-7.0. For example, the model spread for summer and autumn, by 2090 under SSP3-7.0, is approximately 2.5°C.

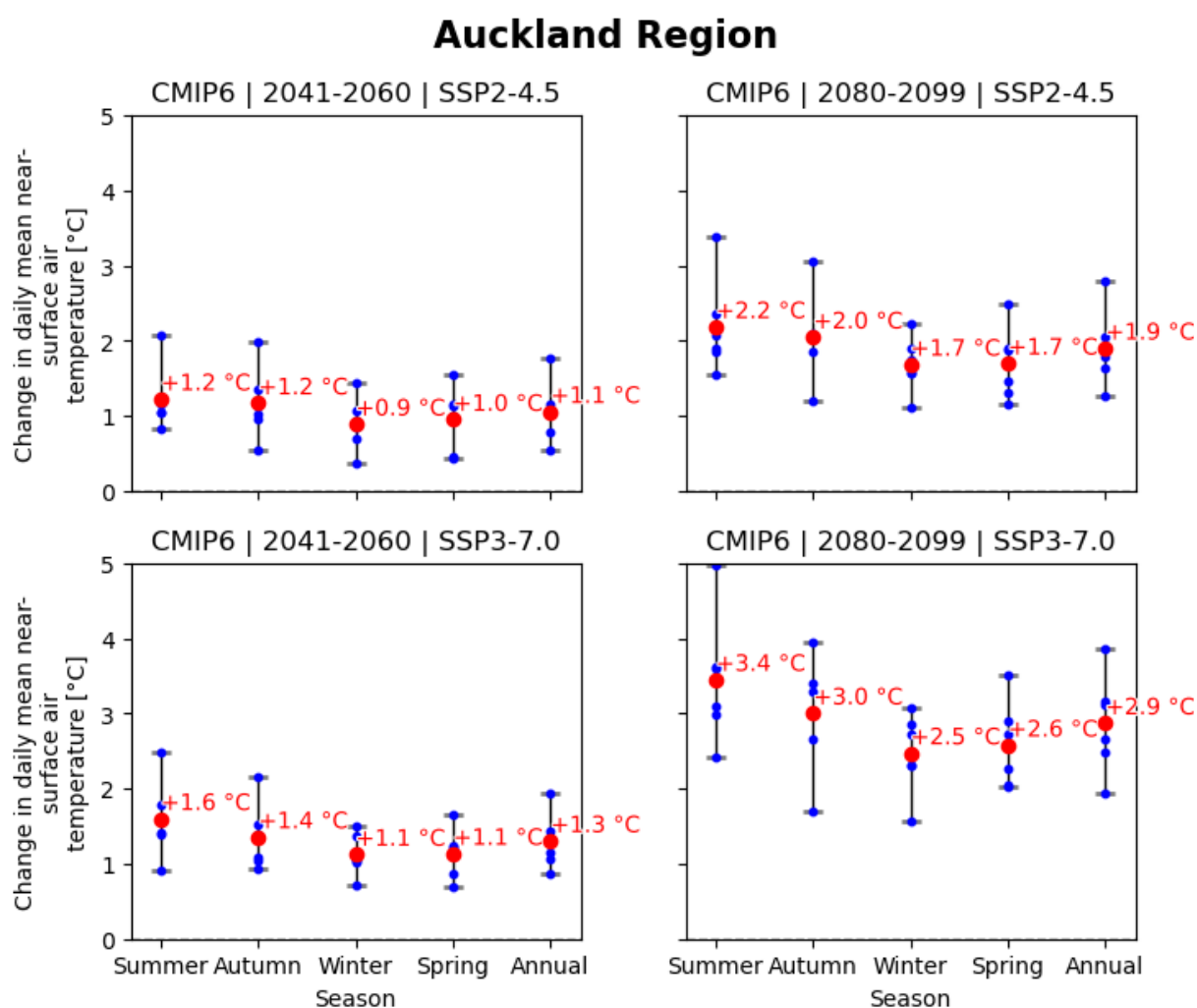


Figure 5-1: Projected seasonal and annual mean temperature changes for Auckland. Panels in the left column are for 2050, panels in the right column are for 2090. Panels in the top and bottom row are for SSP2-4.5 and SSP3-7.0, respectively. Blue dots represent the 6 individual model results, while the red dot (and associated value) represent the ensemble mean.

5.2 Total rainfall

The multi-model (ensemble) average projected total rainfall changes presented in Section 4.9 obscures significant variations between the individual models run under each SSP. Figure 5-2 shows the seasonal and annual total rainfall projections from the individual models comprising the multi-model average for the Auckland region. Projections for SSP2-4.5 and SSP3-7.0 are illustrated for both 2050 (2041-2060) and 2090 (2080-2099).

In general, there is little agreement among all the models as to the direction of projected rainfall changes (i.e. increased or decreased rainfall). The exception is for spring, where almost all models project a decrease in rainfall by 2050 and 2090 under both SSP scenarios. Additionally, all models project a decrease in winter rainfall by 2090 under SSP3-7.0.

The general lack of agreement between models means uncertainty remains as to the direction of projected rainfall changes. Greater confidence can be placed on projections where five of the six models project the same direction of change (e.g. increased summer rainfall by 2050 under SSP2-4.5, and decreased annual rainfall by 2090 under SSP3-7.0). The models have the greatest spread for autumn 2050 under SSP3-7.0, where results are spread across approximately -20% to +30%.

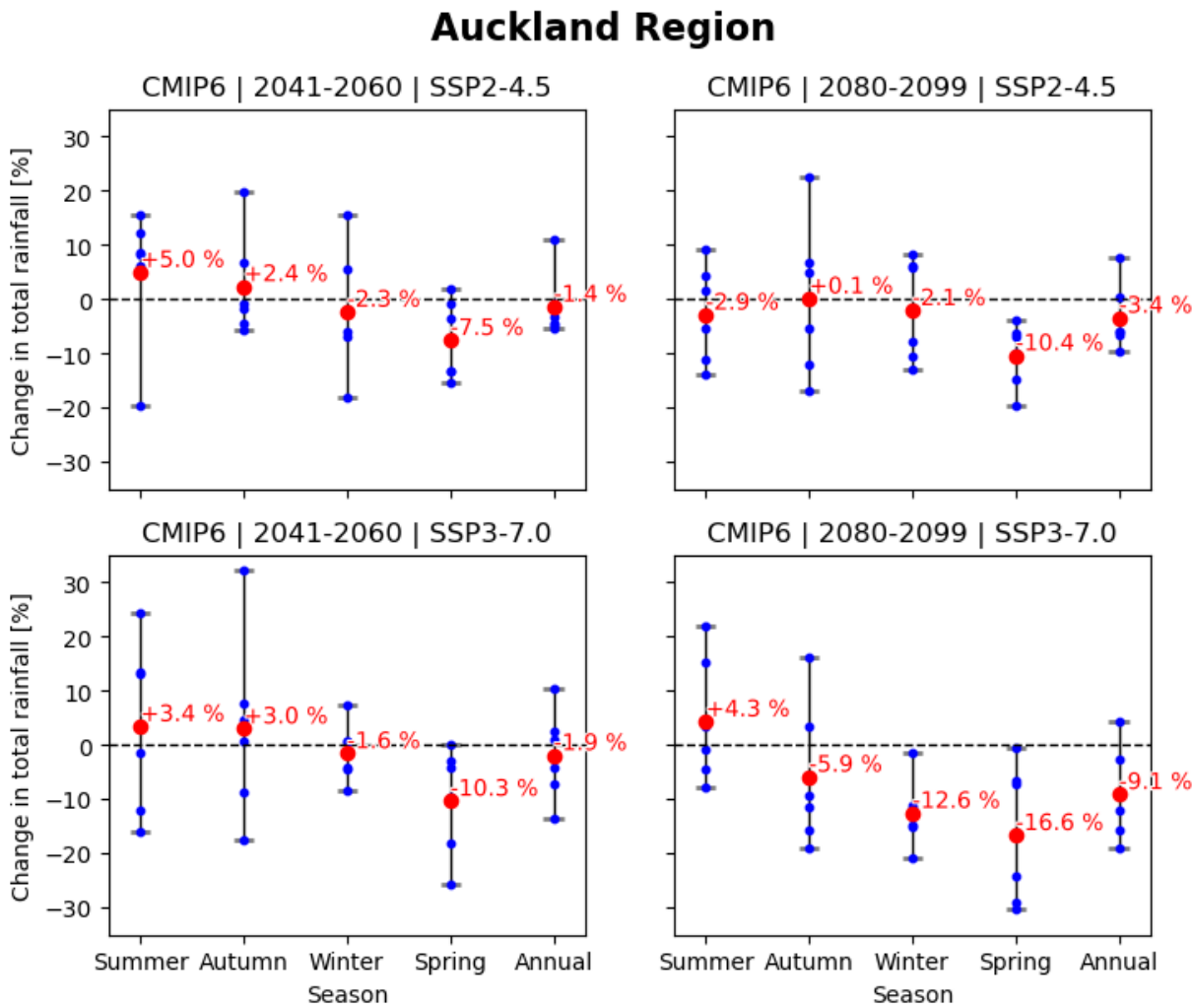


Figure 5-2: Projected seasonal and annual rainfall changes for Auckland. Panels in the left column are for 2050, panels in the right column are for 2090. Panels in the top and bottom row are for SSP2-4.5 and SSP3-7.0, respectively. Blue dots represent the 6 individual model results, while the red dot (and associated value) represent the ensemble mean.

6 Temperature change by 2130

The fits for the multi-model average annual temperature over the Auckland region are shown in Figure 6-1 for the SSP1-2.6 (very low) and SSP5-8.5 (very high) greenhouse gas concentration scenarios. Like the multi-model average, the EBM warms under the SSP1-2.6 scenario until about 2070, then slowly cools, with the EBM continuing that cooling trend past 2100. Under the SSP5-8.5 scenario, the EBM follows the rapid warming in the multi-model average to 2100, with a slight decrease in the warming rate after 2100 in response to a decrease in emissions growth.

The projected warming to 2130 for four scenarios and against the 1986-2005 and 1995-2014 base periods is shown in Table 6-1. Results are also shown for the EBM fits to the temperatures from the hottest and coolest models from the six climate models used to calculate the multi-model (ensemble) average.

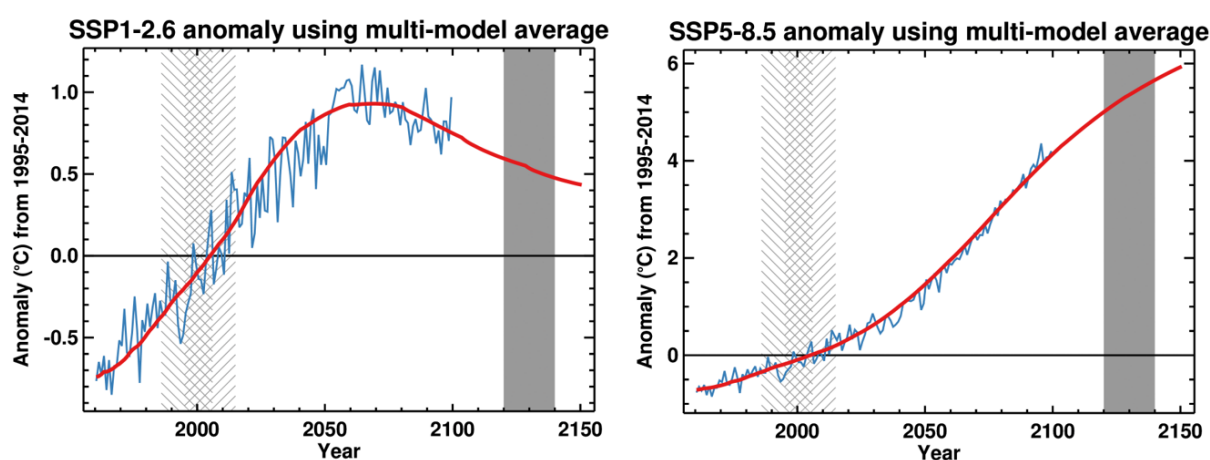


Figure 6-1: Fit of the Energy Balance Model (red) to the multi-model average annual temperature (blue) over the Auckland region. Temperature expressed as anomalies from the 1995-2014 average, for SSP1-2.6 (left) and SSP5-8.5 (right). The grey slanted lines show the 1986-2005 and 1995-2014 reference periods, while the grey shading shows the 20-year period around 2130.

Table 6-1: Estimated warming over the Auckland region to 2130 relative to two base periods. The average, maximum, and minimum value across the six downscaled models are provided for each scenario.

		SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Warming from 2004 (1995-2014) to 2130 (2120-2139)	Average	0.5°C	2.1°C	4.3°C	5.4°C
	Maximum	1.1°C	3.0°C	5.7°C	7.0°C
	Minimum	0.3°C	1.5°C	3.0°C	4.4°C
Warming from 1995 (1986-2005) to 2130 (2120-2139)	Average	0.7°C	2.2°C	4.5°C	5.5°C
	Maximum	1.3°C	3.2°C	5.9°C	7.2°C
	Minimum	0.5°C	1.6°C	3.1°C	4.6°C

7 Discussion

7.1 Temperatures – ongoing increases projected

Auckland's mean annual temperature has increased at a rate of +0.17°C per decade from 1910-2024 (Section 3). Ongoing temperature increases are projected for Auckland, with greater increases by the end of the century under high (SSP3-7.0) and very high (SSP5-8.5) greenhouse gas concentration scenarios (Section 4.1). At the seasonal scale, greatest increases in mean temperature are projected for summer. All models project increases to mean temperature for each future period and SSP scenario (Section 5.1), which provides a high degree of confidence that future warming will occur. There is uncertainty as to the precise amount of warming that will occur under each SSP, therefore the multi-model (ensemble) average values presented in Section 4 are the most appropriate estimate for projected changes in Auckland.

Overall, average daily maximum temperatures are projected to increase more than average daily minimum temperatures, with more prominent differences emerging by the end of the century. The average daily temperature range is projected to increase both annually and seasonally as a result, but by no more than 0.4°C. Increasing daily maximum temperatures contribute to an increase in projected hot days (daily maximum temperature above 25°C) and very hot days (daily maximum temperature above 30°C). These changes will be perceptible for Aucklanders, particularly the increase in hot days observed in autumn and spring. In effect, the projections result in an extension of the historic summer season, with summer-like temperatures occurring more regularly during spring, and persisting deeper into autumn.

In this report, calendar-day percentile thresholds of daily maximum temperatures were used to measure heatwaves (see Section 4.7). This recognises that the appropriate measurement of heatwaves requires more than just simple counts above a threshold (Perkins, 2015). It also means the assessment was tailored to Auckland's climate, enabling a more refined analysis of future changes to heatwaves. Both heatwave frequency and duration are projected to increase, with up to 80 (40) more days of heatwave by 2090 under SSP3-7.0 (SSP2-4.5). As noted by Harrington and Frame (2022), minimum overnight temperatures are also relevant when contextualising the overall risks associated with a heatwave. This is because humans need lower nighttime temperatures to recuperate so they can handle any extreme heat on the following day (Perkins, 2015). Therefore, future investigations of projected heatwave changes in Auckland could also incorporate daily minimum temperatures. Humidity-based heat stress metrics could also be prioritised in future research (Harrington and Frame, 2022).

Higher temperatures increase the rate of moisture loss from land and plants via evapotranspiration. As a result, increases in drought frequency (Section 4.16), duration (Section 4.17), and severity (Section 4.15) are projected for Auckland. Annual meteorological drought frequency is projected to increase by 53 (25) days by 2090 under SSP3-7.0 (SSP2-4.5).

7.2 Rainfall – drier in spring, more intense heavy rainfall events

For annual and seasonal total rainfall, projected changes mostly fall within the range of ±10% (Section 4.9). Notably, there is disagreement (and therefore uncertainty) among the models as to whether future increases or decreases in annual and seasonal rainfall will be observed (Section 5.2). The exception is for spring, where almost all models project a decrease in rainfall

by 2050 and 2090 under both SSP2-4.5 and SSP3-7.0. The uncertainty as to the direction and amount of change under each SSP means the multi-model (ensemble) average values presented in Section 4 are the most appropriate estimate for projected rainfall changes in Auckland. Nevertheless, the spread of model results under each SSP implies that these projections should be interpreted carefully. Emphasis should be placed on ongoing monitoring of rainfall throughout Auckland to track observed changes in total rainfall. Additionally, improvements to GCM capabilities are likely, as well as refinements to downscaling and bias-correction procedures, and this may result in reduced uncertainty when future iterations of rainfall projections are generated.

A warmer atmosphere can hold more water – the Clausius-Clapeyron relationship predicts an increase in the moisture capacity of air of approximately 7% per degree Celsius (Held and Soden, 2006). Indeed, a growing body of evidence demonstrates that observed extreme rainfall events have already been exacerbated by climate change (e.g. Vasconcelos Junior et al., 2024; Tradowsky et al., 2023; Otto et al., 2023). In Auckland, heavy rainfalls are projected to become more intense. Changes to heavy rainfall events have been examined using the *heavy rainfall (99th percentile) amount* (Section 4.13). Based on this measure, a heavy rainfall event in summer historically brings 69 mm of daily rainfall. By 2090 under SSP3-7.0, this could increase by 31% to 90 mm. The historic *heavy rainfall (99th percentile) amount* is lower in spring (50 mm) compared to the remaining seasons (61–69 mm). This carries through to future projections, with comparatively small increases of approximately 1–3% projected for spring under SSP2-4.5 and SSP3-7.0.

Extreme rainfalls of sub-daily duration were not assessed directly in this report, but are important to consider given their propensity to cause sudden and significant impacts. Carey-Smith et al. (2018) presented New Zealand’s future changes to rainfall depths for event durations/average recurrence intervals (ARI) spanning 1–120 hours/2–100 years. Per degree of warming, the percentage change factors for rainfall depths ranged from 4.8% to 13.6%, with greater increases for shorter duration/higher ARI event combinations (Carey-Smith et al., 2018).

Ex-tropical cyclones (ex-TCs) are an irregular feature of Auckland’s climate, but they can cause considerable damage across the region. In February 2023, ex-TC Gabrielle passed along the northern coast of New Zealand. Extreme rainfall, strong winds, and storm surges associated with *Gabrielle* caused considerable flooding, infrastructure damage, power outages, and coastal inundation across Auckland. Human influence on this system was demonstrated by Stone et al. (2024). The authors found that ex-TC Gabrielle delivered 10% more total rainfall, and 20% higher peak hourly rainfall, because of anthropogenic climate change. As noted in Section 4.23, extreme precipitation associated with ex-TCs impacting New Zealand is projected to increase by approximately 30–35% by the end of the century under SSP3-7.0 (Gibson et al., 2025). These findings highlight the potential for more intense rainfall associated with ex-TCs in the future, increasing the risk of impacts for vulnerable communities across Auckland in lieu of preventative and protective measures.

7.3 Sea-surface temperatures and sea-level rise

The Earth is currently out of energy balance, and around 90% of the surplus energy goes into warming the ocean (WMO, 2025). Most of the oceans around New Zealand have warmed significantly in recent decades, and the average warming rate of sea-surface temperatures for the country’s Exclusive Economic Zone was 0.2°C per decade between 1981 and 2023

(Pinkerton et al., 2023). Ongoing increases are projected for surface temperatures of the sea near Auckland (Section 4.24), ranging from 1.25°C (by 2050 under SSP2-4.5) to 3.75°C (by 2090 under SSP3-7.0).

Auckland has extensive coastlines, and sea-level rise will directly impact those who live, work, and recreate in the coastal zone. Sea-level rise projections were not assessed in this report, because these are covered comprehensively in the Ministry for the Environment's *Coastal hazards and climate change guidance* (MfE, 2024). This MfE guidance incorporates the latest IPCC Sixth Assessment Report scenarios (SSPs; described in Section 2.3), and these align with the RCP scenarios and used in the preceding 2017 version of the coastal hazards and climate change guidance (MfE, 2017). In addition, the 2024 guidance incorporates rates of vertical land movement around the coast, resulting in estimates of sea-level rise relative to the local landmass (MfE, 2024). For a central location in New Zealand, absolute sea-level rise could reach 0.6 m (SSP2-4.5) to 0.7 m (SSP3-7.0) by 2100 (MfE, 2024).

7.4 Impacts of future climate change

Projected increases to mean temperature, hot days, and heavy rainfall in Auckland are consistently higher under CMIP6 scenarios compared to the corresponding CMIP5 scenarios (Macara et al., 2024). Nevertheless, the fundamental projected changes to variables presented here generally align with those derived from the previous CMIP5 scenarios presented by Pearce et al. (2020). Therefore, the impacts associated with higher temperatures, more intense severe rainfalls, and increasing drought severity that are described in Pearce et al. (2020) remain relevant. Readers are referred to that report for a comprehensive discussion of future impacts associated with projected climate change in Auckland. Some of the more prominent impacts anticipated in Auckland are highlighted below:

- Flooding will continue to be an issue in Auckland. More frequent and intense extreme rainfall events will worsen existing impacts associated with these events including urban flooding causing damage to properties and other assets, floodwaters blocking roads, and slips for hilly areas of the region. Slips and soil erosion will lead to increased sedimentation in waterways as well as habitat loss. Insurance may increasingly become an issue for owners of flood-prone properties.
- Auckland's citizens will be accustomed to the existing 'typical' climate of the region. Extreme departures from 'typical' (such as during heatwaves) are associated with increased demand for energy use (e.g. for cooling homes and offices), and adverse health impacts for elderly, children, and those with underlying medical conditions. Therefore, an increase in heat-related impacts (such as heat-related illnesses) are anticipated for citizens of Auckland. These impacts may be exacerbated by the urban heat island that has been identified in the city centre (Arup, 2024).
- Climate change will impact the cultural, social, environmental, and economic wellbeing of Māori. Sea-level rise and flooding will increasingly compromise marae, Māori land holdings, urupā, wāhi tapu, and papakāinga. Indigenous species and ecosystems are vulnerable to a changing climate which is likely to disturb the relationships Māori have with these taonga, including impacts on mahinga kai. Ocean acidification and increasing sea-surface temperatures will

impact marine ecosystems, and this may affect fisheries and access to kai moana.

- Natural ecosystems are finely in tune with their surrounding habitats, and are generally only tolerant to specific temperatures (Perkins, 2015). Higher temperatures and increased heatwaves bring a greater threat of invasive species and diseases becoming established in Auckland, as well as increasing the prominence of existing weeds. Endangered native bird species such as those on Auckland's sanctuary islands may be especially vulnerable to the impacts of climate change given the limited extent of their habitats.
- Increasing drought frequency and duration will have an impact on water sensitive activities and industries. The agricultural and horticultural sectors may be particularly affected, with reduced pasture and produce yields impacting farm and orchard incomes. Water storage levels in Auckland's dams will be reduced during time of drought. This may lead to impacts for Auckland residents through water use restrictions, intensifying the increased demand for irrigation during times of drought.
- Sea-level rise will amplify the coastal inundation and erosion impacts associated with severe storm events such as ex-tropical cyclones. Coastal erosion and flooding can damage homes, roads, and other infrastructure, and affect access to coastal areas. Extensive development near beaches, estuaries and marshes limits the natural adjustment of the coast, so rising seas will destroy large areas of habitat at the current coastal margin.
- Higher sea-surface temperatures will compromise aquatic biosecurity, as species not usually seen in New Zealand waters may arrive and become established.

8 Summary and recommendations

Auckland's future climate will be warmer, with increased intensity of extreme events. The region can expect more hot days and heatwaves, increasingly frequent and intense heavy rainfall events, and greater severity of drought. Table 8-1 highlights some of the more notable annual and seasonal projected changes for SSP2-4.5 and SSP3-7.0.

Table 8-1: Projected changes to selected climate variables in Auckland. Note the changes presented here are relative to the 2004 (1995-2014) historic baseline.

Variable	Time of year	Historic avg.	Future period	Projected changes	
				SSP2-4.5	SSP3.7.0
Mean temperature	Annual	15.0°C	2050	+1.1°C	+1.3°C
			2090	+1.9°C	+2.9°C
Hot days (>25°C)	Annual	20 days	2050	+25 days	+34 days
			2090	+49 days	+78 days
Heatwave frequency	Annual	2.3 days	2050	+16 days	+23 days
			2090	+40 days	+80 days
Total rainfall	Spring	309 mm	2050	-7%	-11%
			2090	-10%	-17%
Heavy rainfall (99 th percentile) amount	Annual	62 mm	2050	+10%	+12%
			2090	+13%	+19%
Meteorological drought frequency	Annual	66 days	2050	+10 days	+19 days
			2090	+25 days	+53 days
Windy days (daily mean wind speed > 10 m s ⁻¹)	Annual	55 days	2050	-6 days	-7 days
			2090	-10 days	-15 days

Considering the climate change projections presented in this report, a list of recommendations for Auckland Council's consideration are presented below:

- Continue to monitor the weather and climate across the region. Reliable observations are critical for understanding how our climate is changing.
- Utilise future iterations of climate projections when they become available. This is especially relevant for annual and seasonal total rainfall, where in many cases the direction and amount of change is rather uncertain.
- Despite the uncertainty in annual and seasonal rainfall projections, take heed of the projected changes to extreme rainfall events. Fundamental physical and climatological processes mean more intense and frequent severe rainfall events are expected in future.
- Increased drought severity is expected. Given the concurrent projected increases to heavy and extreme rainfalls, this highlights an increased intensity of extreme

events in future. Water management therefore becomes a critical consideration: from the storage, access and use of water during dry periods, to the capacity and resilience of infrastructure, urban and rural communities to both cope with, and recover from, extreme rainfall events.

- Future investigations of projected heatwave changes in Auckland could incorporate daily minimum temperatures, as well as examining humidity-based heat stress metrics.
- While not a focus of this report, sea-level rise is an incessant component of climate change in Auckland and will require ongoing consideration given the region's extensive coastal margin. Refer to the Ministry for the Environment's *Coastal hazards and climate change guidance* (MfE, 2024) for comprehensive coverage of sea-level rise in New Zealand.

9 Acknowledgements

Erica Williams (Earth Sciences New Zealand) provided review and feedback for the Māori impacts text which is presented in this and the summary report. Mark Tucker (Earth Sciences New Zealand) made significant contributions to the summary report associated with this technical report. Stuart Mackay (Earth Sciences New Zealand) made significant contributions to the summary video associated with this technical report. Petra Pearce (Auckland Council) is thanked for her feedback on i) draft versions of this technical report, and ii) the associated summary video and summary report.

10 Glossary of abbreviations and terms

Anthropogenic	Originating in human activity.
ARI	Average recurrence interval. The average time interval (averaged over a very long time period and many "events") that is expected to elapse between recurrences of an infrequent event.
ARs	Atmospheric rivers. These are features of the lower atmosphere, which transport considerable amounts of water vapour from tropical and sub-tropical regions to the mid-latitudes. They often produce extreme rainfall events across New Zealand.
Bias-corrected	The process of using climate observations (e.g. data from existing climate stations) to calibrate climate model data. This ensures climate model output resemble a given location's climate and weather characteristics appropriately.
CCAM	Conformal Cubic Atmospheric Model, which uses dynamical downscaling to simulate climate and weather at finer resolutions than GCMs. Developed by CSIRO in Australia.
Climate variable	An element of the climate that is liable to vary or change, e.g. temperature, rainfall.
CMIP5	Fifth Coupled Model Intercomparison Project. This project involved a number of experiments with coupled atmosphere-ocean global climate models, most of which were reported on in the IPCC Fifth Assessment Report, Working Group I.
CMIP6	Sixth Coupled Model Intercomparison Project. This project involved a number of experiments with coupled atmosphere-ocean global climate models, most of which were reported on in the IPCC Sixth Assessment Report, Working Group I.
Downscaling	Deriving local climate information from larger-scale model or observational data. Two main methods exist – statistical and dynamical. Statistical methods develop statistical relationships between large-scale atmospheric variables (e.g., circulation and moisture variations) and local climate variables (e.g., rainfall variations). Dynamical methods use the output of a regional climate/weather model driven by a larger-scale global model.
EBM	Energy balance model. A simplified climate model primarily simulating the balance between energy entering Earth and released back into space.
Ensemble	Referring here to the collection of six GCMs that were selected for downscaling and bias-correction in New Zealand.

Evapotranspiration	The process where water held in the soil is gradually released to the atmosphere through a combination of direct evaporation and transpiration from plants. As the growing season advances, the amount of water lost from the soil through evapotranspiration typically exceeds rainfall, giving rise to an increase in soil moisture deficit.
Ex-TCs	Ex-tropical cyclones. Tropical cyclones lose structure and strength as they travel away from the relatively warm SSTs of the tropics, and meet the relatively high wind shear environments of the mid-latitudes. In this case, TCs undergo extratropical transformation and become known as ex-TCs.
GCMs	Global Climate Models.
Homogenised	The process whereby non-climatic changes (e.g. those resulting from station relocations or instrumentation changes) are removed from a climate dataset.
IPCC	Intergovernmental Panel on Climate Change. This body was established in 1988 by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP) to objectively assess scientific, technical and socioeconomic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation. One of its major outputs is regular assessments of the climate system and our knowledge of climate change, known as Assessment Reports.
NIWA	National Institute of Water and Atmospheric Research.
PED	Potential evapotranspiration deficit. The difference between PET and actual evapotranspiration. It is a robust measure of meteorological drought intensity and duration.
Radiative forcing	The difference between the energy entering our atmosphere and the energy leaving it. If the number is greater than zero, our atmospheric temperature can increase.
RCPs	Representative Concentration Pathways. These comprise scenarios used in CMIP5 modelling. They describe four possible climate futures represented by the concentration of greenhouse gases in the atmosphere, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. The four RCPs, RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W m ² , respectively).

SSPs	Shared Socioeconomic Pathways. These comprise scenarios of projected socioeconomic global changes up to 2100, used in CMIP6 modelling.
SST	Sea-surface temperature. The temperature of the uppermost layer of the ocean.
TCs	Tropical cyclones. These form in tropical regions near the equator. They are fuelled by relatively warm sea-surface temperatures, and occur most frequently during November-April in the southwest Pacific region.

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