Waimakariri District Climate Change Scenario: Technical Report

Prepared for Waimakariri District Council

May 2022

Prepared by:
Ashley Broadbent
Abha Sood
Stephen Stuart
Gregor Macara
Christian Zammit

For any information regarding this report please contact:

Ashley Broadbent, PhD
+64-4-386 0383
ashley.broadbent@niwa.co.nz

National Institute
of Water & Atmospheric
Research Ltd (NIWA)

301 Evans Bay Parade
Hataitai
Wellington 6021
Private Bag 14901
Kilbirnie
Wellington 6241

Phone +64 4 386 0300

NIWA CLIENT REPORT No: 2022095WN
Report date: May 2022
NIWA Project: WDC22301

Quality Assurance Statement		
	Reviewed by:	Petra Pearce
	Formatting checked by:	Alex Quigley
	Approved for release by:	Andrew Tait Chief Scientist – Climate, Atmosphere and Hazards

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Executive summary

It is widely accepted that human activities are the main cause of observable contemporary global climate change, and that further changes to the climate will occur during the 21st Century due to ongoing greenhouse gas emissions to the atmosphere. Waimakariri District Council has commissioned NIWA to analyse projected climate changes for the district and provide a summary of potential impacts of climate change for the region. This report summarises projected changes for 13 different climate variables for mid-century (2031-2050) and end-century (2081-2100) time slices. Future changes to climate variables are presented as changes relative to a historical baseline period (1986-2005) for two greenhouse gas (GHG) concentration scenarios: a moderate GHG scenario (RCP4.5) and a high GHG scenario (RCP8.5). Potential climate change impacts on important sectors in the district are discussed but a detailed climate impact assessment was not completed.

Future climate changes are likely to be significant and could impact the entire Waimakariri District. For the moderate GHG scenario, the district's average air temperature is expected to increase by 0.8 °C by the mid-century and 1.2 °C by the end-century. However, for a high GHG scenario, the district's average air temperature could increase by 0.9 °C by the mid-century and 2.4 °C by the end-century. The high GHG scenario causes twice as much end-century warming in the district than the moderate GHG scenario. This highlights the uncertainty generated by the differing impacts of GHG concentrations at the end of the century.

Changes to extreme temperatures are likely, with the number of hot days (days > 25°C) in the district projected to double by the end-century under a moderate GHG scenario and more than triple under a high concentration GHG scenario. The mean annual rainfall is projected to increase across most of the district under both GHG concentration scenarios. The general trend in precipitation change within the district will follow an east-to-west gradient, with projected increased rainfall across the lower altitude plains and coastal areas, and slight decreases (or no change) in rainfall in the western high-altitude regions east of the main divide. The lower elevations could experience 12% more rainfall annually under the high intensity GHG scenario. The district is projected to experience a relatively consistent increase in rainfall across all seasons, except spring when decreased rainfall is projected in some scenarios.

Extreme rainfall intensity is likely to increase in the Waimakariri District because a warmer atmosphere can hold more moisture. In addition, the district is projected to experience a widespread increase in potential evaporation deficit – a drought indicator – suggesting the district will likely become more drought prone in the future as temperatures increase and precipitation changes. Wind speed is generally projected to increase and relative humidity to decrease as the climate warms during the 21st century.

Climatic changes in the region will likely result in changes to river flow in the Ashley/Rakahuri and Waimakariri catchments with decreasing low flows and increasing high flows projected. Climate changes in the regions will likely have a broad range of impacts; the most relevant impacts based on the profile of the district and climate changes expected are possible increases in river flooding, drought, coastal inundation and flooding, and wildfire. In addition to these impacts, some possible effects on primary industries are explored given the importance of this sector for the district.

1 Introduction

According to the Intergovernmental Panel on Climate Change (IPCC) sixth Assessment Report (AR6), it is now unequivocal that human activities have warmed the atmosphere, ocean, and land.

Global climatic warming has accelerated in the last 50 years with each of the last four decades being successively warmer than any decade that preceded it since 1850 (IPCC, 2021). New Zealand's official temperature record has exhibited warming since measurements began in 1909 and is virtually certain to continue to do so. The country's mean annual temperature has increased, on average, by 1.1 °C per century since 1909 (Figure 1-1). In addition to rising average temperatures, climate change may increase the frequency and intensity of hot extremes, marine heatwaves, heavy precipitation, damaging storms, and droughts, as well as melting glaciers, ice, and snow cover, and causing sea level rise (IPCC, 2013; IPCC, 2021). Understanding the nature of New Zealand's changing climate and its potential impacts at local scales is critical to developing successful adaptation planning, policy, and interventions.

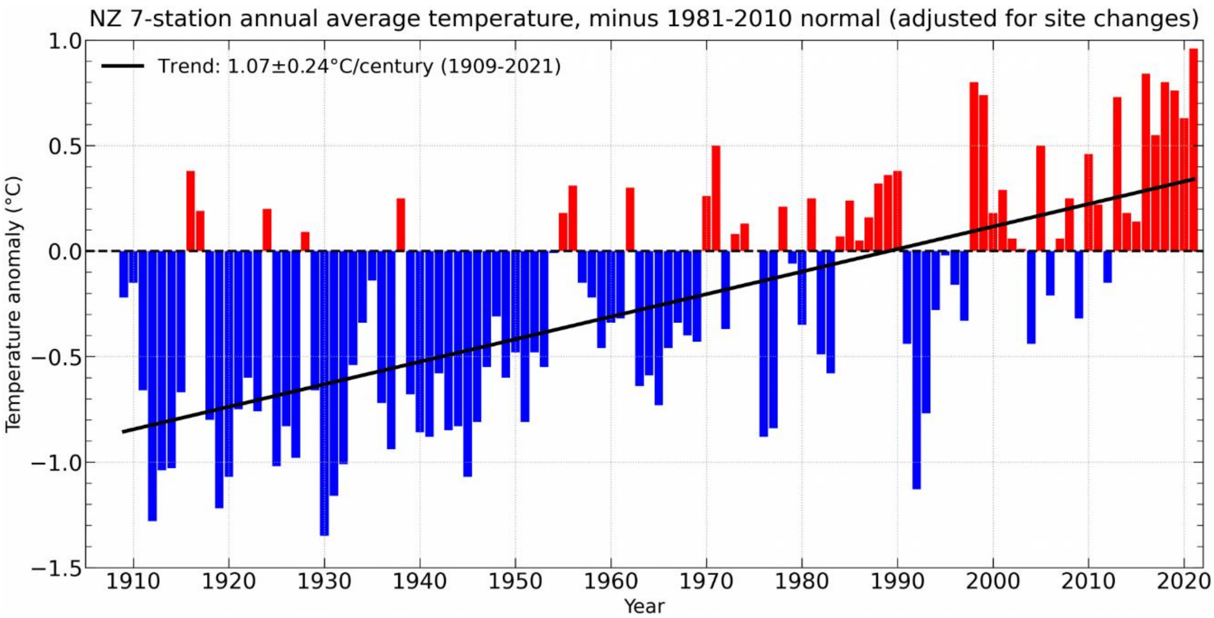

Figure 1-1: New Zealand temperature anomaly timeseries for 1909-2019. More information about the New Zealand seven-station temperature series can be found at https://niwa.co.nz/seven-stations.

Waimakariri District Council (WDC) has commissioned the National Institute of Water and Atmospheric Research (NIWA) to undertake a climate change technical report for the Waimakariri District. The report will underpin WDC's strategic planning, including a forthcoming Climate Change Risk Assessment and Climate Change Adaptation Strategy. This report is based on an earlier NIWA report examining climate change projections and impacts for the greater Canterbury Region (Macara et al., 2020). Following the publication of that report, WDC has requested an additional condensed report focussing exclusively on the climate change projections for the district. This work follows the IPCC AR6, which was published in 2021. However, NIWA has not completed regional climate projections for the AR6 and the climate projections used here are based on the IPCC Fifth Assessment Report (AR5) (IPCC, 2014). The contents of this report include analysis of climate projections for the Waimakariri District in greater detail than the Canterbury regional scale analysis.

District-scale climate projection maps have been provided for 13 different climate variables and indices. This report focuses on the changes that are likely to occur over the 21st Century to the climate of the Waimakariri District. Climatic variables covered here include air temperature, rainfall, soil moisture deficit, potential evapotranspiration deficit (a measure of drought), wind speed, solar radiation, and relative humidity. A brief commentary on climate change impacts and possible implications for the district is provided, but no formal impact and risk analyses were conducted. The report was prepared with consideration given to how findings of the report can be directly applied to a forthcoming WDC risk assessment. For more information about the wider Canterbury Region and a detailed summary of historical and future climate please see the Environment Canterbury Climate Change report (Macara et al., 2020; available here).

2 Methodology

This section outlines abridged methodological information intended to contextualise the information provided in the report. This section will outline the following: 1) representative concentration pathways, 2) modelling methodology overview, 3) how the climate maps and tabulated climate projections in this report were derived, and 4) limitations on the data presented. For a more detailed summary of climate projections and associated limitations, refer to the Ministry for the Environment climate change projections summary report (MfE, 2018; accessible here).

2.1 Representative Concentration Pathways

Assessing changes to climate due to human activity is challenging because climate projections depend strongly on future greenhouse gas concentrations. Representative concentration pathways (RCPs) are scenarios (used by the IPCC and climate scientists) that describe how atmospheric greenhouse gas (GHG) concentrations might change during the 21st Century. In this report, for brevity, we present climate projections for two commonly used RCPs: the RCP4.5 and RCP8.5 scenarios. RCP4.5 represents a moderate scenario with some stabilisation (mitigation) of GHG concentrations during the 21st Century, whereas RCP8.5 is a high-intensity scenario with no stabilisation of future GHG concentrations. RCP8.5 is a high-risk scenario, with GHG concentrations increasing at the current or an elevated future rate. The RCP8.5 projections serve the purpose of defining the likely “upper limit” of future climate warming, representing high-risk climate changes and impacts. RCP4.5 is an intermediate concentration scenario that could be a realistic outcome if global action is taken towards mitigating greenhouse gas emissions during the 21st Century. These two RCPs represent a plausible range for future global climate change. For a full summary of climate changes resulting from four separate RCPs see the full Environment Canterbury Climate Change report (Macara et al., 2020). Table 2-1 summarises IPCC AR5 projections of global mean surface air temperature change for four separate RCPs including the two covered in this report.

Note that the most recent IPCC report (AR6) has adopted Shared Socio-Economic Pathways (SSPs), which are narratives describing different global-scale socio-economic development paths that could occur. Regional climate change projections of New Zealand using the AR6 SSPs have not yet been completed but work on these is underway at NIWA (due for completion in 2024). The AR6 SSP2-4.5 and SSP5-8.5 scenarios are broadly comparable with AR5 RCP4.5 and RCP8.5 scenarios. A short commentary on the implications of AR6 for the district are provided in Section 9.

Table 2-1: Projected change in global mean surface air temperature for the mid- and late- 21st Century relative to the reference period of 1986-2005 for different RCPs. After IPCC (2014).

Scenario	2046-2065 (mid-century)		2081-2100 (end-century)	
	Mean	Likely range	Mean	Likely range
RCP2.6	1.0 °C	0.4 to 1.6 °C	1.0 °C	0.3 to 1.7 °C
RCP4.5	1.4 °C	0.9 to 2.0 °C	1.8 °C	1.1 to 2.6 °C
RCP6.0	1.3 °C	0.8 to 1.8 °C	2.2 °C	1.4 to 3.1 °C
RCP8.5	2.0 °C	1.4 to 2.6 °C	3.7 °C	2.6 to 4.0 °C

2.2 Modelling methodology

Climate information specific to the Waimakariri District is based on national scale climate modelling first published in 2016 by NIWA (MfE, 2018). These data were generated by "dynamic downscaling" of global climate model simulations referenced in the IPCC AR5. Dynamic downscaling is the process of running Regional Climate Models (RCM) on the "regional scale" (e.g., 30 km horizontal) using lateral boundary conditions taken from global climate projections at coarse resolution (e.g., 200 km). NIWA's regional climate projections of air temperature and rainfall have subsequently been bias-corrected (Sood, 2014) and all climate variables have been further downscaled to the Virtual Climate Station Network (VCSN) resolution of 5 km using physics-based semi-empirical methods (See Figure 2-1 for a graphical summary of the modelling methodology).

This dynamical downscaling method was completed with six different global climate models from the IPCC AR5. All projections presented in this report are the ensemble average of the six downscaled models. Although we focus on ensemble averages in this report, it is important to understand the uncertainty associated with dynamically downscaling different global climate model simulations and we have provided a discussion of model spread and uncertainty in Section 5. Finally, for more information on modelling methodology, please refer to NIWA's regional climate projections summary report prepared for the Ministry of the Environment (MfE, 2018).

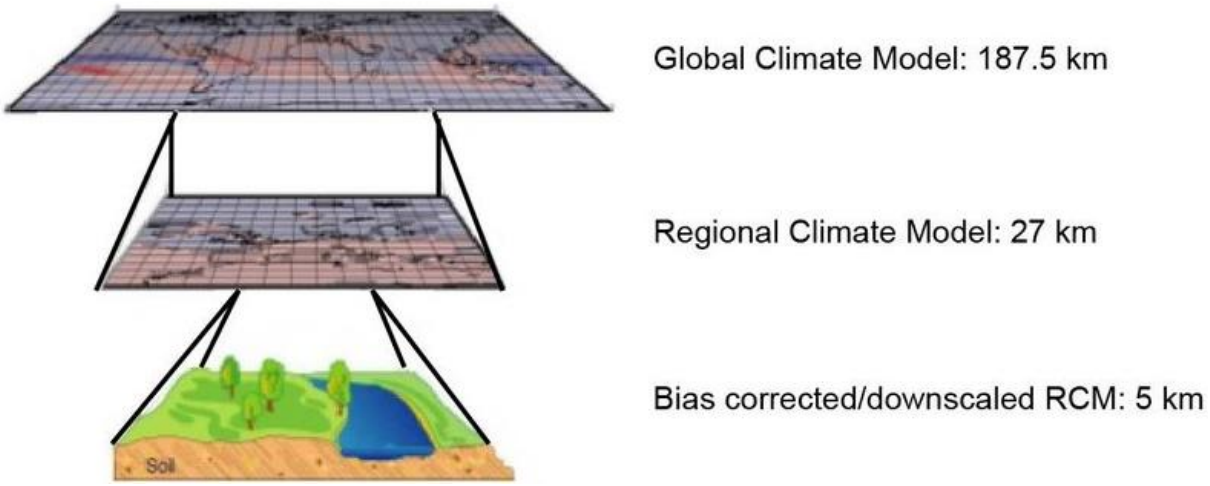

Figure 2-1: Summary of NIWA regional climate modelling methodology (Pearce et al., 2018).

2.3 Climate maps and data tabulation

The climate projections presented here are based on the same model data that were presented in the Environment Canterbury commissioned report entitled Climate Change projections for the Canterbury Region (Macara et al., 2020). This report focusses on the Waimakariri District, with climate maps produced in a way which improves visualisation of relevant variables for the district. Dynamically downscaled climate projection data are presented as 5 km x 5 km grid squares over New Zealand's land area. In some instances, where grid squares cover land and ocean, NIWA has undertaken interpolation to extend the climate projections to the coast. Nearest neighbour interpolation method was used to do this, meaning that the value of the empty coastal grid square was calculated using the value of the nearest neighbouring cells. The values at these locations are estimates generated simply for presentation purposes (i.e. not a direct output of the climate change model).

For each climate variable, we have provided summary tables to present an overview of the projected changes across sub-districts within the Waimakariri District. Additionally, in Appendix C, we provide seasonal breakdowns of projected changes in each climate variable. Changes in climate variables are calculated for two time periods – referred to as "mid-century" (2031-2050) and "end-century" (2081-2100) – relative to the 1986-2005 baseline period. These time periods are consistent with those used in the IPCC AR5. The mean changes in climate variables across three sub-district zones (shown in Figure 2-2) are provided. These sub-district scale zones include upper high elevation regions (referred to as "Upper"), lower elevation inland plains (referred to as "Inland"), and the coastal zone (referred to as "Coastal")**.** Readers of this report are referred to the limitations associated with the interpretation of data in this report found in Section 2.4. Finally, please note that the legend increments for many of the maps presented in this report are not linear. This was done to ensure the variability across the district is clearly shown.

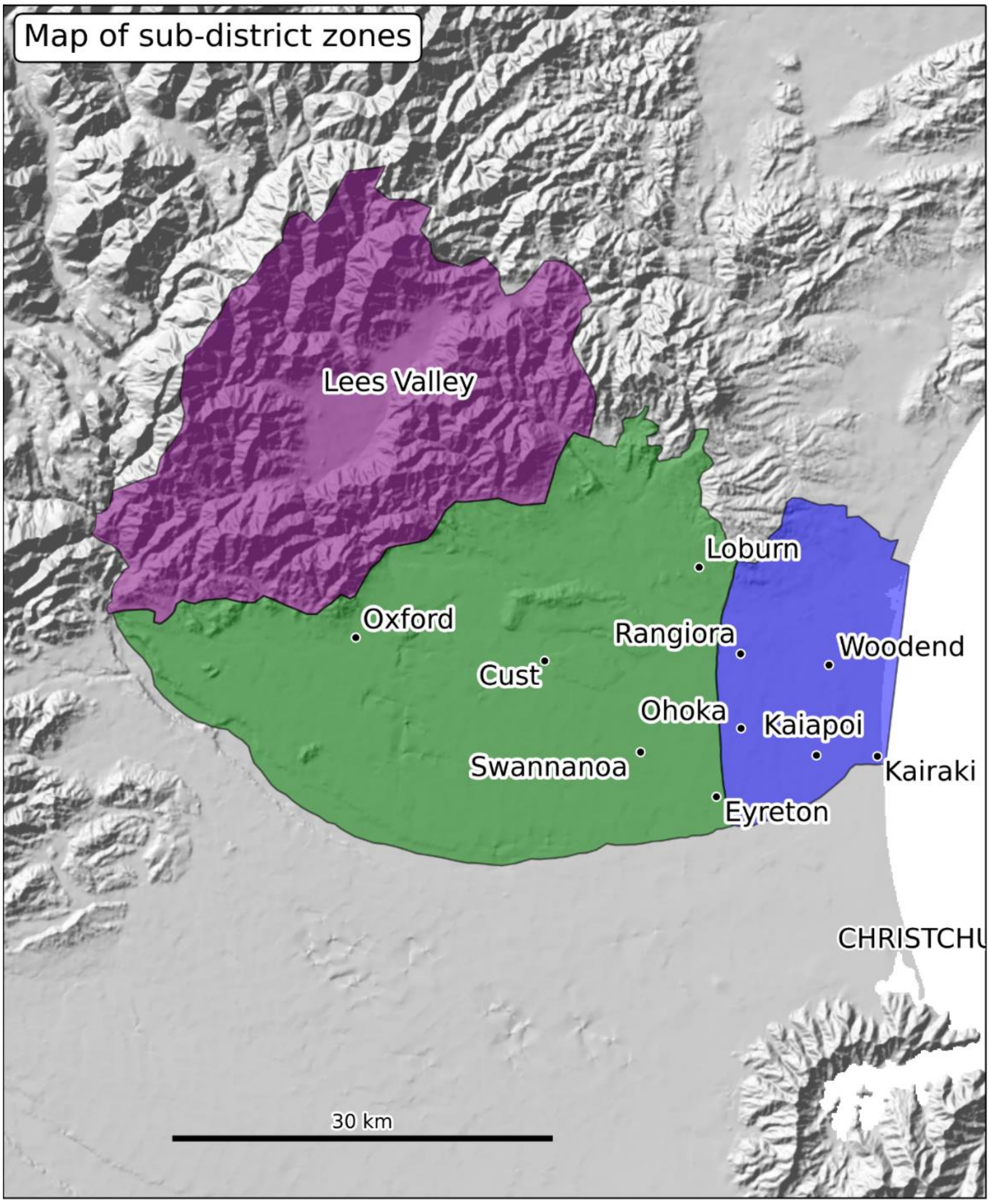

Figure 2-2: Map of sub-regional zones in Waimakariri District. Purple = "Upper", Green = "Inland", and blue = "Coastal".

2.4 Limitations

The reader should consider the following limitations and caveats when interpreting and using this report. Regional climate simulations were derived from a relatively small subset (6) of AR5 global climate model simulations due to the large computing resources required to run climate simulations. However, these six global models were carefully selected such that the historic New Zealand climate is well represented, and they span a wide range of future outcomes. The average of the six downscaled global models is used in this report; however, data from individual models is available for further assessment if required.

The time slices chosen for historical and future periods in this report are 20-years in length; this is a relatively short timeframe from a climate perspective, to capture climatologically representative conditions in the historic period and in the future periods, as there is likely an influence of underlying climate variability (e.g. decadal scale signals from climate drivers like the Interdecadal Pacific Oscillation). However, as climate data is subject to significant trends, a short period is more homogenous and representative. Moreover, the IPCC uses 20-year periods, so we have followed that approach for consistency.

Care needs to be taken when interpreting grid-point-scale projections. The data have been bias-corrected, downscaled and interpolated from the 30 km regional climate model grid to the 5 km VCSN grid across New Zealand using physically based models and interpolation (Sood, 2014). **The regional climate model bias correction and further downscaling can broadly represent the role of the Southern Alps in blocking rainfall from the Tasman Sea, and the maritime influence of the sea on temperature indices**.

Additionally, when interpreting model outputs, it is more appropriate to consider relative patterns rather than absolute values, e.g. the magnitude of change at different time periods is primarily referred to in this report. Although there are some limitations and caveats in the approach used here, considerable effort has been made to generate physically consistent climate change projections for the Waimakariri District at unprecedented temporal and spatial resolutions. **A considerable research effort has also been dedicated to validating simulated climate variables, and thus the projections provide a good basis for risk assessments and adaptation plans.**

3 Climate of Waimakariri District

Here we provide a short summary of the historical climate of the Waimakariri District. The purpose of this summary is to provide contextual information for the following technical report. For more detailed information on the historical climate of Canterbury please see the Environment Canterbury Report (Macara et al., 2020) or NIWA's summary report on the Climate and Weather of Canterbury (Macara, 2016; see here).

The Waimakariri District's climate can be broadly classified as a *Temperate Oceanic Climate,* meaning that the climate is temperate, with no dry season and a relatively warm summer. The high-altitude regions in the western parts of the district are cooler than the inland and coastal plains. These high elevation regions also receive more rainfall, snow, and frosts than the lower elevation plains of the district. Summary maps of historical climate data from model simulations are provided in Appendix A.

The district receives year-round precipitation with no strong seasonal trends. However, there is a notable difference in annual rainfall totals recorded throughout the region, with coastal areas (~680 mm annual rainfall) drier than the inland (~860 mm annual rainfall) and upper (~1020 mm annual rainfall) areas. The wetter upper part of the district also receives fewer dry days (~219 dry days per year) than the coastal zone (~263 dry days).

Weather within the district is influenced by the presence of the Southern Alps and the ocean. For example, the Southern Alps form a barrier to rain-bearing systems arriving from the west. During such events, there can be spill over rainfall that reaches western parts of the Waimakariri District region, but eastern areas towards the coast typically remain dry. The Southern Alps contribute to the development of Foehn winds. In the Waimakariri District, these winds are characterised by moderate to strong northwest winds and warm temperatures, and they are often accompanied by a *Norwest Arch* lenticular cloud formation overhead.

The ocean acts as a moderating influence on the intensity of air temperatures observed in the Waimakariri District. As a result, average winter daily minimum temperatures at coastal areas (~2.3°C) are higher than those at inland areas (~1.2°C). This is also reflected in average annual frost days, where coastal areas observe approximately 26 frost days, compared to 35 frost days at inland areas. The average summer daily maximum temperature for much of the Waimakariri District is 22.0°C, with inland and coastal areas averaging 30-32 hot days annually, while high elevation regions experience far fewer hot days (~16 hot days annually).

4 Future climate of the Waimakariri District

In this section we focus on the projected changes in a range of climate variables. Projected changes will be given for the mid-century (2031-2050) and end-century (2081-2100) time periods relative to the historical period (1986-2005). Each sub-section is structured around four key questions:

- *How much will [climate variable] change in the district?*
- *What parts of the district can expect the largest changes in [climate variable]?*
- *What is the difference in projected [climate variable] for the high concentration and moderate concentration GHG scenarios?*
- *Are there any noteworthy seasonal changes in [climate variable]?*

4.1 Air temperature

This report will consider four separate measures of air temperature:

1. The *mean air temperature* (the average temperature of air during a given time period).
2. The *mean minimum temperature*, which is the average of the daily minimum temperatures ("mean daily low").
3. The *mean maximum temperature,* which is the average of the daily maximum temperatures ("mean daily high").
4. "Hot days" defined as days where the maximum air temperature exceeds 25 °C.

4.1.1 Mean air temperature

- Mid-century mean air temperature is projected to increase by 0.8 °C (RCP4.5) to 0.9 °C (RCP8.5).
- End-century mean air temperature is projected to increase by 1.2 °C (RCP4.5) to 2.4 °C (RCP8.5) – end-century air temperature will strongly depend on GHG scenario.
- Largest increase in mean air temperature is projected in high-elevation regions.
- Changes in mean temperature are projected to be uniform across seasons.

How much will mean air temperature change in the district?

The mean mid-century air temperature in the district is predicted to increase by 0.8 °C for the moderate GHG concentration scenario and 0.9 °C for the high concentration GHG scenario. By the end of the century, mean air temperature in the district is predicted to increase by 1.2 °C for the moderate GHG concentration scenario and 2.4 °C for the high concentration GHG scenario (see district average changes in bottom row of Table 4-1).

Table 4-1: Overview of projected changes in daily mean temperature (°C) for different parts of the Waimakariri District. Mid-century = 2031-2050, end-century = 2081-2100, moderate GHGs = RCP4.5, high GHGs = RCP8.5. Note that the coloured bars are representative of the magnitude of change.

	moderate GHGs			*high GHGs*			*difference between GHG scenarios**	
ANNUAL	*mid-century*	*end-century*	*50-yr change †*	*mid-century*	*end-century*	*50-yr change†*	*mid-century*	*end-century*
UPPER	**0.8**	**1.3**	**0.5**	**0.9**	**2.5**	**1.6**	**0.1**	**1.3**
COAST	**0.7**	**1.2**	**0.4**	**0.8**	**2.4**	**1.5**	**0.1**	**1.2**
INLAND	**0.7**	**1.2**	**0.4**	**0.8**	**2.4**	**1.5**	**0.1**	**1.2**
DISTRICT	**0.8**	**1.2**	**0.4**	**0.9**	**2.4**	**1.6**	**0.1**	**1.2**

† = "50-yr change" is the projected change in average daily mean temperature for a given GHG scenario between end-century and mid-century time periods (i.e., how will average daily mean temperature change between 2040 and 2090 for a given GHG scenario?).

**The two columns on the right-hand side ("high – moderate GHGs") show the difference in projected average daily mean temperature between high and moderate GHG concentration scenarios (what is the difference in projected average daily mean temperature for the RCP4.5 and RCP8.5 scenarios?).*

What parts of the district can expect the largest changes in mean air temperature?

Shown in Table 4-1 are the projected changes in mean air temperature for the three sub-district zones. The projected increase in mean air temperature (°C) is spatially consistent within the Waimakariri District for the future time periods/GHG concentration scenarios (see Figure 4-1). Meaning that regions and settlements within the district are expected to see very similar changes in mean air temperature. These changes are consistent at the annual and seasonal time scales implying that **approximately uniform changes in air temperature are predicted across the district** and throughout the year (see Table C-1 for a seasonal summary of projected changes in air temperature). The only regional pattern worth mentioning here is that **the highest altitude regions of the district are predicted to see the largest air temperature increase with 0.5 °C more warming predicted in the mountains than the lowland plains for the high GHGs scenario**. This high-altitude warming is broadly consistent with enhanced warming trends expected throughout New Zealand's high elevation regions due to reduced snow cover.

What is the difference in projected mean temperature for the high concentration and moderate concentration GHG scenarios?

Predicted temperature changes for moderate vs. high GHG concentrations are comparable at mid-century – meaning **decision-makers can be more confident in mid-century temperature predictions**, regardless of the profile of future GHG concentration. However, this is not the case for end-of-century wherein the difference in predicted mean temperature due to high and low GHG concentration scenarios could become large. For example, **by the end of century, the district could expect an additional 1.2 ˚C of warming under the high GHG concentration scenario as compared to moderate GHG emissions** (as shown by the difference between the two right-hand panels in Figure 4-1).

Are there any noteworthy seasonal changes in mean air temperature?

The projected changes in mean air temperature in the Waimakariri District are consistent across all seasons and GHG concentration scenarios. See Table C-1 for a full breakdown.

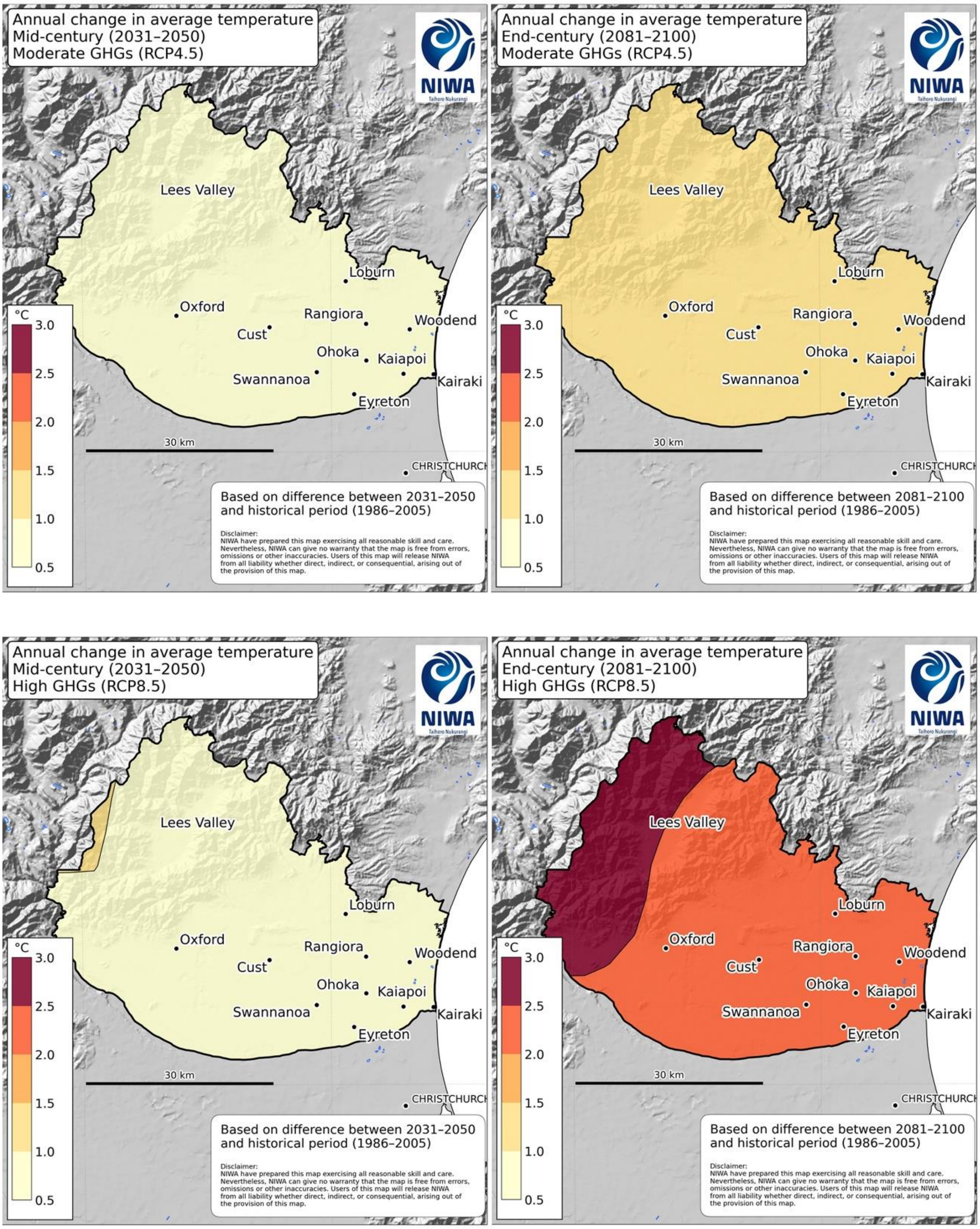

Figure 4-1: Projected changes in average daily mean air temperature (°C) for Waimakariri District. Projected changes are relative to the historic period (1986-2005).

4.1.2 Mean minimum air temperature

- Mid-century mean minimum air temperature is projected to increase by 0.5 °C for both GHG concentration scenarios.
- End-century mean minimum air temperature is projected to increase by 0.8 °C (RCP4.5) to 1.6 °C (RCP8.5).
- Changes in mean minimum air temperature are largely uniform across the district.

How much will mean minimum air temperature change in the district?

The mean minimum mid-century air temperature in the district is likely to increase in the future but by less than the mean air temperature. Warmer mean minimum air temperature suggests night-time temperatures in the district will increase as the climate warms. The district mean minimum mid-century air temperature is projected to increase by 0.5 °C for the moderate GHG concentration scenario and also 0.5 °C for the high concentration GHG scenario. By the end of the century, mean minimum air temperature in the district is predicted to increase by 0.8 °C for the moderate GHG concentration scenario and 1.6 °C for the high concentration GHG scenario (Table 4-2).

Table 4-2: Overview of projected changes in average daily minimum temperature (°C) for different parts of the Waimakariri District. Mid-century = 2031-2050, end-century = 2081-2100, moderate GHGs = RCP4.5, high GHGs = RCP8.5. Note that the coloured bars are representative of the magnitude of change.

	moderate GHGs			*high GHGs*			*difference between GHG scenarios**	
ANNUAL	*mid-century*	*end-century*	*50-yr change †*	*mid-century*	*end-century*	*50-yr change†*	*mid-century*	*end-century*
UPPER	**0.5**	**0.8**	**0.3**	**0.5**	**1.5**	**1.0**	**0.1**	**0.7**
COAST	**0.5**	**0.8**	**0.3**	**0.6**	**1.7**	**1.1**	**0.1**	**0.8**
INLAND	**0.5**	**0.8**	**0.3**	**0.6**	**1.6**	**1.0**	**0.1**	**0.8**
DISTRICT	**0.5**	**0.8**	**0.3**	**0.6**	**1.6**	**1.0**	**0.1**	**0.8**

† = "50-yr change" is the projected change in average daily minimum temperature for a given GHG scenario between end-century and mid-century time periods (i.e., how will average daily minimum temperature change between 2040 and 2090 for a given GHG scenario?).

**The two columns on the right-hand side ("high – moderate GHGs") show the difference in projected average daily minimum temperature between high and moderate GHG concentration scenarios (what is the difference in projected average daily minimum temperature for the RCP4.5 and RCP8.5 scenarios?).*

What parts of the district can expect the largest changes in mean minimum air temperature?

The projected increase in mean minimum air temperature (°C) is essentially consistent across the Waimakariri District (Figure B-1 in Appendix B).

What is the difference in projected daily mean minimum temperature for the high concentration and moderate concentration GHG scenarios?

Much like the mean air temperature the mean minimum air temperature changes for moderate vs. high GHG concentrations are similar for the mid-century time period. Yet, this is not the case for end-of-century wherein the difference in projected mean minimum air temperature due to high and low GHG concentration scenarios could be up to 0.8 °C for the district (see Table 4-2).

Are there any noteworthy seasonal changes in mean minimum air temperature?

The projected changes in mean minimum air temperature are consistent across the seasons.

4.1.3 Mean maximum air temperature

- Mid-century mean maximum air temperature is projected to increase by 1.0 °C (RCP4.5) to 1.2 °C (RCP8.5).
- End-century mean maximum air temperature is projected to increase by 1.6 °C (RCP4.5) to 3.3 °C (RCP8.5).
- The upper high elevation regions could experience the largest increase in maximum air temperature in the district.
- Changes in mean maximum air temperature are projected to be uniform across seasons.

How much will mean maximum air temperature change in the district?

The mean maximum air temperature is projected to increase by more than the mean and minimum air temperature**. This implies that the largest absolute change to the daily profile of air temperature could be reflected in higher daytime temperatures in the district**. The mean maximum mid-century air temperature in the district is predicted to increase by 1.0 °C for the moderate GHG concentration scenario and 1.2 °C for the high concentration GHG scenario. By the end of the century, mean maximum air temperature in the district is predicted to increase by 1.6 °C for the moderate GHG concentration scenario and 3.3 °C for the high concentration GHG scenario (see bottom row of Table 4-3 for district results).

What parts of the district can expect the largest changes in mean maximum air temperature?

The projected increase in mean maximum air temperature is consistent across the Waimakariri District (Figure B-2 in Appendix B). Much like the mean air temperature, regions and settlements within the district are expected to see similar changes in mean maximum air temperature during the 21st Century. **The upper high elevation regions could experience the largest increase in maximum air temperature,** with maximum temperatures projected to increase by 0.5 °C more than lowland plains under the high GHG scenario.

Table 4-3: Overview of projected changes in average daily maximum temperature (°C) for different parts of the Waimakariri District. Mid-century = 2031-2050, end-century = 2081-2100, moderate GHGs = RCP4.5, high GHGs = RCP8.5. Note that the coloured bars are representative of the magnitude of change.

	moderate GHGs			*high GHGs*			*difference between GHG scenarios**	
ANNUAL	*mid-century*	*end-century*	*50-yr change †*	*mid-century*	*end-century*	*50-yr change†*	*mid-century*	*end-century*
UPPER	**1.1**	**1.7**	**0.6**	**1.3**	**3.5**	**2.3**	**0.1**	**1.8**
COAST	**1.0**	**1.5**	**0.5**	**1.1**	**3.0**	**2.0**	**0.1**	**1.6**
INLAND	**1.0**	**1.6**	**0.6**	**1.1**	**3.2**	**2.1**	**0.1**	**1.6**
DISTRICT	**1.0**	**1.6**	**0.6**	**1.2**	**3.3**	**2.1**	**0.1**	**1.7**

† = "50-yr change" is the projected change in average daily maximum temperature for a given GHG scenario between end-century and mid-century time periods (i.e., how will average daily maximum temperature change between 2040 and 2090 for a given GHG scenario?).

**The two columns on the right-hand side ("high – moderate GHGs") show the difference in projected average daily maximum temperature between high and moderate GHG concentration scenarios (what is the difference in projected average daily maximum temperature for the RCP4.5 and RCP8.5 scenarios?).*

What is the difference in projected daily mean maximum temperature for the high concentration and moderate concentration GHG scenarios?

Much like the mean air temperature, the mean maximum air temperature changes for moderate vs. high GHG concentrations are comparable for the mid-century time period, and quite different by the end of the century. For example, **by the end of century, the district could expect an additional 1.7 °C of warming to the mean maximum air temperature under the high GHG concentration scenario as compared to moderate GHG emissions (as shown in Table 4-3 and Figure B-2, Appendix B).**

Are there any noteworthy seasonal changes in mean air temperature?

The projected changes in mean maximum air temperature in the Waimakariri District are consistent across all seasons and GHG concentration scenarios. See Table C-3 for a full summary.

4.1.4 Hot days

Hot days are defined as any day when the maximum air temperature exceeds 25 °C. This threshold has been used historically in New Zealand to define conditions when humans and livestock may experience heat stress.

- Mid-century hot days are projected to increase by 13 (RCP4.5) to 15 (RCP8.5) days per year.
- End-century hot days are expected to increase by 20 (RCP4.5) to 44 (RCP8.5) days per year.
- 44 additional hot days would represent a tripling of historical hot days for the district on average.
- Hot days in the Lees Valley and western plains could see the largest increase by the end of century with upwards of 50 additional hot days projected per year.

How much will hot days change in the district?

By the mid-century the district is projected to experience an additional 13 to 15 hot days per year for moderate and high GHG concentration scenarios, respectively. **Therefore, mid-century hot days are projected to double from historical levels. End-century hot days are projected to increase by 20 and 44 days for the moderate and high GHG concentration scenarios, respectively** (Table 4-4); 44 additional hot days would represent a threefold increase in hot days for the district on average.

Table 4-4: Overview of projected changes in hot days (> 25 °C) per year for different parts of the Waimakariri District. Mid-century = 2031-2050, end-century = 2081-2100, moderate GHGs = RCP4.5, high GHGs = RCP8.5. Note that the coloured bars are representative of the magnitude of change.

	moderate GHGs			*high GHGs*			*difference between GHG scenarios**	
ANNUAL	*mid-century*	*end-century*	*50-yr change †*	*mid-century*	*end-century*	*50-yr change†*	*mid-century*	*end-century*
UPPER	**12**	**18**	**6**	**13**	**43**	**30**	**1**	**25**
COAST	**13**	**20**	**7**	**15**	**41**	**26**	**2**	**21**
INLAND	**15**	**22**	**7**	**17**	**46**	**29**	**2**	**24**
DISTRICT	**13**	**20**	**7**	**15**	**44**	**29**	**1**	**24**

† = "50-yr change" is the projected change in hot days for a given GHG scenario between end-century and mid-century time periods (i.e., how will hot days change between 2040 and 2090 for a given GHG scenario?).

**The two columns on the right-hand side ("high – moderate GHGs") show the difference in projected hot days between high and moderate GHG concentration scenarios (what is the difference in projected hot days for the RCP4.5 and RCP8.5 scenarios?).*

What parts of the district can expect the largest changes in hot days?

The number of hot days mirrors the mean temperature changes outlined above in the sense that hot days are projected to increase relatively consistently across the district (see Figure 4-2). **The Lees Valley and western and central areas near Oxford could see the largest increase in hot days by the end of century with upwards of 50 additional hot days projected per year.**

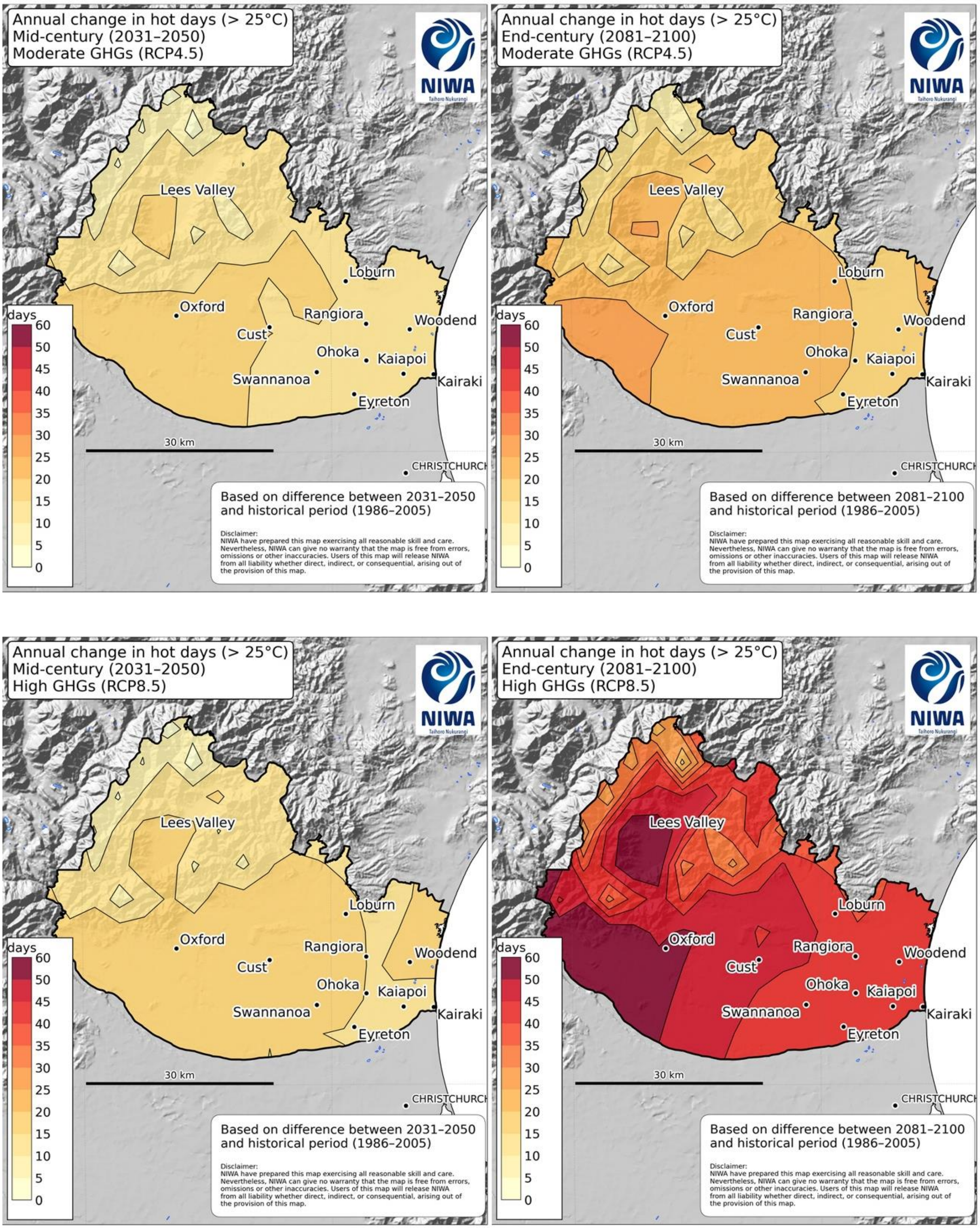

Figure 4-2: Projected changes in hot days (> 25 °C) per year for Waimakariri District. Projected changes are relative to the historic period (1986-2005).

What is the difference in projected hot days for the high concentration and moderate concentration GHG scenarios?

For the mid-century period the difference in hot days between moderate and high GHG concentration scenarios is negligible. However, by the end of the century, the difference between high and moderate GHG scenarios is substantial with more than double the number of additional hot days under the high GHG concentration scenario. This finding emphasises that different concentration pathways could produce *quite different climatic outcomes* in the district, especially towards the end of the 21st Century. For projecting hot days, the impact of GHG concentration uncertainty becomes a lot larger towards the end of century.

Are there any noteworthy seasonal changes in hot days?

The majority (~75%) of projected additional hot days (i.e., the projected increase) are likely occur in summer (see Table C-4 for seasonal breakdown). Hot days in autumn and spring are relatively rare in the district with ~6 per year in spring and autumn, historically. Projections suggest spring and autumn hot days could become much more frequent with upwards of ~20 spring and autumn hot days per year by the end of century expected under the high concentration GHG scenario.

4.2 Rainfall

4.2.1 Mean rainfall

- Mid-century rainfall is projected to increase for both RCP 4.5 and RCP 8.5.
- Increased rainfall is projected across the lower altitude plains and coastal areas, and *no change (or slight decreases)* in annual rainfall are projected in the western high-altitude zones.
- Seasonal trends in projected rainfall change are broadly consistent with the annual change, except spring which has inconsistencies in spatial pattern and the ± change signal.

Rising global temperatures are expected to increase average annual precipitation, according to the AR6 IPCC report: “*The average annual global land precipitation is projected to increase by 0–5% under the very low GHG emissions scenario (SSP1-1.9), 1.5–8% for the intermediate GHG emissions scenario (SSP2-4.5) and 1–13% under the very high GHG emissions scenario (SSP5-8.5) by 2081–2100 relative to 1995–2014 (likely ranges)”.*

How much will mean annual rainfall change in the district?

Rainfall is projected to increase across much of the district in the mid-century and end-century time periods for both GHG concentration scenarios (Table 4-5). However, the upper regions are projected to experience a smaller increase (or decrease) in annual rainfall than the lower elevation regions.

Table 4-5: Overview of projected changes in mean annual rainfall for different parts of the Waimakariri District. Mid-century = 2031-2050, end-century = 2081-2100, moderate GHGs = RCP4.5, high GHGs = RCP8.5. Note that the coloured bars are representative of the magnitude of change.

	moderate GHGs			*high GHGs*			*difference between GHG scenarios**	
ANNUAL	*mid-century*	*end-century*	*50-yr change †*	*mid-century*	*end-century*	*50-yr change†*	*mid-century*	*end-century*
UPPER	**1.6%**	**0.8%**	**-0.8%**	**1.3%**	**3.0%**	**1.7%**	**-0.3%**	**2.2%**
COAST	**2.6%**	**4.2%**	**1.5%**	**3.4%**	**8.2%**	**4.9%**	**0.7%**	**4.1%**
INLAND	**2.5%**	**3.1%**	**0.6%**	**3.0%**	**7.6%**	**4.6%**	**0.5%**	**4.5%**
DISTRICT	**2.2%**	**2.4%**	**0.2%**	**2.4%**	**5.9%**	**3.5%**	**-0.2%**	**1.8%**

† = "50-yr change" is the projected change in mean annual rainfall for a given GHG scenario between end-century and mid-century time periods (i.e., how will mean annual rainfall change between 2040 and 2090 for a given GHG scenario?).

**The two columns on the right-hand side ("high – moderate GHGs") show the difference in projected mean annual rainfall between high and moderate GHG concentration scenarios (what is the difference in projected mean annual rainfall for the RCP4.5 and RCP8.5 scenarios?).*

What parts of the district can expect the largest changes in mean annual rainfall?

The general trend in annual precipitation change follows an east-to-west gradient, with projected increased rainfall across the lower altitude plains and coastal areas (shown by the green colours in Figure 4-3), and *no change (or slight decreases)* in rainfall in the western high-altitude regions and Lees Valley (show by the brown and absence of colour in Figure 4-3). **The largest increases in mean annual rainfall of +12% or more are projected under the end-century, high GHG scenario along the southern edge of the district (west of Swannanoa) and along the north-east edge of the district (near Loburn).**

What is the difference in projected rainfall for the high concentration and moderate concentration GHG scenarios?

In general, the district can expect more annual precipitation under the high GHG concentration scenario than the moderate scenario (Table 4-5). This is consistent with IPCC guidance (outlined pg. 51) as warmer oceans can evaporate more moisture into the atmosphere, and NIWA's AR5 regional climate modelling that showed a possible strengthening of southern hemisphere storm tracks. **This trend of increasing rainfall for the higher concentration GHG scenario is also apparent in the seasonal rainfall change projections, with increased total rainfall projected in the future for nearly all instances except notably spring** (see seasonal data in Table C-5). End-century spring rainfall is projected to *decrease* under the moderate GHG concentration scenario.

Are there any noteworthy seasonal changes in rainfall?

As mentioned above predicted changes to mean spring rainfall are inconsistent in spatial pattern and signal (i.e., positive vs. negative changes) when comparing across GHG concentration scenarios and time periods (observe that the top right panel in Figure B-6 is different to the other panels). Further investigation of the model spread (i.e., not just the 6-model ensemble mean rainfall) could be worthwhile in order to better understand the uncertainties associated with changing seasonal precipitation in the district (this issue is discussed further in Section 5).

The aforementioned east-west gradient of projected rainfall change is most apparent in autumn and summer (see Figure B-3-B.6 for seasonal maps of projected rainfall changes). Finally, for winter rainfall, projections suggest an increase in rain across the upper and coastal regions – while the central parts of the district (near Cust) may see a decrease in winter rainfall (Figure B-5).

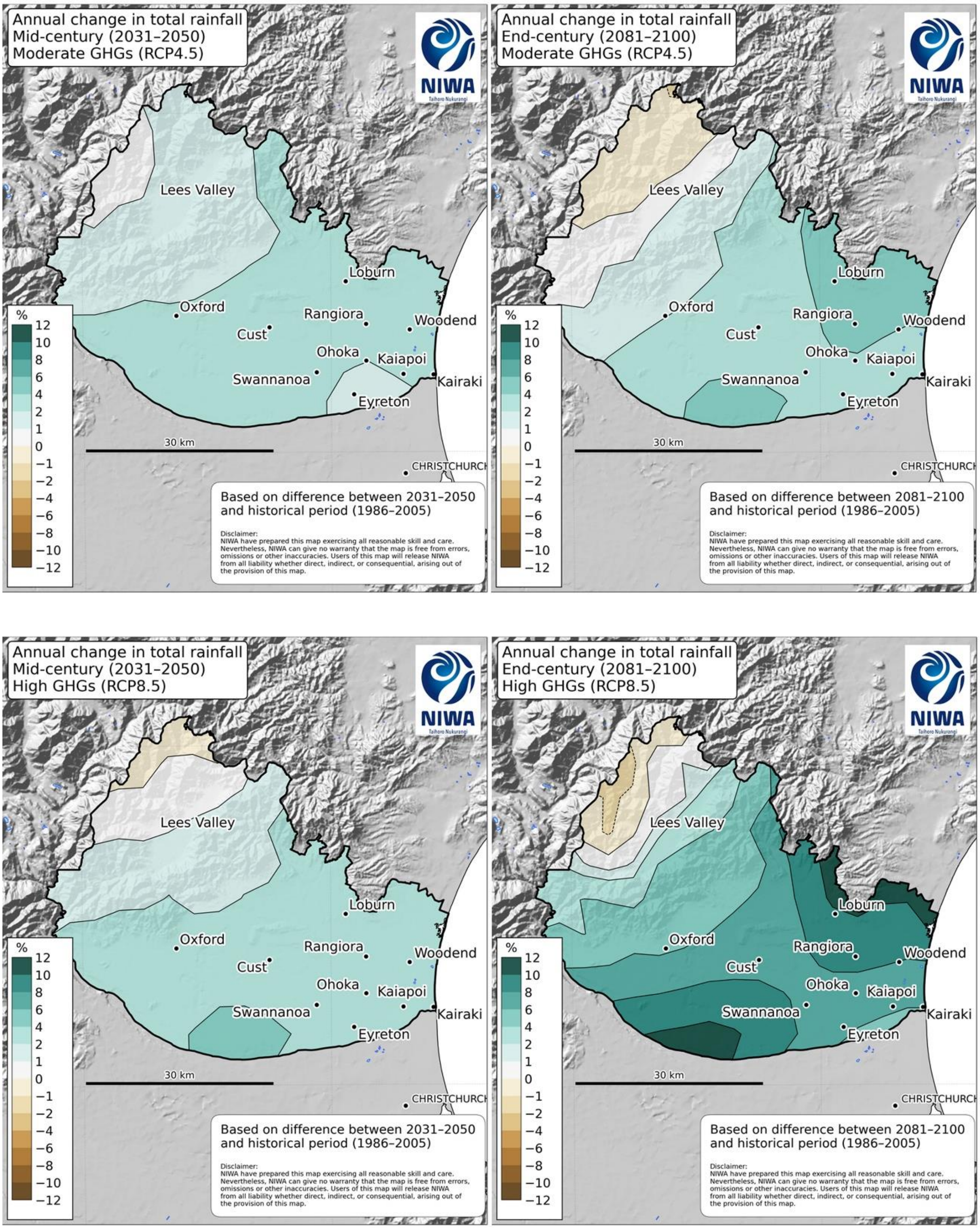

Figure 4-3: Projected changes in mean annual rainfall (%) for Waimakariri District. Projected changes are relative to the historic period (1986-2005).

4.2.2 Dry days

- Dry days are projected to increase slightly in the upper elevations and decrease in the coastal regions and inland plains.
- Inland and coastal areas are projected to experience the largest decreases in dry days – under the high GHG scenario those areas are projected to experience 4 to 5 fewer dry days per year by the end of the century.
- Under the high GHG scenario, the projected reductions in dry days will primarily occur in summer and autumn.

Another metric for evaluating changes in rainfall are "dry days", which are defined as any day where less than 1 mm of rainfall occurs.

What parts of the district can expect the largest changes in dry days?

Similar to the projected change to total annual rainfall, changes in dry days throughout the district will likely follow the east-west gradient with slight *increases* in dry days in the upper high elevation areas and decreases in dry days in the lowland and coastal areas (Figure 4-4). Inland and coastal areas are projected to see the largest decreases in dry days under the high GHG concentrations scenario with 4 to 5 fewer dry days per year by the end of the century.

Table 4-6: Overview of projected changes in dry days (< 1 mm rain) per year for different parts of the Waimakariri District. Mid-century = 2031-2050, end-century = 2081-2100, moderate GHGs = RCP4.5, high GHGs = RCP8.5. Note that the coloured bars are representative of the magnitude of change.

	moderate GHGs			*high GHGs*			*difference between GHG scenarios**	
ANNUAL	*mid-century*	*end-century*	*50-yr change †*	*mid-century*	*end-century*	*50-yr change†*	*mid-century*	*end-century*
UPPER	1	2	2	1	1	0	0	-1
COAST	-1	-2	-1	-2	-4	-2	-1	-3
INLAND	-2	-1	0	-3	-5	-3	-1	-4
DISTRICT	-1	0	1	-1	-3	-1	-1	-3

† = "50-yr change" is the projected change in dry days for a given GHG scenario between end-century and mid-century time periods (i.e., how will dry days change between 2040 and 2090 for a given GHG scenario?).

** The two columns on the right-hand side ("high – moderate GHGs") show the difference in projected dry days between high and moderate GHG concentration scenarios (what is the difference in projected dry days for the RCP4.5 and RCP8.5 scenarios?).*

What is the difference in projected dry days for the high concentration and moderate concentration GHG scenarios?

Overall, the projections show there will be slightly more dry days per year under the under high GHG scenario than the low GHG scenario, especially at the end of century (as shown by a larger decrease in dry days under high GHG concentrations than low GHG concentrations).

Are there any noteworthy seasonal changes in dry days?

The modest reduction in dry days across the district is primarily projected to occur in summer and autumn (see Table C-6 for seasonal breakdown of projected changes in dry days).

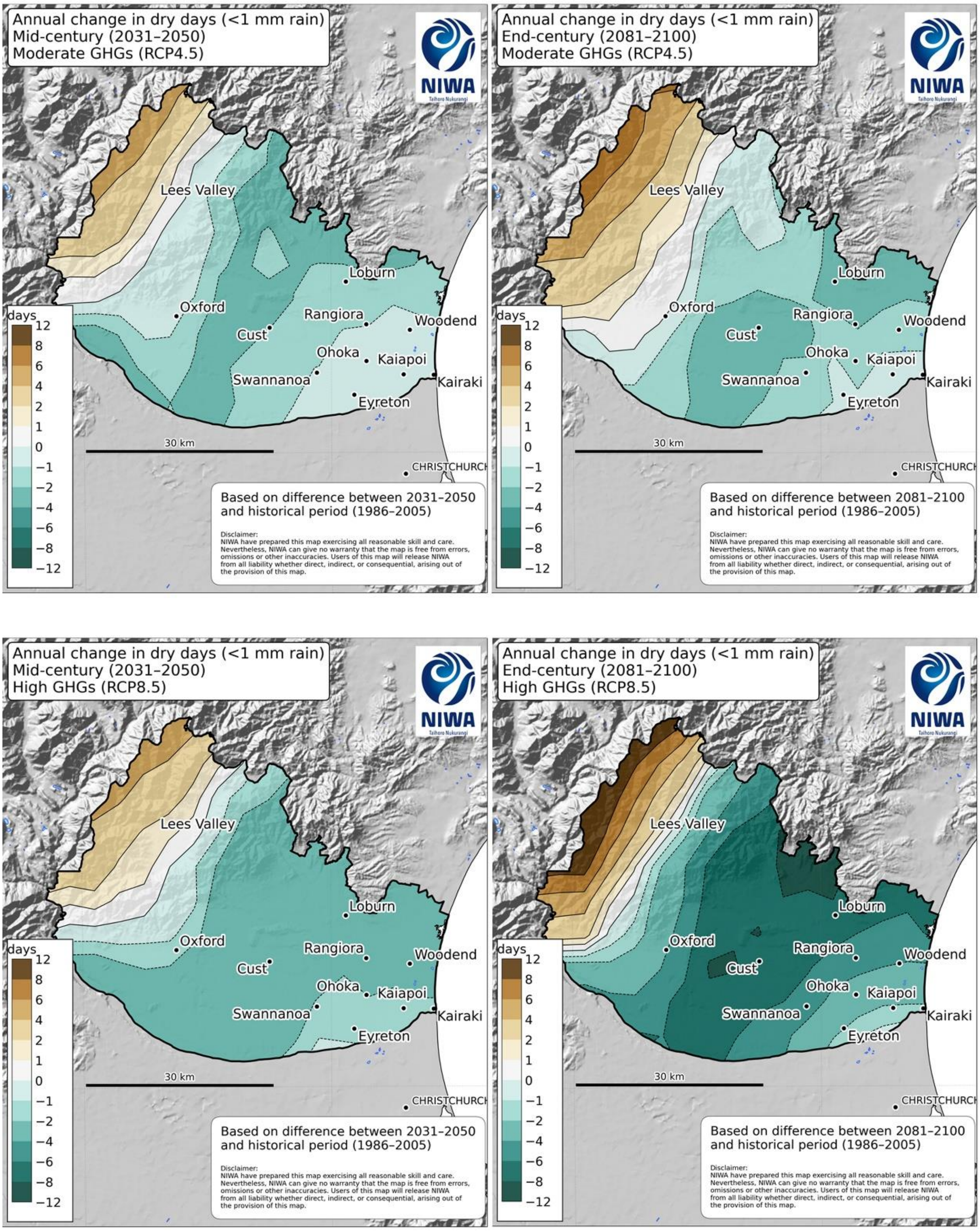

Figure 4-4: Projected changes in dry days for Waimakariri District. Projected changes are relative to the historic period (1986-2005).

4.2.3 Extreme heavy rainfall

- Extreme rainfall will likely increase by approximately 7% per 1 °C of climate warming.
- However, shorter duration rainfall events (e.g., hourly) could increase by as much as 15% per 1 °C of climate warming.
- Further research and modelling are needed to further explain the impacts of climate change on extreme precipitation.

The impacts of climate change on rare meteorological events such as extreme rainfall is extremely challenging for climate scientists to characterise. For this reason, this report (and the Canterbury Region Report) primarily focus on the projected average changes in climatic means rather than changes to the extreme events. Nevertheless, extreme rainfall can result in significant hazards such as flooding and landslides. A full analysis of the implications of climate change for extreme rainfall is outside the scope of this report. However, given the importance of extreme rainfall and potential flooding to the district some high-level findings from NIWA's High-intensity Rainfall Design System (HIRDS; Carey-Smith, et al. 2018, see full report here) are provided Appendix E to give an indication of how extreme precipitation could change in the Waimakariri District.

As noted above in Section 4.2.1 there is likely to be an increase in rainfall across New Zealand and in the Waimakariri District overall. However, the extent to which extreme precipitation will change due to climate change in New Zealand and globally is a matter of ongoing research. According to the AR6, there is "high confidence" that extreme precipitation will increase in intensity by about 7% per 1 °C of climatic warming. However, there is growing evidence the most extreme precipitation events, including sub-daily (i.e., less than 24 hrs) events, could increase by more than 7% per 1 °C of warming.

Figure 4-5 shows the possible change in rainfall across New Zealand per 1 °C of climatic warming associated with 50-year events of different durations. The Figure shows that a 1-in-50-year event of duration 1 hr could increase in intensity by ~10-15% per 1 °C of warming; and that a 1-in-50-year event of duration 24 hrs might increase by ~5-10% per 1 °C of warming. **Overall, it is likely that extreme events in the district will intensify by at least 7% per 1 °C of warming, but it also quite possible that damaging short duration storm events will intensify by more than 7% per 1 °C in future.** Projections of future extreme precipitation for the district can be accessed through the HIRDS online portal (https://hirds.niwa.co.nz/) and summary tables for locations of interest are provided in Appendix E.

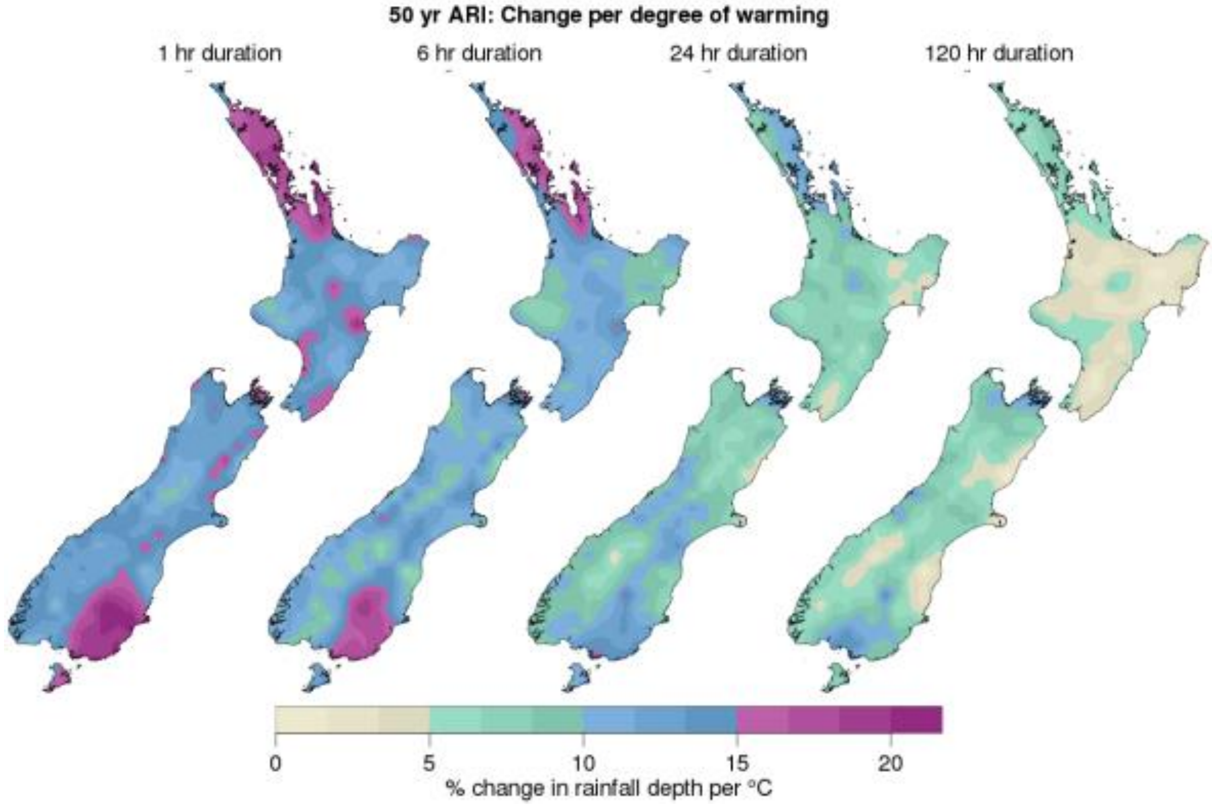

Figure 4-5: Percentage changes in the 50-year event magnitude for four different event durations. Each map combines all 24 different RCM simulations and shows the change per degree of warming. ARI indicates the average time between events of given duration (source: Carey-Smith et al., 2018).

4.3 Soil moisture and potential evaporation

4.3.1 Soil moisture deficit days

- Mid-century soil moisture deficit days are projected to *decrease* by 2 (RCP8.5) to 5 (RCP4.5) days per year.
- End-century soil moisture deficit days are expected to *increase* by 3 (RCP4.5) to 2 (RCP8.5) days per year.
- Mid-century soil moisture deficit days will likely decrease consistently across the district.
- End-century soil moisture deficit days will likely increase consistently across the district, except in the coastal zone and higher elevation regions.

Soil moisture deficit is calculated based on incoming daily rainfall (mm), outgoing daily potential evapotranspiration (mm), and a fixed available water capacity (the amount of water in the soil 'reservoir' that plants can use). Soil moisture deficit days are days when a moisture deficit occurs, and it is a commonly used indicator of days when plants are water-stressed.

How much will soil moisture deficit days change in the district?

Soil moisture deficit days are projected to decrease by mid-century across the district with net changes of -5 and -2 days for the moderate and high GHG concentration scenarios, respectively (Table 4-7). By contrast, projections suggest there will be more soil moisture deficit days in the district by the end of the century with +3 and +2 soil moisture deficit days for moderate and high GHG scenarios, respectively. **These results imply that for both GHG concentration scenarios the Waimakariri District is projected on average to have moister soil conditions in the mid-century and drier soil conditions by the end-century, but the changes are quite small.**

Table 4-7: Overview of projected changes in soil moisture deficit days per year for different parts of the Waimakariri District. Mid-century = 2031-2050, end-century = 2081-2100, moderate GHGs = RCP4.5, high GHGs = RCP8.5. Note that the coloured bars are representative of the magnitude of change.

	moderate GHGs			*high GHGs*			*difference between GHG scenarios**	
ANNUAL	*mid-century*	*end-century*	*50-yr change †*	*mid-century*	*end-century*	*50-yr change†*	*mid-century*	*end-century*
UPPER	-4	4	8	-2	5	7	2	1
COAST	-6	3	9	-2	-1	1	4	-4
INLAND	-5	2	7	-3	2	5	2	-1
DISTRICT	-5	3	8	-2	2	5	2	-1

† = "50-yr change" is the projected change in soil moisture deficit days for a given GHG scenario between end-century and mid-century time periods (i.e., how will soil moisture deficit days change between 2040 and 2090 for a given GHG scenario?).

**The two columns on the right-hand side ("high – moderate GHGs") show the difference in projected soil moisture deficit days between high and moderate GHG concentration scenarios (what is the difference in projected soil moisture deficit days for the RCP4.5 and RCP8.5 scenarios?).*

What parts of the district can expect the largest changes in soil moisture deficit days?

The spatial patterns of changing soil moisture deficit days are quite consistent across the district for mid-century and end of century time periods (see Figure 4-6). The two panels on the left show decreasing (green) soil deficit moisture days for the mid-century, and the right panels show increasing (brown) soil moisture deficit days across most of the district at the end of the century.

What is the difference in projected soil moisture deficit days for the high concentration and moderate concentration GHG scenarios?

As mentioned above, the projected change in soil moisture deficit days is comparable when comparing GHG concentration scenarios.

Are there any noteworthy seasonal changes in soil moisture deficit?

For mid-century, there is no clear seasonal pattern and projected reductions in soil moisture deficit days will occur throughout the year. At the end of the century, soil moisture deficit days will likely increase in the winter and spring seasons (see Table C-7 for seasonal breakdown of soil moisture deficit days).

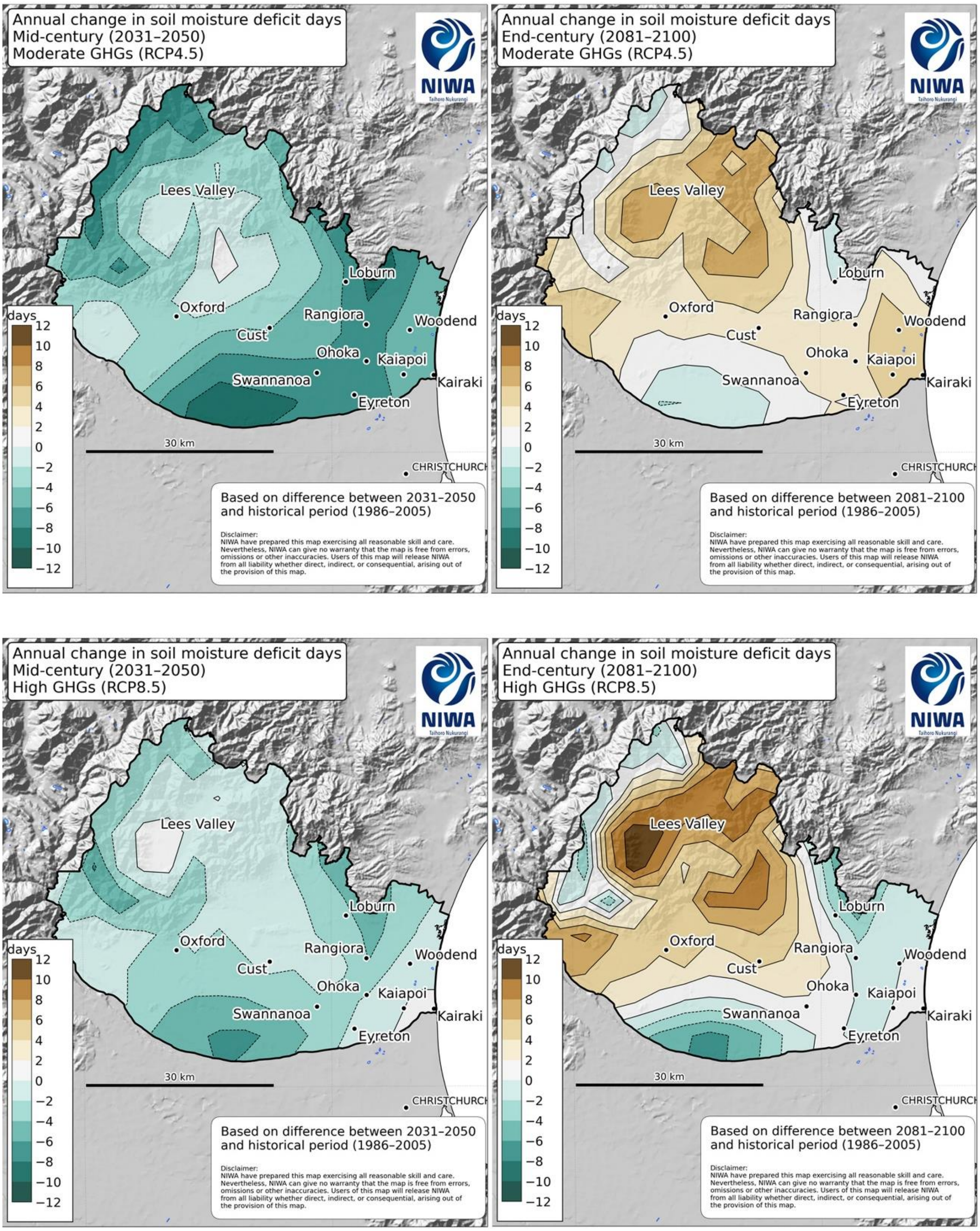

Figure 4-6: Projected changes in soil moisture deficit days for Waimakariri District. Projected changes are relative to the historic period (1986-2005).

4.3.2 Potential evapotranspiration deficit

- Mid-century accumulated potential evaporation deficit is projected to increase by 75.7 mm (RCP8.5) to 91.2 mm (RCP4.5).
- End-century accumulated potential evaporation deficit is expected to increase by 88.9 mm (RCP4.5) to 97.6 mm (RCP8.5).
- Upper mountainous regions and the Lees valley may see an increase in PED of approximately 15-30 mm greater than the lowland plains

Potential evapotranspiration (PET) is the anticipated amount of water that will evaporate and/or be transpired if a sufficient water source is available. The difference between potential evapotranspiration (PET) and actual evapotranspiration is called the Potential Evapotranspiration Deficit (PED). In practice, PED characterizes the amount of water required for irrigation, or that needs to be replenished by rainfall, to maintain plant growth at levels unimpeded by soil water shortage. Therefore, PED estimates provide a robust measure of drought intensity and duration. The accumulated PED is the sum of daily PED values throughout the year.

How much will potential evapotranspiration deficit change in the district?

PED is projected to increase across the district regardless of location within the district, GHG concentration scenario, and time period. The mid-century time period will see district average PED increase by 91.2 mm and 75.7 mm for the GHG scenarios, and end-century PED will increase by 88.9 mm and 97.6 mm (Table 4-8). **Increased PED across the entire Waimakariri District suggests the district will likely become more drought prone in the future as temperatures increase and precipitation changes.**

Increased PED across the district implies that increased temperatures and associated increased evapotranspiration will not be offset by increased rainfall across the district, meaning that demand for irrigation may increase in the district despite an overall increase in annual rainfall projected.

What parts of the district can expect the largest changes in potential evapotranspiration deficit?

Overall, the predicted increase in PED across the district is spatially consistent, however, the upper mountainous regions and the Lees valley may see an increase in PED of approximately 15-30 mm greater than the in lowland plains (Figure B-7).

Table 4-8: Overview of projected changes in potential evapotranspiration deficit accumulated (mm) for different parts of the Waimakariri District. Mid-century = 2031-2050, end-century = 2081-2100, moderate GHGs = RCP4.5, high GHGs = RCP8.5. Note that the coloured bars are representative of the magnitude of change.

	moderate GHGs			*high GHGs*			*difference between GHG scenarios**	
ANNUAL	*mid-century*	*end-century*	*50-yr change †*	*mid-century*	*end-century*	*50-yr change†*	*mid-century*	*end-century*
UPPER	**101.4**	**104.5**	**3.1**	**85.4**	**120.1**	**34.7**	**-15.9**	**15.6**
COAST	**86.8**	**77.8**	**-9.1**	**73.3**	**87.7**	**14.5**	**-13.6**	**9.9**
INLAND	**82.7**	**77.2**	**-5.4**	**66.9**	**78.4**	**11.6**	**-15.8**	**1.2**
DISTRICT	**91.2**	**88.9**	**-2.3**	**75.7**	**97.6**	**21.9**	**-15.5**	**8.8**

† = "50-yr change" is the projected change in potential evapotranspiration deficit accumulated for a given GHG scenario between end-century and mid-century time periods (i.e., how will potential evapotranspiration deficit accumulated change between 2040 and 2090 for a given GHG scenario?).

**The two columns on the right-hand side ("high – moderate GHGs") show the difference in potential evapotranspiration deficit accumulated between high and moderate GHG concentration scenarios (what is the difference in potential evapotranspiration deficit accumulated for the RCP4.5 and RCP8.5 scenarios?).*

What is the difference in projected potential evapotranspiration deficit for the high concentration and moderate concentration GHG scenarios?

There is not a large difference in projected PED when comparing moderate and high concentration scenarios (see Table 4-8 and Figure B-7).

4.4 Snow and frost

- Mid-century frost days are projected to decrease by 9 (RCP4.5) to 14 (RCP8.5) days per year.
- End-century frost days are projected to decrease by 10 (RCP4.5) to 26 (RCP8.5) days per year.
- Frost days will likely reduce across the district but the largest reductions in total days are projected in the upper high-altitude regions and Lees Valley.
- For the high GHG scenario end-of century snow days in the mountainous regions could be nearly eliminated according to projections.

4.4.1 Frost

Frost days are defined as days when minimum air temperature is equal to or lower than 0 °C.

How much will frost days change in the district?

Mid-century frost days are projected to decrease by 9 and 14 days per year across the district for moderate and high GHG concentration scenarios, respectively. While, end-century frost days could decrease by 10 and 26 days for moderate and high GHGs, respectively (Table 4-9).

Table 4-9: Overview of projected changes in frost days for different parts of the Waimakariri District. Mid-century = 2031-2050, end-century = 2081-2100, moderate GHGs = RCP4.5, high GHGs = RCP8.5. Note that the coloured bars are representative of the magnitude of change.

	moderate GHGs			*high GHGs*			*difference between GHG scenarios**	
ANNUAL	*mid-century*	*end-century*	*50-yr change †*	*mid-century*	*end-century*	*50-yr change†*	*mid-century*	*end-century*
UPPER	-12	-18	-6	-13	-34	-21	-1	-16
COAST	-6	-8	-2	-7	-16	-9	-1	-7
INLAND	-8	-12	-4	-9	-21	-12	-1	-10
DISTRICT	-9	-14	-5	-10	-26	-15	-1	-12

† = "50-yr change" is the projected change in frost days for a given GHG scenario between end-century and mid-century time periods (i.e., how will frost days change between 2040 and 2090 for a given GHG scenario?).

**The two columns on the right-hand side ("high – moderate GHGs") show the difference in frost days between high and moderate GHG concentration scenarios (what is the difference in projected frost days for the RCP4.5 and RCP8.5 scenarios?).*

What parts of the district can expect the largest changes in frost days?

Frost days are projected to reduce across the district but the largest reductions in total days are projected to occur in the upper high-altitude regions and Lees Valley (Figure 4-7). For the moderate GHG scenario, projections suggest that up to 33% of historical frost days may no longer occur in the inland parts of the district. For the high concentration GHG scenarios upwards of ~43% of historical frost days in the high elevation region could no longer happen, and 60% of historical frost days in the low elevation regions could no longer happen.

What is the difference in projected frost days for the high concentration and moderate concentration GHG scenarios?

For the mid-century period the difference in frost days between moderate and high GHG concentration scenarios is relatively small (5 days); however, this represents a larger mid-century difference than other variables (e.g., air temperature) when comparing high vs low GHG scenarios. This implies that a threshold driven metric like frost days could be more sensitive to subtle temperature changes - meaning that relatively large differences in projected frost could occur even if the mean temperature does not change substantively.

By the end of the century, the difference between high and moderate GHG scenarios could be substantial with a more than a twofold reduction in the number of frost days under the high GHG concentration scenario. This finding emphasises that different concentration pathways could produce *quite different climatic outcomes* across the district, especially towards the end of the 21st Century. When projecting frost days, the effect of GHG concentration uncertainty becomes a lot larger towards the end of century.

Are there any noteworthy seasonal changes to frost days?

At the seasonal level, 66% of the district's projected lost frost days (i.e., the projected decrease) are projected to be during winter. The other absent frost days are projected to be during Autumn (19%) and Spring (15%).

4.4.2 Snow

Snow days are defined in these projections as days when the air temperature is below zero and precipitation occurs.

Snow days will likely decrease substantially (upwards of 20 fewer days per year) across the higher elevation regions of the district (Figure 4-8). For the high concentration GHG scenario, end-of century snow days in the mountainous regions could be nearly eliminated according to projections. However, it is important to note that snow day projections are simply reported as days when temperature is below zero and precipitation occurs, but snow can fall when temperature is above zero so there is likely some underestimation of snow days. Also, it is important to note that the metric "snow days" is not the same as "snow amount" – snow amount could increase due to increasing precipitation in mountainous areas. Nevertheless, despite these caveats, it is very likely that rising temperatures will decrease snowpack across the mountainous regions of the district.

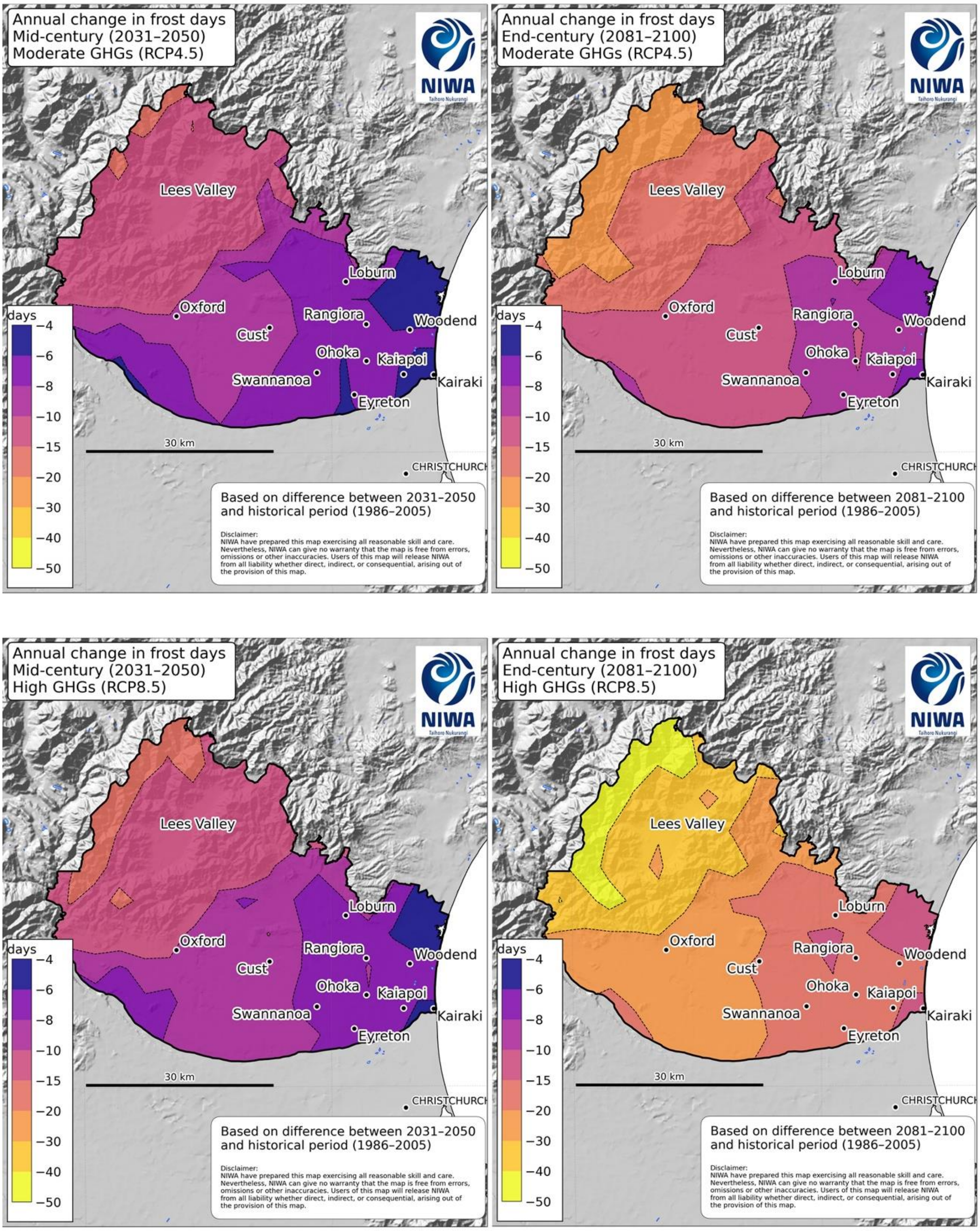

Figure 4-7: Projected changes in frost days for Waimakariri District. Projected changes are relative to the historic period (1986-2005).

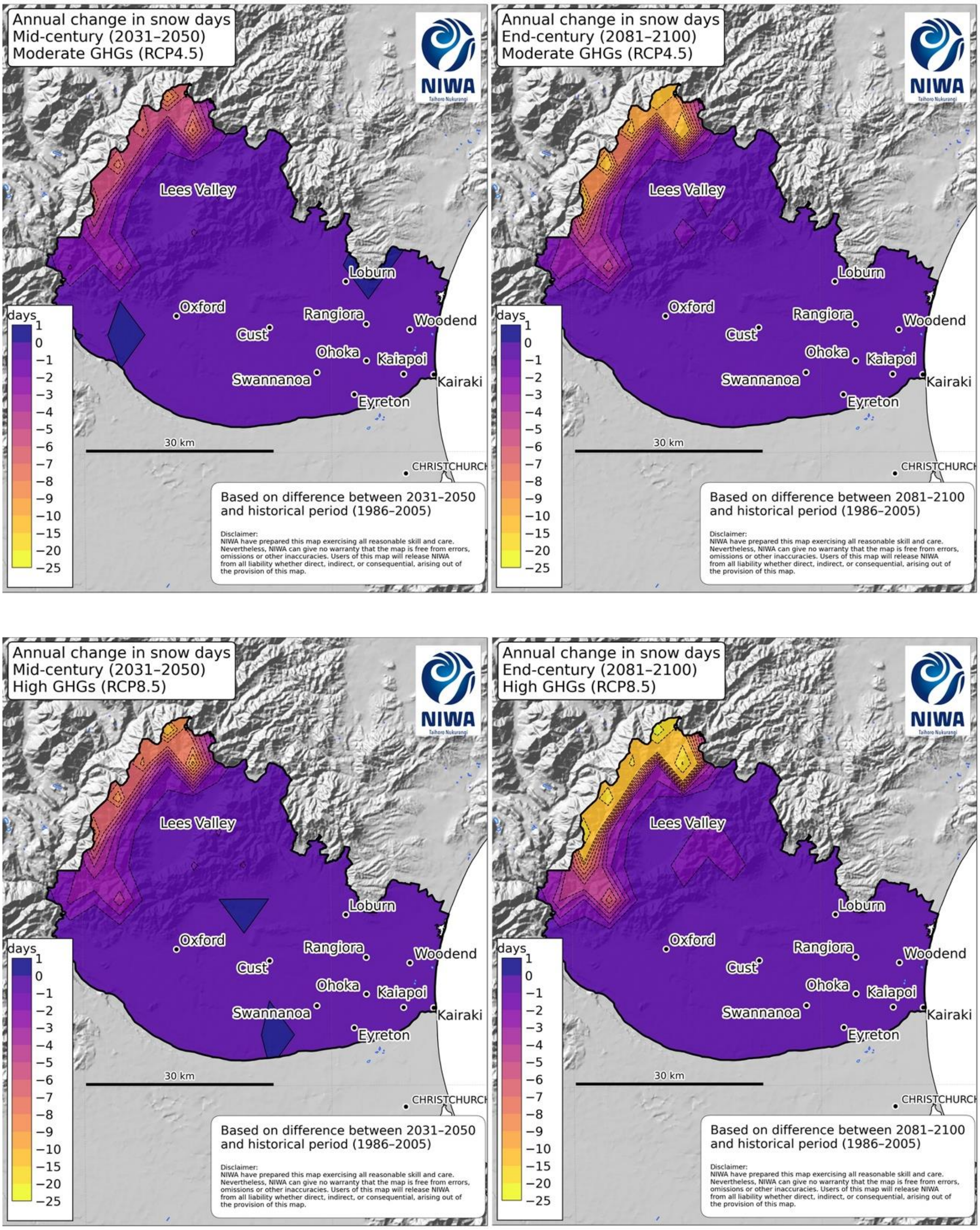

Figure 4-8: Projected changes in snow days for Waimakariri District. Projected changes are relative to the historic period (1986-2005).

4.5 Humidity, radiation, and wind speed

4.5.1 Relative Humidity

Relative humidity is a function of both water vapor (moisture) in the atmosphere and air temperature – as air warms it expands, meaning it can hold more water. Therefore, if air warms but water vapour remains constant the relative humidity will *decrease*.

- Mid-century relative humidity is projected to *decrease* by 0.8% (RCP4.5) to 0.9% (RCP8.5).
- End-century relative humidity is expected to *decrease* by 1.1% (RCP4.5) to 2.2% (RCP8.5).
- The largest reductions in relative humidity are projected to occur in the Lees Valley region and the higher elevation areas, with generally smaller reductions projected near the coast.
- Relative humidity will decrease most notably during winter and spring.

How much will relative humidity change in the district?

Relative humidity is projected to decrease across the Waimakariri District in the future. For the mid-century time period, average relative humidity could decrease by 0.8% and 0.9% for moderate and high GHG scenarios, respectively (Table 4-10). By the end of the century the average relative humidity is projected to decrease by 1.1% for moderate GHGs and 2.4% for high GHGs.

Table 4-10: Overview of projected changes in relative humidity (%) for different parts of the Waimakariri District. Mid-century = 2031-2050, end-century = 2081-2100, moderate GHGs = RCP4.5, high GHGs = RCP8.5. Note that the coloured bars are representative of the magnitude of change.

	moderate GHGs			*high GHGs*			*difference between GHG scenarios**	
ANNUAL	*mid-century*	*end-century*	*50-yr change †*	*mid-century*	*end-century*	*50-yr change†*	*mid-century*	*end-century*
UPPER	**-1.0%**	**-1.5%**	**-0.5%**	**-1.1%**	**-3.1%**	**-2.0%**	**-0.1%**	**-1.6%**
COAST	**-0.4%**	**-0.7%**	**-0.3%**	**-0.6%**	**-1.4%**	**-0.8%**	**-0.1%**	**-0.7%**
INLAND	**-0.7%**	**-1.0%**	**-0.3%**	**-0.8%**	**-2.1%**	**-1.3%**	**-0.1%**	**-1.1%**
DISTRICT	**-0.8%**	**-1.1%**	**-0.4%**	**-0.9%**	**-2.4%**	**-1.5%**	**-0.1%**	**-1.3%**

† = "50-yr change" is the projected change in relative humidity for a given GHG scenario between end-century and mid-century time periods (i.e., how will relative humidity change between 2040 and 2090 for a given GHG scenario?).

**The two columns on the right-hand side ("high – moderate GHGs") show the difference in relative humidity between high and moderate GHG concentration scenarios (what is the difference in projected relative humidity for the RCP4.5 and RCP8.5 scenarios?).*

What parts of the district can expect the largest changes in relative humidity?

The largest reductions in relative humidity are projected to occur in the higher elevation regions of the district, while lowland coastal areas are projected to see minimal changes in relative humidity (see Figure B-8).

What is the difference in projected relative humidity for the high concentration and moderate concentration GHG scenarios?

For the mid-century there is not a difference in the projected change in relative humidity between high and moderate GHG concentration scenarios. However, by the end of century the high concentration scenario suggests that average relative humidity could be 1.3% lower than the moderate GHG scenario.

Are there any noteworthy seasonal changes in relative humidity?

The largest reductions in relative humidity are projected to occur in winter and spring, while relative humidity in summer and autumn is not projected to change substantially (see Table C-9 for seasonal summary).

4.5.2 Solar radiation

- Mid-century solar radiation is projected to decrease approximately 1.0 (RCP4.5) to 1.6 Wm^{-2} (RCP8.5).
- End-century relative humidity is expected to decrease by 1.1 Wm^{-2} (RCP4.5) to 2.6 Wm^{-2} (RCP8.5).
- The projected changes in absolute solar radiation are small and likely to be of second order importance for primary industries relative to other meteorological variables.

Solar radiation is essentially sunlight that passes through the earth's atmosphere and reaches the surface of the earth. We typically measure solar radiation in the unit "Watts per square-meter (Wm^{-2})" – this reveals the average amount of solar energy reaching 1 m^2 of the earth's surface every second. The primary driver of changing solar radiation in the future will be changing types and amounts of clouds that move over the district.

How much will solar radiation change in the district?

For the mid-century time period, average solar radiation could decrease by approximately 1.0 Wm^{-2} to 1.6 Wm^{-2} for both the moderate and high GHG scenarios. By the end of the century the average solar radiation is projected to decrease by 1.1 Wm^{-2} for moderate GHGs and decrease by 2.6 Wm^{-2} for the high GHG scenarios (Table 4-11). These reductions in solar radiation are broadly consistent with increased cloud cover and precipitation. However, the projected changes in absolute solar radiation are small and likely to be of second order importance for primary industries relative to changes in other meteorological variables such as precipitation, temperature, and soil moisture.

What parts of the district can expect the largest changes in solar radiation?

Solar radiation is projected to decrease most notably in the lower altitude coastal zone and to change negligibly in the upper high-altitude regions (Figure B-9). End of century solar radiation in the coastal zone could see an average decrease of 4.4 Wm^{-2} under the high concentration GHGs scenarios.

Table 4-11: Overview of projected changes in incoming solar radiation (Wm-2) for different parts of the Waimakariri District. Mid-century = 2031-2050, end-century = 2081-2100, moderate GHGs = RCP4.5, high GHGs = RCP8.5. Note that the coloured bars are representative of the magnitude of change.

	moderate GHGs			***high GHGs***			***difference between GHG scenarios****	
ANNUAL	*mid-century*	*end-century*	*50-yr change †*	*mid-century*	*end-century*	*50-yr change†*	*mid-century*	*end-century*
UPPER	-0.6	-0.6	0.0	-1.1	-1.2	-0.1	-0.5	-0.6
COAST	-1.4	-1.8	-0.4	-2.3	-4.4	-2.1	-0.9	-2.5
INLAND	-1.1	-1.3	-0.2	-1.8	-3.2	-1.4	-0.7	-1.9
DISTRICT	-1.0	-1.1	-0.2	-1.6	-2.6	-1.0	-0.6	-1.4

† = "50-yr change" is the projected change in solar radiation for a given GHG scenario between end-century and mid-century time periods (i.e., how will solar radiation change between 2040 and 2090 for a given GHG scenario?).

**The two columns on the right-hand side ("high – moderate GHGs") show the difference in solar radiation between high and moderate GHG concentration scenarios (what is the difference in projected solar radiation for the RCP4.5 and RCP8.5 scenarios?).*

What is the difference in projected solar radiation for the high concentration and moderate concentration GHG scenarios?

For the mid-century there is not a substantial difference in the projected change in solar radiation between high and moderate GHG concentration scenarios. By the end of century, the high concentration scenario suggests that average solar radiation could be 1.5 Wm^{-2} lower than for the moderate GHG scenario.

Are there any noteworthy seasonal changes in solar radiation?

For moderate GHG concentrations, solar radiation is projected to decrease consistently during summer, winter, and spring (see Table C-10). However, for the high GHG concentration scenario, the largest reductions in solar radiation are projected during summer, followed by autumn and then winter.

4.5.3 Wind speed

The wind speed presented here is the average simulated wind speed at the earth's surface (approximately 10 m above the ground).

- Mid-century wind speed is projected to increase by approximately 1.8% (RCP4.5) to 2.2% (RCP8.5).
- End-century wind speed is projected to increase by approximately 2.8% (RCP4.5) to 6.5% (RCP8.5).
- Winter wind speed in the high elevation regions could increase by 16.4% by the end of the century under a high GHG concertation scenario.

How much will wind speed change in the district?

For the mid-century time period, average wind speed could increase by approximately 1.8% for the moderate GHG scenario and 2.2% for the high GHG scenario (Table 4-12). By the end of the century, the average wind speed is projected to increase by 2.8% for the moderate GHG scenario and 6.5% for the high GHG scenario.

Table 4-12: Overview of projected changes in wind speed (%) for different parts of the Waimakariri District. Mid-century = 2031-2050, end-century = 2081-2100, moderate GHGs = RCP4.5, high GHGs = RCP8.5. Note that the coloured bars are representative of the magnitude of change.

	moderate GHGs			*high GHGs*			*difference between GHG scenarios**	
ANNUAL	*mid-century*	*end-century*	*50-yr change †*	*mid-century*	*end-century*	*50-yr change†*	*mid-century*	*end-century*
UPPER	**2.6%**	**3.7%**	**1.1%**	**2.8%**	**8.8%**	**6.0%**	**0.1%**	**5.0%**
COAST	**0.6%**	**1.2%**	**0.7%**	**1.2%**	**2.5%**	**1.3%**	**0.6%**	**1.3%**
INLAND	**1.6%**	**2.4%**	**0.8%**	**2.0%**	**5.8%**	**3.8%**	**0.4%**	**3.4%**
DISTRICT	**1.8%**	**2.8%**	**0.9%**	**2.2%**	**6.5%**	**4.3%**	**0.3%**	**3.7%**

† = "50-yr change" is the projected change in wind speed for a given GHG scenario between end-century and mid-century time periods (i.e., how will wind speed change between 2040 and 2090 for a given GHG scenario?).

**The two columns on the right-hand side ("high – moderate GHGs") show the difference in wind speed between high and moderate GHG concentration scenarios (what is the difference in projected wind speed for the RCP4.5 and RCP8.5 scenarios?).*

What parts of the district can expect the largest changes in wind speed?

Wind speed is predicted to increase more in the high elevation regions than the lower elevation plains and coastal regions of the district (Figure B-10).

What is the difference in projected wind speed for the high concentration and moderate concentration GHG scenarios?

For the mid-century there is not a substantial difference in the projected increase in wind speed between high and moderate GHG concentration scenarios. However, by the end of century, the high concentration scenario suggests that average wind speed could be 3.7% higher than the moderate GHG scenario.

Are there any noteworthy seasonal changes in wind speed?

Winter wind speed is projected to increase notably more than the other seasons; winter wind speed in the upper region of the district could increase by 16.4% by the end of the century under a high GHG concentration scenario. Spring wind speed is also projected to increase more notably than other seasons, while summer and autumn wind speed changes are projected to be negligible (see Table C-11 for seasonal wind speed projections).

4.5.4 Extreme winds

As noted in Section 4.2.3 the focus of this report is the projected changes in climatic means rather than changes to the extreme events. Nevertheless, changes to extreme wind and storm events are highly relevant for the district's economy, ecosystems, and communities. Generally, the AR6 suggests that New Zealand's regional wind patterns are projected to become more north-easterly in summer, and westerlies are projected to become stronger in winter (with *low confidence*). This is consistent with findings from the AR5 regional climate modelling, which suggested a strengthening of the southern hemisphere storm tracks and increased extreme wind speeds across the South Island (see MfE, 2018). Overall, the evidence broadly suggests that future extreme wind speeds and storm events may increase in the district, but more research is needed in this area.

5 Model spread and uncertainty

There are three main sources of uncertainty in projections of climate:

1. Uncertainty due to future emissions (e.g., RCPs).
2. Uncertainty due to internal climate variability – natural variations in climate can occur over annual to decadal timescales.
3. Uncertainty due to inter-model differences – different models represent the climate system with differing methods and assumptions.

This report has partially addressed the first two sources of uncertainty by analysing two different RCPs and taking averages of climate variables over 20-year time periods. However, the third source of uncertainty has not yet been discussed in this report. All climate variables in the report are calculated by taking the ensemble mean of six simulations (per GHG scenario) driven by independent global climate models. It is possible to examine one aspect of model uncertainty by exploring the spread of ensemble members in the regional climate simulations and not simply the ensemble mean.

Analysing the spread of model predictions is most important for projections of rainfall where model uncertainty can be relatively large. For example, see Figure 5-1, which shows the spread of projected changes in rainfall for Christchurch for each RCP at the end-century. The coloured vertical bars, and inset (black, dynamical simulations) stars, show all the individual models, so a range of model uncertainty associated with different global climate models is displayed. The average of all the models generally project an increase in rainfall, as indicated by the horizontal black line on each bar in Figure 5-1. However, not all models predict an increase in precipitation, some project decreased precipitation. In this report we have provided ensemble means as a best estimate of the likely change in climatic variables.

However, readers should be aware of model uncertainty when interpreting this report. A positive signal showing increased precipitation does not imply that all six models represented a positive trend. Additional analyses of the NIWA's climate data to reveal the model spread for the Waimakariri District could be a useful exercise. Further information on model uncertainty can be found in the Ministry for Environment report on New Zealand's regional climate projections (MfE 2018; see here).

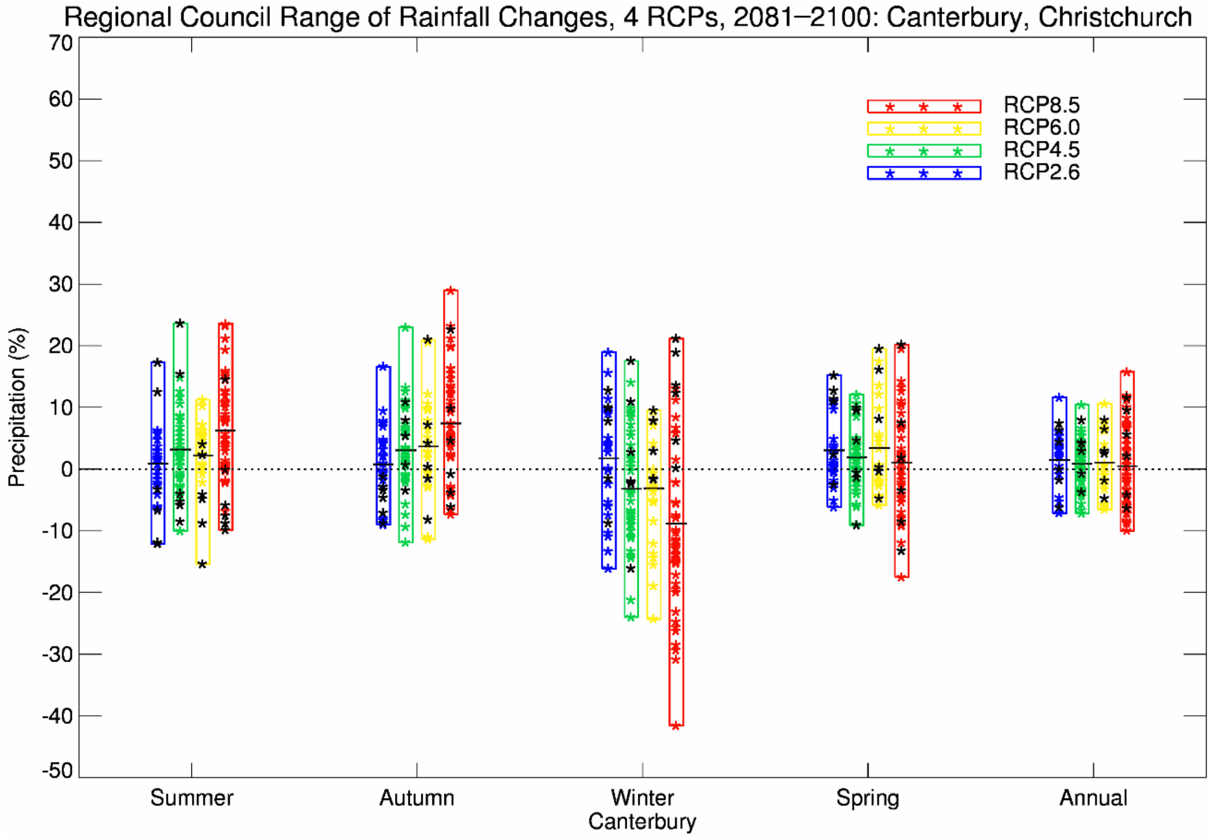

Figure 5-1: Projected seasonal and annual rainfall change for Christchurch by 2090 (2081-2100). Coloured stars represent all models as derived by statistical downscaling. Black stars correspond to the six-model RCM downscaling, and the horizontal bars are the average over all downscaled results (statistical and RCM) (source: MfE, 2018).

6 Coastal Erosion and Sea Water Inundation (Jacobs report)

In 2018 Jacobs prepared a report for the Waimakariri District council entitled “Coastal Erosion and Sea Water Inundation Assessment”. NIWA was asked to identify whether the underlying assumptions of Jacob’s report are consistent with, or differ from, the findings of this report. The key assumptions to evaluate from NIWA’s perspective is the assumed level of sea level rise (SLR) as it relates to future climate change scenarios (i.e., RCPs).

The Jacobs report used New Zealand SLR estimates taken from the Ministry for the Environment 2017 report entitled *Coastal Hazards and Climate Change: Guidance for Local Government* (MfE, 2017) but the authors slightly updated the projections to align SLR change relative to a 2015 baseline. These SLR figures come from Kopp et al. (2014) who used AR5 global climate models in combination with various other models and data sources (see Figure 6-1 below) to derive global scale probabilistic estimates of SLR through the 21st and 22nd Centuries. NIWA’s regional climate modelling utilises sea ice and sea surface temperature fields from six different AR5 GCMs and four RCPs to derive regional climate predictions for New Zealand through a combination of dynamical downscaling and bias-correction methods (see Section 2.2 for more details), whereas the Kopp et al. (2014) SLR projections are based on the full ensemble of CMIP5 models, three RCPs, and various other data sources and modelling techniques.

Overall, the Kopp et al. (2014) and subsequent MfE (2017) SLR figures are widely used in New Zealand, including by NIWA in the Canterbury Regional climate assessment. The underlying assumptions that are used to generate the projections in the two reports (NIWA and Jacobs) are by NIWA’s judgment compatible.

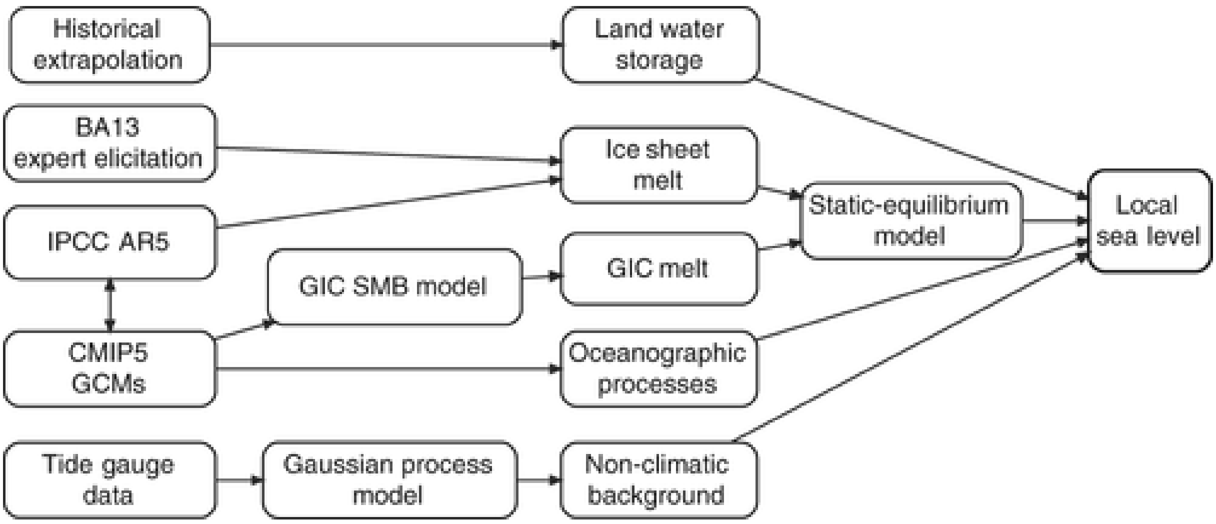

Figure 6-1: Logical flow of sources of information used in Kopp et al., 2014 local sea-level projections. GCMs=global climate models; GIC= glaciers and ice caps; SMB- surface mass balance (from Kopp et al., 2014).

7 Climate change impacts for the district

Climate change impacts can be extremely wide-ranging and complex. The changing climate can impact many inter-related sectors of society. A full assessment of the impacts of climate change on the Waimakariri District is outside the scope of this report. However, here we provide a broad summary of possible impacts of climate change most relevant for the district given the projected changes outlined in this report and the nature of the district.

7.1 Hydrological impacts

The Waimakariri District contains two major river catchments: The Waimakariri River catchment and the Ashley/Rakahuri River catchment. Understanding the impacts of climate change on the district's freshwater resources is extremely important for a range of reasons. Freshwater ecosystems support important native flora and fauna; rivers and lakes are critical sources of fresh water for consumption and irrigation; and flooding causes millions of dollars of damage to infrastructure in New Zealand every year. The recent 2021 Canterbury Region floods – which were driven by 1-in-200-year rainfall in some areas – highlight the importance of understanding the impacts of climate change on the district's rivers.

While a full hydrological assessment of the impacts of climate change on the district is outside the scope of this report, this section will provide a brief summary of the hydrological modelling analyses presented in the Climate change projections for the Canterbury Region report (Macara et al., 2020). Hydrological statistics between the baseline period (1986-2005) and two future periods are presented. The mid-century (2036-2056) and end-century (2086-2099) time periods are slightly different to the time periods used in the climate modelling.

7.1.1 Mean flow

The Waimakariri District is marked in Figure D-1-D.4, and the two major river catchments in the district can also be seen. Hydrological simulations suggest that mid-century mean flow could remain largely unchanged in the Ashley/Rakahuri and Waimakariri River catchments (Figure D-1, top row). For the end-century period mean flow will likely remain largely unchanged under the moderate GHG scenario and slightly increase by 5-10% under the high emissions scenario in the southern Waimakariri river basin and coastal Ashley/Rakahuri river catchment.

7.1.2 Mean annual low flow

Mean annual low flow is defined as the mean of the lowest seven-day average flows in each hydrological year of a simulation period. Mean annual low flow does not necessary characterise low flow conditions during the summer season as snow affected catchments tend to exhibit low flow conditions during winter. Mean annual low flow in the district is generally projected to decrease by mid-century under both GHG concentration scenarios (Figure D-2, top row), likely due to reduced seasonal snow fall/melt and longer periods of low rainfall (i.e., drought).

The moderate GHG concentration scenario produces a larger decrease in the mean annual low flow than the high GHG concentration scenario with mid-century decreases of upwards of 20% projected in some parts of the district. By the end-century, mean annual low flow could decrease by 20-50% across the district (Figure D-2, bottom row). **These projections suggest that although average annual rainfall is projected to increase, the district's freshwater waterways may become more prone to periods of very low flow and hydrological drought conditions.**

7.1.3 Mean high flows

The mean high flow characteristics are represented by Q5% flow and the mean annual flood characteristics.

The Q5% flow – which represents the top 5% of flows – is not projected to change by mid-century under the moderate GHG scenario. However, under the high GHG scenario mid-century Q5% is projected to increase by 10-20% in parts of the Ashley/Rakahuri River catchment. For the end-century, Q5% flows could similarly increase by ~10-20% under moderate GHGs and upwards of 50% under the high GHG concentration scenario.

Finally, the mean annual flood is the average of the annual maximum discharge occurring in a river over the simulation period, which typically has a recurrence interval of once every 2.33 years. **Note that mean annual flood is a relatively low threshold for engineering purposes.** The mean annual flood is projected to increase by 50% or more in the Ashley/Rakahuri and Waimakariri Rivers for both time periods and GHG scenarios. The signal is most apparent in the end-century high GHG concentration scenario where an increased mean annual flood is projected widely across both catchments in the district. However, as noted in The Canterbury Regional climate change report (Macara et al., 2020), the mean annual flood "should not be considered a comprehensive metric for the possible impact of climate change on New Zealand flooding".

Nevertheless, the **increasing mean annual flood and Q5% flows are consistent with projected increases to extreme rainfall, which is expected to occur as the planet warms. It is increasingly likely that more frequent and extreme rainfall will cause increased severe flooding risk in the district** with damaging implications for primary industries, infrastructure, private property, human life, and native ecosystems.

7.2 Sea level rise

Sea-level rise is triggered by melting of the polar ice caps and the thermal expansion of the ocean as water warms. In New Zealand, the sea may rise by up to a metre by the end of the century, and this rising sea level is associated with a range of potential broad impacts:

- increased frequency of damaging coastal flooding events,
- exacerbated coastal erosion of shorelines and unconsolidated cliffs,
- increased incursion of saltwater in rivers and nearby groundwater aquifers, potentially rising water tables in tidal groundwater systems.

There are several settlements situated in the Waimakariri District that are located within 5 km of the coastline, **and sea-level rise could directly impact those living in the coastal zone. This sea level rise will likely increase coastal erosion and flooding, which will damage homes and infrastructure such as pipes and roads**. Coastal erosion and inundation impacts have not been directly evaluated by NIWA but are described in the Jacobs Report on this topic previously commissioned by the Council. For a broad indication of the possible timing of sea-level rise impacts, the time window when various SLR levels could be reached is shown for three GHG concentration scenarios in Table 7-1. Please also refer to the NZ SeaRise tool for additional information about SLR in the Waimakariri District (https://www.searise.nz/).

Table 7-1: Approximate years, from possible earliest to latest, when specific SLR increments (metres above 1986-2005 baseline) could be reached for various projections. Table is from Pearce et al., (2018) after Stephens et al. (2014).

Sea-level rise (m)	Year achieved for RCP8.5 (83%ile)	Year achieved for RCP8.5 (median)	Year achieved for RCP4.5 (median)	Year achieved for RCP2.6 (median)
0.3	2045	2050	2060	2070
0.4	2055	2065	2075	2090
0.5	2060	2075	2090	2110
0.6	2070	2085	2110	2130
0.7	2075	2090	2125	2155
0.8	2085	2100	2140	2175
0.9	2090	2110	2155	2220
1.0	2100	2115	2170	>2200
1.2	2110	2130	2200	>2200
1.5	2130	2160	>2200	>2200
1.8	2145	2180	>2200	>2200
1.9	2150	2195	>2200	>2200

7.3 Wildfire

Fire risk in New Zealand is projected to increase in the future, due to a range of reasons (Pearce et al., 2011):

- warmer air temperature and stronger winds;
- increased drought frequency, and associated increases in fuel (vegetation) drying;
- a potentially longer fire season;
- more thunderstorms and lightning;
- drier and possibly windier conditions would cause faster fire spread and larger areas to be burned.

Many of the above factors are projected to occur in the Waimakariri District including increased temperatures, stronger winds, and more drought prone conditions (i.e., increased PED). **For these reasons damaging wildfires that could negatively impact forestry, agriculture, and private property could become more prevalent across the district in future.**

7.4 Impacts on primary industries

The primary sector makes up a large part of the district's economy. While many of the climate impacts listed above can have an indirect effect on primary industries it is worth describing how climate change could directly impact this sector given its importance in the region.

Primary industries are at risk from more frequent extreme weather events, in particular drought and flood. Drought and lack of reliable rain can negatively impact the productivity of land and present challenges to many primary industries, particularly those that are water intensive. **PED is projected to increase essentially everywhere throughout the Waimakariri District in the future, suggesting**

the region will likely become more drought prone. More water could be needed for irrigation across the district as PED is projected to increase in the future regardless of GHG concentration scenario. Increased PED implies that increased temperature and increased evapotranspiration will not be offset by increased total rainfall across the district, meaning that soils will likely be drier despite an increase in annual rainfall.

Flooding will continue to be an issue in the district particularly for primary sector activities located near the district's larger rivers, such as the Ashley/Rakahuri and Waimakariri, or in areas experiencing high amounts of rainfall.

Increased temperatures may cause increased heat stress for livestock animals, resulting in increased animal mortality during heatwaves. Higher temperatures could also enhance the risk of pests and diseases that impact primary industries. Potential invasive species, like the Queensland fruit fly, may be able to live in wider parts of New Zealand as our climate warms, increasing the risk of outbreak and contamination.

7.5 Impacts on people

The health and wellbeing of many people living in the Waimakariri District could be affected by a changing climate. Higher temperatures could bring more heat-related illnesses to residents of the district. Vulnerable groups such as the elderly, disabled people, infants, and outdoor workers (e.g., labourers and farmers) are particularly susceptible to potential health impacts from climatic warming.

More frequent and intense weather events such as flooding, storms, and forest fire are also likely to directly impact people's health and wellbeing. Climate change may also have a negative effect on many people's mental health. Various communities are already anxious about the implications of climate change and as impacts become more severe, anxieties could get worse.

The northern Pegasus Bay coastal area is culturally significant to Ngāi Tahu and Ngāi Tūāhuriri including Fenton Reserves and entitlements used to access waterways for mahinga kai purposes. Changes to the coastal environment could therefore also have cultural impacts on Māori communities in the district.

Additionally, the district should expect social and economic impacts and disruption caused by communities retreating from the coast due to sea-level rise and coastal flooding. Protecting coastal properties (including insurance) in the coastal zone may become increasingly difficult with economic and wellbeing implications for communities in flood prone coastal regions.

7.6 Impacts on species and ecosystems

Ecosystems are complex interconnected communities of different plants, animals, and other organisms. In an ecosystem, when one animal or plant is affected by a change in the environment (e.g., rising temperatures), all the species within the ecosystem are potentially affected. The implications of climate change for ecosystems in the Waimakariri District will require careful expert analysis. However, broadly speaking some important ecosystems in the district include alpine, freshwater (lakes, rivers, and wetlands), coastal, and forests.

7.6.1 Alpine ecosystems

Projections suggest warming could be enhanced in the district's alpine areas and snow days will be reduced. Organisms living in higher elevation areas are adapted to survive in cold and often freezing environments. Snowlines will move to higher elevations and species living in these environments may also have to move upslope. This may cause a habitat "squeeze" on alpine ecosystems in the Waimakariri District. For example, the hills around the Lees Valley are listed in Council's proposed District Plan as an "outstanding natural landscape" and the Okuku Triassic Monotis geo-preservation site. These significant landscapes and associated alpine ecosystems could come under significant threat as the climate changes. It is also possible that alpine ecosystems will increasingly be affected by pest species such as rats and hedgehogs as higher temperatures allow them to survive at higher elevations.

7.6.2 Freshwater ecosystems

Higher temperatures will cause water in the district's rivers, lakes, and wetlands to become warmer. Warmer waters will likely impact the range – the habitat in which animals can comfortably live – of many aquatic species, as well as nutrient cycling and primary productivity. Warming of waterways could lead to the proliferation of invasive species (e.g., water hyacinth). Additionally, weather patterns (especially changing wind and temperature) could increase the likelihood of algal blooms occurring in the district's rivers and lakes. These changes could have serious implications for human and animal health and impact on recreational activities in the region.

7.6.3 Coastal ecosystems

The district's coastal ecosystems will likely experience rising seas and increased coastal erosion with implications for all coastal dwelling species. These processes will create a habitat 'squeeze' between coastal ecosystems and developed land.

The internationally significant Ashley/Rakahuri estuarine ecological area is an important feeding, roosting, and breeding ground for many native birds including some critically endangered species and climatic changes to this environment could endanger these delicate ecosystems further.

7.6.4 Terrestrial ecosystems

Numerous native birds and insects could be affected by climate change. Increasing temperatures will likely make New Zealand a more suitable habitat for invasive flora and fauna. Invasive species from warmer climates may outcompete native species. The timing of seasonal activities like breeding, flowering, growth and migration may alter as the climate changes, disrupting relationships between species.

Warmer and drier winters in the district could extend the breeding seasons of some mammalian predators (e.g. rats, mice, goats, pigs and possums). As the climate warms, it is possible that more of these mammalian predators will survive the winter months, with negative implications for native terrestrial species.

8 Sixth Assessment Report Considerations

The IPCC Sixth Assessment Report (AR6) from Working Group 1 (WG1) was published in August 2021. The WG1 report uses data from a suite of updated GCMs to provide "…the most up-to-date physical understanding of the climate system and climate change…". The models are collated and managed by the World Climate Research Programme (WCRP) in the Coupled Model Intercomparison Project Phase 6 (CMIP6). While the WG1 report is predominantly a global assessment, it does include some global-regional (e.g., Australasia) climate change summary information. However, the WG1 report provides limited information on projected climate change at the scale useful for the Waimakariri District (i.e. to a spatial resolution of a few kilometres). **Since the findings of this report are based on the AR5 global climate modelling we will provide a brief summary of New Zealand relevant information from the AR6** (see Bodeker et al., 2022 for more details)**.** It must be noted that all information and conclusions given here are based on interpretation of AR6 model data and related publications only. More detailed information on New Zealand's regional climate will come with the forthcoming AR6 downscaling effort, which is being led by NIWA and is expected in 2024.

With regards to historical climate warming, the AR6 states that the mean global temperature change from the preindustrial time period (1850-1900) up to 2011-2020 is 1.09°C, meaning the planet is already quite close to the Paris Agreement thresholds of 1.5 and 2°C. The AR5 reported a 0.78 °C increase in temperature up to 2003-2012. The reasons for the 0.31°C increase in global warming include methodological changes, the calculated global-mean temperature of the preindustrial period (1850-1900) decreasing, and significant ongoing warming since 2003-2012 of around 0.19°C in the last decade.

As mentioned previously in this report the AR6 modelling uses SSPs rather than the RCPs used in AR5. The SSPs developed for the IPCC AR6 were designed so that the GHG concentration scenarios used in climate modelling originate from a wider and more realistic array of socioeconomic drivers. These factors include population growth, technological development, and economic development. The resulting emissions scenarios represent narratives for energy use, air pollution control, land use and GHG emissions. The SSP storylines are "sustainability: (SSP1), "middle of the road" (SSP2), "regional rivalry" (SSP3), "inequality" (SSP4) and "fossil-fuel intensive development" (SSP5). The AR6 SSPs and AR5 RCPs are not directly comparable, however, for reference a comparison of AR5 and AR6 projected global mean temperature changes are provided in Table 8-1.

Table 8-1: Projected global mean warming in 2081-2100, relative to 1850-1900, in AR5 and AR6. The AR5 values are originally relative to the mean temperature of 1986-2005. Following AR5, 0.6°C has been added to represent warming between 1850-1900 and 1986-2005. 'SPM' refers to the WG1 Summary for Policymakers reports for AR5 and AR6 (source: Bodeker et al. 2022).

End-of-century nominal radiative forcing (Wm-2)	Warming in 2081-2100 (°C) under RCP scenarios (likely range; AR5 table SPM.2)	Warming in 2081-2100 (°C) under SSP scenarios (very likely range; AR6 SPM table B.1.2)
1.9	-	1.4 (1.0-1.8)
2.6	1.6 (0.9-2.3)	1.8 (1.3-2.4)
4.5	2.4 (1.7-3.2)	2.7 (2.1-3.5)
7.0	-	3.6 (2.8-4.6)
8.5	4.3 (3.2-5.4)	4.4 (3.3-5.7)

Table 8-1 shows that AR6 projections present a slight increase in global warming, but the uncertainty ranges overlap with those from AR5. Importantly, the uncertainty ranges have decreased under AR6 meaning there is more agreement on the range of likely warming associated with future GHG concentrations. Of the scenarios considered in AR6, only the aggressive GHG mitigation scenario SSP1-1.9 will *more likely than not* result in end-of-century warming of less than 1.5°C. The SSP1-1.9 scenario involves extensive net CO_2 sequestration in the second half of this century and will require rapid development and deployment of these technologies.

Evidence of changes in extreme weather events and their attribution to GHG induced warming has strengthened since the AR5. The large number of event attribution studies that have been published since AR5 have contributed to a growing body of evidence that changes in individual weather events can be attributed to increased GHG concentrations. We can generally be more confident attributing large-scale heatwaves and longer duration extreme precipitation events (e.g., 2021 Canterbury Floods) have higher confidence than shorter and more localised events.

Though attribution is difficult, especially in a complex climate like New Zealand, the findings in AR6 further increase our confidence that extreme climatic events like extreme precipitation, drought, tropical cyclones and compound extremes (including dry/hot events and fire weather) will increase throughout New Zealand due to human activities and GHG warming.

9 Glossary of abbreviations and terms

IPCC	Intergovernmental Panel on Climate Change
AR5	IPCC Fifth Assessment Report
AR6	IPCC Sixth Assessment Report
WDC	Waimakariri District Council
NIWA	National Institute of Weather and Atmospheric Research
RCP	Representative concentration pathway
GHG	Greenhouse gas
SSP	Shared Socio-Economic Pathways
VCSN	Virtual Climate Station Network
SLR	Sea-level rise
PED	Potential evaporation deficit
PET	Potential evapotranspiration
WG1	IPCC Working Group 1
WCRP	World Climate Research Programme
CMIP6	Coupled Model Intercomparison Project Phase 6

10 References

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Appendix A Historical Climate Maps

The following figures are historical climate maps of the Waimakariri District. These data are derived from modelled historical climate simulations.

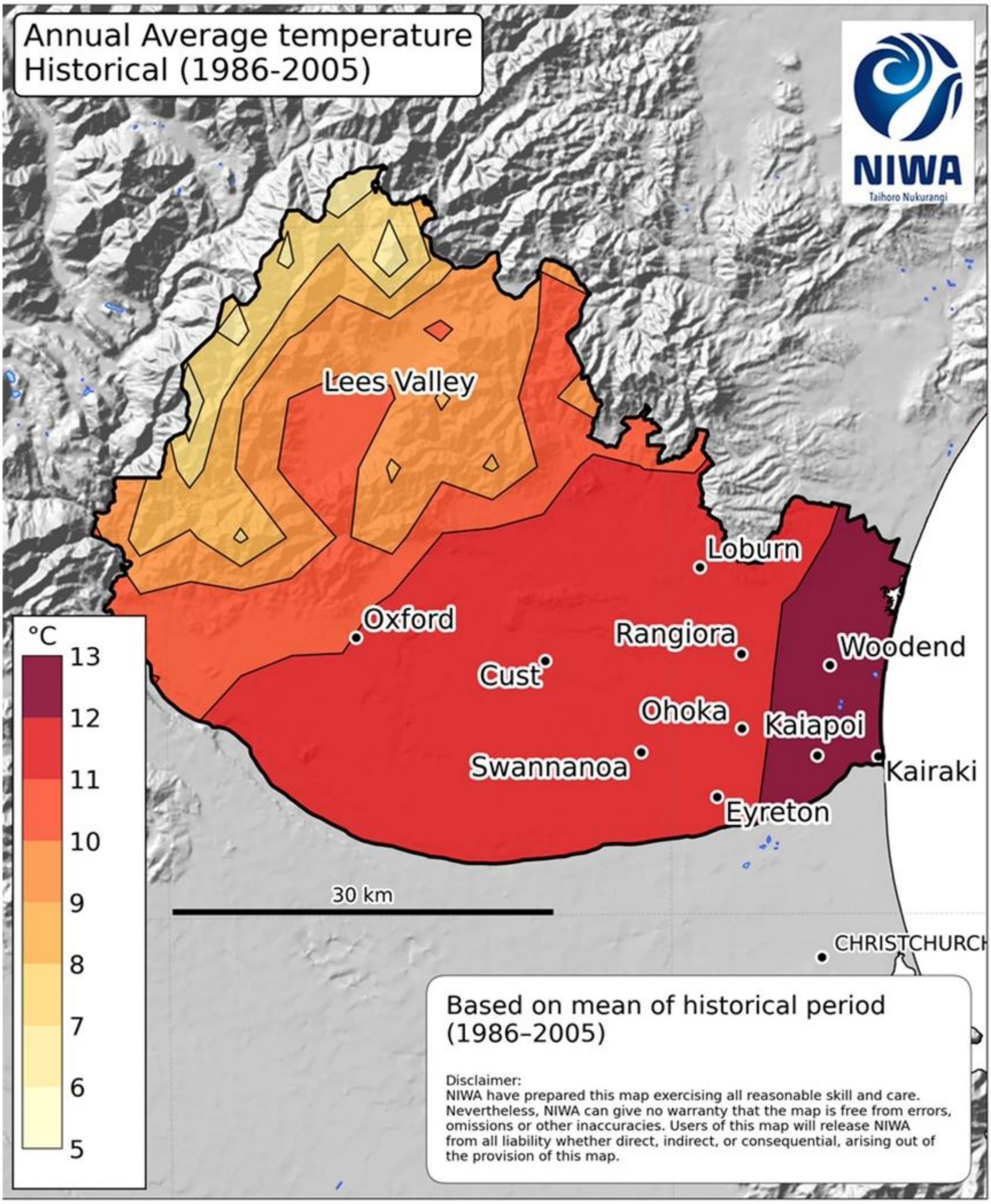

Figure A-1: Daily mean air temperature (°C) for Waimakariri District for the historic period (1986-2005).

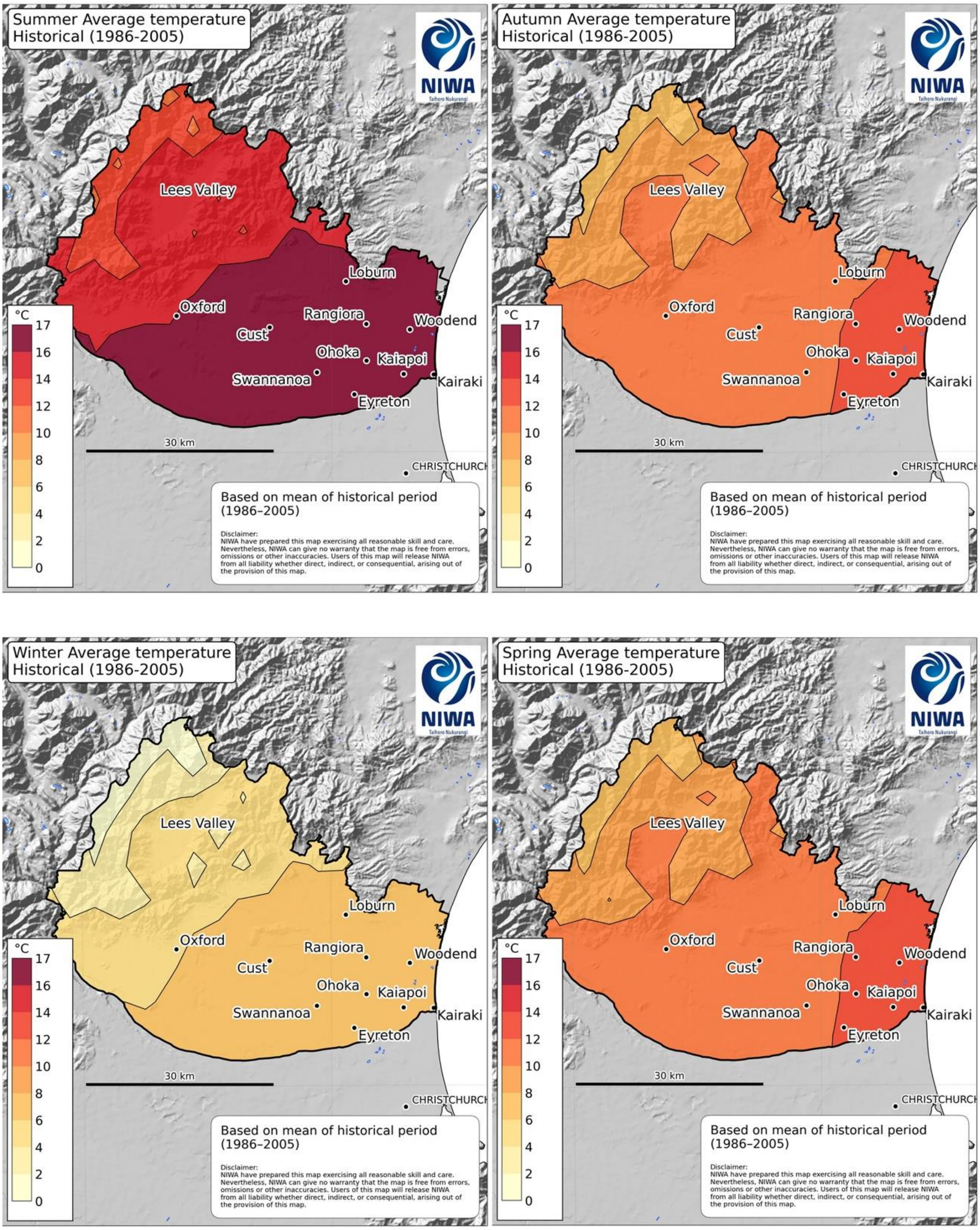

Figure A-2: Daily mean air temperature (°C) by season in the Waimakariri District for the historic period (1986-2005).

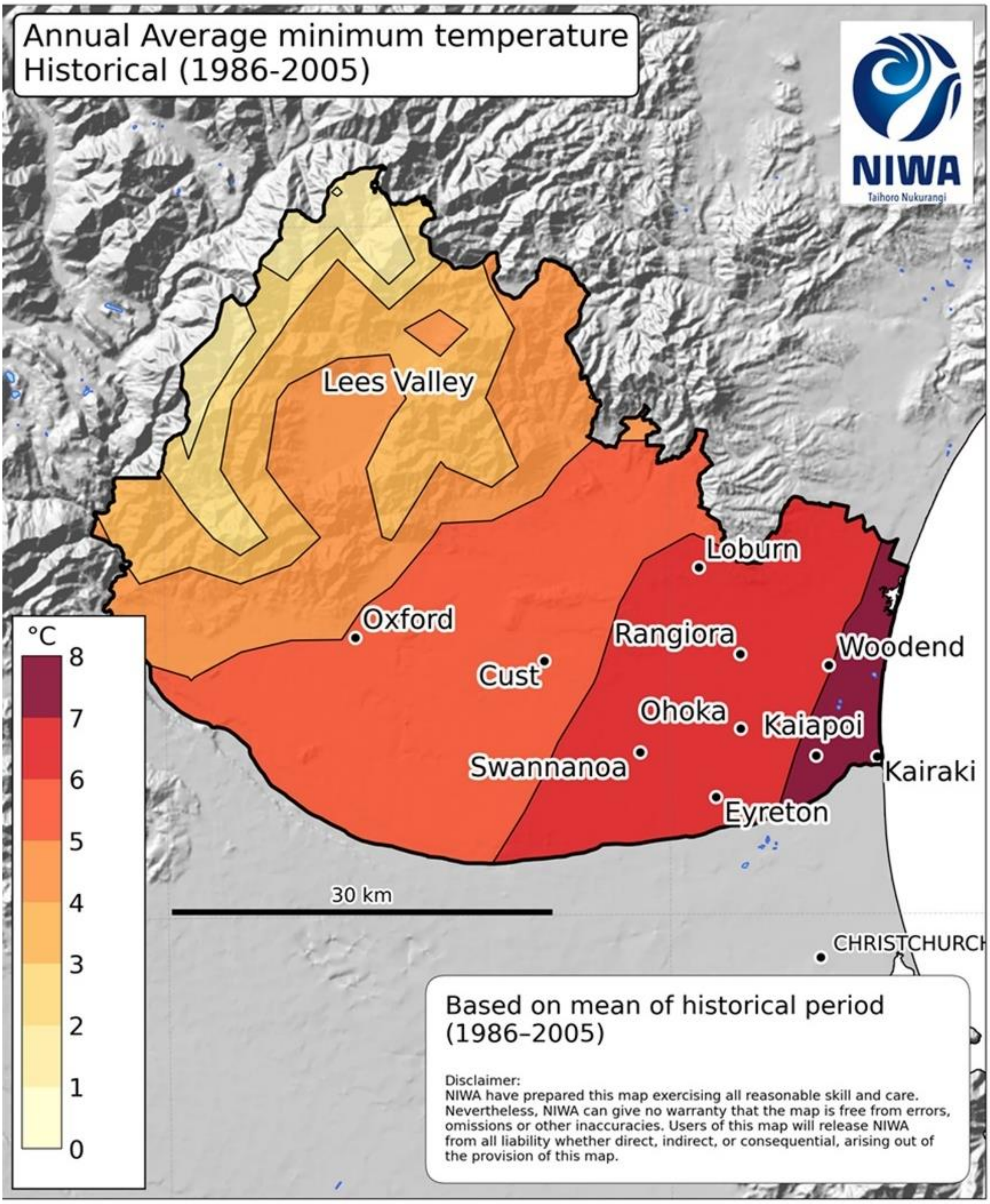

Figure A-3: Average daily minimum air temperature (°C) for Waimakariri District for the historic period (1986-2005).

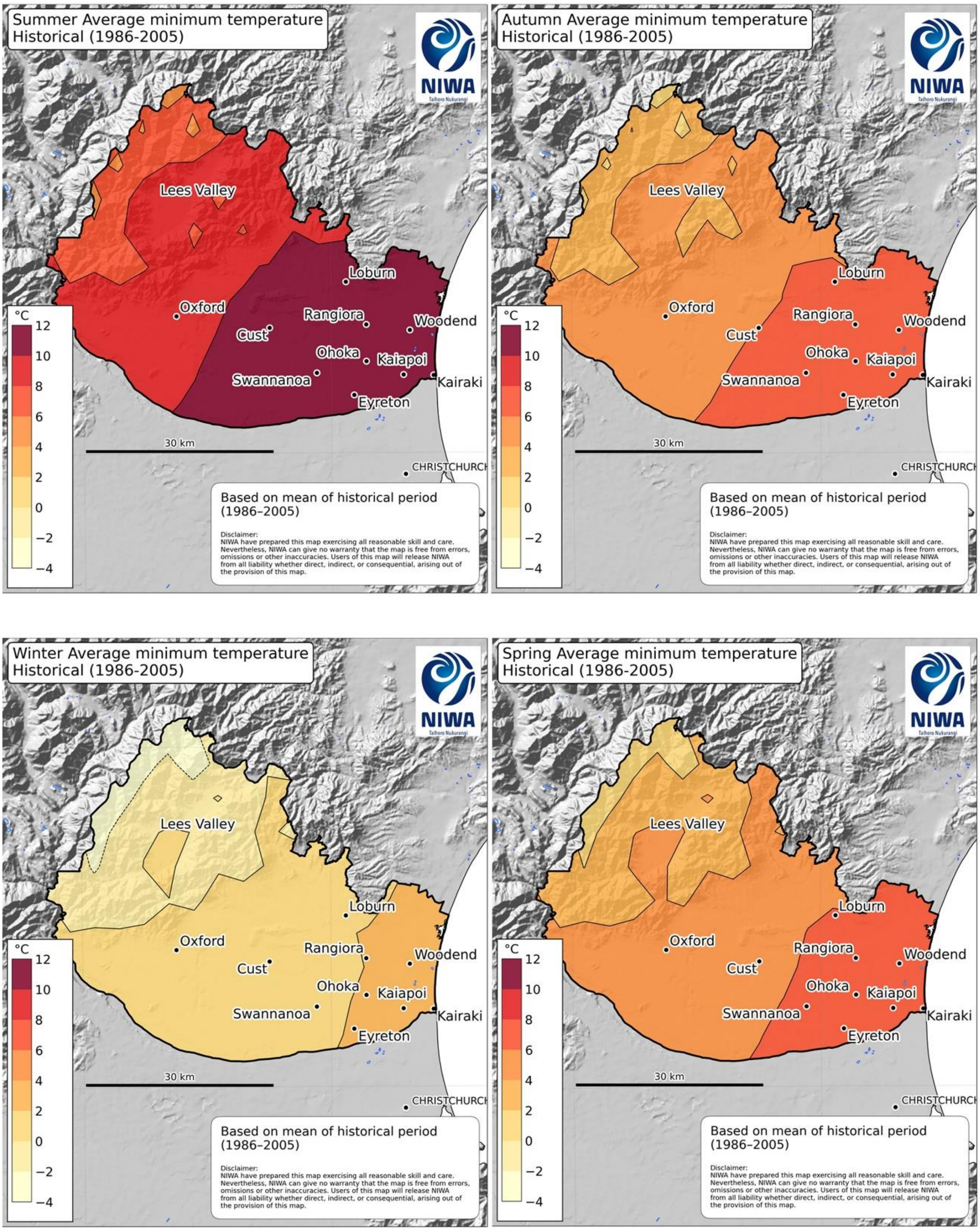

Figure A-4: Average daily minimum air temperature (°C) by season in the Waimakariri District for the historic period (1986-2005).

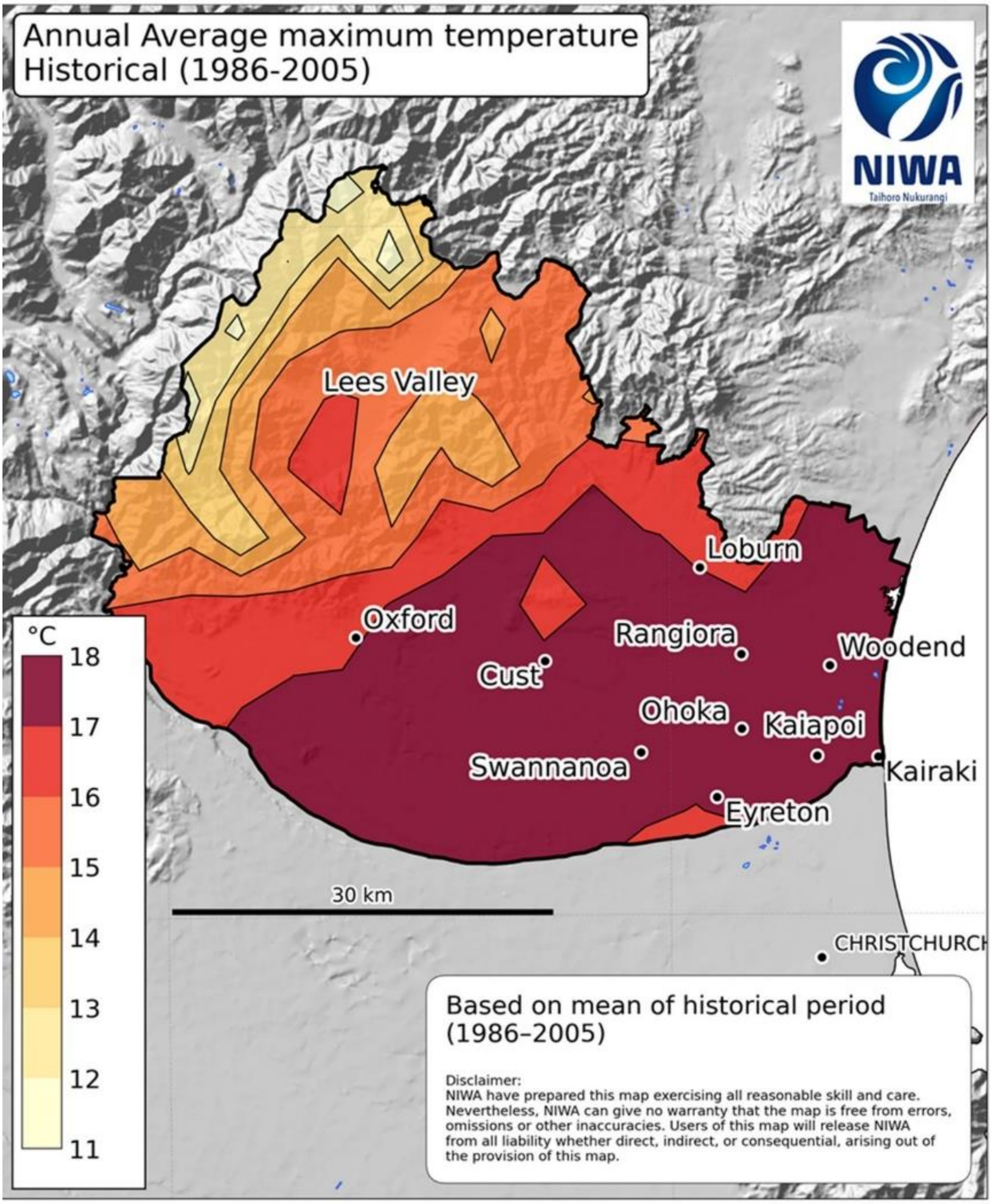

Figure A-5: Average daily maximum air temperature (°C) for Waimakariri District for the historic period (1986-2005).

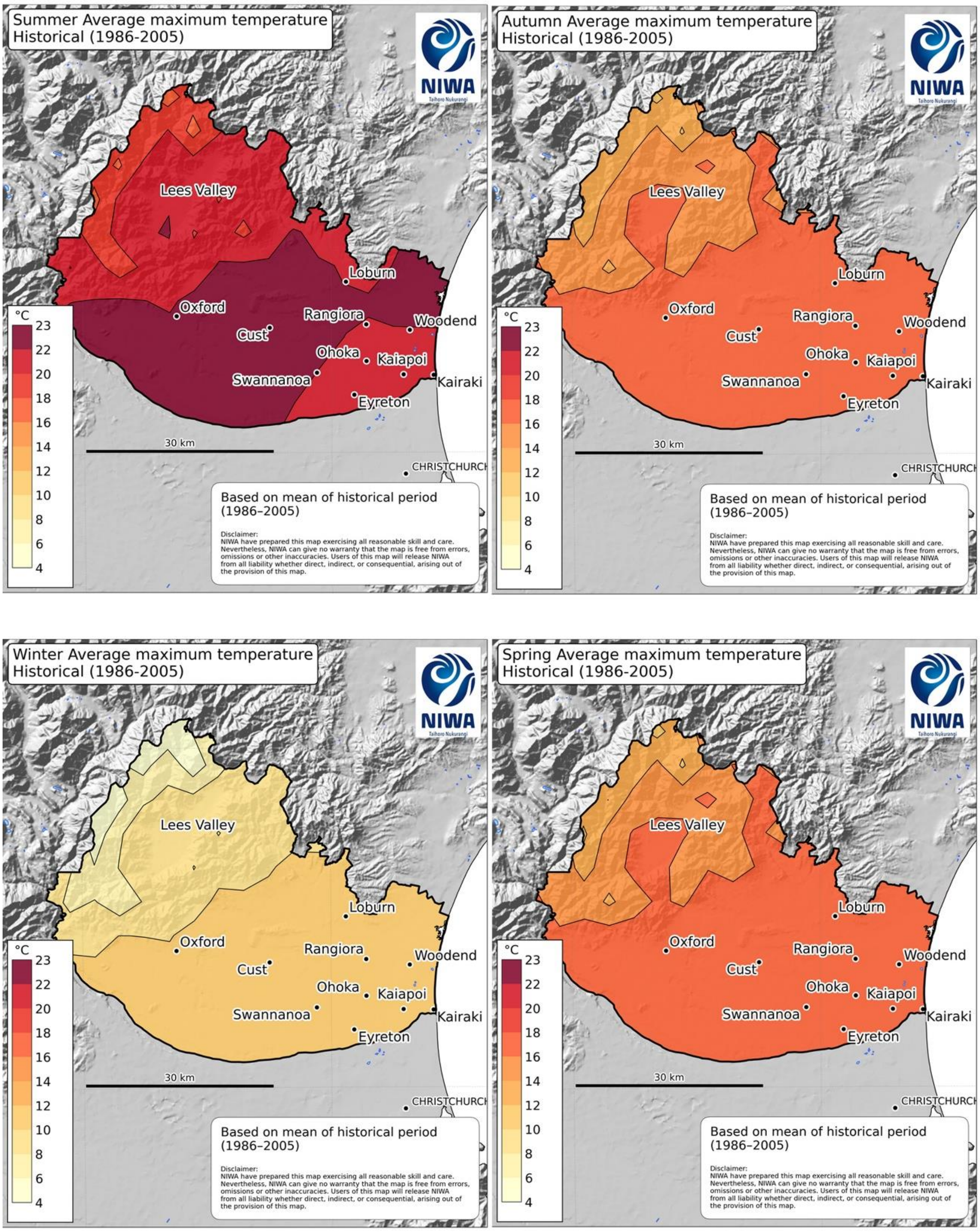

Figure A-6: Average daily maximum air temperature (°C) by season for Waimakariri District for the historic period (1986-2005).

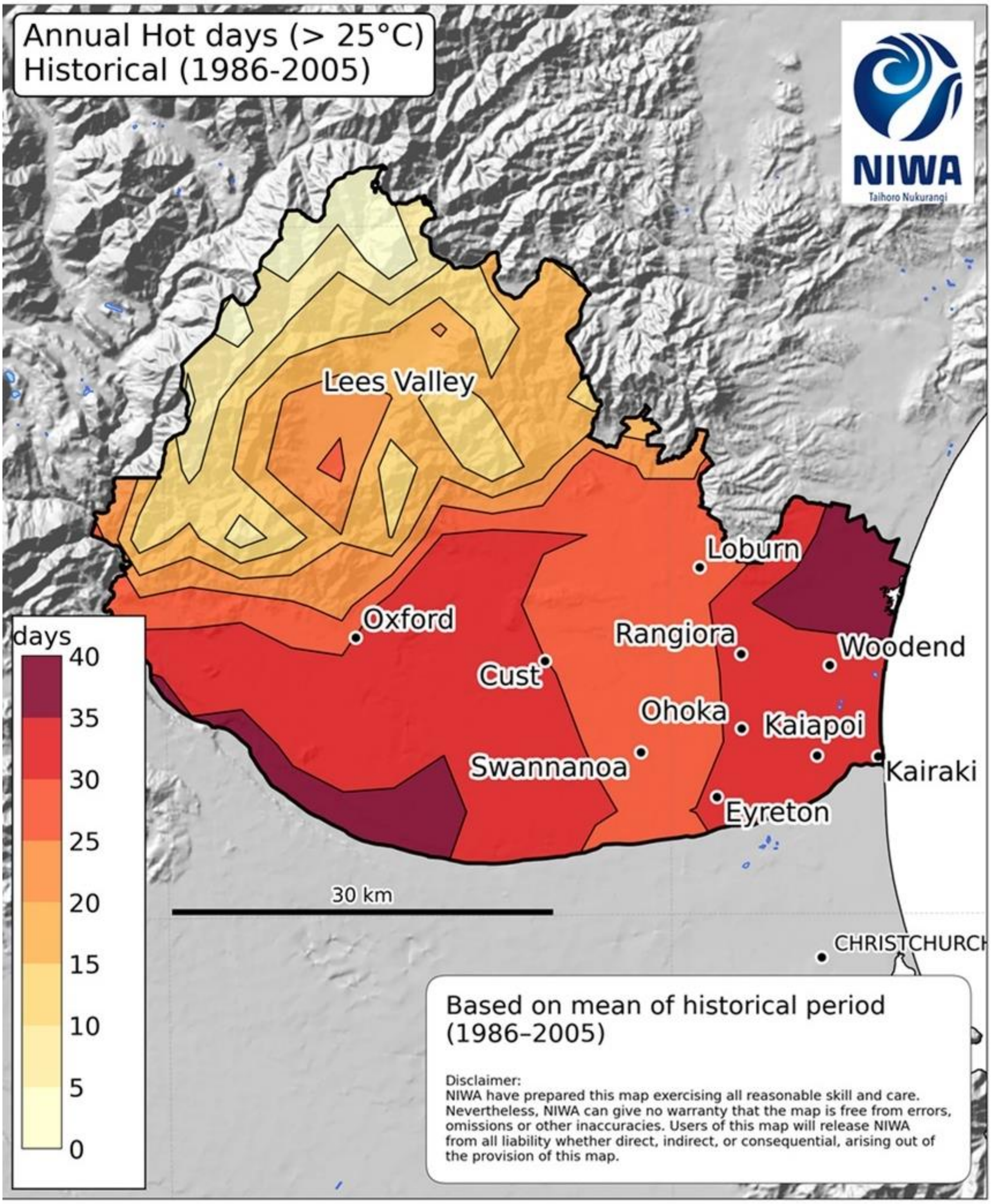

Figure A-7: Average number of hot days per year for Waimakariri District for the historic period (1986-2005).

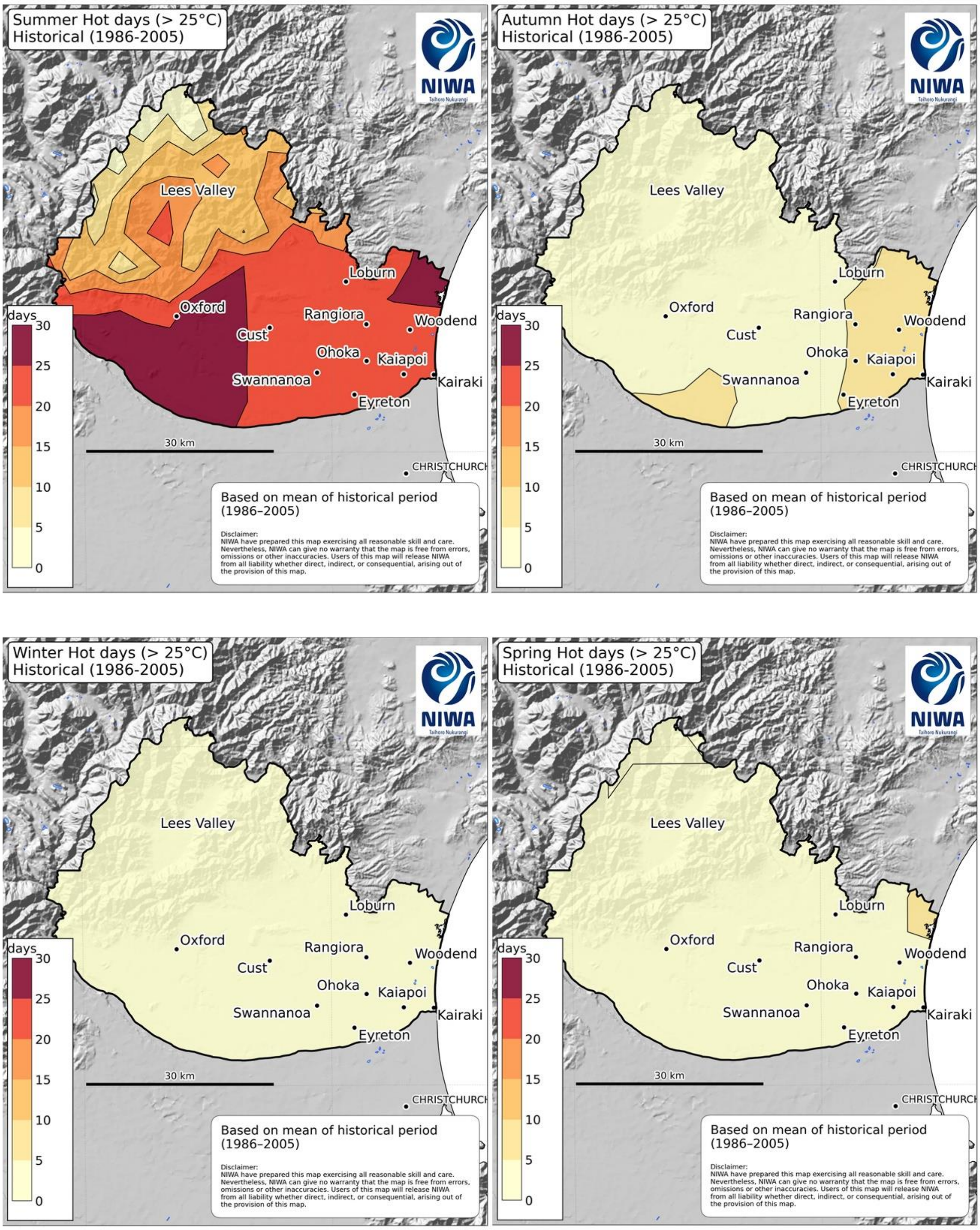

Figure A-8: Average number of hot days per year by season for Waimakariri District for the historic period (1986-2005).

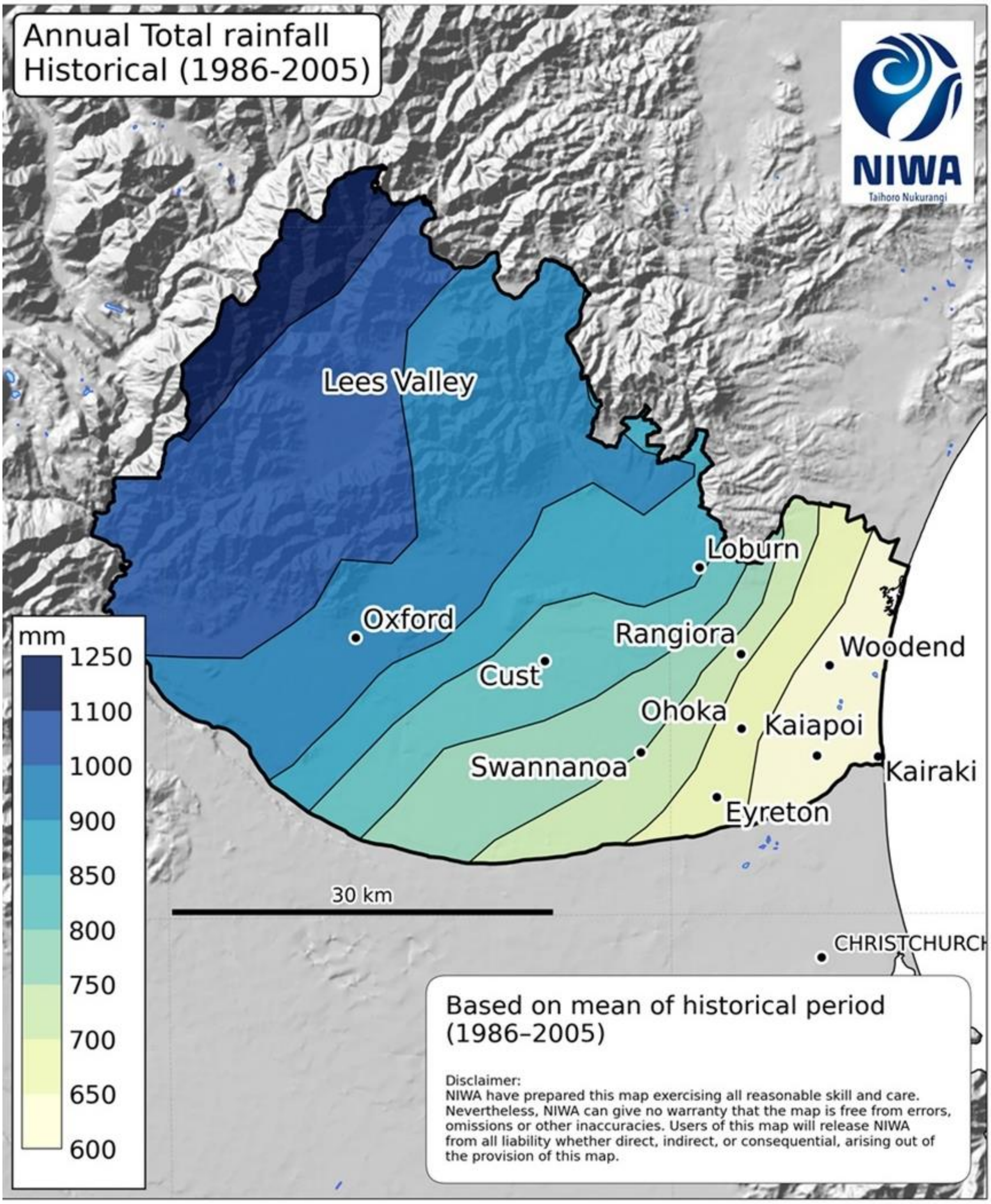

Figure A-9: Average rainfall for Waimakariri District for the historic period (1986-2005).

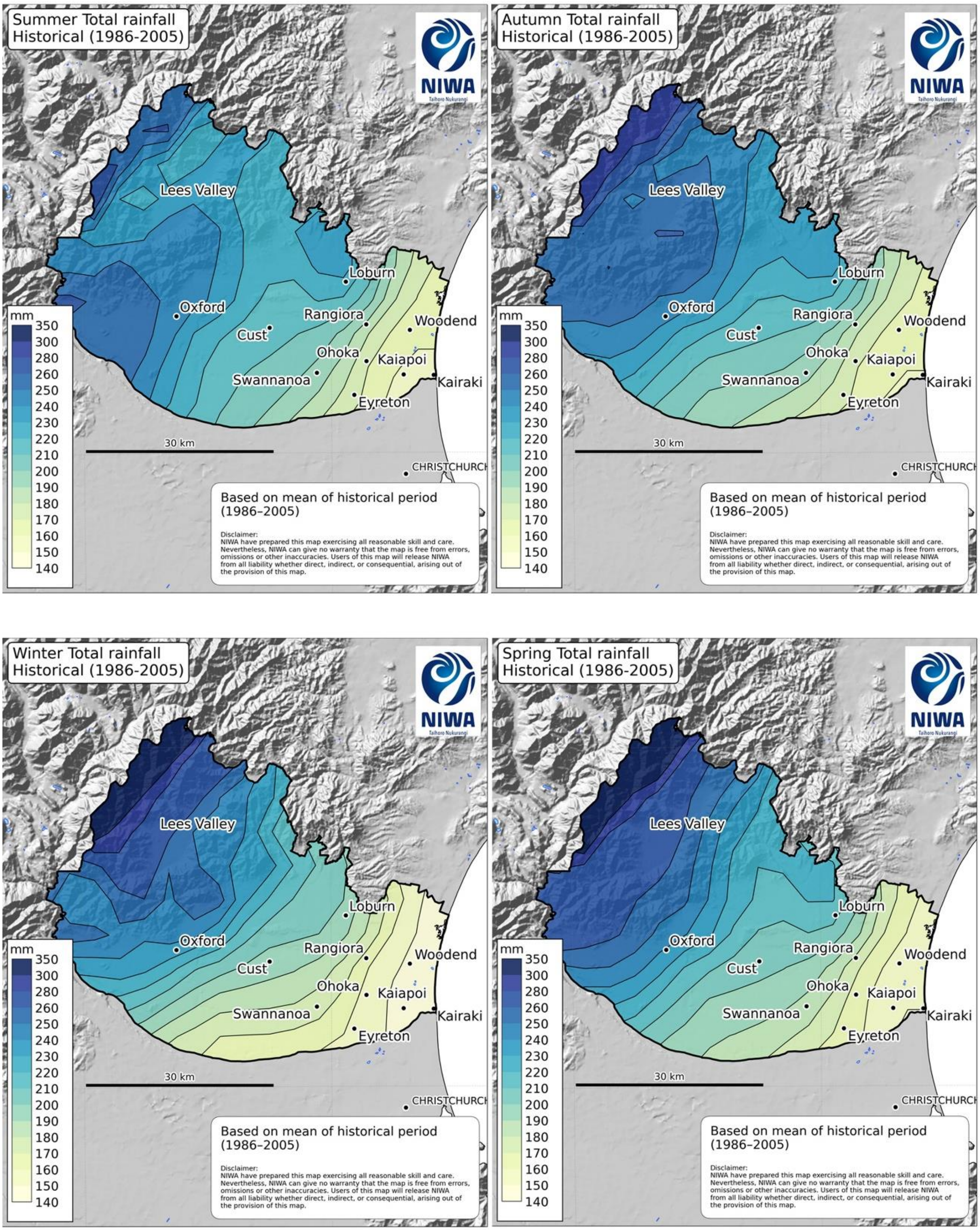

Figure A-10: Average rainfall for Waimakariri District by season for the historic period (1986-2005).

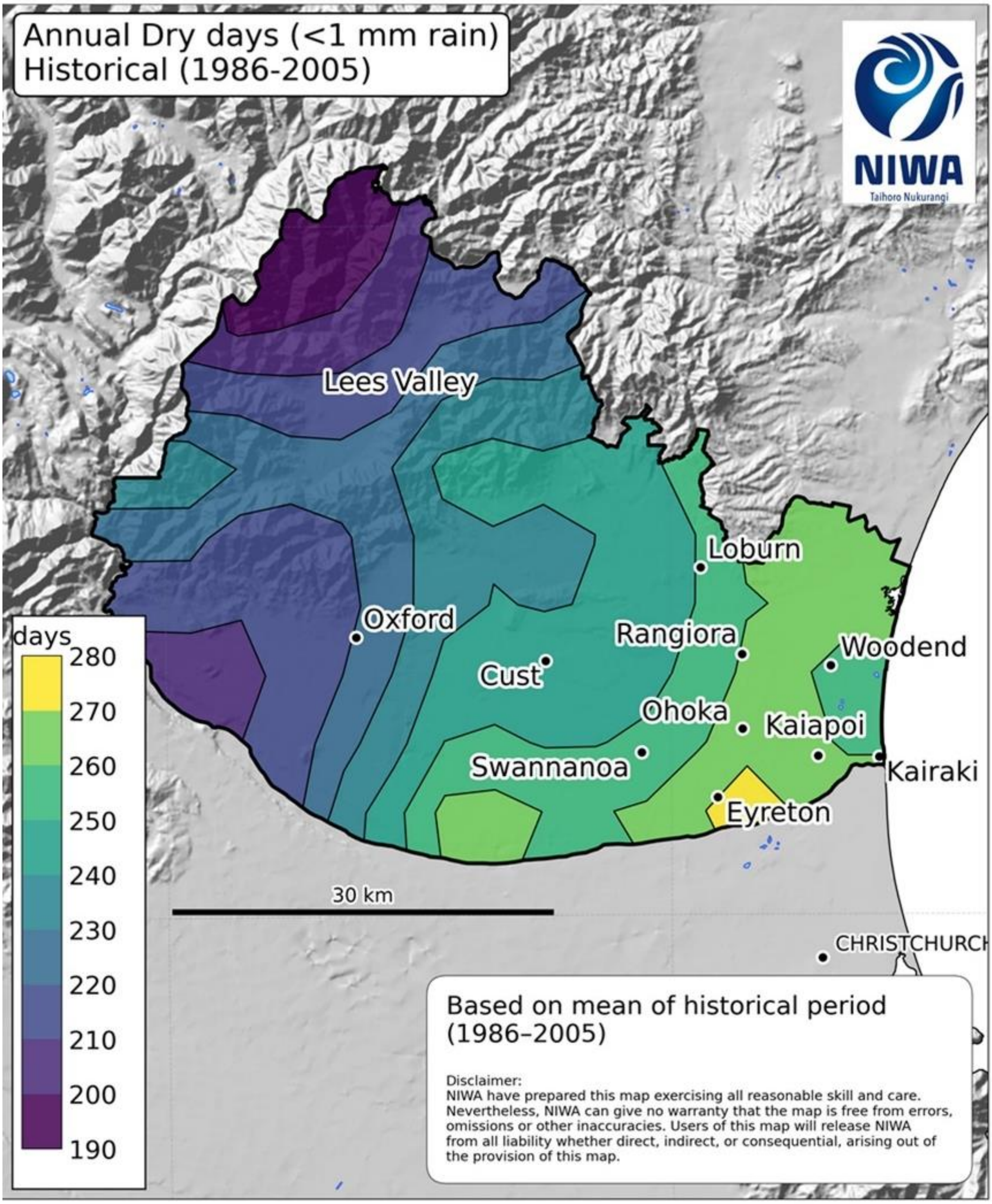

Figure A-11: Average number of dry days per year for Waimakariri District for the historic period (1986-2005).

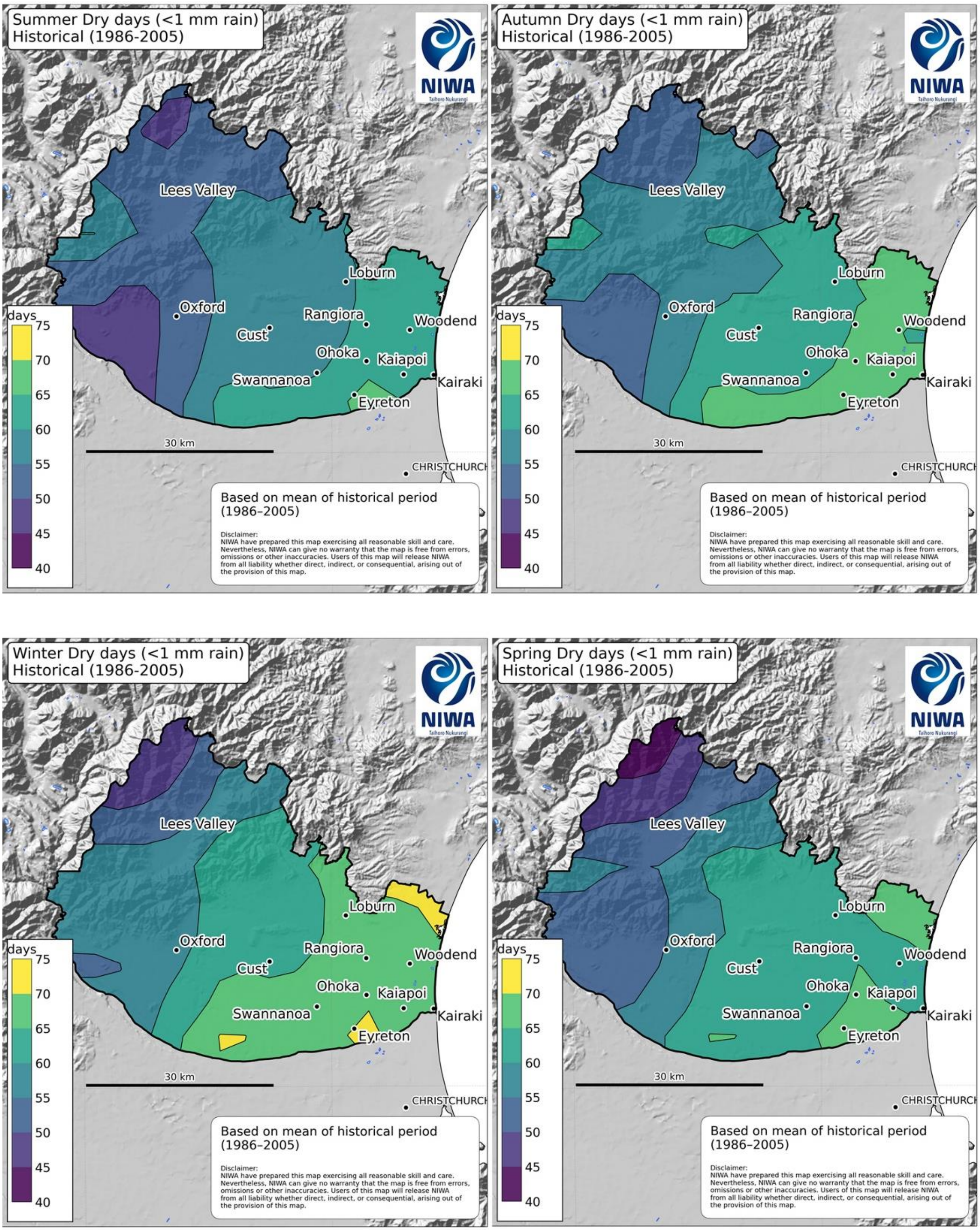

Figure A-12: Average number of dry days per year for Waimakariri District by season for the historic period (1986-2005).

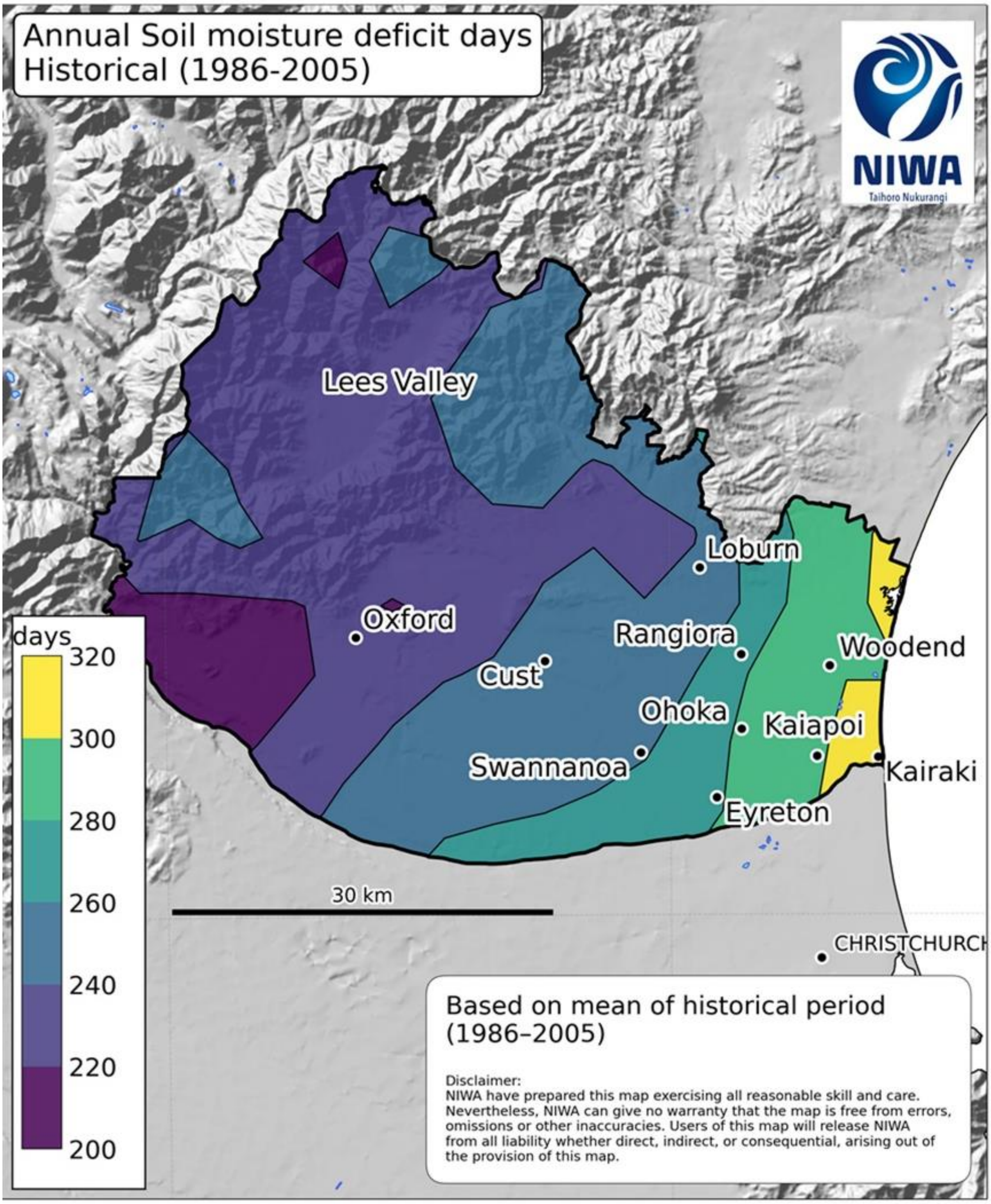

Figure A-13: Average number of soil moisture deficit days per year for Waimakariri District for the historic period (1986-2005).

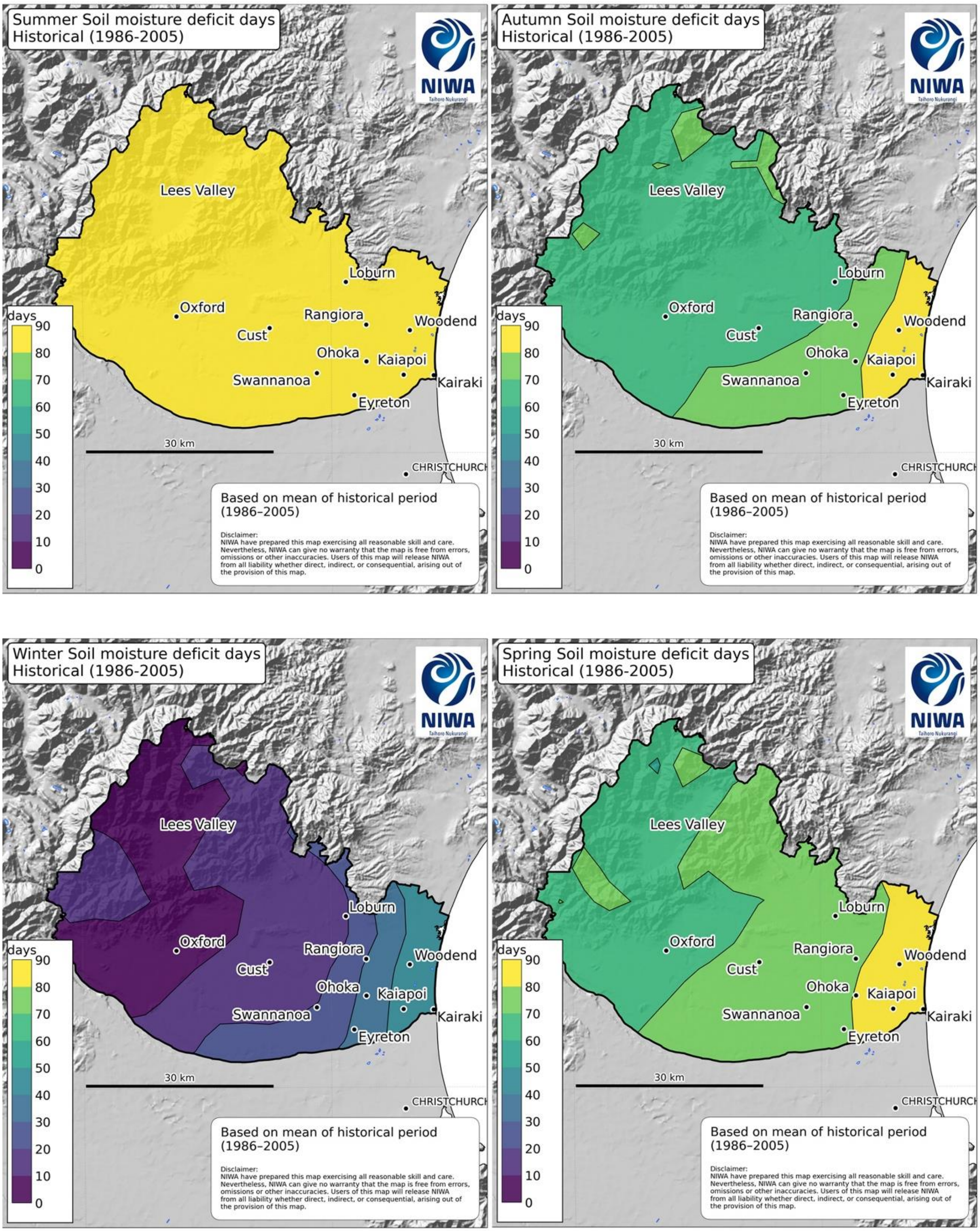

Figure A-14: Average number of soil moisture deficit days per year by season for Waimakariri District for the historic period (1986-2005).

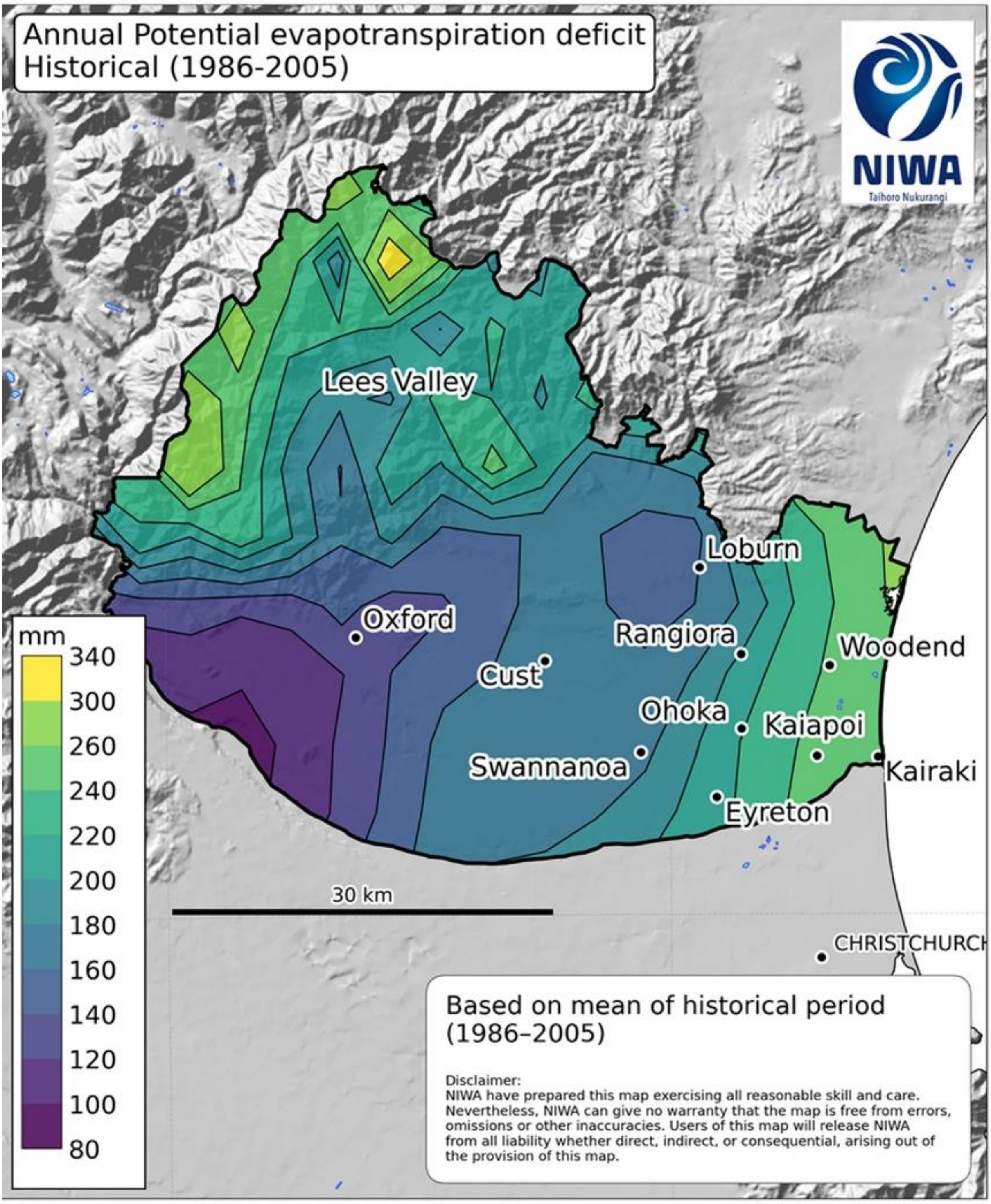

Figure A-15: Average annual potential evaporation deficit for Waimakariri District for the historic period (1986-2005).

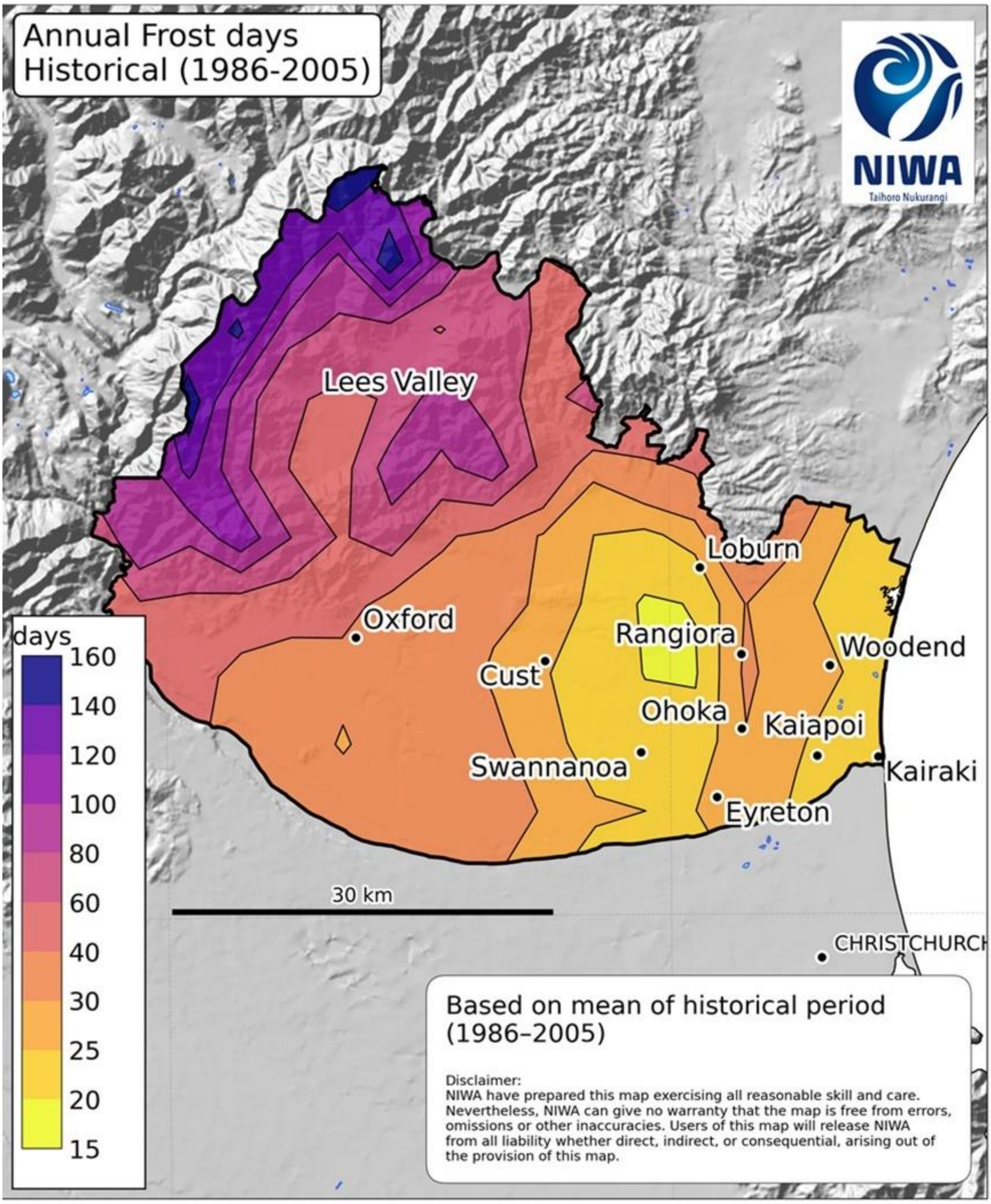

Figure A-16: Average number of frost days per year for Waimakariri District for the historic period (1986-2005).

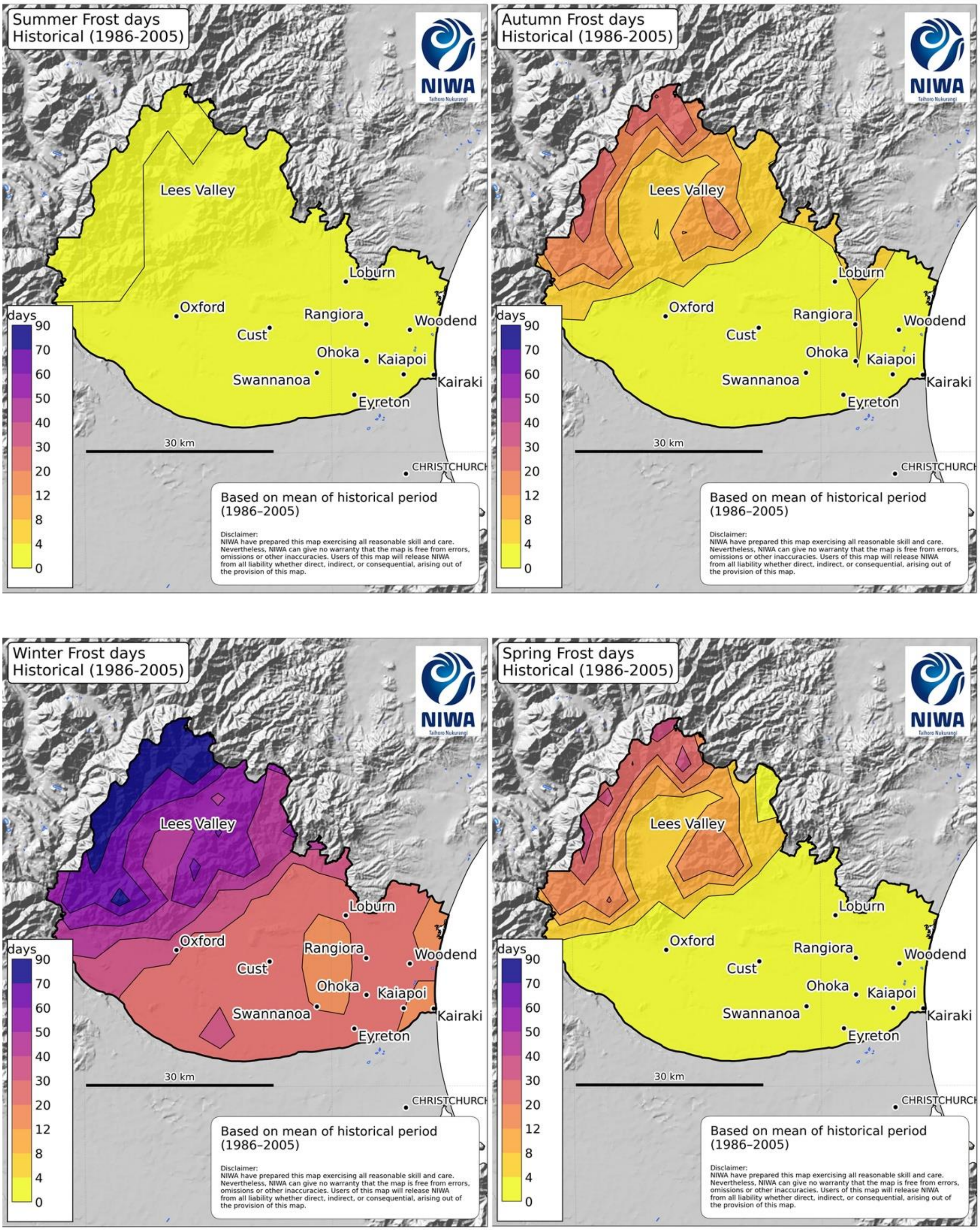

Figure A-17: Average number of frost days per year by season for Waimakariri District for the historic period (1986-2005).

Appendix B Supplementary Climate Change Projection Maps

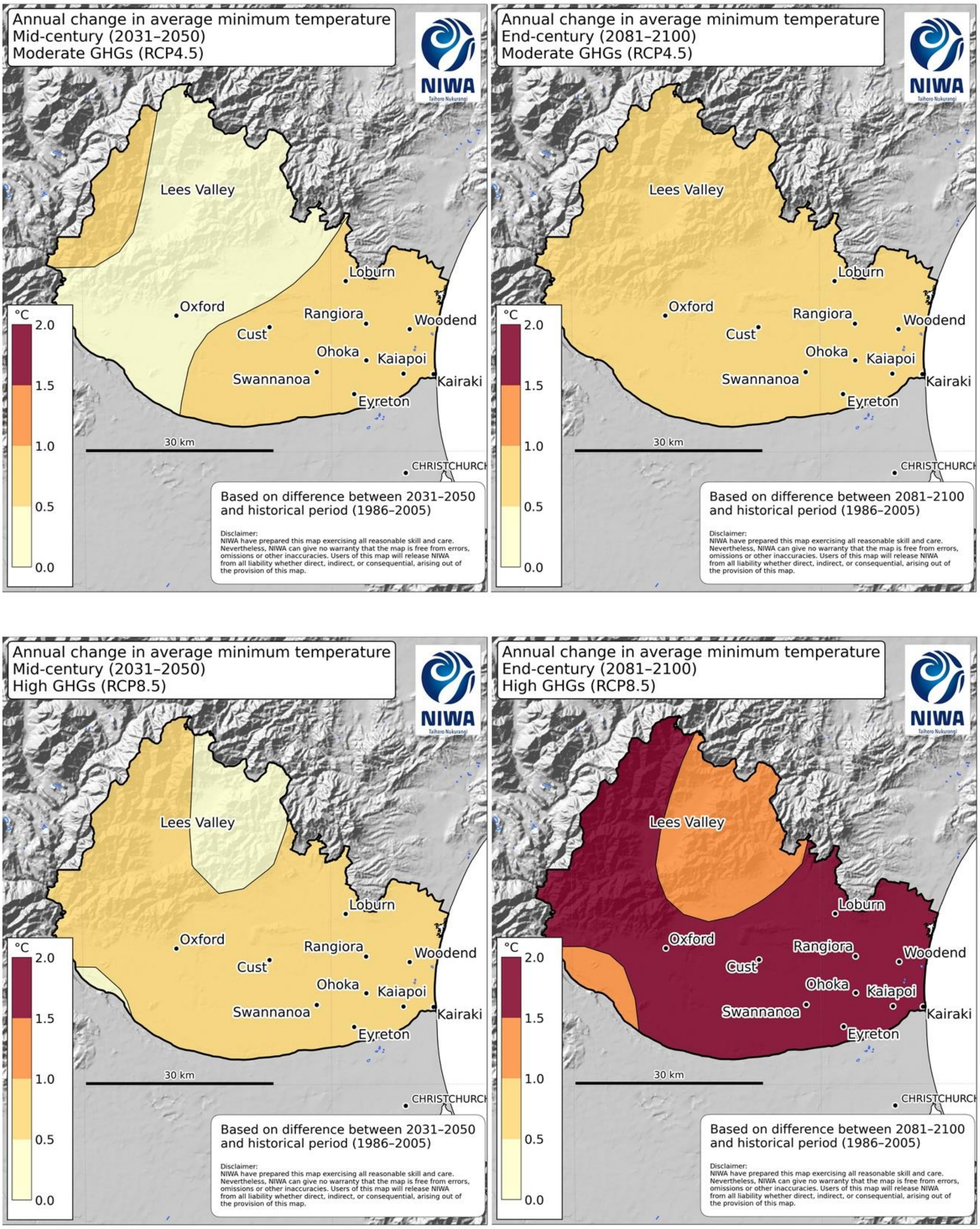

Figure B-1: Projected changes in average daily mean minimum air temperature (°C) for Waimakariri District. Projected changes are relative to the historic period (1986-2005).

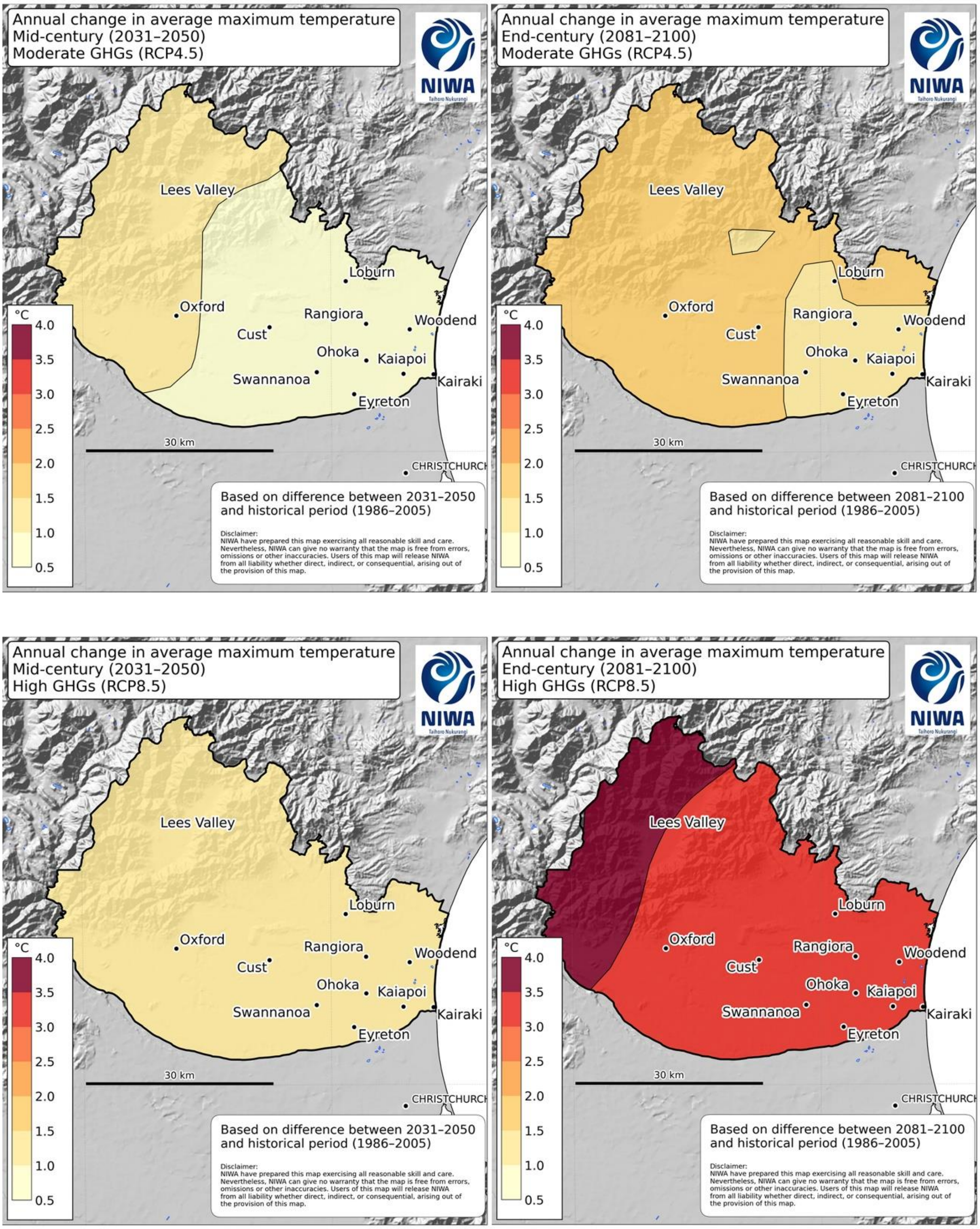

Figure B-2: Projected changes in average daily mean maximum air temperature (°C) for Waimakariri District. Projected changes are relative to the historic period (1986-2005).

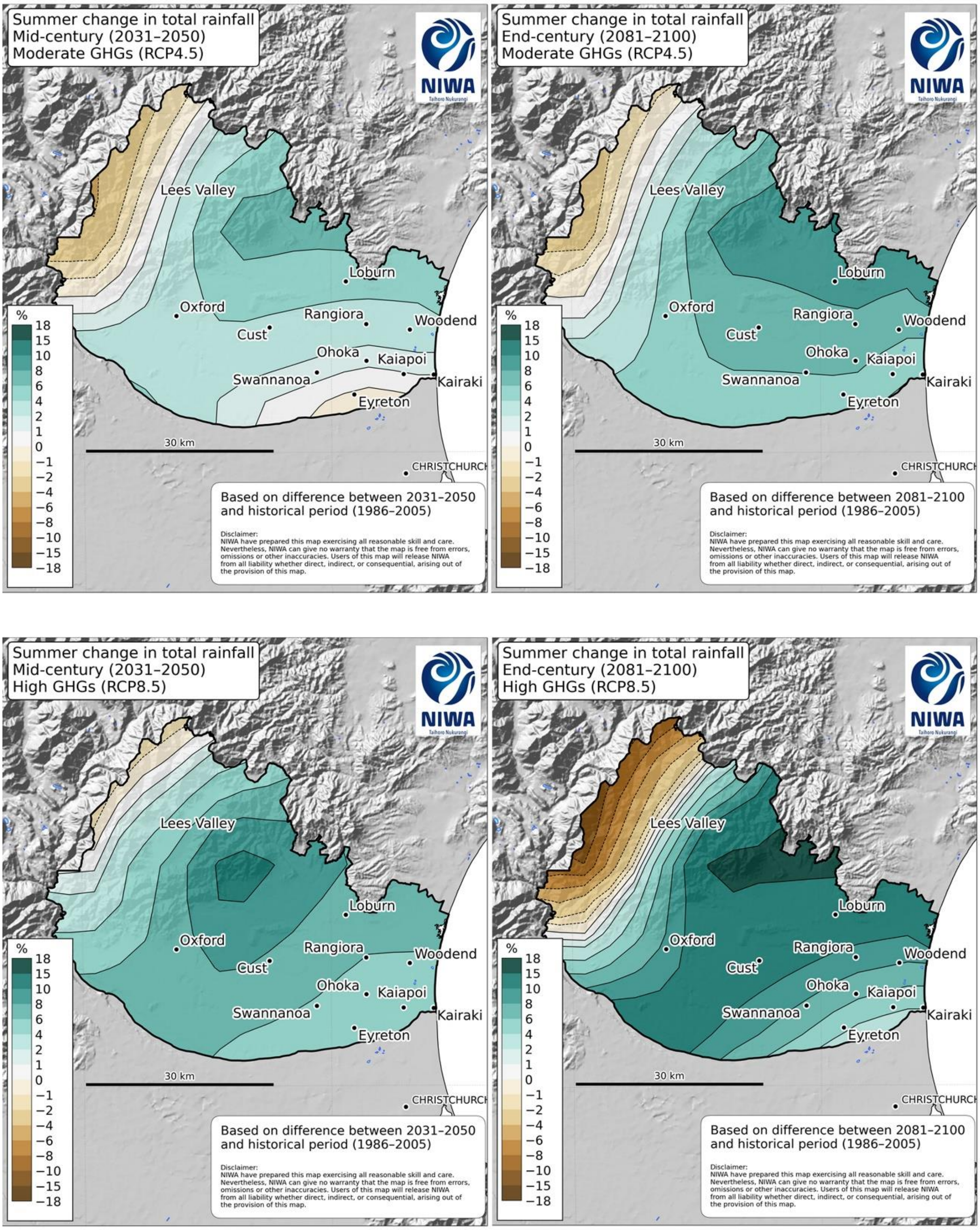

Figure B-3: Projected changes in summer total rainfall for Waimakariri District. Projected changes are relative to the historic period (1986-2005).

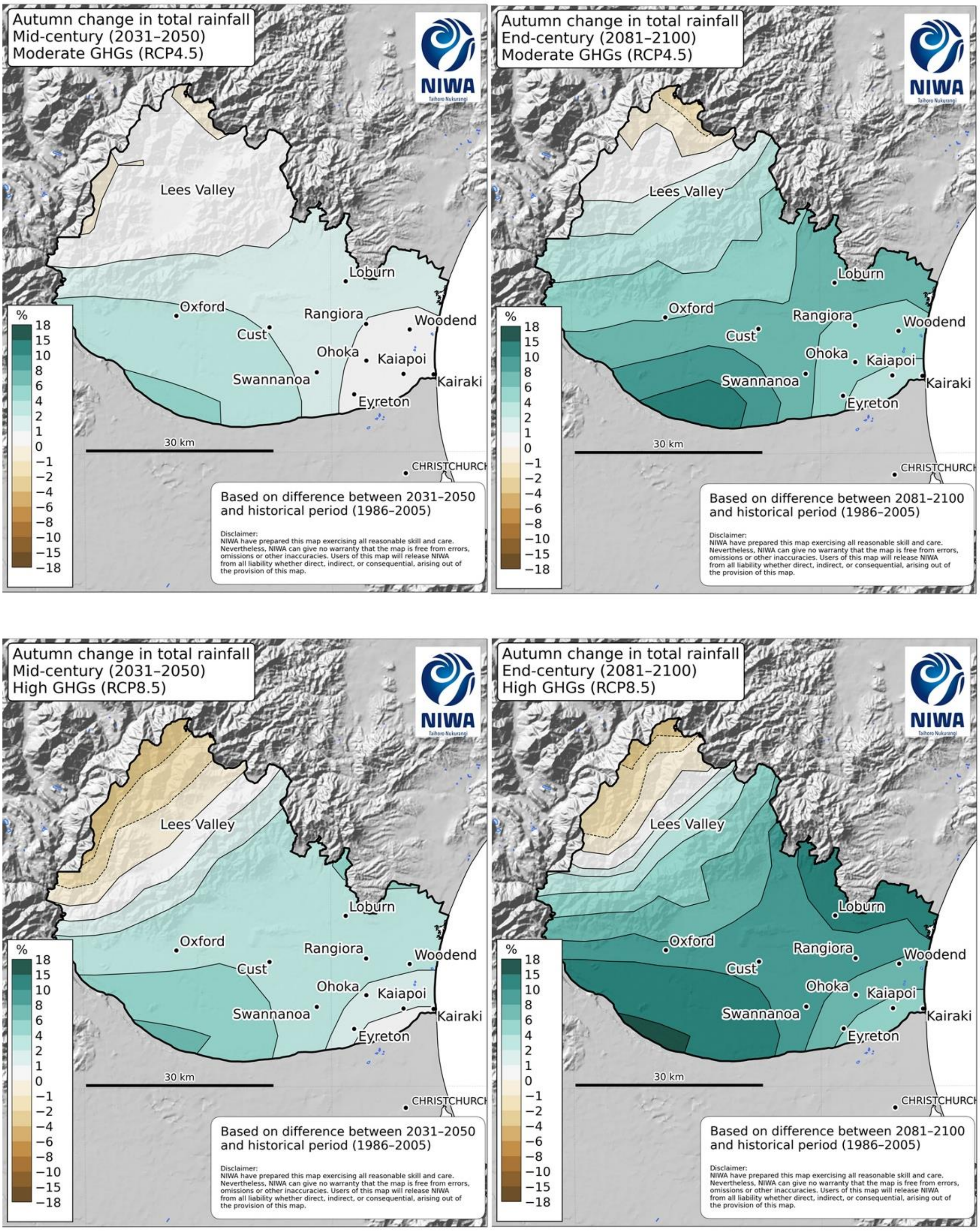

Figure B-4: Projected changes in autumn total rainfall for Waimakariri District. Projected changes are relative to the historic period (1986-2005).

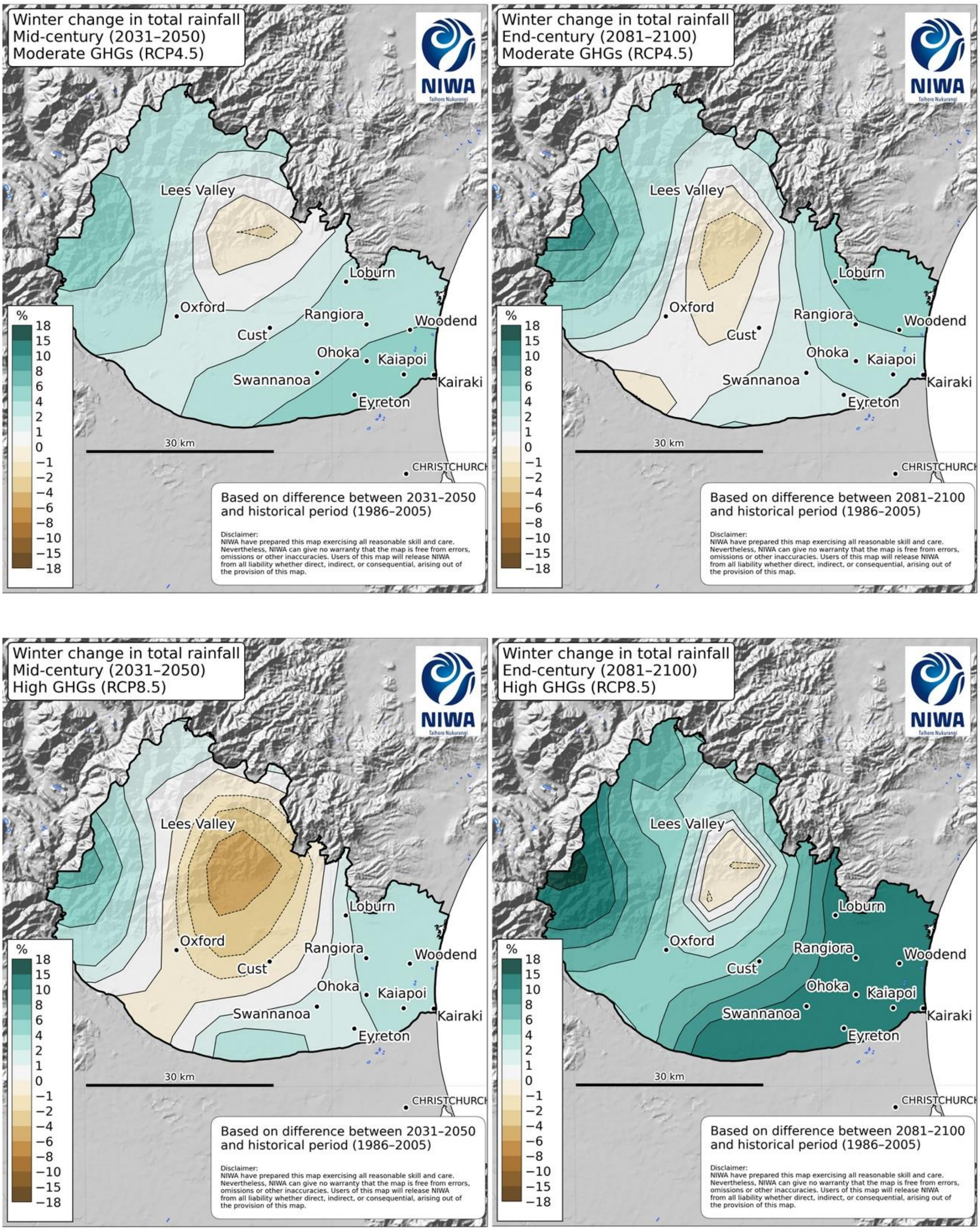

Figure B-5: Projected changes in winter total rainfall for Waimakariri District. Projected changes are relative to the historic period (1986-2005).

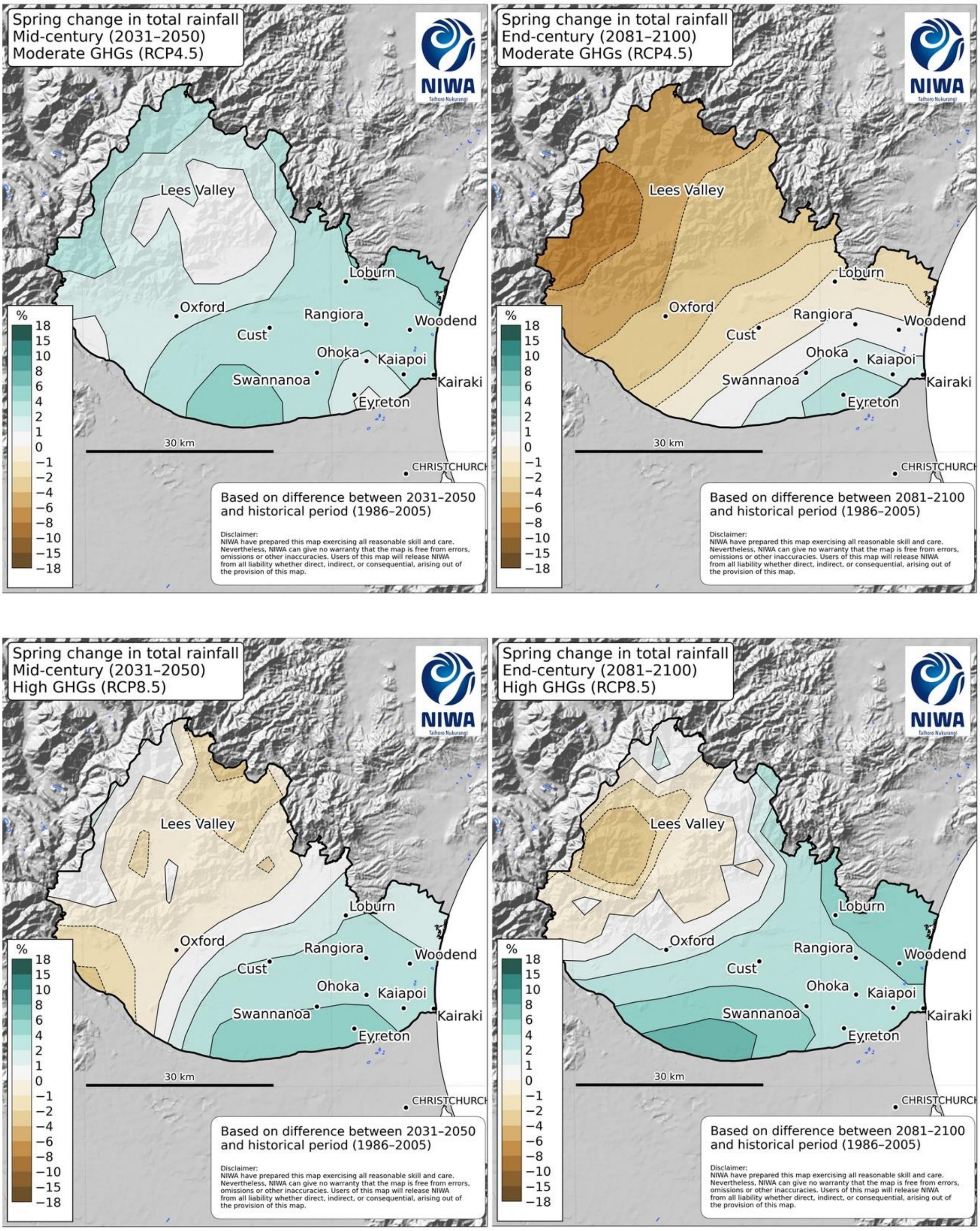

Figure B-6: Projected changes in spring total rainfall for Waimakariri District. Projected changes are relative to the historic period (1986-2005).

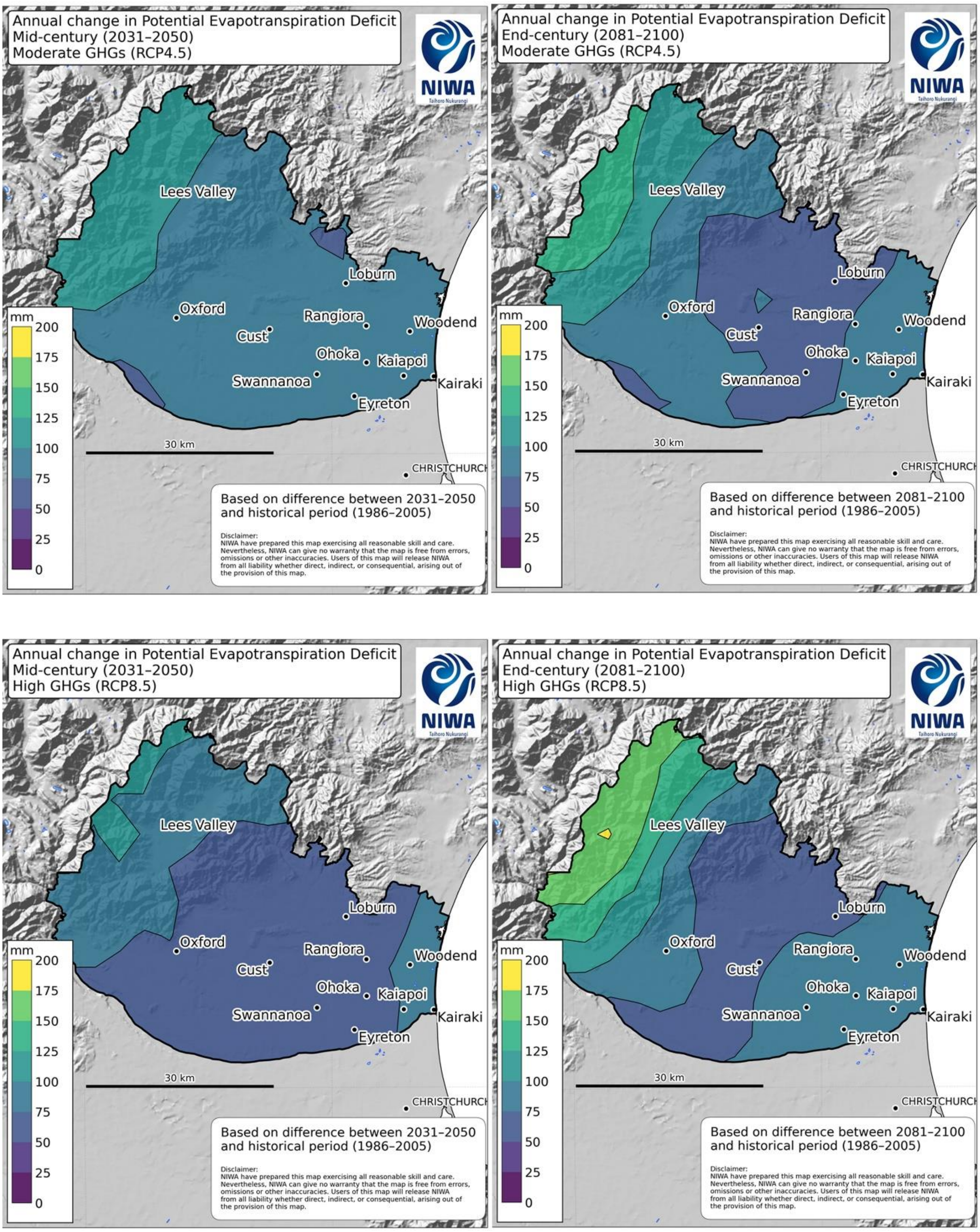

Figure B-7: Projected changes in potential evaporation deficit (mm) for Waimakariri District. Projected changes are relative to the historic period (1986-2005).

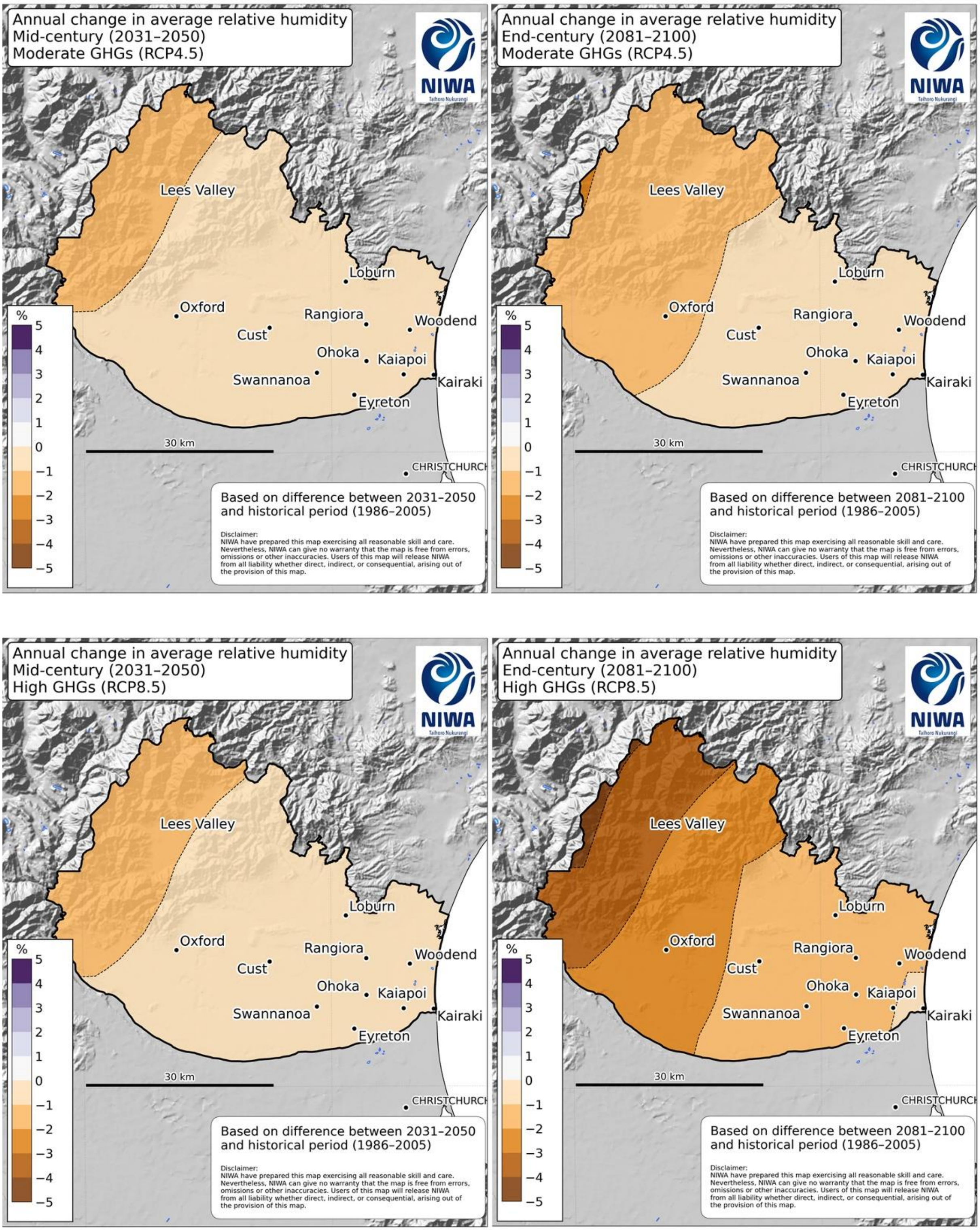

Figure B-8: Projected changes in relative humidity (%) for Waimakariri District. Projected changes are relative to the historic period (1986-2005).

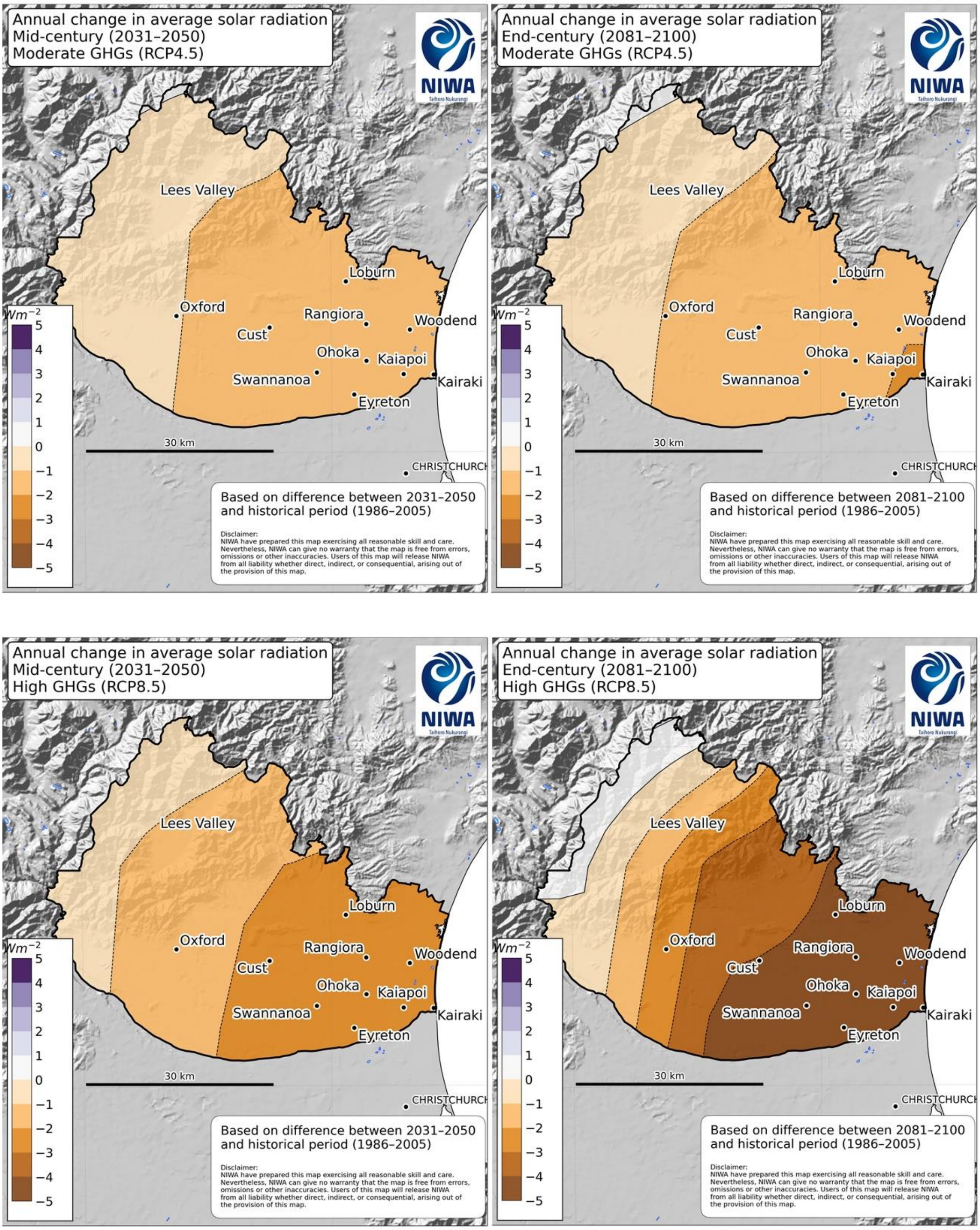

Figure B-9: Projected changes in solar radiation (Wm-2) for Waimakariri District. Projected changes are relative to the historic period (1986-2005).

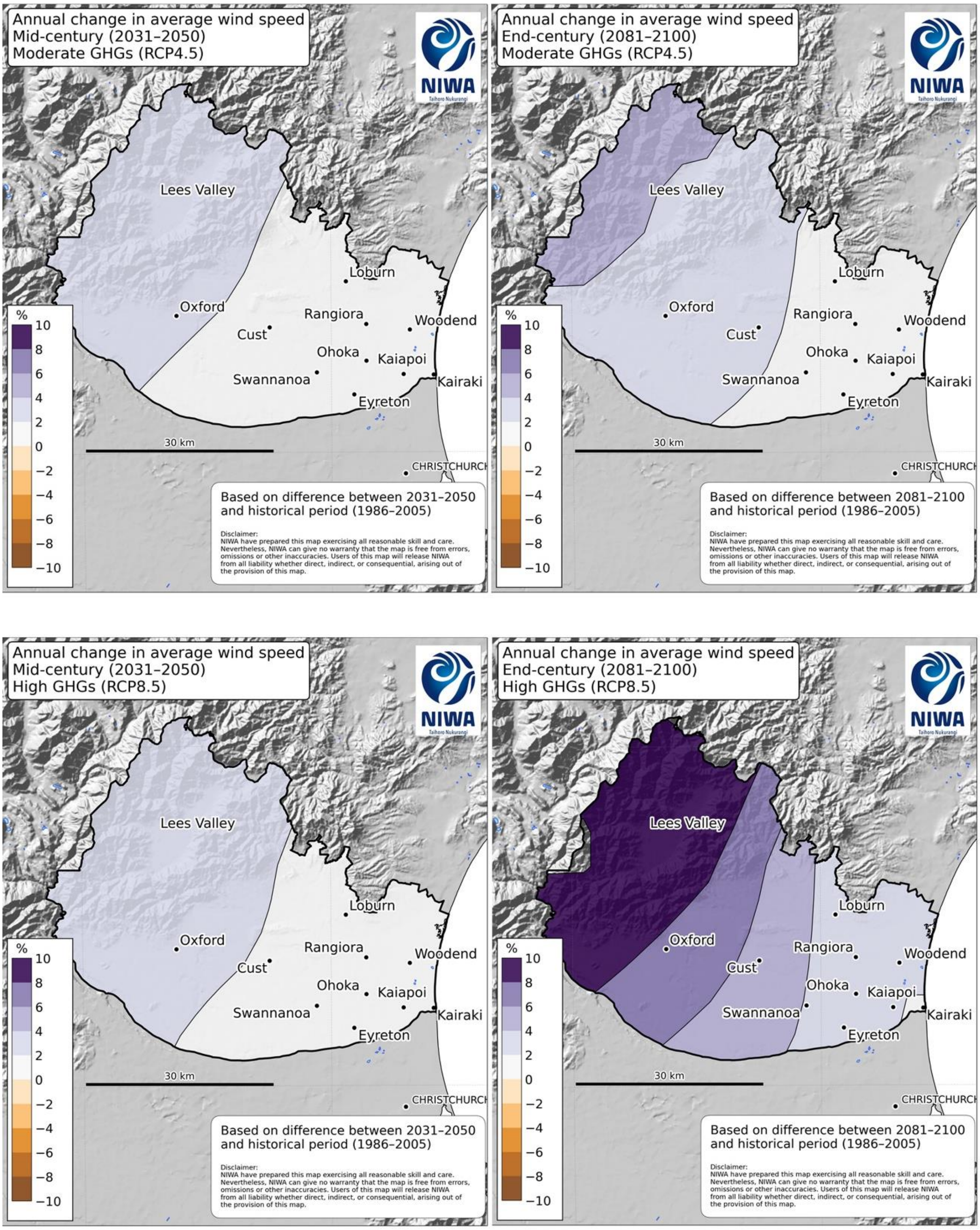

Figure B-10: Projected changes in wind speed (%) for Waimakariri District. Projected changes are relative to the historic period (1986-2005).

Appendix C Supplementary Tables

The following tables show the projected changes in climatic variables for different GHG scenarios. The tables include the projected annual and seasonal averages for different parts of the Waimakariri District. See Figure 2-2 for a map of sub-regional zones.

Table C-1: Overview of projected changes in daily mean temperature (°C) for different parts of the Waimakariri District. Mid-century = 2031-2050, end-century = 2081-2100, moderate GHGs = RCP4.5, high GHGs = RCP8.5. Note that the coloured bars are representative of the magnitude of change.

	moderate GHGs			*high GHGs*			*high - moderate GHGs**	
ANNUAL	*mid-century*	*end-century*	*50-yr change †*	*mid-century*	*end-century*	*50-yr change†*	*mid-century*	*end-century*
UPPER	0.8	1.3	0.5	0.9	2.5	1.6	0.1	1.3
COAST	0.7	1.2	0.4	0.8	2.4	1.5	0.1	1.2
INLAND	0.7	1.2	0.4	0.8	2.4	1.5	0.1	1.2
LEES VALLEY	0.8	1.2	0.5	0.9	2.5	1.6	0.1	1.2
DISTRICT	0.8	1.2	0.4	0.9	2.4	1.6	0.1	1.2
SUMMER								
UPPER	0.8	1.2	0.4	0.8	2.5	1.7	0.0	1.3
COAST	0.6	1.0	0.4	0.7	2.0	1.3	0.1	1.0
INLAND	0.7	1.0	0.4	0.7	2.1	1.4	0.0	1.1
LEES VALLEY	0.8	1.2	0.4	0.8	2.4	1.6	0.0	1.2
DISTRICT	0.7	1.1	0.4	0.8	2.2	1.5	0.0	1.1
AUTUMN								
UPPER	0.9	1.3	0.5	0.9	2.7	1.7	0.1	1.4
COAST	0.8	1.3	0.4	0.9	2.6	1.7	0.1	1.3
INLAND	0.8	1.3	0.4	0.9	2.6	1.7	0.1	1.3
LEES VALLEY	0.8	1.3	0.4	0.9	2.6	1.7	0.1	1.3
DISTRICT	0.8	1.3	0.5	0.9	2.6	1.7	0.1	1.3
WINTER								
UPPER	0.7	1.2	0.5	0.8	2.5	1.6	0.1	1.3
COAST	0.8	1.2	0.4	0.9	2.5	1.7	0.1	1.3
INLAND	0.7	1.2	0.4	0.8	2.5	1.7	0.1	1.3
LEES VALLEY	0.7	1.1	0.5	0.8	2.4	1.6	0.1	1.3
DISTRICT	0.7	1.2	0.5	0.8	2.5	1.7	0.1	1.3
SPRING								
UPPER	0.7	1.2	0.5	0.9	2.4	1.5	0.2	1.2
COAST	0.7	1.1	0.4	0.8	2.3	1.5	0.1	1.2
INLAND	0.7	1.1	0.5	0.8	2.3	1.5	0.1	1.2
LEES VALLEY	0.7	1.2	0.5	0.9	2.4	1.5	0.2	1.2
DISTRICT	0.7	1.2	0.5	0.8	2.3	1.5	0.1	1.2

† = "50-yr change" is the projected change in average daily mean temperature for a given GHG scenario between end-century and mid-century time periods (i.e., how will average daily mean temperature change between 2040 and 2090 for a given GHG scenario?).

**The two columns on the right-hand side ("high – moderate GHGs") show the difference in projected average daily mean temperature between high and moderate GHG concentration scenarios (what is the difference in projected average daily mean temperature for the RCP4.5 and RCP8.5 scenarios?).*

Table C-2: Overview of projected changes in average daily minimum temperature (°C) for different parts of the Waimakariri District. Mid-century = 2031-2050, end-century = 2081-2100, moderate GHGs = RCP4.5, high GHGs = RCP8.5. Note that the coloured bars are representative of the magnitude of change.

	moderate GHGs			***high GHGs***			***high - moderate GHGs****	
ANNUAL	*mid-century*	*end-century*	*50-yr change †*	*mid-century*	*end-century*	*50-yr change†*	*mid-century*	*end-century*
UPPER	0.5	0.8	0.3	0.5	1.5	1.0	0.1	0.7
COAST	0.5	0.8	0.3	0.6	1.7	1.1	0.1	0.8
INLAND	0.5	0.8	0.3	0.6	1.6	1.0	0.1	0.8
LEES VALLEY	0.5	0.7	0.3	0.5	1.5	1.0	0.0	0.7
DISTRICT	0.5	0.8	0.3	0.5	1.6	1.0	0.1	0.8
SUMMER								
UPPER	0.4	0.7	0.3	0.4	1.3	0.9	0.0	0.7
COAST	0.4	0.7	0.3	0.5	1.3	0.8	0.0	0.6
INLAND	0.4	0.7	0.3	0.4	1.3	0.9	0.0	0.6
LEES VALLEY	0.4	0.7	0.3	0.4	1.3	0.9	0.0	0.6
DISTRICT	0.4	0.7	0.3	0.4	1.3	0.9	0.0	0.6
AUTUMN								
UPPER	0.6	0.9	0.3	0.6	1.9	1.2	0.1	1.0
COAST	0.7	1.1	0.4	0.8	2.3	1.5	0.1	1.2
INLAND	0.6	1.0	0.4	0.7	2.1	1.4	0.1	1.1
LEES VALLEY	0.6	0.9	0.3	0.6	1.8	1.2	0.0	0.9
DISTRICT	0.6	1.0	0.4	0.7	2.1	1.3	0.1	1.1
WINTER								
UPPER	0.4	0.7	0.2	0.5	1.3	0.9	0.0	0.7
COAST	0.5	0.7	0.2	0.5	1.5	0.9	0.0	0.8
INLAND	0.5	0.7	0.2	0.5	1.4	0.9	0.0	0.7
LEES VALLEY	0.4	0.6	0.2	0.4	1.3	0.8	0.0	0.6
DISTRICT	0.4	0.7	0.2	0.5	1.4	0.9	0.0	0.7
SPRING								
UPPER	0.4	0.8	0.3	0.5	1.5	1.0	0.1	0.7
COAST	0.5	0.8	0.3	0.5	1.6	1.0	0.1	0.8
INLAND	0.4	0.7	0.3	0.5	1.5	1.0	0.1	0.7
LEES VALLEY	0.4	0.7	0.3	0.5	1.4	0.9	0.1	0.7
DISTRICT	0.4	0.8	0.3	0.5	1.5	1.0	0.1	0.7

† = "50-yr change" is the projected change in average daily minimum temperature for a given GHG scenario between end-century and mid-century time periods (i.e., how will average daily minimum temperature change between 2040 and 2090 for a given GHG scenario?).

**The two columns on the right-hand side ("high – moderate GHGs") show the difference in projected average daily minimum temperature between high and moderate GHG concentration scenarios (what is the difference in projected average daily minimum temperature for the RCP4.5 and RCP8.5 scenarios?).*

Table C-3: Overview of projected changes in average daily maximum temperature (°C) for different parts of the Waimakariri District. Mid-century = 2031-2050, end-century = 2081-2100, moderate GHGs = RCP4.5, high GHGs = RCP8.5. Note that the coloured bars are representative of the magnitude of change.

	moderate GHGs			***high GHGs***			***high - moderate GHGs****	
ANNUAL	*mid-century*	*end-century*	*50-yr change †*	*mid-century*	*end-century*	*50-yr change†*	*mid-century*	*end-century*
UPPER	1.1	1.7	0.6	1.3	3.5	2.3	0.1	1.8
COAST	1.0	1.5	0.5	1.1	3.0	2.0	0.1	1.6
INLAND	1.0	1.6	0.6	1.1	3.2	2.1	0.1	1.6
LEES VALLEY	1.1	1.7	0.6	1.2	3.5	2.2	0.1	1.8
DISTRICT	1.0	1.6	0.6	1.2	3.3	2.1	0.1	1.7
SUMMER								
UPPER	1.2	1.7	0.5	1.2	3.7	2.4	0.1	1.9
COAST	0.9	1.3	0.4	0.9	2.6	1.7	0.1	1.3
INLAND	1.0	1.4	0.4	1.0	2.9	1.9	0.0	1.5
LEES VALLEY	1.1	1.7	0.5	1.2	3.5	2.3	0.1	1.9
DISTRICT	1.0	1.5	0.5	1.1	3.2	2.1	0.1	1.7
AUTUMN								
UPPER	1.1	1.7	0.6	1.2	3.5	2.2	0.1	1.7
COAST	1.0	1.5	0.5	1.1	2.9	1.8	0.1	1.4
INLAND	1.0	1.5	0.5	1.1	3.0	1.9	0.1	1.5
LEES VALLEY	1.1	1.7	0.6	1.2	3.4	2.2	0.1	1.7
DISTRICT	1.0	1.6	0.5	1.1	3.2	2.0	0.1	1.6
WINTER								
UPPER	1.0	1.7	0.7	1.2	3.6	2.4	0.2	1.9
COAST	1.0	1.7	0.7	1.2	3.6	2.4	0.2	1.9
INLAND	1.0	1.7	0.7	1.2	3.6	2.4	0.2	1.9
LEES VALLEY	1.0	1.7	0.7	1.2	3.5	2.4	0.2	1.9
DISTRICT	1.0	1.7	0.7	1.2	3.6	2.4	0.2	1.9
SPRING								
UPPER	1.0	1.7	0.7	1.2	3.3	2.1	0.2	1.6
COAST	0.9	1.4	0.5	1.0	3.0	1.9	0.2	1.6
INLAND	0.9	1.5	0.6	1.1	3.1	2.0	0.2	1.6
LEES VALLEY	1.0	1.7	0.7	1.2	3.3	2.1	0.2	1.6
DISTRICT	0.9	1.6	0.6	1.1	3.2	2.0	0.2	1.6

† = "50-yr change" is the projected change in average daily maximum temperature for a given GHG scenario between end-century and mid-century time periods (i.e., how will average daily maximum temperature change between 2040 and 2090 for a given GHG scenario?).

**The two columns on the right-hand side ("high – moderate GHGs") show the difference in projected average daily maximum temperature between high and moderate GHG concentration scenarios (what is the difference in projected average daily maximum temperature for the RCP4.5 and RCP8.5 scenarios?).*

Table C-4: Overview of projected changes in hot days (> 25 °C) per year for different parts of the Waimakariri District. Mid-century = 2031-2050, end-century = 2081-2100, moderate GHGs = RCP4.5, high GHGs = RCP8.5. Note that the coloured bars are representative of the magnitude of change.

	moderate GHGs			*high GHGs*			*high - moderate GHGs**	
ANNUAL	*mid-century*	*end-century*	*50-yr change †*	*mid-century*	*end-century*	*50-yr change†*	*mid-century*	*end-century*
UPPER	12	18	6	13	43	30	1	25
COAST	13	20	7	15	41	26	2	21
INLAND	15	22	7	17	46	29	2	24
LEES VALLEY	14	21	7	15	47	33	1	26
DISTRICT	13	20	7	15	44	29	1	24
SUMMER								
UPPER	9	13	4	9	29	19	0	15
COAST	8	11	3	8	19	11	0	9
INLAND	9	12	3	10	23	14	0	11
LEES VALLEY	11	15	4	11	31	20	0	16
DISTRICT	9	12	3	9	25	16	0	12
AUTUMN								
UPPER	2	3	1	2	8	6	1	5
COAST	3	4	2	3	10	6	1	5
INLAND	3	5	2	4	11	7	1	6
LEES VALLEY	2	3	1	3	9	7	1	6
DISTRICT	2	4	2	3	9	6	1	5
WINTER								
UPPER	0	0	0	0	0	0	0	0
COAST	0	0	0	0	0	0	0	0
INLAND	0	0	0	0	0	0	0	0
LEES VALLEY	0	0	0	0	0	0	0	0
DISTRICT	0	0	0	0	0	0	0	0
SPRING								
UPPER	1	2	1	1	6	5	0	4
COAST	3	5	2	4	12	8	1	7
INLAND	3	5	2	3	12	9	1	7
LEES VALLEY	1	2	1	1	7	6	0	5
DISTRICT	2	4	2	2	10	7	1	6

† = "50-yr change" is the projected change in hot days for a given GHG scenario between end-century and mid-century time periods (i.e., how will hot days change between 2040 and 2090 for a given GHG scenario?).

** The two columns on the right-hand side ("high – moderate GHGs") show the difference in projected hot days between high and moderate GHG concentration scenarios (what is the difference in projected hot days for the RCP4.5 and RCP8.5 scenarios?).*

Table C-5: Overview of projected changes in percentage of rainfall for different parts of the Waimakariri District. Mid-century = 2031-2050, end-century = 2081-2100, moderate GHGs = RCP4.5, high GHGs = RCP8.5. Note that the coloured bars are representative of the magnitude of change.

	moderate GHGs			*high GHGs*			*high - moderate GHGs**	
ANNUAL	*mid-century*	*end-century*	*50-yr change †*	*mid-century*	*end-century*	*50-yr change†*	*mid-century*	*end-century*
UPPER	1.6%	0.8%	-0.8%	1.3%	3.0%	1.7%	-0.3%	2.2%
COAST	2.6%	4.2%	1.5%	3.4%	8.2%	4.9%	0.7%	4.1%
INLAND	2.5%	3.1%	0.6%	3.0%	7.6%	4.6%	0.5%	4.5%
LEES VALLEY	1.4%	0.7%	-0.7%	1.2%	2.4%	1.3%	-0.2%	1.8%
DISTRICT	2.2%	2.4%	0.2%	2.4%	5.9%	3.5%	-0.2%	1.8%
SUMMER								
UPPER	1.4%	2.6%	1.2%	4.5%	3.0%	-1.5%	3.0%	0.3%
COAST	3.0%	7.0%	4.0%	5.9%	8.2%	2.3%	2.9%	1.3%
INLAND	3.3%	5.9%	2.6%	7.0%	7.6%	0.6%	3.7%	1.8%
LEES VALLEY	2.3%	3.5%	1.2%	5.9%	2.4%	-3.5%	3.7%	-1.1%
DISTRICT	2.4%	4.6%	2.2%	5.6%	6.3%	0.7%	3.3%	1.7%
AUTUMN								
UPPER	0.7%	2.3%	1.6%	0.4%	3.4%	3.0%	-0.3%	1.1%
COAST	0.9%	5.4%	4.5%	2.4%	8.3%	5.8%	1.5%	2.9%
INLAND	2.2%	6.8%	4.6%	3.7%	10.1%	6.4%	1.5%	3.3%
LEES VALLEY	0.4%	1.7%	1.3%	0.2%	2.5%	2.3%	-0.2%	0.8%
DISTRICT	1.4%	4.9%	3.4%	2.2%	7.2%	5.0%	0.7%	2.3%
WINTER								
UPPER	2.5%	3.1%	0.6%	0.7%	6.4%	5.7%	-1.8%	3.4%
COAST	3.7%	4.0%	0.3%	2.6%	12.0%	9.4%	-1.1%	8.0%
INLAND	2.2%	1.4%	-0.8%	0.1%	7.3%	7.2%	-2.0%	5.9%
LEES VALLEY	2.0%	2.2%	0.2%	-0.5%	4.6%	5.2%	-2.6%	2.4%
DISTRICT	2.6%	2.6%	-0.1%	0.9%	8.0%	7.0%	-1.7%	5.4%
SPRING								
UPPER	1.6%	-4.8%	-6.5%	-0.5%	-0.2%	0.3%	-2.1%	4.7%
COAST	3.0%	0.3%	-2.7%	2.6%	4.0%	1.5%	-0.4%	3.7%
INLAND	2.5%	-1.5%	-4.0%	1.4%	3.2%	1.8%	-1.1%	4.7%
LEES VALLEY	0.9%	-4.9%	-5.7%	-0.8%	-1.3%	-0.4%	-1.7%	3.6%
DISTRICT	2.37%	-2.53%	-4.89%	0.90%	2.14%	1.24%	-1.46%	4.67%

† = "50-yr change" is the projected change in rainfall for a given GHG scenario between end-century and mid-century time periods (i.e., how will rainfall change between 2040 and 2090 for a given GHG scenario?).

** The two columns on the right-hand side ("high – moderate GHGs") show the difference in projected rainfall between high and moderate GHG concentration scenarios (what is the difference in projected rainfall for the RCP4.5 and RCP8.5 scenarios?).*

Table C-6: Overview of projected changes in dry days (< 1 mm rain) per year for different parts of the Waimakariri District. Mid-century = 2031-2050, end-century = 2081-2100, moderate GHGs = RCP4.5, high GHGs = RCP8.5. Note that the coloured bars are representative of the magnitude of change.

	moderate GHGs			***high GHGs***			***high - moderate GHGs****	
ANNUAL	*mid-century*	*end-century*	*50-yr change †*	*mid-century*	*end-century*	*50-yr change†*	*mid-century*	*end-century*
UPPER	1	2	2	1	1	0	0	-1
COAST	-1	-2	-1	-2	-4	-2	-1	-3
INLAND	-2	-1	0	-3	-5	-3	-1	-4
LEES VALLEY	0	2	2	0	-1	-1	0	-2
DISTRICT	-1	0	1	-1	-3	-1	-1	-3
SUMMER								
UPPER	1	0	-1	0	0	-1	-1	-1
COAST	1	0	-1	0	-1	-1	0	-1
INLAND	0	-1	0	-1	-2	-2	-1	-2
LEES VALLEY	1	0	-1	0	-1	-1	-1	-1
DISTRICT	0	0	-1	0	-1	-1	-1	-1
AUTUMN								
UPPER	0	0	0	-1	-1	-1	0	-1
COAST	0	-1	-1	-1	-2	-1	-1	-1
INLAND	-1	-1	0	-2	-3	-2	-1	-2
LEES VALLEY	0	0	0	-1	-2	-1	0	-2
DISTRICT	0	-1	0	-1	-2	-1	-1	-2
WINTER								
UPPER	0	0	1	0	1	1	0	0
COAST	-1	-1	0	-1	-1	0	0	0
INLAND	0	0	1	0	0	0	0	0
LEES VALLEY	0	0	1	0	1	1	1	0
DISTRICT	0	0	0	0	0	1	0	0
SPRING								
UPPER	0	2	1	1	2	1	1	0
COAST	-1	0	1	0	0	0	0	-1
INLAND	0	0	1	0	0	0	0	0
LEES VALLEY	0	2	1	1	2	1	1	0
DISTRICT	0	1	1	0	1	0	1	0

† = "50-yr change" is the projected change in dry days for a given GHG scenario between end-century and mid-century time periods (i.e., how will dry days change between 2040 and 2090 for a given GHG scenario?).

** The two columns on the right-hand side ("high – moderate GHGs") show the difference in projected dry days between high and moderate GHG concentration scenarios (what is the difference in projected dry days for the RCP4.5 and RCP8.5 scenarios?).*

Table C-7: Overview of projected changes in soil moisture deficit days per year for different parts of the Waimakariri District. Mid-century = 2031-2050, end-century = 2081-2100, moderate GHGs = RCP4.5, high GHGs = RCP8.5. Note that the coloured bars are representative of the magnitude of change.

	moderate GHGs			*high GHGs*			*high - moderate GHGs**	
ANNUAL	*mid-century*	*end-century*	*50-yr change †*	*mid-century*	*end-century*	*50-yr change†*	*mid-century*	*end-century*
UPPER	-4	4	8	-2	5	7	2	1
COAST	-6	3	9	-2	-1	1	4	-4
INLAND	-5	2	7	-3	2	5	2	-1
LEES VALLEY	-2	6	8	0	9	9	2	2
DISTRICT	-5	3	8	-2	2	5	2	-1
SUMMER								
UPPER	-1	-1	0	-1	-1	0	0	0
COAST	-1	-1	0	0	-1	0	0	0
INLAND	-1	-1	0	-1	-1	0	0	-1
LEES VALLEY	-1	-1	0	-1	-1	0	0	0
DISTRICT	-1	-1	0	-1	-1	0	0	0
AUTUMN								
UPPER	0	0	0	-1	1	1	0	0
COAST	0	0	0	-1	-2	-1	-1	-2
INLAND	-1	-1	0	-2	-3	-2	-1	-2
LEES VALLEY	0	1	1	0	2	2	-1	1
DISTRICT	-1	-1	0	-1	-2	0	0	-1
WINTER								
UPPER	-1	3	3	0	3	3	1	1
COAST	-4	3	7	0	1	1	4	-2
INLAND	-1	3	4	0	4	3	2	1
LEES VALLEY	0	4	4	1	5	3	1	1
DISTRICT	-2	3	4	0	3	3	2	0
SPRING								
UPPER	-2	2	3	-1	2	2	1	0
COAST	-1	1	2	0	1	1	1	0
INLAND	-1	2	3	0	3	3	0	1
LEES VALLEY	-1	2	3	0	3	3	1	1
DISTRICT	-1	2	3	0	2	3	1	0

† = "50-yr change" is the projected change in soil moisture deficit days for a given GHG scenario between end-century and mid-century time periods (i.e., how will soil moisture deficit days change between 2040 and 2090 for a given GHG scenario?).

**The two columns on the right-hand side ("high – moderate GHGs") show the difference in projected soil moisture deficit days between high and moderate GHG concentration scenarios (what is the difference in projected soil moisture deficit days for the RCP4.5 and RCP8.5 scenarios?).*

Table C-8: Overview of projected changes in number of frost days for different parts of the Waimakariri District. Mid-century = 2031-2050, end-century = 2081-2100, moderate GHGs = RCP4.5, high GHGs = RCP8.5. Note that the coloured bars are representative of the magnitude of change.

	moderate GHGs			*high GHGs*			*high - moderate GHGs**	
ANNUAL	*mid-century*	*end-century*	*50-yr change †*	*mid-century*	*end-century*	*50-yr change†*	*mid-century*	*end-century*
UPPER	-12	-18	-6	-13	-34	-21	-1	-16
COAST	-6	-8	-2	-7	-16	-9	-1	-7
INLAND	-8	-12	-4	-9	-21	-12	-1	-10
LEES VALLEY	-12	-18	-6	-13	-32	-19	-1	-15
DISTRICT	-9	-14	-5	-10	-26	-15	-1	-12
SUMMER								
UPPER	0	0	0	0	0	0	0	0
COAST	0	0	0	0	0	0	0	0
INLAND	0	0	0	0	0	0	0	0
LEES VALLEY	0	0	0	0	0	0	0	0
DISTRICT	0	0	0	0	0	0	0	0
AUTUMN								
UPPER	-3	-4	-1	-3	-7	-4	0	-3
COAST	-1	-2	-1	-2	-3	-1	0	-1
INLAND	-1	-2	-1	-1	-3	-1	0	-1
LEES VALLEY	-2	-3	-1	-2	-5	-3	0	-2
DISTRICT	-2	-3	-1	-2	-4	-3	0	-2
WINTER								
UPPER	-7	-10	-4	-7	-20	-13	-1	-10
COAST	-4	-6	-2	-5	-12	-7	0	-6
INLAND	-6	-9	-3	-7	-17	-10	0	-8
LEES VALLEY	-8	-12	-4	-9	-22	-13	-1	-11
DISTRICT	-6	-9	-3	-7	-17	-11	0	-8
SPRING								
UPPER	-2	-4	-2	-3	-7	-4	-1	-3
COAST	0	-1	0	-1	-1	0	0	0
INLAND	-1	-1	0	-1	-2	-1	0	-1
LEES VALLEY	-2	-3	-1	-2	-5	-3	0	-2
DISTRICT	-1	-2	-1	-2	-4	-2	0	-1

† = "50-yr change" is the projected change in number of frost days for a given GHG scenario between end-century and mid-century time periods (i.e., how will the number of frost days change between 2040 and 2090 for a given GHG scenario?).

**The two columns on the right-hand side ("high – moderate GHGs") show the difference in projected number of frost days between high and moderate GHG concentration scenarios (what is the difference in projected number of frost days for the RCP4.5 and RCP8.5 scenarios?).*

Table C-9: Overview of projected changes in relative humidity (%) for different parts of the Waimakariri District. Mid-century = 2031-2050, end-century = 2081-2100, moderate GHGs = RCP4.5, high GHGs = RCP8.5. Note that the coloured bars are representative of the magnitude of change.

	moderate GHGs			*high GHGs*			*high - moderate GHGs**	
ANNUAL	*mid-century*	*end-century*	*50-yr change †*	*mid-century*	*end-century*	*50-yr change†*	*mid-century*	*end-century*
UPPER	-1.0%	-1.5%	-0.5%	-1.1%	-3.1%	-2.0%	-0.1%	-1.6%
COAST	-0.4%	-0.7%	-0.3%	-0.6%	-1.4%	-0.8%	-0.1%	-0.7%
INLAND	-0.7%	-1.0%	-0.3%	-0.8%	-2.1%	-1.3%	-0.1%	-1.1%
LEES VALLEY	-1.0%	-1.5%	-0.5%	-1.1%	-3.0%	-1.9%	-0.1%	-1.5%
DISTRICT	-0.8%	-1.1%	-0.4%	-0.9%	-2.4%	-1.5%	-0.1%	-1.3%
SUMMER								
UPPER	-1.0%	-1.1%	-0.1%	-0.5%	-1.8%	-1.3%	0.5%	-0.7%
COAST	-0.1%	-0.2%	-0.2%	0.2%	0.5%	0.3%	0.2%	0.7%
INLAND	-0.4%	-0.6%	-0.2%	0.0%	-0.4%	-0.4%	0.4%	0.2%
LEES VALLEY	-0.9%	-1.0%	-0.1%	-0.4%	-1.5%	-1.1%	0.5%	-0.5%
DISTRICT	-0.6%	-0.8%	-0.2%	-0.2%	-0.9%	-0.7%	0.4%	-0.1%
AUTUMN								
UPPER	-0.8%	-1.1%	-0.3%	-0.6%	-1.3%	-0.7%	0.2%	-0.2%
COAST	-0.3%	-0.4%	-0.2%	-0.1%	-0.1%	0.0%	0.2%	0.4%
INLAND	-0.5%	-0.7%	-0.2%	-0.3%	-0.6%	-0.3%	0.2%	0.1%
LEES VALLEY	-0.8%	-1.1%	-0.3%	-0.6%	-1.2%	-0.6%	0.2%	-0.1%
DISTRICT	-0.6%	-0.8%	-0.2%	-0.4%	-0.8%	-0.4%	0.2%	0.0%
WINTER								
UPPER	-1.1%	-2.0%	-0.9%	-1.4%	-4.8%	-3.4%	-0.3%	-2.7%
COAST	-0.6%	-1.1%	-0.5%	-0.8%	-2.8%	-1.9%	-0.3%	-1.7%
INLAND	-0.7%	-1.4%	-0.6%	-1.0%	-3.6%	-2.6%	-0.3%	-2.2%
LEES VALLEY	-1.1%	-2.0%	-0.9%	-1.4%	-4.8%	-3.4%	-0.3%	-2.8%
DISTRICT	-0.8%	-1.6%	-0.7%	-1.1%	-3.9%	-2.8%	-0.3%	-2.3%
SPRING								
UPPER	-1.1%	-1.7%	-0.6%	-1.9%	-4.5%	-2.6%	-0.8%	-2.7%
COAST	-0.7%	-0.9%	-0.2%	-1.5%	-3.0%	-1.6%	-0.7%	-2.2%
INLAND	-1.0%	-1.3%	-0.3%	-1.7%	-3.9%	-2.2%	-0.7%	-2.6%
LEES VALLEY	-1.1%	-1.7%	-0.6%	-1.9%	-4.4%	-2.6%	-0.7%	-2.7%
DISTRICT	-1.0%	-1.4%	-0.4%	-1.7%	-4.0%	-2.2%	-0.8%	-2.6%

† = "50-yr change" is the projected change in relative humidity for a given GHG scenario between end-century and mid-century time periods (i.e., how will relative humidity change between 2040 and 2090 for a given GHG scenario?).

**The two columns on the right-hand side ("high – moderate GHGs") show the difference in projected relative humidity between high and moderate GHG concentration scenarios (what is the difference in projected relative humidity for the RCP4.5 and RCP8.5 scenarios?).*

Table C-10: Overview of projected changes in incoming solar radiation (Wm-2) for different parts of the Waimakariri District. Mid-century = 2031-2050, end-century = 2081-2100, moderate GHGs = RCP4.5, high GHGs = RCP8.5. Note that the coloured bars are representative of the magnitude of change.

	moderate GHGs			***high GHGs***			***high - moderate GHGs****	
ANNUAL	*mid-century*	*end-century*	*50-yr change †*	*mid-century*	*end-century*	*50-yr change†*	*mid-century*	*end-century*
UPPER	-0.6	-0.6	0.0	-1.1	-1.2	-0.1	-0.5	-0.6
COAST	-1.4	-1.8	-0.4	-2.3	-4.4	-2.1	-0.9	-2.5
INLAND	-1.1	-1.3	-0.2	-1.8	-3.2	-1.4	-0.7	-1.9
LEES VALLEY	-0.7	-0.7	0.0	-1.3	-1.6	-0.3	-0.5	-0.8
DISTRICT	-1.0	-1.1	-0.2	-1.6	-2.6	-1.0	-0.6	-1.4
SUMMER								
UPPER	0.1	-0.4	-0.5	-1.7	-1.3	0.5	-1.8	-0.9
COAST	-2.6	-3.5	-0.8	-4.8	-8.4	-3.7	-2.1	-5.0
INLAND	-1.9	-2.3	-0.5	-3.7	-6.9	-3.2	-1.9	-4.6
LEES VALLEY	-0.4	-0.9	-0.5	-2.2	-2.6	-0.3	-1.8	-1.7
DISTRICT	-1.1	-1.7	-0.5	-3.0	-4.8	-1.7	-1.9	-3.1
AUTUMN								
UPPER	0.1	-0.1	-0.1	-1.5	-2.5	-1.0	-1.5	-2.4
COAST	-0.4	-0.5	-0.2	-2.1	-4.0	-1.9	-1.7	-3.5
INLAND	-0.1	-0.3	-0.2	-2.0	-3.7	-1.7	-1.9	-3.5
LEES VALLEY	-0.1	-0.2	-0.2	-1.7	-3.0	-1.3	-1.6	-2.8
DISTRICT	-0.1	-0.2	-0.2	-1.8	-3.2	-1.5	-1.7	-3.0
WINTER								
UPPER	-1.8	-1.7	0.1	-2.3	-2.4	-0.2	-0.5	-0.7
COAST	-1.2	-0.8	0.4	-1.5	-1.6	-0.1	-0.3	-0.8
INLAND	-1.3	-0.8	0.4	-1.5	-1.1	0.4	-0.3	-0.3
LEES VALLEY	-1.6	-1.4	0.2	-2.0	-1.9	0.1	-0.4	-0.6
DISTRICT	-1.5	-1.2	0.3	-1.8	-1.8	0.1	-0.4	-0.6
SPRING								
UPPER	-0.9	-0.4	0.4	1.0	1.4	0.4	1.9	1.8
COAST	-1.5	-2.5	-1.1	-0.8	-3.4	-2.6	0.7	-0.8
INLAND	-1.3	-1.8	-0.6	0.0	-1.2	-1.2	1.3	0.7
LEES VALLEY	-0.9	-0.5	0.4	0.9	1.2	0.3	1.8	1.7
DISTRICT	-1.1	-1.4	-0.2	0.3	-0.5	-0.8	1.4	0.9

† = "50-yr change" is the projected change in solar radiation for a given GHG scenario between end-century and mid-century time periods (i.e., how will solar radiation change between 2040 and 2090 for a given GHG scenario?).

**The two columns on the right-hand side ("high – moderate GHGs") show the difference in projected solar radiation between high and moderate GHG concentration scenarios (what is the difference in projected solar radiation for the RCP4.5 and RCP8.5 scenarios?).*

Table C-11: Overview of projected changes in wind speed (% change) for different parts of the Waimakariri District. Mid-century = 2031-2050, end-century = 2081-2100, moderate GHGs = RCP4.5, high GHGs = RCP8.5. Note that the coloured bars are representative of the magnitude of change.

	moderate GHGs			***high GHGs***			***high - moderate GHGs****	
ANNUAL	*mid-century*	*end-century*	*50-yr change †*	*mid-century*	*end-century*	*50-yr change†*	*mid-century*	*end-century*
UPPER	2.6%	3.7%	1.1%	2.8%	8.8%	6.0%	0.1%	5.0%
COAST	0.6%	1.2%	0.7%	1.2%	2.5%	1.3%	0.6%	1.3%
INLAND	1.6%	2.4%	0.8%	2.0%	5.8%	3.8%	0.4%	3.4%
LEES VALLEY	2.7%	3.9%	1.2%	2.9%	9.2%	6.3%	0.2%	5.2%
DISTRICT	1.8%	2.8%	0.9%	2.2%	6.5%	4.3%	0.3%	3.7%
SUMMER								
UPPER	1.2%	2.4%	1.1%	-0.1%	1.4%	1.5%	-1.3%	-0.9%
COAST	-0.4%	1.1%	1.5%	-0.1%	-0.2%	-0.1%	0.3%	-1.3%
INLAND	0.3%	1.7%	1.4%	-0.3%	0.3%	0.6%	-0.6%	-1.3%
LEES VALLEY	1.2%	2.4%	1.1%	-0.2%	1.4%	1.5%	-1.4%	-1.0%
DISTRICT	0.6%	1.9%	1.3%	-0.2%	0.7%	0.9%	-0.8%	-1.2%
AUTUMN								
UPPER	2.0%	3.2%	1.3%	0.8%	2.6%	1.8%	-1.1%	-0.6%
COAST	0.2%	1.6%	1.4%	-0.7%	-0.6%	0.0%	-0.9%	-2.3%
INLAND	1.0%	2.2%	1.2%	0.0%	0.5%	0.5%	-1.0%	-1.7%
LEES VALLEY	2.1%	3.3%	1.3%	0.9%	2.8%	1.9%	-1.2%	-0.5%
DISTRICT	1.3%	2.6%	1.3%	0.3%	1.2%	0.9%	-1.0%	-1.4%
WINTER								
UPPER	4.1%	7.1%	2.9%	4.4%	20.8%	16.4%	0.3%	13.7%
COAST	1.8%	1.9%	0.2%	2.1%	6.3%	4.2%	0.3%	4.3%
INLAND	2.4%	3.9%	1.5%	2.7%	13.5%	10.9%	0.3%	9.6%
LEES VALLEY	4.4%	7.5%	3.1%	4.8%	21.8%	17.0%	0.4%	14.3%
DISTRICT	3.0%	4.8%	1.9%	3.2%	15.2%	12.0%	0.3%	10.4%
SPRING								
UPPER	3.1%	2.4%	-0.7%	5.9%	10.3%	4.5%	2.8%	8.0%
COAST	0.7%	0.2%	-0.5%	3.5%	4.7%	1.2%	2.8%	4.5%
INLAND	2.7%	1.9%	-0.8%	5.5%	8.8%	3.3%	2.8%	6.9%
LEES VALLEY	3.2%	2.5%	-0.7%	6.1%	10.7%	4.6%	2.9%	8.2%
DISTRICT	2.6%	1.8%	-0.7%	5.3%	8.8%	3.5%	2.8%	7.0%

† = "50-yr change" is the projected change in wind speed for a given GHG scenario between end-century and mid-century time periods (i.e., how will wind speed change between 2040 and 2090 for a given GHG scenario?).

**The two columns on the right-hand side ("high – moderate GHGs") show the difference in projected wind speed between high and moderate GHG concentration scenarios (what is the difference in projected wind speed for the RCP4.5 and RCP8.5 scenarios?).*

Appendix D Hydrological Modelling Maps

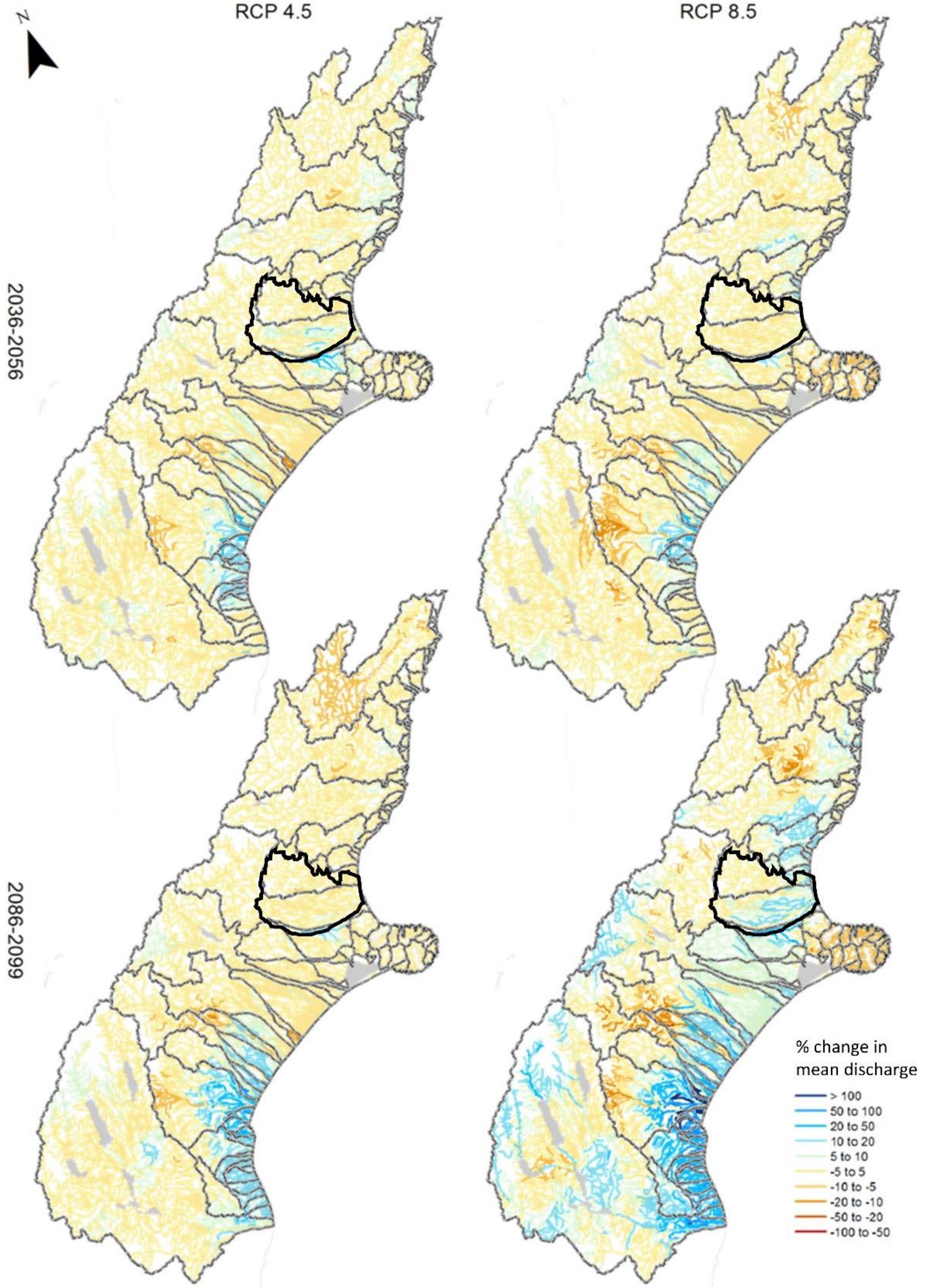

Figure D-1: Percent changes in multi-model median of the mean discharge across Canterbury for mid (top) and late century (bottom). Climate change scenarios: RCP4.5 (left panels) and RCP8.5 (right panels). Time periods: mid-century (2036-2056) and end-century (2086-2099) (source: Macara et al., 2020).

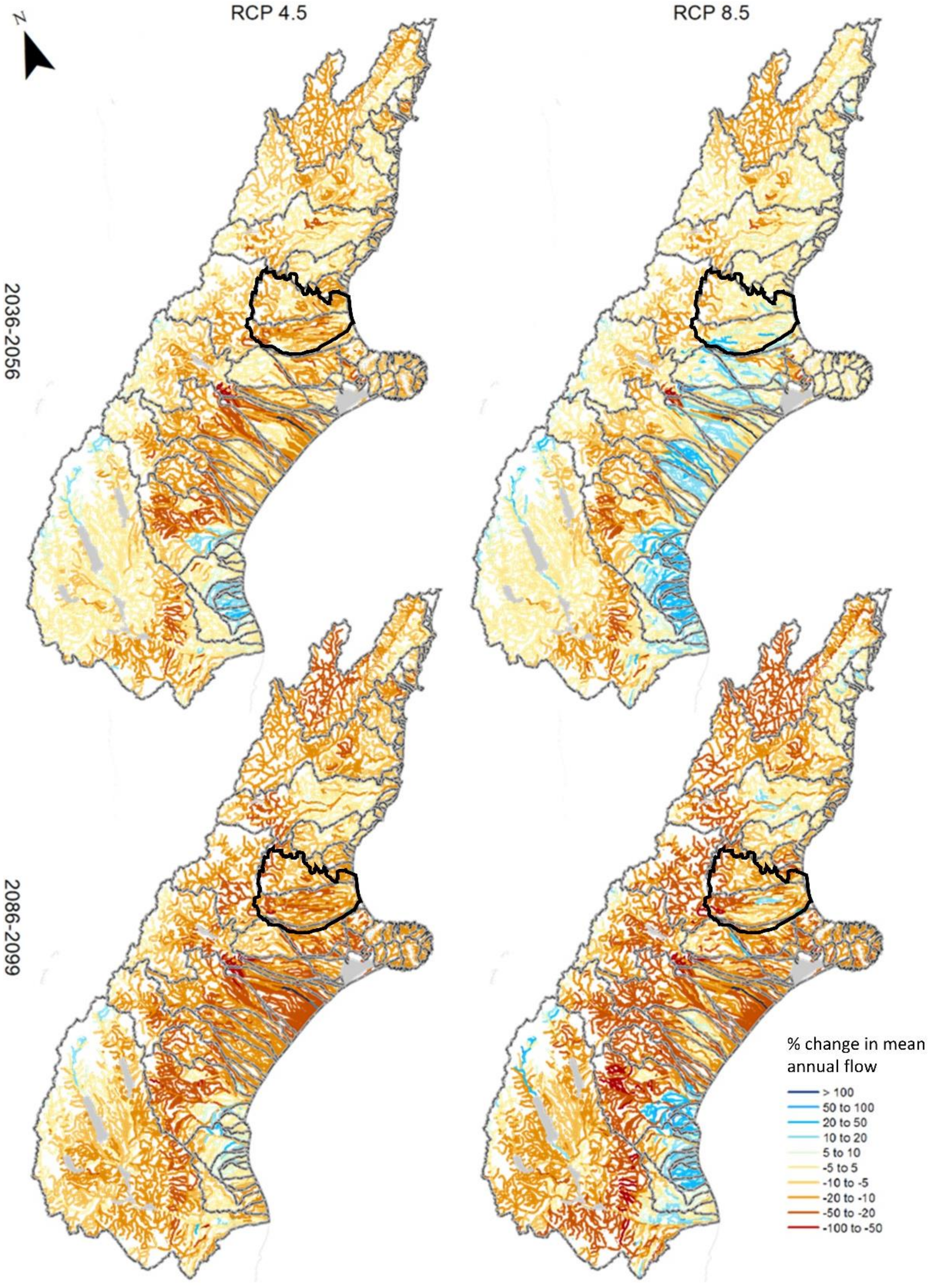

Figure D-2: Percent changes in multi-model median of the mean annual low flow across Canterbury for mid(top) and late-century (bottom). Climate change scenarios: RCP4.5 (left panels) and RCP8.5 (right panels). Time periods: mid-century (2036-2056) and end-century (2086-2099) (source: Macara et al., 2020).

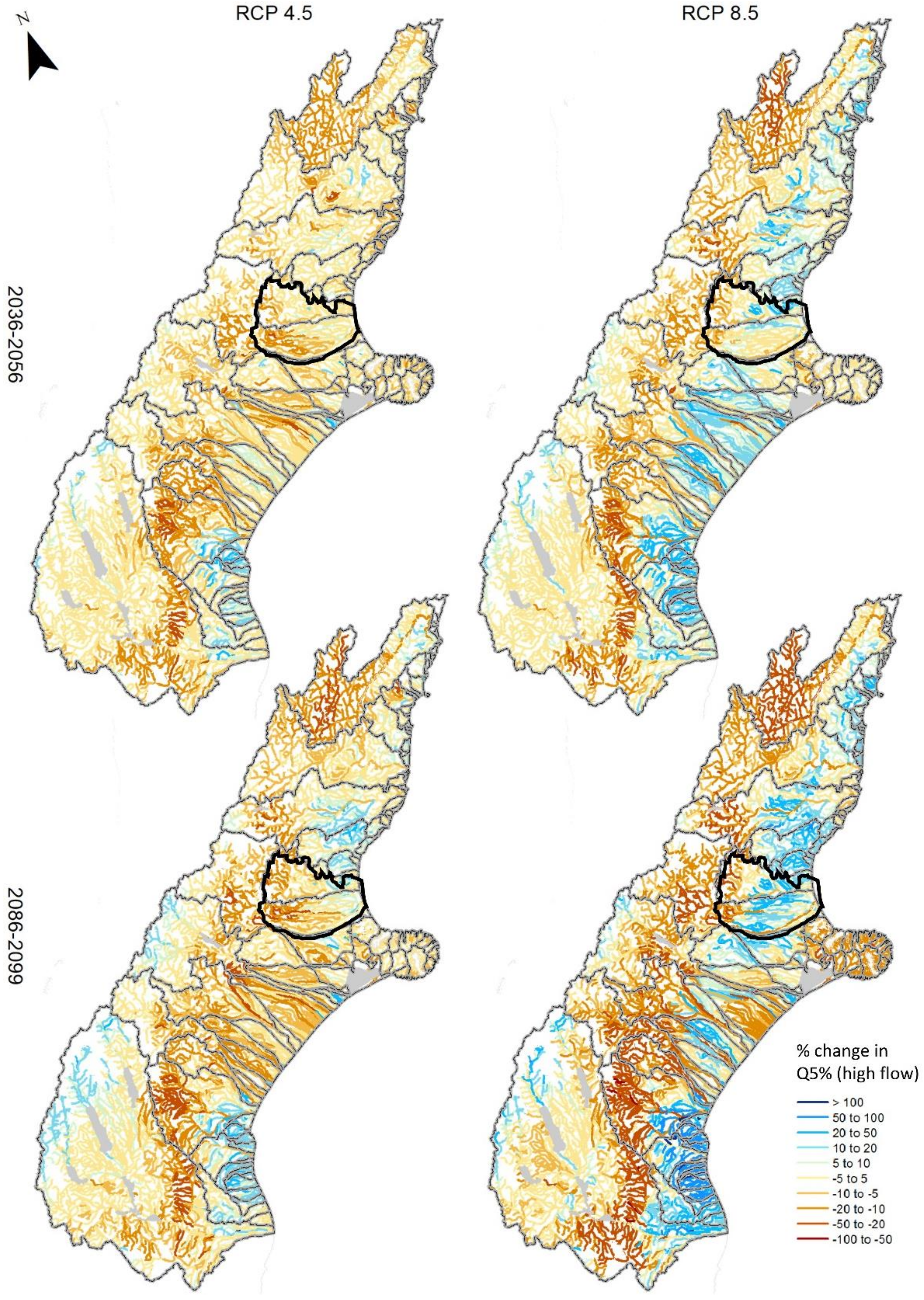

Figure D-3: Percent changes in multi-model median Q5% across Canterbury for mid (top) and end of century (bottom). Climate change scenarios: RCP4.5 (left panels) and RCP8.5 (right panels). Time periods: mid-century (2036-2056) and end-century (2086-2099) (source: Macara et al., 2020).

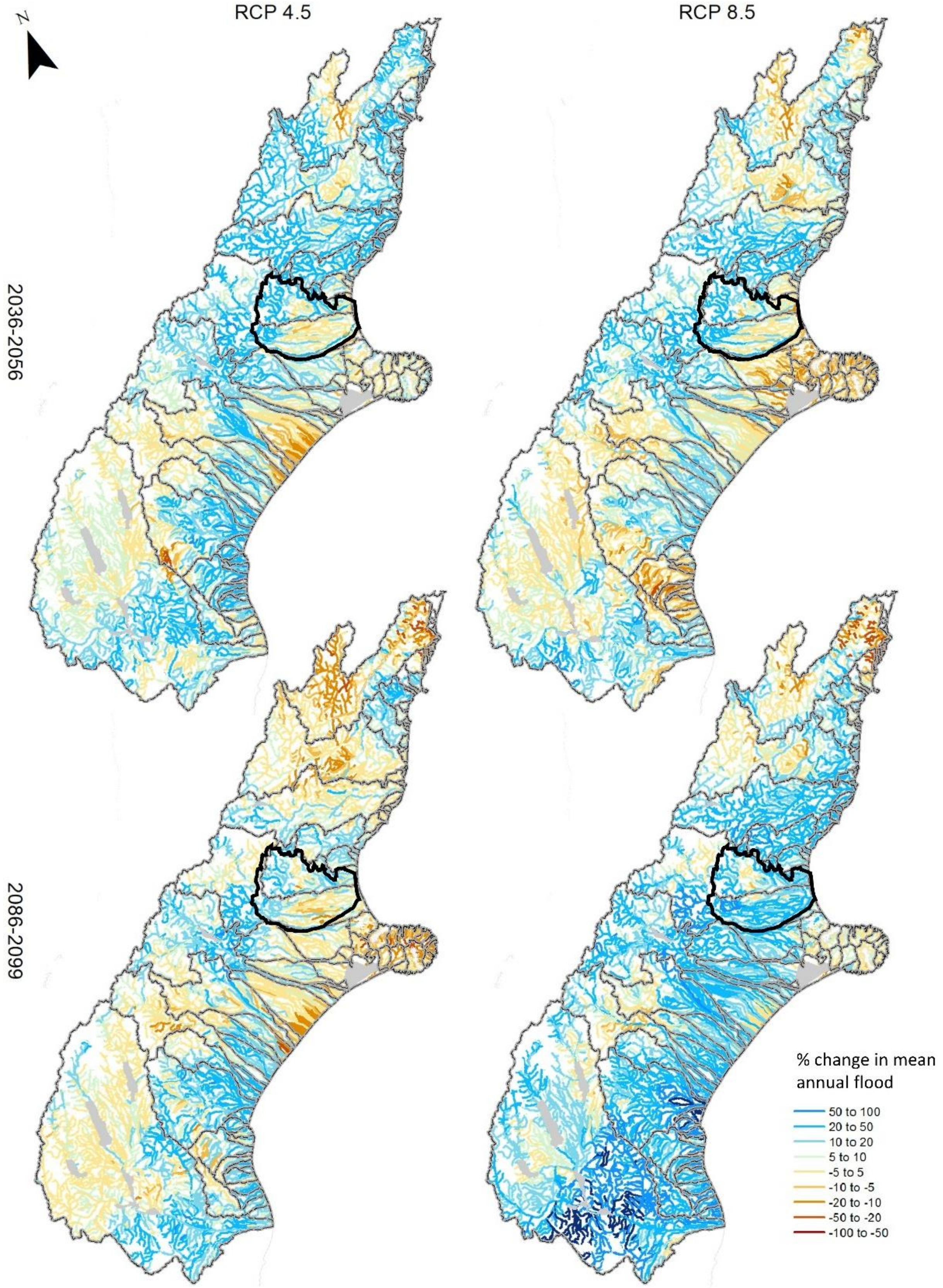

Figure D-4: Percent changes in multi-model median of mean annual flood across Canterbury for mid (top) and end of century (bottom). Climate change scenarios: RCP2.6 (left panels) and RCP4.5 (right panels). Time periods: mid-century (2036-2056) and end-century (2086-2099) (source: Macara et al., 2020).

Appendix E Extreme Rainfall Projections

Extreme rainfall events are often considered in the context of return periods (e.g. 1-in-100-year rainfall events). A return period, also known as an average recurrence interval (ARI), is an estimate of the likelihood of an event. It is a statistical measure typically based on historical data and probability distributions which calculate how often an event of a certain magnitude may occur. Return periods are often used in risk analysis and infrastructure design.

The theoretical return period is the inverse of the probability that the event will be exceeded in any one year. For example, a 1-in-10-year rainfall event has a 1/10 = 0.1 or 10% chance of being exceeded in any one year, and a 1-in-100-year rainfall event has a 1/100 = 0.01 or 1% chance of being exceeded in any one year. However, this does not mean that a 1-in-100-year rainfall event will happen regularly every 100 years, or only once in 100 years. With a changing climate, the return periods used below should be thought of only within the 20-year period in which they are defined. For instance, if extreme heavy rainfall events are becoming a lot more frequent under climate change then the 1-in-100-year rainfall event for 2040 as defined as the 2031-2050 period will be less than the 1-in-100-year rainfall event when defined under 2001-2080, because the latter is dominated by the more frequent heavy events during the 2070s. The events with larger return periods (i.e. 1-in-100-year events) have larger rainfall amounts for the same duration as events with smaller return periods (i.e. 1-in-2-year events) because larger events occur less frequently (on average).

NIWA's High Intensity Rainfall Design System (HIRDS version 4) allows rainfall event totals (depth; measured in mm) at various recurrence intervals to be calculated for any location in New Zealand (Carey-Smith et al., 2018). The rainfall event durations presented in HIRDS range from 10 minutes to 120 hours. HIRDS calculates historic rainfall event totals for given recurrence intervals as well as future potential rainfall event totals for given recurrence intervals based on climate change scenarios. The future rainfall increases calculated by the HIRDS v4 tool are based on a per cent change per degree of warming, which is averaged across New Zealand. The short duration, rare events have the largest relative increases of around 14% per degree of warming, while the longest duration events increase by about 5 to 6%. HIRDS v4 can be accessed at https://hirds.niwa.co.nz/, and more background information to the HIRDS methodology can be found at https://www.niwa.co.nz/informationservices/hirds/help.

HIRDS rainfall projections for selected sites in the Waimakariri District are presented in this section. For each site there are two tables; the first table presents data for 1-in-50-year rainfall events, and the second table presents data for 1-in-100-year rainfall events, with each of these tables listing the modelled historical and projected rainfall depths for one to 48-hour rain events. The results for the district are presented in Tables E-1 to E-22.

For each of the selected locations, rainfall depths are projected to increase across all the future scenarios, and both return periods. For example, Table E-1 shows that the projected rainfall depth for a 12-hour rainfall event a location in the Lees Valley site (50-year ARI) is projected to increase under RCP4.5 from 140m (historical depth) to 150 mm by 2040, and 157 mm by 2090. Under RCP8.5 and for the same rainfall event duration, the projected amounts are 152 mm by 2040, and 176 mm by 2090, which indicate a 17 mm and 36 mm rise respectively compared with historical depth.

Table E-1: Modelled historical and projected rainfall depths (mm) for Ashley at Townshend, Lees Valley (Longitude: 172.0673, Latitude: -43.1917) for different event durations with a 50-year return period (ARI). Source: HIRDS v4.

Rainfall event duration	Historical depth (mm)	Projected depth (mm)			
		Mid-century (2031-2050)		Late-century (2081-2100)	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
1-hour	33.1	36.4	36.9	38.5	44.7
6-hour	97.2	105.0	107.0	111.0	126.0
12-hour	140.0	150.0	152.0	157.0	176.0
24-hour	191.0	203.0	205.0	211.0	233.0
48-hour	246.0	259.0	261.0	268.0	293.0

Table E-2: Modelled historical and projected rainfall depths (mm) for Ashley at Townshend, Lees Valley (Longitude: 172.0673, Latitude: -43.1917) for different event durations with a 100-year return period (ARI). Source: HIRDS v4.

Rainfall event duration	Historical depth (mm)	Projected depth (mm)			
		Mid-century (2031-2050)		Late-century (2081-2100)	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
1-hour	38.5	42.4	42.9	44.8	52.0
6-hour	112.0	121.0	123.0	127.0	145.0
12-hour	160.0	172.0	174.0	180.0	202.0
24-hour	218.0	232.0	234.0	241.0	267.0
48-hour	279.0	295.0	297.0	304.0	333.0

Table E-3: Modelled historical and projected rainfall depths (mm) for View Hill (Longitude: 172.034, Latitude: -43.298) for different event durations with a 50-year return period (ARI). Source: HIRDS v4.

Rainfall event duration	Historical depth (mm)	Projected depth (mm)			
		Mid-century (2031-2050)		Late-century (2081-2100)	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
1-hour	31.5	34.7	35.2	36.7	42.5
6-hour	82.9	89.9	90.9	94.3	107.0
12-hour	116.0	124.0	125.0	129.0	145.0
24-hour	154.0	164.0	165.0	170.0	188.0
48-hour	195.0	206.0	207.0	212.0	232.0

Table E-4: Modelled historical and projected rainfall depths (mm) for View Hill (Longitude: 172.034, Latitude: -43.298) for different event durations with a 100-year return period (ARI). Source: HIRDS v4.

Rainfall event duration	Historical depth (mm)	Projected depth (mm)			
		Mid-century (2031-2050)		Late-century (2081-2100)	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
1-hour	36.8	40.5	41.0	42.8	49.7
6-hour	95.9	104.0	105.0	109.0	124.0
12-hour	133.0	143.0	145.0	150.0	168.0
24-hour	177.0	189.0	190.0	196.0	217.0
48-hour	223.0	236.0	237.0	243.0	266.0

Table E-5: Modelled historical and projected rainfall depths (mm) for Wharfdale, Lees Valley (Longitude: 172.203, Latitude: -43.15) for different event durations with a 50-year return period (ARI). Source: HIRDS v4..

Rainfall event duration	Historical depth (mm)	Projected depth (mm)			
		Mid-century (2031-2050)		Late-century (2081-2100)	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
1-hour	34.8	38.2	38.7	40.4	46.9
6-hour	96.9	105.0	106.0	110.0	125.0
12-hour	136.0	146.0	147.0	152.0	171.0
24-hour	181.0	192.0	194.0	199.0	220.0
48-hour	225.0	238.0	239.0	245.0	268.0

Table E-6: Modelled historical and projected rainfall depths (mm) for Wharfdale, Lees Valley (Longitude: 172.203, Latitude: -43.15) for different event durations with a 100-year return period (ARI). Source: HIRDS v4.

Rainfall event duration	Historical depth (mm)	Projected depth (mm)			
		Mid-century (2031-2050)		Late-century (2081-2100)	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
1-hour	40.4	44.4	45.0	47.0	54.5
6-hour	112.0	121.0	123.0	127.0	145.0
12-hour	156.0	168.0	170.0	175.0	197.0
24-hour	207.0	220.0	222.0	229.0	253.0
48-hour	257.0	272.0	274.0	281.0	307.0

Table E-7: Modelled historical and projected rainfall depths (mm) for Loburn (Longitude: 172.49, Latitude: -43.194) for different event durations with a 50-year return period (ARI). Source: HIRDS v4.

Rainfall event duration	Historical depth (mm)	Projected depth (mm)			
		Mid-century (2031-2050)		Late-century (2081-2100)	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
1-hour	31.3	34.4	34.9	36.4	42.2
6-hour	87.0	94.3	95.4	98.9	112.0
12-hour	125.0	134.0	135.0	140.0	156.0
24-hour	171.0	182.0	184.0	189.0	209.0
48-hour	224.0	236.0	238.0	244.0	266.0

Table E-8: Modelled historical and projected rainfall depths (mm) for Loburn (Longitude: 172.49, Latitude: -43.194) for different event durations with a 100-year return period (ARI). Source: HIRDS v4.

Rainfall event duration	Historical depth (mm)	Projected depth (mm)			
		Mid-century (2031-2050)		Late-century (2081-2100)	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
1-hour	36.2	39.9	40.4	42.2	49.0
6-hour	100.0	109.0	110.0	114.0	130.0
12-hour	143.0	154.0	155.0	160.0	180.0
24-hour	196.0	208.0	210.0	216.0	239.0
48-hour	255.0	269.0	271.0	278.0	304.0

Table E-9: Modelled historical and projected rainfall depths (mm) for Oxford (Longitude: 172.193, Latitude: -43.277) for different event durations with a 50-year return period (ARI). Source: HIRDS v4.

Rainfall event duration	Historical depth (mm)	Projected depth (mm)			
		Mid-century (2031-2050)		Late-century (2081-2100)	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
1-hour	33.0	36.3	36.8	38.4	44.5
6-hour	80.7	87.5	88.5	91.8	104.0
12-hour	112.0	120.0	122.0	126.0	141.0
24-hour	151.0	161.0	162.0	167.0	184.0
48-hour	196.0	207.0	208.0	213.0	233.0

Table E-10: Modelled historical and projected rainfall depths (mm) for Oxford (Longitude: 172.193, Latitude: -43.277) for different event durations with a 100-year return period (ARI). Source: HIRDS v4.

Rainfall event duration	Historical depth (mm)	Projected depth (mm)			
		Mid-century (2031-2050)		Late-century (2081-2100)	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
1-hour	38.5	42.3	42.9	44.8	52.0
6-hour	93.3	101.0	102.0	106.0	121.0
12-hour	129.0	139.0	140.0	145.0	163.0
24-hour	174.0	185.0	186.0	192.0	212.0
48-hour	224.0	236.0	238.0	244.0	267.0

Table E-11: Modelled historical and projected rainfall depths (mm) for Okuku (Longitude: 172.4483, Latitude: -43.2383) for different event durations with a 50-year return period (ARI). Source: HIRDS v4.

Rainfall event duration	Historical depth (mm)	Projected depth (mm)			
		Mid-century (2031-2050)		Late-century (2081-2100)	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
1-hour	29.5	32.4	32.9	34.3	39.7
6-hour	74.5	80.7	81.7	84.7	96.2
12-hour	102.0	110.0	111.0	115.0	129.0
24-hour	135.0	143.0	144.0	149.0	164.0
48-hour	168.0	177.0	179.0	183.0	200.0

Table E-12: Modelled historical and projected rainfall depths (mm) for Okuku (Longitude: 172.4483, Latitude: -43.2383) for different event durations with a 100-year return period (ARI). Source: HIRDS v4.

Rainfall event duration	Historical depth (mm)	Projected depth (mm)			
		Mid-century (2031-2050)		Late-century (2081-2100)	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
1-hour	34.4	37.9	38.4	40.1	46.5
6-hour	85.8	93.2	94.2	97.8	111.0
12-hour	117.0	126.0	127.0	132.0	148.0
24-hour	154.0	164.0	165.0	170.0	188.0
48-hour	191.0	201.0	203.0	208.0	227.0

Table E-13: Modelled historical and projected rainfall depths (mm) for Kaiapoi (Longitude: 172.6518, Latitude: -43.3849) for different event durations with a 50-year return period (ARI). Source: HIRDS v4.

Rainfall event duration	Historical depth (mm)	Projected depth (mm)			
		Mid-century (2031-2050)		Late-century (2081-2100)	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
1-hour	23.4	25.7	26.1	27.2	31.5
6-hour	61.2	66.4	67.1	69.6	79.1
12-hour	85.9	92.2	93.2	96.2	108.0
24-hour	116.0	123.0	124.0	128.0	141.0
48-hour	149.0	157.0	158.0	162.0	177.0

Table E-14: Modelled historical and projected rainfall depths (mm) Kaiapoi (Longitude: 172.6518, Latitude: -43.3849) for different event durations with a 100-year return period (ARI). Source: HIRDS v4.

Rainfall event duration	Historical depth (mm)	Projected depth (mm)			
		Mid-century (2031-2050)		Late-century (2081-2100)	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
1-hour	27.3	30	30.5	31.8	36.9
6-hour	70.4	76.4	77.3	80.2	91.3
12-hour	98.2	106	107	110	124
24-hour	132	140	141	145	161
48-hour	168	177	179	183	201

Table E-15: Modelled historical and projected rainfall depths (mm) for Rangiora (Longitude: 172.583, Latitude: -43.299) for different event durations with a 50-year return period (ARI). Source: HIRDS v4.

Rainfall event duration	Historical depth (mm)	Projected depth (mm)			
		Mid-century (2031-2050)		Late-century (2081-2100)	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
1-hour	28.4	31.2	31.6	33.0	38.3
6-hour	73.5	79.7	80.6	83.6	95.0
12-hour	103.0	111.0	112.0	115.0	129.0
24-hour	139.0	148.0	149.0	154.0	170.0
48-hour	179.0	189.0	191.0	195.0	214.0

Table E-16: Modelled historical and projected rainfall depths (mm) Rangiora (Longitude: 172.583, Latitude: -43.299) for different event durations with a 100-year return period (ARI). Source: HIRDS v4.

Rainfall event duration	Historical depth (mm)	Projected depth (mm)			
		Mid-century (2031-2050)		Late-century (2081-2100)	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
1-hour	32.8	36.1	36.6	38.2	44.4
6-hour	84.3	91.5	92.5	96.0	109.0
12-hour	118.0	127.0	128.0	132.0	148.0
24-hour	159.0	169.0	170.0	175.0	194.0
48-hour	203.0	215.0	216.0	222.0	243.0

Table E-17: Modelled historical and projected rainfall depths (mm) for Kairaki (Longitude: 172.7087, Latitude: -43.3837) for different event durations with a 50-year return period (ARI). Source: HIRDS v4.

Rainfall event duration	Historical depth (mm)	Projected depth (mm)			
		Mid-century (2031-2050)		Late-century (2081-2100)	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
1-hour	24.7	25.8	27.6	28.8	33.3
6-hour	62.1	64.1	68.1	70.6	80.2
12-hour	85.0	87.2	92.2	95.2	107.0
24-hour	112.0	114.0	120.0	124.0	137.0
48-hour	142.0	144.0	151.0	155.0	169.0

Table E-18: Modelled historical and projected rainfall depths (mm) Kairaki (Longitude: 172.7087, Latitude: -43.3837) for different event durations with a 100-year return period (ARI). Source: HIRDS v4.

Rainfall event duration	Historical depth (mm)	Projected depth (mm)			
		Mid-century (2031-2050)		Late-century (2081-2100)	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
1-hour	28.9	31.8	32.2	33.6	39.0
6-hour	71.4	77.5	78.4	81.3	92.6
12-hour	97.2	104.0	106.0	109.0	123.0
24-hour	128.0	136.0	137.0	141.0	156.0
48-hour	161.0	170.0	171.0	175.0	192.0

Table E-19: Modelled historical and projected rainfall depths (mm) for Waikuku (Longitude: 172.6897, Latitude: -43.2912) for different event durations with a 50-year return period (ARI). Source: HIRDS v4.

Rainfall event duration	Historical depth (mm)	Projected depth (mm)			
		Mid-century (2031-2050)		Late-century (2081-2100)	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
1-hour	25.7	28.3	28.6	29.9	33.4
6-hour	65.0	70.4	71.2	73.8	82.1
12-hour	90.2	96.8	97.8	101.0	112.0
24-hour	121.0	128.0	129.0	133.0	148.0
48-hour	154.0	162.0	163.0	168.0	185.0

Table E-20: Modelled historical and projected rainfall depths (mm) for Waikuku (Longitude: 172.6897, Latitude: -43.2912) for different event durations with a 100-year return period (ARI). Source: HIRDS v4.

Rainfall event duration	Historical depth (mm)	Projected depth (mm)			
		Mid-century (2031-2050)		Late-century (2081-2100)	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
1-hour	30.0	33.0	34.6	34.9	40.5
6-hour	74.8	81.1	83.9	85.2	96.9
12-hour	103.0	111.0	113.0	116.0	130.0
24-hour	138.0	146.0	147.0	152.0	168.0
48-hour	174.0	184.0	183.0	190.0	208.0

Table E-21: Modelled historical and projected rainfall depths (mm) for Woodend (Longitude: 172.68, Latitude: -43.323) for different event durations with a 50-year return period (ARI). Source: HIRDS v4.

Rainfall event duration	Historical depth (mm)	Projected depth (mm)			
		Mid-century (2031-2050)		Late-century (2081-2100)	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
1-hour	26.8	29.5	29.9	31.2	36.2
6-hour	70.1	75.9	76.8	79.6	90.5
12-hour	96.2	103.0	104.0	108.0	121.0
24-hour	126.0	134.0	135.0	139.0	153.0
48-hour	154.0	163.0	164.0	168.0	184.0

Table E-22: Modelled historical and projected rainfall depths (mm) for Woodend (Longitude: 172.68, Latitude: -43.323) for different event durations with a 100-year return period (ARI). Source: HIRDS v4.

Rainfall event duration	Historical depth (mm)	Projected depth (mm)			
		Mid-century (2031-2050)		Late-century (2081-2100)	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
1-hour	31.0	34.1	34.6	36.1	41.9
6-hour	80.2	87.0	88.0	91.3	104.0
12-hour	110.0	118.0	119.0	123.0	138.0
24-hour	143.0	152.0	153.0	158.0	174.0
48-hour	175.0	184.0	186.0	190.0	208.0