NIWA
Taihoro Nukurangi

Hawke's Bay Climate Change Projections

Prepared for Landcare Research New Zealand Limited

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Contents

1 Introduction

Landcare Research New Zealand Limited contracted NIWA to produce a report describing downscaled climate change projections for the Hawke's Bay Region of New Zealand, based on global climate models updated for the publication of the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report in 2013 and 2014, and also used in the New Zealand climate change report published by the Ministry for the Environment in 2016 (Mullan et al., 2016).

This report describes climate changes which may occur over the coming century for the Hawke's Bay. The report does not address the issue of mitigation (reducing greenhouse gas emissions, or increasing "sinks" such as areas of growing forest).

Data for climate factors provided and discussed include temperature, precipitation, wind and evaporation. The climate data (also provided as GIS data files) was requested to provide an indication of what could potentially occur within the region to underpin multi-stakeholder conversations (Hawke's Bay Regional Council, industries, sectors and others) regarding how the region could be impacted and how they might adapt.

The funding for this report did not allow for new data analysis and modelling, but enabled us to draw on information which is already available from various sources. Much of this information is new, resulting from the latest assessments of the Intergovernmental Panel on Climate Change (IPCC, 2013, IPCC, 2014c, IPCC, 2014b), and scenarios for New Zealand generated by NIWA scientists based on downscaling from global climate model runs undertaken for these IPCC assessments (undertaken through NIWA's core-funded Regional Modelling Programme). The climate change information presented in this report is entirely consistent with recently-updated climate change guidance produced for the Ministry of the Environment (Mullan et al., 2016).

2 Background: Global and New Zealand climate change

2.1 Global climate change

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

2.1.1 The Physical Science Basis (IPCC Working Group I)

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

- Warming of the climate system is 'unequivocal', and since the 1950s, many of the observed climate changes are unprecedented over short and long timescales (decades to millennia). These changes include warming of the atmosphere and ocean, diminishing of ice and snow, sea-level rise, and increases in the concentration of greenhouse gases.
- The atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased to levels unprecedented in at least the last 800,000 years. Carbon dioxide concentrations have increased by 40% since pre-industrial times, primarily from fossil fuel emissions and secondarily from net land use change emissions. The ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide, causing ocean acidification.
- Climate change is already influencing the intensity and frequency of many extreme weather and climate events globally.
- It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century.

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

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

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

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

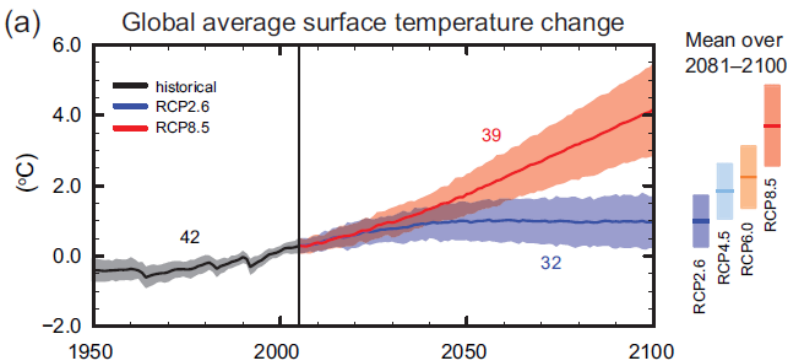

Figure 2-1: CMIP5 multi-model simulated time series from 1950-2100 for change in global annual mean surface temperature relative to 1986-2005. Time series of projections and a measure of uncertainty (shading) are shown for scenarios RCP 2.6 (blue) and RCP 8.5 (red). Black (grey shading) is the modelled historical evolution using historical reconstructed forcings. The mean and associated uncertainties averaged over 2081−2100 are given for all RCP scenarios as coloured vertical bars to the right of the graph (the mean projection is the solid line in the middle of the bars). The numbers of CMIP5 models used to calculate the multi-model mean is indicated on the graph. After IPCC (2013).

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

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

2.2 New Zealand climate change

Published information about the expected impacts of climate change on New Zealand is summarised and assessed in the Australasia chapter of the IPCC Working Group II assessment report (Reisinger et al., 2014) as well as a recent report published by the Royal Society of New Zealand (Royal Society of New Zealand, 2016). Key findings from these publications include:

The regional climate is changing. The Australasia region continues to demonstrate long-term trends toward higher surface air and sea surface temperatures, more hot extremes and fewer cold extremes, and changed rainfall patterns. Over the past 50 years, increasing greenhouse gas

concentrations have contributed to rising average temperatures in New Zealand. Changing precipitation patterns have resulted in increases in rainfall for the south and west of the South Island and west of the North Island, and decreases in the northeast of the South Island and the east and north of the North Island. Some heavy rainfall events already carry the fingerprint of a changed climate, in that they have become more intense due to higher temperatures allowing the air to carry more moisture (Dean et al., 2013). Cold extremes have become rarer and hot extremes have become more common.

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

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

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

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

Additional information about past New Zealand climate change can be found in Mullan et al. (2016).

3 Projections of future climate changes to 2100

The future climate of the Hawke's Bay Region will be influenced by a combination of the effects of anthropogenic climate change plus the natural year-to-year and decade-to-decade variability resulting from "climate noise" and features such as the El Niño-Southern Oscillation (ENSO), the Interdecadal Pacific Oscillation (IPO), and the Southern Annular Mode (SAM) (see Fedaeff and Fauchereau, 2015). This section outlines the projected changes due to anthropogenic climate change in the Hawke's Bay Region. Note that the projected changes use 20-year averages, which will not entirely remove effects of natural variability.

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

This has been dealt with by the Intergovernmental Panel on Climate Change through consideration of 'scenarios' describing concentrations of greenhouse gases in the atmosphere associated with a range of possible economic, political, and social developments during the 21st century, and by

considering results from several different climate models for a given scenario. In the 2013 IPCC Fifth Assessment Report, the atmospheric greenhouse gas concentration component of these scenarios are called Representative Concentrations Pathways (RCPs).

Global climate model output based on two RCPs has been downscaled to produce future projections for temperature, precipitation, evaporation and wind for the Hawke's Bay Region (see maps later in this section). The RCPs are based on 21st century climate policies, and thus differ from the previous IPCC SRES emissions scenarios and their 'no-climate policy' (IPCC, 2013). RCP 4.5 is a low-mid range emissions scenario, which is also called a 'stabilisation' scenario where radiative forcing stabilises by 2100. RCP 8.5 is a scenario with very high greenhouse gas emissions, and radiative forcing continues to increase beyond 2100. Each RCP provides spatially-resolved data sets of land use change and sector-based emissions of air pollutants, and it specifies annual greenhouse gas concentrations and anthropogenic emissions up to 2500 (although this section of the report only considers changes to 2100). RCPs are based on a combination of integrated assessment models, simple climate models, atmospheric chemistry and global carbon cycle models.

NIWA has used climate model data from the IPCC Fifth Assessment (IPCC, 2013) to update climate change scenarios for New Zealand, through a regional climate model (dynamical) process. The dynamical downscaling processes are described in detail in an updated climate guidance manual prepared for the Ministry for the Environment (Mullan et al., 2016), but a short explanation is provided below.

All climate projections start as simulations by global climate models, which have coarse spatial resolution. Dynamical downscaling means using a higher resolution climate model or weather prediction model to get finer scale detail (5 km resolution in this report). Several different models are used to simulate future climate (6 for dynamical downscaling). The projections from each of the models are averaged together, creating an ensemble average (which is displayed in the figures in this section).

Note that in the maps presented here there are some pixels around the coast of the Hawke's Bay region where no projection data are displayed. Data is downscaled only where low resolution cells are land points and overlap high resolution cells. In most cases interpolating over mixed sea and land point creates artificial biases, for example lower temperatures.

3.1 Changes to temperature

The magnitude of the temperature change projections varies with the RCP and with the climate models used. In this report, temperature projections were carried out by dynamical downscaling of two RCPs using NIWA's Regional Climate Model - a stabilisation scenario (RCP 4.5) and a high emissions scenario (RCP 8.5).

3.1.1 Mean temperature projections

The seasonal patterns of projected temperature changes over the Hawke's Region are presented in this section. Projections for 2040 for the RCP 4.5 scenario are shown in Figure 3-1. Figure 3-2 shows corresponding patterns for 2090. Figure 3-3 shows the seasonal patterns of projected temperature increase for 2040 for the RCP 8.5 scenario, and Figure 3-4 shows the corresponding patterns for 2090. These nominal years represent the mid-points of bi-decadal periods: 2040 is the average over 2031-2050, and 2090 the average over 2081-2100. All maps show changes relative to the baseline climate of 1986-2005.

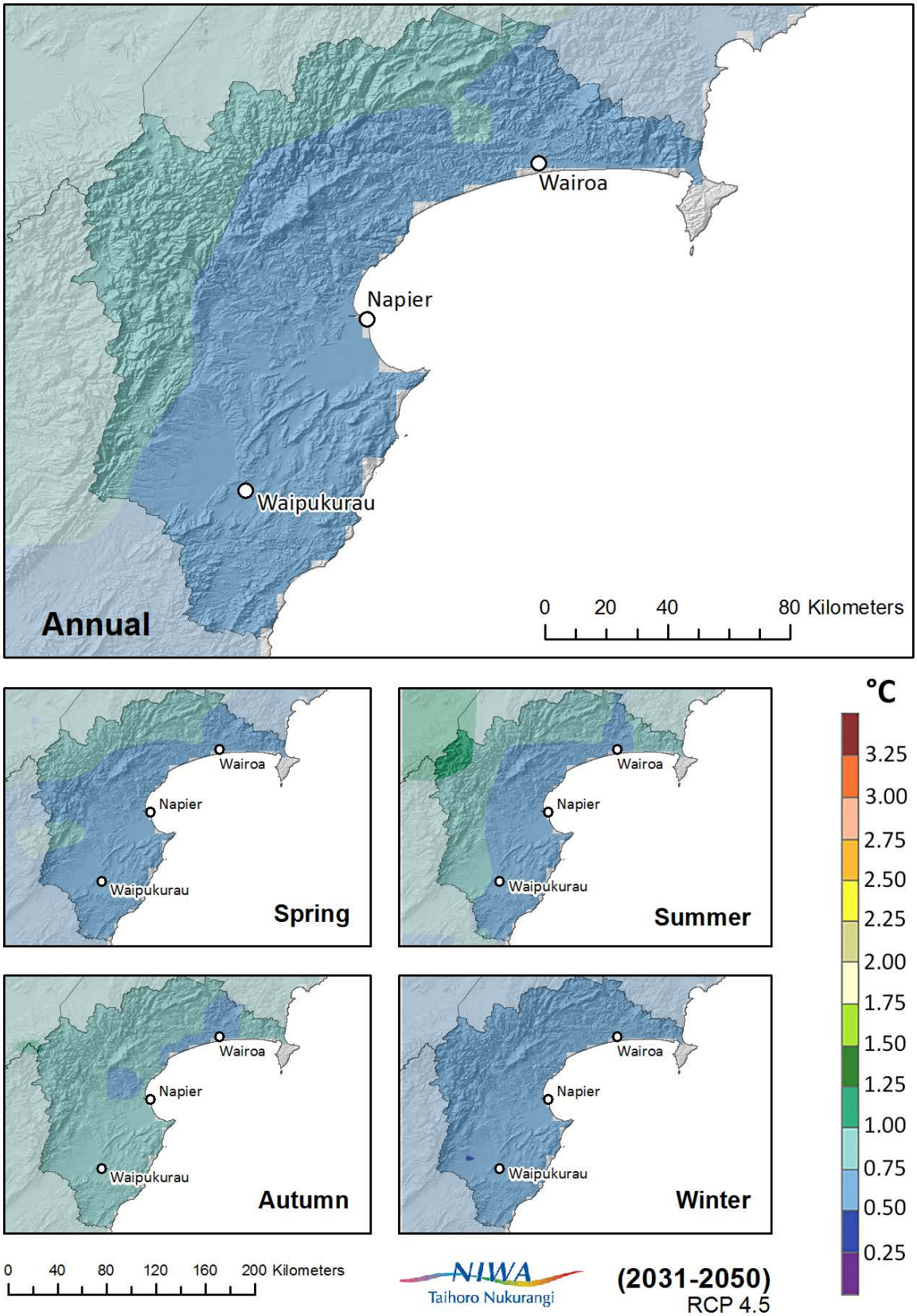

Figure 3-1: Projected annual and seasonal mean temperature changes at 2040 (2031-2050 average). Relative to 1986-2005 average, for the IPCC RCP 4.5 scenario, averaged over 6 climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km. ©NIWA.

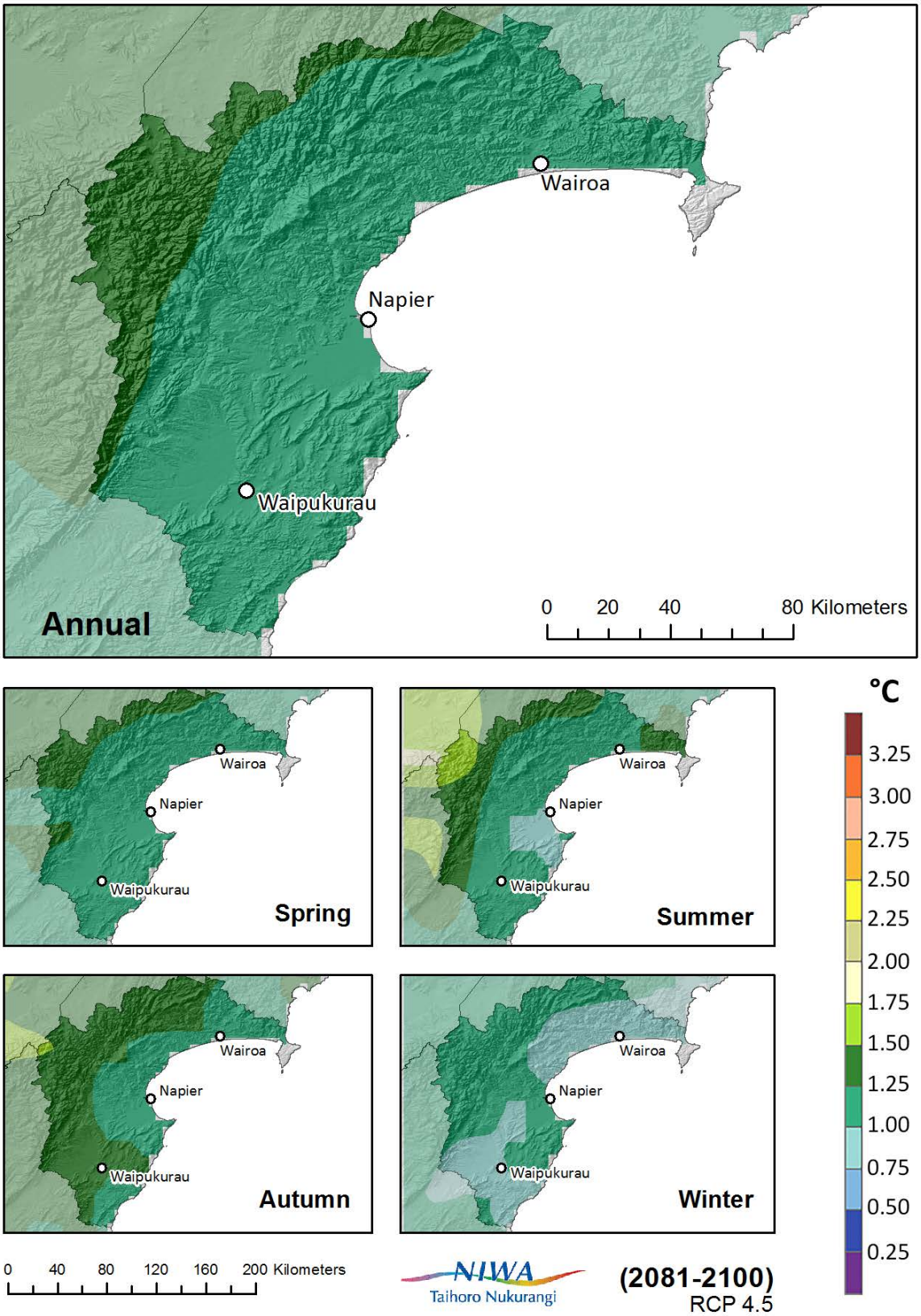

Figure 3-2: Projected annual and seasonal mean temperature changes at 2090 (2081-2100 average).

Relative to 1986-2005 average, for the IPCC RCP 4.5 scenario, averaged over 6 climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km. ©NIWA.

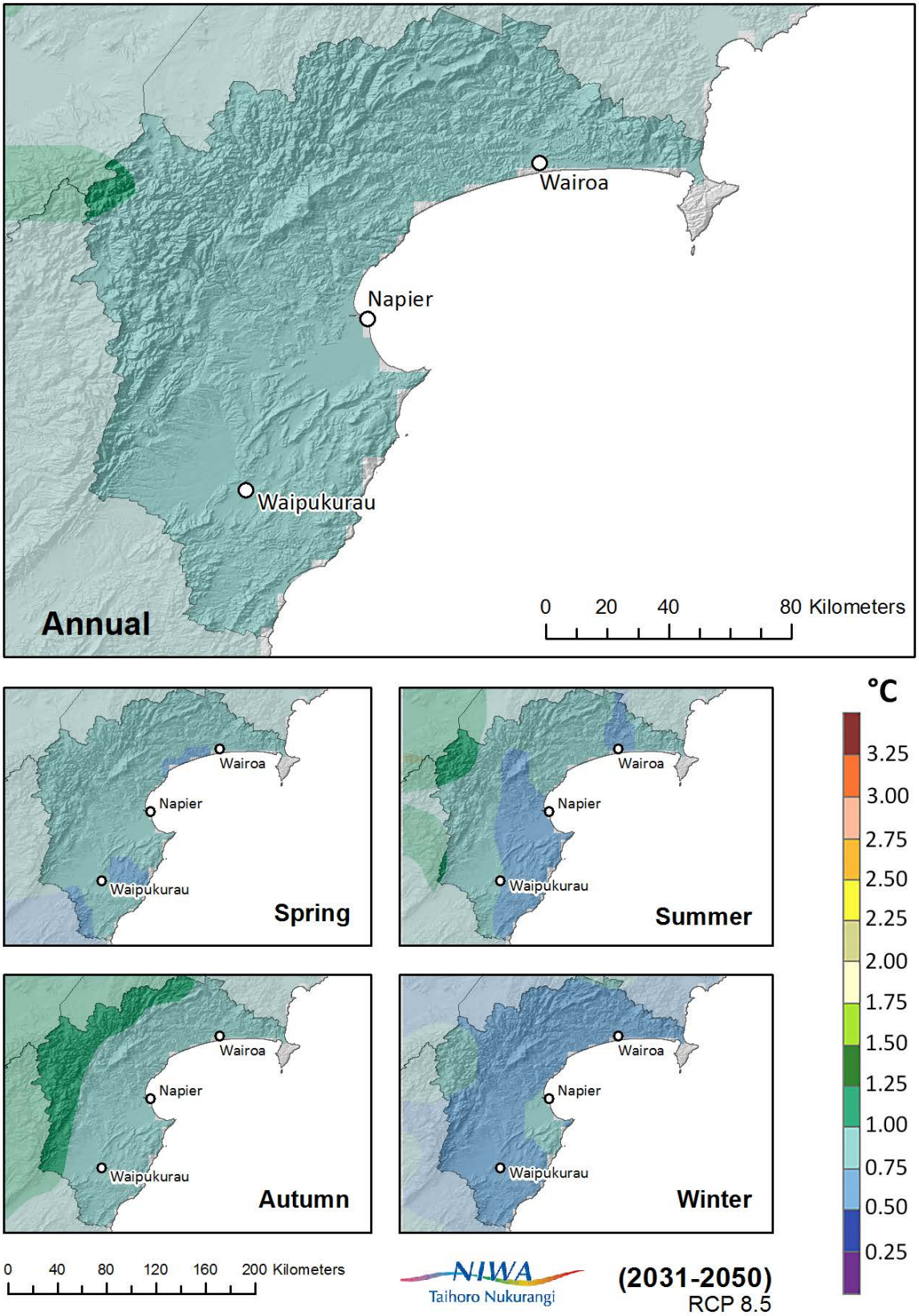

Figure 3-3: Projected annual and seasonal mean temperature changes at 2040 (2031-2050 average). Relative to 1986-2005 average, for the IPCC RCP 8.5 scenario, averaged over 6 climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km. ©NIWA.

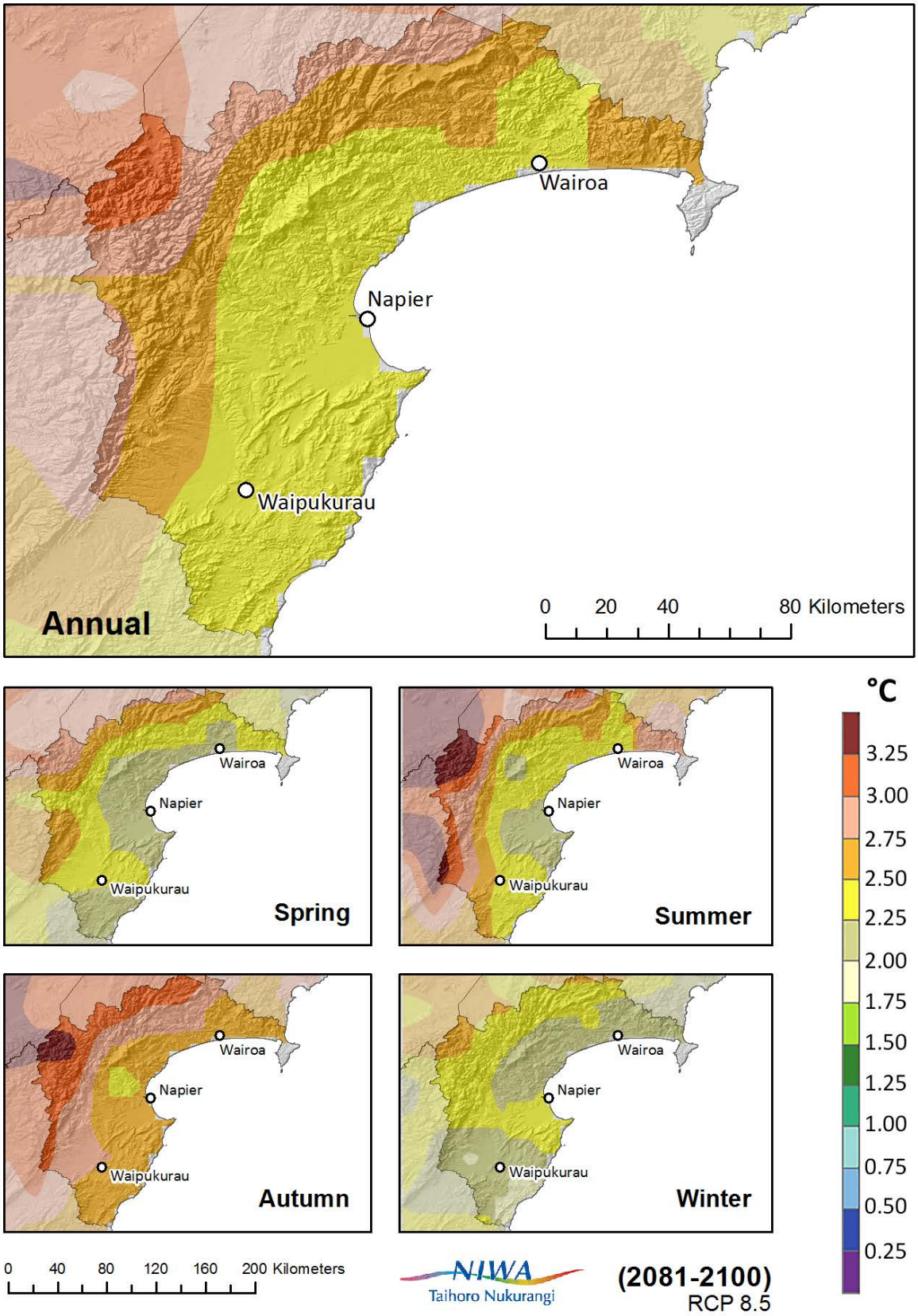

Figure 3-4: Projected annual and seasonal mean temperature changes at 2090 (2081-2100 average). Relative to 1986-2005 average, for the IPCC RCP 8.5 scenario, averaged over 6 climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km. ©NIWA.

As shown by Figure 3-1, projected future warming in the Hawke's Bay Region at 2040 under the RCP 4.5 scenario is more pronounced over the ranges (Huiarau, Kaweka and Ruahine) when averaged over six climate models analysed by NIWA. Most warming is between 0.5°C - 1˚C under this scenario. Warming is most pronounced in autumn and least pronounced in winter. Figure 3-2 shows mean seasonal temperature change under RCP 4.5 at 2090. A similar pattern is shown to Figure 3-1, but the magnitude of warming is larger. The warming is most pronounced in autumn and summer with the ranges projected to see increases in temperature between 1.25°C and 1.75°C.

Figure 3-3 shows projected warming for the Hawke's Bay Region under RCP 8.5 at 2040 – warming of >0.5˚C is observed everywhere. The region is projected to warm by up to 0.75°C - 1.25°C in autumn. By 2090 under RCP 8.5 (Figure 3-4), significant warming is observed over the entire Hawke's Bay Region, with winter observing the least amount of warming and autumn observing the most. The Huiarau, Kaweka and Ruahine ranges are projected to experience increases in mean temperatures during summer and autumn by at least 2.75°C. At the annual scale, a minimum warming of 2.25°C is projected for the region.

As mentioned prior, Figure 3-1 to 3-4 are model ensemble averages. If you look at individual models, some give less warming and others give a faster rate of warming (IPCC, 2013).

3.1.2 Frosts and hot days projections

As the seasonal mean temperature increases over time, we also expect to see changes in temperature extremes. In general, an increase in high temperature extremes, and a decrease in low temperature extremes is expected. Natural variability, of course, will continue to influence the climate of specific years, and the specific time variation of this variability cannot be predicted by the climate models due to the chaotic interactions that affect development of individual weather systems and larger-scale climate modes (such as El Niño events) (Mullan et al., 2016).

For this report, high temperature extremes (i.e. 'hot days') are considered as the number of days per year with a maximum temperature of 25°C or above, and low temperature extremes (i.e. 'cold nights' or frosts) are considered as the number of nights per year of 0°C or below. These extremes were determined directly from the daily dynamically downscaled maximum (for 'hot days') and minimum (for 'cold nights') temperature for each (of six) model by averaging the number of daily exceedances (greater than or equal to 25°C, or less than or equal to 0°C, for hot days and cold nights, respectively) for the selected RCP and time period over the number of years. Finally the climate change signal was computed by averaging the change (with respect to the reference period) over the number of models (6).

The projected increase in the number of hot days per year at 2040 (2031-2050) and 2090 (2081-2100) relative to 1986-2005, for RCP 4.5 and RCP 8.5 is shown in Figure 3-5. Higher elevation areas, particularly around the ranges are projected to experience the least increase in hot days at all time slices and all RCPs.

At 2040, the ranges are projected to experience increases in hot days by no more than 10 days per year for RCP 4.5 and RCP 8.5. Much of the Central Hawke's Bay, Hastings and Napier districts are projected to see an increase of up to 15 hot days per year for RCP 4.5 and up to 20 hot days per year for RCP 8.5. Wairoa district is projected to see up to 20 more hot days per year under both RCP 4.5 and 8.5 with isolated parts of the district projected to experience up to 30 hot days per year for RCP 8.5

At 2090, the ranges are projected to experience increases in hot days by up to 20 days per year for RCP 4.5 and RCP 8.5. The remaining majority of the region is projected to experience up to 30 more hot days per year for RCP 4.5 and up to 60 more hot days per year for RCP 8.5. Under RCP 8.5 at 2090, parts of Wairoa district and the Takapau Plains are projected to see 60-70 more hot days per year than experienced relative to the 1986-2005 climatology.

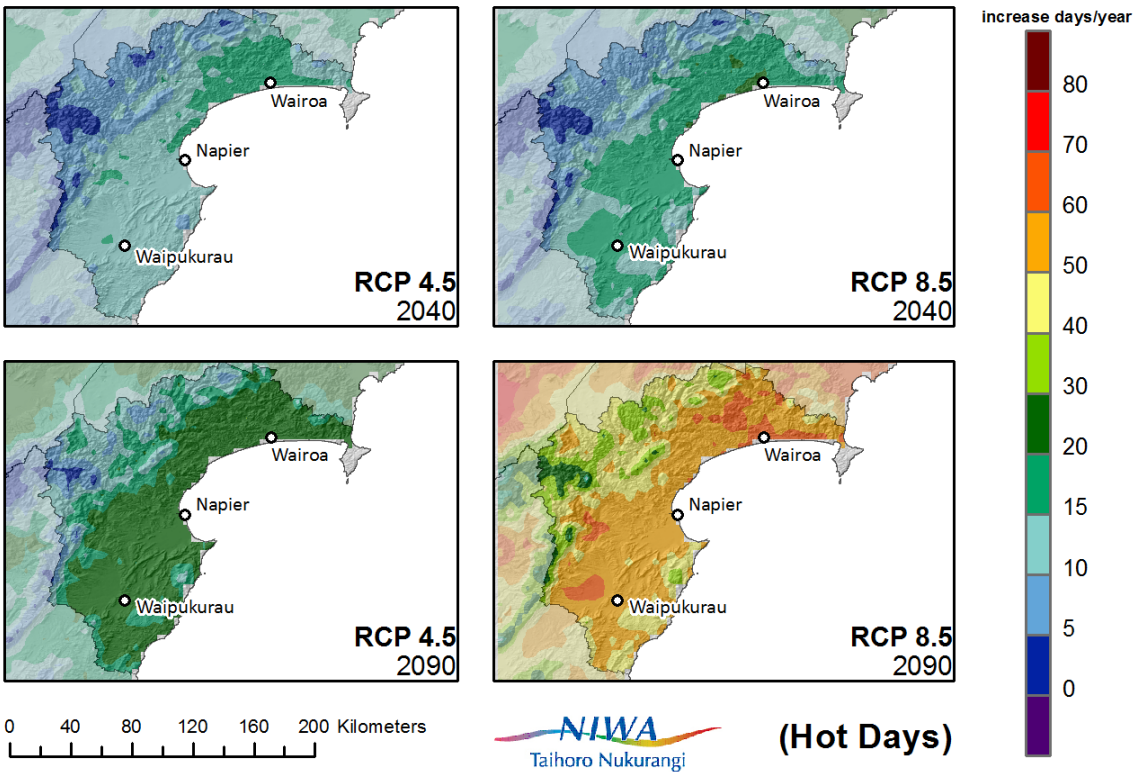

Figure 3-5: Projected increase in number of hot days per year (Tmax >25°C) at 2040 & 2090 for RCP 4.5 (left panels) and RCP 8.5 (right panels), for the Hawke's Bay Region. Projected change in hot days is relative to 1986-2005. The numbers on the scale refer to the *increase* in the number of hot days. Results are based on dynamically downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km. © NIWA.

The projected decrease in the number of cold nights (i.e. frosts) per year at 2040 (2031-2050) and 2090 (2081-2100) relative to 1986-2005, for RCP 4.5 and RCP 8.5 is shown in Figure 3-6. One thing to note is that large parts of the Central Hawke's Bay and Wairoa districts experience 5 cold nights or fewer per year based on the 1986-2005 climatology and so do not show much change in cold nights regardless of the time slice and RCP.

Similar patterns are shown for changes in cold nights at 2040 under both RCP 4.5 and RCP 8.5. Most parts of the region outside the highest elevations of the Huiarau, Kaweka and Ruahine Ranges are projected to experience a decrease of fewer than five cold nights per year. Cold nights at high elevations are projected to decrease by up to 10 nights per year.

By 2090, the pattern for RCP 4.5 is similar to that at 2040 except the area projecting up to 10 fewer cold nights per year spreads to lower elevations. The highest parts of the Kaweka and Ruahine Ranges in the Hawke's Bay region are projected to see up to 20 fewer cold nights. Under RCP 8.5 at 2090, up to 40 fewer cold nights are projected for parts of the Kaweka and Ruahine Ranges. The remainder of the region is projected to see a decrease of up to 10 cold days per year. Given the

climatology of the region this means that in the future, some areas such as coastal parts of the Wairoa district and the Takapau plains will very rarely experience frosts.

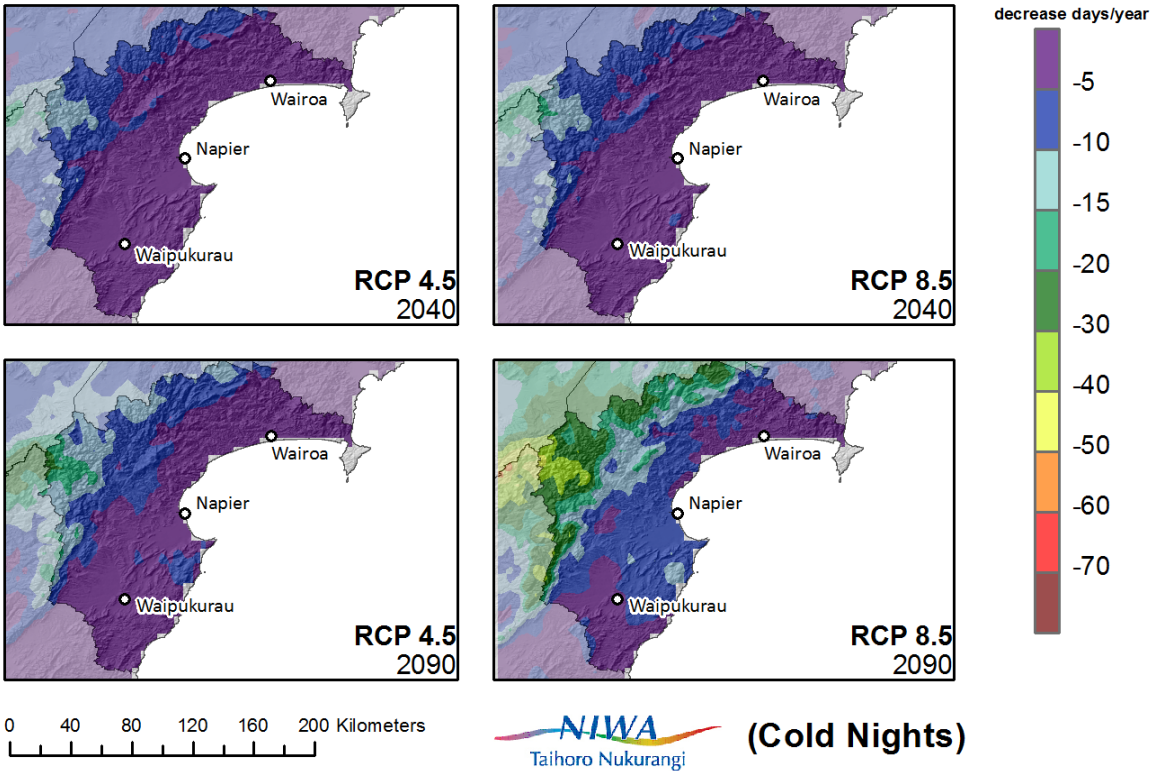

Figure 3-6: Projected decrease in number of cold nights per year (Tmin <0°C) at 2040 & 2090 for RCP 4.5 (left panels) and RCP 8.5 (right panels), for the Hawke's Bay Region. Projected change in cold nights is relative to 1986-2005. The numbers on the scale refer to the *decrease* in the number of cold nights. Results are based on projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km. © NIWA.

3.2 Changes to precipitation

Precipitation projections are presented in this section. Variables covered include seasonal and annual precipitation (Section 3.2.1) and extreme rainfall (Section 3.2.2)

3.2.1 Precipitation projections

The ensemble averages for dynamically downscaled projections, using NIWA's Regional Climate Model, for precipitation are presented in this section. Figure 3-7 and Figure 3-8 show the projected seasonal patterns of precipitation change over the Hawke's Bay Region at 2040 and 2090 for RCP 4.5, and Figure 3-9 and Figure 3-10 show the same for RCP 8.5.

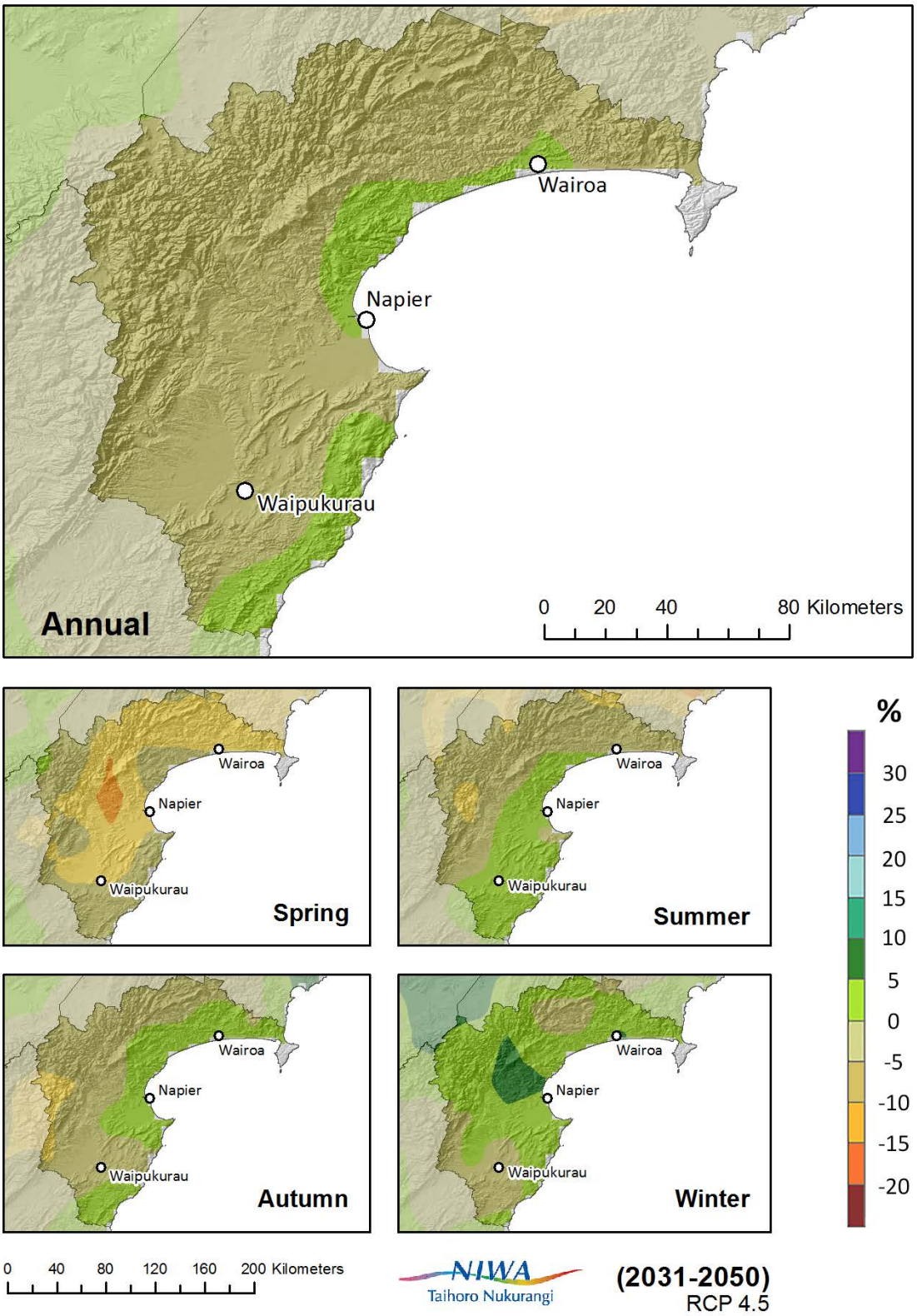

Figure 3-7: Projected annual and seasonal precipitation changes (in %) at 2040 (2031-2050 average). Relative to 1986-2005 average, for the IPCC RCP 4.5 scenario, averaged over 6 climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km. ©NIWA.

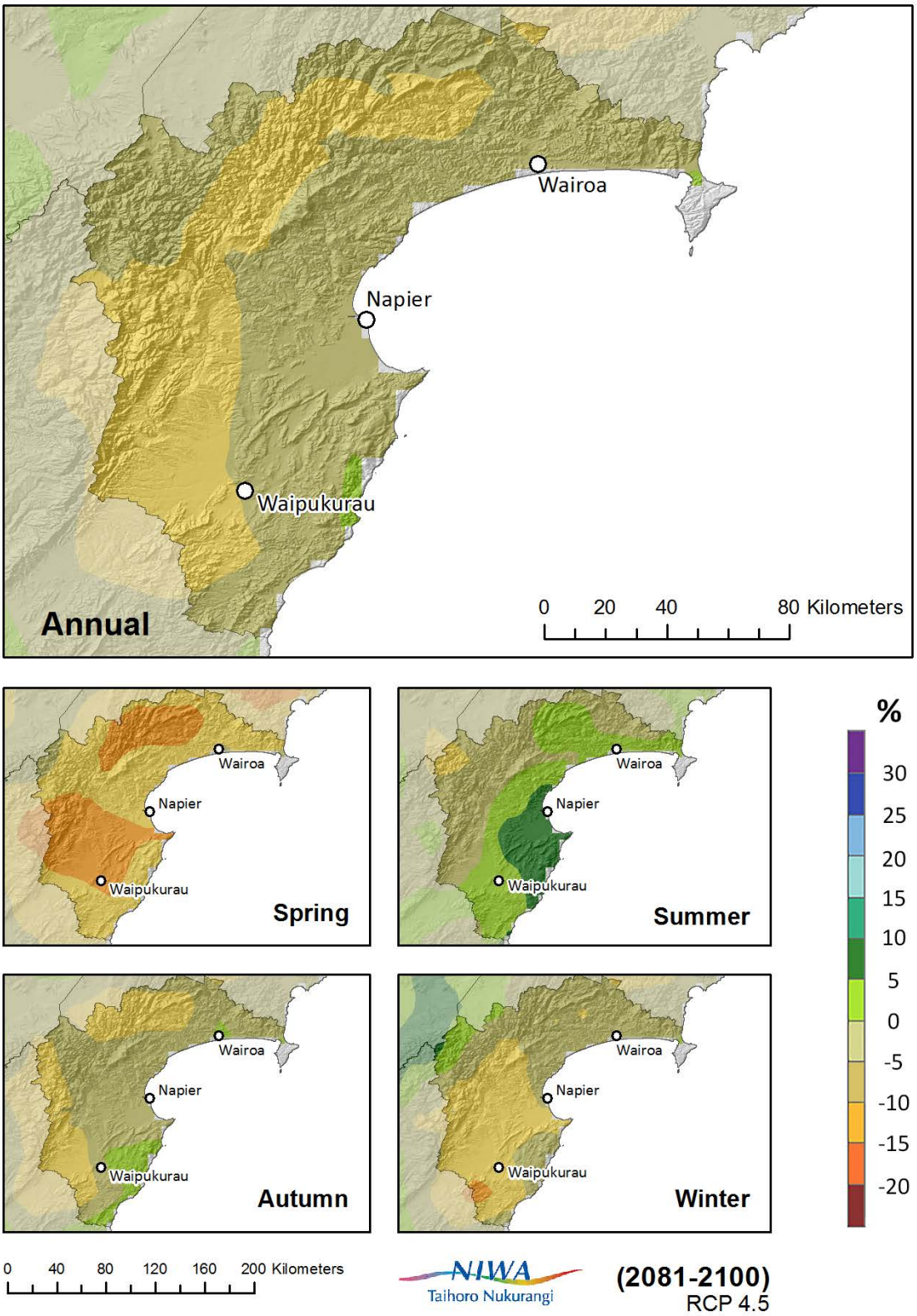

Figure 3-8: Projected annual and seasonal precipitation changes (in %) at 2090 (2081-2100 average). Relative to 1986-2005 average, for the RCP 4.5 scenario, averaged over 6 climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km. ©NIWA.

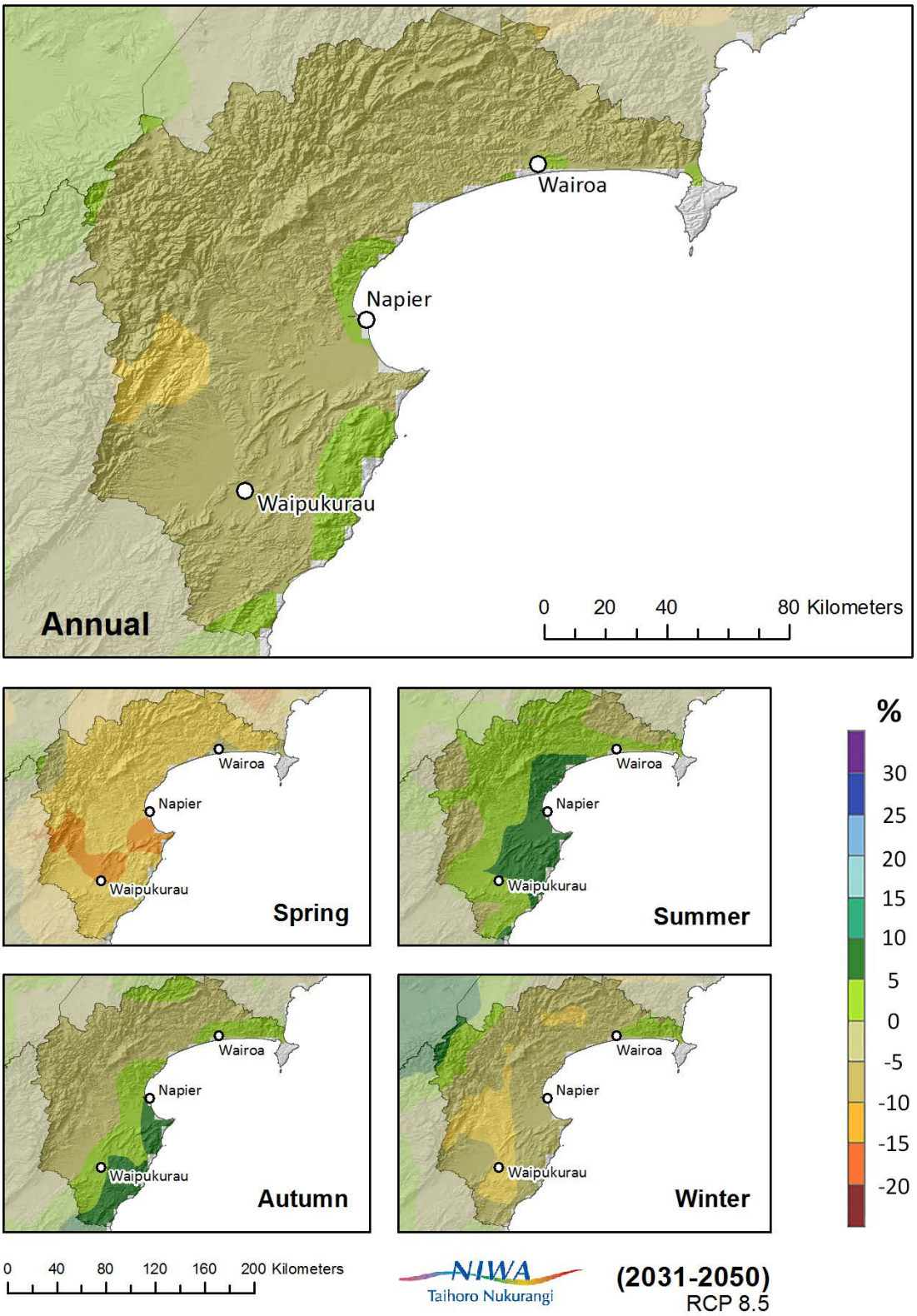

Figure 3-9: Projected annual and seasonal precipitation changes (in %) at 2040 (2031-2050 average). Relative to 1986-2005 average, for the IPCC RCP 8.5 scenario, averaged over 6 climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km. ©NIWA.

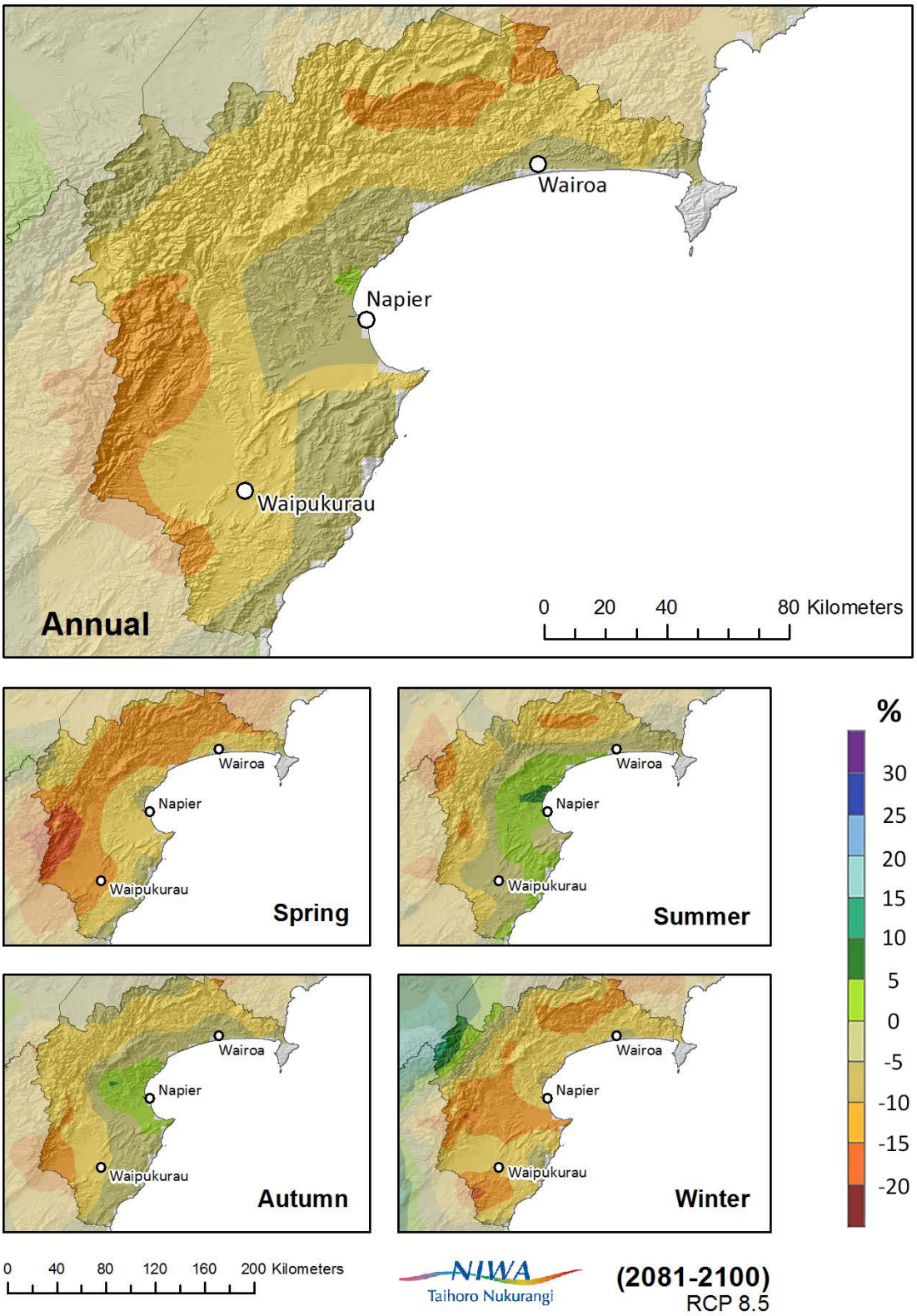

Figure 3-105: Projected annual and seasonal precipitation changes (in %) at 2090 (2081-2100 average). Relative to 1986-2005 average, for the IPCC RCP 8.5 scenario, averaged over 6 climate models. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km. ©NIWA.

In general, rainfall is projected to decrease across the region but there are seasonal differences. Under RCP 4.5 at 2040 (Figure 3-7), decreases in annual rainfall of up to 5% are projected for most of the region. The exceptions are coastal areas where an increase in annual rainfall of up to 5% is projected. At the seasonal scale, spring exhibits a drying signal across the region. In parts of the Hastings district the decrease in spring rainfall is projected to be up to 15%. Winter is the season with the largest increase in rainfall projected, with up to 10% more rainfall projected for parts of the Hastings district. For 2090 under RCP 4.5 (Figure 3-8), a greater drying signal is seen across the region, with up to 10% less annual rainfall projected for the ranges. Summer rainfall is projected to have the largest increase in rainfall for Napier and parts of Hastings and Central Hawke's Bay with up to 10% more rainfall projected. Spring is projected to see the largest decrease in seasonal rainfall with up to 15% less rainfall in parts of the region.

Similar patterns are seen for RCP 8.5 at 2040 and 2090, but these patterns are amplified. At 2040 (Figure 3-9), summer and autumn rainfall is projected to increase in parts of the region near the coastline by up to 10% while spring and winter shows a decrease in rainfall for much of the region (up to 15% less in parts of Hastings during spring). For 2090 (Figure 3-10), only small areas of the region show an increase in rainfall during summer and spring. The overall pattern during all seasons is for a decrease in rainfall. The decrease in rainfall is most pronounced during spring with parts of the Ruahine Ranges projected to see a decrease in rainfall of around 20%.

3.2.2 Extreme rainfall

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

Changes in the magnitude of extreme precipitation across the Hawke's Bay Region have been dynamically downscaled using NIWA's Regional Climate Model in Figure 3-11. The magnitude of extreme precipitation, as quantified by the changes in the 99th percentile of the daily precipitation distribution (i.e. the top 1% of rain days[1]), shows increases across the region (no part of the region projects decreases in extreme rainfall). The most increases in 99th percentile daily precipitation are generally around the Wairoa district, as well as in the coastal areas of the region.

Under RCP 4.5 at 2040, most areas expect a 5% increase in extreme daily precipitation, with some small parts of the region experiencing up to a 10% and 15% increase in extreme daily precipitation. By 2090 under RCP 4.5, Wairoa and some coastal parts of Hastings and Central Hawke's Bay may receive up to 15% more extreme precipitation.

Under RCP 8.5 at 2040, the majority of the region is projected to see an increase is extreme daily precipitation of up to 5%. However, by 2090, most areas are likely to see at least a 5-10% increase in extreme daily precipitation, with some coastal areas projected to receive up to 20% more extreme precipitation.

[1] Note that the 99th percentile is a relatively low threshold for engineering purposes (see Ministry for the Environment, 2008, Chapter 5.2). We would expect that, on average, approximately one day per year would exceed this threshold.

As a cautionary aside, the climate models being used do not have the resolution to realistically simulate tropical cyclones, so extreme rainfall from these phenomena are likely to be underestimated in our results.

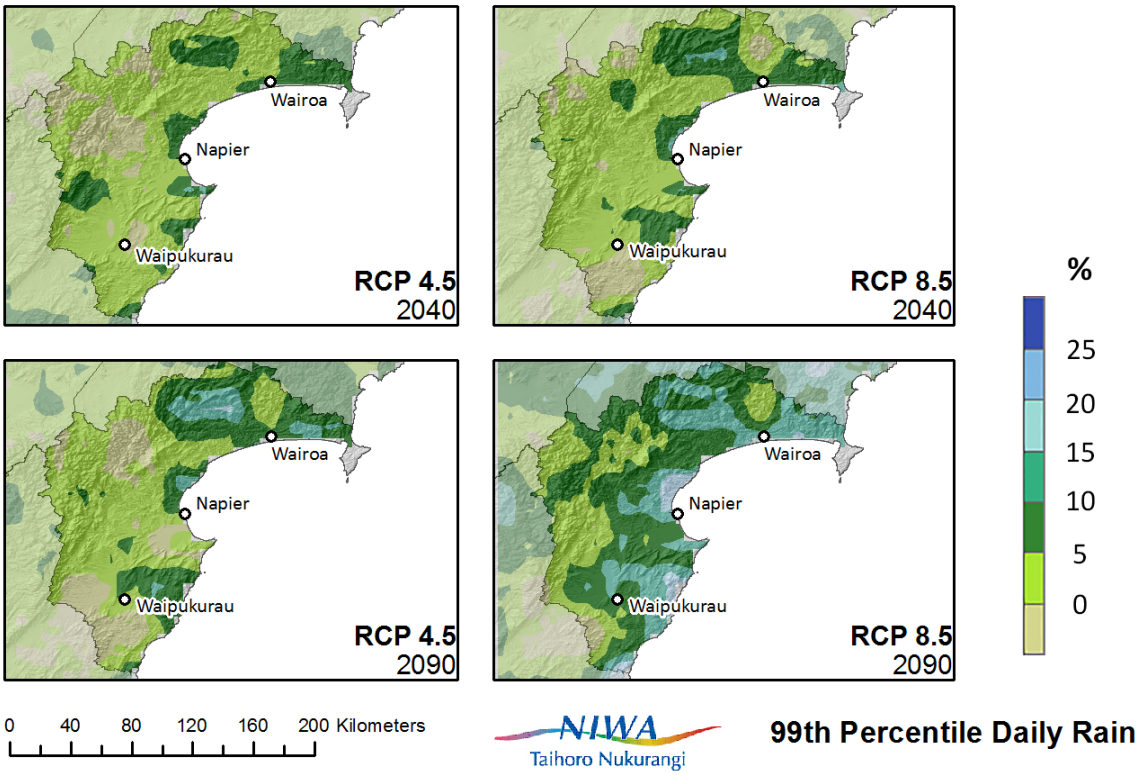

Figure 3-11: Change in the magnitude of the 99th percentile of daily precipitation (in %) for RCP 4.5 and 8.5, at 2040 and 2090. Projected change in 99th percentile of daily precipitation is relative to 1986-2005. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km. © NIWA.

3.3 Changes to evaporation and climatic drought

The increase in frequency and intensity of climatic droughts in a changing climate is of deep concern for the New Zealand society and economy, not the least for the stakeholders of the primary sector. Drought intensity is affected by increasing temperature which in turn increases moisture loss through higher evapotranspiration rates, and also by the lack of sufficient moderate intensity precipitation required to recharge aquifers and replenish soil moisture.

Potential evapotranspiration deficit (PED) is the cumulative difference between potential evapotranspiration (PET) and rainfall from 1 July of a calendar year to 30 June of the next year, for days of soil moisture under half of available water capacity (AWC), where an AWC of 150mm for silty-loamy soils is consistent with estimates in previous studies (e.g. Mullan et al., 2005). PED, in units of mm, can be thought of as the amount of rainfall needed in order to keep pastures growing at optimum levels. An increase in PED of 30 mm or more corresponds to an extra week of reduced grass growth.

A regional map of projected changes in potential evapotranspiration deficit is presented in Figure 3-12. The maps are plotted with an annual accumulated PED anomaly with respect to the historical annual average.

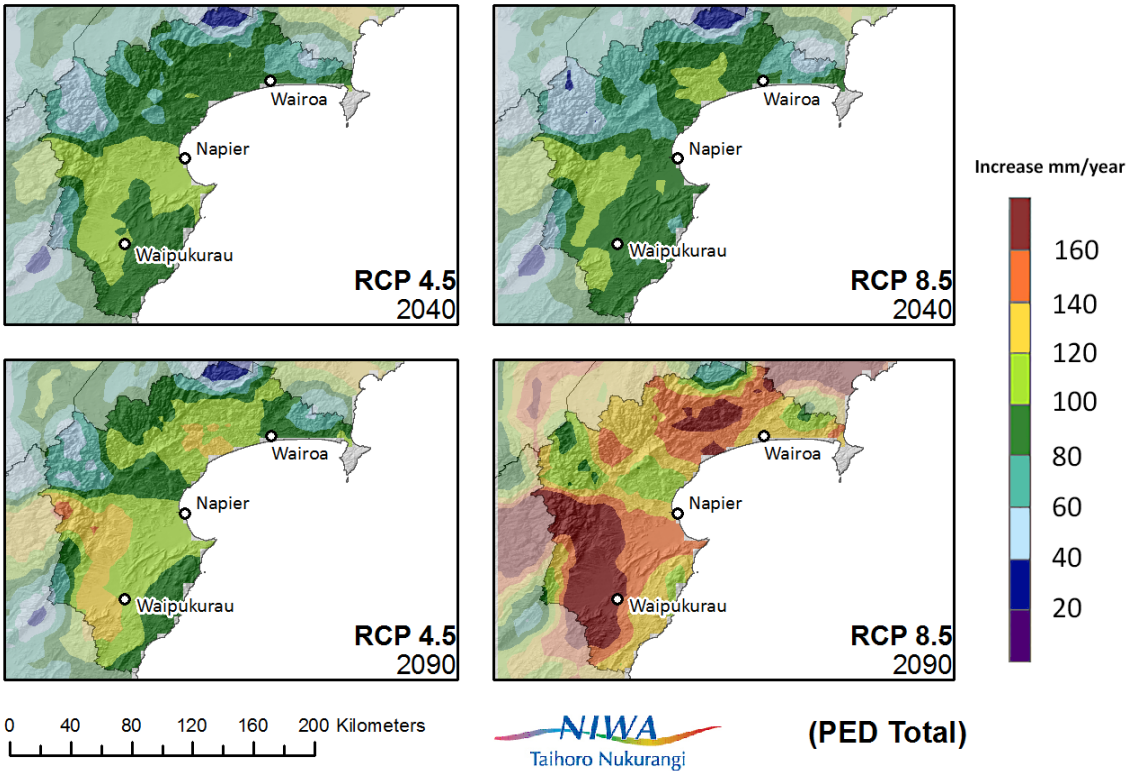

Figure 3-12: Projected changes in Potential Evapotranspiration Deficit (PED, in mm accumulation over the July-June 'hydrologic year') for the Hawke's Bay Region, for RCP 4.5 and 8.5, at 2040 and 2090. Projected change in PED is relative to 1986-2005. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km. © NIWA.

As shown by Figure 3-12, projected PED varies across the Hawke's Bay Region. Generally, smaller increases in PED are projected for the highest elevations of the Huiarau, Kaweka and Ruahine Ranges, and larger increases in PED are projected for parts of the Hastings district. By 2090 under RCP 8.5, increases in PED of over 160 mm/year are projected for parts of the Wairoa and Hastings districts. This indicates that these areas are likely to become more drought prone in the future.

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

The study established distinct regional differences across New Zealand in changes to climatic drought vulnerability projected under future climate change, with an increase in climatic drought on the east coast of the North and South Islands being the most plausible and consistent outcome. This is consistent with previous studies on climate change impacts on climatic drought in a New Zealand

context (e.g. Mullan et al., 2005). The study concluded that climatic drought risk is expected to increase during this century in all areas that are currently drought prone, under both the 'low-medium' and 'medium-high' scenarios. The 'drought risk' was analysed in terms of soil moisture levels – drought initiation occurs when soil moisture falls below the historically established 10th percentile for the given time of year for a period greater than one month, and drought termination occurs when soil moisture is above the 10th percentile for one month.

During this century, evidence for increases in time spent in climatic drought is apparent for Canterbury, Hawke's Bay, Gisborne, and Northland (Clark et al., 2011).

Under the most likely mid-range emissions scenario the projected increase in percentage of time spent in drought from 1980-99 levels is about is at least 5% for 2030-2050 and at least 10% for the whole region for 2070-2090 (Figure 3-13). Note that these results are based on the IPCC's Fourth Assessment Report.

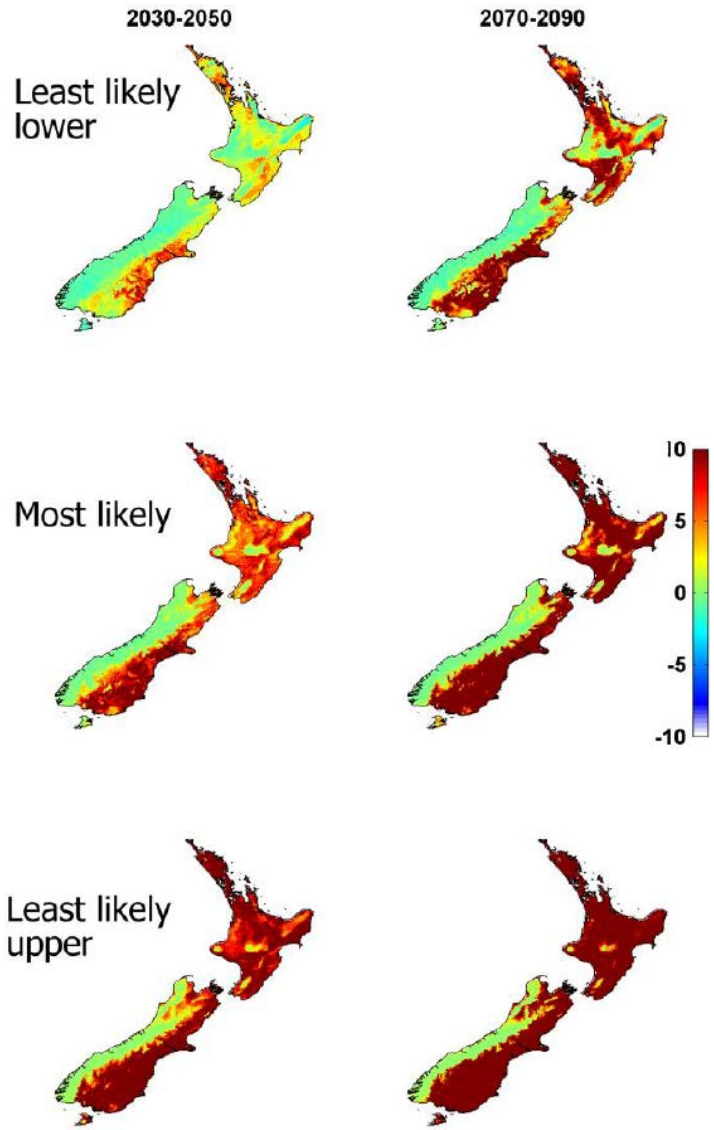

Figure 3-6: Projected increase in percentage of time spent in climatic drought from 1980-99 levels for the A1B emissions scenario. Results summarise 19 global climate models. After Clark et al. (2011).

3.4 Changes to wind and storms

3.4.1 Extreme wind

The 99th percentile of daily-mean wind speed was evaluated over the historical 1986-2005 period at each VCSN grid-point in the downscaled (but not bias-corrected) regional model output data, by Mullan et al. (2016). Figure 3-14 maps how the 99th percentiles at 2040 and 2090 differ from the current climate for RCP 4.5 and RCP 8.5.

Relatively small increases or decreases in extreme daily winds are projected in Figure 3-14 for the Hawke's Bay Region. The greatest decreases are projected for the Napier and Hastings districts. For 2090 under RCP 8.5, a decrease of up to around 3% in the 99th percentile of daily mean wind speeds is projected in these areas. For the remainder of the region, a slight increase in the 99th percentile of daily mean wind speeds is projected.

No seasonal breakdown of extremes is given, but it is expected that the higher winds are primarily due to the increased westerly pressure gradient in winter and spring. Very localised extreme winds from more vigorous summer convection are also potentially a problem in the future, but such events are not resolved by the regional model being used here.

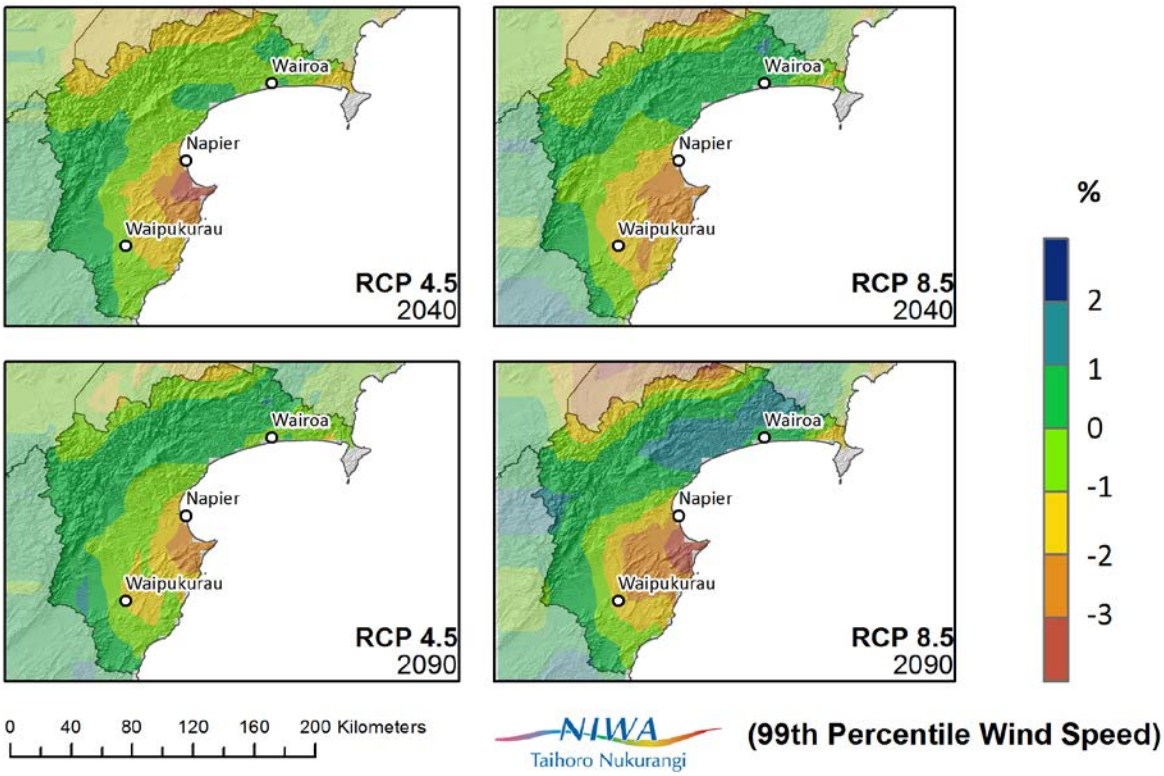

Figure 3-14: Change in the magnitude of the 99th percentile of daily-mean wind speed, for RCP 4.5 and 8.5 at 2040 and 2090. Projected change in 99th percentile of daily mean wind speed is relative to 1986-2005. Results are based on dynamical downscaled projections using NIWA's Regional Climate Model. Resolution of projection is 5km x 5km. © NIWA.

3.4.2 Storms

Tropical and ex-tropical cyclones

Across the world, it is considered likely that the global frequency of tropical cyclones will either decrease or remain essentially unchanged over the 21st century, concurrent with a likely increase in both global mean tropical cyclone maximum wind speed and rain rates (IPCC, 2013). The influence of future climate change on tropical cyclones is likely to vary by region, but there is low confidence in region-specific projections. The frequency of some storms will more likely than not increase in some basins. More extreme precipitation near the centres of tropical cyclones making landfall is projected in some regions including Australia and many Pacific Islands – this is important as tropical cyclones generated in these areas may affect New Zealand.

The Hawke's Bay Region is sometimes adversely affected by cyclones of tropical origin. These storms, which bring heavy rain and strong winds to northern parts of New Zealand, are usually weaker by the time they affect the Hawke's Bay Region. However, occasionally they retain characteristics which have the potential to cause flooding, generate primary and secondary wind damage to vegetation and infrastructure, and higher-than-normal wave heights and coastal storm surges. On average, New Zealand currently experiences at least one ex-tropical cyclone passing within 550km of the country every year.

Overall, there is significant uncertainty surrounding projections of tropical cyclones into the future. It is likely that storms making landfall will be stronger and cause more damage. However, the IPCC (2013) projections are for tropical cyclones – storms that are in the tropics and thus at their full strength, not ex-tropical cyclones that have undergone extratropical transition where they begin to lose their strength, as they do upon their southwards path where they may influence New Zealand. Therefore, the frequency with which ex-tropical cyclones and other tropical depressions may reach the Hawke's Bay Region in the future is uncertain.

Extra-tropical cyclones

The IPCC comments that the global number of extra-tropical cyclones (the low pressure systems that affect New Zealand every few days, with origins outside of the tropics) is *unlikely* to decrease by more than a few per cent, and future changes in storms are *likely* to be small compared to natural inter-annual variability. This statement applies globally, and regionally-specific changes can be quite different. The storm track response to global warming is more consistent between AR5 models (and between AR4 and AR5 models) in the Southern Hemisphere than in the Northern Hemisphere. Extratropical storm tracks will tend to shift poleward by several degrees (Figure 3-15), but the reduction in storm frequency is only a few per cent.

The mid-latitude jet associated with the storm tracks (usually lying well south of New Zealand) is projected to increase in strength (Barnes and Polvani, 2013). This analysis also found that the pattern of variability of the Southern Hemisphere jet was predicted to change in the CMIP5 models; less north-south vacillation was expected in the future, but more pulsing in intensity (with the opposite behaviour in the Northern Hemisphere jet). Just what this means for New Zealand is unclear, however, and further analysis of regional consequences is needed.

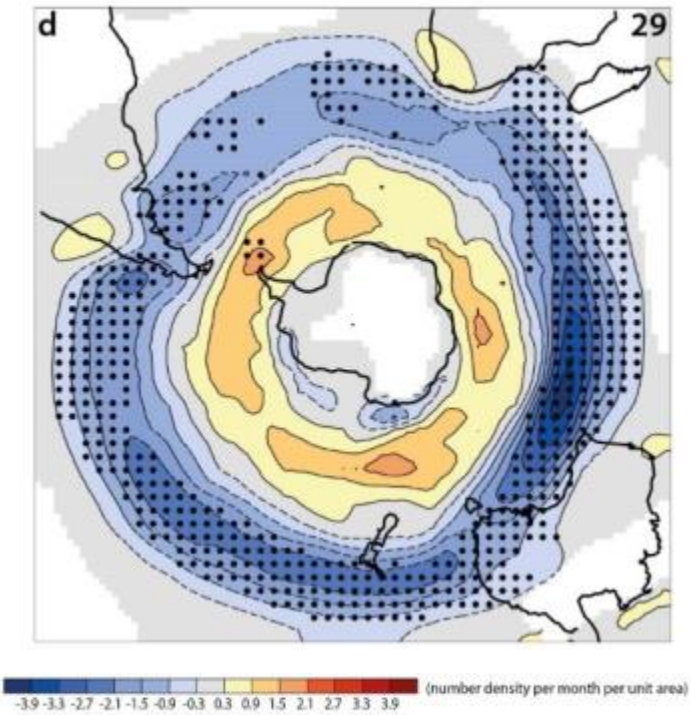

Figure 3-15: Change in winter Southern Hemisphere storm track between 1986–2005 and 2081–2100, under RCP8.5, from a 29-member CMIP5 multi-model ensemble. Blue shading indicates a decrease, and yellow-orange shading an increase in the number of storm 'centres'. Stippling is added where 90 per cent of the models agree on the sign of the change. Reproduced from IPCC AR5 Figure 12.20(d), which gives further detail on the figure and underlying analysis.

One regional study is that of Dowdy et al. (2013), who analysed the IPCC Fourth Assessment projections of "East Coast Lows", low pressure systems which develop in the Tasman Sea off the east coast of Australia, usually in the winter season, and can have serious consequences with extreme rainfall, winds and waves. Such lows then generally move south-eastwards and affect New Zealand. Dowdy et al. (2013) found that such lows reduced in frequency by 30% (mainly in winter) between the late 20th century and the late 21st century.

Information on possible changes to New Zealand storminess and extremes can be found in Mullan et al. (2011) (based on AR4 global models). Evidence is presented that suggests some increase in storm intensity, small-scale wind extremes and thunderstorms is likely to occur in the New Zealand region.

4 Conclusions

The climate is changing. It is internationally accepted that further changes will result from increasing amounts of greenhouse gases in the atmosphere. In addition, the climate will also vary from year to year and decade to decade owing to natural processes such as El Niño. Climate change effects over the next decades are predictable with some certainty, and will vary from place to place. This report has shown the futire projections for some of these changes for the Hawke's Bay Region

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