Fire Research Report

Impact of Climate Change on Long-term Fire Danger

NIWA/Forest Research

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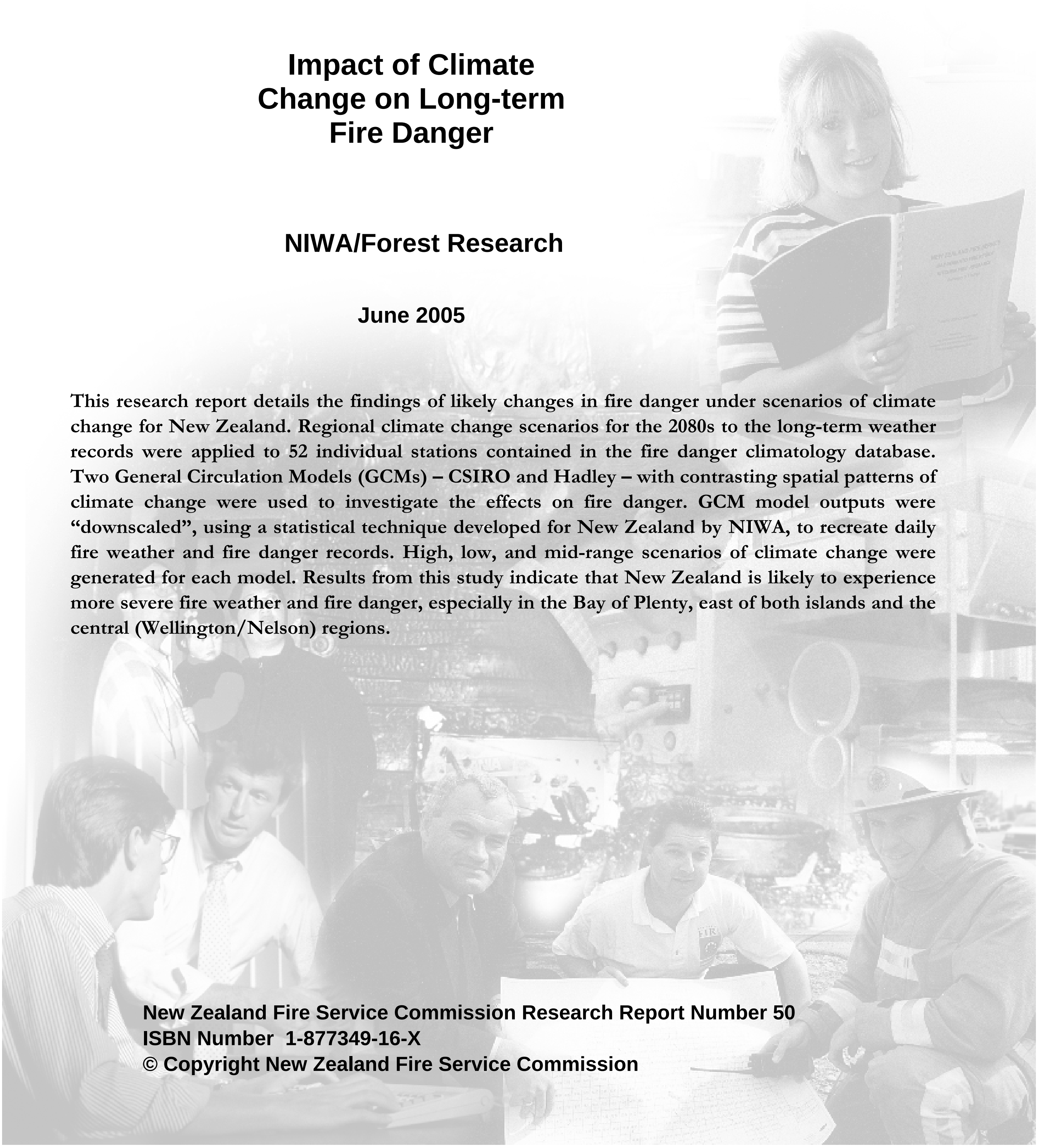

This research report details the findings of likely changes in fire danger under scenarios of climate change for New Zealand. Regional climate change scenarios for the 2080s to the long-term weather records were applied to 52 individual stations contained in the fire danger climatology database. Two General Circulation Models (GCMs) – CSIRO and Hadley – with contrasting spatial patterns of climate change were used to investigate the effects on fire danger. GCM model outputs were "downscaled", using a statistical technique developed for New Zealand by NIWA, to recreate daily fire weather and fire danger records. High, low, and mid-range scenarios of climate change were generated for each model. Results from this study indicate that New Zealand is likely to experience more severe fire weather and fire danger, especially in the Bay of Plenty, east of both islands and the central (Wellington/Nelson) regions.

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Executive Summary

- New Zealand experiences around 3000 vegetation wildfires each year that burn around 7000 hectares of rural lands. Strong winds, high temperatures, low humidity and seasonal drought can combine to produce dangerous fire weather situations. Evidence suggests that future fire activity is likely to increase as a result of global warming and associated climate change.

- Previous compilations of a comprehensive database of daily fire weather and fire danger information provide a better description of New Zealand's fire climate. This allows investigation of the effects of potential climate change on future fire danger, through application of climate change scenarios to the long-term fire weather records.

- The main objective of the current research is to determine likely changes in fire danger under scenarios of climate change for New Zealand. This research applies regional climate change scenarios for the 2080s to the long-term weather records for individual stations contained in the fire danger climatology database.

- The indications of possible future fire activity and increased suppression and management requirements associated with climate change highlighted within this study will enable New Zealand rural fire authorities to make more informed fire management decisions on fire prevention and preparedness activities now and in the future.

- The fire weather and fire danger database was updated to include data to 31 December 2004. Fifty-two of these stations providing good spatial coverage were then selected for analysis of the effects of climate change. Sites selected required at least 11 or more unbroken calendar years of data (i.e., 10 complete fire seasons) to 31 December 2004, a fairly representative period of climate.

- Two General Circulation Models (GCMs) – CSIRO and Hadley – with contrasting spatial patterns of climate change were used to investigate the effects on fire danger. GCM model outputs were "downscaled", using a statistical technique developed for New Zealand by NIWA, to recreate daily fire weather and fire danger records at each of the 52 weather stations. High, low, and mid-range scenarios of climate change were generated for each model.

- Summary statistics of weather inputs, FWI System components and fire danger class frequencies were calculated for each station for the range of scenarios. Mean values of temperature, rainfall, Fine Fuel Moisture Code (FFMC), Build Up Index (BUI), Cumulative Daily Severity Rating (CDSR) and number of days of Very High (VH) plus Extreme (E)

Forest fire danger were compared on an annual and seasonal basis. Annual differences were compared to those for fire season months when most fires are expected to occur.

- The results of the comparison showed changes in temperature and rainfall followed the original patterns in offset values for each scenario. Temperature changes of +0.5 to +2.4 ºC were significantly higher than current climate for all but the Hadley low extreme scenario. Rainfall changes were more variable. The Hadley model scenarios resulted in reductions of -15% to -35% (-100 to -330 mm) in annual rainfalls for stations in Northland, Bay of Plenty and eastern parts of both the North and South Islands, and increases of +10% to +25% (+80 to +800 mm) for stations from the West Coast and Southland. Changes in rainfall under the CSIRO scenarios were not significant, apart from a 12% increase (+70 to +80 mm) at Invercargill.

- Increased FFMC values occurred in most places under both the Hadley and CSIRO high extreme and mid-range scenarios, in particular the Auckland, Bay of Plenty, Gisborne, Wellington and coastal Canterbury areas. However, average changes were small at less than +2 to +3 points (i.e., <4% of current values). Small decreases in FFMC (up to -0.5 points, or -1%) were obtained for some stations in the southern South Island under the Hadley model. Similarly, significant increases in BUI (up to +20 points, or +60%) were found from the Bay of Plenty and central (Wellington/Nelson) regions under both the Hadley and CSIRO model scenarios. While stations in north and east of the North Island and east of the South Island increased significantly under only the Hadley model scenarios. Stations in the west and south showed increases solely under the CSIRO model, as a result of drier winters and wetter springs in the south and west under this model.

- Significantly higher CDSR values and more days of VH+E Forest fire danger were found for stations in the east of both islands, the Bay of Plenty and central (Wellington/Nelson) regions under both the Hadley and CSIRO high extreme and mid-range scenarios. In several cases (e.g., Gisborne, Napier and Christchurch Airports), average CDSR values increased by more than 300-580 points (25-65%), and the total number of days of VH+E Forest fire danger by more than 20 days (>50%). Smaller, but still statistically significant, increases in CDSR (10-110 points, or 15-25%) were found under the CSIRO high extreme scenario for stations in the west of both islands and south of the South Island. Several stations (typically those in the south and west with low or no existing fire danger) showed little or no change in CDSR or VH+E Forest fire danger but, in one case (Tara Hills under the Hadley high extreme scenario), showed a very slight decrease in VH+E fire danger.

- Evidence from changes in mean monthly temperatures, FFMC and MSR values, and VH+E Forest fire danger class frequencies under the model scenarios suggests that fire season length could well be extended, by starting earlier and/or finishing later, in many parts of the country. However, no adequate method exists to test this result properly.

- Given New Zealand's maritime climate any subtle changes in relative humidity (RH), which was not modelled, are unlikely to have any significant effect on future fire dangers. However, indicative wind speed increases from global climate models almost certainly suggest further increases in future fire dangers. Modelled changes in the mean westerly wind speed component across New Zealand show an increase of about 10% of its current value over the next 50 years, with a mid-range projection of 60% by the 2080s. This will increase the Initial Spread Index (ISI) value; and result in increased drying, and therefore higher FFMC values and subsequent ISI and FWI values. The general trend is expected to be a further increase in fire weather severity.

- Results from this study indicate that New Zealand is likely to experience more severe fire weather and fire danger, especially in the Bay of Plenty, east of both islands and the central (Wellington/Nelson) regions. This will result in increased fire risk including:

  - easier ignition, and therefore a greater number of fires;

  - drier and windier conditions, resulting in faster fire spread, greater areas burned, and increased fire suppression costs and damages;

  - longer fire seasons and increased drought frequency, and associated increases in fuel drying, greater fuel availability and increased fire intensities, more prolonged mop-up, increased resource requirements and more difficult fire suppression;

  - increased frequency of thunderstorms and lightning.

  It is possible that some of this risk might be offset by increased rainfall.

1. Introduction

Although not having one of the most severe fire climates in the world, New Zealand still experiences around 3000 rural vegetation fires each year that burn some 7500 ha of rural lands[1]. Strong winds, often associated with high temperatures, low humidity and seasonal drought, can combine to produce dangerous fire weather situations. To effectively manage this risk, New Zealand fire managers require indications of likely trends in fire danger and fire season severity, and comparisons with previous seasons and long-term averages. This includes potential changes in long-term fire danger such as those associated with projections of future global warming and climate change.

The production of a comprehensive climatology of daily fire weather and fire danger in prior research (Pearce *et al*. 2003) has provided a better description of New Zealand's fire climate. In itself, this enables rural fire authorities and the National Rural Fire Authority (NRFA) to increase the focus of fire prevention and mitigation activities. However, the compilation of a database of current and historical fire climate data also allows investigation of the effects of potential climate change on future fire danger, through application of climate change scenarios to the long-term weather records for individual stations contained within the fire danger climatology database. Armed with a knowledge of the impacts of future fire climate on fire danger, fire authorities will then be better able to prepare for the risks associated with this changing fire climate.

2. Scope of the Study

This report summarises research completed by Forest Research as part of the joint NIWA-Forest Research project "Impacts of Climate Variability and Change on Seasonal Fire Danger". The joint project aimed to continue investigation (by NIWA under phases 1 & 2 of the research) of the effects of current climate variability on seasonal fire climate severity, as well as to initiate new research (by Forest Research, with the assistance of NIWA) to investigate the effect of climate change on future fire danger.

This latter phase (Phase 3) of the joint project aimed to "**Analyse the impact of climate change and variability on long-term fire danger"** by determining likely changes in fire danger under actual scenarios of climate variability and change for New Zealand. This was achieved by applying regional climate variability and climate change scenarios to the long-term weather records for

[1] From statistics for the period 1993/94-2002/03 produced by the National Rural Fire Authority, based on the Annual Return of Fires form completed by New Zealand fire authorities.

individual stations contained in the fire danger climatology database developed previously (Pearce *et al*. 2003). The key steps in this study included:

- Defining scenarios of climate variability and change for New Zealand to be applied to long-term weather records for individual stations;

- Updating long-term fire weather records to include data for recent fire seasons, and re-running current fire danger climatologies for as many as possible of the existing 127 weather stations, and any additional stations with sufficient length of record;

- Applying likely changes in weather inputs (i.e., temperature, humidity, wind speed and rainfall) from regional climate scenarios to station weather records, and recalculating Fire Weather Index (FWI) System components, severity ratings and fire danger class frequencies for each station;

- Comparing fire danger climatologies produced under scenarios of climate variability and change with those under current fire climate to predict potential impacts of regional fire danger and seasonal severity; and

- Indicating possible future fire behaviour and suppression requirements to enable rural fire authorities to make more informed fire management decisions on fire prevention and preparedness activities.

3. Background

3.1 Fire danger rating in New Zealand

Assessment of the effect of fire weather (and other fire environment factors of fuels and topography) on potential fire occurrence and fire behaviour is assisted by the use of the New Zealand Fire Danger Rating System (NZFDRS) (Fig. 1a), which is based on the Canadian Forest Fire Danger Rating System (CFFDRS). The NZFDRS is used by New Zealand fire authorities to assess the probability of a fire starting, spreading and doing damage. New Zealand’s adoption and continued adaptation of the CFFDRS has been described by Fogarty *et al*. (1998).

The Fire Weather Index (FWI) subsystem of the CFFDRS was adopted by the former New Zealand Forest Service in 1980. Based solely on weather observations, the FWI System (Fig. 1b) provides numerical ratings of relative ignition potential and fire behaviour which can be used as guides in a wide variety of fire management activities including (after Alexander 1992a):

- prevention planning (e.g., informing the public of pending fire danger, regulating access and risk associated with public and industrial use of forest and rural areas);
- preparedness planning (e.g., level of readiness and prepositioning of suppression resources);
- detection planning (e.g., lookout manning and aerial patrol routing);
- initial attack dispatching;
- suppression tactics and strategies on active wildfires; and
- prescribed fire planning and execution.

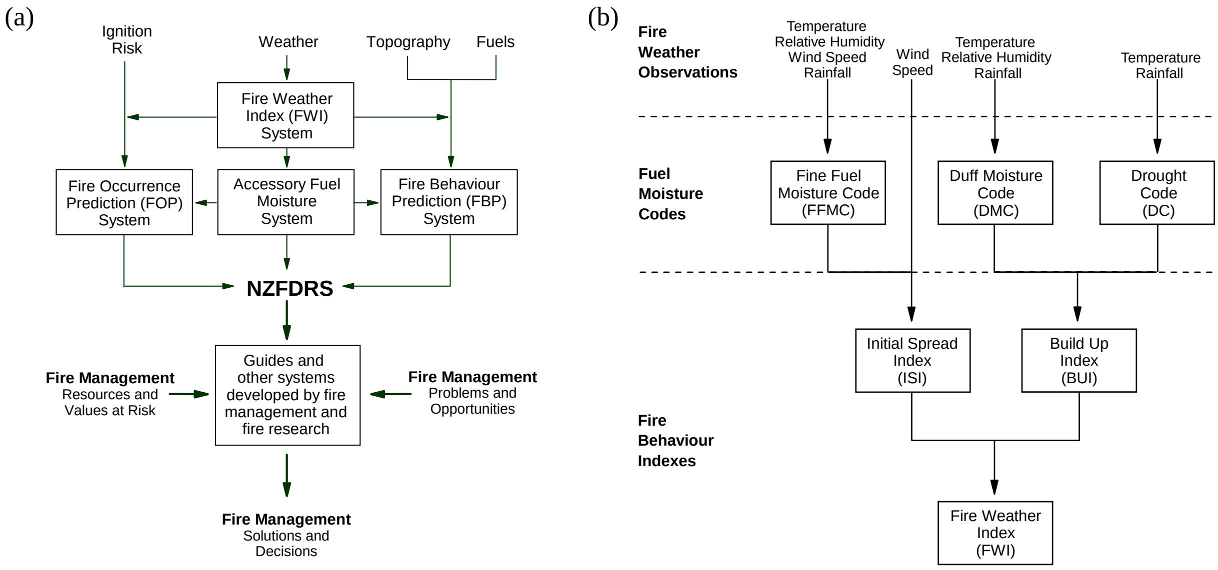

Figure 1. Simplified structure diagrams for (a) the New Zealand Fire Danger Rating System (NZFDRS), illustrating the linkage to fire management actions (after Fogarty *et al*. 1998); and (b) the Fire Weather Index (FWI) System (after Anon. 1993).

Daily observations made at noon local standard time of temperature, relative humidity, wind speed, and 24-hour accumulated rainfall recorded by a network of remote automatic weather stations located around the country are used to compute values of the three fuel moisture codes and three fire behaviour indexes. These may be determined from tables (e.g., Anon. 1993) or by computer calculation (Van Wagner and Pickett 1985).

While production of climatologies for the standard weather elements are commonplace (e.g., NZMS 1983a), analyses of fire danger are much less routine (Nikleva 1973, Tapper *et al*. 1993). Despite a clear need being expressed for such analyses (Valentine 1978, p. 35, Alexander 1992c), few New Zealand examples of fire climate studies exist. In trialling the FWI System prior to its introduction, Valentine (1978) compared fire season climatologies for British Columbia and New Zealand, and Cooper and Ashley-Jones (1987) used fire danger class frequencies to investigate the economics of fire prevention activities. Pearce (1996) produced a fire climatology for 20 weather stations (Fig. 2) and, based on the example of Simard and Valenzuela (1972) from Canada, presented long-term average and extreme values for both weather inputs and fire danger components in a summary table for each station. This database was extended in 1998 to investigate the potential impact of the 1997/98 El Nino event on regional fire dangers (Anon. 1998, Pearce 1998), and in 2001 to further illustrate the use of severity ratings to compare and predict fire season conditions (Majorhazi and Pearce 2001).

The high value of fire climatological information for fire management is evidenced by the vast number of studies and wide variety of applications illustrated in the literature. A significant number of these studies have attempted to use fire climatologies to describe fire activity (Cheney 1976, Haines *et al*. 1980, Harrington *et al*. 1983). However, fire danger climatologies have also been used to illustrate seasonal trends in fire danger (McAlpine 1990), to determine length of fire season (Wotton and Flannigan 1993), and to delineate fire climate zones (Simard 1973, Stocks 1978, Heydenrych and Salinger 2002). They have also been used to define impacts of El Nino-Southern Oscillation events (Williams 1998) and climate change (Wotton *et al*. 1998). Perhaps more importantly, fire climatologies have also been used to develop systems to assist with the full range of fire management activities, including prevention (OMNR 1989, Borger 1997), preparedness (Gray and Janz 1985, Fogarty and Smart 1994), fire suppression (Andrews *et al*. 1998, Fogarty and Slijepcevic 1998), and prescribed fire planning (Martell 1978, Furman 1979, Andrews and Bradshaw 1990).

To this end, a major effort was undertaken by Forest Research in 2002/03 to develop a more comprehensive fire climatological database for New Zealand as part of the preceding NZFSC-funded project “Fire danger climatology analyses and tools” (Pearce *et al*. 2003). This project resulted in the production of data sets of weather and fire danger components for 127 of the weather stations contained within the NRFA’s fire weather network (see Fig. 2). As well as the 20 stations included in the original Pearce (1996) study, the analysis included all stations that had greater than 5 years of record available. The principal output from the analysis was a summary table for each of the 127 stations containing the long-term average and extreme values of each of the weather and FWI System components and fire danger classes summarised by month, fire season and year (see Pearce *et al*. 2003). Summary statistics for each station were also used to identify the individual weather stations and geographic regions with the most severe fire climates. Stations in Marlborough and Canterbury demonstrated the highest values of the three fire climate severity measures contrasted.

The compilation of a comprehensive database of daily fire weather and fire danger information for 127 of the 179 weather stations for which data was available was the other major output from the analysis. In its own right, this database also provides an extremely useful tool for the NRFA and fire managers in making more informed fire management decisions on prevention, preparedness, and prescribed burning activities. The database has also been an essential component of associated research conducted by both NIWA and Forest Research on links between climate and severe fire seasons, and prediction and forecasting of fire season severity.

Based on the results of a pilot study (Salinger *et al*. 1999), the closely aligned research undertaken by NIWA as part of the NZFSC-funded "Climate and severe fire seasons" and "Prediction of fire season severity" projects identified large scale global and regional climate factors influencing fire season severity (Heydenrych *et al*. 2001, Heydenrych and Salinger 2002, Gosai *et al*. 2003, Gosai *et al*. 2004) as a basis for improving fire danger forecasts (Gosai and Salinger 2004, Renwick and Salinger 2003, Gosai and Griffiths 2004). As part of the joint NIWA-FR "Prediction of fire season severity" project, Forest Research has developed a methodology for predicting fire season severity using the long-term station datasets contained within the fire danger climatology database (Pearce and Moore 2004).

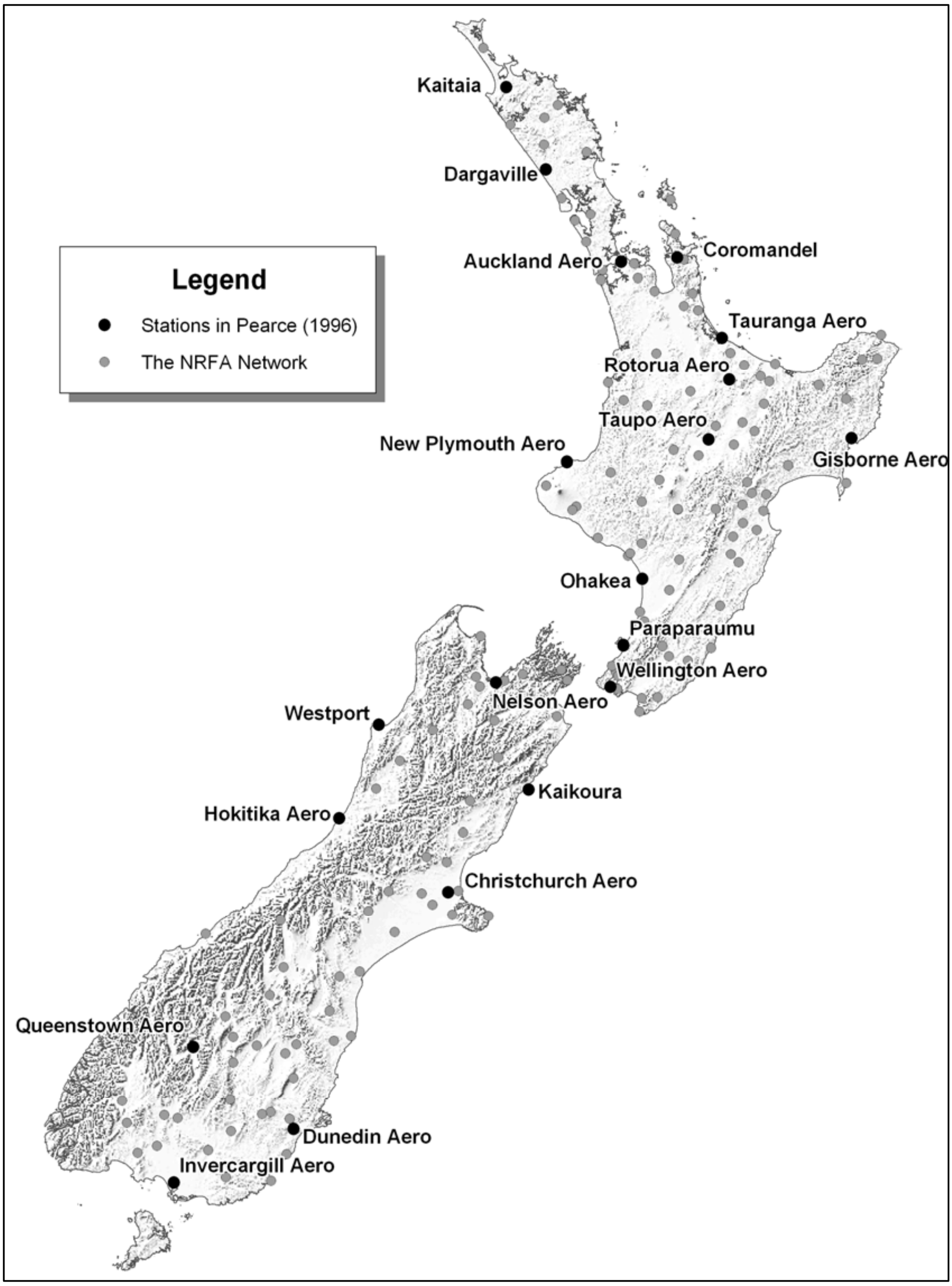

Figure 2. Weather stations (•) included in the fire danger climatology analysis of Pearce (1996), and current station coverage (•) included on the National Rural Fire Authority's (NRFA) fire weather monitoring network.

3.2 Climate change

The impact of potential global warming and climate change is drawing increasing attention from land managers, fire management agencies and the public in general. While the occurrence and extent of global warming is still the subject of much debate, it is now widely accepted that global mean temperatures have increased over the last century as a result of human influence. The majority of this warming, and of more extreme warming to come in the future, is attributed to anthropogenic emissions of carbon dioxide (CO_2) and other greenhouse gases into the atmosphere.

Climate change therefore refers to changes in climate over time resulting from increasing greenhouse gases and associated global warming, as distinct from natural changes in climate associated with interannual variability or other longer-term variations or shifts; i.e., El Nino-Southern Oscillation (ENSO) events (Gordon 1986, Nicholls 1992, Hay *et al*. 1993, Salinger *et al*. 1996) or decadal variability such as the Interdecadal Pacific Oscillation (IPO) (Salinger and Mullan 1999). It typically considers long-term changes in climate over periods of 30-50 and up to 100 years. The sizes of current natural variations of the climate about the long-term mean are comparable to the mid-range projected human-induced changes we might expect over the next 30-50 years. This means that what currently is an unusually warm year could be the norm in 30-50 years, while an unusually warm year in 30-50 years' time is very likely be warmer than anything we experience at present (Wratt *et al*. 2004). In addition to altered frequencies of wildfire events in various parts of the world (Overpeck *et al*. 1990, Sweetnam 1993, Stocks 1993, Pinol *et al*. 1998, Stocks *et al*. 1998), future climate change has been predicted to result in increased flooding and droughts, sea-level rise, and more frequent extreme events including storms and tropical cyclones (e.g., Salinger and Hicks 1990, Warrick *et al*. 2001, Pittock and Wratt 2001).

3.2.1 Use of scenarios in climate change studies

Definitive quantitative predictions of exactly how much a particular climatic element (e.g., rainfall) will change over coming decades is not feasible (Wratt *et* al. 2004). This is because rates of climate change will depend on future global emissions of greenhouse gases, which in turn depend on global social, economic and environmental policies and development. Incomplete scientific knowledge about some of the processes governing the climate, and natural year to year variability, also contribute to future uncertainty.

The usual approach to addressing the possible impacts of climate change is therefore to consider *scenarios* spanning the likely range of future conditions. Climate change scenarios should not be considered as predictions of what <u>will</u> occur in the future. Rather, they are plausible and often simplified descriptions of how the future <u>may</u>

develop, based on a coherent and internally consistent set of assumptions about key driving forces. A scenario approach is necessary because of the many uncertainties about how the future might develop. A major unknown is how global greenhouse gas and aerosol emissions could change over the coming century. The Intergovernmental Panel on Climate Change (IPCC), in its Third Assessment Report (IPCC 2001), developed a number of scenario 'story lines' (Special Report on Emission Scenarios, SRES), about how future societies and economies might develop, and the consequences for future emissions. The other major factor that contributes to future uncertainty is the disagreement between climate models. These models are driven by atmospheric concentrations of greenhouse gases, derived from emissions via a global carbon cycle model. Different models can simulate quite different future changes, globally as well as regionally, even when forced by exactly the same atmospheric concentrations. Thus, scenarios recognise explicitly that there is no single "best guess" at the present time for how climate might change over the century. In this context, it is advisable to present more than one scenario when developing local impact studies.

3.2.2 Future climate

In its Third Assessment Report, the IPCC (2001) projects a global temperature increase of between 1.4°C and 5.8°C by 2100, a rate of warming which is probably without precedent during at least the last 10,000 years (Wratt *et al.* 2004). They also predict both increases and decreases in annual rainfall (depending on location) of typically 5-20% at regional scales during the 21st century, continued widespread retreat of glaciers, a rise in global mean sea level of 0.09 to 0.88 m between 1990 and 2100, and a range of beneficial and adverse effects on both environmental and socioeconomic systems.

Projected changes for New Zealand cover a wide range, reflecting the diverse range of greenhouse gas emission scenarios used by the IPCC and also climate model uncertainties. In general, temperature changes are expected to be less than the global average, as a result of a lag in warming of the oceans surrounding New Zealand. The broad expected pattern of change (after Wratt *et al.* 2004) includes: increased temperatures (with greater increases in the winter season, and in the north of New Zealand); decreased frost risk, but increased risk of very high temperatures; a stronger west-east rainfall gradient (wetter in the west, and drier in the east); increased frequency of extreme (heavy) daily rainfalls; increased westerly winds; and increased sea level. More specifically, mid-range projections in annual-average temperature and precipitation are (again, after Wratt *et* al. 2004; also see Figs. 4-7):

- temperature increases of 0.6 to 0.7°C from 1990 to 2030s (45-year change), and 1.6 to 2.0°C from 1990 to 2080s (95-year change);

- rainfall changes between about -5 to +5% from 1990 to 2030s, and about -10 to +15% from 1990 to 2080s (the sign and amount varies around the country).

3.2.3 Effects of climate change on wildfires

Wildfire occurrence and climate are known to be intimately linked, at short time scales (e.g., prevailing conditions: Vines 1974, Cheney 1976, Brotak and Reifsnyder 1977, Flannigan and Harrington 1988, Takle *et al*. 1994) as well as at medium (e.g., drought: Gill 1985; ENSO events: Simard *et al*. 1985, Skidmore 1987, Brenner 1991) and much longer term time scales (e.g., historical climate change: Clark 1990, Sweetnam 1993, Pinol *et al*. 1998).

It is not surprising then that from as early as the late 1980s, postulated increases in global temperatures associated with climate change have been related to possible increases in fire weather severity and fire danger. While the greater majority of this research has been done in Canada (see below), studies have also been undertaken elsewhere. For example, Beer *et al*. (1988), and later Beer and Williams (1995), tested the effect of potential climate change on Australian fire danger based on several modifications of actual daily weather using two early CSIRO General Circulation Models (GCMs), with both models predicting increases in fire danger (quantified using the McArthur forest fire danger meter) over much of Australia for their double CO_2 scenarios. Torn and Fried (1992) projected increased in area burned and frequency of escaped fires in northern California for $2\times CO_2$ simulations compared with present climate. However, they noted that the magnitude of these increases was strongly influenced by the choice of vegetation type, GCM scenario and climate forcing variables, with the greatest projected increase in fire severity occurring in grasslands with wind speed, temperature, humidity and precipitation as driving variables. Price and Rind (1994a,b) modelled lightning fires in the U.S. and used a GCM to estimate the change in lightning fires and area burned for a $2\times CO_2$ scenario. They reported a 44% increase in lightning-caused fires with an associated 78% increase in area burned. An increase in lightning frequency across the northern hemisphere under a doubled CO_2 scenario has also been reported by Fosberg *et al*. (1990). Takle *et al*. (1994) looked at surface pressure patterns in the northeastern U.S. corresponding with high fire danger events, and then used the Canadian GCM to project future impacts. Their results suggested an increased frequency of drying under the $2\times CO_2$ scenario, although the results were not statistically significant.

In Canada, determination of the possible impacts of climate change has been aided through use of the FWI System. Street (1989) first used current daily weather observations and the FWI System together with monthly averages for changes in mean monthly temperature and total precipitation under $2\times CO_2$ scenarios (for 2040) to suggest a fire regime of increased length and severity for Ontario. Flannigan and Van Wagner (1991) used results from three early GCMs to compare seasonal fire weather severity under a $2\times CO_2$ climate by superimposing monthly anomalies from GCM simulation results over historical sequences of daily weather. Their results suggested that fire danger (represented by the Seasonal Severity Rating (SSR) from the FWI System[2]) could increase by nearly 50% across Canada with climate warming, with a similar increase in area burned. Wotton and Flannigan (1993) used the Canadian GCM to predict that fire season length across Canada would increase by up to 30 days in a $2\times CO_2$ climate. Bergeron and Flannigan (1995) also used the FWI System and daily GCM output to study relative changes in fire severity across Canada by contrasting $1\times CO_2$ (current) and $2\times CO_2$ (future) scenarios. Daily data, rather than monthly data, were used because the weather and, consequently, fire behaviour can change dramatically over time periods much shorter than a month. They reported wider regional variation in potential fire danger across Canada than previous studies, largely as a result of differences in rainfall patterns. Fosberg *et al*. (1996) used the Canadian GCM along with recent weather data to evaluate the relative occurrence of extreme fire danger across Canada and Russia, and showed a significant increase in the geographical expanse of worst fire danger conditions in both countries under a warming climate. Flannigan *et al*. (1998a) used similar methods to those of Bergeron and Flannigan (1995) to study future fire danger levels in North America and Europe, and compared these results with changes in historical fire frequency. They showed a great deal of regional variability in future fire danger (described using FWI index values), with some regions showing significant increases while other areas decreased due to increased rainfall mounts and frequency.

In one of the more comprehensive studies, Stocks *et al*. (1998) used the FWI System, monthly anomalies from 4 different GCMs and daily data from a series of over 400 weather stations to look at seasonal and monthly fire danger levels across Canada, Alaska and Russia. They showed increases in fire danger across the entirety of this region, together with large increases in the number of high severity days, which are the periods when most burned area is likely to occur. Flannigan *et al*. (1998b,c) used the Canadian GCM to model past as well as present and future fire weather by calculating FWI System indices for $1\times CO_2$ and $2\times CO_2$ scenarios. They used maximum daily temperature, RH derived from specific humidity, 24-hour precipitation and noon mean wind speed to calculate FWI System values during their fire season. Extreme FWI maximums, in addition to 9-year mean FWI values, were compared for each simulation. Extremes were used on the basis that most of the burned area occurs on a few days with extreme fire weather (after Flannigan and Harrington 1988). Wotton *et al*. (1998) used the results of a Regional Climate Model (RCM) to study the effects of climate change on fire danger in Western Canada. Outputs from the RCM were used with the FWI System to estimate fire season severity (using the Daily Severity Rating (DSR) component[2]) for both current ($1\times CO_2$) and future ($2\times CO_2$) climate. However, they noted that the spatial and temporal aspects of the RCM outputs meant that these

[2] See Pearce and Moore (2004) for a discussion of severity rating measures, including those derived from the Daily Severity Rating (DSR) in the Canadian FWI System.

were not exactly representative of the noon FWI inputs. Flannigan *et al*. (2000) used the output from two different GCMs to calculate ratios of the SSR component of the FWI System for a 2×CO_2 and current climates. They suggest increases of 10-50% in fire season severity across the U.S. by 2060, although also reported areas of little change or where SSR decreased under future climate. Flannigan *et al*. (2001) used the Canadian GCM together with a nested RCM to model daily FWI inputs for 1×CO_2, 2×CO_2 and past (6000 years BP) climates, suggesting past climate and associated fire history might be an analogue for future warming and fire activity. They showed similar increases in fire danger (expressed using mean FWI values) across most of Canada to previous studies, but reported significant regional variability including a decrease in much of eastern Canada. They also suggest more pronounced changes in fire weather and fire danger in future with greenhouse gas-induced warming, as well as feedbacks via increased carbon emissions and reduced carbon stocks, than indicated through use of the historical climate analogue. Flannigan *et al*. (in review) used GCM and RCM outputs to illustrate changes in SSR and resulting projections of area burned, while Logan *et al*. (2003) investigated changes in SSR from a 1×CO_2 (1975-1990) to 3×CO_2 (2080-2100) climate, based on averaging results of the Canadian and Hadley GCMs. Most recently, De Groot *et al*. (2003) also used a combination of GCM and RCM outputs to illustrate changes in SSR, area burned and resulting fire suppression costs under a 3×CO_2 (2080-2100) climate, and discussed possible fire management scenarios for managing the effects of climate change on fire regimes.

4. Methodology

The broad aim of the current research was to maximise the utility of the updated and extended fire climatology database (Pearce *et al*. 2003) by developing a number of analytical tools, including methods for comparing and predicting fire season severity (Pearce and Moore 2004). More specifically, the objective of this particular component of the study was to analyse the impact of climate change and variability on long-term fire danger.

As noted previously, the key steps involved in the study were to:

1. Define scenarios of climate variability and change for New Zealand to be applied to long-term weather records for individual stations;

2. Update long-term fire weather records to include data for recent fire seasons, and re-run current fire danger climatologies for existing weather stations, and any additional stations with sufficient length of record;

3. Apply likely changes in weather inputs (i.e., temperature, humidity, wind speed and rainfall) from regional climate scenarios to station weather records;

4. Recalculate Fire Weather Index (FWI) System components, severity ratings and fire danger class frequencies for each station; and

5. Compare fire danger climatologies produced under scenarios of climate variability and change with those under current fire climate to predict potential impacts of regional fire danger and seasonal severity.

4.1 Defining climate change scenarios for analysis

4.1.1 Downscaling New Zealand Climate Projections

Future projections of climate change are made by complex mathematical models of the atmosphere and ocean, which are run on powerful computers. These coupled Ocean-Atmosphere General Circulation Models (OAGCMs) cover the whole globe with a three-dimensional mesh of points, and typically simulate forward in time for a century or more. Because this is so time-consuming, the models use a fairly coarse horizontal scale that is unable to resolve local detail such as land surface type or topography variations. In order to provide the local detail that is required for impact studies, such as the present one on changes in fire dangers for New Zealand, it is necessary to “downscale” the model changes.

Two downscaling approaches are possible. Statistical downscaling develops statistical relationships (e.g., regression equations) linking local changes to the broader-scale circulation and climate resolvable by the OAGCMs. The equations are developed from observed past data, and then applied to the model projections. Dynamical downscaling uses another numerical model of the climate system that covers only the geographical region of interest, and draws boundary conditions from the OAGCMs (i.e., a Regional Climate Model (RCM) “nested” within the GCMs). The first approach, statistical downscaling, is the method applied in this study. The downscaling methodology is described in Mullan *et al*. (2001a), and has been used in the New Zealand CLIMPACTS system (Warrick *et al*. 2001, Mullan 2001, Mullan *et al*. 2001b) and a number of other New Zealand studies (e.g., Wratt *et al*. 2004). Instead of the limited station data set of Mullan *et al*. (2001a), this study uses downscaled changes recently developed for a high-resolution grid (0.05° latitude by 0.05° longitude) over New Zealand. Changes were taken from the grid-point nearest to each weather station on the NRFA’s fire weather monitoring network.

4.1.2 Future fire danger scenarios

Discussion between NIWA and Forest Research led to the following decisions on future scenarios:

- Temperature and precipitation (rainfall) offsets for 2080s (100-yr change between 1970-99 and 2070-99), provided for each month of the year;

- Two OAGCM patterns used, taken from the CSIRO and Hadley models (see Mullan *et al*. 2001a);

- The model changes, which apply to a 1% per year compounding carbon dioxide concentration, to be rescaled to match the IPCC low extreme, mid-point and high extreme at the 2080s.

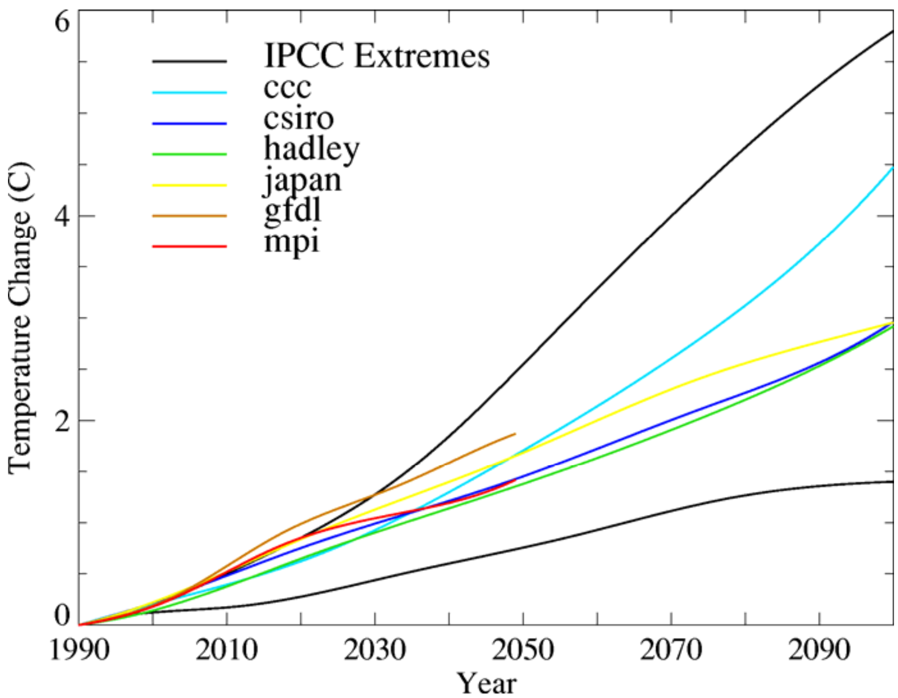

Figure 3. Global surface temperature change (°C) from 1990 (after Wratt *et al*. 2004), for the six OAGCMs downscaled over New Zealand by Mullan *et al.* (2001b), and (black lines) the IPCC extremes from Figure 9.14 of the IPCC Third Assessment Report (Cubasch *et al.* 2001). The IPCC range includes uncertainty due to emissions as well as variation between models. The CSIRO and Hadley models are the two 'cooler' models of the four still available by the 2080s.

Compared with temperature and precipitation, changes in relative humidity and wind speed – the other key weather variables required for fire danger rating – are not as well understood. Relative humidity changes have not been downscaled for the New Zealand region, and changes in scalar wind speed cannot be inferred from modelled changes in monthly mean pressures (Mullan *et al*. 2001a). Due to a lack of more specific offsets for individual station locations applicable to the climate change scenarios being investigated, relative humidity and wind speed changes were therefore not included as part of the present study.

The CSIRO and Hadley models were chosen because they have been used in a number of other studies, and have contrasting spatial patterns over New Zealand. The IPCC rescaling is discussed in Wratt *et al*. (2004), and can be understood with reference to Figure 3, which shows the time evolution of global warming. Scaling factors are calculated that bring the coldest model down to the IPCC lower bound, and the warmest model up to the IPCC upper bound for the 2080s period. (This is as close to reproducing the IPCC scaling procedure with the models for which downscaled results for New Zealand are available).

Figures 4-7 show maps of the scenario offsets for each season, for the IPCC mid-point. Tabular lists of the corresponding monthly temperature and precipitation offsets for the two models at fire RAWS sites are included as Appendix 1. Factors of 0.476 and 1.255 should be applied to generate the low and high IPCC extremes, respectively. These monthly mean offsets are applied to observed daily data to create time series appropriate to a future mean climate for which fire risk can be evaluated. The high and low IPCC extreme scenarios were used to cover the range of possible future climate outcomes and, together with the time series of daily weather, encompass likely daily and interannual variability in future fire climate, although it has been suggested that the frequency of extreme events may increase with climate change.

The CSIRO and Hadley models produce contrasting patterns over New Zealand. For precipitation in the annual mean, there is an overall tendency for drier conditions in the north and east of the country and wetter conditions in the south and west. This is very marked for the Hadley model for all seasons, especially in winter and spring, but only found in spring for the CSIRO model. Indeed, the CSIRO model has the reverse pattern in winter – drier in the south and west, and wetter in the east of the North Island. For temperature, the CSIRO model shows a rather uniform change over the country of about 2.2-2.3°C in the annual mean, and relatively small seasonal variations about this. The Hadley model is somewhat colder, with a gradient from coldest in the southwest to warmest in the northeast.

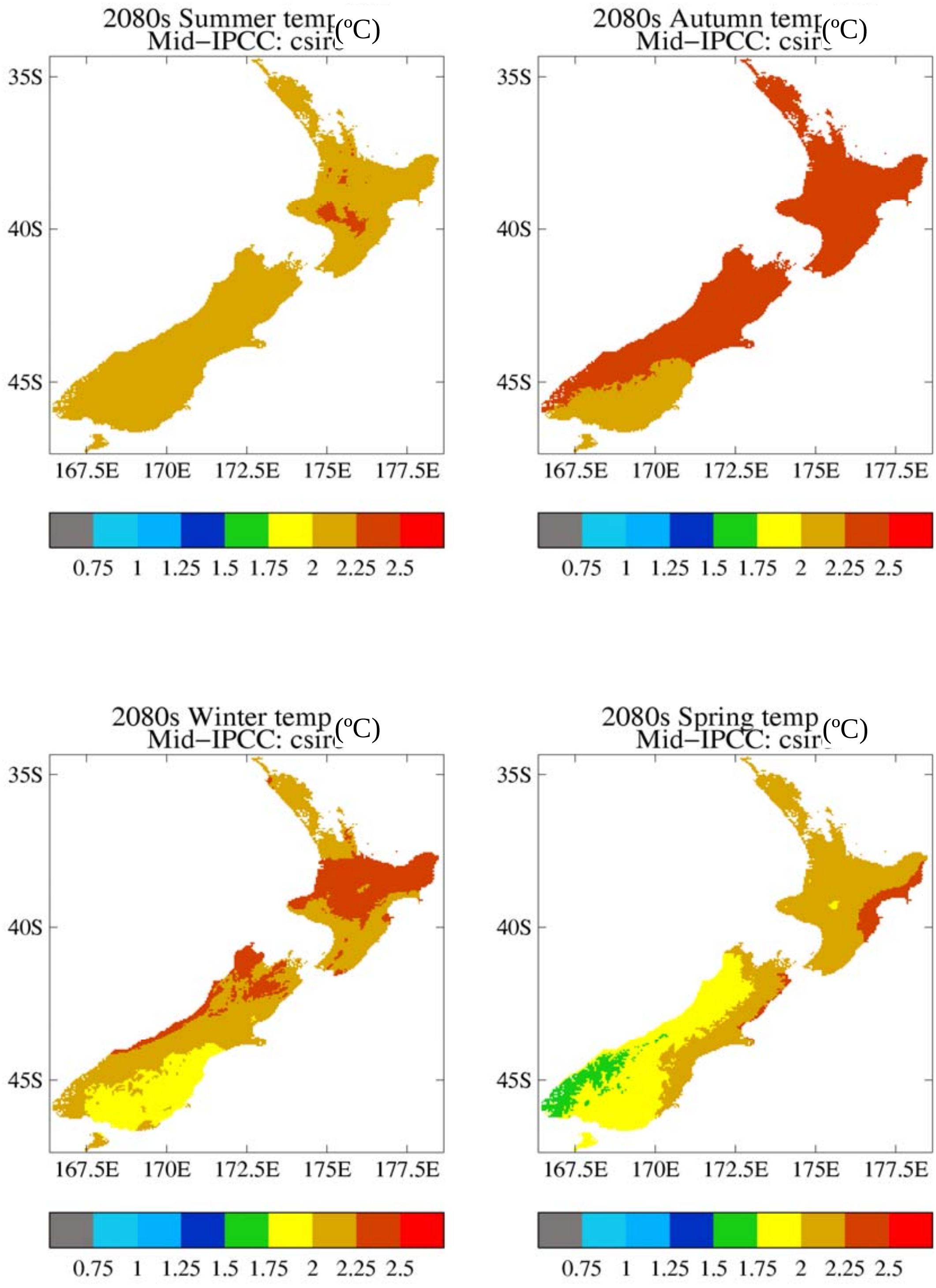

Figure 4. Scenario of mean seasonal <u>temperature</u> changes (in degrees C) over a 100-year period, derived from downscaling projections of the <u>CSIRO</u> OAGCM, scaled to "mid-IPCC" global temperature changes. Colour boundaries are evenly spaced from 0.75 to 2.50°C.

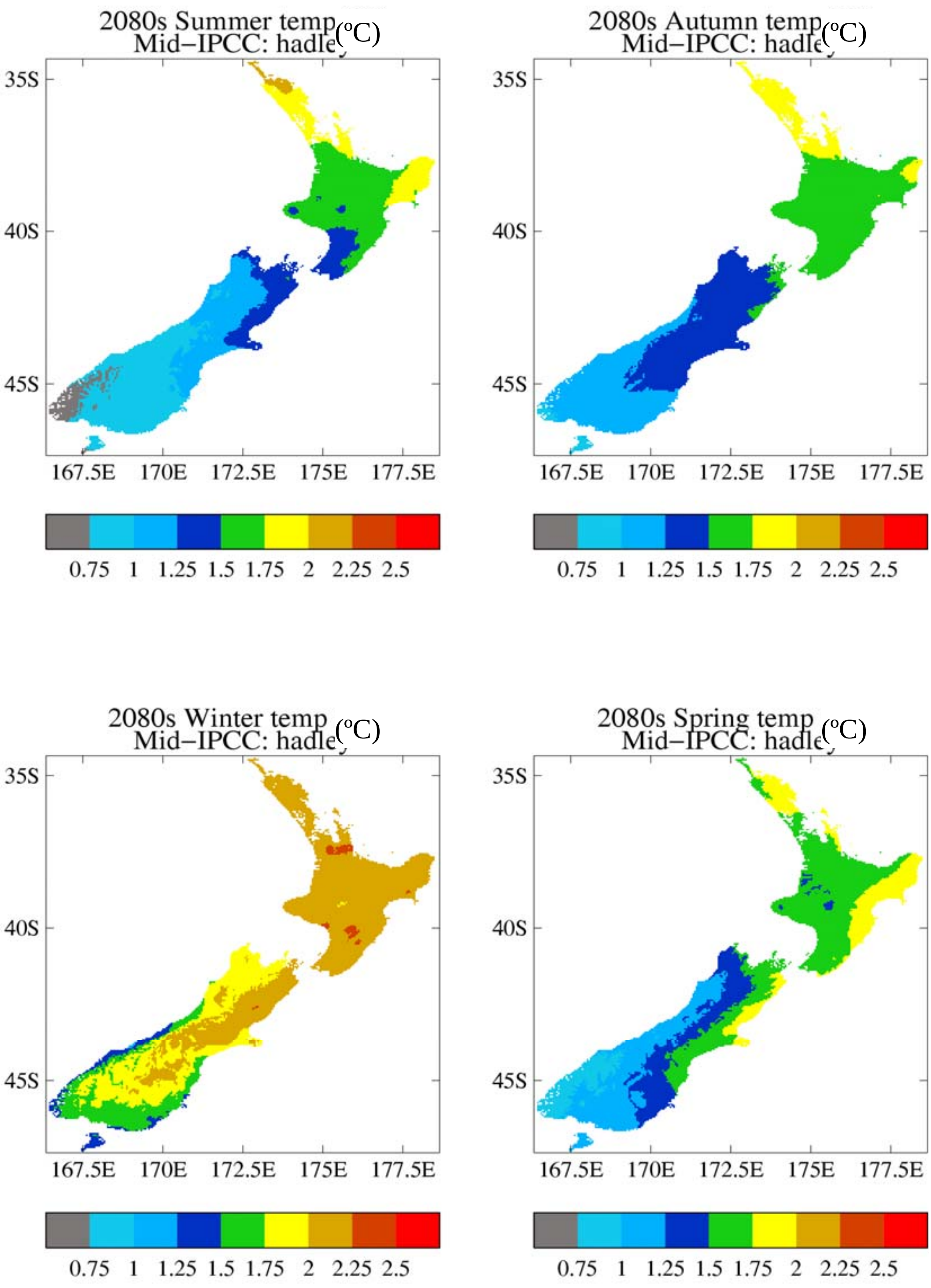

Figure 5. Scenario of mean seasonal <u>temperature</u> changes (in degrees C) over a 100-year period, derived from downscaling projections of the <u>Hadley</u> (HADCM2) OAGCM, scaled to "mid-IPCC" global temperature changes. Colour boundaries are evenly spaced from 0.75 to 2.50°C.

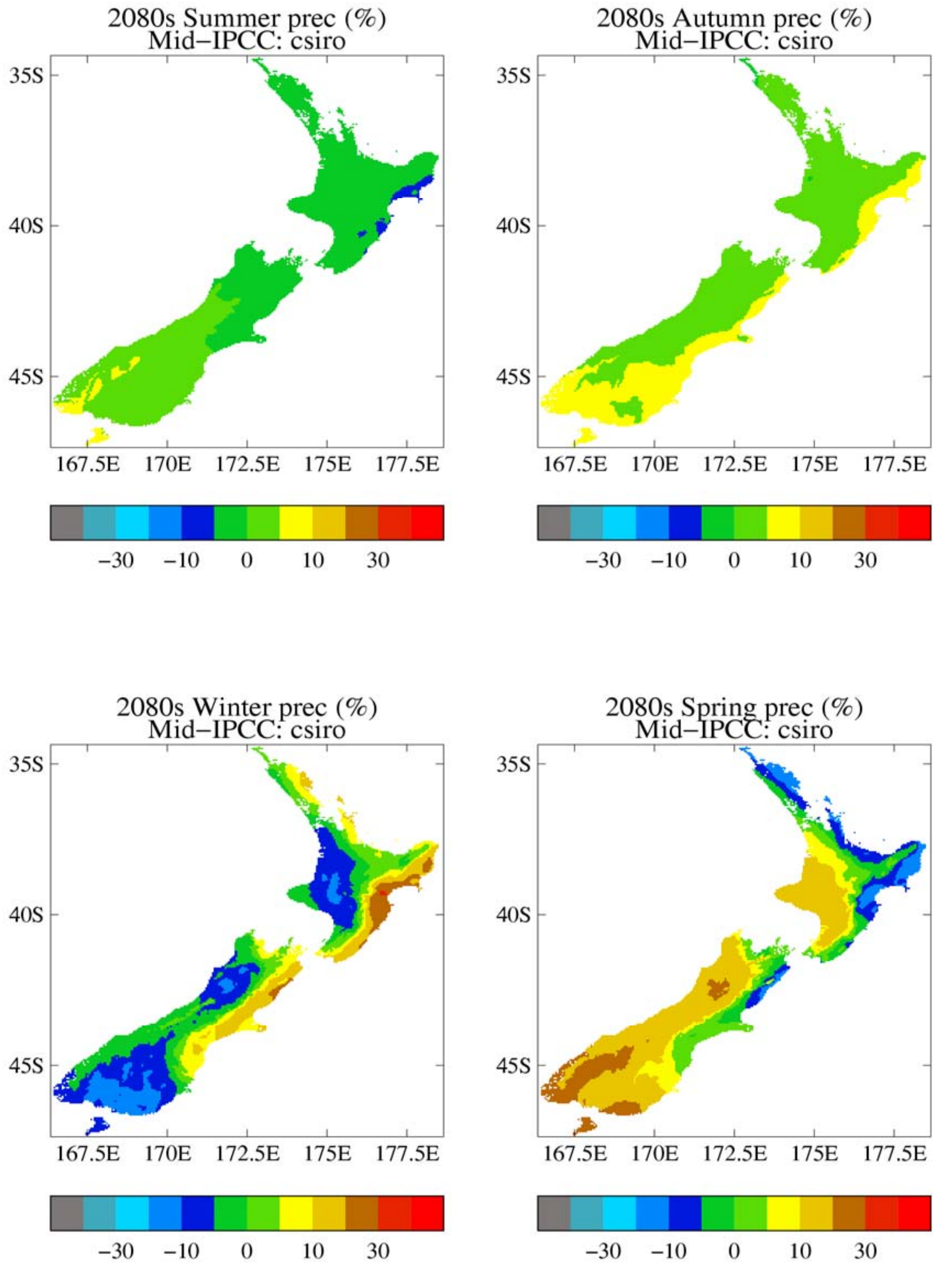

Figure 6. Scenario of seasonal <u>precipitation</u> changes (in %) over a 100-year period, derived from downscaling projections of the <u>CSIRO</u> OAGCM, scaled to "mid-IPCC" global temperature changes. Colour boundaries are unevenly spaced at 0, ±5, ±10, ±20, ±30 and ±40%.

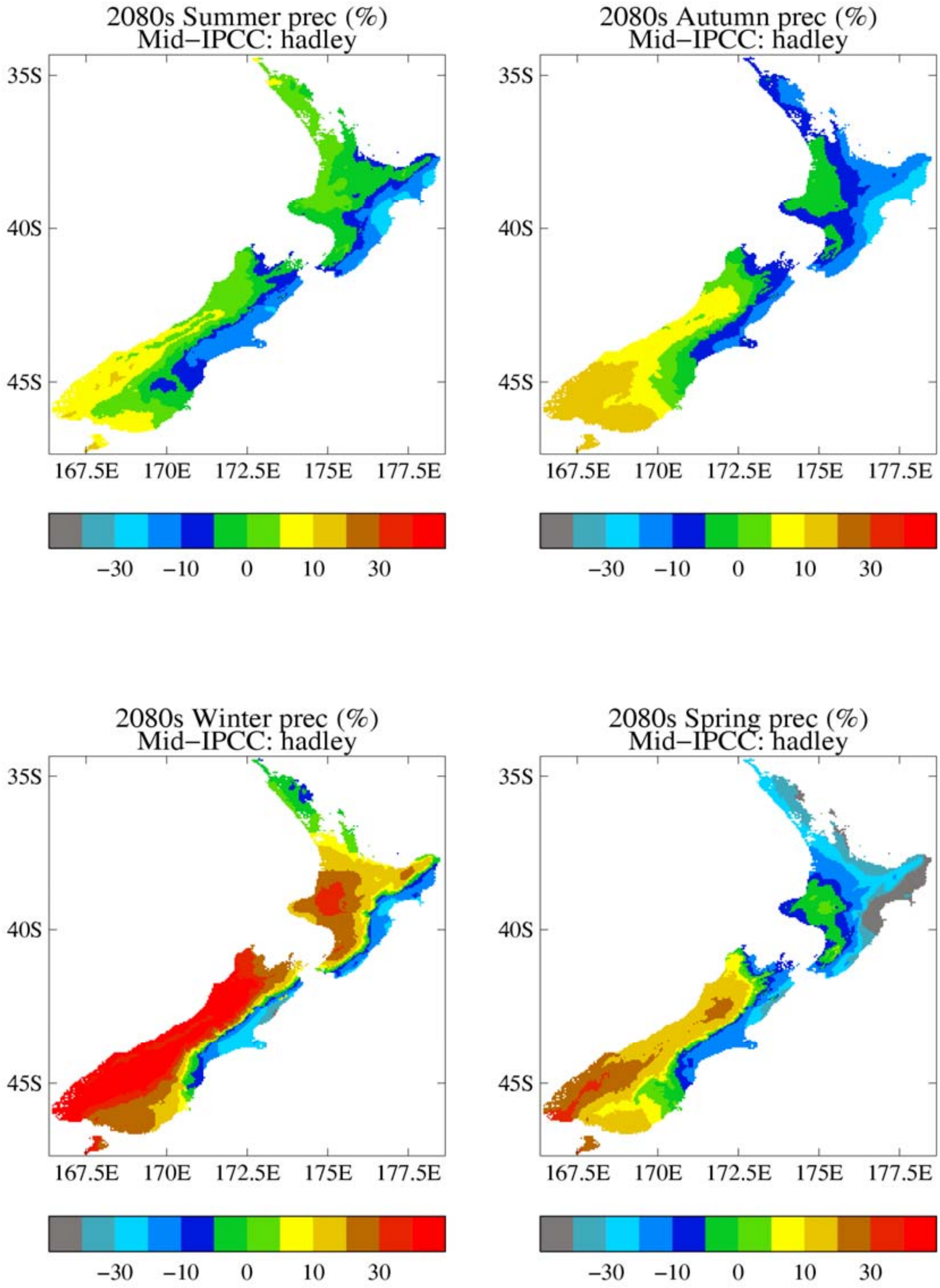

Figure 7. Scenario of seasonal <u>precipitation</u> changes (in %) over a 100-year period, derived from downscaling projections of the <u>Hadley</u> (HADCM2) OAGCM, scaled to "mid-IPCC" global temperature changes. Colour boundaries are unevenly spaced at 0, ±5, ±10, ±20, ±30 and ±40%.

4.2 Updating long-term fire weather records

As it was desirable to have the data sets for analysis as up-to-date as possible, the long-term data sets for as many as possible of the climate stations contained in the NRFA fire weather network were updated to include weather records to 31 December 2004. In some cases, this could be achieved by adding 1200 noon NZST weather inputs from the same or a nearby alternative station from the National Climate Database (CLIDB). However, in many cases, periods of missing 1200 noon data were required to be substituted using the procedures outlined in Pearce *et al*. (2003), in particular using 1200 noon data from the closest substitute station on the NRFA. Where rainfall data were missing, and a suitable alternative station from the NRFA network was not available, 24-hour rainfall totals reported for 0800/0900 NZST from the CLIDB were used as the best estimate of onsite rainfall (after Pearce *et al*. 2003).

In total, 150 (of the 179 available) station datasets were updated to 31 December 2004, with a further 22 stations added to the 2003 analysis (Pearce *et al*. 2003). Some 52 of these 150 stations were then selected for further analysis of the effects of climate change based on their available length of record. A decision was made to limit analysis to stations with 11 or more unbroken calendar years of data (i.e., 10 complete fire seasons) to 31 December 2004, on the basis that this length of record is sufficient for fire climate studies (Simard 1972, Main *et al*. 1982, Pearce and Hawke 1999). In addition, "the last ten years have been reasonably typical, with some years of above and below average temperatures" (J. Salinger, NIWA, *pers.comm.*). The 52 selected stations (see Fig. 8) also provide relatively good spatial coverage across the country, and the NRFA Regional Rural Fire Committee (RRFC) and fire climate regions identified by NIWA (Heydenrych and Salinger 2002).

4.3 Application of climate offsets to fire weather records

Precipitation (rainfall) and temperature offsets for the 2080s (representing 100-yr changes between 1970-99 and 2070-99) were provided by NIWA for each month of the year at each of the stations on the NRFA fire weather network (see Appendix 1). These offsets were then applied to daily records of noon NZST temperature and 24-hour rainfall for each of the 52 selected stations.

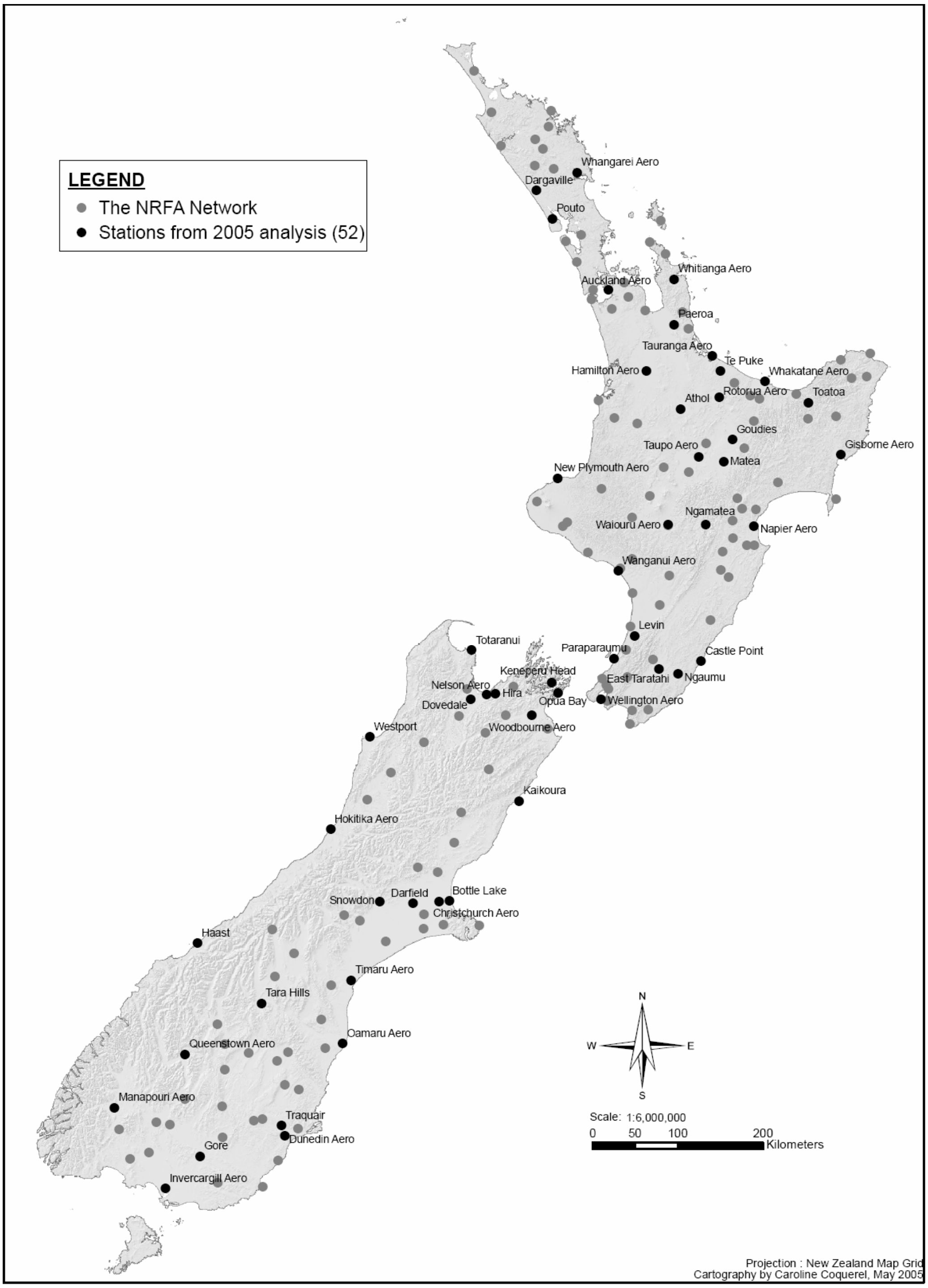

Figure 8. Weather stations (•) included in the present analysis on the effects of climate change, and current station coverage (•) for the National Rural Fire Authority's (NRFA) fire weather monitoring network.

In the case of temperature, monthly offset values (representing the change in mean monthly temperature) were added to the actual daily value to estimate time series of daily temperature for 2080. For rainfall, daily rainfall amounts (if any) were multiplied by the monthly offset values (representing the percentage change in the monthly precipitation total) to provide similar time series estimates of daily rainfall for the

2080s. As well as the mid-IPCC range offsets for each of the CSIRO and Hadley scenarios, multiplication factors of 0.476 and 1.255 were applied to the 2080 daily temperature and rainfall time series to get IPCC low and high extreme scenarios for each of the two model scenarios, so that a total of 6 new daily time series of future weather inputs were developed in addition to that for current climate.

4.4 Recalculation of FWI System components and fire danger ratings

FWI System values and fire danger ratings were calculated for each of the 7 time series of daily values (current; CSIRO high, mid and low; and Hadley high, mid and low) for each of the 52 stations included in the analysis. As well as the standard FWI System components (see Fig. 1b), this included the Daily Severity Rating (DSR) (Van Wagner 1987) and Forest fire danger class (Alexander 1994), which have been used to describe fire climate severity in previous analyses (Pearce 1996, Pearce *et al*. 2003, Pearce and Moore 2004). An Excel™ spreadsheet developed by Forest Research's Fire Research Programme was used for this purpose. Pearce *et al*. (2003) contains a more detailed explanation of the methods used to calculate FWI System values and fire danger ratings. The resulting records of daily weather and fire danger ratings for current and future model scenarios at each station (grouped by region) are included as an electronic appendix to this report (Appendix 3).

4.5 Comparison of current and future fire dangers

In addition to the daily time series of FWI System values and fire danger ratings, summary statistics (i.e., mean, median, minimum and maximum) for the weather inputs, FWI System components and fire danger class frequencies were calculated for each station for the range of scenarios. These summaries were calculated on a monthly, seasonal and annual basis using S-Plus (Version 6, Insightful Corporation, Seattle, WA), and are also included as an electronic appendix to this report (Appendix 4).

Mean values of temperature, rainfall, Fine Fuel Moisture Code (FFMC) and Buildup Index (BUI) (after Van Wagner 1987, Alexander 1992b), along with the Cumulative Daily Severity Rating (CDSR) (after Pearce 1996) and the number of days in the Very High and Extreme (VH+E) Forest fire danger classes (after Alexander 1994) were compared on an annual and fire season (1 October to 31 May) basis. For each variable, box plots were produced visually comparing the model scenario results for each station and indicating the variability of the data (Fig. 9). A complete set of box plots for all 52 stations is included as an electronic appendix to this report (Appendix 5). An analysis of variance (ANOVA) was conducted to determine whether there was a statistically significant difference between scenarios. Each of the six scenarios where the climate was modified were compared to the current climate (i.e., control) at the

90% significance level using the Dunnett test (Dunnett 1955). The 90% level of significance was chosen instead of the more common 95% level so that instances where there was substantial evidence of a difference would not be excluded. For a phenomenon such as climate change where there is considerable amount of uncertainty in the scenarios, a 90% significance level is still a strong indicator of potential trends.

The assumptions of analysis of variance were also examined. Mean values of temperature, rainfall, FFMC and BUI were expected to be normally distributed because of the central limit theorem. However, CDSR had a somewhat skewed distribution and the number of days in the VH+E classes was expected to have a Poisson distribution as this is the common underlying distribution for data on counts of rare events. Therefore, in addition to the normal parametric ANOVA, a Kruskal-Wallis non-parametric ANOVA (Kruskal and Wallis 1952) was also undertaken for CDSR and days in VH+E to verify that the use of the Dunnett test was appropriate in these cases.

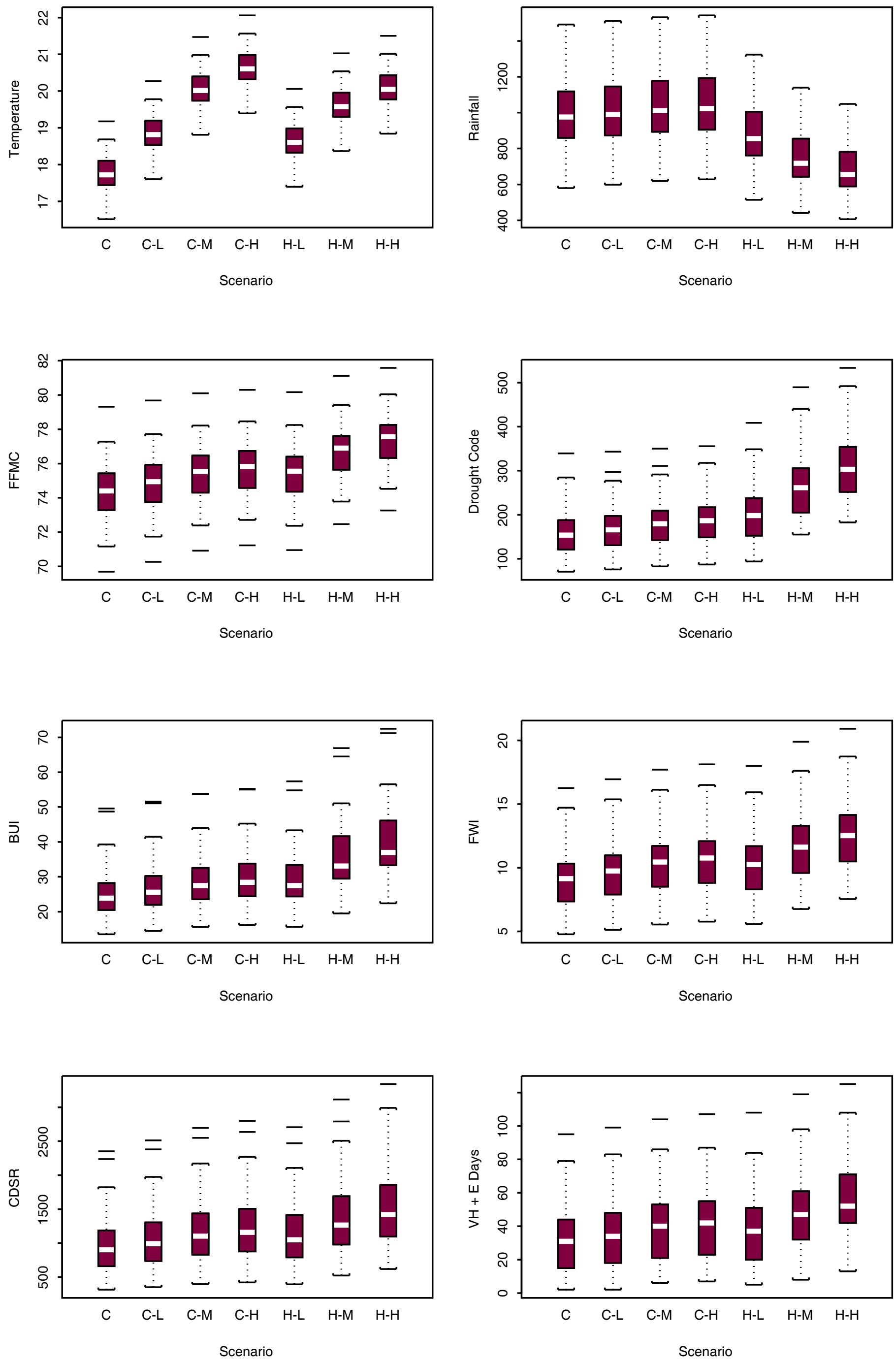

Figure 9. Example box plots for the Gisborne Aero weather station comparing current fire climate (C) with that under the CSIRO (C-L, C-M, C-H) and Hadley (H-L, H-M, H-H) low, mid-range and extreme scenarios (for the full calendar year). Within each box plot, the central white line indicates the median value, the shaded box the upper and lower quartiles in the data, and the brackets the 95% confidence interval. The horizontal lines above and/or below these brackets indicate observations falling outside this confidence interval, and are considered outliers.

5. Results and discussion

5.1 Updated station datasets

In the first step of the analysis, a total of 149 of the 179 available station datasets from the NRFA fire weather network were updated to include data to 31 December 2004, with a further 22 station datasets being added to those from the previous analysis (Pearce *et al*. 2003). Of these, 52 stations with available lengths of record exceeding 11 complete years (i.e., 10 full fire seasons) were then selected for analysis of the effects of climate change on future fire danger (see Table 1; also see Fig. 8). For consistency, all selected stations had complete, unbroken records to December 2004, and several other stations were not included in the analysis despite records of greater than 10 years due to either having breaks in record (e.g., Lauder), not having data to December 2004 (e.g., Kaitaia, Normanby), or both (e.g., Ohakea). A further 24 stations could have been included in the analysis had the length of record requirement been restricted to 10 calendar years (i.e., 9 full fire seasons). See Appendix 2 for a summary of full station details.

As in previous analyses, summary tables containing the long-term average and extreme values of each of the weather, FWI System components and fire danger classes summarised by month, fire season (i.e., 1 October to 31 April) and year (after Pearce *et al*. 2003) were produced for each of the 7 scenario outputs for each of the 52 selected stations. These summary tables are available as an electronic appendix to this report (Appendix 4).

Table 1. Details of stations included in the analysis by region.

Station Code	Station Name	NRFA RRFC Region	NIWA Fire Climate Region	Start Date	End date	Length of Record (years)
DAR	Dargaville	Northland	Far North	01/01/79	31/12/04	26
WRA	Whangarei Aero	Northland	Far North	01/01/92	31/12/04	13
PTU	Pouto	Northland	Auckland West Waikato	01/12/93	31/12/04	11
AKL	Auckland Aero	Auckland	Auckland West-Waikato	01/01/67	31/12/04	38
HNA	Hamilton Aero	Waikato	Auckland West-Waikato	02/10/91	31/12/04	13
WTA	Whitianga Aero	Waikato	Auckland East-Coromandel	01/01/92	31/12/04	13
PAX	Paeroa	Waikato	Auckland East-Coromandel	01/10/91	31/12/04	13
ATH	Athol	Waikato	Bay of Plenty	03/11/92	31/12/04	12
ROA	Rotorua Aero	CNI	Bay of Plenty	01/01/65	31/12/04	40
TGA	Tauranga Aero	CNI	Bay of Plenty	01/01/71	31/12/04	34
APA	Taupo Aero	CNI	Bay of Plenty	01/01/79	31/12/04	26
TPE	Te Puke	CNI	Bay of Plenty	01/10/91	31/12/04	13
WKA	Whakatane Aero	CNI	Bay of Plenty	01/01/92	31/12/04	13
TTA	Toatoa	CNI	Bay of Plenty	12/11/93	31/12/04	11
MTE	Matea	CNI	Bay of Plenty	18/10/93	31/12/04	11
GDE	Goudies	CNI	Bay of Plenty	18/10/93	31/12/04	11
GSA	Gisborne Aero	Eastern	East Coast	01/01/63	31/12/04	42
NRA	Napier Aero	Eastern	East Coast	30/09/91	31/12/04	13
NPA	New Plymouth Aero	Taranaki	Taranaki-Wanganui	01/01/76	31/12/04	29

WUA	Wanganui Aero	Wanganui/Manawatu	Taranaki-wanganui	01/01/79	31/12/04	26
RUX	Waiouru Aero	Wanganui/Manawatu	Taranaki-Wanganui	01/10/91	31/12/04	14
LNX	Levin	Wanganui/Manawatu	Manawatu-Wairarapa	01/10/91	31/12/04	14
NTA	Ngamatea	Wanganui/Manawatu	Taranaki-Wanganui	22/10/93	31/12/04	11
MSX	East Taratahi	Wairarapa	Manawatu-Wairarapa	01/10/91	31/12/04	14
CPX	Castle Point	Wairarapa	Manawatu-Wairarapa	01/10/91	31/12/04	14
NMU	Ngaumu	Wairarapa	Manawatu-Wairarapa	04/11/93	31/12/04	11
WNA	Wellington Aero	Wellington	Wellington-Nelson/Marlb.	01/01/61	31/12/04	44
PPA	Paraparaumu	Wellington	Manawatu-Wairarapa	01/01/63	31/12/04	42
NSA	Nelson Aero	Nelson	Wellington-Nelson/Marlb.	01/01/63	31/12/04	42
TNI	Totaranui	Nelson	West Coast	05/11/93	31/12/04	11
HIR	Hira	Nelson	Wellington-Nelson/Marlb.	07/12/93	31/12/04	11
DOV	Dovedale	Nelson	West Coast	29/12/93	31/12/04	11
KIX	Kaikoura	Marlborough	Northern Canterbury	01/01/65	31/12/04	40
KHD	Keneperu Head	Marlborough	Wellington-Nelson/Marlb.	25/10/93	31/12/04	11
OSN	Opua Bay	Marlborough	Wellington-Nelson/Marlb.	10/12/93	31/12/04	11
WBA	Woodbourne Aero	Marlborough	Wellington-Nelson/Marlb.	01/01/92	31/12/04	13
HKA	Hokitika Aero	West Coast	West Coast	01/01/65	31/12/04	40
WSA	Westport	West Coast	West Coast	01/01/71	31/12/04	34
HTX	Haast	West Coast	West Coast	09/04/93	31/12/04	11
CHA	Christchurch Aero	Canterbury	Coastal Mid/South Canty.	01/01/61	31/12/04	44
SDN	Snowdon	Canterbury	Northern Canterbury	27/10/93	31/12/04	11
FPL	Darfield	Canterbury	Coastal Mid/South Canty.	28/10/93	31/12/04	11
BTL	Bottle Lake	Canterbury	Coastal Mid/South Canty.	28/10/93	31/12/04	11
THE	Tara Hills	South Canterbury	Mackenzie Basin	01/10/91	31/12/04	13
OUA	Oamaru Aero	South Canterbury	Coastal Otago	01/10/91	31/12/04	13
TUA	Timaru Aero	South Canterbury	Coastal Mid/South Canty.	01/01/92	31/12/04	13
QNA	Queenstown Aero	Otago	Central Otago Inland South.	01/01/79	31/12/04	26
DNA	Dunedin Aero	Otago	Coastal Otago	01/01/64	31/12/04	41
TRQ	Traquair	Otago	Coastal Otago	04/11/93	31/12/04	11
NVA	Invercargill Aero	Southland	Southland-Fiordland	01/01/61	31/12/04	44
GCE	Gore	Southland	Central Otago Inland South.	01/10/91	31/12/04	13
MOA	Manapouri Aero	Southland	Southland-Fiordland	30/09/91	31/12/04	13

5.2 Comparisons of current and future fire dangers

Comparisons between current and future fire climate under each of the 6 climate change scenarios were made for weather inputs and resulting FWI System components and fire season severity measures.

Statistically significant changes (at the 90% level) were found at one or more stations for the mid-range or high extreme scenarios for all variables investigated, driven by the warmer temperatures across the country, and generally drier conditions in the north and east of the country and wetter conditions in the south and west under both models (although with marked seasonal differences).

5.2.1 Temperature and rainfall

Temperature changes were found to be significantly higher at the 90% level for all but the Hadley low extreme scenario, apart from at a few stations (i.e., Ngamatea in the central North Island, Opua Bay in the Marlborough Sounds, and Snowdon in inland Canterbury) where the CSIRO low extreme scenario offsets were also not significant. Temperature changes of +0.5 to +2.4 ºC tended to be more significant when averaged across the full calendar year (Table 2) than just for the fire season months (3-20% of current values) (Table 3), due to the influence of higher winter temperatures. Changes in temperature across the country for both the full calendar year and fire season months are illustrated in Figure 10In contrast, considerably fewer stations had rainfall changes that were significant at the 90% level. Under the Hadley high, mid-range and, to a much lesser extent, low extreme scenarios, reductions in annual rainfall of -100 to -330 mm (-15% to -35%) were found to be significant when averaged across the full calendar year for Northland and Bay of Plenty stations, and stations from the east of both North and South Islands (Table 4). Stations from the West Coast and Southland were also significant under the Hadley scenarios, but as a result of significant increases (+80 to +890 mm, or +7% to +25%) in annual rainfall. Similar results were obtained for seasonal rainfalls totalled across just the fire season months (Table 5), with the Hadley high and mid-range scenarios proving significantly lower (-50 to -170 mm, or -17% to -32%) in the Bay of Plenty and east of both islands, and significantly higher (+60 to +80 mm, or +10 to +13%) for the high and mid-range scenarios from both the Hadley and CSIRO models at Invercargill. Spatial changes in rainfall (as %) over New Zealand are shown in Figure 11.

Table 2. Changes in temperature (ºC) associated with climate change model scenarios averaged across all months. Positive values indicate an increase, and negative values a decrease. Values statistically significant at the 90% level are highlighted in **bold**.

Station Code	Station Name	Current	Difference (Scenario - Current)					
			CSIRO(L)	CSIRO(M)	CSIRO(H)	Hadley(L)	Hadley(M)	Hadley(H)
DAR	Dargaville	17.9	**1.06**	**2.22**	**2.79**	**0.90**	**1.90**	**2.38**
WRA	Whangarei Aero	18.0	**1.07**	**2.24**	**2.81**	**0.92**	**1.94**	**2.44**
PTU	Pouto	17.2	**1.07**	**2.24**	**2.82**	**0.90**	**1.90**	**2.38**
AKL	Auckland Aero	17.4	**1.07**	**2.25**	**2.82**	**0.88**	**1.86**	**2.33**
HNA	Hamilton Aero	16.8	**1.07**	**2.25**	**2.82**	**0.85**	**1.77**	**2.23**
WTA	Whitianga Aero	17.7	**1.08**	**2.27**	**2.85**	**0.91**	**1.91**	**2.40**
PAX	Paeroa	17.3	**1.07**	**2.25**	**2.82**	**0.89**	**1.87**	**2.35**
ATH	Athol	15.1	**1.07**	**2.25**	**2.82**	**0.81**	**1.70**	**2.14**
ROA	Rotorua Aero	15.5	**1.09**	**2.28**	**2.86**	**0.85**	**1.79**	**2.24**
TGA	Tauranga Aero	17.3	**1.08**	**2.28**	**2.86**	**0.87**	**1.83**	**2.30**
APA	Taupo Aero	14.0	**1.08**	**2.26**	**2.84**	**0.86**	**1.80**	**2.26**
TPE	Te Puke	17.6	**1.09**	**2.28**	**2.86**	**0.85**	**1.78**	**2.23**
WKA	Whakatane Aero	17.4	**1.09**	**2.29**	**2.88**	**0.85**	**1.78**	**2.24**
TTA	Toatoa	16.0	**1.09**	**2.28**	**2.86**	**0.87**	**1.82**	**2.28**
MTE	Matea	13.1	**1.08**	**2.26**	**2.84**	**0.85**	**1.79**	**2.24**
GDE	Goudies	14.4	**1.08**	**2.27**	**2.85**	**0.85**	**1.79**	**2.24**
GSA	Gisborne Aero	17.7	**1.09**	**2.30**	**2.88**	**0.88**	**1.85**	**2.33**
NRA	Napier Aero	16.9	**1.10**	**2.30**	**2.89**	**0.89**	**1.86**	**2.34**
NPA	New Plymouth Aero	15.9	**1.07**	**2.26**	**2.83**	**0.81**	**1.69**	**2.12**
WUA	Wanganui Aero	16.1	**1.07**	**2.24**	**2.81**	**0.84**	**1.76**	**2.21**
RUX	Waiouru Aero	12.1	**1.08**	**2.26**	**2.84**	0.81	**1.71**	**2.14**
LNX	Levin	15.7	**1.06**	**2.23**	**2.80**	**0.78**	**1.64**	**2.06**
NTA	Ngamatea	11.4	1.08	**2.28**	**2.86**	0.83	**1.75**	**2.20**
MSX	East Taratahi	16.0	**1.07**	**2.26**	**2.83**	**0.82**	**1.72**	**2.16**
CPX	Castle Point	14.9	**1.07**	**2.25**	**2.82**	**0.84**	**1.75**	**2.20**
NMU	Ngaumu	16.1	**1.07**	**2.25**	**2.82**	**0.82**	**1.71**	**2.15**
WNA	Wellington Aero	15.2	**1.06**	**2.23**	**2.80**	**0.81**	**1.69**	**2.12**
PPA	Paraparaumu	15.4	**1.06**	**2.23**	**2.80**	**0.80**	**1.68**	**2.11**
NSA	Nelson Aero	15.5	**1.07**	**2.24**	**2.81**	**0.75**	**1.57**	**1.97**
TNI	Totaranui	16.6	**1.06**	**2.23**	**2.80**	**0.82**	**1.73**	**2.17**
HIR	Hira	15.4	**1.06**	**2.23**	**2.80**	0.74	**1.55**	**1.94**
DOV	Dovedale	15.2	**1.06**	**2.22**	**2.79**	0.72	**1.52**	**1.90**
KIX	Kaikoura	13.6	**1.05**	**2.21**	**2.77**	**0.83**	**1.75**	**2.19**
KHD	Keneperu Head	15.7	**1.07**	**2.24**	**2.81**	**0.78**	**1.63**	**2.04**
OSN	Opua Bay	16.4	**1.06**	**2.23**	**2.80**	**0.79**	**1.66**	**2.08**
WBA	Woodbourne Aero	16.3	**1.07**	**2.24**	**2.81**	**0.83**	**1.75**	**2.20**
HKA	Hokitika Aero	14.2	**1.03**	**2.16**	**2.71**	**0.60**	**1.26**	**1.58**
WSA	Westport	14.7	**1.04**	**2.18**	**2.73**	**0.64**	**1.34**	**1.68**
HTX	Haast	13.6	**1.02**	**2.14**	**2.69**	0.52	**1.10**	**1.38**
CHA	Christchurch Aero	14.7	**1.04**	**2.19**	**2.74**	**0.76**	**1.60**	**2.00**
SDN	Snowdon	13.0	**1.02**	**2.14**	**2.68**	0.73	**1.53**	**1.93**
FPL	Darfield	15.0	**1.03**	**2.16**	**2.71**	**0.76**	**1.60**	**2.01**
BTL	Bottle Lake	15.5	**1.04**	**2.18**	**2.74**	**0.75**	**1.57**	**1.97**
THE	Tara Hills	12.7	**0.99**	**2.07**	**2.60**	0.64	**1.35**	**1.69**
OUA	Oamaru Aero	13.3	**1.00**	**2.11**	**2.64**	**0.66**	**1.38**	**1.73**
TUA	Timaru Aero	14.0	**1.02**	**2.14**	**2.68**	**0.69**	**1.45**	**1.82**
QNA	Queenstown Aero	11.7	**0.98**	**2.05**	**2.58**	**0.59**	**1.24**	**1.56**
DNA	Dunedin Aero	13.4	**0.98**	**2.06**	**2.59**	**0.60**	**1.25**	**1.57**
TRQ	Traquair	10.8	**0.98**	**2.06**	**2.59**	0.59	**1.23**	**1.54**
NVA	Invercargill Aero	12.3	**0.96**	**2.03**	**2.54**	**0.56**	**1.17**	**1.47**
GCE	Gore	11.9	**0.96**	**2.02**	**2.54**	0.56	**1.19**	**1.49**
MOA	Manapouri Aero	12.0	**0.97**	**2.04**	**2.56**	0.56	**1.16**	**1.46**

Table 3. Changes in temperature (ºC) associated with climate change model scenarios averaged across fire season months. Positive values indicate an increase, and negative values a decrease. Values statistically significant at the 90% level are highlighted in **bold**.

Station Code	Station Name	Current	Difference (Scenario - Current)					
			CSIRO(L)	CSIRO(M)	CSIRO(H)	Hadley(L)	Hadley(M)	Hadley(H)
DAR	Dargaville	17.9	**1.06**	**2.22**	**2.78**	**0.89**	**1.87**	**2.35**
WRA	Whangarei	20.0	**1.06**	**2.23**	**2.80**	**0.90**	**1.90**	**2.38**
PTU	Pouto	19.0	**1.07**	**2.25**	**2.82**	0.88	**1.85**	**2.32**
AKL	Auckland Aero	19.8	**1.07**	**2.24**	**2.81**	**0.84**	**1.76**	**2.21**
HNA	Hamilton Aero	19.4	**1.06**	**2.23**	**2.80**	**0.79**	**1.66**	**2.08**
WTA	Whitianga Aero	20.0	**1.08**	**2.26**	**2.84**	**0.87**	**1.83**	**2.29**
PAX	Paeroa	19.8	**1.07**	**2.25**	**2.82**	**0.84**	**1.77**	**2.22**
ATH	Athol	17.6	**1.06**	**2.23**	**2.80**	0.76	**1.59**	**1.99**
ROA	Rotorua Aero	18.2	**1.07**	**2.24**	**2.82**	**0.80**	**1.67**	**2.10**
TGA	Tauranga Aero	19.6	**1.07**	**2.25**	**2.82**	**0.82**	**1.72**	**2.16**
APA	Taupo Aero	16.6	**1.07**	**2.25**	**2.82**	**0.79**	**1.65**	**2.08**
TPE	Te Puke	19.6	**1.07**	**2.25**	**2.82**	**0.81**	**1.70**	**2.13**
WKA	Whakatane	19.9	**1.07**	**2.25**	**2.83**	**0.81**	**1.69**	**2.12**
TTA	Toatoa	18.5	**1.08**	**2.26**	**2.84**	0.83	**1.75**	**2.19**
MTE	Matea	15.9	**1.07**	**2.25**	**2.83**	**0.80**	**1.67**	**2.10**
GDE	Goudies	17.0	**1.07**	**2.25**	**2.82**	**0.80**	**1.68**	**2.11**
GSA	Gisborne Aero	20.4	**1.08**	**2.28**	**2.86**	**0.84**	**1.77**	**2.22**
NRA	Napier Aero	19.4	**1.09**	**2.30**	**2.89**	**0.84**	**1.76**	**2.21**
NPA	New Plymouth	18.1	**1.06**	**2.23**	**2.80**	**0.74**	**1.56**	**1.95**
WUA	Wanganui Aero	18.2	**1.07**	**2.25**	**2.83**	**0.75**	**1.57**	**1.98**
RUX	Waiouru Aero	14.6	**1.06**	**2.24**	**2.81**	0.75	**1.57**	**1.97**
LNX	Levin	17.9	**1.06**	**2.23**	**2.80**	0.70	**1.48**	**1.85**
NTA	Ngamatea	13.8	1.08	**2.26**	**2.84**	0.78	**1.64**	**2.05**
MSX	East Taratahi	18.7	**1.07**	**2.26**	**2.83**	0.75	**1.58**	**1.99**
CPX	Castle Point	16.8	**1.07**	**2.26**	**2.83**	**0.76**	**1.61**	**2.01**
NMU	Ngaumu	18.8	**1.07**	**2.25**	**2.83**	0.75	**1.58**	**1.99**
WNA	Wellington	17.4	**1.06**	**2.23**	**2.80**	**0.72**	**1.52**	**1.91**
PPA	Paraparaumu	17.6	**1.06**	**2.23**	**2.80**	**0.72**	**1.51**	**1.89**
NSA	Nelson Aero	18.2	**1.05**	**2.21**	**2.78**	**0.68**	**1.44**	**1.80**
TNI	Totaranui	18.9	**1.07**	**2.25**	**2.83**	0.76	**1.59**	**1.99**
HIR	Hira	18.1	**1.06**	**2.22**	**2.78**	0.69	**1.44**	**1.81**
DOV	Dovedale	18.0	**1.05**	**2.21**	**2.78**	**0.67**	**1.41**	**1.78**
KIX	Kaikoura	15.8	**1.07**	**2.24**	**2.82**	**0.74**	**1.56**	**1.96**
KHD	Keneperu Head	18.3	**1.06**	**2.23**	**2.80**	0.71	**1.49**	**1.87**
OSN	Opua Bay	19.2	1.07	**2.24**	**2.81**	0.72	**1.52**	**1.90**
WBA	Woodbourne	19.1	**1.07**	**2.25**	**2.83**	0.76	**1.59**	**2.00**
HKA	Hokitika Aero	16.3	**1.00**	**2.10**	**2.63**	**0.53**	**1.12**	**1.41**
WSA	Westport	16.7	**1.01**	**2.12**	**2.66**	**0.57**	**1.20**	**1.51**
HTX	Haast	15.4	**0.99**	**2.07**	**2.60**	0.50	**1.05**	**1.32**
CHA	Christchurch	17.7	**1.05**	**2.21**	**2.77**	**0.68**	**1.44**	**1.80**
SDN	Snowdon	15.7	1.03	**2.17**	**2.72**	0.63	**1.33**	**1.67**
FPL	Darfield	17.8	**1.05**	**2.20**	**2.76**	0.67	**1.41**	**1.77**
BTL	Bottle Lake	18.1	**1.05**	**2.21**	**2.77**	0.68	**1.42**	**1.78**
THE	Tara Hills	16.4	**1.00**	**2.11**	**2.65**	0.55	**1.16**	**1.45**
OUA	Oamaru Aero	15.5	**1.03**	**2.16**	**2.71**	0.59	**1.24**	**1.56**
TUA	Timaru Aero	16.5	**1.04**	**2.18**	**2.74**	0.63	**1.31**	**1.65**
QNA	Queenstown	14.9	**0.99**	**2.08**	**2.61**	**0.49**	**1.02**	**1.28**
DNA	Dunedin Aero	16.2	**1.00**	**2.11**	**2.64**	**0.52**	**1.08**	**1.36**
TRQ	Traquair	13.2	**1.00**	**2.11**	**2.64**	0.51	**1.07**	**1.34**
NVA	Invercargill	14.8	**0.99**	**2.07**	**2.60**	**0.47**	**1.00**	**1.25**
GCE	Gore	14.5	**0.99**	**2.07**	**2.60**	0.47	**0.99**	**1.24**
MOA	Manapouri	14.9	**0.98**	**2.07**	**2.59**	0.47	**1.00**	**1.25**

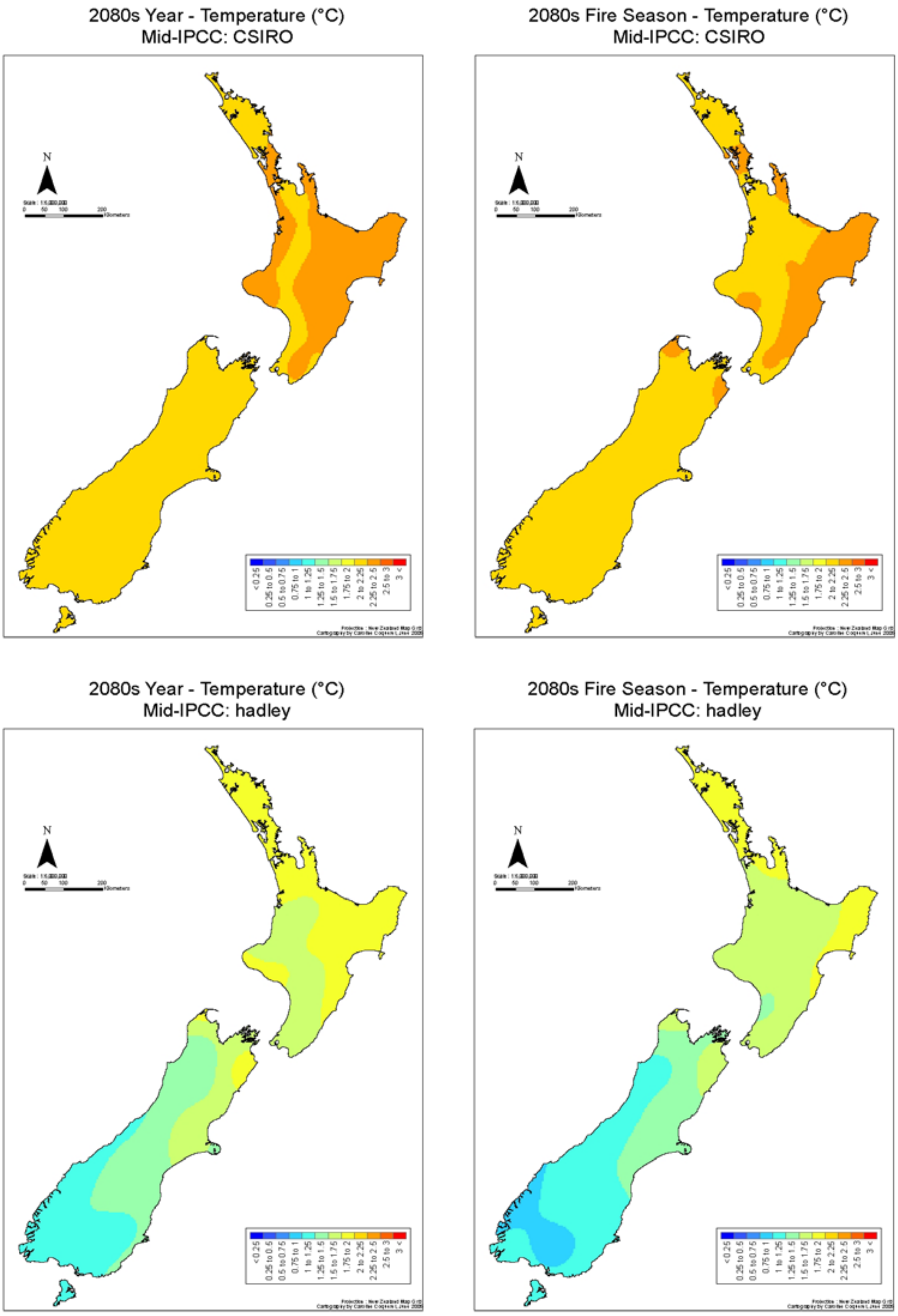

Figure 10. Changes in temperature averages (ºC) for the full calendar year and fire season months for the CSIRO and Hadley mid-range climate change scenarios.

Table 4. Changes in annual rainfall (mm) associated with climate change model scenarios totalled across all months. Positive values indicate an increase, and negative values a decrease. Values statistically significant at the 90% level are highlighted in **bold**.

Station Code	Station Name	Current	Difference (Scenario - Current)					
			CSIRO(L)	CSIRO(M)	CSIRO(H)	Hadley(L)	Hadley(M)	Hadley(H)
DAR	Dargaville	1191.0	-5.2	-10.8	-13.6	-43.4	-91.1	**-114.0**
WRA	Whangarei Aero	1319.1	6.7	14.1	17.7	-91.3	-192.0	**-241.0**
PTU	Pouto	1134.5	-0.3	-0.6	-0.8	-42.0	-88.3	-111.0
AKL	Auckland Aero	1110.9	-5.8	-12.2	-15.3	-26.2	-55.1	-69.1
HNA	Hamilton Aero	1281.6	-3.5	-7.3	-9.1	-7.4	-15.5	-19.4
WTA	Whitianga Aero	1854.4	10.4	21.8	27.4	-111.0	-234.0	-294.0
PAX	Paeroa	1253.5	4.6	9.8	12.2	-63.5	-133.0	-167.0
ATH	Athol	1565.9	-1.2	-2.5	-3.2	20.2	42.5	53.4
ROA	Rotorua Aero	1419.5	-0.4	-0.9	-1.1	-56.1	-118.0	**-148.0**
TGA	Tauranga Aero	1214.7	-1.5	-3.2	-4.0	-61.8	**-130.0**	**-163.0**
APA	Taupo Aero	986.5	3.9	8.2	10.3	-18.8	-39.4	-49.5
TPE	Te Puke	1432.2	-0.8	-1.6	-2.0	-71.2	-150.0	-188.0
WKA	Whakatane Aero	1296.5	-0.8	-1.7	-2.1	-57.6	-121.0	-152.0
TTA	Toatoa	2469.7	3.5	7.4	9.2	-30.6	-64.2	-80.6
MTE	Matea	1392.4	11.0	23.2	29.1	-28.6	-60.2	-75.5
GDE	Goudies	1216.6	7.2	15.2	19.0	-36.4	-76.6	-96.1
GSA	Gisborne Aero	1011.1	16.2	34.1	42.8	**-124.0**	**-261.0**	**-328.0**
NRA	Napier Aero	845.2	25.2	53.0	66.5	-110.0	-231.0	**-290.0**
NPA	New Plymouth Aero	1435.3	9.6	20.2	25.3	16.9	35.5	44.5
WUA	Wanganui Aero	1079.7	4.1	8.6	10.7	16.1	33.7	42.3
RUX	Waiouru Aero	1454.3	3.2	6.8	8.5	10.5	22.0	27.7
LNX	Levin	1073.2	10.0	21.1	26.4	33.8	70.9	89.0
NTA	Ngamatea	894.5	11.4	24.0	30.1	-57.8	-121.0	-152.0
MSX	East Taratahi	999.9	16.0	33.6	42.1	-59.6	-125.0	-157.0
CPX	Castle Point	978.5	23.7	49.9	62.6	-107.0	-226.0	**-283.0**
NMU	Ngaumu	1001.6	24.7	51.9	65.1	-95.0	-200.0	-250.0
WNA	Wellington Aero	1000.4	16.7	35.0	44.0	-40.2	-84.5	**-106.0**
PPA	Paraparaumu	1026.0	9.1	19.0	23.9	17.2	36.1	45.2
NSA	Nelson Aero	1010.6	13.3	28.0	35.1	-3.9	-8.2	-10.3
TNI	Totaranui	1550.4	15.9	33.5	42.0	-39.5	-83.1	-104.0
HIR	Hira	1048.6	10.6	22.3	28.0	-7.2	-15.1	-18.9
DOV	Dovedale	1052.5	14.8	31.2	39.1	-4.1	-8.7	-10.9
KIX	Kaikoura	804.7	17.3	36.4	45.7	**-108.0**	**-226.0**	**-284.0**
KHD	Keneperu Head	1509.7	23.9	50.3	63.1	0.4	0.9	1.2
OSN	Opua Bay	1194.5	19.8	41.6	52.3	-22.3	-46.9	-58.8
WBA	Woodbourne Aero	738.9	9.3	19.5	24.5	-15.0	-31.5	-39.5
HKA	Hokitika Aero	2839.1	40.9	85.9	108.0	**228.0**	**479.0**	**601.0**
WSA	Westport	2214.8	23.1	48.5	60.8	156.0	**329.0**	**412.0**
HTX	Haast	3387.7	87.0	183.0	229.0	337.0	709.0	**890.0**
CHA	Christchurch Aero	624.6	10.3	21.6	27.1	-49.1	**-103.0**	**-129.0**
SDN	Snowdon	1004.7	16.7	35.0	43.9	-37.1	-78.0	-97.8
FPL	Darfield	637.9	12.2	25.5	32.0	-48.2	-101.0	-127.0
BTL	Bottle Lake	487.6	7.4	15.6	19.6	-38.9	-81.7	-103.0
THE	Tara Hills	490.9	9.7	20.4	25.6	45.4	95.4	120.0
OUA	Oamaru Aero	703.0	13.3	28.0	35.1	-20.8	-43.7	-54.9
TUA	Timaru Aero	713.9	16.9	35.6	44.6	-34.2	-71.9	-90.2
QNA	Queenstown Aero	812.0	17.8	37.4	46.9	98.4	**207.0**	**259.0**
DNA	Dunedin Aero	691.6	13.3	27.9	35.1	18.9	39.7	49.9
TRQ	Traquair	622.7	12.0	25.3	31.7	16.8	35.3	44.4
NVA	Invercargill Aero	1097.5	26.3	55.3	69.4	**81.1**	**170.0**	**214.0**
GCE	Gore	857.2	18.4	38.7	48.6	53.0	111.0	140.0
MOA	Manapouri Aero	1400.1	31.3	65.7	82.5	189.0	397.0	498.0

Table 5. Changes in seasonal rainfall (mm) associated with climate change model scenarios totalled across fire season months. Positive values indicate an increase, and negative values a decrease. Values statistically significant at the 90% level are highlighted in **bold**.

Station Code	Station Name	Current	Difference (Scenario - Current)					
			CSIRO(L)	CSIRO(M)	CSIRO(H)	Hadley(L)	Hadley(M)	Hadley(H)
DAR	Dargaville	1007.6	-5.0	-10.5	-13.2	-36.3	-76.3	-95.7
WRA	Whangarei Aero	644.9	-11.9	-24.9	-31.3	-40.9	-85.8	-108.0
PTU	Pouto	576.5	-1.1	-2.3	-2.8	-21.3	-44.7	-56.1
AKL	Auckland Aero	563.2	2.1	4.4	5.6	-19.0	-40.0	-50.2
HNA	Hamilton Aero	675.1	6.2	13.0	16.4	-20.2	-42.4	-53.2
WTA	Whitianga Aero	864.5	-11.3	-23.7	-29.8	-56.8	-119.0	-150.0
PAX	Paeroa	623.7	-6.5	-13.6	-17.0	-39.4	-82.9	-104.0
ATH	Athol	823.5	11.8	24.9	31.2	-18.9	-39.6	-49.7
ROA	Rotorua Aero	765.7	-3.6	-7.6	-9.6	-46.3	**-97.3**	**-122.0**
TGA	Tauranga Aero	662.7	-6.1	-12.7	-16.0	-44.9	**-94.3**	**-118.0**
APA	Taupo Aero	559.9	3.6	7.6	9.5	-24.6	-51.7	-64.9
TPE	Te Puke	773.8	-7.6	-15.9	-19.9	-57.5	-121.0	-152.0
WKA	Whakatane Aero	669.4	-5.4	-11.3	-14.2	-47.5	-99.7	-125.0
TTA	Toatoa	1265.1	1.1	2.3	2.8	-61.9	-130.0	-163.0
MTE	Matea	752.1	5.1	10.6	13.3	-35.3	-74.3	-93.2
GDE	Goudies	663.9	2.7	5.6	7.1	-36.3	-76.3	-95.7
GSA	Gisborne Aero	516.3	-9.9	-20.8	-26.1	-62.9	**-132.0**	**-166.0**
NRA	Napier Aero	423.5	-6.9	-14.6	-18.3	-56.2	-118.0	**-148.0**
NPA	New Plymouth Aero	779.7	12.6	26.4	33.1	-14.9	-31.2	-39.2
WUA	Wanganui Aero	589.0	9.8	20.6	25.9	-11.9	-25.0	-31.4
RUX	Waiouru Aero	724.2	14.8	31.1	39.0	-25.4	-53.3	-66.9
LNX	Levin	620.7	12.4	26.1	32.8	-6.0	-12.5	-15.7
NTA	Ngamatea	478.3	-0.3	-0.6	-0.8	-42.4	-89.0	-112.0
MSX	East Taratahi	532.7	0.7	1.4	1.8	-40.2	-84.4	-106.0
CPX	Castle Point	532.6	-5.1	-10.7	-13.4	-60.3	-127.0	**-159.0**
NMU	Ngaumu	506.6	-3.7	-7.7	-9.7	-53.2	-112.0	-140.0
WNA	Wellington Aero	506.3	1.7	3.5	4.4	-27.4	-57.5	**-72.2**
PPA	Paraparaumu	542.9	7.2	15.0	18.9	-12.1	-25.3	-31.8
NSA	Nelson Aero	535.9	3.1	6.6	8.3	-27.2	-57.1	-71.7
TNI	Totaranui	868.9	3.3	7.0	8.8	-49.9	-105.0	-131.0
HIR	Hira	606.0	2.8	5.8	7.3	-31.5	-66.1	-83.0
DOV	Dovedale	576.5	5.3	11.1	13.9	-26.9	-56.5	-70.8
KIX	Kaikoura	426.2	-6.1	-12.7	-15.9	-44.0	**-92.3**	**-116.0**
KHD	Keneperu Head	822.7	7.6	15.9	20.0	-22.5	-47.2	-59.2
OSN	Opua Bay	629.6	3.3	6.9	8.7	-27.4	-57.5	-72.2
WBA	Woodbourne Aero	372.9	1.4	3.0	3.7	-20.3	-42.7	-53.6
HKA	Hokitika Aero	1649.8	46.6	98.0	123.0	44.7	93.9	118.0
WSA	Westport	1229.2	34.1	71.6	89.8	22.9	48.0	60.3
HTX	Haast	1928.3	79.1	166.0	208.0	84.6	178.0	223.0
CHA	Christchurch Aero	331.8	1.1	2.3	2.9	-21.1	-44.4	**-55.7**
SDN	Snowdon	581.9	5.7	12.0	15.0	-29.2	-61.4	-77.0
FPL	Darfield	361.1	1.1	2.4	3.0	-24.4	-51.3	-64.3
BTL	Bottle Lake	257.2	1.0	2.0	2.6	-16.9	-35.5	-44.5
THE	Tara Hills	286.6	10.9	22.8	28.6	7.5	15.7	19.7
OUA	Oamaru Aero	437.5	5.7	11.9	14.9	-12.5	-26.3	-33.0
TUA	Timaru Aero	367.5	4.6	9.7	12.1	-15.7	-32.9	-41.3
QNA	Queenstown Aero	463.1	22.8	47.8	60.0	28.2	59.3	74.4
DNA	Dunedin Aero	429.5	14.4	30.2	37.9	5.4	11.3	14.1
TRQ	Traquair	418.1	14.2	29.9	37.5	5.5	11.4	14.4
NVA	Invercargill Aero	657.5	31.6	**66.3**	**83.2**	31.8	**66.9**	**83.9**
GCE	Gore	544.2	25.0	52.6	66.0	22.2	46.7	58.6
MOA	Manapouri Aero	712.2	41.3	86.8	109.0	49.9	105.0	131.0

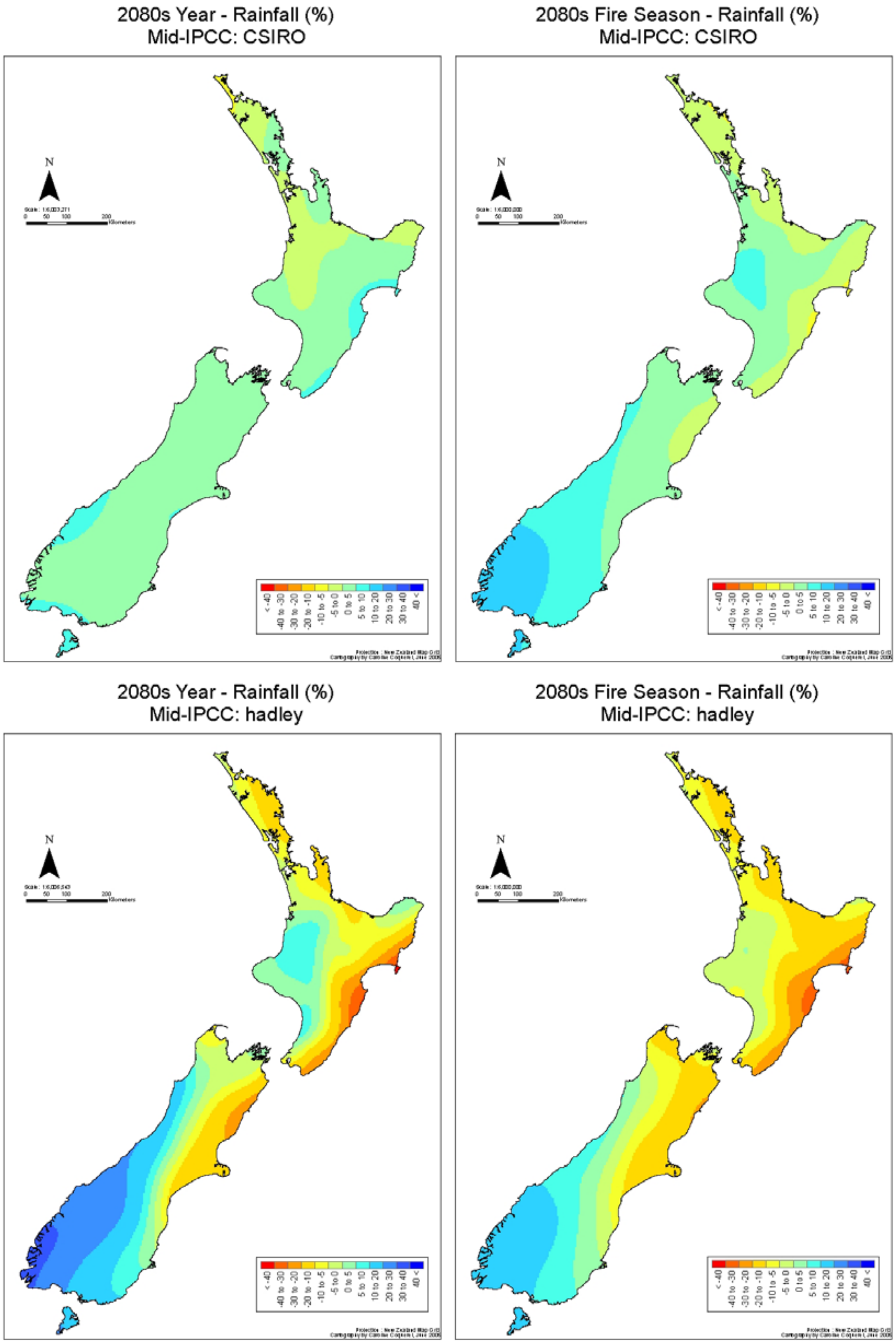

Figure 11. Changes in seasonal <u>rainfall</u> totals (%) for the full calendar year and fire season months for the CSIRO and Hadley mid-range climate change scenarios.

5.2.2 FWI System Components

The Fine Fuel Moisture Code (FFMC) represents the moisture content of fine, flashy fuels and as such is dependent on wetting and drying associated with rainfall, humidity and, to a lesser extent, temperature. Therefore increased temperatures and reduced rainfall are likely to result in increased FFMC values. This was found to be the case under both the Hadley and CSIRO high extreme and mid-range scenarios for stations in the Auckland, Bay of Plenty, Gisborne, Wellington and coastal Canterbury areas (Tables 6 & 7). However, even under the most extreme scenarios for both models, average changes in FFMC were relatively small at less than 2 points for the CSIRO and 3 points for the Hadley scenarios (i.e., <4% of current values). Whilst FFMC changes were generally positive (i.e., increased), small negative values (up to -0.5, or –1%) were obtained for some stations in the southern part of the South Island under the Hadley model (but only for the full calendar) reflecting the effect of significantly higher rainfalls in winter and spring in this part of the country on lowering average station FFMC values (Fig. 12).

While the stations found to be significant at the 90% level for FFMC under both the Hadley and CSIRO models remained the same for the full year and fire season months, the stations significant under just the Hadley high and/or mid-range scenarios varied widely between annual and fire season FFMC analyses (i.e., Whangarei and Napier Aeros, and Bottle Lake versus Whitianga and Whakatane Aero, respectively) due to the marked seasonal variability in rainfall under this model (see Tables 6 & 7). Similarly, a number of stations from the west of both islands and south of the South Island were found to be significant under just the CSIRO high and/or mid-range scenarios for the full calendar year, but only one of these (New Plymouth Aero) remained significant for the fire season months due to the relatively unchanged and more uniform summer rainfalls in this model.

The Buildup Index (BUI), which represents the combined moisture status of medium and larger woody fuels and deep soil organic layers, is also strongly dependent on rainfall and temperature. Again, increased temperatures and/or lower rainfalls in particular will result in increased BUI values, whereas increased rainfalls will produce lower BUI values. Significant increases in BUI values (up to +20 points, or +60%) were found for both full year and fire season analyses (Tables 8 & 9). Very minor decreases in BUI (up to -0.40, or –2%) were observed under the Hadley scenarios at some stations from the south of the South Island, again reflecting the effect of significantly higher winter and spring rainfalls in this model on reducing average BUI values.

Stations from the Bay of Plenty and central (Wellington/Nelson) regions showed increases under both the Hadley and CSIRO model scenarios, while stations in north and east of the North Island and east of the South Island increased significantly under only the Hadley model scenarios (see Fig. 13). Stations in the west and south showed increases solely under the CSIRO model, although significant changes were restricted to the full year analysis only as a result of drier winters and wetter springs in the south and west under this model.

5.2.3 Fire season severity

The CDSR and VH+E Forest fire danger classes have previously been used as measures of fire season severity (Pearce *et al*. 2003, Pearce and Moore 2004). They integrate the drying influences of higher temperatures and decreased rainfall and, although not studied here, increased wind speeds.

As might have been expected, the increased temperatures and significantly decreased rainfalls under both the Hadley and CSIRO high extreme and mid-range scenarios produced significantly higher CDSR values and more days of VH+E Forest fire danger at stations in the east of both islands, the Bay of Plenty and central (Wellington/Nelson) regions. same or similar) stations were found to be significant at the 90% level for VH+E Forest fire danger (Tables 10 & 11) compared with CDSR (Tables 12 & 13), and for fire season months compared with the full calendar year. In many cases (e.g., Gisborne, Napier and Christchurch Aeros), average CDSR values increased by more than 300-580 points (25-65%) (Fig. 14), and the total number of days of VH+E Forest fire danger by more than 20 days (>50%) (Fig. 15).

However, in contrast to the VH+E Forest fire danger severity measure, lower but still statistically significant increases in CDSR (10-110 points, or 15-25%) were found under the CSIRO high extreme scenario for stations in the west of both islands and south of the South Island (see Tables 12 & 13). In this case, significantly increased temperatures across all months of the year offset any effect of the slightly increased rainfalls under this scenario. Again, the trend was consistent for both the full year and fire season months, although at fewer stations for the latter.

The CDSR is simply a cumulative measure of fire season severity and, if averaged over the period of interest (e.g., the fire season months), it produces a value equivalent to the Seasonal Severity Rating (SSR) used in other studies (e.g., Flannigan and Van Wagner 1991, Stocks *et al*. 1998). In addition, changes in either measure when

Table 6. Changes in Fine Fuel Moisture Code (FFMC) (points) associated with climate change model scenarios averaged across all months. Positive values indicate an increase, and negative values a decrease. Values statistically significant at the 90% level are highlighted in **bold**.

Station Code	Station Name	Current	Difference (Scenario - Current)					
			CSIRO(L)	CSIRO(M)	CSIRO(H)	Hadley(L)	Hadley(M)	Hadley(H)
DAR	Dargaville	66.9	0.76	1.59	1.99	0.86	1.81	2.27
WRA	Whangarei	70.5	0.66	1.37	1.72	0.99	**2.10**	**2.67**
PTU	Pouto	68.0	0.65	1.36	1.70	0.76	1.60	2.01
AKL	Auckland	70.7	0.72	**1.49**	**1.86**	0.71	**1.48**	**1.86**
HNA	Hamilton Aero	67.9	0.73	1.52	1.90	0.63	1.32	1.66
WTA	Whitianga	67.6	0.69	1.45	1.81	0.91	1.93	2.45
PAX	Paeroa	69.2	0.71	1.48	1.85	0.97	2.07	2.63
ATH	Athol	59.6	0.79	1.65	2.07	0.56	1.18	1.49
ROA	Rotorua Aero	69.1	0.69	**1.43**	**1.78**	0.74	**1.56**	**1.97**
TGA	Tauranga	71.5	0.64	1.33	1.66	0.76	1.61	2.04
APA	Taupo Aero	70.1	0.66	**1.37**	**1.72**	0.63	**1.32**	**1.66**
TPE	Te Puke	60.1	0.71	1.49	1.86	0.86	1.85	2.36
WKA	Whakatane	72.2	0.63	1.30	1.63	0.68	1.44	1.82
TTA	Toatoa	63.9	0.79	1.66	2.08	0.71	1.50	1.89
MTE	Matea	58.4	0.64	1.33	1.66	0.69	1.45	1.83
GDE	Goudies	63.3	0.65	1.35	1.68	0.73	1.54	1.94
GSA	Gisborne Aero	74.4	0.52	**1.09**	**1.38**	**1.07**	**2.33**	**2.99**
NRA	Napier Aero	74.8	0.46	0.98	1.24	0.99	**2.16**	**2.79**
NPA	New Plymouth	66.2	0.69	**1.45**	**1.82**	0.48	1.02	1.28
WUA	Wanganui	69.6	0.68	1.42	1.78	0.45	0.97	1.22
RUX	Waiouru Aero	54.4	0.82	1.74	2.18	0.65	1.39	1.75
LNX	Levin	67.3	0.68	1.43	1.79	0.33	0.72	0.92
NTA	Ngamatea	63.2	0.57	1.20	1.50	1.02	2.19	2.77
MSX	East Taratahi	69.9	0.57	1.19	1.50	0.86	1.81	2.27
CPX	Castle Point	70.1	0.51	1.09	1.37	1.08	2.35	3.01
NMU	Ngaumu	68.0	0.51	1.07	1.35	1.05	2.26	2.87
WNA	Wellington	71.6	0.52	1.09	**1.37**	0.65	**1.36**	**1.70**
PPA	Paraparaumu	71.1	0.59	**1.24**	**1.55**	0.40	0.85	**1.08**
NSA	Nelson Aero	71.7	0.53	1.11	**1.39**	0.42	0.89	1.13
TNI	Totaranui	64.3	0.59	1.23	1.53	0.60	1.25	1.58
HIR	Hira	64.9	0.50	1.04	1.30	0.40	0.85	1.08
DOV	Dovedale	62.4	0.50	1.04	1.30	0.41	0.88	1.11
KIX	Kaikoura	71.1	0.48	1.01	**1.28**	1.08	**2.38**	**3.07**
KHD	Keneperu	69.1	0.61	1.27	1.60	0.49	1.04	1.30
OSN	Opua Bay	65.4	0.57	1.19	1.49	0.58	1.21	1.52
WBA	Woodbourne	76.2	0.47	0.97	1.22	0.48	1.01	1.26
HKA	Hokitika Aero	56.1	0.76	1.59	**2.00**	0.10	0.28	0.39
WSA	Westport	58.4	0.78	1.64	**2.07**	0.14	0.37	0.50
HTX	Haast	50.4	0.74	1.56	1.96	-0.05	-0.01	0.04
CHA	Christchurch	74.7	0.42	0.89	**1.12**	0.73	**1.55**	**1.96**
SDN	Snowdon	67.2	0.51	1.07	1.34	0.61	1.28	1.61
FPL	Darfield	72.6	0.40	0.85	1.06	0.71	1.52	1.92
BTL	Bottle Lake	73.8	0.42	0.88	1.11	0.73	1.56	**1.97**
THE	Tara Hills	75.1	0.39	0.83	1.05	-0.10	-0.14	-0.13
OUA	Oamaru Aero	70.7	0.49	1.02	1.28	0.53	1.12	1.40
TUA	Timaru Aero	73.6	0.41	0.87	1.09	0.55	1.16	1.46
QNA	Queenstown	71.2	0.54	1.16	**1.46**	-0.29	-0.46	-0.50
DNA	Dunedin Aero	71.9	0.48	**1.00**	**1.26**	0.15	0.33	0.42
TRQ	Traquair	68.0	0.45	0.95	1.20	0.10	0.23	0.30
NVA	Invercargill	64.3	0.64	**1.37**	**1.73**	-0.18	-0.29	-0.32
GCE	Gore	65.5	0.59	1.26	1.59	-0.10	-0.14	-0.14
MOA	Manapouri	60.8	0.61	1.31	1.67	-0.30	-0.48	-0.53

Table 7. Changes in Fine Fuel Moisture Code (FFMC) (points) associated with climate change model scenarios averaged across fire season months. Positive values indicate an increase, and negative values a decrease. Values statistically significant at the 90% level are highlighted in **bold**.

Station Code	Station Name	Current	Difference (Scenario - Current)					
			CSIRO(L)	CSIRO(M)	CSIRO(H)	Hadley(L)	Hadley(M)	Hadley(H)
DAR	Dargaville	66.8	0.77	1.60	2.00	0.86	1.81	2.27
WRA	Whangarei Aero	75.1	0.64	1.34	1.67	0.77	1.65	2.09
PTU	Pouto	72.9	0.57	1.19	1.49	0.64	1.33	1.67
AKL	Auckland Aero	76.0	0.54	**1.12**	**1.40**	0.59	**1.24**	**1.56**
HNA	Hamilton Aero	73.8	0.58	1.22	1.52	0.59	1.24	1.55
WTA	Whitianga Aero	73.6	0.67	1.39	1.73	0.77	1.65	**2.11**
PAX	Paeroa	74.9	0.66	1.37	**1.71**	0.80	**1.71**	**2.17**
ATH	Athol	65.7	0.64	1.35	1.69	0.63	1.31	1.64
ROA	Rotorua Aero	73.3	0.63	**1.31**	**1.63**	0.72	**1.53**	**1.93**
TGA	Tauranga Aero	75.2	0.58	1.22	1.52	0.70	1.49	1.90
APA	Taupo Aero	74.0	0.58	1.20	**1.50**	0.64	**1.35**	**1.70**
TPE	Te Puke	64.5	0.70	1.46	1.82	0.85	1.85	2.38
WKA	Whakatane Aero	76.1	0.57	1.18	1.48	0.63	1.35	**1.71**
TTA	Toatoa	68.9	0.72	1.49	1.87	0.74	1.55	1.94
MTE	Matea	66.1	0.61	1.28	1.60	0.71	1.50	1.89
GDE	Goudies	68.6	0.60	1.25	1.56	0.72	1.52	1.92
GSA	Gisborne Aero	78.1	0.59	**1.22**	**1.52**	0.85	**1.86**	**2.38**
NRA	Napier Aero	78.2	0.54	1.12	1.40	0.80	1.75	2.24
NPA	New Plymouth Aero	70.2	0.57	1.18	**1.48**	0.53	1.11	1.39
WUA	Wanganui Aero	73.2	0.56	1.17	1.46	0.52	1.08	1.35
RUX	Waiouru Aero	64.5	0.69	1.45	1.82	0.78	1.64	2.06
LNX	Levin	70.9	0.57	1.20	1.50	0.48	1.01	1.27
NTA	Ngamatea	68.8	0.58	1.21	1.51	0.94	2.02	2.56
MSX	East Taratahi	75.1	0.57	1.20	1.49	0.74	1.56	1.96
CPX	Castle Point	73.1	0.58	1.22	1.52	0.85	1.84	2.35
NMU	Ngaumu	74.2	0.56	1.17	1.47	0.83	1.79	2.27
WNA	Wellington Aero	75.5	0.50	1.04	**1.30**	0.54	**1.13**	**1.42**
PPA	Paraparaumu	74.4	0.51	**1.05**	**1.32**	0.46	0.96	**1.21**
NSA	Nelson Aero	75.9	0.50	1.04	**1.30**	0.51	1.06	**1.33**
TNI	Totaranui	68.7	0.57	1.18	1.48	0.59	1.24	1.56
HIR	Hira	69.3	0.49	1.03	1.29	0.51	1.08	1.36
DOV	Dovedale	67.5	0.48	1.00	1.26	0.51	1.06	1.34
KIX	Kaikoura	73.0	0.60	1.26	**1.57**	0.84	**1.80**	**2.29**
KHD	Keneperu Head	73.8	0.57	1.20	1.50	0.50	1.04	1.30
OSN	Opua Bay	72.4	0.56	1.17	1.46	0.57	1.20	1.50
WBA	Woodbourne Aero	79.7	0.44	0.91	1.14	0.47	0.99	1.24
HKA	Hokitika Aero	59.5	0.64	1.35	1.70	0.29	0.63	0.79
WSA	Westport	62.1	0.63	1.32	1.66	0.34	0.73	0.92
HTX	Haast	52.9	0.64	1.37	1.72	0.23	0.50	0.64
CHA	Christchurch Aero	79.0	0.43	0.90	**1.13**	0.50	**1.05**	**1.32**
SDN	Snowdon	69.9	0.52	1.09	1.36	0.56	1.18	1.49
FPL	Darfield	76.0	0.46	0.95	1.19	0.56	1.18	1.49
BTL	Bottle Lake	78.0	0.43	0.90	1.13	0.52	1.10	1.39
THE	Tara Hills	78.7	0.31	0.66	0.83	0.14	0.29	0.38
OUA	Oamaru Aero	72.0	0.54	1.12	1.41	0.49	1.02	1.28
TUA	Timaru Aero	75.7	0.46	0.96	1.20	0.50	1.05	1.32
QNA	Queenstown Aero	75.6	0.35	0.76	0.96	0.02	0.08	0.11
DNA	Dunedin Aero	74.7	0.38	0.81	1.02	0.21	0.45	0.57
TRQ	Traquair	69.9	0.35	0.74	0.94	0.20	0.42	0.52
NVA	Invercargill Aero	68.8	0.40	0.87	1.10	0.03	0.09	0.14
GCE	Gore	68.9	0.39	0.84	1.07	0.05	0.14	0.19
MOA	Manapouri Aero	69.1	0.41	0.88	1.12	0.00	0.05	0.09

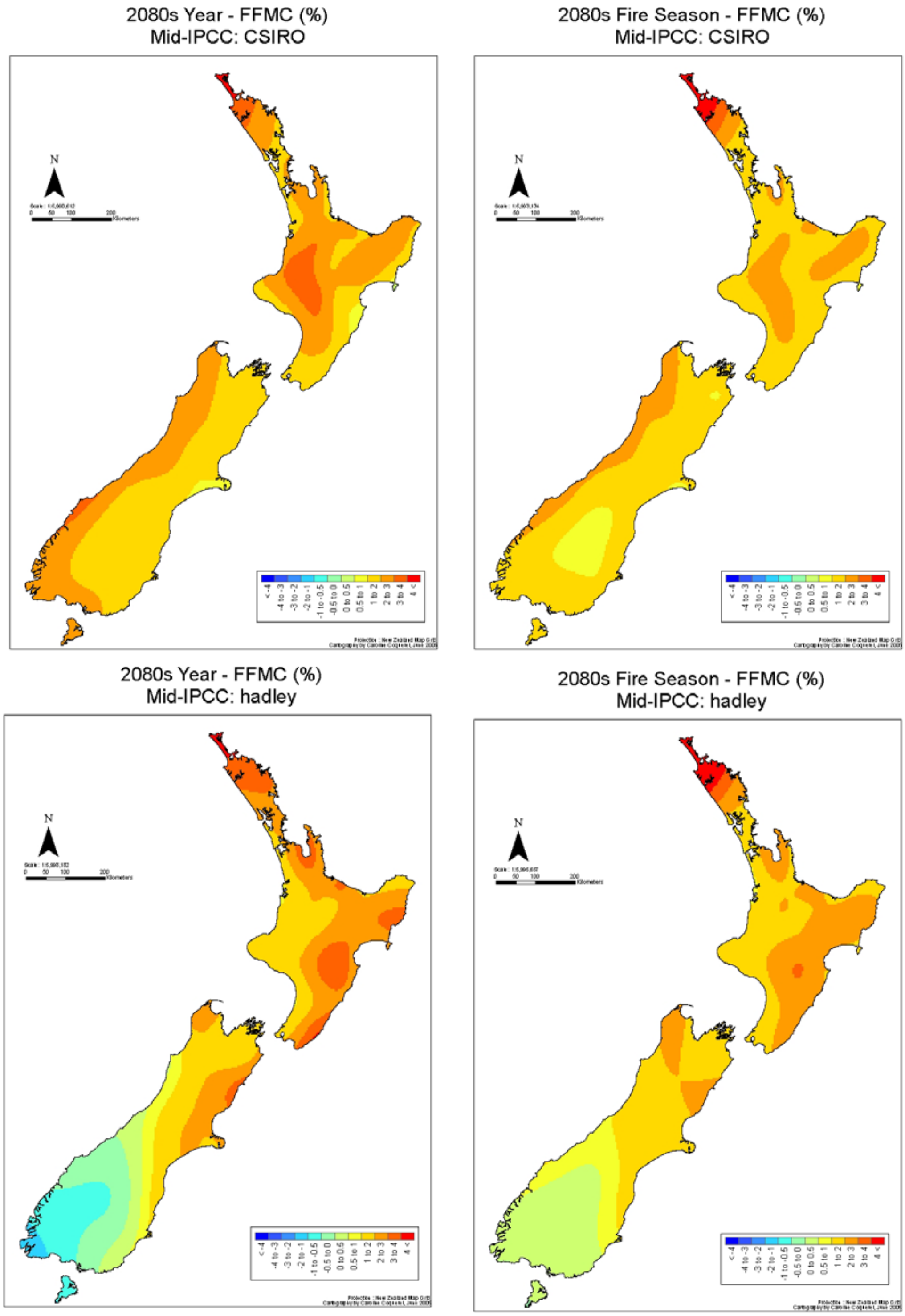

Figure 12. Changes in Fine Fuel Moisture Code (FFMC) (%) averaged over the full calendar year and fire season months for the CSIRO and Hadley mid-range climate change scenarios.

Table 8. Changes in Buildup Index (BUI) (points) associated with climate change model scenarios averaged across all months. Positive values indicate an increase, and negative values a decrease. Values statistically significant at the 90% level are highlighted in **bold**.

Station Code	Station Name	Current	Difference (Scenario - Current)					
			CSIRO(L)	CSIRO(M)	CSIRO(H)	Hadley(L)	Hadley(M)	Hadley(H)
DAR	Dargaville	14.1	0.90	1.91	2.43	1.11	2.51	**3.21**
WRA	Whangarei	16.8	1.11	2.40	3.06	1.60	3.90	**5.28**
PTU	Pouto	14.8	1.04	2.20	2.77	1.21	2.76	3.52
AKL	Auckland	15.6	0.92	1.97	2.49	1.04	2.35	**3.05**
HNA	Hamilton Aero	13.7	0.82	1.75	2.19	0.87	1.91	2.46
WTA	Whitianga	13.2	0.85	1.82	2.31	1.10	2.70	3.62
PAX	Paeroa	16.0	1.07	2.28	2.86	1.52	3.57	**4.78**
ATH	Athol	8.9	0.56	1.20	1.50	0.53	1.12	1.42
ROA	Rotorua Aero	13.1	0.92	**1.97**	**2.49**	1.16	**2.67**	**3.52**
TGA	Tauranga	17.1	1.16	**2.51**	**3.17**	1.64	**3.84**	**5.10**
APA	Taupo Aero	13.3	0.99	**2.10**	**2.65**	1.12	**2.47**	**3.19**
TPE	Te Puke	13.0	0.86	1.85	2.33	1.12	2.66	3.53
WKA	Whakatane	18.1	1.17	2.51	3.16	1.55	3.71	**4.95**
TTA	Toatoa	9.1	0.63	1.33	1.68	0.62	1.39	1.77
MTE	Matea	8.8	0.62	1.32	1.65	0.79	1.68	2.16
GDE	Goudies	9.9	0.69	1.48	1.86	0.93	2.03	2.62
GSA	Gisborne Aero	25.2	1.64	3.55	4.52	4.03	**10.10**	**14.20**
NRA	Napier Aero	27.3	1.74	3.73	4.70	4.44	**11.30**	**15.90**
NPA	New Plymouth	9.2	0.59	1.27	1.60	0.53	1.14	1.44
WUA	Wanganui	12.5	0.87	1.84	2.32	0.74	1.61	2.04
RUX	Waiouru Aero	7.8	0.58	1.22	1.55	0.63	1.40	1.76
LNX	Levin	13.6	0.83	1.78	2.23	0.62	1.36	1.74
NTA	Ngamatea	11.8	1.02	2.16	2.74	1.70	4.05	5.35
MSX	East Taratahi	18.5	1.12	2.35	2.94	2.13	4.99	6.55
CPX	Castle Point	14.5	1.07	2.28	2.88	2.28	**5.64**	**7.76**
NMU	Ngaumu	21.1	1.31	2.75	3.46	2.74	6.36	**8.48**
WNA	Wellington	15.6	1.00	2.14	**2.69**	1.38	**3.06**	**3.96**
PPA	Paraparaumu	14.8	0.92	1.97	**2.48**	0.85	1.84	2.34
NSA	Nelson Aero	19.1	1.14	2.42	**3.05**	1.30	2.84	**3.68**
TNI	Totaranui	13.3	0.81	1.71	2.14	0.98	2.12	2.69
HIR	Hira	16.2	0.99	2.10	2.63	1.05	2.31	2.94
DOV	Dovedale	14.7	0.80	1.69	2.12	0.88	1.91	2.43
KIX	Kaikoura	18.7	1.39	2.97	3.74	3.14	**7.88**	**10.90**
KHD	Keneperu	15.8	0.96	2.03	2.54	0.94	2.02	2.55
OSN	Opua Bay	15.2	0.85	1.81	2.28	0.96	2.09	2.66
WBA	Woodbourne	33.4	1.76	3.71	4.62	2.41	5.29	6.73
HKA	Hokitika Aero	4.6	0.31	**0.65**	**0.82**	0.13	0.29	0.37
WSA	Westport	5.1	0.34	0.72	**0.91**	0.18	0.40	0.51
HTX	Haast	3.4	0.23	0.48	0.61	0.07	0.16	0.20
CHA	Christchurch	30.9	1.70	3.60	4.53	3.37	**7.76**	**10.10**
SDN	Snowdon	14.0	0.85	1.79	2.24	1.09	2.47	3.17
FPL	Darfield	27.0	1.42	2.98	3.73	2.83	6.89	8.96
BTL	Bottle Lake	37.2	1.82	3.82	4.80	3.54	8.34	10.90
THE	Tara Hills	34.6	1.51	3.14	3.93	-0.25	-0.37	-0.41
OUA	Oamaru Aero	17.0	1.06	2.21	2.78	1.28	2.84	3.60
TUA	Timaru Aero	27.6	1.48	3.08	3.84	2.25	5.01	6.40
QNA	Queenstown	16.8	0.86	1.86	2.36	-0.25	-0.31	-0.30
DNA	Dunedin Aero	18.7	0.97	2.09	2.63	0.38	0.82	1.04
TRQ	Traquair	13.6	0.92	1.97	2.48	0.38	0.79	0.99
NVA	Invercargill	7.4	0.32	0.75	**0.96**	-0.05	-0.04	-0.02
GCE	Gore	9.3	0.48	1.08	1.37	0.00	0.00	0.02
MOA	Manapouri	9.6	0.38	0.82	1.03	-0.07	-0.13	-0.13

Table 9. Changes in Buildup Index (BUI) (points) associated with climate change model scenarios averaged across fire season months. Positive values indicate an increase, and negative values a decrease. Values statistically significant at the 90% level are highlighted in **bold**.

Station Code	Station Name	Current	Difference (Scenario - Current)					
			CSIRO(L)	CSIRO(M)	CSIRO(H)	Hadley(L)	Hadley(M)	Hadley(H)
DAR	Dargaville	14.0	0.90	1.91	2.42	1.12	2.54	**3.25**
WRA	Whangarei Aero	25.7	1.62	3.52	4.47	2.26	5.44	7.38
PTU	Pouto	21.0	1.35	2.83	3.57	1.52	3.47	4.46
AKL	Auckland Aero	24.2	1.27	2.72	3.42	1.49	3.39	**4.40**
HNA	Hamilton Aero	20.8	1.10	2.33	2.91	1.21	2.66	3.44
WTA	Whitianga Aero	19.9	1.21	2.61	3.31	1.57	3.86	**5.20**
PAX	Paeroa	23.4	1.49	3.16	3.97	2.06	4.81	**6.46**
ATH	Athol	13.5	0.76	1.63	2.05	0.76	1.63	2.05
ROA	Rotorua Aero	19.9	1.26	2.69	3.39	1.63	**3.79**	**5.01**
TGA	Tauranga Aero	25.1	1.59	3.43	**4.34**	2.30	**5.42**	**7.24**
APA	Taupo Aero	19.9	1.28	2.70	3.40	1.55	3.43	**4.44**
TPE	Te Puke	18.9	1.13	2.43	3.07	1.48	3.50	4.64
WKA	Whakatane Aero	26.6	1.61	3.43	4.34	2.19	5.32	7.12
TTA	Toatoa	13.3	0.79	1.68	2.12	0.82	1.83	2.36
MTE	Matea	13.7	0.88	1.86	2.32	1.09	2.32	2.99
GDE	Goudies	15.2	0.97	2.08	2.61	1.35	2.92	3.76
GSA	Gisborne Aero	37.0	2.44	5.28	6.74	5.45	**13.60**	**19.10**
NRA	Napier Aero	38.7	2.47	5.34	6.75	5.67	**14.70**	**20.80**
NPA	New Plymouth Aero	13.8	0.77	1.64	2.07	0.75	1.60	2.03
WUA	Wanganui Aero	17.8	1.02	2.15	2.69	1.03	2.24	2.85
RUX	Waiouru Aero	12.1	0.83	1.77	2.22	0.99	2.21	2.79
LNX	Levin	19.3	0.98	2.09	2.62	0.94	2.06	2.62
NTA	Ngamatea	18.3	1.42	3.03	3.84	2.39	5.67	7.50
MSX	East Taratahi	27.2	1.55	3.26	4.09	2.86	6.77	8.93
CPX	Castle Point	21.0	1.55	3.29	4.17	2.99	7.27	**10.00**
NMU	Ngaumu	31.5	1.91	4.02	5.06	3.72	8.60	11.40
WNA	Wellington Aero	23.4	1.41	3.01	3.78	1.87	**4.17**	**5.40**
PPA	Paraparaumu	21.7	1.18	2.50	3.13	1.19	2.59	3.29
NSA	Nelson Aero	28.0	1.49	3.14	3.94	1.87	4.11	**5.34**
TNI	Totaranui	19.4	1.05	2.21	2.77	1.29	2.81	3.58
HIR	Hira	23.5	1.26	2.67	3.35	1.53	3.38	4.33
DOV	Dovedale	21.8	1.13	2.39	3.00	1.38	3.00	3.82
KIX	Kaikoura	25.0	1.93	4.15	5.25	3.51	**8.80**	**12.20**
KHD	Keneperu Head	22.4	1.17	2.46	3.07	1.18	2.57	3.24
OSN	Opua Bay	22.7	1.21	2.57	3.23	1.38	3.02	3.85
WBA	Woodbourne Aero	46.7	2.25	4.76	5.93	3.27	7.17	9.17
HKA	Hokitika Aero	6.3	0.34	0.72	0.90	0.18	0.38	0.49
WSA	Westport	7.2	0.40	0.83	1.05	0.26	0.56	0.70
HTX	Haast	4.8	0.26	0.55	0.69	0.11	0.23	0.29
CHA	Christchurch Aero	44.5	2.35	4.96	6.23	4.31	**9.84**	**12.80**
SDN	Snowdon	20.0	1.12	2.37	2.97	1.44	3.21	4.15
FPL	Darfield	37.0	1.94	4.10	5.14	3.39	8.30	10.80
BTL	Bottle Lake	51.5	2.56	5.39	6.77	4.50	10.60	13.80
THE	Tara Hills	48.3	1.63	3.37	4.20	-0.03	0.02	0.07
OUA	Oamaru Aero	21.2	1.28	2.70	3.40	1.41	3.15	4.02
TUA	Timaru Aero	34.6	1.73	3.62	4.52	2.47	5.52	7.02
QNA	Queenstown Aero	25.1	0.88	1.88	2.37	-0.26	-0.33	-0.34
DNA	Dunedin Aero	25.6	0.98	2.11	2.63	0.49	1.08	1.36
TRQ	Traquair	18.1	0.98	2.03	2.52	0.49	1.03	1.28
NVA	Invercargill Aero	11.2	0.36	0.82	1.04	-0.06	-0.04	-0.03
GCE	Gore	13.8	0.53	1.18	1.47	0.03	0.05	0.08
MOA	Manapouri Aero	15.1	0.51	1.08	1.34	-0.11	-0.19	-0.20

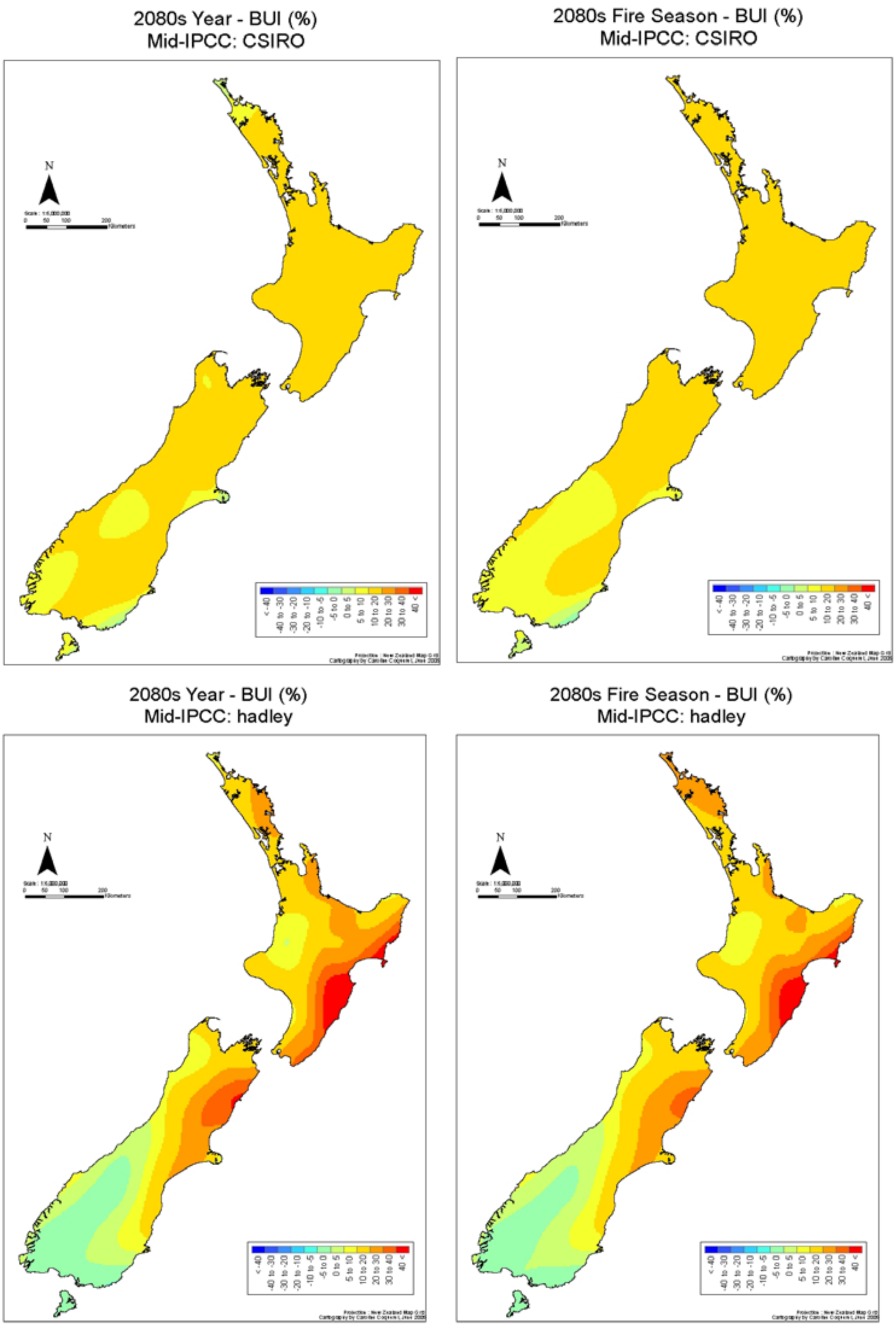

Figure 13. Changes in Buildup Index (BUI) (%) averaged over the full calendar year and fire season months for the CSIRO and Hadley mid-range climate change scenarios.

expressed as a percentage of present climate produce an equivalent result. However, unlike some international studies (e.g., Flannigan *et al*. 1998a, 2000, 2001), no New

Zealand stations included in this analysis showed decreases in fire climate severity described using FWI System severity ratings (see Fig. 14), despite the significant rainfall increases projected under the high extreme model scenarios. Several stations (typically those in the south and west with low or no existing fire danger) showed little or no change in CDSR or VH+E Forest fire danger but, in one case (Tara Hills under the Hadley high extreme scenario), showed a very slight decrease (-0.08, or -0.2% change from 36.8 to 36.7 days) in VH+E fire danger.

5.2.4 Fire season length

Several authors have reported potential increases in fire season length associated with climate change. Wotton and Flannigan (1993) reported that fire season length could increase by an average of 22% or 30 days across Canada in a 2×CO_2 climate, with the highest changes in British Columbia (39% or 51 days). However, they noted that the limitations of the GCM (low confidence of rainfall simulations, and their seasonal and spatial variability) at the time meant that it was unclear whether these increases in fire season length resulting from higher temperatures would be offset or even amplified by accompanying rainfall changes over summer months. Street (1989), in his study of the effect of climate change on forest fire danger in Ontario, suggested that the fire season there will become longer and that there will be a shift in the severe fire months to later in the fire season due to increases in rainfall during spring months and decreases in the later summer months. In New Zealand, the "fire season" historically refers to the seven-month period from October 1 to April 30. However, the term is not entirely appropriate as fires can potentially occur all year round due to New Zealand's temperate climate with relatively mild winters.

Wotton and Flannigan (1993) state that the critical issue in determining fire season length is to first define criteria for starting and ending the fire season. Typically, this is based on fire activity; however, in the absence of fire occurrence data, a number of other approaches are available. Simard *et al*. (1989) used the concept of burning-days to define the days following loss of snow cover on which fires can occur, and defined fire season as starting after three consecutive days with maximum temperatures greater than 7.2 ºC (45 ºF), and ending after a 3-day period of temperatures below this same threshold. Wotton and Flannigan (1993) used a modification of these criteria, with the fire season starting after 3 consecutive days with maximum temperatures above 12 ºC, and ending after 3 days with temperatures less than 5 ºC. These modified criteria

Table 10. Changes in Cumulative Daily Severity Rating (CDSR) (points) associated with climate change model scenarios averaged across all months. Positive values indicate an increase, and negative values a decrease. Values statistically significant at the 90% level are highlighted in **bold**.

Station Code	Station Name	Current	Difference (Scenario - Current)					
			CSIRO(L)	CSIRO(M)	CSIRO(H)	Hadley(L)	Hadley(M)	Hadley(H)
DAR	Dargaville	191.6	21.1	46.5	59.7	23.0	52.6	68.2
WRA	Whangarei Aero	291.4	33.6	74.8	96.3	40.4	97.6	132.0
PTU	Pouto	359.0	36.6	79.6	102.0	38.2	86.7	112.0
AKL	Auckland Aero	401.6	38.0	83.4	107.0	38.3	87.0	**113.0**
HNA	Hamilton Aero	212.6	21.2	46.6	59.5	19.6	43.9	57.1
WTA	Whitianga Aero	254.7	26.8	59.1	76.1	29.7	71.9	96.7
PAX	Paeroa	225.5	24.2	53.0	67.9	27.5	64.6	87.1
ATH	Athol	62.1	6.8	15.2	19.5	5.7	12.6	16.2
ROA	Rotorua Aero	218.1	24.6	54.3	**69.7**	26.3	**61.3**	**81.1**
TGA	Tauranga Aero	403.1	42.8	94.4	**121.0**	50.2	**118.0**	**158.0**
APA	Taupo Aero	214.9	25.0	**54.9**	**70.4**	24.9	**56.1**	**73.0**
TPE	Te Puke	107.5	12.6	28.0	36.0	13.7	32.4	43.4
WKA	Whakatane Aero	470.9	47.5	104.0	133.0	52.4	126.0	168.0
TTA	Toatoa	85.0	9.4	20.8	26.8	8.5	19.2	24.8
MTE	Matea	188.8	18.8	41.2	52.5	18.9	41.9	54.7
GDE	Goudies	250.8	25.1	55.1	70.7	27.7	62.4	81.2
GSA	Gisborne Aero	985.2	94.7	208.0	267.0	165.0	**406.0**	**565.0**
NRA	Napier Aero	1018.7	91.8	201.0	257.0	166.0	418.0	**582.0**
NPA	New Plymouth Aero	169.2	18.5	40.8	52.3	15.3	33.6	43.0
WUA	Wanganui Aero	301.5	32.4	70.7	**90.4**	26.4	58.1	74.6
RUX	Waiouru Aero	79.8	9.2	20.4	26.2	8.8	19.9	25.5
LNX	Levin	168.5	17.3	38.2	48.7	13.1	29.0	37.3
NTA	Ngamatea	459.4	48.4	106.0	136.0	65.4	155.0	205.0
MSX	East Taratahi	496.2	46.6	101.0	129.0	62.9	149.0	196.0
CPX	Castle Point	888.7	85.5	186.0	238.0	135.0	330.0	453.0
NMU	Ngaumu	535.1	49.0	106.0	135.0	70.4	163.0	215.0
WNA	Wellington Aero	741.4	70.0	**153.0**	**194.0**	74.7	**167.0**	**217.0**
PPA	Paraparaumu	301.7	31.2	68.4	**87.3**	25.6	56.6	72.4
NSA	Nelson Aero	509.7	47.4	103.0	**131.0**	45.5	101.0	**130.0**
TNI	Totaranui	149.9	15.5	33.7	43.0	15.4	34.1	43.8
HIR	Hira	301.0	28.9	62.9	80.2	26.4	58.6	75.3
DOV	Dovedale	184.6	18.1	39.5	50.4	16.6	36.6	46.9
KIX	Kaikoura	353.8	39.4	86.7	**111.0**	67.9	**171.0**	**238.0**
KHD	Keneperu Head	227.9	22.8	49.6	63.3	18.8	41.3	52.6
OSN	Opua Bay	224.2	22.3	48.9	62.4	20.5	45.3	58.1
WBA	Woodbourne Aero	1516.6	114.0	247.0	312.0	123.0	270.0	344.0
HKA	Hokitika Aero	42.5	5.2	11.5	**14.7**	2.5	5.5	7.1
WSA	Westport	55.7	6.7	14.8	19.0	3.8	8.5	10.9
HTX	Haast	32.3	3.8	8.2	10.6	1.5	3.4	4.3
CHA	Christchurch Aero	1277.5	105.0	226.0	**287.0**	142.0	**324.0**	**421.0**
SDN	Snowdon	704.7	59.1	128.0	163.0	57.7	131.0	169.0
FPL	Darfield	1100.8	84.1	181.0	230.0	111.0	270.0	351.0
BTL	Bottle Lake	502.5	41.8	90.4	115.0	55.1	129.0	168.0
THE	Tara Hills	1223.4	78.0	167.0	211.0	13.1	31.2	40.6
OUA	Oamaru Aero	356.2	33.8	73.3	93.6	31.4	70.8	90.6
TUA	Timaru Aero	592.3	51.6	111.0	141.0	57.3	128.0	164.0
QNA	Queenstown Aero	332.0	26.3	58.0	74.4	1.8	7.4	10.6
DNA	Dunedin Aero	447.1	37.9	83.4	**106.0**	17.5	38.2	48.5
TRQ	Traquair	428.0	39.7	86.5	111.0	18.3	38.8	48.8
NVA	Invercargill Aero	138.2	10.6	24.2	**31.3**	1.6	4.4	6.0
GCE	Gore	193.5	15.6	35.0	44.9	3.6	7.9	10.5
MOA	Manapouri Aero	139.8	11.0	23.9	30.5	1.4	3.6	5.0

Table 11. Changes in Cumulative Daily Severity Rating (CDSR) (points) associated with climate change model scenarios averaged across fire season months. Positive values indicate an increase, and negative values a decrease. Values statistically significant at the 90% level are highlighted in **bold**.

Station Code	Station Name	Current	Difference (Scenario - Current)					
			CSIRO(L)	CSIRO(M)	CSIRO(H)	Hadley(L)	Hadley(M)	Hadley(H)
DAR	Dargaville	160.0	17.6	38.8	49.8	19.2	44.0	57.1
WRA	Whangarei Aero	276.4	30.8	68.6	88.3	36.6	87.5	118.0
PTU	Pouto	304.8	31.1	67.5	86.3	31.9	72.4	93.9
AKL	Auckland Aero	381.2	35.0	76.5	97.7	35.3	80.1	**104.0**
HNA	Hamilton Aero	203.3	20.3	44.3	56.5	18.8	42.0	54.7
WTA	Whitianga Aero	237.2	24.9	54.9	70.6	27.0	65.6	88.2
PAX	Paeroa	210.9	23.6	51.7	66.2	26.5	61.8	83.1
ATH	Athol	58.9	6.8	15.1	19.3	5.7	12.6	16.2
ROA	Rotorua Aero	204.2	22.2	48.9	**62.7**	23.7	55.3	**73.4**
TGA	Tauranga Aero	370.6	38.4	84.5	108.0	45.0	106.0	**142.0**
APA	Taupo Aero	199.2	22.1	48.3	**61.8**	22.3	50.3	**65.4**
TPE	Te Puke	98.6	11.7	25.9	33.2	12.6	29.8	40.0
WKA	Whakatane Aero	442.2	43.5	95.3	122.0	48.3	116.0	155.0
TTA	Toatoa	80.6	9.2	20.2	25.9	8.3	18.7	24.3
MTE	Matea	181.4	18.4	40.2	51.2	18.5	40.8	53.2
GDE	Goudies	237.1	24.3	53.3	68.3	27.0	60.6	78.7
GSA	Gisborne Aero	897.9	85.1	187.0	240.0	143.0	**348.0**	**481.0**
NRA	Napier Aero	914.5	85.2	187.0	239.0	143.0	361.0	502.0
NPA	New Plymouth Aero	152.7	15.5	34.1	43.7	13.2	29.0	37.0
WUA	Wanganui Aero	270.1	27.1	58.8	75.1	23.3	51.1	65.6
RUX	Waiouru Aero	76.9	9.1	20.1	25.8	8.8	20.0	25.6
LNX	Levin	151.5	14.9	32.6	41.5	12.2	27.0	34.6
NTA	Ngamatea	429.3	45.1	98.4	126.0	61.0	144.0	191.0
MSX	East Taratahi	467.1	44.3	96.1	122.0	57.7	137.0	180.0
CPX	Castle Point	772.5	76.7	167.0	214.0	112.0	270.0	370.0
NMU	Ngaumu	503.9	46.5	101.0	128.0	64.2	147.0	194.0
WNA	Wellington Aero	680.1	62.8	137.0	**174.0**	64.9	**145.0**	**188.0**
PPA	Paraparaumu	272.9	26.5	57.8	**73.6**	22.3	49.1	62.8
NSA	Nelson Aero	475.8	42.5	92.3	117.0	41.8	92.3	120.0
TNI	Totaranui	140.0	14.3	31.2	39.8	14.1	31.3	40.2
HIR	Hira	282.9	26.9	58.4	74.5	25.0	55.7	71.7
DOV	Dovedale	174.7	16.9	36.7	46.8	15.7	34.7	44.4
KIX	Kaikoura	280.1	32.3	71.1	91.2	46.6	**116.0**	**160.0**
KHD	Keneperu Head	202.3	20.0	43.5	55.4	16.4	35.9	45.8
OSN	Opua Bay	205.9	20.7	45.4	58.0	18.7	41.3	53.0
WBA	Woodbourne Aero	1386.6	102.0	220.0	278.0	110.0	241.0	308.0
HKA	Hokitika Aero	34.2	3.8	8.4	**10.7**	2.0	4.3	5.5
WSA	Westport	47.6	5.2	11.5	14.7	3.2	7.1	9.0
HTX	Haast	26.2	2.7	6.0	7.6	1.2	2.6	3.3
CHA	Christchurch Aero	1174.0	94.1	203.0	257.0	123.0	277.0	**358.0**
SDN	Snowdon	616.6	52.7	114.0	145.0	50.2	112.0	144.0
FPL	Darfield	982.3	77.8	168.0	213.0	93.7	226.0	294.0
BTL	Bottle Lake	460.5	39.0	84.1	107.0	47.5	110.0	144.0
THE	Tara Hills	1124.2	69.7	149.0	188.0	16.6	36.6	46.8
OUA	Oamaru Aero	292.2	28.7	62.1	79.4	24.5	55.2	70.8
TUA	Timaru Aero	496.2	40.6	87.5	111.0	42.8	95.4	122.0
QNA	Queenstown Aero	314.9	23.3	51.1	65.3	2.1	7.2	10.0
DNA	Dunedin Aero	389.0	29.7	65.0	82.7	14.9	32.6	41.3
TRQ	Traquair	357.9	31.1	67.1	85.3	15.4	32.8	41.1
NVA	Invercargill Aero	128.9	9.2	20.8	26.8	1.5	4.2	5.6
GCE	Gore	174.7	13.7	30.5	38.8	3.7	8.0	10.3
MOA	Manapouri Aero	133.9	10.5	23.0	29.2	1.5	3.7	5.0

NIWA
Taihoro Nukurangi

Table 12. Changes in the average number of days of <u>Very High and Extreme (VH+E) Forest fire danger</u> associated with climate change model scenarios totalled across <u>all months</u>. Positive values indicate an increase, and negative values a decrease. Values statistically significant at the 90% level are highlighted in **bold**.

Station Code	Station Name	Current	Difference (Scenario - Current)					
			CSIRO(L)	CSIRO(M)	CSIRO(H)	Hadley(L)	Hadley(M)	Hadley(H)
DAR	Dargaville	1.7	0.40	0.96	1.12	0.48	1.00	1.20
WRA	Whangarei Aero	3.8	0.75	1.42	2.17	0.83	2.00	2.83
PTU	Pouto	6.0	0.82	2.73	3.64	0.82	2.91	3.64
AKL	Auckland Aero	7.4	1.19	3.08	4.16	1.11	3.05	4.16
HNA	Hamilton Aero	2.3	0.39	1.15	1.54	0.31	0.77	1.46
WTA	Whitianga Aero	2.2	0.50	1.08	1.50	0.42	1.17	1.58
PAX	Paeroa	2.2	0.39	1.00	1.15	0.39	0.92	1.31
ATH	Athol	0.1	0.00	0.00	0.00	0.00	0.00	0.00
ROA	Rotorua Aero	2.0	0.44	1.23	1.54	0.49	1.26	2.00
TGA	Tauranga Aero	7.6	1.45	3.18	3.94	1.76	3.79	4.67
APA	Taupo Aero	2.2	0.68	1.20	1.72	0.64	1.20	1.60
TPE	Te Puke	0.3	0.08	0.23	0.23	0.15	0.31	0.31
WKA	Whakatane Aero	10.8	1.92	3.83	5.25	1.83	4.58	7.17
TTA	Toatoa	0.0	0.00	0.09	0.09	0.00	0.09	0.09
MTE	Matea	2.8	0.36	0.64	0.82	0.36	0.64	0.91
GDE	Goudies	3.1	0.55	1.27	1.82	0.64	1.64	2.09
GSA	Gisborne Aero	31.3	3.88	8.61	11.40	7.05	**18.20**	**25.00**
NRA	Napier Aero	29.2	3.00	7.46	9.31	6.62	17.90	**24.20**
NPA	New Plymouth Aero	1.4	0.36	0.71	0.93	0.25	0.54	0.71
WUA	Wanganui Aero	3.1	0.80	1.88	2.16	0.68	1.64	2.20
RUX	Waiouru Aero	0.6	0.08	0.15	0.23	0.08	0.15	0.23
LNX	Levin	1.5	0.23	0.77	1.31	0.15	0.54	0.92
NTA	Ngamatea	9.5	1.27	3.00	3.73	1.91	4.64	5.91
MSX	East Taratahi	12.9	1.54	3.31	3.85	2.00	4.23	6.38
CPX	Castle Point	16.5	2.38	4.46	6.15	4.08	10.10	16.20
NMU	Ngaumu	14.9	2.36	4.36	5.55	3.00	6.45	8.55
WNA	Wellington Aero	26.8	2.77	6.23	**7.98**	3.00	6.84	**9.07**
PPA	Paraparaumu	3.3	0.95	2.00	2.61	0.71	1.68	2.10
NSA	Nelson Aero	10.0	2.20	4.61	5.54	2.15	4.59	**5.85**
TNI	Totaranui	0.4	0.09	0.18	0.55	0.09	0.27	0.46
HIR	Hira	4.6	0.91	2.27	2.82	0.73	2.27	2.64
DOV	Dovedale	1.3	0.55	1.00	1.55	0.55	0.91	1.27
KIX	Kaikoura	5.2	0.87	2.13	2.74	1.49	**4.18**	**6.26**
KHD	Keneperu Head	1.8	0.27	0.55	0.64	0.27	0.36	0.73
OSN	Opua Bay	1.8	0.55	1.18	1.64	0.27	0.91	1.36
WBA	Woodbourne Aero	44.8	4.50	9.25	10.70	5.08	10.10	12.10
HKA	Hokitika Aero	0.0	0.00	0.00	0.00	0.00	0.00	0.00
WSA	Westport	0.0	0.00	0.06	0.06	0.00	0.00	0.00
HTX	Haast	0.0	0.00	0.00	0.00	0.00	0.00	0.00
CHA	Christchurch Aero	39.6	3.49	8.28	**10.70**	5.44	**13.00**	**16.80**
SDN	Snowdon	12.4	1.64	3.09	3.45	1.64	3.09	4.27
FPL	Darfield	29.0	2.73	5.27	6.82	3.55	9.36	12.20
BTL	Bottle Lake	10.5	1.36	3.55	4.64	1.55	5.27	6.64
THE	Tara Hills	36.8	1.31	4.31	5.31	0.00	0.23	-0.08
OUA	Oamaru Aero	5.8	0.54	1.69	2.00	0.46	1.31	1.77
TUA	Timaru Aero	13.6	1.42	3.83	4.92	1.75	4.17	5.42
QNA	Queenstown Aero	5.8	0.80	1.68	2.40	0.00	0.16	0.32
DNA	Dunedin Aero	7.1	1.12	2.55	3.20	0.65	1.07	1.50
TRQ	Traquair	5.1	1.27	2.45	3.18	0.46	1.18	1.45
NVA	Invercargill Aero	0.4	0.14	0.16	0.16	0.02	0.07	0.09
GCE	Gore	1.9	0.15	0.31	0.31	0.08	0.08	0.08
MOA	Manapouri Aero	1.5	0.15	0.46	0.46	0.08	0.08	0.08

Table 13. Changes in the average number of days of Very High and Extreme (VH+E) Forest fire danger associated with climate change model scenarios totalled across fire season months. Positive values indicate an increase, and negative values a decrease. Values statistically significant at the 90% level are highlighted in **bold**.

Station Code	Station Name	Current	Difference (Scenario - Current)					
			CSIRO(L)	CSIRO(M)	CSIRO(H)	Hadley(L)	Hadley(M)	Hadley(H)
DAR	Dargaville	1.4	0.36	0.84	1.00	0.44	0.88	1.08
WRA	Whangarei Aero	3.4	0.50	1.25	1.92	0.58	1.75	2.67
PTU	Pouto	5.3	0.55	2.18	3.09	0.55	2.36	3.09
AKL	Auckland Aero	7.4	1.22	3.08	4.16	1.14	3.05	4.16
HNA	Hamilton Aero	2.3	0.39	1.15	1.54	0.31	0.77	1.46
WTA	Whitianga Aero	2.2	0.58	1.42	1.92	0.58	1.42	1.92
PAX	Paeroa	2.2	0.39	1.00	1.15	0.39	0.92	1.31
ATH	Athol	0.1	0.00	0.00	0.00	0.00	0.00	0.00
ROA	Rotorua Aero	2.0	0.44	1.23	1.54	0.49	1.26	2.00
TGA	Tauranga Aero	7.5	1.42	3.24	3.97	1.73	3.82	4.70
APA	Taupo Aero	2.1	0.68	1.20	1.72	0.64	1.20	1.60
TPE	Te Puke	0.3	0.08	0.23	0.23	0.15	0.31	0.31
WKA	Whakatane Aero	10.6	1.83	4.17	5.67	1.75	4.92	7.58
TTA	Toatoa	0.0	0.00	0.09	0.09	0.00	0.09	0.09
MTE	Matea	2.8	0.36	0.64	0.82	0.36	0.64	0.91
GDE	Goudies	3.1	0.64	1.36	1.91	0.64	1.73	2.18
GSA	Gisborne Aero	30.4	3.71	8.27	11.00	6.61	**17.10**	**23.40**
NRA	Napier Aero	28.8	3.15	7.85	9.69	6.54	16.50	21.80
NPA	New Plymouth Aero	1.3	0.32	0.68	0.89	0.25	0.50	0.68
WUA	Wanganui Aero	3.0	0.80	1.80	2.12	0.68	1.64	2.16
RUX	Waiouru Aero	0.6	0.08	0.15	0.23	0.08	0.15	0.23
LNX	Levin	1.5	0.23	0.77	1.31	0.15	0.54	0.92
NTA	Ngamatea	9.4	1.36	3.18	3.82	2.00	4.82	6.18
MSX	East Taratahi	12.8	1.46	3.23	3.85	1.85	4.23	6.38
CPX	Castle Point	16.4	2.15	4.08	5.62	3.54	8.69	13.80
NMU	Ngaumu	14.8	2.36	4.36	5.55	3.00	6.45	8.55
WNA	Wellington Aero	26.7	2.74	6.12	**7.84**	2.86	6.65	**8.84**
PPA	Paraparaumu	3.3	0.93	1.98	2.54	0.68	1.66	2.07
NSA	Nelson Aero	9.8	2.22	4.59	5.49	2.20	4.56	5.78
TNI	Totaranui	0.4	0.09	0.18	0.55	0.09	0.18	0.36
HIR	Hira	4.6	0.91	2.27	2.82	0.73	2.27	2.64
DOV	Dovedale	1.3	0.55	1.00	1.55	0.55	0.91	1.27
KIX	Kaikoura	4.9	0.80	1.90	2.46	1.10	3.33	**4.67**
KHD	Keneperu Head	1.8	0.27	0.55	0.64	0.27	0.36	0.73
OSN	Opua Bay	1.8	0.55	1.18	1.73	0.27	0.91	1.36
WBA	Woodbourne Aero	41.8	3.58	7.75	9.33	4.08	8.67	10.80
HKA	Hokitika Aero	0.0	0.00	0.00	0.00	0.00	0.00	0.00
WSA	Westport	0.0	0.00	0.06	0.06	0.00	0.00	0.00
HTX	Haast	0.0	0.00	0.00	0.00	0.00	0.00	0.00
CHA	Christchurch Aero	38.4	3.16	7.60	**9.88**	4.77	**11.50**	**14.80**
SDN	Snowdon	12.4	1.64	3.09	3.55	1.55	3.09	4.45
FPL	Darfield	27.8	2.73	5.00	6.36	3.36	8.18	10.60
BTL	Bottle Lake	10.5	1.36	3.64	4.73	1.55	5.09	6.45
THE	Tara Hills	34.8	1.08	3.77	4.77	0.15	0.39	0.23
OUA	Oamaru Aero	5.2	0.54	1.69	2.08	0.46	1.31	1.69
TUA	Timaru Aero	11.0	1.25	3.08	4.00	1.42	3.50	4.50
QNA	Queenstown Aero	5.7	0.84	1.72	2.48	0.00	0.16	0.32
DNA	Dunedin Aero	6.8	0.98	2.42	3.05	0.58	0.98	1.40
TRQ	Traquair	4.9	1.18	2.18	2.82	0.46	1.09	1.36
NVA	Invercargill Aero	0.4	0.14	0.16	0.19	0.02	0.07	0.09
GCE	Gore	1.9	0.15	0.31	0.31	0.08	0.08	0.08
MOA	Manapouri Aero	1.5	0.15	0.46	0.46	0.08	0.08	0.08

NIWA
Taihoro Nukurangi

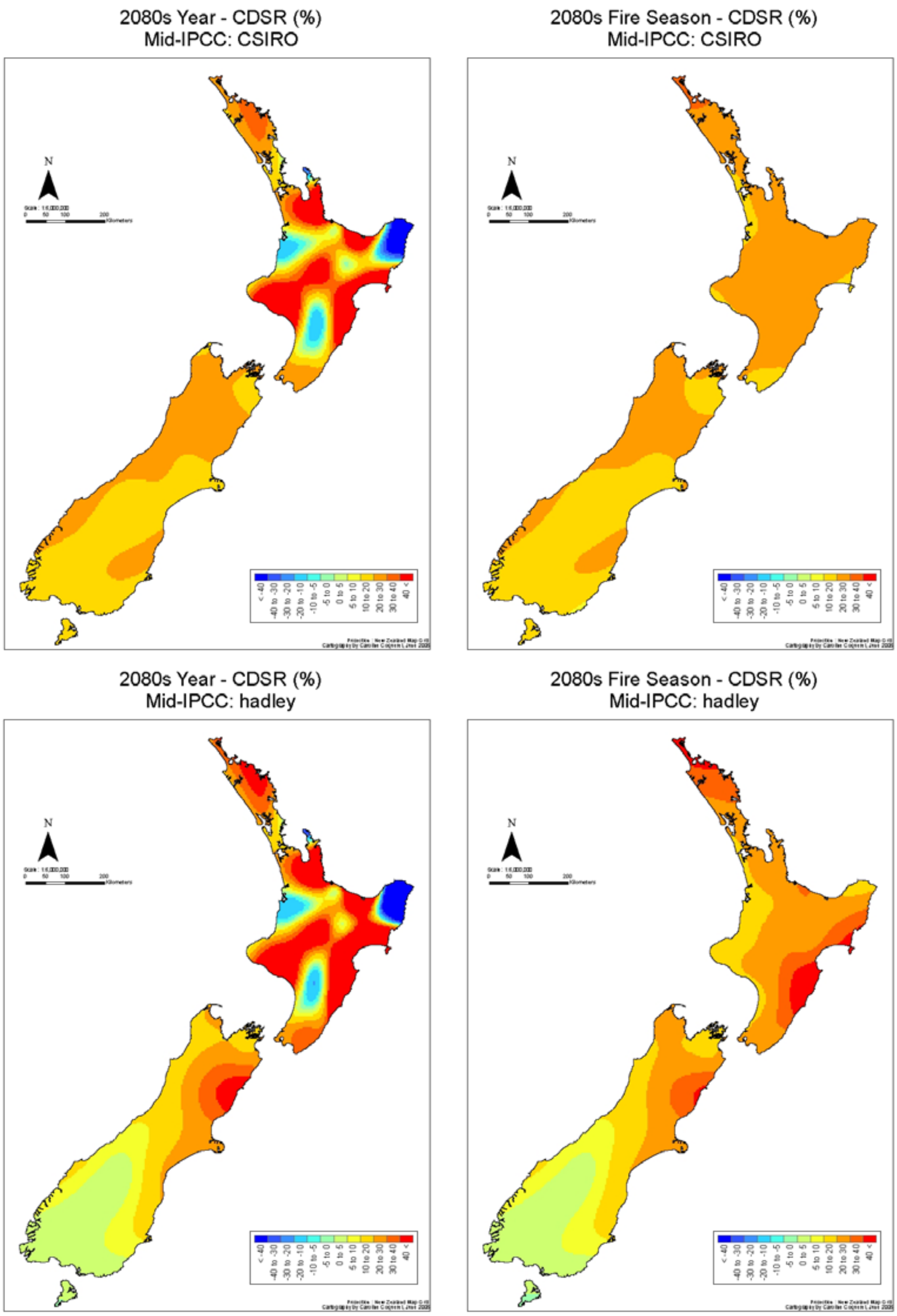

Figure 14. Changes in average Cumulative Daily Severity Rating (CDSR)/Seasonal Severity Rating (SSR) (%) for the full calendar year and fire season months for the CSIRO and Hadley mid-range climate change scenarios.

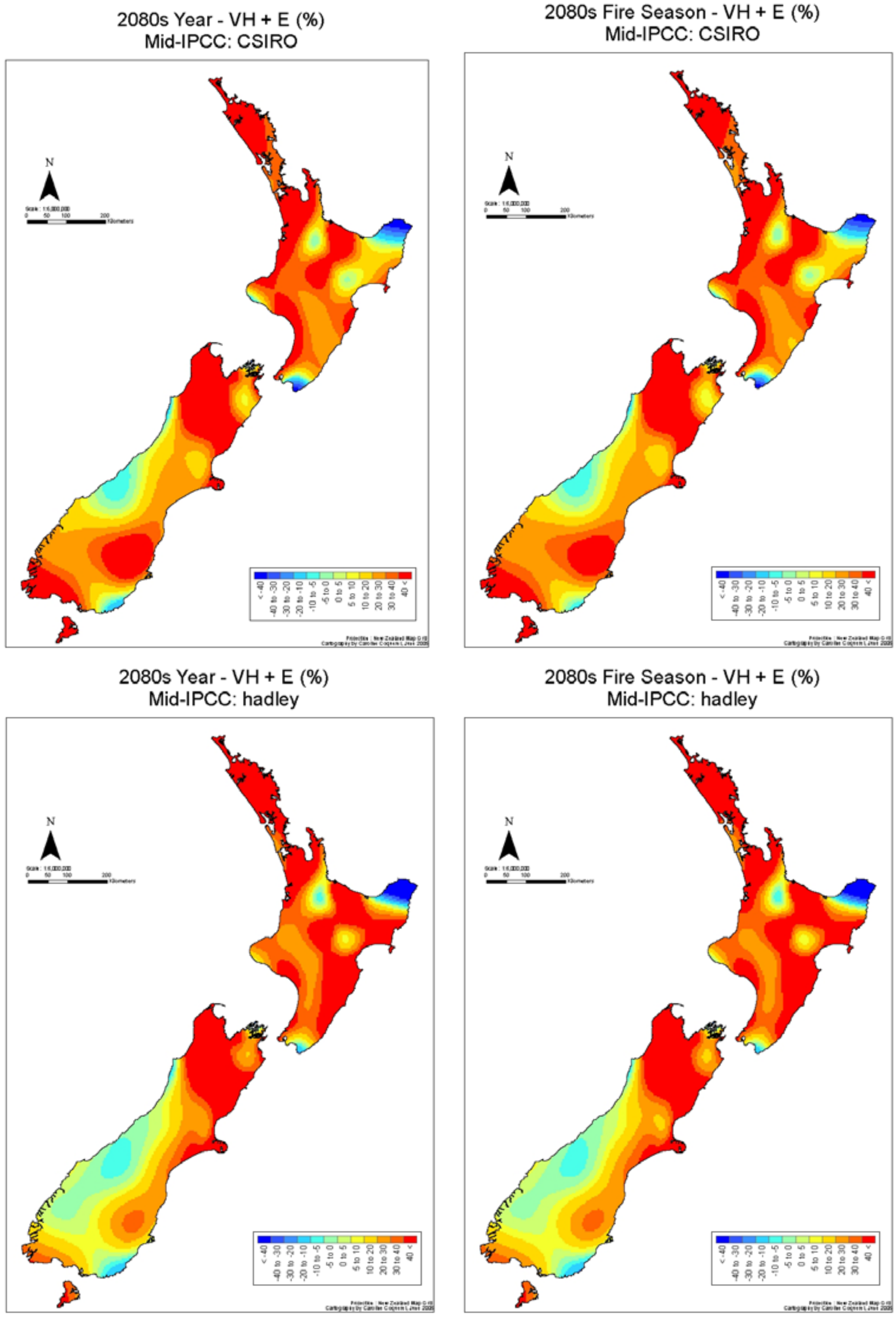

Figure 15. Changes in the average number of days of Very High and Extreme (VH+E) Forest fire danger (%) occurring over the full calendar year versus fire season months for the CSIRO and Hadley mid-range climate change scenarios.

are not practical in New Zealand, as many stations have year-round temperatures above this season end cut-off. However, the original thresholds recommended by Simard *et al*. (1989) (7.2 ºC for both the start and end of the fire season) may have some validity here as evidenced by the example for Gisborne Aero contained in Table 14. When applied to average monthly minimum values (i.e., temperatures are consistently above 7.2 ºC), the current climate reflects the recognised fire season period from October to April. Under all climate change scenarios, use of this threshold results in fire season start dates occurring earlier in August (the September omission is likely the result of a single anomalous temperature value), and end dates extending into May in all but the Hadley low extreme scenario.

Table 14. Changes in fire season length example for Gisborne Aero for climate change model scenarios using temperature thresholds for fire season start and end dates of Simard *et al*. (1989). Shaded cells indicate the fire season period where temperatures consistently exceed 7.2 ºC.

Scenario	Measure	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Season
Current	Mean	22.8	22.5	21.0	18.4	15.8	13.3	12.5	13.5	15.3	17.4	19.3	21.4	**17.7**	20.4
	Max	35.0	37.0	31.8	27.0	25.0	22.0	35.0	30.0	23.2	28.0	32.0	34.0	**37.0**	37.0
	Min	13.0	13.0	11.0	9.0	6.1	3.7	2.0	6.1	1.1	7.7	10.0	10.0	**1.1**	7.7
CSIRO-L	Mean	23.8	23.6	22.1	19.6	16.9	14.4	13.6	14.6	16.4	18.5	20.3	22.4	**18.8**	21.5
	Max	36.1	38.1	32.9	28.2	26.1	23.1	36.1	31.1	24.3	29.1	33.0	35.0	**38.1**	38.1
	Min	14.1	14.1	12.1	10.2	7.2	4.8	3.1	7.2	2.2	8.8	11.0	11.0	**2.2**	8.8
CSIRO-	Mean	25.0	24.8	23.4	20.9	18.2	15.6	14.8	15.8	17.6	19.7	21.5	23.6	**20.0**	22.7
	Max	37.2	39.3	34.2	29.4	27.4	24.3	37.3	32.4	25.5	30.3	34.2	36.2	**39.3**	39.3
	Min	15.2	15.3	13.4	11.4	8.5	6.0	4.3	8.5	3.4	10.0	12.2	12.2	**3.4**	10.0
CSIRO-H	Mean	25.6	25.3	24.0	21.5	18.8	16.1	15.3	16.4	18.2	20.3	22.0	24.1	**20.6**	23.2
	Max	37.8	39.8	34.8	30.0	28.0	24.9	37.8	32.9	26.1	30.8	34.7	36.7	**39.8**	39.8
	Min	15.8	15.8	14.0	12.0	9.1	6.6	4.8	9.0	4.0	10.5	12.7	12.7	**4.0**	10.5
Hadley-L	Mean	23.6	23.4	21.9	19.2	16.7	14.2	13.5	14.4	16.2	18.3	20.1	22.2	**18.6**	21.2
	Max	35.8	37.9	32.7	27.8	25.9	22.9	36.0	31.0	24.1	28.9	32.8	34.8	**37.9**	37.9
	Min	13.8	13.9	11.9	9.8	7.0	4.6	3.0	7.1	2.0	8.6	10.8	10.8	**2.0**	8.6
Hadley-	Mean	24.5	24.3	22.8	20.1	17.6	15.2	14.6	15.5	17.2	19.3	21.0	23.2	**19.6**	22.2
	Max	36.8	38.8	33.6	28.7	26.8	24.0	37.1	32.1	25.1	29.9	33.7	35.8	**38.8**	38.8
	Min	14.8	14.8	12.8	10.7	7.9	5.7	4.1	8.2	3.0	9.6	11.7	11.8	**3.0**	9.6
Hadley-	Mean	25.0	24.8	23.3	20.6	18.1	15.7	15.1	16.1	17.7	19.8	21.4	23.6	**20.1**	22.6
	Max	37.2	39.3	34.0	29.1	27.3	24.4	37.6	32.6	25.6	30.3	34.1	36.2	**39.3**	39.3
	Min	15.2	15.3	13.2	11.1	8.4	6.1	4.6	8.7	3.5	10.0	12.1	12.2	**3.5**	10.0

Another alternative is to base fire season start and end dates on recognised ignition thresholds, derived using FWI relationships for various fuel types (e.g., Lawson *et al*. 1996) or fuel moisture models (e.g., Blackmarr 1972). Within the FWI System, the Fine Fuel Moisture Code (FFMC) reflects the moisture content of fine, flashy litter fuels and can therefore be related to ignition potential (Alexander 1992a). A threshold of FFMC value of 74 (corresponding to a moisture content of approximately 25%) is commonly quoted as the threshold for ignitions in pine forest fuels. Hence this FFMC threshold value could be used to define the fire season period when wildfire ignitions are likely to occur (Table 15). For the example of Gisborne Aero, this method represents the current recognised fire season reasonably well, and shows extension of the fire season to October-April for the majority of the future climate scenarios, and even further out to September-May for the Hadley high extreme scenario.

Table 15. Changes in fire season length example for Gisborne Aero for climate change model scenarios using Fine Fuel Moisture Code (FFMC) thresholds. Shaded cells indicate the fire season period where FFMC consistently exceeds 74, a commonly recognized threshold for ignition within the FWI System (Alexander 1992a).

Scenario	Measure	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Season
Current	Mean	81.2	78.9	76.6	73.8	71.7	66.9	64.7	69.3	73.4	77.2	79.2	79.7	**74.4**	78.1
	Max	94.8	95.7	93.8	91.6	90.0	88.7	97.3	94.6	91.2	93.0	94.6	96.6	**97.3**	96.6
	Min	0.0	7.9	0.0	2.4	1.9	0.8	0.0	0.0	2.1	8.4	11.7	2.5	**0.0**	0.0
CSIRO-L	Mean	81.7	79.4	77.2	74.4	72.3	67.3	64.9	69.6	74.1	78.0	79.8	80.1	**74.9**	78.7
	Median	86.7	85.9	84.6	82.6	80.8	76.0	71.4	77.4	81.9	84.4	85.5	86.2	**83.0**	85.2
	Min	0.0	8.2	0.0	2.4	1.9	0.7	0.0	0.0	2.1	8.7	11.9	2.7	**0.0**	0.0
CSIRO-	Mean	82.2	80.0	77.9	75.0	72.9	67.8	65.3	70.0	74.7	78.8	80.5	80.6	**75.4**	79.3
	Max	95.2	96.2	94.2	92.0	90.4	89.1	97.7	95.2	91.7	93.5	95.1	97.0	**97.7**	97.0
	Min	0.0	8.6	0.0	2.5	2.0	0.6	0.0	0.0	2.2	9.0	12.2	2.8	**0.0**	0.0
CSIRO-H	Mean	82.4	80.3	78.2	75.3	73.2	68.0	65.5	70.2	75.1	79.2	80.8	80.9	**75.7**	79.6
	Max	95.3	96.3	94.3	92.2	90.5	89.2	97.8	95.3	91.8	93.6	95.2	97.1	**97.8**	97.1
	Min	0.0	8.8	0.0	2.5	2.0	0.6	0.0	0.0	2.2	9.2	12.3	2.9	**0.0**	0.0
Hadley-L	Mean	81.8	79.5	77.2	74.8	72.8	68.1	66.0	71.0	75.0	78.7	80.1	80.4	**75.4**	78.9
	Max	95.0	95.9	93.9	91.8	90.1	88.9	97.5	95.1	91.5	93.2	94.8	96.8	**97.5**	96.8
	Min	0.0	8.8	0.0	3.0	2.5	1.1	0.0	0.0	3.6	9.3	12.6	3.4	**0.0**	0.0
Hadley-	Mean	82.4	80.1	77.9	75.8	74.0	69.5	67.4	73.0	77.1	80.5	81.2	81.4	**76.7**	79.9
	Max	95.1	96.1	94.1	91.9	90.3	89.0	97.7	95.4	91.7	93.4	95.0	96.9	**97.7**	96.9
	Min	0.2	10.0	0.0	4.0	3.3	1.6	0.0	0.0	6.4	11.1	14.2	4.9	**0.0**	0.0
Hadley-	Mean	82.7	80.5	78.3	76.4	74.6	70.2	68.1	74.0	78.2	81.6	81.8	81.8	**77.3**	80.5
	Max	95.2	96.2	94.2	92.0	90.4	89.1	97.8	95.5	91.7	93.5	95.0	97.0	**97.8**	97.0
	Min	0.4	10.7	0.0	4.6	3.7	1.9	0.0	0.0	8.7	12.8	15.3	5.9	**0.0**	0.0

Fire weather severity measures such as the FWI System's severity ratings (i.e., Daily Severity Rating (DSR), Monthly Severity Rating (MSR), Seasonal Severity Rating (SSR), and Cumulative Daily Severity Rating (CDSR); after Harvey *et al*. 1986) and fire danger class criteria (i.e., days of VH+E fire danger) could also be utilised to define fire season start and end dates, as these measures describe the periods with greater likelihood of increased fire activity (given other factors such as fuels and ignitions, etc. being equal). Stocks *et al*. (1998) have identified MSR (or SSR) frequency distributions relating to fire potential, in which values above 7 represent extreme fire behaviour potential, values between 3 and 7 constitute high to very high potential, values 1-3 moderate fire potential, and values <1 equate to low fire potential. Hence, the use of these first and second MSR classes may also adequately describe fire season length (Table 16).

A similar approach could be adopted using the average number of days in the Very High (VH) and/or Extreme (E) Forest fire danger class(es); for example, based on the average number of days exceeding 1.0, either just for the Extreme class or in combination with the Very High (VH) class (i.e., VH+E). In the case of the Gisborne Aero example (Table 17), this method is much less discriminating than the MSR method, and only the Hadley high extreme scenario results in a change in fire season length. However, to date all the approaches have only been tested on the one set of station summary data, and considerably more investigation is required before the most appropriate method can be defined and the effect of climate change on fire season length properly tested.

Table 16. Changes in fire season length example for Gisborne Aero for climate change model scenarios using Monthly Severity Rating (MSR) thresholds. Shaded cells indicate the fire season period where MSRs consistently exceed 7.0 (and/or 3.0), thresholds identified for extreme fire behaviour potential (after Stocks *et al*. 1998).

Scenario	Measure	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Season
Current	Mean	6.7	5.4	3.3	1.9	1.0	0.3	0.2	0.4	1.0	2.4	4.3	5.5	**2.7**	4.2
	Max	23.3	18.1	20.5	13.3	4.4	1.3	0.8	1.8	4.5	10.5	13.8	17.3	**23.3**	23.3
	Min	0.7	0.6	0.2	0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.7	0.7	**0.0**	0.1
CSIRO-L	Mean	7.2	5.8	3.6	2.1	1.1	0.3	0.2	0.5	1.1	2.7	4.8	6.0	**3.0**	4.6
	Max	24.6	19.1	21.4	14.0	4.8	1.4	0.9	1.9	5.0	11.6	15.1	18.6	**24.6**	24.6
	Min	0.8	0.7	0.2	0.2	0.1	0.0	0.0	0.0	0.1	0.3	0.9	0.8	**0.0**	0.2
CSIRO-	Mean	7.9	6.4	3.9	2.3	1.2	0.4	0.2	0.5	1.2	3.1	5.4	6.6	**3.3**	5.1
	Max	26.0	20.3	22.5	14.7	5.1	1.6	0.9	2.1	5.6	12.9	16.7	20.1	**26.0**	26.0
	Min	0.9	0.8	0.3	0.2	0.1	0.0	0.0	0.0	0.1	0.3	1.0	0.9	**0.0**	0.2
CSIRO-H	Mean	8.2	6.6	4.1	2.4	1.3	0.4	0.2	0.5	1.3	3.3	5.8	6.9	**3.4**	5.3
	Max	26.7	20.9	23.0	15.1	5.3	1.6	1.0	2.2	5.8	13.6	17.5	20.9	**26.7**	26.7
	Min	0.9	0.9	0.3	0.2	0.1	0.0	0.0	0.0	0.1	0.3	1.1	0.9	**0.0**	0.2
Hadley-L	Mean	7.6	6.0	3.6	2.2	1.2	0.4	0.2	0.5	1.3	3.1	5.3	6.4	**3.2**	4.9
	Max	25.0	19.4	21.5	14.0	5.0	1.5	0.9	2.2	5.6	14.1	15.9	19.1	**25.0**	25.0
	Min	0.8	0.7	0.2	0.2	0.1	0.0	0.0	0.0	0.1	0.3	1.0	0.8	**0.0**	0.2
Hadley-	Mean	8.7	6.8	4.1	2.5	1.4	0.5	0.3	0.7	1.8	4.3	6.8	7.8	**3.8**	5.8
	Max	28.0	20.8	22.7	14.7	5.8	1.9	1.2	2.8	7.1	18.3	18.8	22.3	**28.0**	28.0
	Min	1.0	0.9	0.3	0.2	0.1	0.0	0.0	0.1	0.1	0.5	1.4	1.0	**0.0**	0.2
Hadley-	Mean	9.4	7.2	4.3	2.7	1.6	0.5	0.3	0.9	2.2	5.2	7.8	8.6	**4.2**	6.5
	Max	29.5	21.6	23.3	15.0	6.2	2.1	1.3	3.3	8.4	20.7	21.0	24.0	**29.5**	29.5
	Min	1.2	1.0	0.3	0.2	0.1	0.0	0.0	0.1	0.2	0.7	1.7	1.2	**0.0**	0.2

5.3 Possible improvements in the analytical methods

5.3.1 Consideration of current and future fire dangers

As noted previously, changes in relative humidity and wind speed – the other key weather inputs required within the FWI System for calculation of fire danger – under future climate change scenarios are not as well understood as those for temperature and rainfall, and were therefore not considered in the present analysis.

In their study of potential changes in Australian fire danger under 2×CO_2 scenarios, Beer *et al*. (1995) found that relative humidity (RH) was the most significant weather parameter in the estimation of mean annual variations in forest fire danger, but noted that the climate models they used tended to produce RH values that were slightly too low so that fire dangers were overestimated. They concluded that RH under an altered climate regime was dependent on the modelled relation between actual and potential evaporation, present RH values and evaporation rate, and on expected changes in wind speed.

Relative humidity changes have not been downscaled for the New Zealand region, but are not expected to change very much, if at all. The suggestion that RH might be a few percentage points lower if future temperatures were 1-2 ºC warmer at noon (particularly in eastern areas as more and stronger westerlies are expected) is not entirely valid, as it cannot simply be assumed that RH will be lower on the basis of temperature being higher because water vapour pressures (or specific humidity) are also expected to increase. Without a range of model projections for guidance, the best approach is probably to assume no change in RH. While marginally lower RH values may have some impact on day-to-day fire dangers in these regions, New Zealand's maritime climate and strong coastal influences are such that any subtle changes in RH would be unlikely to have any significant effect on future fire dangers.

Table 17. Changes in fire season length example for Gisborne Aero for climate change model scenarios using Forest fire danger class thresholds. Shaded cells indicate the fire season period where the average number of days of Very High and Extreme (VH+E) Forest fire danger class frequencies consistently exceed 1.0.

Scenario	Class	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Season
Current	L	6.6	7.6	13.1	15.9	21.0	26.9	29.9	26.8	20.8	13.8	8.7	7.9	**199.0**	72.7
	M	8.8	9.9	11.0	10.5	8.3	3.0	1.1	4.1	8.3	12.3	11.6	10.0	**99.0**	73.1
	H	7.1	4.8	3.7	2.0	1.3	0.1	0.0	0.1	0.8	3.3	5.7	7.0	**36.0**	33.2
	VH	3.7	2.5	1.3	0.6	0.3	0.0	0.0	0.0	0.2	0.9	1.9	2.5	**13.9**	13.4
	E	4.8	3.5	1.8	0.9	0.1	0.0	0.0	0.0	0.0	0.6	2.1	3.5	**17.4**	17.0
CSIRO-L	L	6.0	7.1	12.2	15.1	20.3	26.5	29.7	26.5	20.2	12.8	8.0	7.3	**191.8**	68.0
	M	8.7	9.4	11.3	11.1	8.9	3.4	1.3	4.4	8.5	12.6	11.0	9.5	**100.2**	72.5
	H	6.9	5.3	4.0	2.2	1.4	0.1	0.0	0.1	1.1	3.6	6.1	7.4	**38.0**	34.9
	VH	4.0	2.6	1.4	0.6	0.4	0.0	0.0	0.0	0.2	1.2	2.3	2.6	**15.2**	14.6
	E	5.4	3.9	2.1	1.0	0.1	0.0	0.0	0.0	0.0	0.8	2.5	4.2	**20.0**	19.5
CSIRO-	L	5.6	6.6	11.1	14.4	19.5	26.0	29.5	25.9	19.3	11.8	7.3	6.8	**183.9**	62.9
	M	8.4	9.2	11.7	11.3	9.3	3.9	1.5	4.9	9.1	13.0	10.5	9.2	**102.0**	72.3
	H	6.6	5.3	4.2	2.5	1.6	0.2	0.0	0.2	1.3	3.9	6.5	7.3	**39.5**	35.7
	VH	4.2	2.8	1.5	0.8	0.4	0.0	0.0	0.0	0.2	1.4	2.8	3.1	**17.3**	16.5
	E	6.1	4.3	2.5	1.1	0.1	0.0	0.0	0.0	0.0	1.0	2.9	4.5	**22.5**	22.0
CSIRO-H	L	5.2	6.4	10.6	14.1	19.1	25.7	29.3	25.6	18.9	11.2	6.7	6.7	**179.7**	60.3
	M	8.5	9.0	11.8	11.3	9.6	4.1	1.7	5.2	9.4	13.1	10.6	9.0	**103.1**	72.2
	H	6.4	5.4	4.5	2.6	1.8	0.1	0.0	0.2	1.4	4.0	6.3	7.2	**39.9**	35.8
	VH	4.5	2.9	1.5	0.9	0.4	0.0	0.0	0.0	0.3	1.6	3.1	3.2	**18.4**	17.5
	E	6.5	4.6	2.6	1.1	0.1	0.0	0.0	0.0	0.0	1.0	3.2	4.9	**24.2**	23.6
Hadley-L	L	5.8	6.8	11.9	14.6	19.5	25.7	29.3	25.0	18.3	11.4	7.3	6.7	**182.2**	63.8
	M	8.6	9.5	11.5	11.4	9.4	4.2	1.7	5.8	10.0	13.1	10.9	9.5	**105.7**	73.4
	H	6.7	5.2	3.8	2.2	1.6	0.1	0.0	0.2	1.4	4.1	6.4	7.3	**39.1**	35.3
	VH	4.3	2.7	1.5	0.7	0.4	0.0	0.0	0.0	0.3	1.3	2.6	3.0	**16.8**	15.9
	E	5.7	4.0	2.2	1.1	0.1	0.0	0.0	0.0	0.0	1.1	2.8	4.5	**21.5**	21.0
Hadley-	L	4.7	6.2	10.6	12.9	17.3	24.0	28.1	22.3	14.8	7.6	5.1	5.3	**159.0**	51.8
	M	8.3	8.9	11.7	12.3	10.9	5.7	2.9	8.1	11.7	13.6	9.9	8.4	**112.3**	72.0
	H	6.3	5.5	4.5	2.7	2.1	0.2	0.0	0.6	2.8	5.6	6.9	7.3	**44.6**	38.3
	VH	4.4	2.9	1.5	0.9	0.4	0.0	0.0	0.0	0.5	2.2	3.4	4.2	**20.5**	19.4
	E	7.2	4.7	2.7	1.2	0.3	0.0	0.0	0.0	0.2	2.0	4.7	5.8	**28.8**	28.0
Hadley-	L	4.4	5.6	10.1	12.2	16.2	23.1	27.1	20.5	12.7	5.3	4.2	4.7	**146.2**	46.0
	M	8.1	8.8	11.7	12.6	11.5	6.5	3.8	9.5	12.3	13.6	8.5	7.9	**114.8**	70.1
	H	6.0	5.9	4.7	3.0	2.3	0.4	0.0	1.0	4.0	6.3	7.3	7.3	**48.2**	39.8
	VH	4.3	2.7	1.6	0.9	0.6	0.0	0.0	0.0	0.5	2.9	4.1	4.4	**22.1**	20.7
	E	8.2	5.2	2.9	1.3	0.3	0.0	0.0	0.0	0.5	2.9	5.8	6.8	**33.9**	32.7

There are a number of potential options for modelling RH changes, for example, using mean ambient and dew-point temperatures, and use of water vapour pressure or specific humidity. However, all these approaches require extra GCM data, and a consistent set of data from a group of models that is currently not available but is being considered for future model simulations.

Changes in wind speed have been modelled for the New Zealand context, and global climate models suggest that the mean westerly wind component across New Zealand will increase by about 10% of its current value over the next 50 years, with a mid-range projection of 60% by the 2080s (Wratt *et al*. 2004). Monthly mean pressure data are available from the study of Mullan *et al*. (2001a), and changes in pressure gradients have been scaled to the full IPCC range of Special Report on Emission Scenarios (SRES), in the same way as mean temperature and rainfall. Results are presented in Table 18 (after Wratt *et al*. 2004) for west-east and north-south wind components across central New Zealand. The west-east component is derived from the Auckland to Christchurch pressure difference (positive changes indicate more westerly flow in the mean), and the north-south component from the Hobart to Chatham Island pressure difference (positive changes indicate more southerly flow in the mean).

Table 18. Changes in seasonal and annual westerly and southerly wind components (in km/h), for 1990 to 2020-2040 (the "2030s") and for 1990 to 2070-2099 (the "2080s"), scaled to the full IPCC range of global warming. For comparison, the current climatology (1969-1998) is also given (adapted from Wratt *et al*. 2004).

	Summer	Autumn	Winter	Spring	Annual
Current Climate					
Westerly	10.6	8.2	7.8	15.4	10.5
Southerly	-1.1	2.6	3.1	0.5	1.3
Change by 2030s					
Westerly	-2.2 to +4.3	-0.6 to +7.3	-3.0 to +8.6	-3.5 to +5.1	-0.8 to +5.3
Southerly	-0.3 to +1.9	-0.4 to +2.1	-2.1 to +0.4	-1.1 to +1.9	-0.3 to +1.0
Change by 2080s					
Westerly	+0.0 to +6.6	-2.3 to +13.4	-6.5 to +19.8	-1.0 to +10.0	-0.4 to +12.3
Southerly	-0.6 to +2.1	-1.9 to +0.7	-5.3 to -0.3	+0.3 to +2.8	-1.4 to +1.2

Table 18 shows that under the current climate the means westerlies across New Zealand have a strength of about 10.5 km/h (2.92 m/sec) in the annual mean, and are substantially stronger in spring than any other season. There is weak southerly flow in the annual mean (1.3 km/h or 0.35 m/sec), and in all seasons individually except summer when it is northerly. The future scenarios show a strong bias towards increasing westerly flow, particularly in the annual mean. By the 2080s, there could be almost no change up to more than double the current mean speed of westerly airflow in the annual mean. Changes in the north-south wind component are less clear cut, although there is a bias towards more southerly in summer and more northerly in winter (Wratt *et al*. 2004). These wind changes are partly responsible for the projected weaker warming in summer and greater warming in winter outlined above. Unfortunately,. The above estimates are based on the best current understanding for New Zealand, but are likely to be revised as further research and model results become available.

While these potential changes in wind speed have not been included in this current analysis, due to the difficulty of inferring changes in scalar wind speed from modelled changes in monthly mean pressures, it is likely that they will almost certainly lead to a general increase in fire dangers in the majority of model scenarios. These changes are also likely to be highly variable at individual weather station locations, and could lead to increases in fire danger in some areas and decreases in others; however, the general trend is expected to be a further increase in fire weather severity. Increases in wind speed have two major effects on fire danger. Higher wind speeds result in increased drying through evaporation, and therefore higher FFMC values and subsequent Initial Spread Index (ISI) and Fire Weather Index (FWI) values. Wind speed increases will also directly increase the ISI value, so that increases in ISI, FWI and subsequent fire climate severity measures (e.g., CDSR/SSR values and VH+E fire danger class frequencies) will be two-fold.

5.3.2 Alternative modelling approaches

The present study uses a statistical downscaling technique (Mullan *et al*. 2001a) to "downscale" General Circulation Model (GCM) changes to provide the local detail that is required for impact studies. While this approach is a significant advancement over use of global model outputs, where a region such as New Zealand may be covered by only a very small number of GCM grid points, dynamical downscaling using a Regional Climate Model (RCM) nested within a GCM may provide more spatially accurate information on the influence of topography on local climate (Giorgi 1990, Gordon *et al*. 1996, Wratt *et al*. 2000) and fire danger (Wotton *et al*. 1998, Stocks *et al*. 1998, Flannigan *et al*. 2001). This nested approach has the scientific advantage that it is more firmly based on atmospheric physics; however, it requires substantially more computing power than statistical downscaling (Wratt *et al*. 2000). Some work on regional modelling simulations using the nested RCM approach has been undertaken for New Zealand (e.g., Kidson and Thompson 1997, Renwick *et al*. 1997, 1998), and any further advances in this area should be considered in future studies of changes in fire danger with climate change.

Unlike "equilibrium" climate analyses which assume future climate has reached an equilibrium based on increased CO_2 levels (i.e., a $2\times CO_2$ scenario versus the current $1\times CO_2$ climate), the projected changes in climate used here have been derived using "transient" model runs where CO_2 concentration increases with time (in this case, CO_2 compounds by 1% per year. The analysis is valid for a particular period in time (i.e., the 2080s or 2070-2099). Although this is the 'average' over that 30-year period (the standard for climatological averages), in practice a continuing trend in temperatures and resulting fire danger would be expected, such that circumstances were more extreme at the end point than at the beginning, unless atmospheric CO_2 concentrations were to stabilise about that point in time. While a significant improvement over equilibrium climate analyses, the present study remains a "static" analysis that compares changes under a particular scenario to those under current climate. Stocks *et al*. (1998) note that static analyses such as these, while informative, do not reflect the rate of change in fire climate and fire regimes as greenhouse gas concentrations increase towards the 2×CO_2 level. Rather than just the overall projected change in climate and fire danger for a point (period) in the future, what may be more important is the rate of change and/or point in time when the change becomes significantly different from the present. While this requires definition of critical points in climate or fire danger to be reached, such analyses may offer greater insights into when significant change may be experienced.

Several authors have suggested that more detailed, multiple analyses using transient projections from OAGCMs, in which carbon dioxide concentrations (as well as other greenhouse gases and aerosols) are gradually increased with time in line with projected greenhouse gas growth, are required to address future fire impacts in the most realistic manner (Kurz and Apps 1995, Whetton *et al*. 1996, Stocks *et al*. 1998). Currently, climate change models do not consider the influence of fires themselves in increasing the natural emissions of wildfires to the atmosphere CO_2 (Auclair and Carter 1993, Amiro *et al*. 2001a,b) and reducing forest cover and global carbon storage (Kasischke *et al*. 1995, Flannigan *et al*. 1998a, 2000, 2001), and therefore exacerbating the rate of global warming and climate change. It remains to be seen whether these feedbacks will ever entirely be included within global models. The results of incorporating such links on the global scale circulation and climate may be almost invisible, whereas effects at the regional scale can be enormous, so that it could be more efficient to include these feedbacks within higher resolution regional models. Models do exist that look at the entire carbon cycle, and there are plans to link these interactively with global climate models that contain realistic land-surface interactions. At present, computer processing speed is again the main limiting factor to including such interactions. In the future, models will need to include these direct and indirect feedbacks from wildfire to more accurately predict future fire climate and associated impacts.

5.4 Future implications for fire management

Many studies have reported that the increased severity of future fire weather will result in increases in the number of fires and area burned, and greater fire suppression costs and risk to life and property as the population continues to grow and expand into rural environments. Fire management will therefore need to adapt if it is meet environmental, social and economic goals in the future.

Forest fire activity is related to FWI, and Harrington *et al*. (1983) correlated FWI System components to area burned. Under future climate change, increases in FWI would therefore be expected to correlate with increases in area burned, and they predicted significant increases in area burned by wildfires in Manitoba, eastern Saskatchewan and northwestern Ontario, but decreases in Quebec and northern

Ontario due to lower fire weather severity. These relationships were subsequently updated by Flannigan and Van Wagner (1991), who predicted a >40% increase in burned area resulting from SSR increases of 46%. Flannigan and Harrington (1988) found that the monthly provincial area burned across Canada was strongly influenced by long sequences of days without rain (<1.5 mm), confirming the widely held principle that the sequence of precipitation events is more important in explaining burned area than the cumulative precipitation amount. De Groot *et al*. (2003) examined different fire management strategies for adapting to future fire regimes in Canada. They investigated effects of climate change on future area burned estimates, fire suppression costs and wildfire losses, and proposed a number of possible fire management scenarios based on different levels of fire suppression capability coupled with economic, social and environmental values. They also provided an indication of likely future impacts at the national level. De Groot *et al*. (2003) heavily utilised previous work by Flannigan *et al*. (in review) who had used a combination of GCM and RCM outputs to illustrate changes in SSR and derive resulting projections of area burned.

Results from this study indicate that under future fire climate New Zealand is likely to experience more severe fire weather and fire danger. As suggested overseas, this will result in increased fire risk including:

- longer fire seasons and increased drought frequency, and associated increases in fuel drying;
- easier ignition, and therefore a greater number of fires;
- drier and windier conditions, resulting in faster fire spread, greater areas burned, and increased fire suppression costs and damages;
- greater fuel availability and increased fire intensities, increased resource requirements and more difficult fire suppression;
- increased frequency of thunderstorms and lightning.

It is possible that some of this risk might be offset by increased rainfall, including greater rain amounts and more frequent rainfall events. There is also an increased likelihood of extreme rain events, including fire season-ending rain events of significant magnitude.

The international studies mentioned above were only made possible by the availability of high quality data on current and historical fire occurrence, area burned, fire suppression costs and wildfire losses/damages. No such national fire statistics are available for New Zealand and, until they are, similar analyses cannot be undertaken (e.g., Pearce 1998). However, indications of possible future fire behaviour and suppression requirements associated with climate change will enable New Zealand rural fire authorities to make more informed fire management decisions on fire prevention and preparedness activities now and in the future.

6. Conclusions

The effects of future climate change on fire danger have been investigated using two contrasting General Circulation Model (GCM) scenarios for New Zealand. Mean monthly temperature and rainfall offsets for the 2080s obtained by NIWA through statistically downscaling of the CSIRO and Hadley climate change models were applied to updated long-term weather records for 52 climate stations contained in the fire danger climatology database. The stations were selected on the basis of having 11 or more unbroken calendar years of data (i.e., 10 complete fire seasons) to 31 December 2004, including a fairly representative period of climate, and afforded good spatial coverage across the country. Summary statistics of weather inputs, FWI System components and fire danger class frequencies were calculated for each station for high, low, and mid-range scenarios of climate change for each model. These included mean values of temperature, rainfall, FFMC, BUI, CDSR, and the number of days of Very High plus Extreme (VH+E) Forest fire danger. Annual differences were compared to those for fire season months when most fires are expected to occur. Evidence from these analyses suggests that future fire dangers, and therefore associated fire activity, are likely to increase significantly across much of New Zealand as a result of global warming and associated climate change.

The combination of increased temperatures and decreased rainfall in many parts of the country is likely to result in higher mean values of the majority of FWI System components for fire season months, and winter months in particular. Changes in temperature and rainfall followed the original patterns in offset values for each scenario. Temperature changes of +0.5 to +2.4 ºC were significantly higher than current climate for all but the Hadley low extreme scenario. Rainfall changes were more variable. The Hadley model scenarios resulted in reductions of -15% to -35% (-100 to -330 mm) in annual rainfalls for stations in Northland, Bay of Plenty and eastern parts of both the North and South Islands, and increases of +10% to +25% (+80 to +800 mm) for stations from the West Coast and Southland. Changes in rainfall under the CSIRO scenarios were not significant, apart from a 12% increase (+70 to +80 mm) at Invercargill. Increased FFMC values occurred in most places under both the Hadley and CSIRO high extreme and mid-range scenarios, in particular the Auckland, Bay of Plenty, Gisborne, Wellington and coastal Canterbury areas. However, average changes were small at less than +2 to +3 points (i.e., <4% of current values). Small decreases in FFMC (up to -0.5 points, or -1%) were obtained for some stations in the southern South Island under the Hadley model. Similarly, significant increases in BUI (up to +20 points, or +60%) were found from the Bay of Plenty and central (Wellington/Nelson) regions under both the Hadley and CSIRO model scenarios, while stations in north and east of the North Island and east of the South Island increased significantly under only the Hadley model scenarios. Stations in the west and south showed increases solely under the CSIRO model, as a result of drier winters and wetter springs in the south and west under this model.

Seasonal severity and fire season length were also found likely to increase under future fire climate. Significantly higher CDSR values and more days of VH+E Forest fire danger were found for stations in the east of both islands, the Bay of Plenty and central (Wellington/Nelson) regions under both the Hadley and CSIRO high extreme and mid-range scenarios. In several cases (e.g., Gisborne, Napier and Christchurch Airports), average CDSR values increased by more than 300-580 points (25-65%), and the total number of days of VH+E Forest fire danger by more than 20 days (>50%). Smaller, but still statistically significant, increases in CDSR (10-110 points, or 15-25%) were found under the CSIRO high extreme scenario for stations in the west of both islands and south of the South Island. Several stations (typically those in the south and west with low or no existing fire danger) showed little or no change in CDSR or VH+E Forest fire danger but, in one case (Tara Hills under the Hadley high extreme scenario), showed a very slight decrease in VH+E fire danger. Observational evidence from changes in mean monthly temperatures, FFMC and Monthly Severity Rating (MSR) values, and VH+E Forest fire danger class frequencies under the model scenarios indicates that fire season length could well be extended, by both starting earlier and/or finishing later, in many parts of the country. However, no adequate method exists to test this result properly.

In considering changes in fire danger based only on modelled changes in temperature and rainfall, the future climate change scenarios leave out the possible effects of relative humidity (RH) and wind speed, two key inputs into fire danger rating. Wind speed and RH were not included because changes in these elements under future climate change scenarios are not as well understood as those for temperature and rainfall and, in the case of wind speed, not as readily downscalable from GCM outputs. Given New Zealand's maritime climate, any subtle changes in RH are unlikely to have any significant effect on future fire dangers. However, indicative wind speed increases from global climate models almost certainly suggest further increases in future fire dangers. Modelled changes in the mean westerly wind speed component across New Zealand show an increase of about 10% of its current value over the next 50 years, with a mid-range projection of 60% by the 2080s. This will increase the Initial Spread Index (ISI) value directly, and also result in increased drying and therefore higher FFMC values and even higher ISI and FWI values. The general trend is expected to be a further increase in fire weather severity.

Results from this study clearly indicate that New Zealand <u>is</u> likely to experience more severe fire weather and fire danger, especially in the Bay of Plenty, east of both islands and the central (Wellington/Nelson) regions. These increases in fire weather severity will result in increased fire risk, including: longer fire seasons and increased drought frequency, and associated increases in fuel drying; easier ignition, and therefore a greater number of fires; drier and windier conditions, resulting in faster fire spread, greater areas burned, and increased fire suppression costs and damages; greater fuel availability and increased fire intensities, meaning more prolonged mop-up, increased resource requirements and more difficult fire suppression; and increased frequency of thunderstorms and lightning. It is possible that some of this risk might be offset by increased rainfall in some parts of the country (e.g., the southern South Island). These indications of possible increases in future fire activity and subsequent fire suppression requirements associated with climate change highlighted within this study enable New Zealand rural fire authorities to start considering strategies to manage this increased fire risk, and to begin making more informed fire management decisions on fire prevention and preparedness activities now and in the future.

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Appendices

Appendix 1. Climate change off sets for temperature and precipitation

(a) Temperature offsets (ºC) for:
(i) Mid-IPCC Changes (ºC) to 2080s for CSIRO model: Temperature.
(ii) Mid-IPCC Changes (ºC) to 2080s for Hadley model: Temperature.

(b) Precipitation offsets (%) for:
(i) Mid-IPCC Changes (%) to 2080s for CSIRO model: Precipitation.

Mid-IPCC Changes (%) to 2080s for Hadley model: Precipitation.

Appendix 1(a). Temperature Offsets.

(i) Mid-IPCC Changes (ºC) to 2080s for CSIRO model: Temperature.

(Multiply by 0.476 and 1.255 to get IPCC low and high extremes, respectively).

Site	Lat(S)	Lon	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Auckland Aero	37	174.8	2.23	2.26	2.33	2.41	2.39	2.26	2.23	2.26	2.19	2.13	2.09	2.22
Taupo Aero	38.73	176.07	2.23	2.28	2.35	2.43	2.39	2.26	2.24	2.27	2.22	2.15	2.11	2.21
Aupouri Penins	34.7	173.02	2.19	2.22	2.3	2.41	2.37	2.27	2.23	2.24	2.11	2.04	2.03	2.19
Ashburton Plain	43.9	171.75	2.14	2.25	2.32	2.28	2.21	2.03	2.01	2.06	2.19	2.18	2.09	2.07
Ashley	43.17	172.51	2.17	2.27	2.34	2.3	2.24	2.04	2.03	2.08	2.22	2.19	2.11	2.09
Athol	38.25	175.23	2.25	2.28	2.33	2.45	2.42	2.32	2.29	2.31	2.16	2.04	2.03	2.23
Awhitu	37.97	175.58	2.24	2.27	2.34	2.44	2.41	2.31	2.28	2.3	2.17	2.07	2.05	2.22
Awatere Valley	41.65	174.07	2.19	2.28	2.38	2.36	2.31	2.17	2.17	2.23	2.31	2.25	2.17	2.12
Belmont	41.18	174.89	2.19	2.27	2.34	2.38	2.34	2.21	2.2	2.22	2.23	2.16	2.11	2.15
Bendigo	44.93	169.03	2.1	2.21	2.21	2.25	2.18	2.01	1.99	1.95	1.91	1.84	1.85	2.06
Balmoral	42.86	172.75	2.18	2.27	2.35	2.31	2.26	2.05	2	2.04	2.2	2.2	2.11	2.09
Blackmount	45.77	167.68	2.08	2.19	2.21	2.22	2.13	1.98	1.97	1.93	1.91	1.85	1.86	2.02
Bodley Road	38.4	175.23	2.25	2.27	2.32	2.45	2.42	2.32	2.29	2.3	2.15	2.03	2.02	2.23
Big Pokororo	41.17	172.25	2.18	2.22	2.23	2.42	2.41	2.33	2.29	2.26	2.07	1.93	1.92	2.18
Bridge Pa	39.65	176.77	2.23	2.28	2.4	2.43	2.4	2.29	2.26	2.34	2.35	2.29	2.2	2.17
Bottle Lake	43.47	172.68	2.15	2.25	2.34	2.29	2.22	2.09	2.1	2.16	2.27	2.23	2.14	2.07
Burnham	43.62	172.75	2.15	2.25	2.33	2.28	2.21	2.06	2.08	2.14	2.28	2.24	2.15	2.07
Cannington	44.36	170.94	2.12	2.22	2.28	2.25	2.19	2.01	1.95	1.98	2.15	2.18	2.11	2.05
Cat Creeki	41.52	173.48	2.19	2.25	2.33	2.38	2.34	2.25	2.24	2.27	2.25	2.15	2.1	2.13
Cornwallis Depo	37	174.6	2.23	2.26	2.33	2.41	2.39	2.27	2.23	2.26	2.19	2.13	2.1	2.22
Christchurch Aer	43.48	172.53	2.15	2.25	2.34	2.29	2.22	2.08	2.09	2.15	2.26	2.22	2.13	2.06
Clevedon Coast	36.92	175.01	2.23	2.26	2.33	2.42	2.39	2.27	2.23	2.26	2.19	2.13	2.1	2.22
Clyde	45.2	169.32	2.11	2.23	2.25	2.23	2.15	1.9	1.82	1.8	1.92	1.95	1.93	2.05
Cape Colville	36.48	175.33	2.21	2.24	2.32	2.41	2.39	2.27	2.22	2.26	2.24	2.2	2.16	2.21
Castle Point	40.9	176.2	2.22	2.28	2.39	2.39	2.34	2.21	2.2	2.25	2.29	2.22	2.15	2.14
Cricklewood	38.97	177.15	2.24	2.29	2.41	2.42	2.37	2.25	2.23	2.31	2.34	2.29	2.2	2.18
Crownthorpe	39.58	176.57	2.23	2.29	2.4	2.42	2.38	2.25	2.22	2.3	2.35	2.31	2.22	2.18
Glenledi	46.18	170.07	2.08	2.19	2.22	2.2	2.1	1.98	1.98	2	2.03	1.99	1.96	2.02
Dargaville	35.96	173.84	2.22	2.25	2.33	2.39	2.37	2.23	2.17	2.2	2.17	2.15	2.12	2.21
Dunedin Aero	45.92	170.18	2.09	2.21	2.24	2.21	2.1	1.96	1.95	1.97	2.03	2.01	1.98	2.02
Dansey Pass	45.03	170.27	2.13	2.23	2.27	2.24	2.15	1.95	1.93	1.95	2.02	2.01	1.97	2.05
Dovedale	41.34	172.99	2.18	2.24	2.3	2.39	2.37	2.27	2.23	2.23	2.2	2.11	2.08	2.15
Deep Stream	45.73	169.85	2.11	2.22	2.25	2.23	2.12	1.97	1.99	2	1.98	1.91	1.9	2.04
Dargaville	35.95	173.83	2.22	2.25	2.33	2.39	2.37	2.23	2.17	2.2	2.17	2.15	2.12	2.21
Eltham	39.46	174.3	2.24	2.29	2.35	2.43	2.4	2.26	2.2	2.23	2.21	2.15	2.12	2.21
Darfield	43.49	172.15	2.16	2.27	2.35	2.29	2.22	2.04	2.03	2.08	2.21	2.18	2.1	2.07
Galatea	38.34	176.79	2.23	2.27	2.35	2.44	2.4	2.33	2.34	2.38	2.25	2.12	2.08	2.2
Great Barrier Is	36.25	175.47	2.21	2.24	2.32	2.41	2.38	2.27	2.23	2.26	2.23	2.18	2.14	2.21
Gore	46.1	168.88	2.09	2.21	2.23	2.21	2.11	1.95	1.95	1.94	1.93	1.88	1.87	2.02
Goudies	0	0	******	******	******	******	******	******	******	******	******	******	******	******
Glendhu	45.75	169.72	2.11	2.22	2.24	2.23	2.12	1.97	2	2	1.96	1.88	1.87	2.04
Gisborne Aero	38.65	177.98	2.23	2.27	2.38	2.42	2.38	2.29	2.27	2.35	2.33	2.27	2.19	2.18
Gwavas	39.73	176.44	2.24	2.29	2.4	2.42	2.38	2.25	2.22	2.29	2.32	2.27	2.19	2.18
Hanmer	42.54	172.85	2.17	2.27	2.33	2.34	2.28	2.12	2.13	2.16	2.2	2.12	2.05	2.1
Haurangi	41.44	175.26	2.2	2.28	2.37	2.38	2.32	2.22	2.24	2.3	2.3	2.2	2.14	2.14

Hira	41.28	173.34	2.17	2.23	2.3	2.39	2.36	2.27	2.25	2.26	2.24	2.16	2.1	2.15
Hicks Bay	37.56	178.29	2.21	2.25	2.35	2.42	2.39	2.31	2.31	2.36	2.3	2.21	2.15	2.19
Hokitika Aero	42.7	170.98	2.12	2.19	2.21	2.38	2.37	2.32	2.3	2.24	2.02	1.85	1.85	2.1
Hamilton Aero	37.85	175.33	2.24	2.27	2.33	2.43	2.4	2.29	2.26	2.29	2.18	2.08	2.06	2.23
Hunua East	37.21	175.29	2.24	2.27	2.33	2.41	2.38	2.24	2.19	2.22	2.17	2.13	2.09	2.23
Hunua West	37.07	175.07	2.23	2.27	2.32	2.41	2.39	2.26	2.22	2.25	2.17	2.11	2.08	2.23
Hokianga	35.49	173.38	2.21	2.23	2.31	2.41	2.38	2.27	2.23	2.25	2.14	2.08	2.07	2.2
Haast	43.85	169	2.1	2.17	2.21	2.35	2.31	2.32	2.33	2.28	2	1.81	1.82	2.05
Havelock North	39.65	176.87	2.23	2.27	2.39	2.44	2.41	2.31	2.28	2.35	2.34	2.28	2.19	2.17
Holdsworth Stn	40.9	175.53	2.23	2.29	2.36	2.41	2.36	2.24	2.24	2.28	2.22	2.12	2.07	2.17
Invermay	45.85	170.38	2.09	2.21	2.25	2.21	2.11	1.98	1.98	2	2.07	2.04	2	2.03
Kaipara	36.49	174.23	2.23	2.26	2.34	2.41	2.38	2.26	2.22	2.25	2.19	2.15	2.12	2.22
Kawerau	38.04	176.44	2.22	2.26	2.34	2.44	2.4	2.33	2.33	2.36	2.25	2.13	2.1	2.21
Keneperu Head	41.17	174.12	2.2	2.26	2.34	2.39	2.35	2.25	2.24	2.27	2.26	2.16	2.11	2.15
Kaikoura	42.42	173.68	2.18	2.28	2.38	2.32	2.26	2.07	2.05	2.11	2.28	2.28	2.18	2.09
Kaikohe	35.42	173.82	2.21	2.24	2.33	2.41	2.37	2.26	2.22	2.26	2.16	2.1	2.07	2.19
Kaitoke	41.09	175.18	2.21	2.28	2.35	2.4	2.35	2.24	2.23	2.26	2.23	2.13	2.08	2.16
Kaiwaka	39.28	176.87	2.23	2.29	2.41	2.41	2.37	2.24	2.22	2.31	2.36	2.32	2.23	2.18
Kaitaia Observ	35.13	173.25	2.21	2.23	2.31	2.41	2.38	2.29	2.26	2.28	2.14	2.06	2.05	2.19
Lauder	45.03	169.68	2.11	2.24	2.26	2.24	2.15	1.93	1.9	1.9	1.96	1.95	1.91	2.05
Lauder	45.03	169.68	2.11	2.24	2.26	2.24	2.15	1.93	1.9	1.9	1.96	1.95	1.91	2.05
Le Bons Bay	43.73	173.12	2.14	2.25	2.35	2.28	2.19	2.05	2.05	2.13	2.29	2.28	2.16	2.05
Lees Valley	43.12	172.23	2.17	2.26	2.33	2.31	2.25	2.09	2.08	2.12	2.17	2.11	2.04	2.09
Lower Hutt	41.22	174.92	2.2	2.27	2.35	2.39	2.34	2.22	2.22	2.25	2.25	2.16	2.11	2.15
Lismore	39.83	175.2	2.24	2.29	2.37	2.43	2.41	2.25	2.18	2.2	2.18	2.13	2.09	2.2
Levin	40.65	175.27	2.21	2.28	2.34	2.42	2.38	2.26	2.23	2.25	2.2	2.11	2.06	2.18
Lake Taupo For	38.91	175.94	2.23	2.28	2.34	2.43	2.4	2.29	2.26	2.29	2.22	2.13	2.09	2.21
Lumsden	45.75	168.45	2.08	2.21	2.23	2.21	2.11	1.94	1.91	1.89	1.94	1.93	1.91	2.03
Mahurangi	36.42	174.43	2.22	2.25	2.33	2.41	2.38	2.26	2.22	2.25	2.19	2.15	2.12	2.21
Matawaia	35.52	173.91	2.21	2.24	2.33	2.41	2.37	2.25	2.21	2.25	2.17	2.12	2.09	2.2
Mangatu Forest	38.25	177.89	2.24	2.28	2.4	2.42	2.37	2.29	2.29	2.36	2.31	2.22	2.16	2.18
Mahia	39.12	177.95	2.22	2.27	2.39	2.42	2.38	2.28	2.25	2.34	2.36	2.31	2.21	2.18
Minginui	38.63	176.68	2.23	2.28	2.36	2.43	2.39	2.3	2.3	2.35	2.26	2.15	2.1	2.2
Molesworth	42.08	173.25	2.18	2.25	2.31	2.36	2.31	2.24	2.3	2.32	2.22	2.05	2	2.12
Manapouri Aero	45.53	167.63	2.08	2.2	2.21	2.23	2.14	2.02	2.02	1.99	1.94	1.86	1.86	2.03
Molesworth	42.08	173.25	2.18	2.25	2.31	2.36	2.31	2.24	2.3	2.32	2.22	2.05	2	2.12
Barn Hill	45.71	168.25	2.08	2.21	2.22	2.21	2.12	1.94	1.92	1.9	1.93	1.91	1.9	2.03
East Taratahi	41	175.62	2.23	2.3	2.4	2.39	2.33	2.22	2.23	2.29	2.28	2.2	2.14	2.15
Mount Benger	45.58	169.25	2.11	2.22	2.24	2.23	2.14	1.96	1.96	1.94	1.93	1.87	1.87	2.04
Mount Cook	43.73	170.08	2.13	2.21	2.19	2.31	2.26	2.13	2.16	2.1	1.91	1.74	1.77	2.1
Matea	38.78	176.41	2.24	2.28	2.36	2.43	2.39	2.28	2.27	2.32	2.25	2.16	2.11	2.2
Motukarara	43.72	172.59	2.15	2.24	2.33	2.28	2.21	2.07	2.07	2.14	2.26	2.22	2.13	2.07
Mount Somers	43.67	171.38	2.14	2.24	2.28	2.28	2.22	2.04	2.02	2.04	2.08	2.04	1.98	2.08
Motu	38.28	177.52	2.24	2.28	2.39	2.43	2.38	2.31	2.33	2.38	2.3	2.19	2.14	2.18
Murchison	41.8	172.33	2.16	2.22	2.22	2.4	2.38	2.28	2.25	2.21	2.03	1.88	1.88	2.16
National Park	39.17	175.42	2.24	2.28	2.34	2.46	2.42	2.35	2.35	2.37	2.17	2.03	2	2.21
Nelson Creek	42.4	171.52	2.14	2.21	2.23	2.37	2.36	2.23	2.19	2.13	2	1.88	1.87	2.11
Ngapaenga	38.35	175.92	2.24	2.28	2.35	2.45	2.41	2.32	2.31	2.33	2.2	2.09	2.06	2.21
Ngaruru	41.7	173.2	2.17	2.24	2.31	2.37	2.34	2.23	2.21	2.23	2.21	2.12	2.07	2.13
Nugget Point	46.47	169.78	2.07	2.18	2.21	2.19	2.1	1.98	2	2.02	2.03	1.97	1.94	2.01
Ngaumu	41.04	175.88	2.22	2.29	2.39	2.39	2.33	2.22	2.23	2.28	2.29	2.2	2.14	2.14
Normanby	39.5	174.25	2.24	2.29	2.36	2.43	2.4	2.23	2.17	2.19	2.21	2.18	2.13	2.21
NewPlymouth Ae	39	174.17	2.23	2.26	2.32	2.44	2.43	2.32	2.27	2.28	2.18	2.09	2.07	2.21
Napier Aero	39.45	176.85	2.22	2.28	2.4	2.42	2.38	2.26	2.22	2.31	2.38	2.35	2.25	2.18
Nelson Aero	41.3	173.22	2.17	2.23	2.3	2.39	2.37	2.27	2.24	2.25	2.24	2.15	2.1	2.15
Ngamatea	39.45	176.2	2.24	2.29	2.37	2.43	2.39	2.3	2.3	2.36	2.28	2.18	2.12	2.2
Invercargill Aero	46.42	168.33	2.08	2.18	2.22	2.19	2.09	1.94	1.93	1.92	1.94	1.92	1.91	2
Ngawihi	41.58	175.23	2.19	2.28	2.38	2.37	2.3	2.22	2.26	2.32	2.35	2.24	2.16	2.12
Ohakea	40.2	175.22	2.22	2.28	2.35	2.43	2.39	2.23	2.17	2.19	2.19	2.14	2.09	2.19
Okato	39.25	173.89	2.22	2.27	2.33	2.44	2.41	2.3	2.26	2.26	2.2	2.12	2.09	2.21
Omataroa	38.1	176.85	2.23	2.27	2.35	2.44	2.4	2.34	2.36	2.4	2.26	2.13	2.09	2.2
Ongaonga	39.92	176.43	2.24	2.29	2.41	2.42	2.38	2.25	2.2	2.27	2.31	2.27	2.19	2.17
Opouteke	35.7	173.81	2.22	2.24	2.33	2.41	2.37	2.25	2.21	2.25	2.17	2.11	2.09	2.2
Opua Bay	41.27	174.21	2.19	2.26	2.34	2.38	2.34	2.21	2.2	2.24	2.27	2.2	2.14	2.14
Oamaru Aero	44.97	171.08	2.1	2.2	2.26	2.22	2.16	1.99	1.93	1.96	2.14	2.18	2.11	2.04
Paeroa	37.35	175.68	2.23	2.27	2.35	2.41	2.38	2.25	2.22	2.26	2.21	2.16	2.11	2.21
Pureroa	35.12	174.02	2.19	2.22	2.31	2.4	2.36	2.26	2.22	2.26	2.18	2.12	2.09	2.19
Pukaki Aero	44.23	170.12	2.1	2.22	2.23	2.25	2.2	2	1.95	1.94	2	1.99	1.95	2.07
Pukekohe	37.2	174.85	2.23	2.26	2.32	2.41	2.39	2.26	2.22	2.24	2.17	2.12	2.08	2.23
Palmerston Nth	40.32	175.6	2.23	2.28	2.35	2.44	2.4	2.28	2.24	2.26	2.18	2.09	2.05	2.19
Paraparaumu	40.9	174.98	2.19	2.27	2.34	2.39	2.35	2.21	2.18	2.2	2.22	2.16	2.11	2.16
Pouto	36.26	174.05	2.23	2.25	2.34	2.41	2.38	2.26	2.21	2.24	2.18	2.14	2.11	2.21
Queenstown Aer	45.02	168.73	2.08	2.2	2.19	2.24	2.17	2.02	1.99	1.95	1.95	1.9	1.89	2.06
Rai Valley	41.21	173.59	2.19	2.25	2.32	2.39	2.36	2.28	2.27	2.29	2.26	2.16	2.11	2.15
Raumai	40.2	175.22	2.22	2.28	2.35	2.43	2.39	2.23	2.17	2.19	2.19	2.14	2.09	2.19
Reefton	42.12	171.87	2.15	2.23	2.23	2.37	2.36	2.19	2.12	2.06	1.95	1.86	1.86	2.14
Rimutaka FP	41.35	174.91	2.19	2.27	2.35	2.37	2.32	2.2	2.21	2.24	2.27	2.19	2.13	2.14
Rotoehu	37.87	176.52	2.22	2.26	2.33	2.43	2.4	2.33	2.33	2.36	2.27	2.16	2.12	2.21
Ruatoria	37.83	178.07	2.24	2.28	2.38	2.42	2.37	2.29	2.31	2.38	2.3	2.2	2.14	2.19

Ranfurly	45.13	170.1	2.13	2.24	2.27	2.23	2.15	1.95	1.91	1.92	1.98	1.97	1.94	2.04
Rock and Pillar	45.39	170.21	2.12	2.23	2.27	2.23	2.13	1.96	1.96	1.98	2.01	1.97	1.94	2.04
Rotorua Aero	38.1	176.32	2.23	2.27	2.34	2.44	2.4	2.33	2.33	2.36	2.24	2.13	2.09	2.21
Rotoaira	38.86	175.6	2.24	2.27	2.33	2.46	2.43	2.37	2.37	2.39	2.18	2.02	2	2.22
Porapora	37.81	178.27	2.22	2.26	2.37	2.42	2.38	2.29	2.29	2.35	2.31	2.24	2.16	2.19
Waiouru Aero	39.47	175.7	2.26	2.29	2.37	2.46	2.41	2.33	2.33	2.37	2.2	2.06	2.02	2.2
Snowdon	43.47	171.67	2.15	2.25	2.31	2.29	2.23	2.06	2.06	2.09	2.14	2.08	2.01	2.08
Slopedown	46.39	169.13	2.09	2.19	2.22	2.21	2.1	1.97	2	2	1.96	1.88	1.87	2.02
Spriggins Park	39.97	175.02	2.23	2.29	2.36	2.43	2.4	2.23	2.15	2.17	2.18	2.15	2.11	2.2
Stony Creek	41.43	175.48	2.21	2.29	2.38	2.38	2.31	2.22	2.26	2.31	2.31	2.2	2.13	2.13
Tahorakuri	38.59	176.16	2.24	2.28	2.36	2.43	2.39	2.28	2.26	2.29	2.22	2.14	2.1	2.2
Te Horo	40.8	175.15	2.2	2.28	2.34	2.4	2.36	2.23	2.19	2.22	2.21	2.15	2.09	2.17
Tekapo	44	170.4	2.11	2.24	2.26	2.27	2.19	2.04	2.07	2.07	2.09	2.01	1.96	2.07
Te Pohue	39.27	176.68	2.23	2.29	2.4	2.42	2.37	2.26	2.26	2.34	2.34	2.27	2.18	2.18
Tauranga Aero	37.67	176.2	2.22	2.25	2.33	2.42	2.4	2.3	2.29	2.32	2.27	2.18	2.14	2.21
Te Haroto	39.16	175.61	2.25	2.27	2.33	2.46	2.43	2.42	2.47	2.5	2.19	1.97	1.95	2.21
Tara Hills	44.52	169.9	2.1	2.22	2.24	2.25	2.17	2.01	2	1.99	2.01	1.97	1.94	2.06
Totaranui	40.83	173	2.18	2.24	2.3	2.41	2.39	2.32	2.3	2.31	2.25	2.14	2.1	2.17
Te Puke	37.82	176.32	2.22	2.26	2.33	2.44	2.41	2.33	2.33	2.37	2.28	2.17	2.12	2.21
Tapanui	45.92	169.24	2.09	2.21	2.23	2.23	2.12	1.99	2	2	1.95	1.88	1.87	2.02
Tapuae	0	0	******	******	******	******	******	******	******	******	******	******	******	******
Traquair	45.81	170.13	2.1	2.22	2.25	2.22	2.12	1.98	1.98	2	2.02	1.97	1.95	2.03
Port Taharoa	38.17	174.7	2.24	2.27	2.34	2.46	2.43	2.33	2.29	2.3	2.13	2.02	2.02	2.21
Toatoa	38.11	177.51	2.24	2.28	2.38	2.43	2.39	2.32	2.34	2.39	2.28	2.17	2.12	2.19
Titahi Bay	41.11	174.83	2.19	2.26	2.33	2.38	2.35	2.21	2.18	2.2	2.22	2.16	2.11	2.15
Timaru Aero	44.3	171.23	2.12	2.22	2.28	2.26	2.2	2.04	1.98	2.02	2.18	2.2	2.12	2.06
Tuatapere	46.09	167.82	2.08	2.19	2.21	2.21	2.11	1.97	1.97	1.95	1.94	1.89	1.89	2.01
Tarawera	38.04	176.44	2.22	2.26	2.34	2.44	2.4	2.33	2.33	2.36	2.25	2.13	2.1	2.21
Waimarino For	39.9	175.19	2.24	2.29	2.36	2.43	2.4	2.24	2.18	2.2	2.18	2.13	2.09	2.2
Waihau	39.39	176.56	2.23	2.29	2.41	2.42	2.37	2.24	2.23	2.31	2.35	2.3	2.21	2.18
Waione	40.46	176.31	2.23	2.29	2.39	2.41	2.37	2.23	2.2	2.25	2.28	2.22	2.15	2.16
Waverly	39.78	176.6	2.24	2.29	2.41	2.42	2.38	2.26	2.23	2.31	2.33	2.29	2.2	2.17
Chatham Island	43.95	176.72	******	******	******	******	******	******	******	******	******	******	******	******
Woodbourne Aer	41.52	173.85	2.19	2.28	2.39	2.36	2.3	2.16	2.16	2.21	2.31	2.26	2.18	2.12
Western Bound	41.53	172.82	2.17	2.23	2.28	2.38	2.37	2.26	2.21	2.2	2.15	2.06	2.03	2.15
Waiouru Camp	39.47	175.68	2.26	2.29	2.37	2.46	2.41	2.33	2.33	2.37	2.2	2.06	2.02	2.2
Woodhill	36.71	174.38	2.23	2.26	2.33	2.41	2.38	2.25	2.21	2.24	2.19	2.15	2.12	2.22
Wanaka	44.72	169.23	2.09	2.21	2.22	2.26	2.18	2	1.96	1.92	1.94	1.9	1.89	2.06
Waitangi Forest	35.28	173.99	2.2	2.23	2.32	2.4	2.37	2.25	2.2	2.24	2.17	2.13	2.1	2.19
Whangamata	37.22	175.79	2.24	2.27	2.35	2.41	2.38	2.25	2.22	2.27	2.25	2.2	2.15	2.22
Waihi Gold	37.42	175.87	2.23	2.27	2.35	2.4	2.38	2.23	2.19	2.24	2.25	2.21	2.16	2.22
Waihau Bay	37.64	177.91	2.22	2.25	2.34	2.42	2.4	2.31	2.29	2.32	2.27	2.19	2.14	2.2
Marco	39.1	174.76	2.25	2.27	2.33	2.45	2.43	2.3	2.25	2.26	2.15	2.06	2.04	2.22
Waihaorunga	44.7	170.77	2.12	2.23	2.28	2.23	2.16	1.96	1.92	1.95	2.11	2.13	2.06	2.05
Whakatane Aero	37.92	176.92	2.22	2.26	2.33	2.43	2.4	2.33	2.33	2.37	2.29	2.18	2.14	2.22
Waikawau Bay	36.77	175.46	2.22	2.25	2.33	2.41	2.38	2.26	2.23	2.27	2.25	2.2	2.16	2.21
Wellington Aero	41.33	174.82	2.19	2.27	2.35	2.37	2.33	2.19	2.17	2.2	2.24	2.19	2.13	2.14
Windsor	45.01	170.82	2.1	2.21	2.26	2.22	2.15	1.98	1.93	1.96	2.13	2.15	2.08	2.04
Waipukurau	40	176.54	2.24	2.29	2.41	2.42	2.38	2.26	2.22	2.29	2.3	2.25	2.17	2.17
Whangarei Aero	35.77	174.37	2.21	2.23	2.32	2.4	2.38	2.25	2.2	2.24	2.19	2.15	2.12	2.2
Wreys Bush	46.03	168.11	2.08	2.2	2.22	2.21	2.11	1.95	1.95	1.93	1.94	1.9	1.89	2.02
Westport	41.73	171.57	2.15	2.2	2.22	2.4	2.4	2.33	2.29	2.24	2.03	1.88	1.88	2.13
Whitianga Aero	36.87	175.67	2.23	2.26	2.35	2.41	2.37	2.27	2.25	2.3	2.27	2.21	2.16	2.21
Waitarere For	40.55	175.2	2.21	2.28	2.34	2.42	2.38	2.23	2.19	2.21	2.21	2.14	2.09	2.18
Wanganui Aero	39.97	175.02	2.23	2.29	2.36	2.43	2.4	2.23	2.15	2.17	2.18	2.15	2.11	2.2

(ii) Mid-IPCC Changes (ºC) to 2080s for Hadley model: Temperature.

(Multiply by 0.476 and 1.255 to get IPCC low and high extremes, respectively).

Site	Lat(S)	Lon	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Auckland Aero	37	174.8	1.77	1.95	1.89	1.79	1.91	2.03	2.19	2.04	1.8	1.68	1.52	1.71
Taupo Aero	38.73	176.07	1.61	1.82	1.79	1.71	1.88	2.03	2.2	2.05	1.81	1.67	1.43	1.56
Aupouri Penins	34.7	173.02	2.03	2.13	2.01	1.88	1.93	1.97	2.08	1.97	1.8	1.74	1.71	1.97
Ashburton Plain	43.9	171.75	1.2	1.37	1.4	1.36	1.65	1.79	1.99	2.01	1.8	1.71	1.23	1.26
Ashley	43.17	172.51	1.28	1.47	1.48	1.44	1.77	1.95	2.19	2.15	1.9	1.75	1.27	1.33
Athol	38.25	175.23	1.56	1.85	1.77	1.65	1.84	2	2.18	1.96	1.68	1.53	1.28	1.47
Awhitu	37.97	175.58	1.64	1.88	1.8	1.69	1.86	2.02	2.2	2	1.72	1.58	1.36	1.56
Awatere Valley	41.65	174.07	1.48	1.6	1.59	1.53	1.79	1.94	2.13	2.1	1.9	1.8	1.46	1.51
Belmont	41.18	174.89	1.4	1.6	1.6	1.53	1.77	1.93	2.11	1.99	1.77	1.63	1.31	1.37
Bendigo	44.93	169.03	0.84	1.18	1.26	1.22	1.54	1.7	1.92	1.65	1.35	1.13	0.73	0.78

Balmoral	42.86	172.75	1.32	1.5	1.5	1.46	1.77	1.95	2.2	2.16	1.91	1.75	1.3	1.36
Blackmount	45.77	167.68	0.82	1.09	1.17	1.12	1.4	1.54	1.71	1.53	1.27	1.11	0.74	0.79
Bodley Road	38.4	175.23	1.54	1.83	1.76	1.63	1.83	1.99	2.18	1.96	1.67	1.52	1.25	1.44
Big Pokororo	41.17	172.25	1.13	1.51	1.5	1.38	1.6	1.76	1.94	1.7	1.45	1.3	0.94	1.03
Bridge Pa	39.65	176.77	1.69	1.76	1.72	1.63	1.79	1.91	2.06	2.08	1.91	1.88	1.62	1.7
Bottle Lake	43.47	172.68	1.29	1.41	1.44	1.4	1.64	1.76	1.91	1.97	1.81	1.75	1.34	1.35
Burnham	43.62	172.75	1.27	1.4	1.43	1.39	1.67	1.81	1.99	2.03	1.85	1.77	1.33	1.34
Cannington	44.36	170.94	1.14	1.3	1.35	1.32	1.53	1.62	1.77	1.82	1.7	1.63	1.2	1.19
Cat Creeki	41.52	173.48	1.37	1.56	1.55	1.46	1.68	1.82	1.97	1.89	1.71	1.62	1.29	1.35
Cornwallis Depo	37	174.6	1.77	1.96	1.89	1.79	1.9	2.02	2.17	2.04	1.81	1.7	1.53	1.72
Christchurch Aer	43.48	172.53	1.3	1.42	1.45	1.41	1.65	1.76	1.91	1.97	1.81	1.76	1.34	1.36
Clevedon Coast	36.92	175.01	1.78	1.96	1.89	1.79	1.9	2.01	2.16	2.02	1.8	1.69	1.54	1.72
Clyde	45.2	169.32	0.91	1.19	1.28	1.25	1.57	1.71	1.95	1.79	1.52	1.3	0.86	0.9
Cape Colville	36.48	175.33	1.87	1.97	1.9	1.8	1.9	1.99	2.14	2.04	1.87	1.78	1.68	1.83
Castle Point	40.9	176.2	1.56	1.68	1.65	1.58	1.82	1.99	2.17	2.1	1.87	1.75	1.47	1.55
Cricklewood	38.97	177.15	1.76	1.84	1.8	1.72	1.89	2.03	2.2	2.17	1.97	1.89	1.67	1.78
Crownthorpe	39.58	176.57	1.7	1.79	1.76	1.68	1.85	1.98	2.14	2.14	1.96	1.89	1.64	1.72
Glenledi	46.18	170.07	0.86	1.07	1.14	1.1	1.33	1.41	1.53	1.53	1.36	1.31	0.87	0.89
Dargaville	35.96	173.84	1.93	2.07	1.97	1.87	1.95	2.03	2.17	2.07	1.87	1.77	1.65	1.87
Dunedin Aero	45.92	170.18	0.91	1.12	1.19	1.15	1.38	1.46	1.58	1.59	1.42	1.36	0.91	0.94
Dansey Pass	45.03	170.27	1	1.25	1.31	1.27	1.58	1.72	1.93	1.84	1.58	1.43	0.95	1.02
Dovedale	41.34	172.99	1.32	1.53	1.54	1.45	1.62	1.73	1.86	1.77	1.62	1.53	1.24	1.27
Deep Stream	45.73	169.85	0.88	1.16	1.21	1.15	1.48	1.62	1.82	1.69	1.41	1.26	0.79	0.87
Dargaville	35.95	173.83	1.93	2.07	1.97	1.87	1.95	2.03	2.17	2.07	1.87	1.77	1.65	1.87
Eltham	39.46	174.3	1.53	1.78	1.74	1.65	1.85	2.02	2.22	2.04	1.8	1.64	1.36	1.47
Darfield	43.49	172.15	1.27	1.43	1.46	1.42	1.73	1.89	2.11	2.09	1.85	1.72	1.27	1.32
Galatea	38.34	176.79	1.67	1.83	1.78	1.68	1.84	1.98	2.13	1.99	1.75	1.66	1.47	1.62
Great Barrier Is	36.25	175.47	1.9	2	1.92	1.82	1.91	2	2.14	2.04	1.86	1.78	1.69	1.85
Gore	46.1	168.88	0.83	1.09	1.15	1.11	1.4	1.54	1.72	1.58	1.32	1.17	0.75	0.82
Goudies	0	0	******	******	******	******	******	******	******	******	******	******	******	******
Glendhu	45.75	169.72	0.86	1.15	1.2	1.14	1.49	1.66	1.87	1.7	1.38	1.21	0.74	0.84
Gisborne Aero	38.65	177.98	1.76	1.83	1.79	1.71	1.83	1.95	2.08	2.09	1.91	1.87	1.66	1.77
Gwavas	39.73	176.44	1.66	1.79	1.75	1.68	1.86	2.01	2.18	2.15	1.94	1.85	1.57	1.66
Hanmer	42.54	172.85	1.27	1.48	1.51	1.45	1.78	1.97	2.2	2.09	1.81	1.65	1.22	1.29
Haurangi	41.44	175.26	1.44	1.62	1.6	1.53	1.78	1.93	2.09	2.03	1.82	1.73	1.37	1.44
Hira	41.28	173.34	1.34	1.53	1.54	1.46	1.64	1.75	1.89	1.82	1.67	1.59	1.3	1.32
Hicks Bay	37.56	178.29	1.81	1.87	1.83	1.75	1.86	1.97	2.1	2.03	1.83	1.77	1.66	1.78
Hokitika Aero	42.7	170.98	1.03	1.29	1.32	1.21	1.41	1.52	1.64	1.45	1.25	1.16	0.89	0.95
Hamilton Aero	37.85	175.33	1.64	1.9	1.83	1.72	1.89	2.04	2.22	2.03	1.75	1.61	1.37	1.56
Hunua East	37.21	175.29	1.73	1.95	1.88	1.79	1.92	2.05	2.23	2.07	1.82	1.68	1.49	1.67
Hunua West	37.07	175.07	1.74	1.95	1.89	1.79	1.91	2.03	2.19	2.04	1.79	1.67	1.48	1.68
Hokianga	35.49	173.38	1.94	2.07	1.96	1.85	1.92	1.99	2.13	2	1.8	1.72	1.64	1.87
Haast	43.85	169	1	1.18	1.22	1.1	1.21	1.21	1.22	1.15	1.05	1.08	0.86	0.91
Havelock North	39.65	176.87	1.68	1.76	1.71	1.61	1.77	1.89	2.03	2.05	1.89	1.86	1.6	1.69
Holdsworth Stn	40.9	175.53	1.43	1.68	1.64	1.54	1.79	1.96	2.15	2.02	1.76	1.63	1.26	1.39
Invermay	45.85	170.38	0.94	1.13	1.2	1.16	1.39	1.47	1.6	1.62	1.45	1.4	0.95	0.97
Kaipara	36.49	174.23	1.87	2.01	1.92	1.82	1.91	2	2.14	2.03	1.83	1.73	1.61	1.81
Kawerau	38.04	176.44	1.67	1.84	1.79	1.69	1.84	1.98	2.13	1.98	1.75	1.65	1.47	1.62
Keneperu Head	41.17	174.12	1.4	1.61	1.59	1.5	1.73	1.89	2.06	1.96	1.75	1.64	1.31	1.38
Kaikoura	42.42	173.68	1.44	1.55	1.56	1.53	1.8	1.95	2.15	2.17	1.97	1.86	1.46	1.5
Kaikohe	35.42	173.82	2.01	2.1	1.98	1.87	1.95	2.03	2.17	2.06	1.86	1.78	1.71	1.96
Kaitoke	41.09	175.18	1.39	1.62	1.61	1.52	1.77	1.93	2.12	2	1.75	1.63	1.26	1.36
Kaiwaka	39.28	176.87	1.75	1.81	1.79	1.72	1.89	2.02	2.17	2.18	1.99	1.92	1.69	1.77
Kaitaia Observ	35.13	173.25	2	2.1	1.98	1.86	1.92	1.97	2.08	1.97	1.79	1.73	1.68	1.93
Lauder	45.03	169.68	0.94	1.22	1.31	1.28	1.62	1.78	2.02	1.85	1.54	1.33	0.88	0.94
Lauder	45.03	169.68	0.94	1.22	1.31	1.28	1.62	1.78	2.02	1.85	1.54	1.33	0.88	0.94
Le Bons Bay	43.73	173.12	1.32	1.39	1.43	1.41	1.65	1.75	1.9	2.02	1.87	1.85	1.41	1.41
Lees Valley	43.12	172.23	1.23	1.45	1.46	1.41	1.72	1.9	2.12	2.04	1.78	1.63	1.17	1.25
Lower Hutt	41.22	174.92	1.39	1.61	1.6	1.53	1.78	1.94	2.12	2	1.77	1.64	1.3	1.37
Lismore	39.83	175.2	1.52	1.76	1.72	1.62	1.85	2.03	2.25	2.07	1.81	1.63	1.33	1.46
Levin	40.65	175.27	1.38	1.63	1.62	1.54	1.78	1.94	2.13	1.98	1.74	1.59	1.25	1.34
Lake Taupo For	38.91	175.94	1.57	1.79	1.76	1.67	1.83	1.96	2.12	1.98	1.75	1.64	1.39	1.52
Lumsden	45.75	168.45	0.85	1.11	1.2	1.18	1.43	1.52	1.68	1.59	1.37	1.24	0.82	0.85
Mahurangi	36.42	174.43	1.87	2	1.92	1.82	1.91	1.99	2.13	2.03	1.83	1.74	1.62	1.82
Matawaia	35.52	173.91	1.99	2.09	1.98	1.87	1.95	2.02	2.16	2.07	1.87	1.8	1.71	1.95
Mangatu Forest	38.25	177.89	1.82	1.88	1.83	1.75	1.89	2.02	2.16	2.1	1.88	1.81	1.65	1.8
Mahia	39.12	177.95	1.74	1.8	1.77	1.7	1.82	1.93	2.06	2.1	1.94	1.91	1.69	1.76
Minginui	38.63	176.68	1.66	1.83	1.79	1.69	1.86	2.01	2.17	2.05	1.8	1.7	1.48	1.63
Molesworth	42.08	173.25	1.25	1.51	1.5	1.42	1.71	1.9	2.09	1.93	1.65	1.53	1.13	1.23
Manapouri Aero	45.53	167.63	0.83	1.1	1.19	1.15	1.4	1.49	1.62	1.48	1.26	1.14	0.77	0.8
Molesworth	42.08	173.25	1.25	1.51	1.5	1.42	1.71	1.9	2.09	1.93	1.65	1.53	1.13	1.23
Barn Hill	45.71	168.25	0.84	1.11	1.2	1.18	1.44	1.54	1.71	1.59	1.36	1.21	0.79	0.82
East Taratahi	41	175.62	1.52	1.7	1.66	1.58	1.81	1.95	2.11	2.05	1.83	1.74	1.38	1.5
Mount Benger	45.58	169.25	0.85	1.16	1.22	1.16	1.51	1.67	1.89	1.69	1.39	1.19	0.74	0.82
Mount Cook	43.73	170.08	0.86	1.28	1.33	1.25	1.61	1.84	2.09	1.7	1.31	1.04	0.64	0.76
Matea	38.78	176.41	1.64	1.83	1.78	1.69	1.87	2.03	2.21	2.07	1.82	1.7	1.46	1.6
Motukarara	43.72	172.59	1.26	1.39	1.42	1.37	1.63	1.76	1.93	1.98	1.81	1.74	1.3	1.32
Mount Somers	43.67	171.38	1.11	1.37	1.41	1.37	1.69	1.87	2.11	1.98	1.69	1.51	1.06	1.12
Motu	38.28	177.52	1.79	1.87	1.81	1.72	1.88	2.01	2.14	2.05	1.83	1.75	1.61	1.76

Murchison	41.8	172.33	1.04	1.44	1.45	1.34	1.59	1.75	1.94	1.68	1.41	1.24	0.87	0.95
National Park	39.17	175.42	1.51	1.78	1.72	1.59	1.77	1.92	2.08	1.9	1.63	1.51	1.25	1.43
Nelson Creek	42.4	171.52	1.07	1.37	1.4	1.3	1.56	1.73	1.93	1.67	1.41	1.23	0.93	1
Ngapaenga	38.35	175.92	1.63	1.85	1.78	1.66	1.85	2.02	2.19	2	1.73	1.6	1.38	1.56
Ngaruru	41.7	173.2	1.31	1.52	1.52	1.44	1.65	1.79	1.95	1.86	1.67	1.58	1.24	1.29
Nugget Point	46.47	169.78	0.84	1.03	1.1	1.05	1.28	1.37	1.48	1.47	1.3	1.25	0.84	0.86
Ngaumu	41.04	175.88	1.53	1.68	1.65	1.57	1.79	1.94	2.11	2.05	1.83	1.74	1.41	1.52
Normanby	39.5	174.25	1.54	1.77	1.75	1.67	1.88	2.04	2.24	2.08	1.84	1.67	1.39	1.48
NewPlymouth Ae	39	174.17	1.52	1.77	1.72	1.6	1.77	1.92	2.1	1.91	1.68	1.54	1.32	1.44
Napier Aero	39.45	176.85	1.71	1.78	1.76	1.69	1.84	1.96	2.11	2.15	2	1.95	1.69	1.74
Nelson Aero	41.3	173.22	1.34	1.53	1.54	1.46	1.63	1.75	1.88	1.81	1.67	1.59	1.3	1.31
Ngamatea	39.45	176.2	1.57	1.79	1.75	1.66	1.84	1.98	2.13	2.05	1.82	1.73	1.42	1.55
Invercargill Aero	46.42	168.33	0.86	1.05	1.12	1.08	1.31	1.41	1.55	1.48	1.28	1.18	0.82	0.86
Ngawihi	41.58	175.23	1.46	1.59	1.59	1.53	1.77	1.91	2.05	2.03	1.85	1.78	1.43	1.48
Ohakea	40.2	175.22	1.44	1.69	1.68	1.59	1.83	2.01	2.22	2.06	1.81	1.64	1.31	1.4
Okato	39.25	173.89	1.51	1.75	1.72	1.62	1.79	1.93	2.1	1.92	1.71	1.57	1.34	1.44
Omataroa	38.1	176.85	1.68	1.83	1.78	1.68	1.83	1.97	2.1	1.97	1.73	1.65	1.48	1.63
Ongaonga	39.92	176.43	1.66	1.78	1.73	1.65	1.84	1.97	2.14	2.12	1.93	1.85	1.56	1.66
Opouteke	35.7	173.81	1.97	2.09	1.97	1.86	1.95	2.03	2.17	2.06	1.86	1.77	1.67	1.91
Opua Bay	41.27	174.21	1.42	1.59	1.59	1.53	1.75	1.9	2.07	2	1.81	1.7	1.38	1.42
Oamaru Aero	44.97	171.08	1.05	1.21	1.29	1.26	1.45	1.5	1.62	1.72	1.63	1.6	1.16	1.11
Paeroa	37.35	175.68	1.78	1.94	1.87	1.79	1.94	2.09	2.27	2.11	1.86	1.71	1.56	1.73
Pureroa	35.12	174.02	2	2.08	1.99	1.89	1.95	2	2.12	2.04	1.87	1.82	1.76	1.96
Pukaki Aero	44.23	170.12	0.97	1.26	1.35	1.33	1.6	1.74	1.94	1.81	1.57	1.39	0.96	0.98
Pukekohe	37.2	174.85	1.71	1.93	1.87	1.77	1.9	2.03	2.2	2.04	1.79	1.66	1.47	1.65
Palmerston Nth	40.32	175.6	1.43	1.69	1.65	1.54	1.78	1.96	2.17	2	1.73	1.58	1.25	1.37
Paraparaumu	40.9	174.98	1.4	1.61	1.63	1.57	1.79	1.93	2.11	2	1.78	1.64	1.33	1.38
Pouto	36.26	174.05	1.9	2.04	1.94	1.83	1.92	2.01	2.15	2.04	1.84	1.74	1.62	1.84
Queenstown Aer	45.02	168.73	0.82	1.13	1.25	1.21	1.47	1.58	1.75	1.57	1.35	1.18	0.78	0.78
Rai Valley	41.21	173.59	1.37	1.57	1.56	1.47	1.66	1.78	1.91	1.84	1.68	1.61	1.29	1.34
Raumai	40.2	175.22	1.44	1.69	1.68	1.59	1.83	2.01	2.22	2.06	1.81	1.64	1.31	1.4
Reefton	42.12	171.87	1.04	1.41	1.44	1.35	1.65	1.85	2.1	1.78	1.47	1.22	0.87	0.95
Rimutaka FP	41.35	174.91	1.41	1.6	1.6	1.53	1.77	1.93	2.1	2.02	1.81	1.69	1.34	1.4
Rotoehu	37.87	176.52	1.68	1.84	1.79	1.7	1.83	1.96	2.09	1.98	1.77	1.69	1.51	1.64
Ruatoria	37.83	178.07	1.82	1.91	1.85	1.76	1.91	2.06	2.2	2.11	1.86	1.78	1.63	1.79
Ranfurly	45.13	170.1	0.98	1.24	1.3	1.26	1.55	1.67	1.86	1.77	1.52	1.37	0.91	0.98
Rock and Pillar	45.39	170.21	0.96	1.22	1.27	1.22	1.53	1.67	1.86	1.77	1.51	1.37	0.89	0.97
Rotorua Aero	38.1	176.32	1.67	1.84	1.79	1.69	1.85	1.99	2.14	1.98	1.75	1.64	1.47	1.61
Rotoaira	38.86	175.6	1.52	1.8	1.73	1.59	1.76	1.91	2.05	1.87	1.61	1.5	1.24	1.43
Porapora	37.81	178.27	1.82	1.87	1.83	1.76	1.88	1.99	2.12	2.07	1.88	1.82	1.69	1.82
Waiouru Aero	39.47	175.7	1.55	1.79	1.72	1.6	1.83	2	2.18	2	1.71	1.58	1.29	1.48
Snowdon	43.47	171.67	1.18	1.4	1.43	1.38	1.7	1.88	2.11	2.02	1.74	1.59	1.14	1.21
Slopedown	46.39	169.13	0.83	1.06	1.11	1.05	1.35	1.48	1.65	1.54	1.28	1.16	0.74	0.82
Spriggins Park	39.97	175.02	1.5	1.74	1.71	1.63	1.86	2.04	2.26	2.09	1.84	1.65	1.35	1.45
Stony Creek	41.43	175.48	1.46	1.63	1.6	1.53	1.77	1.92	2.07	2.02	1.81	1.73	1.37	1.46
Tahorakuri	38.59	176.16	1.65	1.85	1.79	1.7	1.88	2.04	2.22	2.05	1.79	1.65	1.44	1.59
Te Horo	40.8	175.15	1.4	1.62	1.63	1.56	1.79	1.95	2.13	2	1.77	1.63	1.3	1.37
Tekapo	44	170.4	1.02	1.28	1.38	1.36	1.65	1.8	1.99	1.86	1.59	1.43	1	1.03
Te Pohue	39.27	176.68	1.7	1.81	1.78	1.71	1.89	2.02	2.18	2.14	1.93	1.85	1.6	1.71
Tauranga Aero	37.67	176.2	1.73	1.86	1.81	1.72	1.87	2.01	2.17	2.03	1.82	1.7	1.57	1.69
Te Haroto	39.16	175.61	1.49	1.77	1.7	1.55	1.72	1.87	1.99	1.81	1.53	1.45	1.18	1.4
Tara Hills	44.52	169.9	0.96	1.24	1.34	1.32	1.57	1.68	1.84	1.73	1.49	1.35	0.93	0.96
Totaranui	40.83	173	1.35	1.57	1.57	1.47	1.63	1.75	1.87	1.79	1.64	1.58	1.28	1.31
Te Puke	37.82	176.32	1.69	1.84	1.79	1.7	1.82	1.94	2.07	1.97	1.77	1.7	1.53	1.65
Tapanui	45.92	169.24	0.84	1.1	1.16	1.1	1.39	1.52	1.68	1.57	1.31	1.2	0.76	0.83
Tapuae	0	0	******	******	******	******	******	******	******	******	******	******	******	******
Traquair	45.81	170.13	0.91	1.15	1.19	1.14	1.41	1.52	1.67	1.63	1.41	1.32	0.86	0.92
Port Taharoa	38.17	174.7	1.64	1.84	1.77	1.64	1.8	1.93	2.09	1.89	1.63	1.5	1.34	1.54
Toatoa	38.11	177.51	1.78	1.87	1.81	1.72	1.87	1.99	2.12	2.02	1.79	1.72	1.58	1.74
Titahi Bay	41.11	174.83	1.4	1.6	1.6	1.53	1.76	1.92	2.11	1.99	1.77	1.62	1.33	1.38
Timaru Aero	44.3	171.23	1.15	1.29	1.35	1.31	1.5	1.56	1.69	1.79	1.69	1.66	1.23	1.2
Tuatapere	46.09	167.82	0.84	1.07	1.14	1.1	1.35	1.47	1.62	1.51	1.29	1.17	0.8	0.83
Tarawera	38.04	176.44	1.67	1.84	1.79	1.69	1.84	1.98	2.13	1.98	1.75	1.65	1.47	1.62
Waimarino For	39.9	175.19	1.51	1.76	1.71	1.62	1.85	2.03	2.25	2.07	1.81	1.63	1.33	1.46
Waihau	39.39	176.56	1.72	1.8	1.78	1.72	1.89	2.03	2.19	2.17	1.97	1.89	1.66	1.74
Waione	40.46	176.31	1.56	1.71	1.68	1.6	1.83	2	2.2	2.12	1.89	1.77	1.46	1.56
Waverly	39.78	176.6	1.69	1.78	1.74	1.66	1.83	1.96	2.12	2.12	1.94	1.87	1.61	1.7
Chatham Island	43.95	176.72	******	******	******	******	******	******	******	******	******	******	******	******
Woodbourne Aer	41.52	173.85	1.51	1.61	1.61	1.56	1.8	1.95	2.13	2.1	1.91	1.81	1.49	1.54
Western Bound	41.53	172.82	1.24	1.51	1.51	1.42	1.62	1.76	1.92	1.79	1.59	1.48	1.14	1.2
Waiouru Camp	39.47	175.68	1.55	1.79	1.72	1.6	1.83	2	2.18	2	1.71	1.58	1.29	1.48
Woodhill	36.71	174.38	1.82	1.99	1.91	1.81	1.91	2.02	2.17	2.04	1.83	1.72	1.58	1.76
Wanaka	44.72	169.23	0.88	1.17	1.28	1.26	1.55	1.68	1.88	1.68	1.42	1.22	0.84	0.85
Waitangi Forest	35.28	173.99	2.01	2.08	1.99	1.88	1.95	2	2.13	2.05	1.87	1.81	1.75	1.97
Whangamata	37.22	175.79	1.81	1.96	1.89	1.8	1.94	2.07	2.24	2.12	1.89	1.76	1.6	1.76
Waihi Gold	37.42	175.87	1.78	1.93	1.88	1.8	1.95	2.1	2.28	2.15	1.91	1.77	1.6	1.75
Waihau Bay	37.64	177.91	1.78	1.87	1.82	1.72	1.85	1.99	2.15	2.02	1.81	1.71	1.61	1.74
Marco	39.1	174.76	1.51	1.8	1.73	1.6	1.81	1.98	2.18	1.97	1.7	1.54	1.26	1.42
Waihaorunga	44.7	170.77	1.08	1.28	1.34	1.32	1.59	1.71	1.9	1.89	1.69	1.57	1.12	1.12

Whakatane Aero	37.92	176.92	1.67	1.84	1.8	1.7	1.82	1.93	2.05	1.96	1.77	1.7	1.52	1.63
Waikawau Bay	36.77	175.46	1.85	1.96	1.9	1.81	1.92	2.03	2.18	2.07	1.87	1.77	1.66	1.81
Wellington Aero	41.33	174.82	1.43	1.6	1.6	1.54	1.77	1.93	2.11	2.02	1.81	1.68	1.37	1.42
Windsor	45.01	170.82	1.05	1.21	1.29	1.27	1.48	1.56	1.7	1.76	1.63	1.57	1.14	1.11
Waipukurau	40	176.54	1.67	1.77	1.72	1.64	1.81	1.94	2.1	2.09	1.9	1.83	1.57	1.67
Whangarei Aero	35.77	174.37	1.96	2.06	1.96	1.85	1.93	2	2.14	2.06	1.88	1.81	1.72	1.92
Wreys Bush	46.03	168.11	0.85	1.09	1.16	1.12	1.39	1.5	1.65	1.55	1.32	1.19	0.79	0.84
Westport	41.73	171.57	1.11	1.41	1.42	1.3	1.47	1.59	1.72	1.51	1.32	1.21	0.95	1.02
Whitianga Aero	36.87	175.67	1.86	1.97	1.9	1.81	1.93	2.04	2.19	2.08	1.88	1.78	1.66	1.82
Waitarere For	40.55	175.2	1.39	1.64	1.64	1.56	1.82	1.99	2.21	2.05	1.8	1.63	1.29	1.36
Wanganui Aero	39.97	175.02	1.5	1.74	1.71	1.63	1.86	2.04	2.26	2.09	1.84	1.65	1.35	1.45

Appendix 2. Summary of data availability for individual weather stations.

CODE	STATION NAME	RRFC AREA	STN TYPE	S		STATUS	% COMPLETE	COMMENTS
KX	Kaitaia Observatory	Northland	Met			FWI data 2002	100	extend from CLIDB?
DAR	Dargaville	Northland				Climate 6 model	100	
WRA	Whangarei Aero	Northland	Met			FWI data 2004	100	
WGF	Waitangi Forest	Northland				FWI data 2001	85	missing 28/08/01-7/04/03 (PEX?)
PTU	Pouto	Northland				FWI data 2004	100	
APP	Aupouri Peninsula	Northland				FWI data 2004	100	
OPO	Opouteke	Northland				FWI data 2004	100	
MAT	Matawaia	Northland				FWI data 2001	100	
KOE	Kaikohe	Northland	Met			FWI data 2004	100	
KAI	Kaipara	Northland				FWI data 2002	100	
HOK	Hokianga	Northland				FWI data 2004	100	
PEX	Purerua	Northland	Met			unprocessed	88	complete from CLIDB?
AKL	Auckland Aero	Auckland	Met			Climate 6 model	100	
CDT	Cornwallis Depot	Auckland				FWI data 2002	96	data to 31/12/04
CLV	Clevedon Coast	Auckland				FWI data 2004	100	
GBI	Great Barrier Island	Auckland				FWI data 2004	100	
MAH	Mahurangi	Auckland				FWI data 2004	100	
WDH	Woodhill	Auckland				FWI data 2004	100	
HNW	Hunua West	Auckland				FWI data 2002	97	data to 19/12/03
PKE	Pukekohe	Auckland	Met			FWI data 2002	80	data to 20/09/99, extend from CLIDB?
HNE	Hunua East	Auckland				FWI data 2002	99	data to 31/12/04
AWH	Awhitu	Auckland	Met			unprocessed	91	complete from CLIDB?
COR	Coromandel	Waikato	Met			FWI data 2000	100	
HNA	Hamilton Aero	Waikato	Met			FWI data 2004	100	
WTA	Whitianga Aero	Waikato	Met			FWI data 2004	100	
PAX	Paeroa	Waikato	Met			FWI data 2004	100	
ATH	Athol	Waikato				FWI data 2004	100	
WGM	Whangamata	Waikato				FWI data 2004	100	
NGA	Ngapaenga	Waikato				FWI data 2004	100	
BOD	Bodley Road	Waikato				unprocessed	82	
WGO	Waihi Gold	Waikato				FWI data 2004	100	
COX	Cape Colville	Waikato	Met			FWI data 1993	100	complete from CLIDB?
WKB	Waikawau Bay	Waikato				unprocessed	90	
TRX	Port Taharoa	Waikato	Met			unprocessed	86	complete from CLIDB?

CODE	STATION NAME	RRFC AREA	STN TYPE	S		STATUS	% COMPLETE	COMMENTS
ROA	Rotorua Aero	CNI	Met			Climate 6 model	100	
TGA	Tauranga Aero	CNI	Met			Climate 6 model	100	
APA	Taupo Aero	CNI	Met			Climate 6 model	100	
TPE	Te Puke	CNI				FWI data 2004	100	
WKA	Whakatane Aero	CNI	Met			FWI data 2004	100	
TTA	Toatoa	CNI				FWI data 2004	100	
MTE	Matea	CNI				FWI data 2004	100	
GDE	Goudies	CNI				FWI data 2004	100	
OMT	Omataroa	CNI				FWI data 2002	100	
TAH	Tahorakuri	CNI				FWI data 2004	100	
KAW	Kawerau	CNI				FWI data 2004	100	
GAL	Galatea	CNI				FWI data 2001	90	data to 31/12/04
RHU	Rotoehu	CNI				FWI data 2004	100	
MIN	Minginui	CNI				FWI data 2004	100	
LTF	Lake Taupo Forest	CNI				unprocessed	93	
ROT	Rotoaira	CNI				FWI data 2004	100	
GSA	Gisborne Aero	Eastern	Met			Climate 6 model	100	
WPK	Waipukurau	Eastern				FWI data 2004	100	
KWK	Kaiwaka	Eastern				FWI data 2004	100	
WAH	Waihau	Eastern				FWI data 2004	100	
TEP	Te Pohue	Eastern				FWI data 2004	100	
NRA	Napier Aero	Eastern	Met			FWI data 2004	100	
THA	Te Haroto	Eastern				FWI data 2004	100	
HIX	Hicks Bay	Eastern	Met			FWI data 2004	100	
MHX	Mahia	Eastern	Met			FWI data 2004	100	
CRK	Cricklewood	Eastern				FWI data 2004	100	
RTF	Porapora	Eastern				FWI data 2004	100	
MGF	Mangatu Forest	Eastern				FWI data 2002	92	data to 31/12/04
RIP	Ruatoria	Eastern				FWI data 2002	93	data to 31/12/04
BRP	Bridge Pa	Eastern				unprocessed	97	
ONG	Ongaonga	Eastern				unprocessed	98	
CRT	Crownthorpe	Eastern				unprocessed	97	
MTX	Motu	Eastern	Met			unprocessed	93	complete from CLIDB?
HVE	Havelock North	Eastern	Met			unprocessed	90	complete from CLIDB?
GWA	Gwavas	Eastern				unprocessed	94	

CODE	STATION NAME	RRFC AREA	STN TYPE	S	STATUS	% COMPLETE	COMMENTS
NPA	New Plymouth Aero	Taranaki	Met		Climate 6 model	100	
NOE	Normanby	Taranaki	Met		FWI data 2004	100	extend from CLIDB?
WHG	Marco	Taranaki			FWI data 2004	100	
WAV	Waverly	Taranaki			FWI data 2004	100	
OKT	Okato	Taranaki			FWI data 2003	87	data to 28/09/04
ELT	Eltham	Taranaki			unprocessed	93	
WUA	Wanganui Aero	Wang/Man	Met		Climate 6 model	100	
OHA	Ohakea	Wang/Man			FWI data 2004	100	missing 1/01/72-31/12/75 (CLIDB?)
RUX	Waiouru Aero	Wang/Man	Met		FWI data 2004	100	
LNX	Levin	Wang/Man	Met		FWI data 2004	100	
NTA	Ngamatea	Wang/Man			FWI data 2004	100	
RAU	Raumai	Wang/Man			FWI data 2004	100	
WTF	Waitarere Forest	Wang/Man			FWI data 2004	100	
WAO	Waione	Wang/Man			FWI data 2004	100	
WAF	Waimarino Forest	Wang/Man			FWI data 2004	100	
LIS	Lismore	Wang/Man			FWI data 2004	100	
NAT	National Park	Wang/Man			FWI data 2004	100	
PMA	Palmerston North Aero	Wang/Man	Met		FWI data 2004	100	
TPU	Tapuae	Wang/Man			FWI data 2004	100	
SPR	Spriggins Park	Wang/Man			unprocessed	96	
MSX	East Taratahi	Wairarapa	Met		FWI data 2004	100	
CPX	Castle Point	Wairarapa	Met		FWI data 2004	100	
NMU	Ngaumu	Wairarapa			FWI data 2004	100	
HWT	Holdsworth Station	Wairarapa			FWI data 2004	100	
STO	Stoney Creek	Wairarapa			FWI data 2004	100	
HAU	Haurangi	Wairarapa			FWI data 2004	100	
NWX	Ngawihi	Wairarapa	Met		FWI data 2004	100	
WNA	Wellington Aero	Wellington	Met		Climate 6 model	100	
PPA	Paraparaumu	Wellington	Met		Climate 6 model	100	
RFP	Rimutaka Forest Park	Wellington			FWI data 2004	100	
WAX	Chatham Island	Wellington	Met		FWI data 2004	100	
BEL	Belmont	Wellington			FWI data 2004	100	
TEH	Te Horo	Wellington			FWI data 1997	100	
LHX	Lower Hutt	Wellington	Met		unprocessed	88	
KTK	Kaitoke	Wellington			unprocessed	96	
TTB	Titahi Bay	Wellington			unprocessed	96	

NIWA
Taihoro Nukurangi

CODE	STATION NAME	RRFC AREA	STN TYPE	S	I	STATUS	% COMPLETE	COMMENTS
NSA	Nelson Aero	Nelson	Met			Climate 6 model	100	
TNI	Totaranui	Nelson				FWI data 2004	100	
HIR	Hira	Nelson				FWI data 2004	100	
DOV	Dovedale	Nelson				FWI data 2004	100	
MUR	Murchison	Nelson	Met			FWI data 2004	100	
BPO	Big Pokororo	Nelson				FWI data 2002	94	data to 31/12/04
WBD	Western Boundary	Nelson				FWI data 2002	81	data to 31/12/04
KIX	Kaikoura	Marlborough	Met			Climate 6 model	100	
KHD	Keneperu Head	Marlborough				FWI data 2004	100	
OSN	Opua Bay	Marlborough				FWI data 2004	100	
AWV	Awatere Valley	Marlborough				FWI data 2004	100	
WBA	Woodbourne Aero	Marlborough	Met			FWI data 2004	100	
RAI	Rai Valley	Marlborough				FWI data 2004	100	
MLX	Molesworth	Marlborough				FWI data 2002	95	data to 31/12/04, also missing 24/08/94-8/0
CAT	Cat Creek	Marlborough				unprocessed	99	
NGU	Ngaruru	Marlborough				unprocessed	94	
HKA	Hokitika Aero	West Coast	Met			Climate 6 model	100	
WSA	Westport	West Coast	Met			Climate 6 model	100	
HTX	Haast	West Coast	Met			FWI data 2004	100	
REF	Reefton	West Coast				FWI data 2004	100	
NCR	Nelson Creek	West Coast				unprocessed	91	
CHA	Christchurch Aero	Canterbury	Met			Climate 6 model	100	
SDN	Snowdon	Canterbury				FWI data 2004	100	
FPL	Darfield	Canterbury				FWI data 2004	100	
BTL	Bottle Lake	Canterbury				FWI data 2004	100	
ASY	Ashley	Canterbury				FWI data 2002	96	data to 31/12/04
BML	Balmoral	Canterbury				FWI data 2004	100	
ASH	Ashburton Plains	Canterbury				FWI data 2004	100	
LBX	Le Bons Bay	Canterbury	Met			FWI data 2004	100	
BUR	Burnham	Canterbury				FWI data 2002	69	data to 31/12/04
HAN	Hanmer	Canterbury				FWI data 2004	100	
LEV	Lees Valley	Canterbury				FWI data 2004	100	
MTS	Mount Somers	Canterbury				unprocessed	99	
MTK	Motukarara	Canterbury				FWI data 2004	100	

CODE	STATION NAME	RRFC AREA	STN TYPE	S		STATUS	% COMPLETE	COMMENTS
THE	Tara Hills	South Canty	Met			FWI data 2004	100	
OUA	Oamaru Aero	South Canty	Met			FWI data 2004	100	
CAN	Cannington	South Canty				FWI data 2004	100	
TUA	Timaru Aero	South Canty	Met			FWI data 2004	100	
MTC	Mount Cook	South Canty				unprocessed	93	
PKA	Pukaki Aero	South Canty				FWI data 2004	100	
WHR	Waihaorunga	South Canty				FWI data 2004	100	
TEK	Tekapo	South Canty				unprocessed	40	
QNA	Queenstown Aero	Otago	Met			Climate 6 model	100	
DNA	Dunedin Aero	Otago	Met			Climate 6 model	100	
LAE	Lauder	Otago				FWI data 2004	100	missing 21/07/94-23/02/97 (CLIDB?)
TRQ	Traquair	Otago				FWI data 2004	100	
CYB	Glenledi	Otago				FWI data 2004	100	
TPN	Tapanui	Otago				FWI data 2004	100	
WFA	Wanaka	Otago	Met			FWI data 2004	100	
DNP	Dansey Pass	Otago				FWI data 2004	100	
RNP	Rock and Pillar	Otago				FWI data 2004	100	
INE	Invermay	Otago	Met			FWI data 1997	100	extend from CLIDB?
CLY	Clyde	Otago				FWI data 2004	100	
DPS	Deep Stream	Otago				FWI data 2004	100	
MTB	Mount Benger	Otago				FWI data 2004	100	
BGO	Bendigo	Otago				FWI data 2004	100	
NGX	Nugget Point	Otago	Met			FWI data 2004	100	
GLD	Glendhu	Otago				unprocessed	93	
WND	Windsor	Otago				FWI data 2004	100	
RLY	Ranfurly	Otago				FWI data 2004	100	
NVA	Invercargill Aero	Southland	Met			Climate 6 model	100	
LUX	Lumsden	Southland	Met			FWI data 2002	100	extend from CLIDB?
GCE	Gore	Southland	Met			FWI data 2004	100	
MOA	Manapouri Aero	Southland	Met			FWI data 2004	100	
BMT	Blackmount	Southland				FWI data 2002	92	data to 31/12/04
TUT	Tuatapere	Southland				FWI data 2004	100	
WRY	Wreys Bush	Southland				FWI data 2002	96	data to 31/12/04
SLP	Slopedown	Southland				FWI data 2004	100	
MOS	Barn Hill	Southland				FWI data 2002	96	data to 31/12/04
No. stations	**179**			**1:**		**150 FWI / 52 ClimChg**		