Improved estimates of the effect of climate change on NZ fire danger

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Client Report No. 18087

Improved estimates of the effect of climate change on NZ fire danger

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EXECUTIVE SUMMARY

This study provides improved estimates of fire danger for New Zealand under future climate. Fire danger ratings for two projection periods (the 2050s, 2040-2059; and 2080s, 2070-2089) were estimated using monthly changes in weather inputs (temperature, humidity, wind speed and rainfall). These ratings were obtained from downscaling IPCC 4th Assessment global climate models for the A1B emissions scenario and applying local weather station observations. Changes in two fire climate severity measures – the Seasonal Severity Rating (SSR), and number of days of Very High and Extreme (VH+E) Forest fire danger – were estimated for 20 station locations.

Results indicate that fire climate severity is likely to rise significantly with climate change in many parts of the country as a result of increases in temperature or wind speed, and lower rainfall or humidity. The areas most likely to increase from current levels are the east and south of the South Island, especially coastal Otago and Marlborough and south-eastern Southland, and the west of the North Island (particularly around Wanganui). Unlike the previous study (Pearce et al. 2005) eastern areas such as Christchurch and Gisborne did not show significantly increased fire potential. There is also potential for increased fire danger under the most extreme model scenarios across the lower North Island and into the Bay of Plenty.

Fire danger in other areas may remain unchanged, or in fact decrease by the 2080s, due mainly to increased rainfall. These areas include the West Coast of the South Island and western areas of the North Island such as Taranaki where fire dangers are already low, and East Cape and the Coromandel. Potential also exists for decreased fire danger in Northland, Southland and parts of Canterbury under some models.

Changes indicated in the present study were generally greater than those of the 2005 study, but also varied more widely between climate models. This variation is due to the greater range in projected changes, especially seasonal differences in rainfall and temperature. While many models show continuing increases through to the 2080s, a feature of several models was for fire danger to increase more rapidly to the 2050s, and then to stabilise or decrease by the 2080s. This levelling off is due to greater predicted increases in rainfall (especially during fire season months) for the latter part of the projection period.

Although not investigated in detail here, results indicate that changes in overall fire climate severity are also associated with significant changes in the contributing fire danger ratings. These in turn indicate that fire managers can expect:

- longer fire seasons in some parts of the country;
- increased drought frequency, and associated increases in fuel drying;
- easier ignition and, therefore, potentially 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, more prolonged mop-up, increased resource requirements and more difficult fire suppression.

Through the use of improved climate models, modelling approaches and outputs not previously available, this study has substantially extended previous work to provide a more comprehensive evaluation of future fire climate and likely impacts. Further improvements could be made through use of Regional Climate Models and/or an increase in the number of sampling locations. This approach would improve the validity of the estimates derived and the ability to interpolate changes to other locations across the country.

The results of this study are valuable in highlighting the likelihood of increased fire risk in many regions of New Zealand with climate change. This improved knowledge will assist fire management agencies, landowners and communities to better develop appropriate future fire management and mitigation strategies.

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Information for Scion abstracting:

Contract number	MAF SLMACC / FRST Contract C04X0809
Client Report No.	18087 (Output No. 47055)
Products investigated	Fire and climate change
Wood species worked on	n/a
Other materials used	Climate change modelling
Location	National

Pearce, H.G.; Kerr, J.; Clark, A.; Mullan, B.; Ackerley, D.; Carey-Smith, T.; Yang, E. 2010. Improved estimates of the effect of climate change on NZ fire danger. Scion, Rural Fire Research Group, Christchurch. Scion Client Report No. 18087. 76 p.

INTRODUCTION

A growing body of international evidence suggests that future fire activity is likely to increase as a result of global warming and associated climate change (IPCC 2007b). In many parts of the world, the warmer, drier and windier conditions associated with climate change are predicted to result in an increase in fire weather severity and/or more frequent fires (e.g. Stocks et al. 1998, Hennessey et al. 2005, Hasson et al. 2008). However, it is also important to note that fire weather severity and the associated fire impacts may undergo little or no change, or even decrease in some areas (e.g. Flannigan et al. 2000), due to the significant regional variability in predicted climate changes that in some areas include increased rainfall amounts and frequency.

In New Zealand, climate change is predicted to result in drier conditions with more frequent and severe drought events in some parts of the country, particularly in eastern areas (Mullan et al. 2005). Drier conditions are likely to result in significantly greater risk of large and damaging wildfires that threaten life and property, and economic and environmental sustainability. Longer fire seasons, increasing population and associated demographic impacts, changing land use and changes in vegetation cover are expected to exacerbate these risks.

The only previous New Zealand study on the effects of climate change on future fire risk was conducted in 2005 (Pearce et al. 2005). It applied regional climate change scenarios for the 2080s (2070-2099) to long-term daily weather records for individual weather station locations obtained from a fire climate database developed and maintained by Scion (Pearce et al. 2003). Two Global Climate Models (GCMs) with contrasting spatial patterns of climate change across New Zealand – CSIRO and Hadley – were used to investigate the effects on fire danger. GCM model outputs were statistically “downscaled” to the New Zealand region (Mullan et al. 2001), and adapted to weather station locations from the National Rural Fire Authority’s fire weather monitoring network using a high-resolution grid over New Zealand. This provided mean monthly offsets for temperature and rainfall that were used to recreate daily fire weather and fire danger records for 52 (of ~170) weather stations. High, low, and mid-range scenarios of climate change were generated for each model in an effort to cover the range of possible future climate outcomes. Summary statistics of weather inputs, FWI System components and fire danger class frequencies for each station for the range of scenarios were then compared against those for current fire climate.

Results showed that fire danger was likely to rise significantly in most areas of New Zealand, particularly the east, and that the length of the fire season could increase. In addition to changes in FWI System values, significantly higher fire season severity ratings and more days of very High and Extreme (VH+E) fire danger were predicted for stations in the east of both islands, the Bay of Plenty and central (Wellington/Nelson) regions under both the Hadley and CSIRO high and mid-range scenarios. In several cases (e.g., Gisborne, Napier and Christchurch), average seasonal severity rating values increased by 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 seasonal severity ratings (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) demonstrated little or no change in severity ratings or number of VH+E Forest fire danger days, and only one location (Tara Hills under the Hadley high extreme scenario) showed a very slight decrease in the number of days of VH+E fire danger.

However, this study was limited, in that it only considered the effects of changes in temperature and rainfall (and not other important factors affecting fire danger, such as wind speed and humidity) for scenarios from two models of global climate (from Assessment Report 3 (AR3); IPCC 2001a). The potential existed to substantially extend this previous study using improved climate models (from AR4; IPCC 2007a), to provide a much more comprehensive and up-to-date evaluation of likely impacts.

Predicting the fire risk with climate change across New Zealand requires a specialised understanding of local vegetation types, how these fuels respond to changes in climatic variables, and how fires will behave in these fuels. Understanding how these complex factors translate into future fire risks will underpin the development of strategies to adapt to and mitigate against changes. Knowledge of potential future fire climate changes will assist agencies to continue protecting economic assets and public and firefighter safety through better preparedness, training and resources. It will also contribute to: enhancing sustainable land use, through protecting biodiversity and reducing erosion and other long-term damage to ecosystems; reducing greenhouse gas emissions from fire; protecting carbon assets; and protecting timber resources that will be important sources for both bioenergy resources and supply of timber as an increasingly recognised and sought-after sustainable resource (Watt et al. 2008).

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) (Anderson 2005). The NZFDRS is used by fire authorities to assess the probability of a fire starting, spreading and doing damage. Components of the NZFDRS can also be utilised to describe fire climate severity, either current or in future as a result of predicted climate change. For a more detailed description of fire danger rating in New Zealand and assessment of current fire climate severity, as well as international literature on fire and climate change, refer to the previous study report (Pearce et al. 2005) and Pearce and Clifford (2008).

Report Scope

The research aims to provide better estimates of how climate change is likely to effect future fire danger levels across the country. This project contributes to the Sustainable Land Management and Climate Change (SLMACC) Plan Theme 3.1 “Impacts of climate change and adaptation to these impacts”, research priority “Fire (increasing frequency/impacts on land managers)”. It seeks to provide fundamental knowledge on fire risks associated with climate change at the regional level to allow sector agencies, landowners and rural residents to develop mitigation and adaptation strategies that increase resilience and reduce vulnerability.

The research sought to address a number of short-comings identified during the previous study. This included consideration of projected changes for all the key weather elements affecting fire danger (wind speed, humidity, temperature and rainfall), and improved estimates of these changes and potential future fire climate variability. This level of information was not available when the Pearce et al. (2005) study was carried out, but has since become available through a broader range of possible climate change scenarios and improved Glocal Circulation Models (GCM) and Regional Climate Models (RCM) to determine regional changes for New Zealand. Specifically, this included:

(i) Changes in relative humidity (a measure of the dryness of the air) under future fire climate that were not previously included, as they could not be estimated directly from downscaling. Humidity is one of the most significant weather parameters affecting fire danger (Beer et al. 1988) due to its influence on fuel moisture, ignition potential, rate of combustion and fire spread. Humidity changes can be incorporated as a direct output from RCM modelling, and through relationships with downscaled temperature guided by RCM changes and the annual cycle in relative humidity.

(ii) Changes in wind speed were also not included in previous estimates, because there was no way of inferring changes in scalar wind speed from modelled changes in zonal wind flows. Wind is a key factor affecting fuel dryness, fire spread and resulting area burned. Previous research (MfE 2004) indicated that wind speeds could change significantly with climate change with, for example, the mean westerly wind component across New Zealand increasing by 60% or more. This would lead to even greater potential for increases in fire danger in future than previously indicated. Wind speed changes under future climate can be estimated from RCM outputs, and from change ratios for daily wind data obtained from grid-scale (rather than downscaled local) GCM output.

(iii) Improved estimates of regional temperature and rainfall changes as a result of applying new climate change modelling techniques and knowledge, including improved statistical downscaling for a greater range of available models and RCM output.

(iv) Availability of a wider range of global model scenarios. Previous New Zealand studies have generally used just a few of the global model scenarios (typically CSIRO and Hadley, which predict different patterns of change across New Zealand, particularly for rainfall) (Mullan 2001) that were available at that time from the IPCC Third Assessment (AR3) (IPCC 2001b). A greater range of global model scenarios are now available from the IPCC's Fourth Assessment (AR4) (IPCC 2007a, MfE 2008), offering the potential to model a wider range of possible scenario outcomes across New Zealand using some or all of the 12+ AR4 models available under the A1B emissions scenario, as well as other emissions scenarios (e.g. A2, or B1, A1T, B2 & A1F1).

(v) Alternative modelling approaches. Previous New Zealand studies have utilised a statistical downscaling technique (Mullan et al. 2001) where changes are based on statistical relationships with current climate for just a few global climate model gridpoints covering the country. RCMs, nested within a GCM, are more firmly based on atmospheric physics and may provide more spatially accurate information on the influence of topography on local climate (Kidson and Thompson 1997) (and fire danger). Recent international studies (e.g. Wotton et al. 1998, Flannigan et al. 2001) show that this approach is increasingly becoming best practice. Some limited investigation of the RCM approach has been undertaken in New Zealand (Renwick et al. 1997, 1999), and 'control' (for current climate, 1970-1999) and future climate 'runs' of NIWA's own New Zealand RCM are planned.

(vi) Future climate variability with climate change. Many experts expect climate variability to increase with climate change, resulting in increased frequency of extreme weather events (Plummer et al. 1999, Hennessey et al. 2005, Hasson et al. 2008), such as drought and strong winds which directly contribute to extreme wildfire events. However, previous New Zealand climate change studies (Mullan et al. 2005, Pearce et al. 2005) determined changes in input weather variables using offsets to current climate, and have not included possible changes in daily or interannual climate variability. Potential changes in year-to-year climate variability can be incorporated by utilising a greater number of downscaled AR4 model scenarios thereby capturing a wider range of possible outcomes, and also through application of RCM runs that incorporate future climate variability directly from the underlying GCM. However, a limitation of the latter approach is that, as the RCM is driven directly by the input GCM, it can only mimic the interannual variability of this input model, and the changes in climate variability (e.g. for ENSO) can vary significantly from one GCM model to another.

By using improved climate models, modelling approaches and outputs not previously available, the proposed research aimed to substantially extend previous work and provide a much more comprehensive and up-to-date evaluation of future fire climate and likely impacts. This information can then be used as the basis for future research, for example, to develop models of future fire risk that predict changes in likely fire occurrence, area burned and fire suppression costs, or the effects of changes in land use, vegetation distribution and flammability. Improved knowledge will assist fire management agencies, landowners and communities to develop future-proof fire management strategies.

METHODS

Several approaches have been utilised to determine the potential effects of climate change on fire risk (Hennessey et al. 2005, Watt et al. 2008). However, most studies have addressed how fire weather and associated fire season severity will change with changing climate. These studies typically use weather scenarios obtained directly from Global Circulation Models (GCM) or downscaled to the region of interest using statistical downscaling methods or, more recently, Regional Climate Model (RCM) output. The majority of the studies that have employed these approaches have looked at changes in fire danger ratings, fire danger class frequency and fire season severity or length using components of fire danger rating systems, such as the Fire Weather Index (FWI) System utilised in Canada and New Zealand (Stocks et al. 1998) or McArthur system used in Australia (Hennessey et al. 2005). Fire danger ratings are easily calculated from weather input variables (rainfall, temperature, wind and humidity) that are available from climate change model output. These ratings provide a general broad-area estimate of fire risk (fuel dryness, ease of ignition, potential spread rates, fire intensity, difficulty of control and damage potential) that is well suited to analysis of the impact of climate change.

The current research employed the same general methodology as was used in the previous analysis of the effects of climate change on fire danger in New Zealand (Pearce et al. 2005). The key steps included:

1. Definition of future climate change scenarios for the 2050s (2040-2059) and 2080s (2070-2089) from improved statistical downscaling [and RCM approaches], and methods for incorporating future climate variability in fire danger calculations.

2. Updating of existing fire climate databases to include up-to-date data (covering the full 1990s (1980-1999) current climate base period).

3. Provision of offsets for weather elements used to determine future fire danger (i.e. changes in temperature, relative humidity, wind speed and rainfall) from statistical downscaling.

[4. Undertaking ‘control’ and climate change scenario runs of the RCM to determine current and future climate under different emissions scenarios, and extraction of RCM model outputs (weather changes) for use in calculating future fire dangers.]

5. Modification of current station fire weather records to account for projected changes in weather inputs for the 2080s from the selected climate change scenarios and downscaling [and RCM modelling] approaches, and calculation of future fire dangers.

6. Statistical comparison of current and future fire dangers for the various scenarios and modelling approaches, and mapping of projected regional changes.

Climate Scenarios and Models

The IPCC's Fourth Assessment Report (AR4; IPCC 2007a) provides a range of climate projections based on scenario analysis for the period 2080-2099 relative to the 1980-1999 current climate base period. These projections are based on modelling using a number of different emissions scenarios and global climate models.

There are six 'illustrative' global SRES scenarios, each broadly representative of its scenario 'family' and spanning a reasonable range of plausible futures (MfE 2008). From lowest to highest in terms of temperature projections for this century, they are: B1, A1T, B2, A1B, A2 and A1FI. A more detailed description of these scenarios is contained in Appendix 1 of MfE (2008). To date, climate change projections for New Zealand have focussed on the 'middle-of-the-road' A1B scenario which gives an intermediate level of warming by the end of the 21st Century, and has more GCM output data available than any other scenario. Some projections have been made for other scenarios (e.g. B2, A2, which flank the A1B scenario; see Figure 1), usually by rescaling of the A1B scenario using the known differences on the global scale between it and other scenarios.

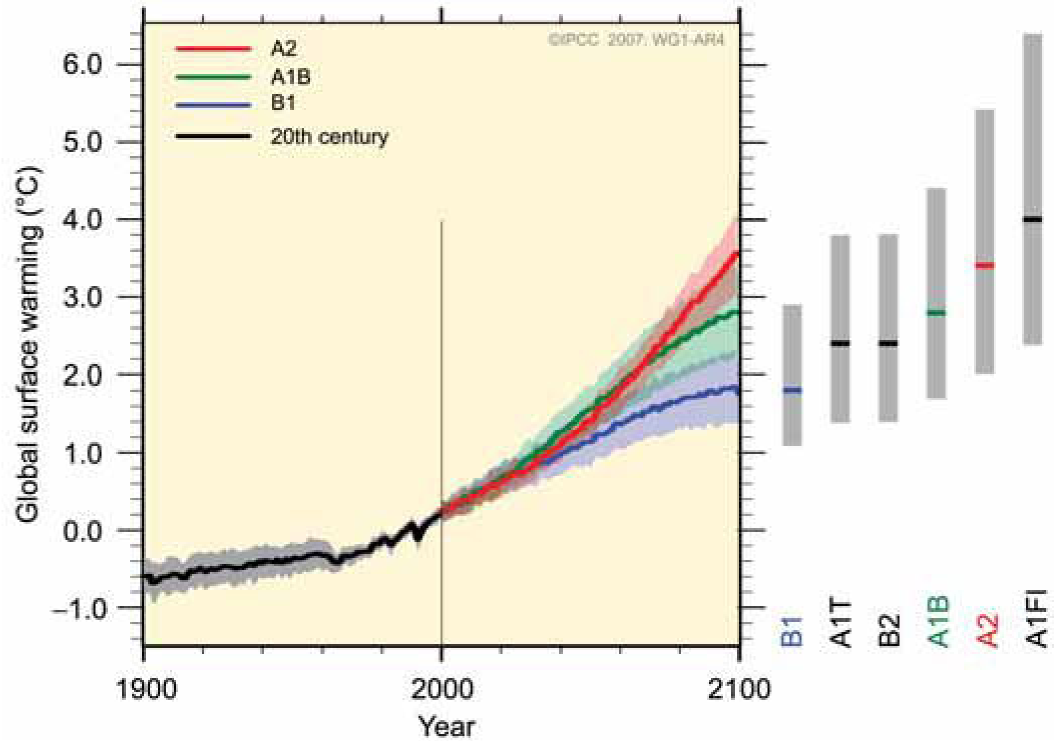

Figure 1. IPCC multi-model temperature projections for selected scenarios. The grey bars to the right show the range in global warming for the scenarios used in MfE (2008).
Note: Solid lines are multi-model global averages of surface warming (relative to 1980-1999) for scenarios B1, A1B and A2, shown as continuations of the 20th century simulations. The coloured shading denotes the ±1 standard deviation range of individual model annual averages. The grey bars at right indicate the best estimate (solid horizontal line within each grey bar) and the 'likely range' for all six SRES illustrative scenarios. Source: IPCC 2007a (Figure SPM.5).

Some 20 Global Circulation Models are available internationally for modelling current and future climates, with the majority of these (Table 1) having been investigated for applicability to the New Zealand region. Validation of control climates for 17 of these models, through comparison of predictions for the 1970-1999 base period with gridded observational data from NCEP re-analysis (Kalnay et al. 1996), found that 5 (including 3 with considerably coarser resolution) of the 17 models performed significantly more poorly than the remaining 12. Therefore these 12 models have generally been used in recent New Zealand climate change studies (e.g. MfE 2008).

Projecting regional and local climate changes across New Zealand from the global projections requires further ‘downscaling’, since the global average does not necessarily apply to a given location in New Zealand. The general projected climate changes outlined for New Zealand in the MfE (2008) report were based on the results from the 12 global climate models (plus additional information provided from a regional climate model), with model changes being statistically “downscaled” to provide increased spatial detail over New Zealand. Historical observations were used to develop regression equations that relate local climate fluctuations to changes at the larger scale (Mullan et al. 2001). These historical observations were then replaced in the regression equations by the modelled changes to produce the fine-scale projections. Downscaled changes were prepared for a 0.05 degrees latitude and longitude grid (approximately 5 km by 4 km) covering New Zealand.

For the MfE (2008) report, downscaling was applied to the projections obtained from 12 GCMs[1] for emissions following the A1B middle-of-the-road emissions scenario (see Figure 1). A range of possible values for each climate variable (temperature, rainfall, etc.) were provided. The range for each variable reflects not only the range of greenhouse gas futures represented by the six SRES illustrative scenarios, but also the range of climate model predictions for individual emission scenarios. Downscaling has also been undertaken for an additional 6 GCMs (see Table 1), and variables expanded to include wind speed (from scaling of westerly and southerly zonal wind components) and relative humidity (through relationships with temperature).

In terms of global changes in temperature and rainfall, the latest AR4 projections include (after MfE 2008):

- Best estimates for global average surface warming ranging from 1.8°C (lowest individual scenario) to 4.0°C warming (highest individual scenario) for the six Special Report on Emissions Scenarios (SRES) illustrative scenarios, with likely ranges for these lowest and highest SRES illustrative scenarios of 1.1-2.9°C, and 2.4-6.4°C, respectively.
- Increases in annual rainfall for some regions and decreases for others (depending on latitude among other factors). For the A1B scenario, which is one of the ‘middle-of-the-road’ SRES illustrative scenarios, these changes are projected to be up to 20%.

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[1] Only 11 of the 12 models used in MfE (2008) were used in the present study (with changes for the NCAR_CCSM30 model not provided).

Table 1. Available Global Climate Models used in the analysis, and projected annual temperature changes (°C) relative to 1980-1999 for 12 GCMs forced by the SRES-A1B scenario (after MfE 2008). Changes are shown for different end periods, for both the global average and downscaled New Zealand average.

Model	Source	Annual temperature changes				
		Global change to 2090-99	Change to 2030-2049		Change to 2080-2099	
			Global avg.	NZ avg.	Global avg.	NZ avg.
BCM2	Bjerknes Centre for Climate Research, Norway [BCCR_BCM2.0]					
CGMR	Canadian Centre for Climate Modelling and Analysis, Canada [CCMA_CGCM3.1]	3.10	1.47	**1.27**	2.99	**2.69**
CNCM3	Météo-France/Centre National de Recherches Météorologiques, France [CNRM_CM3]	2.75	1.30	**0.87**	2.60	**1.83**
CSMK3	CSIRO Atmospheric Research, Australia [CSIRO-MK3.0]	1.98	0.65	**0.54**	1.84	**1.13**
ECHOG	Meteorological Institute of the University of Bonn, Korea Meteorological Administration (KMA), and Model and Data Group, Germany/Korea [MIUB_ECHO-G]	2.86	1.19	**1.12**	2.76	**2.23**
FGOALS	National Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG)/Institute of Atmospheric Physics, China [FGOALS-g1.0]					
GFMC20	National Oceanic and Atmospheric Administration (NOAA)/ Geophysical Fluid Dynamics Laboratory (GFDL), USA [GFDL-CM2.0]	2.90	1.29	**0.82**	2.83	**1.96**
GFMC21	National Oceanic and Atmospheric Administration (NOAA)/ Geophysical Fluid Dynamics Laboratory (GFDL), USA [GFDL-CM2.1]	2.53	1.31	**1.22**	2.44	**2.16**
GIAOM	National Aeronautics and Space Administration (NASA)/Goddard Institute for Space Studies (GISS), USA [GISS-AOM]					
GIEH	National Aeronautics and Space Administration (NASA)/Goddard Institute for Space Studies (GISS), USA [GISS-EH]					
HADCM3	UK Met Office, Hadley Centre, UK [UKMO_HADCM3.0]	2.90	1.24	**0.66**	2.79	**1.56**
HADGEM	UK Met Office, Hadley Centre, UK [UKMO_HADGEM1]	3.36	1.35	**1.14**	3.22	**2.21**
IPCM4	Institut Pierre Simon Laplace, France [IPSL_CM4]					
MIHR	Center for Climate System Research (University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC), Japan [MIROC3.2_hires]	4.34	2.00	**1.35**	4.15	**3.44**
MIMR	Center for Climate System Research (University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC), Japan [MIROC3.2_midres]					
MPEH5	Max Planck Institute for Meteorology, Germany [MPI-OM_ECHAM5]	3.31	1.09	**0.33**	3.15	**1.75**
MRCGCM	Japan [MRI_CGCM232]	2.71	0.97	**0.71**	2.16	**2.07**

NB. The 4th column of temperature changes (e.g. 2.99°C for CGMR) is the one that is comparable to the A1B scenario projections calculated as changes from 1980-1999 to 2080-2099.

While much uncertainty remains regarding the magnitude of regional climate changes, certainty is growing as to the direction of expected changes in New Zealand over the coming century (MfE 2008). These directions include:

- increasing temperatures over the whole country;
- increasing annual average rainfall in the west of the country and decreasing annual average rainfall in Northland and many eastern areas;
- increasing risk of dry periods or droughts in some eastern areas.

Other changes also include reductions in frosts, increasing frequency of heavy rainfall events, and rising sea level.

In the latest guidance on projected changes for New Zealand resulting from the AR4 projections, MfE (2008) suggest the following:

- Best estimates of expected temperature increases of about 1°C by 2040, and 2°C by 2090. However, owing to the different emission scenarios and model climate sensitivities, the projections of future warming cover a wide range, from 0.2-2.0°C by 2040 to 0.7-5.1°C by 2090.
- More marked seasonality in projected rainfall and wind patterns than was evident in models used in the AR3 assessment. Westerly winds are projected to increase in winter and spring, along with more rainfall in the west of both the North and the South Island and drier conditions in the east and north. Conversely, the models suggest a decreased frequency of westerly conditions in summer and autumn, with drier conditions in the west of the North Island and possible rainfall increases in Gisborne and Hawkes Bay.
- Temperature rise is expected to speed up. The rate of temperature increase from these projections is expected to be higher than a linear extrapolation of the historical New Zealand temperature record for the 20th Century.

Further information on the General Circulation Models[2], the downscaling approach, projected changes in weather elements and level of agreement between the model projections can be found in MfE (2008).

Regional Climate Model (RCM) Data

At the outset of the study, it was proposed that fire dangers calculated from application of downscaled GCM model changes also be compared with those obtained through use of the NIWA's Regional Climate Model (RCM). Originally it was proposed that this be undertaken by comparing RCM control and climate change scenario runs for the A2 emissions scenario, with data being obtained for the model grid point closest to each of the 190 weather station locations. Output from a previous ("old") A2 emissions scenario model run was obtained to investigate the feasibility of this methodology while new model runs were undertaken. However, these "new" model runs were delayed due to the installation of a new supercomputer by NIWA, and were not provided in time for this analysis.

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[2] Additional information on the models can also be found in Chapter 10 (Meehl et al. 2007) of the Fourth Assessment Report (Solomon et al. 2007) and on the website http://www-pcmdi.llnl.gov/ipcc/ model_documentation/ipcc

The RCM model was previously run at a 30-km grid spacing over New Zealand, which is an improvement in resolution over the typical global model (100- to 300-km spacing). Computational constraints meant that it had only been run from a single global model (UKMO_HADCM3, see Table 1) and for a limited number of emissions scenarios (A2 and B2). Model output from one of these “old” A2 model runs included daily estimates of surface temperature, relative humidity, wind speed and direction, and total precipitation. However, in the case of temperature, humidity and wind, these were daily mean values rather than specific hour estimates (for 1200 NZST) as usually used for FWI System calculations. In addition, the control run is a free running model so does not match the actual weather of the 20th Century base period, in this case, the 30-year period from 1970-1999 (cf. the 20-year base period from 1980-1999 used in the GCM statistical downscaling). An added complication is that the RCM model is based on a 360-day calendar, with each month (including February) containing 30 days.

This initial investigation of the suitability of RCM output for modelling changes in fire danger with climate change found that the RCM model outputs were not representative of actual observations. Rainfall, in particular, was significantly less than actual values, both on a daily basis and in terms of annual averages, but RCM output contained significantly more (50%) rain days on which rainfall occurs (albeit, in most cases, as relatively small amounts). Temperatures and wind speeds were also lower than actual observations. The result was that when these RCM outputs were used to calculate fire dangers, values (e.g. of Daily (DSR) and Seasonal (SSR) Severity Ratings, and the number of days of Very High and Extreme (VH+E) Forest fire danger) were significantly lower than when determined from actual observations.

As such, it was not considered practical to undertake comparisons of changes in fire danger with future climate change based on such a false assessment of (significantly lower) fire danger values for the current climate base period, and no further investigation of the use of RCM model output was undertaken due to limited time available. However, the potential to adjust RCM model outputs to better reflect actual climate, and modelling of changes under future climate scenarios, warrants greater attention in future.

Virtual Climate Station (VCSN) Data

Initially it was proposed to use time-series of NIWA’s Virtual Climate Station Network (VCSN) gridded data in place of daily (1200 NZST) observations from fire weather stations. This would have enabled datasets of consistent length (covering the 1980-1999 current climate baseline period) for a much greater number of station locations to be utilised (effectively all 190 cf. only 20 stations containing data for the full baseline period). The VCSN dataset contains interpolated estimates of daily 9am or mean temperature, relative humidity, wind speed and precipitation (Tait et al. 2006), although data for some variables (e.g. wind speed) were not available for the early part of this period and had to be reconstructed.

On investigation, however, it was found that the daily VCSN data did not accurately reflect actual station observations, and could not therefore be used in the analyses. Rainfall amounts, in particular, were much higher than actual observations, often by a factor of 3-4 or more and including maximum daily values in excess of 350 mm (and as high as 500 mm), resulting in average annual rainfall totals up to 3 times those from station observations. Similarly, as a result of being averaged from daily wind run measurements, daily mean wind speed values were significantly lower and did not capture the greater day-to-day variability and occasional extreme noon wind speeds observed in station records. Therefore, when combined to calculate fire danger ratings, the daily VCSN values resulted in much lower estimates of the fire climate severity measures, with the number of days of VH+E Forest fire danger being zero and Seasonal Severity Rating values close to zero in all cases. This was only exacerbated when model climate changes were applied which predicted increased rainfall (in some cases, of 800-1000 mm or more for a 24-hour period) and relative humidity values in excess of 100%. It was therefore not possible to realise the intended benefits from the expanded VCSN gridded dataset.

Fire Weather Station Datasets

Therefore the only practical option in the time available was to restrict the analysis to the fire weather station locations from within the Fire Climatology Database (Pearce et al. 2003) that included data for the full 1990s current climate base period (1980-1999). This restricted the number of locations to just 20 stations (Table 2), albeit providing reasonable spatial coverage across the country as well as recognised climate/fire climate regions (Figure 2).

Table 2. Details of fire weather stations used in the current analysis.

Station Code	Station Name	Lat.	Long.	Climate Region[1]	Fire Climate Region[2]
KX	Kaitaia	-35.13	173.25	A1	Far North
DAR	Dargaville	-35.961	173.843	A1	Far North
COR	Coromandel	-36.73	175.5	A2	Auckland East – Coromandel
AKL	Auckland Aero	-37.0	174.8	A1	Auckland West – Waikato
TGA	Tauranga Aero	-37.667	176.2	B1	Bay of Plenty
ROA	Rotorua Aero	-38.1	176.317	A2	Bay of Plenty
GSA	Gisborne Aero	-38.65	177.983	C1	East Coast
APA	Taupo Aero	-38.733	176.067	B2	Bay of Plenty
NPA	New Plymouth Aero	-39.0	174.167	A2	Taranaki – Wanganui
WUA	Wanganui Aero	-39.967	175.017	D1	Taranaki – Wanganui
PPA	Paraparaumu	-40.9	174.983	D1	Manawatu - Wairarapa
WNA	Wellington Aero	-41.333	174.817	D1	Wellington – Nelson/Marl
NSA	Nelson Aero	-41.3	173.217	B1	Wellington – Nelson/Marl.
WSA	Westport	-41.733	171.567	E1	West Coast
HKA	Hokitika Aero	-42.7	170.983	E1	West Coast
KIX	Kaikoura	-42.417	173.683	C1	Northern Canterbury
CHA	Christchurch Aero	-43.483	172.533	F1	Coastal Mid/South Cant'y
QNA	Queenstown Aero	-45.017	168.733	F2	Central Otago – Inland Sthld.
DNA	Dunedin Aero	-45.917	170.183	G1	Coastal Otago
NVA	Invercargill Aero	-46.417	168.333	G2	Southland - Fiordland

[1] New Zealand climate regions, based on seasonal temperature and rainfall; see Figure 1a (after NZMS 1983).

[2] New Zealand fire climate regions, based on responses of fire danger ratings to weather patterns and climate predictors; see Figure 1b (after Heydenrych and Salinger 2002).

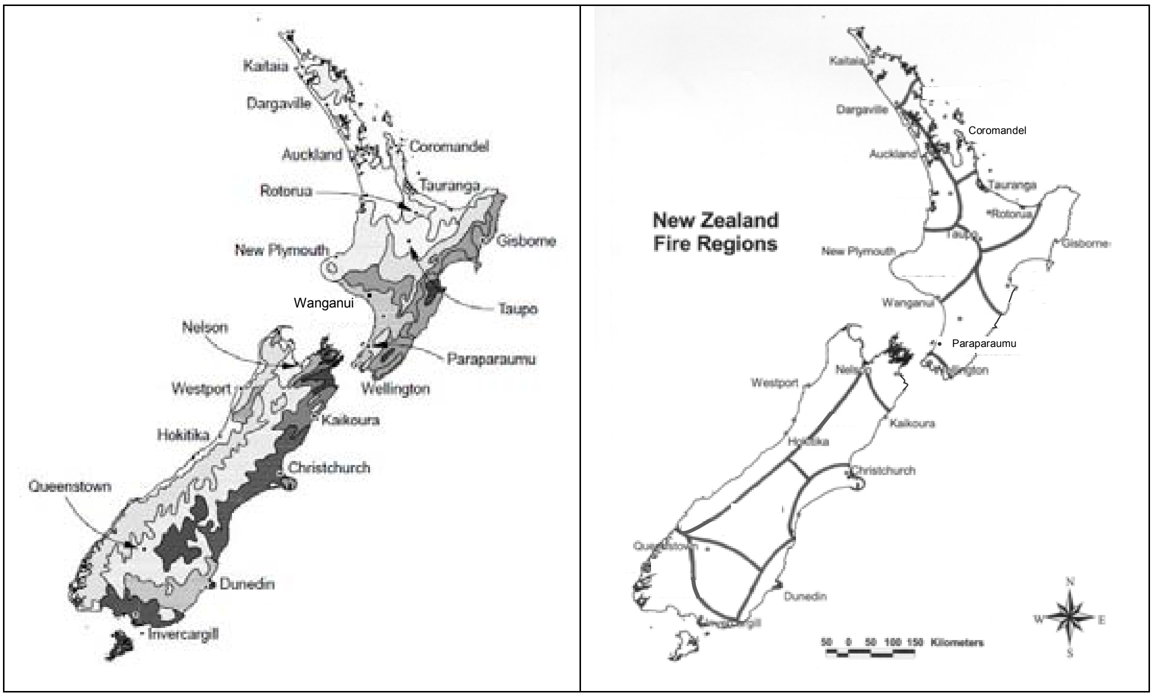

Figure 2. Locations of fire weather stations used in the current analysis, shown in relation to: (a) New Zealand climate regions (after NZMS 1983), and (b) New Zealand fire climate regions (after Heydenrych and Salinger 2002).

These station datasets contained observations of temperature, relative humidity, wind speed and 24-hour rainfall collected at 1200 noon NZST as required for direct input into FWI System calculations. Data checking (for the purposes of extending VCSN data back to 1980) identified some issues with data quality for some stations, especially wind speed, but these were generally able to be easily rectified (usually by converting incorrect units, e.g. m/s to km/h). The resulting datasets for these 20 stations provided the daily time-series used to calculate fire danger for the 1990s current climate base period (1980-1999) for determining changes in changes in fire climate severity under future climate for the 2050s (2040-2059) and 2080s (2070-2089).

Application of Climate Offsets

Changes in weather elements projected for future climate periods (2050s and 2080s) from current climate (“offsets”) were then applied to the weather observations from each of the 20 station’s daily time series. These offsets were obtained by subtracting the values for each weather element from the downscaled VCSN estimates for each future projection period from the VCSN estimates for the current baseline period (1990s) derived for the VCSN grid point closest to each weather station location. Application of these offsets to actual station observations resulted in what were considered more valid values of weather elements for future climate, without the anomalous values (especially of very high daily rainfall) observed in the modelled VCSN datasets, yet still retaining the extremes (of high wind speed, low humidity, and low and high temperatures) again not present in the modelled VCSN data due to use of 9am or mean daily values.

In addition to providing changes for a wider range of models, a key advantage of the data used in the present study was the application of variable estimates of monthly changes for each month from year to year within the projection period, as opposed to a single average monthly offset for each month applied throughout the entire period as was done in the previous (Pearce et al. 2005) study.

Fire Danger Calculations

The adjusted daily time series of weather inputs for each model and projection period were then used to calculate daily and average values of the Fire Weather Index (FWI) System components and two associated fire climate severity measures for current and future fire climate. This involved calculation of values for 35 scenarios for each of the 20 station locations (i.e., current 1990s climate, plus 17 models for each of the 2050s and 2080s).

Two measures of fire climate severity were used to describe the influence of climate change on fire danger levels – the Daily Severity Rating (DSR) and the fire danger class frequency (number of days of Very High and Extreme (VH+E) Forest fire danger. These measures integrate the drying influences of higher temperatures, decreased rainfall and increased wind speeds on potential fire intensity, and indicate the increasing amount of work and difficulty of controlling a fire as fire intensity increases (Van Wagner 1987). The DSR is a numerical rating of the daily fire weather severity at a particular station, based on the Fire Weather Index value, which can be averaged over any period to provide monthly (MSR) or seasonal (SSR) severity ratings (Harvey et al. 1986). The fire danger class scheme currently used in New Zealand includes five fire danger classes – Low, Moderate, High, Very High, and Extreme – that provide an indication of the increasing difficulty of fire suppression as fire intensity increases (Alexander 1994). The fire danger class frequency refers to the number of days occurring in the Very High and Extreme (VH+E) fire danger classes for plantation forest fuels, which represent the conditions under which it will be difficult, if not impossible, to control fires with conventional suppression techniques due to their intensity. These two measures have been used in a number of other studies on New Zealand's fire climate (Pearce et al. 2003, 2007), including the previous study on the effect of climate change (Pearce et al. 2005).

Fire climate severity for current and future fire climates at each location were then compared using the estimates from the different GCMs, including both individual model estimates as well as the average across all 17 models investigated. Projected regional changes were also mapped[3] to illustrate potential changes across the country, again using the 17 model averages, plus examples of high, mid and low-range model estimates. While results were also calculated for the full calendar year (see Appendix 1), those presented in the following section are based on changes predicted for the recognised fire season period (October to April), when higher fire dangers and the majority of fires occur.

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[3] Note that caution should be applied when interpreting the maps of potential changes, due to the interpolation (spline) of estimated changes for such a limited number of station locations (only 20).

RESULTS AND DISCUSSION

Changes in Fire Danger

Estimated changes in fire danger during fire season months[4] (Oct-Apr) using the two fire climate severity measures for the 2050s and 2080s are presented in the figures and tables that follow. Figures 3 & 4 and Tables 3 & 4 illustrate the projected changes from current (1990s) fire climate for the 2050s, and Figures 5 & 6 and Tables 5 & 6 the changes for the 2080s. The tables compare estimates of the fire climate severity measures from the 17 GCMs with the overall model average as well as current (actual) climate, whereas the figures illustrate changes in fire climate severity from current climate (as a % change) across the country. Note that caution should be applied when interpreting the changes depicted in these maps, particularly for locations other than those investigated, due to the limited number of station locations on which the (spline) interpolation is based. Despite this limited number of sampling sites, these maps do still provide an indication of potential spatial changes in fire climate severity in different parts of the country for the two projection periods.

Projected changes for the 2050s

For Seasonal Severity Rating (SSR), the 17 model average (Figure 3a) shows the greatest potential increases (50-100%) in coastal Marlborough and Otago, resulting from the increases projected for the Kaikoura (KIX) and Dunedin Aero (DNA) stations (Table 3). Lower yet still significant increases of 40-50% are indicated for Wellington (based on Wellington Aero, WNA) and 30-40% for Taranaki and Wanganui (based on the responses of New Plymouth, NPA, and Wanganui, WUA). The overall model average indicates no areas of potential decrease in SSR, but predicts smaller increases (of 10-20% or 20-30%) or little or no change (0-10%) over the rest of the country.

By comparison, the low model example (Figure 3b), which is based on the MIMR model which was the model to consistently show the lowest overall changes (see Tables 3-6), indicates the highest potential increases (50-100%) in coastal Otago and slightly lower increases (30-50%) for Marlborough. Increases of 20-30% are projected for the lower North Island, and lesser increases or little or no change (<20%) are indicated over the remainder of the country. No decreases were determined for any stations under this model (Table 3), but their potential is indicated for Fiordland by the interpolation of the limited station changes.

The mid range model example (Figure 3c), which is based on the ECHOG model, extends the area of highest potential increase in SSR (50-100%) from coastal Otago into Southland (based on the response of Invercargill, NVA; see Table 3). The region of slightly lower potential increases (30-50%) also expands to include the rest of the lower South Island (with the exception of the Queenstown, QNA), and to the areas immediately around New Plymouth (NPA) and Taupo (APA) (see Table 3). Under this model, much of the upper South Island and lower North Island falls into the 20-30% increase class, with the exception of the Nelson (NSA), Wellington (WNA) and East Cape (ex Gisborne, GSA) areas which, together with

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[4] Changes for the full calendar year are included in Appendix 1.

Auckland and Northland, showed little or no change (<20%). No areas with decreasing SSR were indicated under this model for this 2050s projection period.

In contrast, the high-range model example (Figure 3d), illustrated using the IPCM4 model which consistently produced the highest increases of all the models (see Tables 3-6), shows the potential for significantly higher SSR values across much of the country. Again the greatest increases, in this instance of greater than 150%, are located around coastal Otago (Dunedin Aero, DNA) and Marlborough (Kaikoura, KIX), with areas of 100-150% increases indicated over the lower North Island based on the responses of Wellington (WNA), Paraparaumu (PPA), Wanganui (WUA) and New Plymouth (NPA) (Table 3). Most of the remainder of the North Island falls into the 30-50% increase classes, with only Gisborne (GSA) and the eastern Bay of Plenty (Rotorua, ROA), and the Coromandel (COR) projected to have lower (<30%) increases in SSR. In the South Island, the central Canterbury (based on Christchurch Aero, CHA) and West Coast (Hokitika, HKA, and Westport, WSA) regions are expected to show little or no change, with interpolation also indicating possible decreases for Fiordland although no decreases in SSR were found at any station for the 2050s under this IPCM4 model (see Table 3).

Changes projected for the number of days of Very High and Extreme (VH+E) forest fire danger, when expressed on a percentage basis, were generally higher (typically about twice) those estimated for the SSR. However, although the values of these projected changes were higher, the spatial pattern of changes (Figure 4) was similar to that found for the SSR for the same (2050s) projection period (see Figure 3).

In the case of the 17 model average, the spatial pattern in days of VH+E fire danger (Figure 4a) was not dissimilar from the SSR high-model example for the 2050s (see Figure 3d), with the areas of greatest increases (>100%) also being found in coastal Otago and Marlborough (based on the responses of Dunedin Aero, DNA, and Kaikoura, KIX; see Table 4), and the lower North Island (driven in particular by the changes observed at Wanganui, WUA). However, the area of slightly less severe increases (50-100%) extended further north into the Bay of Plenty, based on the higher number of days of VH+E projected for Taupo (APA) and Rotorua (ROA). Remaining areas of the North Island showed potential increases in the 20-50% range, with the exception of East Cape where little or no change (<10%) is projected. In the South Island, the Canterbury and West Coast regions also show little or no change, and the potential for some decreases (of up to -20%) based on the changes in VH+E fire danger observed at Hokitika (HKA) (Table 4).

The VH+E low-range model example (based on the MIMR model) for the 2050s (Figure 4b) showed a very similar spattern to the 17 model average (see Figure 4a), particularly in the South Island. In the north, the region of significant increases (>100%) was reduced to the area immediately surrounding Wanganui (WUA), and the Northland and Auckland region also showing lower potential changes of 10-20% based on the responses of the Auckland Aero (AKL), Dargaville (DAR) and Kaitaia (KX) stations (Table 4).

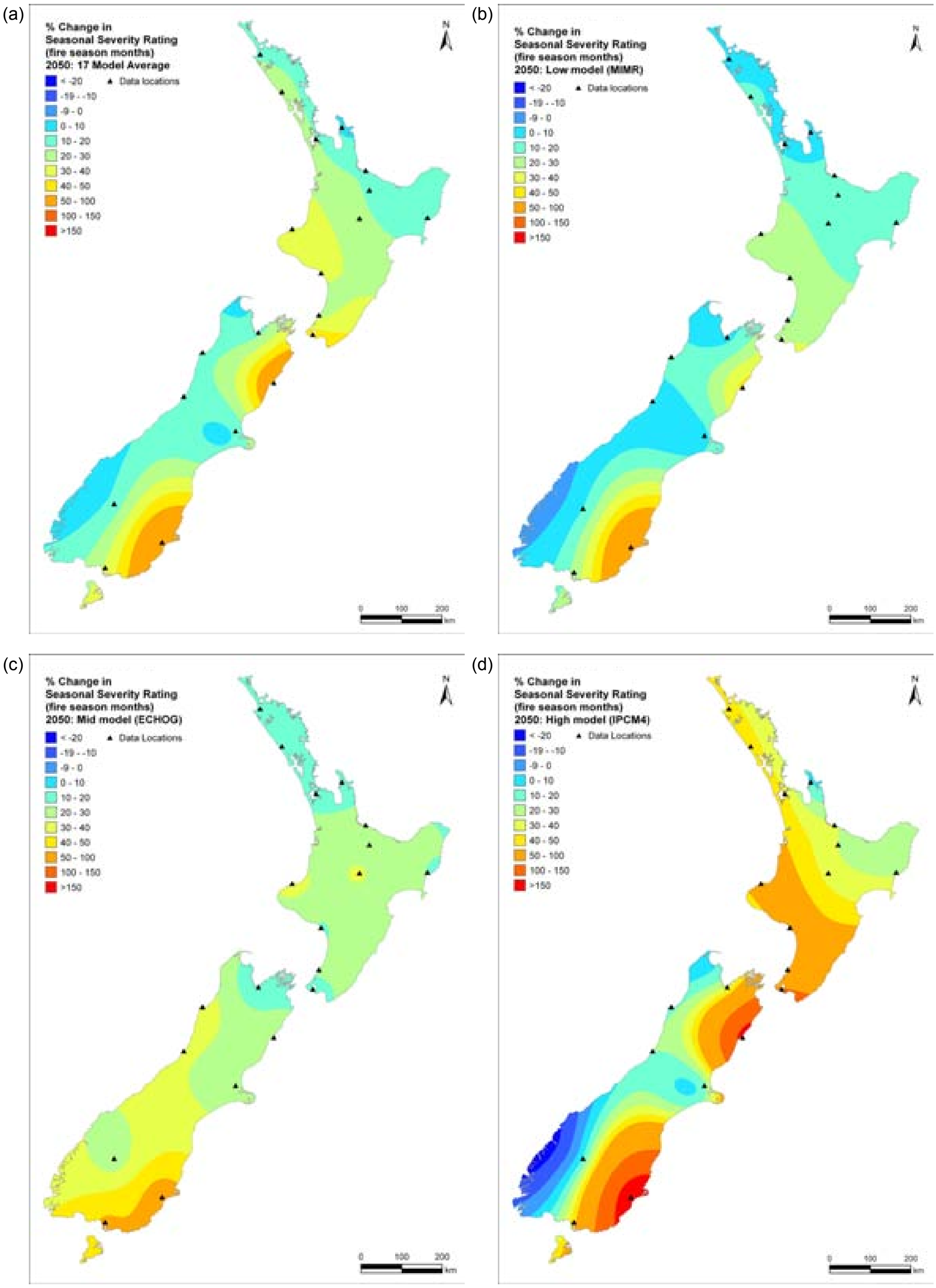

Figure 3. Changes (%) in the average Seasonal Severity Rating (SSR) over fire season months (Oct-Apr) from current climate to the 2050s (2040-2059) for: (a) the average of all 17 models investigated; (b) an example low-range model (MIMR); (c) an example mid-range model (ECHOG); and (d) an example high-range model (IPCM4).

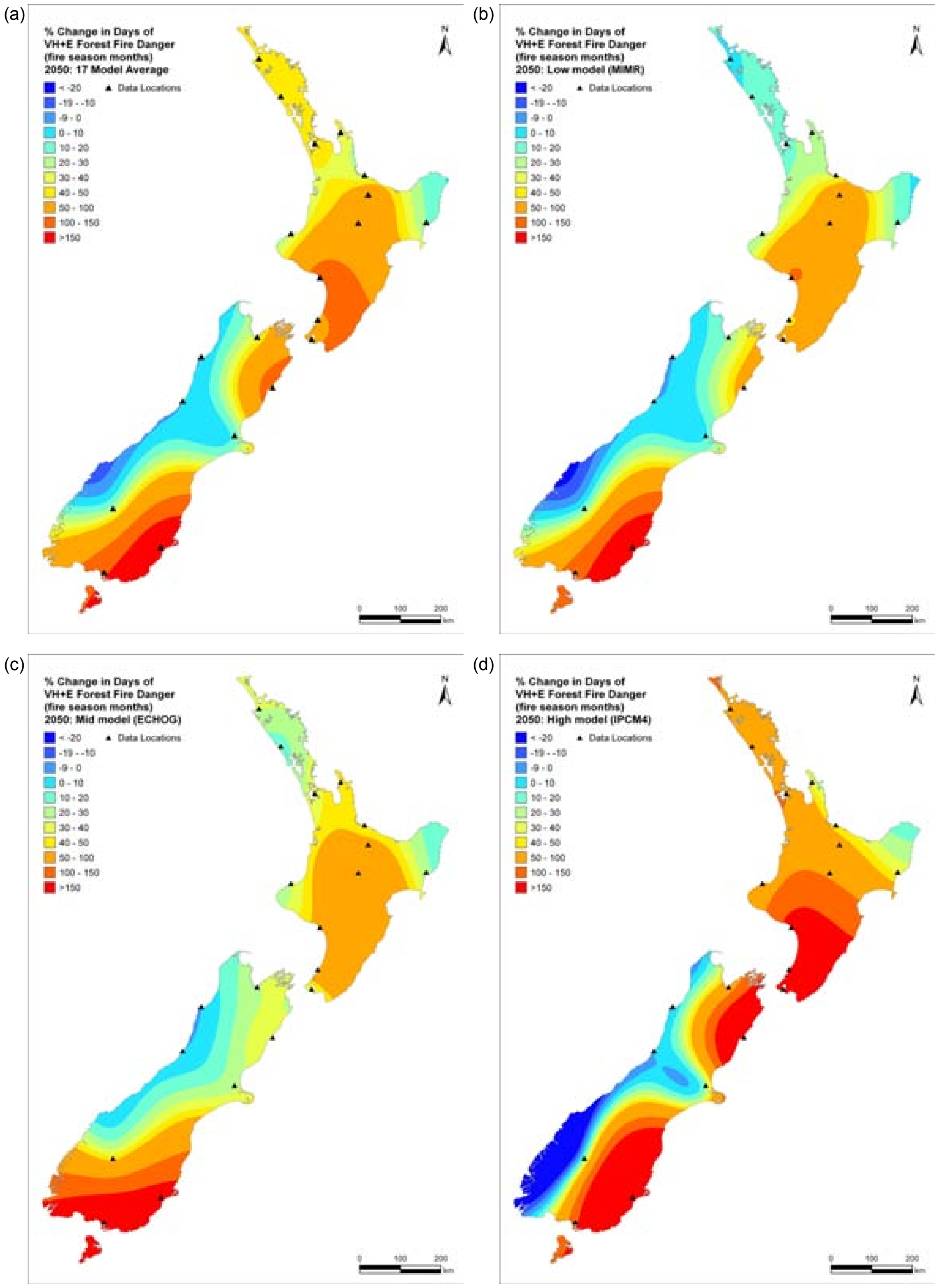

Figure 4. Changes (%) in the average number of days/year of Very High and Extreme (VH+E) Forest Fire Danger over fire season months (Oct-Apr) from current climate to the 2050s (2040-2059) for: (a) the average of all 17 models investigated; (b) an example low-range model (MIMR); (c) an example mid-range model (ECHOG); and (d) an example high-range model (IPCM4).

Table 3. Average Seasonal Severity Rating (SSR) over fire season months (Oct-Apr) estimated for the 2050s (2040-2059) from 17 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	Actual	Models for 2050s – Seasonal Severity Rating (SSR)																	Model avg.
		BCM2	**CGMR**	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**1.51**	1.66	1.91	1.68	1.74	1.67	1.74	1.79	1.62	1.77	1.77	1.69	1.99	2.15	1.84	1.57	1.99	1.87	**1.79**
DAR	**0.87**	1.01	1.19	1.01	1.06	1.01	1.05	1.11	1.00	1.03	1.08	1.01	1.20	1.26	1.10	0.98	1.14	1.10	**1.08**
COR	**0.94**	1.04	1.09	1.02	1.01	1.08	1.00	1.04	1.01	1.01	1.03	0.91	1.07	1.03	0.98	0.97	1.00	1.04	**1.02**
AKL	**1.86**	2.13	2.34	2.11	2.11	2.16	2.17	2.26	2.02	2.18	2.26	2.06	2.50	2.63	2.31	2.00	2.50	2.30	**2.24**
TGA	**1.72**	2.07	2.22	1.90	1.95	2.12	1.89	2.14	1.97	1.96	2.14	1.69	2.20	2.24	1.91	1.96	2.14	2.06	**2.03**
ROA	**0.90**	1.06	1.16	1.01	1.04	1.11	0.98	1.09	1.03	1.02	1.14	0.93	1.15	1.16	1.01	1.01	1.12	1.07	**1.06**
GSA	**4.41**	5.14	5.38	4.97	4.97	5.29	4.82	5.25	4.99	4.88	5.29	4.36	5.34	5.69	5.20	5.02	5.10	5.10	**5.10**
APA	**0.92**	1.13	1.21	1.06	1.08	1.21	1.04	1.20	1.08	1.06	1.21	0.91	1.26	1.26	1.07	1.06	1.19	1.17	**1.13**
NPA	**0.62**	0.71	0.81	0.69	0.73	0.74	0.72	0.72	0.69	0.70	0.78	0.69	0.84	0.84	0.77	0.67	0.79	0.73	**0.74**
WUA	**1.22**	1.51	1.66	1.45	1.44	1.45	1.54	1.62	1.54	1.51	1.64	1.51	1.78	1.90	1.72	1.51	1.79	1.69	**1.60**
PPA	**1.15**	1.36	1.54	1.38	1.37	1.40	1.40	1.46	1.40	1.37	1.49	1.40	1.52	1.83	1.65	1.38	1.55	1.49	**1.47**
WNA	**3.22**	4.00	4.87	4.01	4.19	3.73	4.86	4.55	4.38	4.56	4.32	4.91	4.92	6.53	5.36	4.16	5.07	4.85	**4.66**
NSA	**2.05**	2.29	2.64	2.32	2.26	2.28	2.37	2.42	2.32	2.34	2.46	2.27	2.51	2.75	2.41	2.19	2.52	2.38	**2.40**
WSA	**0.23**	0.27	0.29	0.26	0.27	0.32	0.26	0.28	0.27	0.26	0.28	0.24	0.29	0.27	0.27	0.26	0.29	0.28	**0.27**
HKA	**0.14**	0.16	0.17	0.15	0.16	0.19	0.15	0.16	0.15	0.15	0.17	0.15	0.17	0.17	0.17	0.15	0.16	0.16	**0.16**
KIX	**1.54**	1.98	2.73	2.25	2.40	2.00	2.53	2.83	2.37	2.51	2.10	2.49	2.51	4.03	3.36	2.20	2.73	2.81	**2.58**
CHA	**5.60**	6.29	6.83	6.25	6.29	6.86	6.09	6.46	6.19	6.16	6.56	5.35	6.21	6.63	6.17	6.04	6.21	6.29	**6.29**
QNA	**1.45**	1.70	1.71	1.60	1.69	1.79	1.55	1.75	1.69	1.54	1.74	1.54	1.73	1.62	1.55	1.60	1.67	1.71	**1.66**
DNA	**1.70**	2.07	3.73	2.71	2.93	2.70	2.83	2.99	3.05	2.54	2.15	2.72	2.83	4.75	3.30	2.99	2.56	3.01	**2.93**
NVA	**0.58**	0.72	0.90	0.69	0.75	0.89	0.67	0.79	0.77	0.72	0.85	0.67	0.77	0.86	0.76	0.72	0.78	0.74	**0.77**
Avg.	**1.63**	**1.91**	**2.22**	**1.93**	**1.97**	**2.00**	**1.98**	**2.10**	**1.98**	**1.96**	**2.02**	**1.87**	**2.14**	**2.48**	**2.14**	**1.92**	**2.11**	**2.09**	**2.05**

Table 4. Average number of days/year of Very High and Extreme (VH+E) Forest fire danger for fire season months (Oct-Apr) estimated for the 2050s (2040-2059) from 17 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Actual**	**Models for 2050s – Days of VH+E Fire Danger**																	**Model avg.**
		BCM2	**CGMR**	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**5.9**	7.1	9.3	7.4	8.1	7.6	6.3	8.4	6.2	7.5	7.8	8.6	9.6	11.3	9.4	6.4	10.0	9.1	**8.2**
DAR	**2.2**	2.5	3.6	2.7	3.2	2.5	2.8	3.5	2.7	2.9	2.9	3.4	4.0	3.5	2.9	2.4	3.3	3.3	**3.1**
COR	**1.5**	2.2	2.6	2.1	1.9	2.3	1.7	2.2	2.1	2.4	2.2	2.2	1.9	2.1	1.8	1.9	1.7	2.5	**2.1**
AKL	**8.3**	11.2	13.0	10.0	10.5	11.2	10.9	12.9	9.7	10.9	12.0	12.2	16.0	16.4	12.1	9.7	16.0	12.7	**12.2**
TGA	**7.7**	11.0	11.7	8.5	9.4	10.7	8.4	10.8	9.5	9.7	10.9	8.0	12.2	11.1	9.0	10.2	11.2	10.0	**10.1**
ROA	**1.5**	2.5	3.3	1.9	2.8	2.4	2.1	2.9	1.9	2.1	2.8	3.1	2.9	2.4	2.0	2.6	2.8	2.8	**2.5**
GSA	**34.1**	41.3	44.3	40.6	38.6	42.4	37.3	42.5	39.8	38.5	42.8	34.6	44.0	47.3	43.1	39.9	42.3	40.1	**41.1**
APA	**2.2**	3.3	4.5	3.2	3.1	4.4	3.1	4.4	2.9	3.2	3.6	2.4	4.3	4.3	3.0	3.6	4.0	4.0	**3.6**
NPA	**1.1**	0.9	1.7	1.1	1.1	1.8	1.3	1.3	1.1	1.1	1.6	1.6	1.9	1.7	1.4	1.3	1.4	1.3	**1.4**
WUA	**2.6**	4.9	6.4	4.0	4.5	4.1	5.0	5.8	5.2	4.7	5.9	5.5	7.2	6.9	6.2	5.2	6.8	5.9	**5.5**
PPA	**2.0**	2.6	4.6	3.0	3.8	3.4	3.4	3.6	3.1	3.1	4.1	4.0	4.1	5.2	5.1	2.9	4.8	3.7	**3.8**
WNA	**16.8**	26.1	35.5	25.6	27.0	22.7	33.5	32.4	28.0	31.2	28.0	35.7	36.1	52.2	39.0	27.8	34.4	36.3	**32.4**
NSA	**8.9**	11.6	14.5	11.4	10.9	11.4	11.9	12.4	11.7	11.0	12.4	12.2	12.7	15.6	12.0	10.8	14.0	12.5	**12.3**
WSA	**0**	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0	**0.0**
HKA	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0.0**
KIX	**6.3**	9.4	15.7	11.1	12.1	8.8	14.1	16.6	13.1	13.9	10.2	14.9	13.7	25.8	21.4	10.2	16.2	15.8	**14.3**
CHA	**39.7**	45.4	51.7	44.7	46.2	50.6	42.2	45.7	44.5	42.9	46.9	37.4	45.1	49.1	43.9	43.4	43.2	46.6	**45.2**
QNA	**5.8**	7.4	7.4	7.1	7.5	8.4	6.3	8.4	7.5	6.0	8.2	6.2	8.1	6.9	6.1	6.7	7.1	7.7	**7.2**
DNA	**5.7**	9.7	25.0	15.0	18.7	16.0	15.9	18.3	17.8	14.2	20.8	16.2	16.5	33.7	19.1	18.2	13.2	16.9	**17.9**
NVA	**0.4**	0.8	1.5	0.4	1.0	1.3	0.4	1.5	1.1	0.8	1.4	0.6	1.0	1.0	0.8	0.9	1.5	0.9	**1.0**
Avg.	**7.6**	**10.0**	**12.8**	**10.0**	**10.5**	**10.6**	**10.3**	**11.6**	**10.4**	**10.3**	**11.2**	**10.4**	**12.0**	**14.8**	**11.9**	**10.2**	**11.7**	**11.6**	**11.2**

The mid-range model example (again, based on the ECHOG model) for VH+E fire danger for the 2050s (Figure 4c) also showed a somewhat similar pattern to the low-range model for the same period (see Figure 4b). However, in the South Island, the area of greatest potential increases (>150%) extended to cover more of the Southland region (based on model response for Invercargill, NVA; see Table 4), and potential changes in the Canterbury region were higher (due to greater increases for Christchurch Aero, CHA) than in low-range model. The projected severity of changes for the Marlborough region (30-40%) was also lower, based on changes observed at Kaikoura, KIX). In the North Island, higher potential changes were projected for Auckland and much of Northland, based on higher observed changes at Auckland Aero (AKL) and Kaitaia (KX), but not Dargaville (DAR) (see Table 4).

The high-range model example (illustrated using the IPCM4 model that projected the highest overall increases), predicts the potential for significantly increased numbers of days of VH+E fire danger right across the country for the 2050s (Figure 4d). In the South Island, only inland Canterbury and the West Coast regions are projected to show little or no increase in the potential frequency of VH+E fire weather days, which in Canterbury's case is most likely as a result of the interpolation and insufficient stations in this area. Despite no stations showing decreases for this model (see Table 4), a possible reduction in the number of days of VH+E is also indicated by the interpolation of the low or no changes projected at Queenstown (QNA) and Hokitika (HKA).

Projected changes for the 2080s

Spatial changes in fire climate severity projected for the 2080s were somewhat similar to those found for the 2050s (see Figures 5 & 6, cf. Figures 3 & 4), primarily as a result of the interpolation of values from such a limited number of station sites. However, they were also different due to the greater variability between individual model projections for this longer range time period.

For fire season SSR values in the 2080s, the 17 model average (Figure 5a) shows a very similar spatial pattern and scale of changes to the 2050s (see Figure 3a). Projected changes are greatest (50-100%) for the coastal areas of Otago and Marlborough (again, based on the responses of Dunedin Aero (DNA) and Kaikoura (KIX) to the various GCMs; see Table 5), and lowest (<20%) in Fiordland (largely due to changes for Queenstown, QNA), northwest Nelson (based on Nelson, NSA), inland Canterbury (Christchurch Aero, CHA), and in the coastal areas of the northeastern North Island extending from East Cape to Northland (derived from changes observed at Tauranga (TGA), Coromandel (COR) and Kaitaia (KX); see Table 5).

The low-range model example for SSR (illustrated using the MIMR model) (Figure 5b), is also somewhat similar to the low-range model of SSR for the 2050s (see Figure 3b). This is especially so in the South Island, where only the northwest Nelson area shows lower projected changes and, in this case, a potential reduction in SSR (of up to -20%) from current climate (based on MIMR model projections for Nelson, NSA; see Table 5). The coastal areas around Dunedin Aero (DNA) and Kaikoura (KIX) are the only areas to show the potential for significant increases in SSR (>30%) for this period, with changes over the entire North Island projected to increase only slightly (<30%), or decrease as in Northland (by up to -10%) based on modelled changes for Kaitaia (KX) (see Table 5).

Projected changes in SSR for the mid-range model example (illustrated by the ECHOG model) (Figure 5c) show a somewhat similar pattern to SSR changes for the 2050s (see Figure 3c), but with greater potential increases (40-100%) across the south of the South Island due to higher projected increases at Invercargill (NVA) and Queenstown (QNA) (see Table 5). Potential changes across central New Zealand (<20%) are also lower than for the 2050s due to lower predicted increases for Paraparaumu (PPA) and Wanganui (WUA), no change for Wellington (WNA), and a reduction in SSR (by -13%) at Kaikoura (KIX). Northland also shows a potential reduction (of up to -20%) due to decreases projected for both Kaitaia (KX) and Dargaville (DAR) of -17% and -12%, respectively (see Table 5). In contrast, the central North Island area shows the potential for greater increases (30-40%) due to higher projected increases for Taupo (APA).

The high-range model example for SSR for the 2080s (based on IPCM4) (Figure 5d) shows a more similar pattern to its 2050s counterpart (see Figure 3d), but with generally higher changes projected across the entire country. Peak values of greater than 100% are still centred around Dunedin (DNA) and Kaikoura (KIX), but extend to the lower North Island based on higher projected values for Wellington (WNA) (see Table 5). Increased changes (of >50%) also extend across the central North Island and through western parts of Auckland and Northland, and are also projected (generally >30%) for Canterbury and the West Coast.

The pattern of spatial changes for the 17 model average of days of VH+E fire danger for the 2080s (Figure 6a) shows an almost identical pattern to that for the 2050s (see Figure 4a), with only minor differences resulting from the generally slightly greater increases (typically of up to one map legend class, or around 5-10%) projected for the 2080s than for the 2050s (see Table 6, cf. Table 4).

The spatial pattern of changes for the 2080s low-range model for VH+E fire danger (Figure 6b) is similar to that for its 2050s counterpart (Figure 4b), both of which are based on the MIMR model, and is also not unlike the pattern illustrated for the 2050s high-range model for SSR (which is based on the IPCM4 model), especially over the South Island. Changes in peak fire danger class frequency (>150%) are focussed more around Dunedin Aero (DNA), with lower increases (50%, cf. 100-150% for 2050s low-model VH+E) projected for Invercargill (NVA). Lower values, and potentially a reduction (of up to -10%), are also indicated for the northwest Nelson area that extend up into western Taranaki as a result of modelled changes for Nelson (NSA) and New Plymouth (NPA) (see Table 6). Projected changes across the rest of the North Island for the 2080s are also generally lower for the 2050s low-model for VH+E, including much of the central North Island (Taupo, APA, Rotorua, ROA, and Tauranga, TGA), and Coromandel (COR) and Northland (Dargaville, DAR).

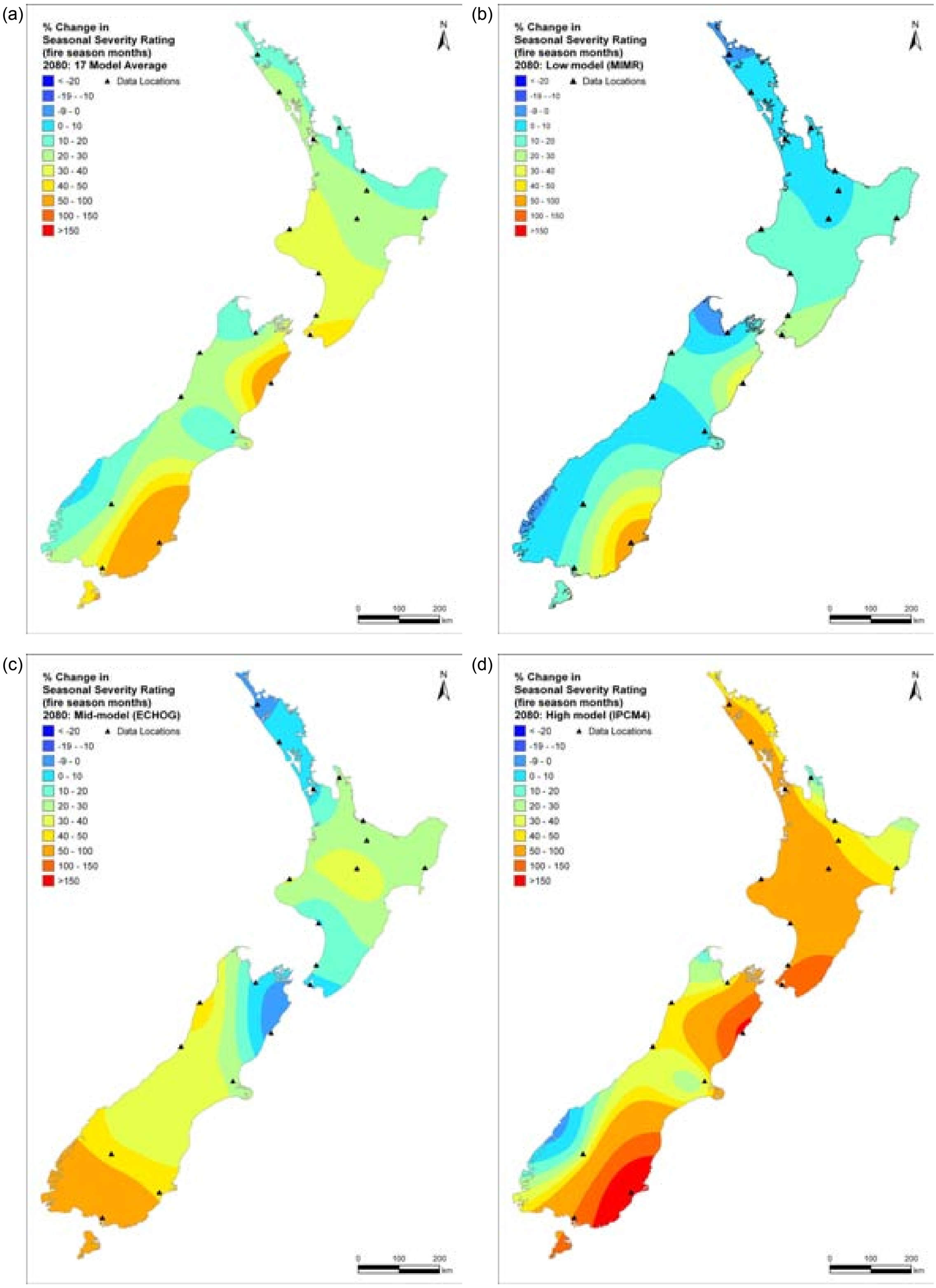

Figure 5. Changes (%) in the average Seasonal Severity Rating (SSR) over fire season months (Oct-Apr) from current climate to the 2080s (2070-2089) for: (a) the average of all 17 models investigated; (b) an example low-range model (MIMR); (c) an example mid-range model (ECHOG); and (d) an example high-range model (IPCM4).

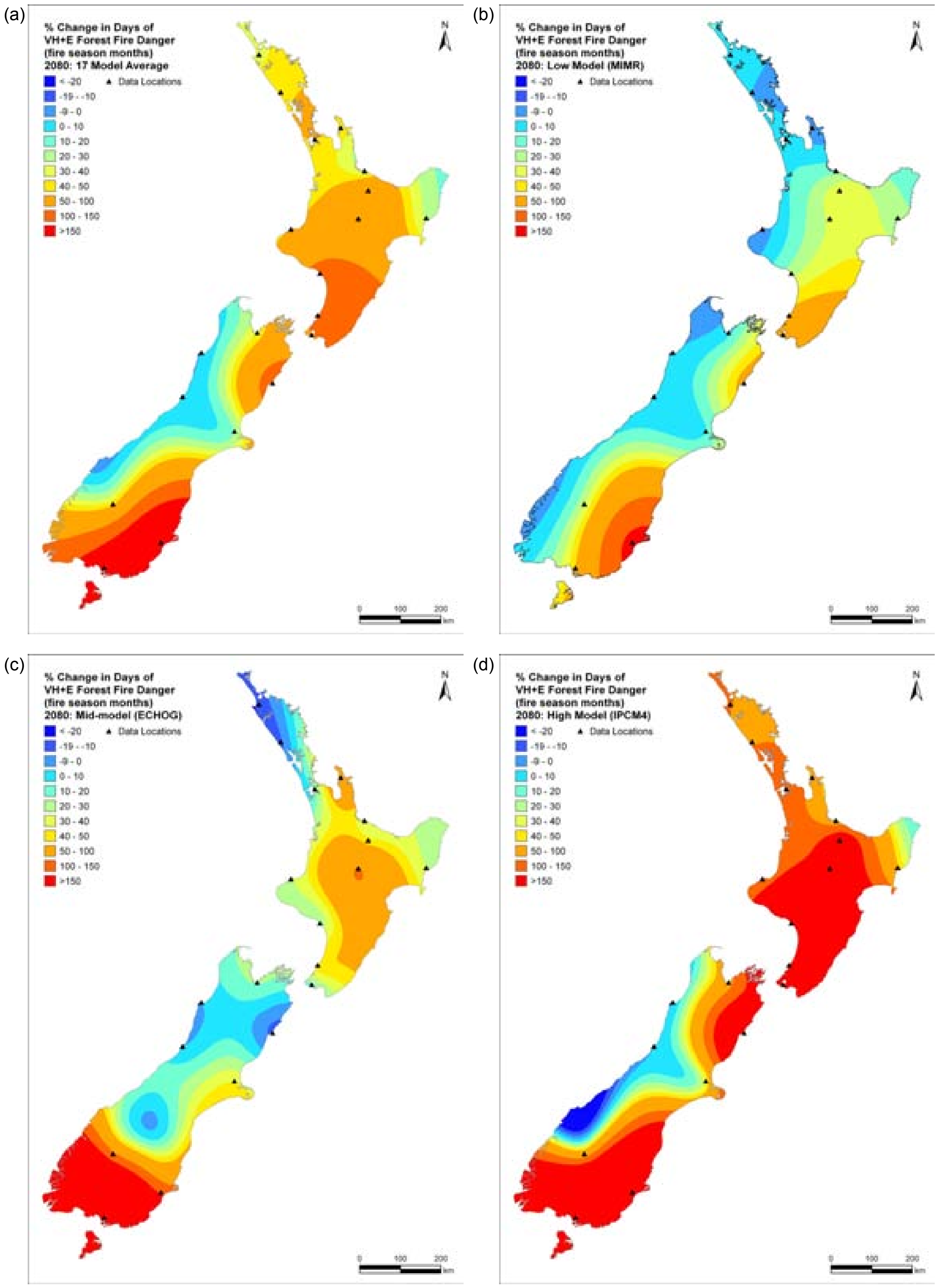

Figure 6. Changes (%) in the average number of days/year of Very High and Extreme (VH+E) Forest Fire Danger over fire season months (Oct-Apr) from current climate to the 2080s (2070-2089) for: (a) the average of all 17 models investigated; (b) an example low-range model (MIMR); (c) an example mid-range model (ECHOG); and (d) an example high-range model (IPCM4).

Table 5. Average Seasonal Severity Rating (SSR) over fire season months (Oct-Apr) estimated for the 2080s (2070-2089) from 17 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	Actual	Models for 2080s – Seasonal Severity Rating (SSR)																	Model avg.
		BCM2	CGMR	CNCM3	CSMK3	ECHOG	FGOALS	GFCM20	GFCM21	GIAOM	GIEH	HADCM3	HADGEM	IPCM4	MIHR	MIMR	MPEH5	MRCGCM	
KX	**1.51**	1.62	2.13	1.74	1.84	1.43	1.79	1.85	1.55	1.70	1.44	1.93	1.88	2.28	1.86	1.49	1.98	1.73	**1.78**
DAR	**0.87**	1.00	1.40	1.07	1.18	0.93	1.08	1.17	0.99	0.99	0.55	1.14	1.12	1.41	1.13	0.91	1.20	1.12	**1.08**
COR	**0.94**	1.11	1.21	1.06	1.08	1.15	1.05	1.08	1.03	0.99	0.93	0.99	1.02	1.12	1.04	0.95	1.04	1.11	**1.06**
AKL	**1.86**	2.15	2.69	2.17	2.30	1.97	2.24	2.43	1.89	2.15	1.83	2.36	2.27	3.01	2.46	1.91	2.49	2.17	**2.26**
TGA	**1.72**	2.03	2.34	1.95	2.12	2.13	1.92	2.17	1.80	1.91	1.74	1.76	2.17	2.48	2.07	1.87	2.32	2.04	**2.05**
ROA	**0.90**	1.05	1.29	1.03	1.13	1.09	1.01	1.11	0.96	0.99	0.90	0.97	1.15	1.33	1.11	0.97	1.21	1.06	**1.08**
GSA	**4.41**	5.27	5.87	5.34	5.22	5.38	5.05	5.60	5.02	5.03	4.85	4.44	5.52	6.18	5.69	5.20	5.70	5.27	**5.33**
APA	**0.92**	1.12	1.35	1.06	1.20	1.27	1.03	1.24	0.98	1.03	0.97	0.95	1.25	1.48	1.18	1.01	1.31	1.16	**1.15**
NPA	**0.62**	0.73	0.95	0.72	0.82	0.71	0.74	0.77	0.66	0.67	0.62	0.76	0.76	0.96	0.79	0.59	0.84	0.78	**0.76**
WUA	**1.22**	1.47	1.90	1.58	1.65	1.33	1.57	1.72	1.39	1.43	1.28	1.62	1.68	2.27	1.82	1.35	1.91	1.57	**1.62**
PPA	**1.15**	1.39	1.82	1.54	1.50	1.35	1.49	1.68	1.35	1.38	1.33	1.53	1.53	2.26	1.83	1.37	1.71	1.51	**1.56**
WNA	**3.22**	3.83	4.97	4.52	4.31	3.24	4.86	5.57	3.86	4.21	3.44	5.54	4.32	6.88	5.51	3.98	5.54	4.26	**4.64**
NSA	**2.05**	2.32	2.90	2.40	2.40	2.17	2.40	2.52	2.18	2.22	2.01	2.57	2.45	2.84	2.46	2.02	2.58	2.38	**2.40**
WSA	**0.23**	0.29	0.32	0.28	0.29	0.35	0.26	0.30	0.27	0.26	0.26	0.27	0.29	0.33	0.30	0.26	0.30	0.32	**0.29**
HKA	**0.14**	0.17	0.19	0.16	0.18	0.19	0.17	0.17	0.15	0.15	0.15	0.17	0.18	0.20	0.18	0.15	0.18	0.18	**0.17**
KIX	**1.54**	1.96	3.11	2.46	2.56	1.46	2.90	3.26	2.23	2.33	1.74	2.95	2.33	4.07	3.15	2.14	2.84	2.30	**2.58**
CHA	**5.60**	6.63	7.90	6.59	6.59	7.16	6.32	6.67	6.21	6.19	6.08	5.89	6.24	7.55	6.99	6.02	6.57	6.87	**6.62**
QNA	**1.45**	1.85	1.93	1.72	1.79	2.09	1.65	1.71	1.79	1.52	1.66	1.64	1.74	1.90	1.75	1.61	1.78	1.88	**1.77**
DNA	**1.70**	2.33	5.12	3.28	3.37	2.51	3.07	3.94	3.28	2.79	2.59	3.37	2.96	5.39	3.60	2.72	3.41	2.89	**3.33**
NVA	**0.58**	0.80	1.17	0.81	0.81	1.05	0.79	0.85	0.75	0.72	0.76	0.73	0.75	1.19	0.89	0.69	0.85	0.92	**0.85**
Avg.	**1.63**	**1.96**	**2.53**	**2.07**	**2.12**	**1.95**	**2.07**	**2.29**	**1.92**	**1.93**	**1.76**	**2.08**	**2.08**	**2.76**	**2.29**	**1.86**	**2.29**	**2.08**	**2.12**

Table 6. Average number of days/year of Very High and Extreme (VH+E) Forest fire danger for fire season months (Oct-Apr) estimated for the 2080s (2070-2089) from 17 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Actual**	**Models for 2080s – Days of VH+E Fire Danger**																	**Model avg.**
		BCM2	**CGMR**	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**5.9**	6.3	11.1	7.4	8.9	4.9	7.7	7.9	6.4	8.3	5.8	10.7	8.9	11.8	8.5	6.3	9.9	7.6	**8.1**
DAR	**2.2**	2.5	5.2	2.7	3.4	1.9	2.6	3.9	2.6	2.8	2.1	4.1	3.2	4.3	3.2	2.2	3.7	3.8	**3.2**
COR	**1.5**	2.3	3.4	2.2	2.3	2.9	2.1	2.5	2.2	1.5	1.5	2.4	1.9	2.6	2.0	1.4	2.1	2.5	**2.2**
AKL	**8.3**	11.4	18.4	11.0	12.8	9.8	11.1	13.9	7.9	11.0	8.5	15.6	11.5	20.0	13.8	8.8	14.9	10.5	**12.4**
TGA	**7.7**	10.1	13.1	9.5	10.5	10.4	8.7	10.8	7.5	9.7	7.7	8.6	11.3	13.3	10.2	9.1	12.9	10.1	**10.2**
ROA	**1.5**	2.5	4.3	2.1	3.0	2.2	1.9	2.8	1.9	2.0	1.4	2.6	3.3	4.4	2.7	2.1	4.5	2.6	**2.7**
GSA	**34.1**	41.7	49.7	44.3	42.4	44.3	40.6	46.7	42.4	40.5	39.4	34.1	45.1	52.5	46.9	42.2	47.2	42.9	**43.7**
APA	**2.2**	3.7	5.3	2.9	3.5	4.4	2.7	3.9	2.5	2.8	2.7	3.3	4.2	5.9	4.1	2.9	4.9	3.3	**3.7**
NPA	**1.1**	1.5	2.5	1.6	2.0	1.2	1.5	0.9	0.9	0.9	1.1	1.4	1.7	2.1	1.6	0.5	2.4	1.6	**1.5**
WUA	**2.6**	4.2	7.4	5.2	5.7	3.2	4.7	6.1	3.9	3.9	3.1	6.2	5.5	11.8	6.3	3.2	8.5	4.5	**5.5**
PPA	**2.0**	2.7	6.6	4.0	4.9	2.9	3.6	5.1	3.1	2.8	2.9	5.3	4.2	12.0	6.3	3.0	5.9	4.1	**4.6**
WNA	**16.8**	24.0	36.5	31.1	30.2	19.8	34.5	43.3	25.3	28.5	20.5	40.4	30.7	57.5	40.3	26.1	41.6	26.3	**32.7**
NSA	**8.9**	11.5	17.0	12.5	12.0	10.7	11.9	12.9	10.7	10.3	9.4	14.8	13.1	16.4	13.1	9.5	14.8	11.9	**12.5**
WSA	**0**	0	0	0	0.1	0.2	0	0	0	0	0	0	0	0.1	0.1	0	0	0.1	**0.0**
HKA	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0.0**
KIX	**6.3**	8.9	19.9	11.7	13.9	5.5	16.6	19.2	11.2	12.4	6.8	19.0	12.3	25.5	19.2	9.9	15.3	12.1	**14.1**
CHA	**39.7**	48.6	59.0	48.7	47.8	55.2	44.9	50.1	45.5	43.6	44.0	40.7	44.2	54.9	49.4	43.7	47.4	50.6	**48.1**
QNA	**5.8**	9.4	9.9	8.0	9.0	12.1	7.3	7.9	8.8	5.9	7.1	7.3	8.3	9.9	8.0	7.5	8.5	9.4	**8.5**
DNA	**5.7**	11.5	38.1	20.5	21.6	13.7	18.1	26.3	21.7	16.5	13.9	21.3	17.5	39.0	23.1	15.1	21.7	17.2	**21.0**
NVA	**0.4**	1.0	2.5	1.0	1.2	2.8	0.8	1.0	0.5	0.7	0.7	0.7	0.9	2.8	0.9	0.6	1.2	1.7	**1.2**
Avg.	**7.6**	**10.2**	**15.5**	**11.3**	**11.7**	**10.4**	**11.0**	**13.2**	**10.2**	**10.2**	**8.9**	**11.9**	**11.4**	**17.3**	**13.0**	**9.7**	**13.4**	**11.1**	**11.8**

The 2080s mid-range model example for VH+E fire danger (based on ECHOG) (Figure 6c) illustrates perhaps the greatest variability in projected changes across the country of any of the model examples. It projects peak increases in VH+E fire danger class frequency greater than 150% over the entire lower South Island, based on large projected increases at Invercargill (NVA), Dunedin Aero (DNA) and Queenstown (QNA) (see Table 6). Increases of greater than 50% are also predicted for the central and eastern North Island based on modelled changes for Taupo (APA), and for Coromandel (COR). Decreases for Northland (Kaitaia, KX, and Dargaville, DAR) and Kaikoura (KIX) of up to -20% (and the West Coast, of up to -10%) are also indicated due to modelled reductions in the projected number of days of VH+E at stations in these areas (see Table 6).

The 2080s VH+E high-range model example (based on the IPCM4 model) (Figure 6d) potentially depicts the worst-case scenario for changes in fire danger across New Zealand from the present analysis. It portrays significant increases (>150%) in the frequency of severe fire danger days across much of the country (also see Table 6), with increases of less than 50% only projected for the West Coast and inland Canterbury (again, likely just due to a lack of station data) in the South Island, and East Cape in the North Island (where interpolation may also be a major contributor). Changes of greater than 100% (indicated in Figure 6 by the areas of dark orange and red) represent a potential doubling of the number of days of VH+E forest fire danger, thereby indicating very significant increases in fire climate severity under this model scenario.

In general, across all the illustrated model examples, projections for SSR appear to show more variable spatial patterns of change than the number days of VH+E fire danger. Patterns also tend to be most similar for the low- and high-range models when changes are more clear-cut, and more variable under the mid-range model when changes are less clear and more widely varying for individual station locations (see Figures 7-10). However, some general conclusions can be drawn from the spatial patterns identified and underlying data on projected changes.

The areas most likely to show the greatest potential increases in fire climate severity would seem to be those areas of the South Island with already moderate to elevated fire danger (Figures 7-10), such as Dunedin Aero (DNA) and Kaikoura (KIX) [but interestingly not Christchurch Aero (CHA) or Gisborne (GSA)], and also areas where fire dangers are currently low and even minor increases for future climate result in significant increases in relative fire danger (i.e. as a % of current fire danger). The latter would therefore include western areas, particularly of the North Island (e.g. Wanganui, WUA), and the south of the South Island (e.g. Invercargill, NVA). There also appears to be significant potential under the most extreme model scenarios across the lower North Island (Wellington, WNA, Paraparaumu, PPA, and again Wanganui, WUA), potentially extending up as far as Taupo (APA) and further into the Bay of Plenty (Rotorua, ROA, and possibly also Tauranga, TGA).

At the other end of the spectrum, the areas most likely to remain the same or show reductions in fire climate severity (see Figures 7-10) are the West Coast of the South Island (Hokitika, HKA, and Westport, WSA) and western areas of the North Island such as Taranaki (New Plymouth, NPA) where fire dangers are already low, and East Cape (Gisborne, GSA) and the Coromandel (COR). Potential also exists for decreases in fire danger in Northland (Kaitaia, KX, and Dargaville, DAR), Auckland (AKL) and Tauranga (TGA) in the north, and at Invercargill (NVA) and even Kaikoura (KIX) and Christchurch (CHA) in the south, under some models.

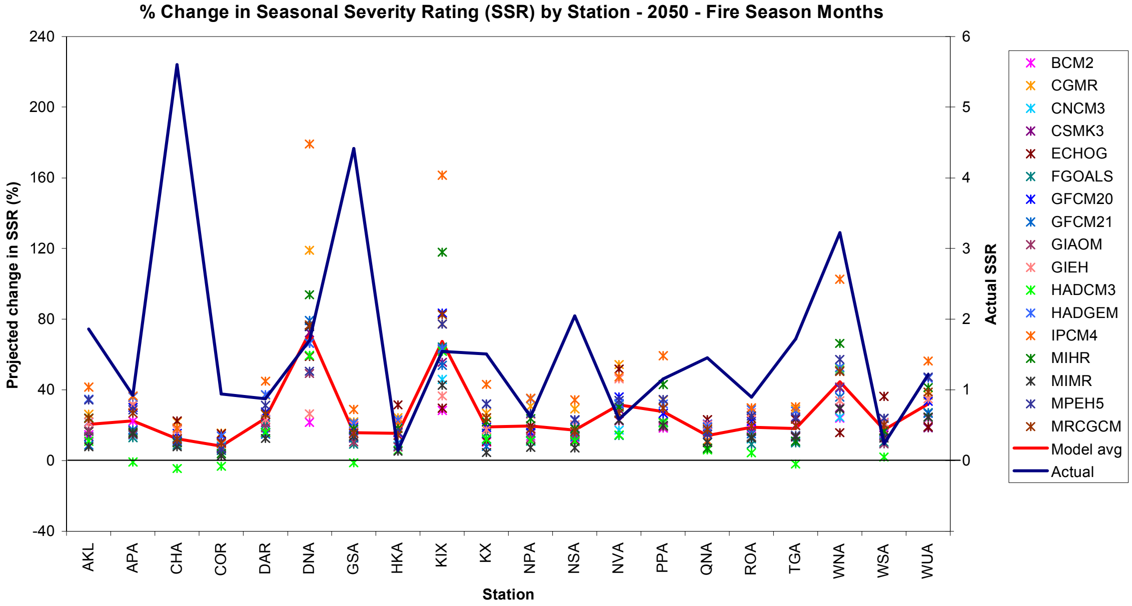

Figure 7. Range in projected changes (%) in Seasonal Severity Rating (SSR) for fire season months (Oct-Apr) for the 2050s (2040-2059) from 17 Global Climate Models for locations across New Zealand. The 17 model average and current (actual) SSR values are also shown for comparison.

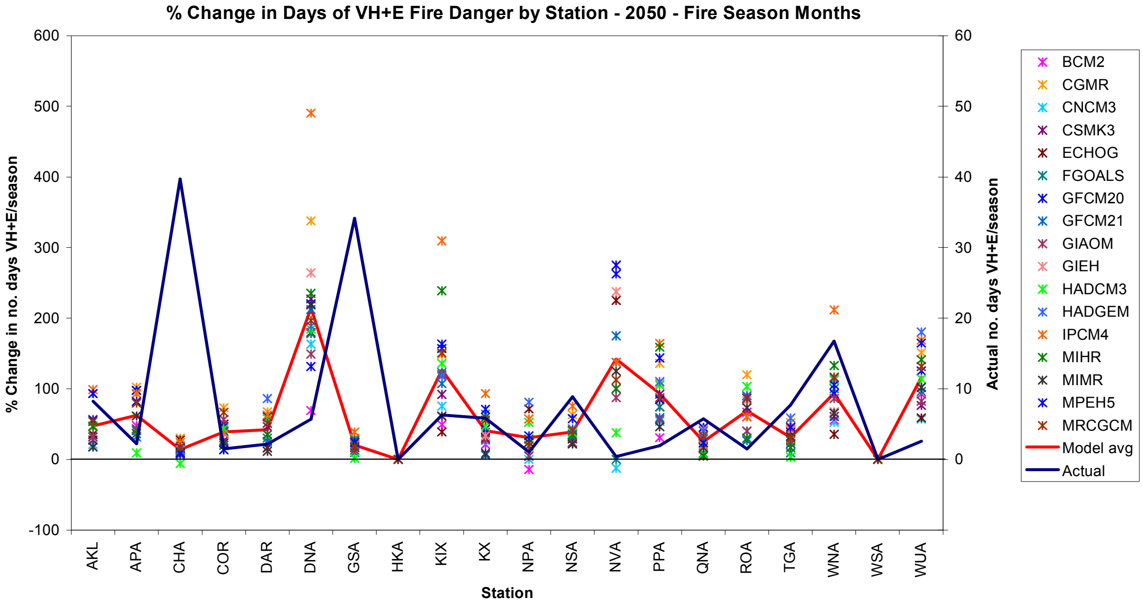

Figure 8. Range in projected changes (%) in the number of days/year of Very High and Extreme (VH+E) Forest fire danger during fire season months (Oct-Apr) for the 2050s (2040-2059) from 17 Global Climate Models for locations across New Zealand. The 17 model average and current (actual) number of days of VH+E fire danger are also shown for comparison.

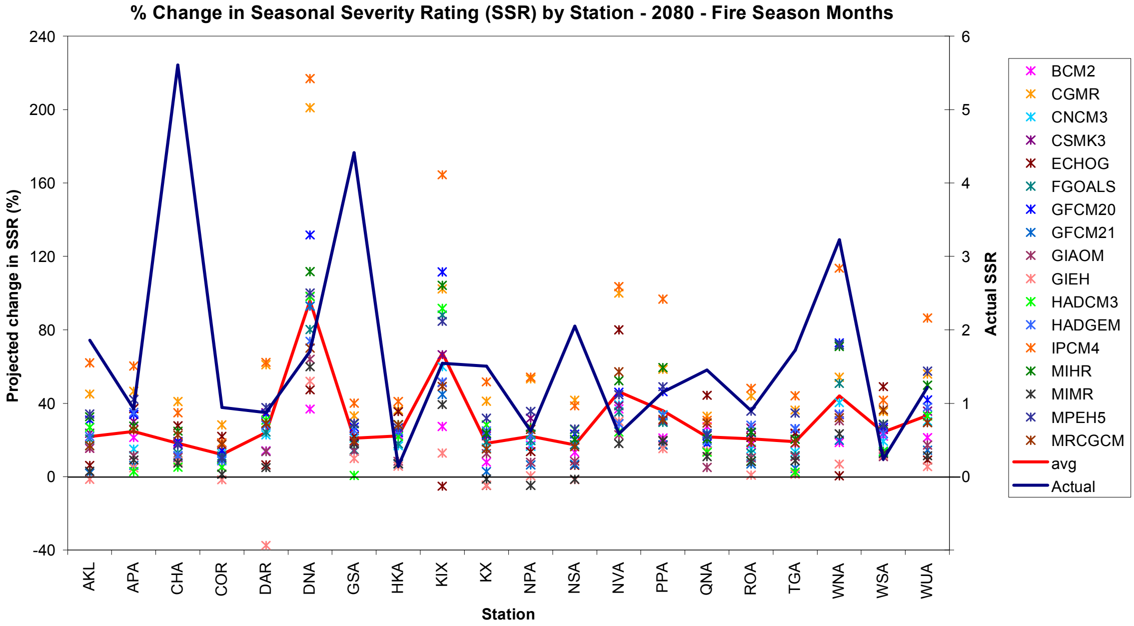

Figure 9. Range in projected change (%) in Seasonal Severity Rating (SSR) for fire season months (Oct-Apr) for the 2080s (2070-2089) from 17 Global Climate Models for locations across New Zealand. The 17 model average and current (actual) values of SSR are also shown for comparison.

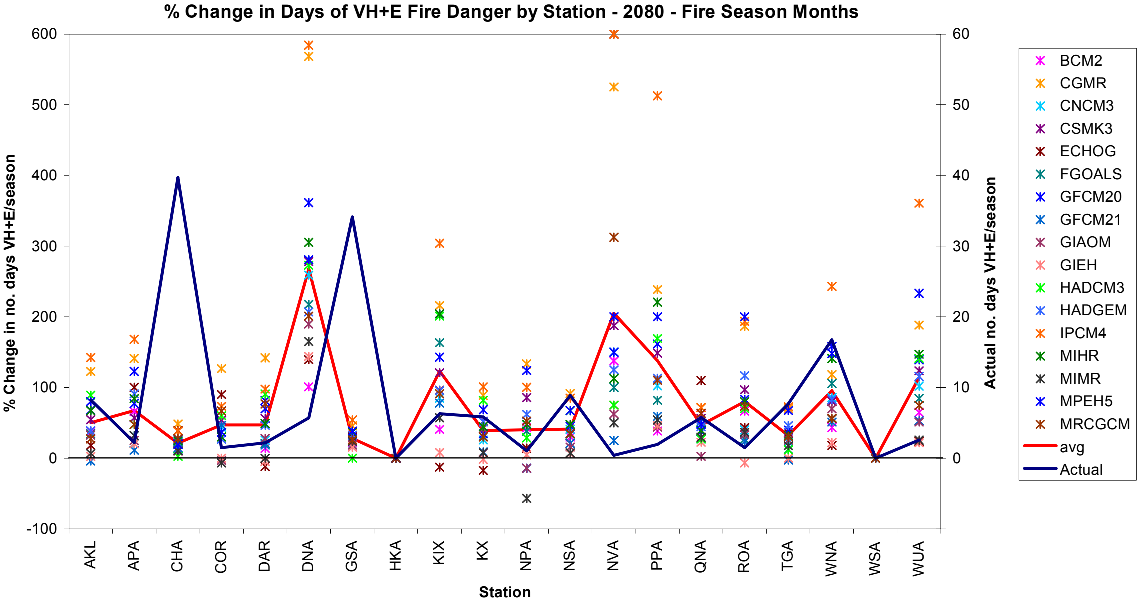

Figure 10. Range in projected changes (%) in the number of days/year of Very High and Extreme (VH+E) Forest fire danger during fire season months (Oct-Apr) for the 2080s (2070-2089) from 17 Global Climate Models for locations across New Zealand. The 17 model average and current (actual) number of days of VH+E fire danger are also shown for comparison.

Trends in rates of change in fire danger

What is apparent from detailed scrutiny of the changes projected for fire season severity in Tables 3-6 (and for full years in Appendix 1) is that not all models show fire dangers continuing to increase at all station locations beyond the 2050s to the

2080s. For some models and at some locations, fire climate severity exhibits a tendency to peak by the 2050s and then remain at about the same level for the 2080s. This is the case at Kaikoura (KIX) for the IPCM4 model, where the SSR and number of days of VH+E fire danger increase significantly to the 2050s (by 161% and 310%, respectively), but then stay the same or even decrease slightly by the 2080s (164% and 304%), indicating little or no change between the two projection periods (-18% and -3%). Kaikoura (KIX) also shows a similar tendency under the HADGEM model, as does Dunedin (DNA) under the MIMR model. Some locations and models also show a greater decrease in fire climate severity from the 2050s to 2080s. Examples of this Dunedin Aero (DNA) under the ECHOG and GIEH models, where SSR increases by 59% & 26% and VH+E by 160% & 264% to the 2050s, and then decreases by -135% & -402% for SSR and -40% & -120% for VH+E from the 2050s to the 2080s, for each model respectively. Wellington (WNA) under HADGEM and MRCGCM, and again Kaikoura (KIX) under a number of models including GFCM21, GIAOM, MIHR, MPEH5 and MRCGCM, also show similar trends.

These variances in trends are further evidenced by differences in the rate of change in fire climate severity projected for the two periods. When averaged across all 17 models and station locations, the number of days of VH+E fire danger during the fire season is projected to increase by 62% from current values for the 2050s and 74% for the 2080s, but only 12% (based on current values) from the 2050s to the 2080s. There is obviously much variability between models in these rates of change, although model ranges for the 1990s to 2050s period (-12% to +490%) are less variable than those for the 2050s to 2080s (-16% to +460%). In real terms, these average changes correspond to an average increase of 3.6 day/season of VH+E fire danger from the 1990s to 2050s (range -2 to +35 days/season), and just 0.81 days/season for the 2050s to 2080s (range -10 to +16 days/season). The rates of change in SSR for the two projection periods vary less, at 26% for the 1990s to 2050s (and 30% for 1990s to 2080s), and 29% from the 2050s to 2080s, although the ranges in these rates between models are much less variable for the 1990s to 2050s (-5% to +160%) than 2050s to 2080s (-400% to +770%)

Variation Between Models

The individual Global Circulation Models (GCMs) are different representations of the climate system with different model sensitivities, rates of warming and interannual variability derived from differences in modelling resolution and the way the represent interactions between the atmosphere, oceans and land surface (and the effects of factors such as the reflective and absorptive properties of atmospheric water vapour, greenhouse gas concentrations, clouds, annual and daily solar heating, ocean temperatures and ice boundaries) (MfE 2008). The advantage of utilising an increased number of GCMs that each model climate slightly differently is that together they encompass a wider range of possible future climate outcomes, and also potentially better capture future climate variability. While the GCMs show some consistency in the relative amplitude and spatial pattern of their respective changes, there is also considerable variability (e.g. in the multi-decadal rates of warming) that results in widely varying estimates of the climate changes that influence fire danger.

Of the 17 GCMs investigated (see Figures 7-10, and Figures 11-12), the IPCM4 model consistently produced the greatest overall increases in fire danger under future climate, averaging 50% and 70% across the 20 stations for SSR, and 110% and 190% for the number of days of VH+E fire danger, for fire season months for the 2050s and 2080s, respectively (with similar values for the full year; see Appendix 2). For this reason, this model was chosen as an example for illustrating potential changes from the high-range models in Figures 3-6(b). It was closely followed by the CGMR model (with 37-60% increases for SSR and 95-160% for VH+E). The MPEH5 model also produced higher fire dangers, especially for the 2080s (80% and 110%, cf. 30% and 80% for the 2050s). The GFCM20 model ranked the next highest of the models (30-40% for SSR and 80-90% for VH+E), together with the MIHR model which projected greater increases for the 2080s (70% and 90%) and lower changes for the 2050s (30% and 50%). The HADGEM model showed the opposite trend, with slightly greater increases for the 2050s (35% and 80%), and lower changes for the 2080s (30% and 70%).

Changes for the MRCGCM (30% for SSR and 70% for VH+E, for both the 2050s and 2080s) and ECHOG (25% and 60%) models were consistently in the middle of the ranges projected by the 17 models (see Figures 7-10, and Figures 11-12). The ECHOG model was therefore chosen to illustrate potential changes for mid-range models in Figures 3-6(c), along with the 17 model average (Figures 3-6(a)). Changes for the CSMK3 model were also mid range, especially for the 2050s (20% and 55%), but higher for the 2080s (30% and 80%). The HADCM3 model, which ranked mid-range in terms of overall changes in fire danger, was the only GCM to show marked differences in changes between fire season months and the full year. This was more apparent for the 2050s (15% cf. 46% for SSR and 28% cf. 60% for VH+E for fire seasons cf. full years, respectively), as a result of small decreases in fire danger at some stations, but was still present for the 2080s (55% cf. 87% for SSR, and 79% cf. 114% for VH+E). The GFCM21 model was also mid range for 2050s (20% and 50%), but slightly lower for the 2080s (20% and 40%) as a result decreases at several stations.

Changes in fire danger for the GIEH model were also mid range for the 2050s (30% for SSR, and 70% for VH+E), but changes averaged across all stations for the 2080s (10% and 20%) were the lowest of the 17 models (see Figures 7-10, and Figures 11-12) as a result of decreases in fire danger at several stations and only minor increases at the remainder. Fire dangers for the CNCM3 and FGOALS models were both mid-range for the 2080s (25-30% and 55-60%), but lower for the 2050s (15-20% and 35-40%), putting them in the lower 4-5 stations for changes across all models. The BCM2, GIAOM and MIMR models were the GCMs that consistently projected the lowest increases in fire danger, with average changes across all stations of 15-20% for SSR and 30-45% for the number of days of VH+E fire danger. This was due to decreases in fire danger being predicted for at least one (and typically 2-3) stations (being New Plymouth (NPA), Coromandel (COR) and/or Invercargill (NVA)). The MIMR model was therefore selected as an example to illustrate the potential changes for these low-range models in Figures 3-6(d).

Apart from the HADCM3 model noted above, BCM2 (-14% at New Plymouth, NPA) and CNCM3 (-13% at Invercargill, NVA) were the only other models to show decreases in fire danger for the 2050s (see Figures 7 & 8). Several different models produced decreases in fire danger over the full projection period to the 2080s (see Figures 9 & 10), albeit relatively minor (generally of less than -15%), including the GIEH, ECHOG, MIMR and, to a lesser extent, GFCM21, GIAOM and GFCM20 models. The greatest decreases for the 2080s were under the MIMR (-57% at New Plymouth, NPA) and GIEH (-37% at Dargaville, DAR) models. The greater number of projected decreases in fire danger for the 2080s (than the 2050s) also reinforces the tendency for fire dangers to decrease from the 2050s to the 2080s at many stations under some models and, overall, to certainly increase less than the much more rapid increase projected from the current climate baseline to the 2050s.

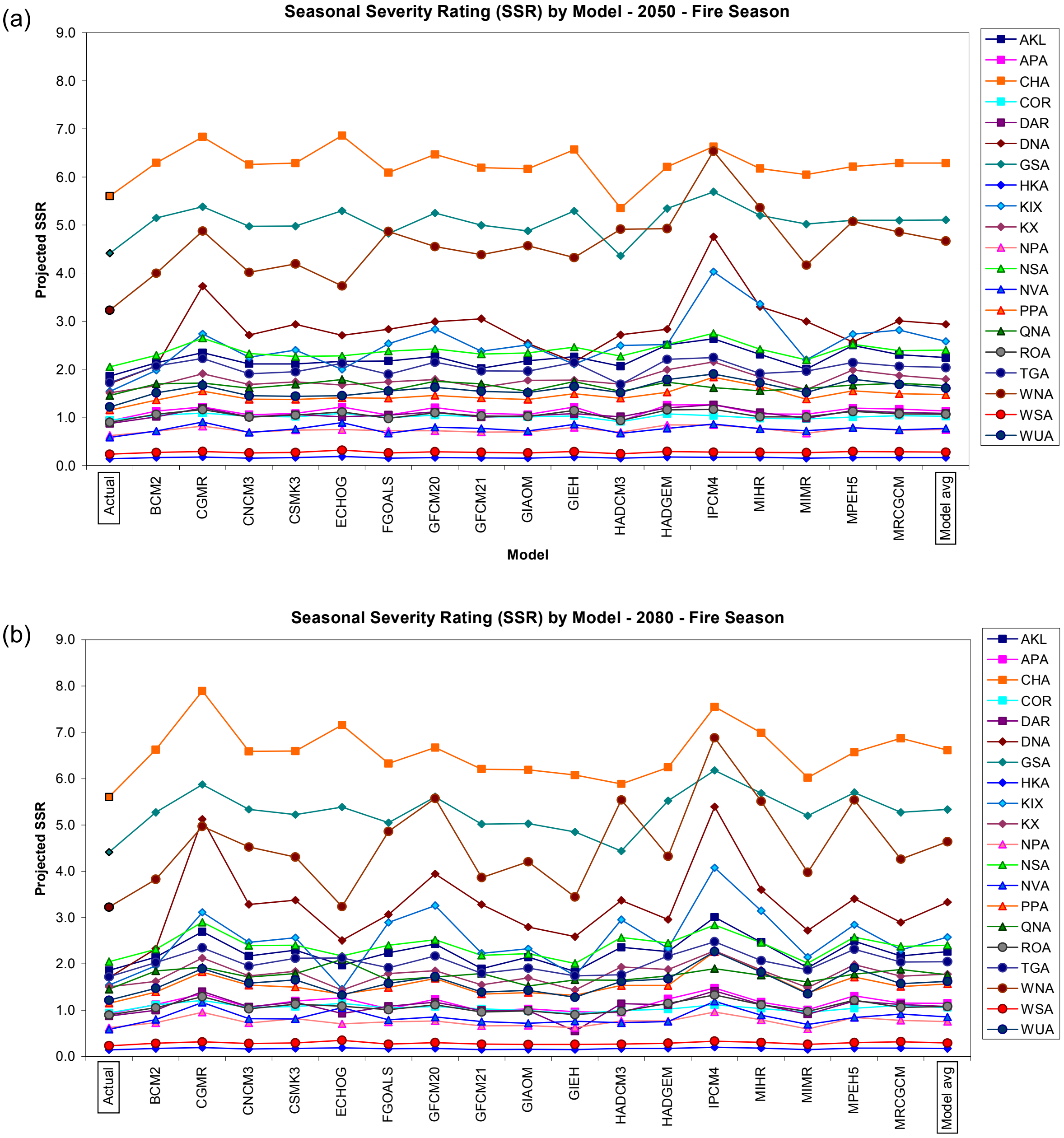

Figure 11. Range in average values of the Seasonal Severity Rating (SSR) over fire season months (Oct-Apr) projected by 17 Global Climate Models for locations across New Zealand for: (a) the 2050s (2040-2059), and (b) the 2080s (2070-2089).

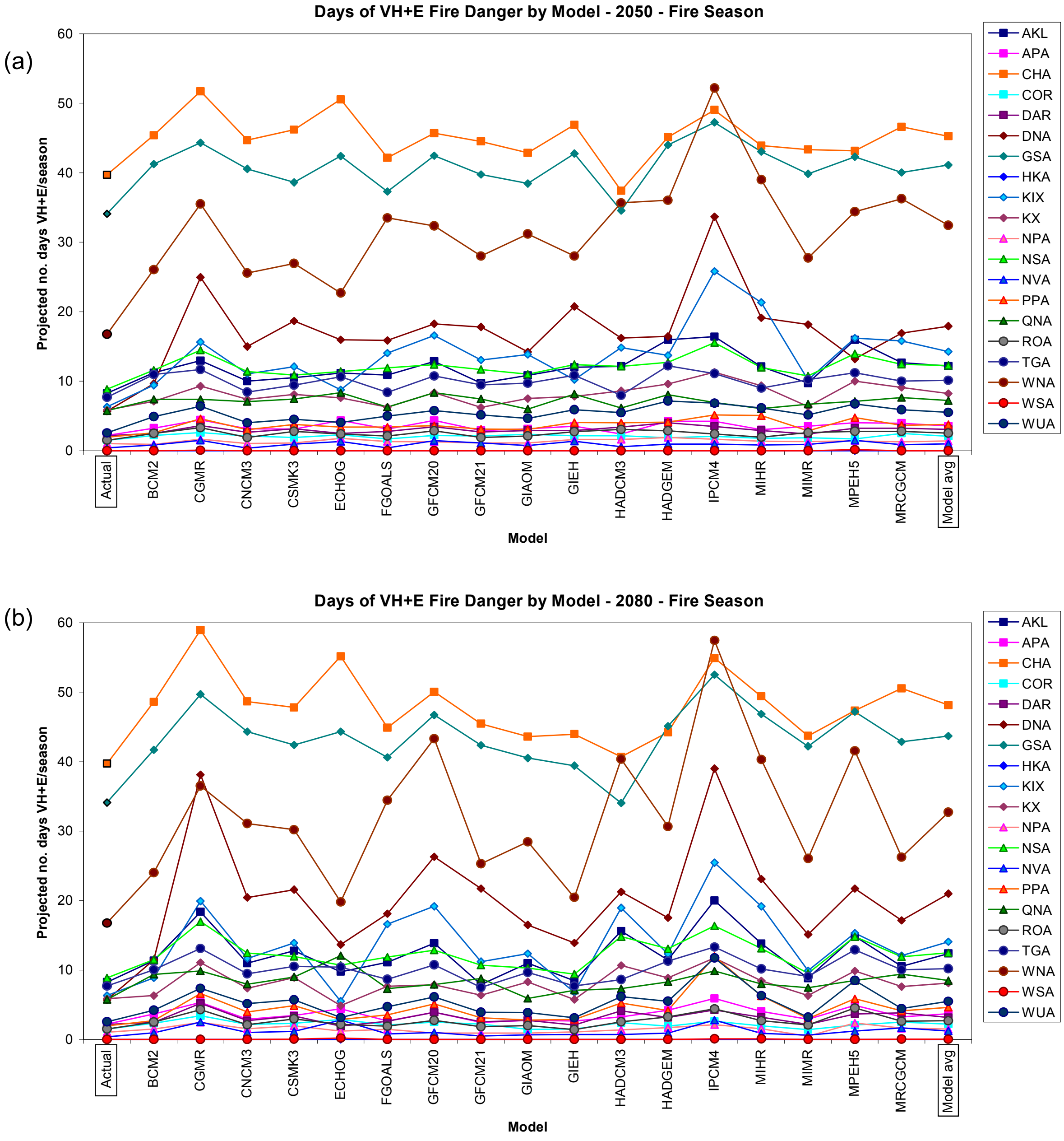

Figure 12. Range in average number of days of Very High and Extreme (VH+E) Forest fire danger during fire season months (Oct-Apr) projected by 17 Global Climate Models for locations across New Zealand for: (a) the 2050s (2040-2059), and (b) the 2080s (2070-2089).

Relationship to Weather Changes

While the influence of rainfall, or more particularly a lack of it, on increasing fire danger ratings, and therefore fire climate severity, may seem obvious, the relative importance of the other weather elements is not so apparent. Increasing wind speeds will result in high fire danger by increasing the rate of evaporation and drying of vegetation fuels. Higher winds also push fires forward so that they spread more rapidly. Lower relative humidity (a drier atmosphere) produces higher fire danger by increasing the moisture exchange between fuels and the air around it, further drying the fuels and increasing the likelihood of spotfires starting from embers. Increasing temperatures also act to raise fuel temperatures so that they ignite more easily, but also influence fire danger through the relationship between air temperature and humidity (and the amount of moisture the air can hold). Hence all of these weather elements have an important part to play in influencing the overall fire danger.

Fire danger ratings and fire climate severity are driven by daily weather and climate, so that the changes projected (for SSR and the number of days of VH+E fire danger) under future climate are the result of the changes in weather elements projected by the GCM models. However, determining exactly how the weather changes affect fire dangers for a particular location is not a straight-forward process, as changes resulting from one weather element can offset changes from others so that fire dangers do not change, or may only increase slightly or even decrease. For example, potential increases in fire danger through increases in temperature and wind speed can be offset by increases in rainfall and relative humidity. In addition to the overall general pattern in changes, and depending on the model, the projected changes in the weather elements may also vary significantly from season to season or month to month, and even throughout the projection period (for example, through changes becoming greater or decreasing over time, e.g. more rapid temperature or rainfall increases for the latter part of the 2080s).

Sensitivity of fire danger to weather inputs

The fire climate severity measures being used to describe potential changes in fire danger with climate change (SSR and days of VH+E Forest fire danger) are derived through combination of the various daily codes and indices from the Fire Weather Index (FWI) System which are, in turn, based on one or more of the four weather inputs (of temperature, relative humidity, wind speed and 24-hour rainfall)[5].

A sensitivity analysis was therefore undertaken to determine the relative importance of projected weather changes on fire danger. This found that the fire climate severity measures were most sensitive to changes in relative humidity, followed by temperature and wind speed, and then rainfall. Indicative analyses for 3 stations representing the range in fire climate severity across the country (Table 7) showed that changes of +/-10% in the RH resulted in changes of -20% to +50% for the SSR and -63% to +100% for days of VH+E fire danger. In comparison, similar changes in seasonal rainfall (of +/-10%) only produced changes of -8% to +10% for SSR and -13% to +25% for days of VH+E.

However, when even small changes in all weather inputs were combined, this resulted in much greater changes in fire climate severity. For example, combined increases (for temperature and wind speed) and reductions (for RH and rainfall) of just 1% produced 6-10% increases in SSR and 5-25% increases in the number of days of VH+E fire danger. Combined increases/decreases of 10% resulted in even more dramatic increases, of 78-136% for SSR and 81-575% for days of VH+E. In the case of the 3 stations in question, this would result in increases in the number of days of VH+E forest fire danger each fire season of 2.3 (from 0.4 to 2.7

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[5] see Anderson (2005) and Van Wagner (1987) for more detailed description of these inputs, FWI System components and their calculation.

Table 7. Sensitivity of two fire climate severity measures (Seasonal Severity Rating (SSR), and number of days of Very High and Extreme (VH+E) Forest Fire Danger) to individual and combined changes in weather inputs for all fire season months (Oct-Apr) at three representative locations (Invercargill = low fire climate severity; Tauranga = moderate fire climate severity; Christchurch = high fire climate severity).

Station	Weather input	Seasonal Severity Rating (SSR)							Days of VH+E Forest Fire Danger						
		-10%	**-5%**	**-1%**	**Actual**	**+1%**	**+5%**	**+10%**	**-10%**	**-5%**	**-1%**	**Actual**	**+1%**	**+5%**	**+10%**
Invercargill (NVA)	Temperature	-19	-10	-2		2	10	21	-25	-25	0		13	25	38
	RH	50	23	4		-4	-20	-38	100	25	25		0	-25	-63
	Wind speed	-19	-10	-2		2	10	21	-25	-13	0		13	13	25
	Rainfall	10	5	1		-1	-4	-8	25	25	13		0	0	-13
	All[1]	**-63**	**-38**	**-9**	**0.58**	**10**	**56**	**136**	**-75**	**-63**	**-13**	**0.4**	**25**	**138**	**575**
Tauranga (TGA)	Temperature	-16	-8	-2		2	9	19	-25	-13	-2		2	16	31
	RH	37	18	3		-3	-16	-30	56	27	3		-5	-22	-43
	Wind speed	-15	-8	-2		2	8	17	-23	-12	-1		1	12	25
	Rainfall	6	3	1		-1	-3	-5	10	5	1		-1	-5	-10
	All	**-54**	**-31**	**-7**	**1.7**	**8**	**43**	**102**	**-77**	**-49**	**-11**	**7.7**	**12**	**65**	**187**
Christchurch (CHA)	Temperature	-15	-8	-2		2	8	16	-19	-9	-2		1	6	16
	RH	24	12	2		-2	-11	-21	29	12	2		-2	-14	-25
	Wind speed	-15	-8	-2		2	8	17	-15	-8	-2		1	5	12
	Rainfall	7	3	1		-1	-3	-6	7	3	0		-1	-5	-8
	All	**-47**	**-27**	**-6**	**5.60**	**6**	**34**	**78**	**-54**	**-31**	**-8**	**39.7**	**5**	**37**	**81**

[1] Changes in all weather inputs combined, where negative changes indicate reduced contributions to fire danger (i.e. lower temperature, higher humidity, lower wind speeds and higher rainfall), and positive changes increased contributions to fire danger (i.e. higher temperature, lower humidity, higher wind speed and lower rainfall).

days/season), 14.4 (from 7.7 to 22.1 days/ season) and 32.2 (from 39.7 to 71.9 days/season), respectively. This shows that even minor changes in weather conditions produced through climate change can result in much more significant changes in future fire climate severity.

Observed model changes

Average fire season changes in the weather inputs for each station location projected from the downscaled models for the 2050s and 2080s are shown in Tables 8-15. Full year changes are also included in Appendix 2. Despite the use of slightly different projection periods in this study compared with most others (that generally use the 2040s and 2090s), these agree well with projected changes for the AR4 models quoted elsewhere (e.g. MfE 2008), as would be expected from use of the same statistical downscaling process. For example, the mean annual temperature change (for all months) across all 17 models at the 20 station locations investigated here was 1.16°C for the 2050s and 2.24°C for the 2080s, compared with the best estimates from MfE (2008) of 1°C (0.2-2.0°C) by 2040 and 2°C (0.7-5.1°C) by 2090. Mean annual rainfall across all models and sites was projected to increase of 0.4% for the 2050s and 0.5% for the 2080s (see Appendix 2).

Fire season averages, at least for temperature, would be expected to be higher than these mean annual estimates, since the fire season months (Oct-Apr) encompass the (normally) warmest period of the year but exclude the (normally) cooler winter months encompass. The average mean fire season temperature changes across all models and station locations were higher at 1.28°C for the 2050s (Table 8), but slightly lower at 2.21°C for the 2080s (Table 9). However, this varied considerably between models and station locations, ranging from 0.34°C (for Taupo (APA) under HADCM3) to 2.70°C (for Dunedin (DNA) and Invercargill (NVA) under MIHR) for the 2050s, and 1.02°C (again, at Taupo (APA) under HADCM3) to 4.46°C (also Invercargill (NVA) under MIHR) for the 2080s.

The average fire season changes for rainfall across all models and locations was significantly higher than for the full year, with increases of 4.4% and 6.0% projected for the 2050s and 2080s, respectively (see Tables 10 & 11). This demonstrates the seasonal variability in rainfall changes contained within many of the GCM models, with lower winter (and in some cases, also spring) rainfall projected as well as potentially higher summer rainfall (MfE 2008). Again, however, the changes varied greatly been models and station sites, ranging from an 88% increase in rainfall (at Wellington (WNA) under HADCM3) to a -48% decrease (Kaikoura (KIX) under IPCM4) for the 2050s, and an 80% increase (Taupo (APA) under HADCM3) to a -35% decrease (Invercargill (NVA) under ECHOG) for the 2080s.

Changes in relative humidity projected on a daily basis by the various models were in most cases relatively small (+/-3%), although in some instances were larger (up to +/-20%). However, when averaged across all years at each station and then for all models and stations, they are considerably smaller. The average changes across all 17 models and 20 station locations were slightly higher (by 0.2-0.4%) for fire season months (Tables 12 & 13) than for the full year (see Appendix 2), but changes were more variable between models and stations for the full year.

Table 8. Average change in temperature (°C) for fire season months (Oct-Apr) estimated for the 2050s (2040-2059) from 17 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Actual** (°C)	**Models for 2050s – Change in Temperature** (°C)																	**Model avg.**
		BCM2	**CGMR**	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**20.0**	1.66	1.46	1.28	1.00	1.52	0.98	1.12	1.60	0.66	1.61	0.57	1.47	1.26	2.36	1.75	0.66	1.17	**1.30**
DAR	**19.9**	1.77	1.55	1.34	1.09	1.60	1.06	1.16	1.72	0.70	1.73	0.65	1.60	1.29	2.51	1.86	0.68	1.24	**1.39**
COR	**19.7**	1.53	1.35	1.07	0.98	1.43	0.85	0.99	1.50	0.51	1.47	0.59	1.35	0.95	2.01	1.56	0.51	0.97	**1.15**
AKL	**19.8**	1.41	1.26	1.10	0.84	1.30	0.80	0.93	1.29	0.58	1.23	0.53	1.25	1.00	1.98	1.43	0.52	0.95	**1.08**
TGA	**19.6**	1.45	1.28	1.14	0.85	1.39	0.79	1.04	1.36	0.55	1.34	0.37	1.19	1.14	1.97	1.50	0.58	0.99	**1.11**
ROA	**18.1**	1.47	1.29	1.16	0.86	1.41	0.81	1.05	1.38	0.56	1.37	0.39	1.21	1.16	2.01	1.52	0.59	1.01	**1.13**
GSA	**20.5**	1.52	1.34	1.20	0.89	1.44	0.85	1.08	1.43	0.59	1.43	0.42	1.27	1.21	2.11	1.58	0.61	1.05	**1.18**
APA	**16.5**	1.45	1.28	1.14	0.85	1.40	0.78	1.05	1.35	0.53	1.33	0.34	1.17	1.13	1.95	1.49	0.57	0.97	**1.11**
NPA	**18.0**	1.77	1.56	1.31	1.10	1.64	1.01	1.17	1.72	0.65	1.70	0.63	1.56	1.23	2.42	1.83	0.65	1.18	**1.36**
WUA	**18.4**	1.55	1.36	1.21	0.93	1.44	0.90	1.07	1.48	0.62	1.49	0.50	1.35	1.20	2.19	1.63	0.62	1.08	**1.21**
PPA	**17.5**	1.74	1.57	1.35	1.05	1.66	1.00	1.22	1.66	0.67	1.70	0.54	1.48	1.40	2.46	1.86	0.68	1.21	**1.37**
WNA	**17.4**	1.74	1.55	1.34	1.07	1.61	1.05	1.17	1.68	0.70	1.72	0.62	1.55	1.35	2.52	1.86	0.68	1.23	**1.38**
NSA	**18.2**	1.78	1.56	1.34	1.10	1.61	1.07	1.16	1.74	0.71	1.75	0.68	1.62	1.28	2.54	1.87	0.68	1.24	**1.40**
WSA	**16.6**	1.63	1.43	1.18	1.02	1.51	0.92	1.07	1.58	0.58	1.56	0.60	1.44	1.08	2.19	1.67	0.58	1.07	**1.24**
HKA	**16.3**	1.46	1.30	1.10	0.91	1.35	0.87	0.97	1.42	0.56	1.44	0.55	1.31	1.06	2.07	1.54	0.55	1.01	**1.14**
KIX	**16.0**	1.74	1.56	1.36	1.08	1.58	1.10	1.16	1.71	0.74	1.78	0.69	1.61	1.39	2.62	1.91	0.70	1.28	**1.41**
CHA	**17.8**	1.69	1.50	1.21	1.09	1.55	1.01	1.07	1.68	0.62	1.69	0.71	1.56	1.11	2.35	1.77	0.59	1.13	**1.31**
QNA	**14.8**	1.76	1.57	1.19	1.15	1.64	1.00	1.10	1.75	0.57	1.73	0.75	1.58	1.05	2.33	1.81	0.55	1.11	**1.33**
DNA	**16.2**	1.77	1.65	1.33	1.15	1.64	1.14	1.15	1.78	0.72	1.90	0.80	1.67	1.39	2.70	1.99	0.66	1.29	**1.45**
NVA	**14.9**	1.85	1.72	1.34	1.21	1.75	1.14	1.21	1.85	0.69	1.94	0.81	1.70	1.36	2.70	2.04	0.65	1.28	**1.48**
Avg.	17.8	**1.64**	**1.46**	**1.23**	**1.01**	**1.52**	**0.96**	**1.10**	**1.58**	**0.63**	**1.60**	**0.59**	**1.45**	**1.20**	**2.30**	**1.72**	**0.61**	**1.12**	1.28

Table 9. Average change in temperature (°C) for fire season months (Oct-Apr) estimated for the 2080s (2070-2089) from 17 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Actual** (°C)	**Models for 2080s – Change in Temperature (°C)**																	**Model avg.**
		BCM2	**CGMR**	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**20.0**	2.73	2.44	2.26	1.42	2.30	1.75	2.03	2.21	1.46	1.85	1.48	2.27	2.71	3.90	2.80	2.15	2.27	**2.24**
DAR	**19.9**	2.91	2.59	2.38	1.53	2.43	1.89	2.14	2.35	1.54	1.99	1.64	2.44	2.82	4.15	2.98	2.28	2.43	**2.38**
COR	**19.7**	2.47	2.21	1.92	1.37	2.23	1.52	1.76	2.03	1.24	1.73	1.27	2.09	2.29	3.39	2.58	1.83	2.03	**2.00**
AKL	**19.8**	2.68	2.40	2.19	1.34	2.20	1.63	1.91	2.08	1.38	1.73	1.34	2.14	2.56	3.64	2.64	2.02	2.13	**2.12**
TGA	**19.6**	2.36	2.13	1.97	1.24	2.12	1.43	1.78	1.92	1.28	1.57	1.06	1.93	2.44	3.29	2.44	1.85	1.93	**1.93**
ROA	**18.1**	2.40	2.16	2.00	1.25	2.13	1.46	1.81	1.95	1.30	1.60	1.10	1.96	2.48	3.35	2.48	1.88	1.96	**1.96**
GSA	**20.5**	2.48	2.24	2.08	1.29	2.17	1.53	1.88	2.01	1.35	1.66	1.18	2.03	2.56	3.49	2.56	1.96	2.04	**2.03**
APA	**16.5**	2.35	2.13	1.95	1.24	2.14	1.41	1.77	1.92	1.27	1.57	1.02	1.92	2.44	3.26	2.44	1.83	1.91	**1.92**
NPA	**18.0**	2.88	2.58	2.32	1.55	2.52	1.81	2.10	2.35	1.50	1.99	1.51	2.41	2.78	4.03	2.99	2.21	2.38	**2.35**
WUA	**18.4**	2.55	2.28	2.12	1.33	2.18	1.61	1.90	2.06	1.37	1.72	1.32	2.11	2.56	3.62	2.62	2.01	2.11	**2.09**
PPA	**17.5**	2.84	2.62	2.37	1.48	2.51	1.80	2.18	2.31	1.55	1.96	1.41	2.35	2.96	4.08	2.98	2.26	2.35	**2.35**
WNA	**17.4**	2.86	2.60	2.38	1.49	2.41	1.87	2.16	2.31	1.54	1.98	1.58	2.39	2.88	4.15	2.97	2.28	2.40	**2.37**
NSA	**18.2**	2.93	2.60	2.39	1.54	2.43	1.91	2.15	2.37	1.54	2.01	1.68	2.46	2.82	4.19	3.00	2.29	2.45	**2.40**
WSA	**16.6**	2.64	2.36	2.10	1.44	2.34	1.65	1.91	2.16	1.36	1.83	1.38	2.22	2.51	3.68	2.74	2.00	2.18	**2.15**
HKA	**16.3**	2.39	2.16	1.95	1.27	2.05	1.54	1.77	1.95	1.26	1.66	1.32	2.01	2.34	3.42	2.48	1.87	2.00	**1.97**
KIX	**16.0**	2.90	2.63	2.43	1.49	2.35	1.96	2.20	2.33	1.57	2.02	1.73	2.44	2.91	4.28	3.00	2.34	2.46	**2.41**
CHA	**17.8**	2.76	2.48	2.19	1.50	2.37	1.79	2.00	2.26	1.41	1.96	1.58	2.35	2.58	3.92	2.88	2.11	2.31	**2.26**
QNA	**14.8**	2.83	2.56	2.18	1.59	2.56	1.77	2.02	2.34	1.40	2.04	1.52	2.41	2.60	3.93	2.99	2.09	2.34	**2.30**
DNA	**16.2**	2.94	2.75	2.43	1.54	2.44	2.03	2.26	2.38	1.57	2.15	1.83	2.51	2.96	4.42	3.12	2.37	2.51	**2.48**
NVA	**14.9**	3.03	2.85	2.46	1.63	2.64	2.03	2.31	2.48	1.59	2.23	1.76	2.58	3.03	4.46	3.25	2.38	2.56	**2.55**
Avg.	17.8	**2.70**	**2.44**	**2.20**	**1.43**	**2.33**	**1.72**	**2.00**	**2.19**	**1.42**	**1.86**	**1.44**	**2.25**	**2.66**	**3.83**	**2.80**	**2.10**	**2.24**	2.21

Table 10. Average change in rainfall (%) for fire season months (Oct-Apr) estimated for the 2050s (2040-2059) from 17 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Actual** (mm)	**Models for 2050s – Change in Rainfall** (%)																	**Model avg.**
		BCM2	**CGMR**	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**642**	3	-9	-7	7	10	9	-4	10	5	-2	57	15	-29	4	12	3	1	**5.0**
DAR	**564**	2	-7	-7	6	12	10	-6	11	5	0	52	11	-27	5	18	6	0	**5.4**
COR	**963**	-4	-6	-1	1	-7	6	-7	2	6	4	30	8	-7	14	7	-2	5	**2.9**
AKL	**562**	4	-5	-4	7	18	5	-4	14	4	-1	56	7	-28	5	21	3	0	**6.1**
TGA	**655**	2	2	-6	6	10	4	-10	14	1	-3	65	6	-29	3	18	2	-5	**4.8**
ROA	**733**	2	-4	-4	2	13	6	-8	8	2	-6	53	6	-27	2	13	2	-1	**3.3**
GSA	**517**	-2	3	-6	4	5	7	-7	25	5	-4	50	15	-25	9	15	6	1	**5.8**
APA	**562**	3	-3	-5	6	13	8	-9	17	-1	-2	68	5	-30	4	14	2	-3	**5.2**
NPA	**785**	3	-9	-6	4	10	10	-7	9	3	-2	43	12	-26	6	21	-1	1	**4.2**
WUA	**607**	3	-5	-3	7	14	6	-8	15	-1	-2	68	15	-28	1	17	-3	-3	**5.4**
PPA	**562**	5	-8	-3	5	12	7	-7	13	2	-2	55	9	-24	8	19	-1	-1	**5.3**
WNA	**491**	14	-7	-5	5	30	-4	-10	24	2	-8	88	5	-44	-8	15	2	-5	**5.5**
NSA	**556**	1	-3	-3	7	23	9	-6	14	2	9	37	17	-26	11	19	5	6	**7.1**
WSA	**1234**	-10	-9	-3	-3	-16	9	-8	-2	8	-4	40	6	-10	11	2	5	3	**1.2**
HKA	**1690**	-5	-12	-3	-1	-9	6	-4	4	9	-3	33	7	-14	9	3	7	2	**1.8**
KIX	**403**	19	-12	-4	-7	44	-2	-2	34	12	-10	45	5	-48	-12	18	31	2	**6.6**
CHA	**321**	-10	-8	-3	-3	-13	5	-5	0	7	-2	29	11	-10	9	8	3	3	**1.2**
QNA	**480**	-9	-9	1	-1	-16	5	-8	0	9	8	37	3	-2	13	8	2	5	**2.9**
DNA	**448**	9.1	-5.2	-4.7	-6.1	12.8	3.7	-4.0	19.1	14.5	-3.5	28.9	20.0	-37.9	5.7	28.1	11.9	-4.8	**5.15**
NVA	**693**	-9	-7	-1	1	-21	5	-4	3	9	1	43	4	-7	16	4	6	3	**2.6**
Avg.	**673**	**1.0**	**-6.1**	**-3.9**	**2.4**	**7.3**	**5.7**	**-6.4**	**11.8**	**5.1**	**-1.6**	**48.9**	**9.3**	**-23.9**	**5.8**	**13.9**	**4.5**	**0.6**	**4.4**

Table 11. Average change in rainfall (%) for fire season months (Oct-Apr) estimated for the 2080s (2070-2089) from 17 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Actual** (mm)	**Models for 2080s – Change in Rainfall** (%)																	**Model avg.**
		BCM2	**CGMR**	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**642**	19	-12	-5	3	7	3	-9	11	21	5	62	10	-32	0	26	-5	8	6.7
DAR	**564**	16	-10	-4	5	7	3	-11	9	19	5	59	12	-29	4	25	-2	11	7.0
COR	**963**	1	-11	-5	-3	-16	4	-2	-2	12	3	38	8	-15	15	10	2	4	2.5
AKL	**562**	22	-6	-2	7	17	5	-8	15	14	11	70	12	-27	3	30	-4	10	9.9
TGA	**655**	17	-5	1	5	8	10	-14	17	11	4	78	8	-32	-1	24	-7	10	7.9
ROA	**733**	18	-4	-3	1	8	10	-14	11	15	6	70	10	-29	-1	22	-5	6	7.0
GSA	**517**	13	-5	-3	2	6	1	-10	20	10	0	61	13	-31	-3	19	-5	11	5.9
APA	**562**	22	-4	-2	3	9	9	-15	23	8	12	80	10	-29	-1	18	-6	12	8.7
NPA	**785**	17	-9	-5	6	5	3	-9	9	13	9	54	7	-27	7	21	-1	5	6.2
WUA	**607**	19	-12	-5	3	7	3	-9	11	21	5	62	10	-32	0	26	-5	8	6.7
PPA	**562**	15	-6	-1	6	9	5	-8	13	11	12	71	15	-23	10	24	1	11	9.8
WNA	**491**	28	0	1	13	54	-3	-17	21	13	9	76	6	-22	-4	28	-1	13	12.6
NSA	**556**	21	-7	-5	-3	16	6	-8	14	14	13	53	13	-27	11	31	0	6	8.8
WSA	**1234**	-5	-19	-4	-8	-29	5	-8	-3	4	-2	60	2	-18	9	1	0	-5	-1.2
HKA	**1690**	3	-20	-3	-7	-20	2	-7	-1	7	-2	47	3	-21	11	5	1	-2	-0.1
KIX	**403**	33	12	7	24	68	-8	-14	20	27	9	42	12	-28	-10	41	11	23	15.8
CHA	**321**	-1	-16	-2	-9	-26	5	-7	-2	9	-2	51	-1	-17	11	0	8	-2	-0.1
QNA	**480**	-4	-11	-1	-11	-30	9	-3	-3	5	8	52	3	-7	19	4	8	-2	2.1
DNA	**448**	26.1	-28.2	-11.6	-7.3	7.4	-10.8	-10.2	2.7	18.8	1.4	28.5	14.8	-27.9	3.4	22.3	6.1	2.5	2.22
NVA	**693**	-4	-15	-1	-7	-35	7	-8	-3	5	3	66	0	-12	17	6	8	-7	1.1
Avg.	**673**	**13.8**	**-9.4**	**-2.7**	**1.1**	**3.7**	**3.4**	**-9.7**	**9.0**	**12.9**	**5.4**	**59.1**	**8.4**	**-24.3**	**5.0**	**19.2**	**0.2**	**6.2**	**6.0**

Table 12. Average change in relative humidity (actual %) for fire season months (Oct-Apr) estimated for the 2050s (2040-2059) from 17 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Actual** (%)	**Models for 2050s – Change in Relative Humidity (%)**																	**Model avg.**
		BCM2	**CGMR**	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**69**	0.3	0.3	0.9	0.1	0.5	0.1	0.8	0.9	-0.1	0.6	1.1	-0.3	1.1	1.6	1.6	0.6	0.7	**0.63**
DAR	**69**	0.3	0.3	0.9	0.1	0.4	0.2	0.8	0.9	-0.1	0.5	1.2	-0.2	0.9	1.5	1.5	0.6	0.6	**0.61**
COR	**69**	0.3	0.4	0.8	0.0	0.3	0.3	0.6	0.6	0.2	0.5	0.8	0.0	1.2	1.5	1.2	0.6	0.6	**0.58**
AKL	**68**	0.3	0.2	0.7	0.1	0.5	-0.2	0.7	0.8	-0.4	0.2	0.8	-0.5	0.4	0.7	1.3	0.3	0.3	**0.36**
TGA	**66**	0.1	0.2	0.9	0.0	0.3	0.2	0.7	0.7	0.0	0.6	0.9	-0.3	1.3	1.7	1.6	0.5	0.8	**0.60**
ROA	**67**	0.1	0.2	0.9	0.0	0.4	0.2	0.8	0.8	0.0	0.6	0.9	-0.3	1.3	1.7	1.6	0.6	0.8	**0.63**
GSA	**60**	0.0	-0.1	0.2	0.0	0.1	-0.1	0.2	0.3	-0.2	0.0	0.4	-0.3	0.2	0.4	0.6	0.1	0.2	**0.11**
APA	**67**	0.1	0.2	0.9	0.0	0.3	0.2	0.7	0.7	0.0	0.6	0.9	-0.3	1.3	1.7	1.6	0.6	0.8	**0.61**
NPA	**75**	0.3	0.3	0.9	0.1	0.4	0.2	0.8	0.9	0.0	0.6	1.2	-0.1	1.0	1.6	1.5	0.7	0.7	**0.64**
WUA	**69**	0.2	-0.1	0.3	0.1	0.5	-0.4	0.6	0.6	-0.5	0.0	0.4	-0.6	-0.1	0.2	1.0	0.0	0.1	**0.14**
PPA	**70**	0.0	-0.3	-0.3	0.0	0.2	-0.5	0.0	0.1	-0.5	-0.3	-0.2	-0.4	-0.8	-0.8	0.0	-0.3	-0.3	**-0.25**
WNA	**68**	0.3	0.1	0.3	0.1	0.6	-0.3	0.6	0.6	-0.5	0.0	0.5	-0.4	-0.1	0.2	0.9	0.1	0.0	**0.18**
NSA	**66**	0.3	0.3	0.8	0.1	0.4	0.2	0.7	0.8	0.0	0.5	1.0	-0.2	1.0	1.4	1.4	0.5	0.6	**0.58**
WSA	**74**	0.3	0.3	0.9	0.1	0.3	0.4	0.6	0.7	0.2	0.6	0.9	0.0	1.2	1.7	1.3	0.6	0.8	**0.64**
HKA	**75**	0.3	0.3	1.0	0.0	0.3	0.3	0.8	0.9	0.0	0.6	1.3	-0.2	1.3	1.8	1.6	0.8	0.8	**0.71**
KIX	**70**	0.4	0.3	0.3	0.2	0.7	-0.3	0.7	0.7	-0.5	0.0	0.4	-0.4	-0.2	0.0	0.8	0.1	-0.1	**0.19**
CHA	**59**	0.1	0.1	0.7	-0.2	0.1	0.1	0.6	0.5	0.0	0.1	1.0	-0.3	0.7	1.0	0.9	0.6	0.4	**0.38**
QNA	**58**	0.4	0.5	0.9	0.1	0.4	0.5	0.7	0.6	0.3	0.7	0.7	0.2	1.4	1.6	1.1	0.7	0.7	**0.68**
DNA	**64**	0.4	0.0	0.0	0.1	0.6	-0.5	0.5	0.4	-0.6	-0.4	-0.1	-0.3	-1.0	-0.9	0.2	-0.1	-0.4	**-0.12**
NVA	**69**	1.0	0.5	0.9	0.3	1.0	0.0	1.2	1.3	-0.3	0.3	0.8	0.1	0.1	0.8	1.4	0.6	0.4	**0.61**
Avg.	**68**	**0.27**	**0.19**	**0.65**	**0.05**	**0.41**	**0.03**	**0.65**	**0.69**	**-0.15**	**0.33**	**0.75**	**-0.24**	**0.62**	**0.97**	**1.14**	**0.41**	**0.43**	**0.42**

Table 13. Average change in relative humidity (actual %) for fire season months (Oct-Apr) estimated for the 2080s (2070-2089) from 17 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Actual** (%)	**Models for 2080s – Change in Relative Humidity (%)**																	**Model avg.**
		BCM2	**CGMR**	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**69**	0.5	0.1	1.4	-0.1	0.8	0.2	1.5	1.7	1.0	2.3	0.5	1.0	1.9	2.1	2.4	1.6	0.6	**1.15**
DAR	**69**	0.5	0.1	1.3	0.0	0.8	0.2	1.3	1.6	1.0	2.1	0.5	1.0	1.7	1.9	2.3	1.4	0.6	**1.07**
COR	**69**	0.5	0.4	1.2	-0.1	0.3	0.5	1.2	1.0	0.8	1.4	0.7	0.9	1.7	2.0	1.7	1.3	0.6	**0.94**
AKL	**68**	0.4	-0.1	1.0	0.0	1.1	-0.3	1.0	1.5	0.7	2.0	-0.2	0.6	1.1	1.0	2.1	1.0	0.3	**0.77**
TGA	**66**	0.4	0.1	1.5	-0.3	0.4	0.3	1.5	1.5	1.1	2.1	0.7	0.7	1.9	2.2	2.1	1.6	0.6	**1.09**
ROA	**67**	0.5	0.1	1.5	-0.3	0.5	0.3	1.6	1.6	1.2	2.2	0.6	0.8	2.0	2.2	2.2	1.7	0.7	**1.14**
GSA	**60**	0.0	-0.3	0.4	-0.2	0.3	-0.2	0.4	0.7	0.4	0.9	0.0	0.1	0.4	0.4	0.9	0.5	0.1	**0.28**
APA	**67**	0.4	0.1	1.5	-0.3	0.4	0.4	1.6	1.5	1.1	2.2	0.7	0.8	2.0	2.2	2.2	1.6	0.7	**1.11**
NPA	**75**	0.6	0.1	1.3	0.0	0.7	0.2	1.4	1.6	1.0	2.1	0.6	1.1	1.7	2.1	2.3	1.5	0.6	**1.10**
WUA	**69**	0.2	-0.5	0.5	0.0	1.1	-0.6	0.7	1.3	0.6	1.6	-0.6	0.3	0.6	0.3	1.7	0.6	0.2	**0.46**
PPA	**70**	0.0	-0.7	-0.3	0.0	0.6	-0.7	-0.3	0.3	-0.1	0.2	-0.8	-0.3	-0.7	-1.0	0.2	-0.3	-0.2	**-0.24**
WNA	**68**	0.3	-0.3	0.5	0.1	1.3	-0.6	0.6	1.2	0.5	1.5	-0.6	0.4	0.6	0.3	1.7	0.5	0.1	**0.48**
NSA	**66**	0.5	0.1	1.2	0.0	0.7	0.2	1.3	1.5	0.9	1.9	0.5	0.9	1.6	1.9	2.1	1.4	0.6	**1.02**
WSA	**74**	0.6	0.4	1.4	0.0	0.3	0.6	1.3	1.2	0.9	1.6	0.9	1.0	1.7	2.2	1.8	1.5	0.7	**1.06**
HKA	**75**	0.5	0.1	1.5	-0.1	0.4	0.4	1.5	1.6	1.0	2.2	0.8	1.2	2.0	2.4	2.4	1.7	0.6	**1.19**
KIX	**70**	0.4	-0.1	0.3	0.3	1.5	-0.6	0.5	1.1	0.3	1.3	-0.8	0.5	0.5	0.2	1.7	0.4	0.1	**0.46**
CHA	**59**	0.1	-0.2	0.8	-0.1	0.3	0.0	0.8	1.0	0.6	1.3	0.3	0.7	1.1	1.2	1.5	1.0	0.2	**0.62**
QNA	**58**	0.7	0.8	1.3	0.1	0.4	0.7	1.3	0.9	0.9	1.2	0.9	1.0	2.0	2.3	1.6	1.4	0.8	**1.07**
DNA	**64**	0.4	-0.5	-0.2	0.4	1.5	-1.0	-0.2	0.7	0.1	0.5	-1.3	0.2	-0.5	-1.0	0.9	-0.2	-0.1	**-0.03**
NVA	**69**	1.3	0.1	1.2	0.7	2.1	-0.3	1.2	2.1	1.0	2.0	-0.2	1.5	1.2	1.5	2.9	1.3	0.8	**1.19**
Avg.	**68**	**0.43**	**-0.01**	**0.96**	**0.00**	**0.77**	**-0.01**	**1.01**	**1.28**	**0.75**	**1.62**	**0.16**	**0.71**	**1.23**	**1.32**	**1.84**	**1.05**	**0.43**	**0.80**

Table 14. Average change in wind speed (km/h) for fire season months (Oct-Apr) estimated for the 2050s (2040-2059) from 17 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Actual** (km/h)	**Models for 2050s – Change in Wind Speed (km/h)**																	**Model avg.**
		BCM2	**CGMR**	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**21.1**	-0.78	-0.81	-0.08	-0.55	-1.19	0.09	-0.60	-0.82	0.32	-0.50	-0.40	-0.16	0.17	-0.06	-0.47	0.27	0.12	**-0.32**
DAR	**14.4**	-0.45	-0.59	-0.12	-0.28	-0.84	0.09	-0.44	-0.43	0.20	-0.33	-0.28	-0.02	-0.01	-0.05	-0.31	0.11	0.03	**-0.22**
COR	**18.5**	-0.64	-0.75	-0.12	-0.47	-0.92	0.07	-0.45	-0.53	0.22	-0.44	0.00	-0.09	-0.06	-0.02	-0.33	0.15	0.09	**-0.25**
AKL	**22.0**	-0.44	-0.58	-0.10	-0.28	-0.51	0.14	-0.31	-0.40	0.27	-0.26	-0.08	0.02	0.03	0.08	-0.07	0.12	0.08	**-0.13**
TGA	**18.9**	0.06	-0.29	-0.03	-0.24	0.00	0.02	-0.05	-0.26	0.17	-0.32	-0.06	0.08	-0.27	-0.23	-0.10	0.09	-0.06	**-0.09**
ROA	**16.2**	-0.14	-0.42	-0.08	-0.26	-0.34	0.06	-0.22	-0.30	0.17	-0.35	0.06	0.09	-0.26	-0.14	-0.18	0.13	-0.04	**-0.13**
GSA	**19.0**	0.11	-0.25	-0.11	-0.07	0.17	0.09	-0.04	-0.23	0.16	-0.13	-0.16	0.18	-0.29	-0.10	0.16	-0.03	-0.02	**-0.03**
APA	**17.2**	0.10	-0.21	-0.01	-0.22	0.07	0.02	0.03	-0.23	0.14	-0.29	-0.13	0.07	-0.24	-0.19	-0.06	0.10	-0.08	**-0.07**
NPA	**21.6**	-0.66	-0.74	-0.18	-0.32	-1.04	0.13	-0.58	-0.59	0.24	-0.40	-0.19	-0.05	-0.02	-0.02	-0.37	0.13	0.04	**-0.27**
WUA	**22.8**	-0.27	-0.42	-0.02	-0.28	-0.35	0.15	-0.23	-0.37	0.27	-0.24	0.04	0.03	0.03	0.13	-0.02	0.17	0.05	**-0.08**
PPA	**21.7**	-0.36	-0.43	-0.05	-0.29	-0.52	0.13	-0.26	-0.40	0.26	-0.24	0.02	-0.05	0.09	0.13	-0.09	0.17	0.06	**-0.11**
WNA	**31.3**	-0.89	-0.91	-0.15	-0.55	-1.35	0.21	-0.64	-0.80	0.42	-0.52	-0.17	-0.22	0.19	0.09	-0.45	0.29	0.08	**-0.31**
NSA	**19.4**	-0.73	-0.80	-0.13	-0.51	-1.16	0.14	-0.54	-0.64	0.27	-0.50	-0.18	-0.11	0.07	-0.06	-0.52	0.21	0.04	**-0.30**
WSA	**17.9**	-0.85	-0.68	-0.01	-0.68	-1.17	0.12	-0.45	-0.67	0.30	-0.59	0.20	-0.27	0.21	0.14	-0.48	0.44	0.11	**-0.25**
HKA	**17.2**	0.10	-0.21	-0.01	-0.22	0.07	0.02	0.03	-0.23	0.14	-0.29	-0.13	0.07	-0.24	-0.19	-0.06	0.10	-0.08	**-0.07**
KIX	**17.9**	-0.66	-0.69	-0.09	-0.41	-1.08	-0.01	-0.48	-0.57	0.22	-0.41	-0.17	-0.20	0.16	0.02	-0.49	0.16	0.09	**-0.27**
CHA	**20.8**	-0.75	-0.65	-0.04	-0.53	-0.84	-0.01	-0.33	-0.82	0.35	-0.34	-1.15	-0.45	0.67	-0.04	-0.44	0.13	0.17	**-0.30**
QNA	**14.4**	-0.77	-0.69	-0.15	-0.42	-1.19	0.11	-0.57	-0.49	0.19	-0.35	-0.10	-0.19	0.12	-0.03	-0.50	0.10	0.09	**-0.29**
DNA	**18.9**	-0.74	-0.66	-0.04	-0.56	-1.16	0.05	-0.45	-0.63	0.23	-0.51	-0.44	-0.29	0.26	-0.15	-0.61	0.30	0.05	**-0.32**
NVA	**22.8**	-0.98	-0.34	0.09	-0.30	-0.88	0.15	-0.33	-0.25	0.26	0.14	-0.06	-0.50	0.89	0.51	-0.14	0.06	0.37	**-0.08**
Avg.	**19.7**	**-0.49**	**-0.56**	**-0.07**	**-0.37**	**-0.71**	**0.09**	**-0.35**	**-0.48**	**0.24**	**-0.34**	**-0.17**	**-0.10**	**0.07**	**-0.01**	**-0.28**	**0.16**	**0.06**	**-0.19**

Table 15. Average change in wind speed (km/h) for fire season months (Oct-Apr) estimated for the 2080s (2070-2089) from 17 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Actual** (km/h)	**Models for 2080s – Change in Wind Speed (km/h)**																	**Model avg.**
		BCM2	**CGMR**	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**21.1**	-0.91	-1.24	-0.35	-0.98	-2.29	0.03	-0.52	-1.03	-0.07	-0.94	0.43	-0.78	-0.70	-0.52	-1.30	-0.11	-0.58	**-0.70**
DAR	**14.4**	-0.51	-0.84	-0.24	-0.56	-1.48	0.06	-0.32	-0.64	-0.05	-0.54	0.33	-0.52	-0.58	-0.32	-0.84	-0.09	-0.32	**-0.44**
COR	**18.5**	-0.65	-0.97	-0.21	-0.72	-1.69	0.08	-0.45	-0.77	-0.07	-0.65	0.73	-0.52	-0.67	-0.36	-0.96	-0.13	-0.33	**-0.49**
AKL	**22.0**	-0.42	-0.89	-0.15	-0.59	-1.05	0.10	-0.15	-0.58	0.04	-0.38	0.46	-0.36	-0.51	-0.10	-0.47	0.06	-0.20	**-0.31**
TGA	**18.9**	0.15	-0.52	-0.12	-0.26	-0.12	-0.10	-0.20	-0.34	-0.01	-0.34	0.06	-0.15	-0.62	-0.35	-0.20	-0.10	-0.11	**-0.20**
ROA	**16.2**	-0.12	-0.71	-0.20	-0.36	-0.66	-0.06	-0.30	-0.44	-0.08	-0.39	0.31	-0.20	-0.72	-0.35	-0.42	-0.13	-0.20	**-0.30**
GSA	**19.0**	0.39	-0.40	-0.05	-0.27	0.08	0.07	0.01	-0.25	0.16	-0.12	0.14	-0.20	-0.54	-0.13	0.04	0.04	0.05	**-0.06**
APA	**17.2**	0.19	-0.39	-0.09	-0.22	0.03	-0.10	-0.14	-0.29	0.02	-0.28	0.02	-0.13	-0.49	-0.30	-0.12	-0.10	-0.09	**-0.15**
NPA	**21.6**	-0.71	-1.12	-0.31	-0.77	-1.95	0.07	-0.46	-0.79	-0.08	-0.68	0.64	-0.63	-0.81	-0.40	-1.05	-0.09	-0.40	**-0.56**
WUA	**22.8**	-0.19	-0.65	-0.03	-0.53	-0.88	0.12	-0.09	-0.54	0.08	-0.32	0.51	-0.29	-0.46	-0.03	-0.35	0.08	-0.19	**-0.22**
PPA	**21.7**	-0.33	-0.68	-0.07	-0.57	-1.09	0.11	-0.14	-0.58	0.03	-0.38	0.53	-0.39	-0.44	-0.06	-0.48	0.06	-0.25	**-0.28**
WNA	**31.3**	-1.03	-1.36	-0.32	-1.08	-2.64	0.11	-0.49	-1.13	-0.10	-0.94	0.88	-0.86	-0.87	-0.37	-1.35	-0.04	-0.63	**-0.72**
NSA	**19.4**	-0.86	-1.14	-0.30	-0.87	-2.18	0.03	-0.52	-0.92	-0.10	-0.87	0.68	-0.71	-0.76	-0.48	-1.20	-0.16	-0.53	**-0.64**
WSA	**17.9**	-1.09	-1.07	-0.24	-0.94	-2.27	0.02	-0.50	-0.99	-0.14	-0.91	1.01	-0.57	-0.58	-0.30	-1.15	-0.05	-0.63	**-0.61**
HKA	**16.0**	-0.72	-0.83	-0.20	-0.63	-1.62	0.10	-0.40	-0.63	-0.11	-0.56	0.78	-0.39	-0.53	-0.21	-0.82	-0.06	-0.38	**-0.42**
KIX	**17.9**	-0.80	-0.88	-0.23	-0.71	-1.88	0.02	-0.46	-0.73	-0.12	-0.75	0.47	-0.61	-0.49	-0.40	-1.08	-0.14	-0.45	**-0.54**
CHA	**20.8**	-0.75	-0.60	-0.03	-0.94	-1.96	0.07	-0.16	-0.90	0.19	-0.97	-0.05	-1.14	0.07	-0.37	-1.33	0.04	-0.41	**-0.54**
QNA	**14.4**	-1.00	-0.92	-0.31	-0.69	-2.13	0.04	-0.45	-0.76	-0.14	-0.72	0.67	-0.68	-0.55	-0.43	-1.24	-0.15	-0.52	**-0.59**
DNA	**18.9**	-1.02	-0.96	-0.30	-0.74	-2.14	-0.09	-0.53	-0.92	-0.16	-0.99	0.22	-0.62	-0.45	-0.59	-1.35	-0.18	-0.62	**-0.67**
NVA	**22.8**	-1.11	-0.08	0.29	-0.65	-1.81	0.38	0.16	-0.44	0.11	-0.27	0.86	-0.62	0.60	0.35	-0.92	0.26	-0.18	**-0.18**
Avg.	19.7	**-0.57**	**-0.81**	**-0.17**	**-0.65**	**-1.49**	**0.05**	**-0.31**	**-0.68**	**-0.03**	**-0.60**	**0.48**	**-0.52**	**-0.51**	**-0.29**	**-0.83**	**-0.05**	**-0.35**	-0.43

Overall changes for fire season relative humidity were also greater for the 2080s (see Table 13) than for the 2050s (see Table 12). The fire season averages over all models and stations were 0.4% for the 2050s and 0.8% for the 2080s, but again these varied widely. Fire season humidity changes ranged from a -1.0% decrease (at Dunedin Aero (DNA) under IPCM4) to a +1.8% increase (for Hokitika (HKA) under MIHR) for the 2050s (Table 12), and from a -1.3% decrease (again, at Dunedin Aero (DNA) under HADCM3) to a +2.9% increase (at Invercargill (NVA) under MIMR) for the 2080s (Table 13).

In real terms, projected changes in daily wind speed values were also relatively small (generally less than +/- 5 km/h), so that when averaged across all years at each station and then for all models and stations they are even smaller. Average changes across models and stations for fire season months (Tables 14 & 15) were however lower than for the full year (see Appendix 2), by around 1% (0.1- 0.2 km/h) with greater differences projected for the 2080s than the 2050s. This again reinforces the seasonality in projected wind speed changes, with lower westerly (Z1) and southerly (M1) wind components projected for summer and autumn (MfE 2008). Across all models and stations for both the 2050s and 2080s, average fire season wind speeds were projected to decrease by 0.2 km/h (-1%) and 0.4 km/h (-2%), respectively. This again varied widely between models and locations, from -1.3 km/h (-8%) (Wellington (WNA) under ECHOG) to +0.9 km/h (4%) (at Invercargill (NVA) under IPCM4) for the 2050s (Table 14), and -2.6 km/h (-15%) (again, at Wellington (WNA) under ECHOG) to +1.0 km/h (6%) (at Westport (WSA) under HADCM3) for the 2080s (Table 15).

Therefore in terms of relative changes in the weather inputs (i.e. expressed as a percentage of their average for the 1990s current climate baseline period, and also by way of comparison with the percentage changes included in the sensitivity study (see Table 7), the projected changes for the four weather elements averaged across the 17 models and 20 stations locations were:

for the 2050s:

- temperature increases ranging from +1.9% (0.34°C) to +18.2% (2.70°C), with an overall average increase of +7.3% (1.28°C);
- relative humidity decreases of -1.5% (relative to 1990s average RH) ranging to increases of +2.8%, with an overall average relative increase of +0.6%;
- wind speed decreases of -8.2% ranging to increases of +3.9%, with an overall average decrease of -1.0%; and
- rainfall decreases ranging from -48% to increases of +88%, with an overall average increase of +4.4%.

for the 2080s:

- temperature increases ranging from +5.4% (0.34°C) to +30.0% (4.46°C), with an overall average increase of +12.6% (2.21°C);
- relative humidity decreases of -2.0% (relative to 1990s average RH) ranging to increases of +4.0%, with an overall average relative increase of +1.2%;
- wind speed decreases of -14.8 % ranging to increases of +5.6%, with an overall average decrease of -2.2%; and
- rainfall decreases of -35% ranging to increases of +80%, with an overall average increase of +6.0% .

The linkages between changes in the contributing weather elements and corresponding changes in fire climate severity are readily apparent for some stations and models, but not so clear at others. As an example, changes for the various models for Dunedin Aero (DNA), which demonstrated the greatest overall potential increases of any of the stations, are shown in Table 16. Increases in fire danger were predicted by all models for this station for both the 2050s and 2080s, with 17-model average increases of 72% and 214% for SSR and days of VH+E fire danger, respectively for the 2050s, and 96% and 268% for the 2080s. The models that produced the greatest projected increases were IPCM4 and CGMR, and for the lowest changes, BCM2 (and variously, ECHG, GIAOM, GIEH, MIMR or MPEH5) (see Table 16).

Under the IPCM4 model, the projected increases for the 2050s were 179% for SSR (i.e. an increase of 3.05 on average, from the current 1.70 for the 1990s to 4.75 for the 2050s), and 490% for the number of days of VH+E fire danger (i.e. an extra 28.0 days/season on average, from the current 5.7 days/season to 33.7 days/season). These increases were the result of drier, hotter and windier conditions produced by projected decreases in average fire season rainfall (by -37.9% or 170 mm) and relative humidity (-1.5%), and increases in average temperature (+8.5% or 1.39°C) and wind speed (+1.04% or 0.3 km/h) (Table 16, top). The changes in all the weather factors therefore were aligned to produce the greatest potential increase in fire danger.

The CGMR model, which produced the 2nd highest increases in fire season SSR (119%) and days of VH+E (338%) fire danger at Dunedin Aero for the 2050s, has a lower projected decrease in rainfall (-5.2%) then the IPCM4 model, and relative humidity (when averaged over the fire season) was not projected to change from current values (see Table 1). Wind speed was also projected to decrease (-3.5%) rather than increase as under IPCM4, but the greater increase in fire season average temperature (+10.2%, or 1.65°C) for the CGMR model somewhat compensated for the reduced effects of the rainfall and wind speed changes.

The importance of temperature (and relative humidity) in driving changes in fire danger was also seen under the MIHR model for Dunedin Aero, which produced the 3rd highest projected increase in fire season SSR (94%) (and 4th highest increase in days of VH+E, of 235%) (see Table 16). In this case, slightly lower wind speeds (-0.8%) but higher rainfall (+5.7%) were projected; however these were offset by lower humidity (-1.4%) and, in particular, higher temperature (+16.6%, or 2.70°C), with the latter being the highest temperature increase of any of the models for Dunedin Aero for the 2050s.

The GIEH model shows a more complex pattern at Dunedin Aero, with an increase in temperature (+11.7%, or 1.90°C), and decreases in fire season rainfall (-3.5%) and humidity (-0.6%), causing it to rank 3rd in terms of greatest changes in the number of days of VH+E fire danger (see Table 16). However, a decrease in wind speed (of -2.7% or, on average, 0.5 km/h), which was one of the largest decreases of all the models, resulted in it ranking well below (16th, the 2nd lowest) most of the other models for SSR. This difference also highlights the varying sensitivity in the two fire climate measures (SSR and days of VH+E) to each of the weather inputs.

Table 16. Average changes (expressed as a % relative to the 1990s baseline average) in weather elements (temperature, relative humidity (RH), wind speed and rainfall) and resulting fire climate severity measures (Seasonal Severity Rating (SSR), and number of days of Very High and Extreme (VH+E) Forest fire danger) for fire season months (Oct-Apr) at Dunedin Aero (DNA), estimated for the 2050s (2040-2059) (top) and 2080s (2070-2089) (bottom) from 17 Global Climate Models.

Station Code	Actual 1990s	Dunedin Aero (DNA) – Model changes for 2050s (%)																	Model avg.
		BCM2	CGMR	CNCM3	CSMK3	ECHOG	FGOALS	GFCM20	GFCM21	GIAOM	GIEH	HADCM3	HADGEM	IPCM4	MIHR	MIMR	MPEH5	MRCGCM	
Temp	16.2°C	10.9	10.2	8.2	7.1	10.1	7.0	7.1	11.0	4.4	11.7	4.9	10.3	8.5	16.6	12.3	4.1	7.9	**8.96**
RH	64%	0.7	0.0	0.0	0.1	1.0	-0.8	0.7	0.6	-0.9	-0.6	-0.2	-0.5	-1.5	-1.4	0.3	-0.1	-0.6	**-0.19**
Wind	18.9 kmh	-3.9	-3.5	-0.2	-3.0	-6.1	0.3	-2.4	-3.3	1.2	-2.7	-2.3	-1.6	1.4	-0.8	-3.2	1.6	0.2	**-1.67**
Rain	448 mm	9.1	-5.2	-4.7	-6.1	12.8	3.7	-4.0	19.1	14.5	-3.5	28.9	20.0	-37.9	5.7	28.1	11.9	-4.8	**5.15**
SSR	1.70	21.6	118.9	59.3	72.3	58.9	66.3	75.7	79.2	49.2	26.4	59.5	66.3	179.1	93.8	75.8	50.5	76.6	**72.3**
VH+E	5.7	69.3	337.7	163.2	227.2	179.8	178.1	220.2	212.3	149.1	264.0	184.2	188.6	490.4	235.1	218.4	131.6	196.5	**214.4**
SSR rank[1]		17	2						4	15	16			1	3		14		
VH+E rank		17	2	14						15	3			1	4		16		

Station Code	Actual 1990s	Dunedin Aero (DNA) – Model changes for 2080s (%)																	Model avg.
		BCM2	CGMR	CNCM3	CSMK3	ECHOG	FGOALS	GFCM20	GFCM21	GIAOM	GIEH	HADCM3	HADGEM	IPCM4	MIHR	MIMR	MPEH5	MRCGCM	
Temp	16.2°C	18.1	16.9	15.0	9.5	15.0	12.5	13.9	14.7	9.7	13.3	11.3	15.4	18.2	27.2	19.2	14.6	15.5	**15.29**
RH	64%	0.5	-0.8	-0.3	0.6	2.3	-1.5	-0.3	1.1	0.1	0.7	-2.0	0.3	-0.8	-1.6	1.4	-0.4	-0.2	**-0.05**
Wind	18.9 kmh	-5.4	-5.1	-1.6	-3.9	-11.3	-0.5	-2.8	-4.8	-0.8	-5.2	1.2	-3.3	-2.4	-3.1	-7.1	-1.0	-3.2	**-2.04**
Rain	448 mm	26.1	-28.2	-11.6	-7.3	7.4	-10.8	-10.2	2.7	18.8	1.4	28.5	14.8	-27.9	3.4	22.3	6.1	2.5	**2.22**
SSR	1.70	36.8	200.9	92.9	98.2	47.3	80.1	131.6	92.8	64.0	51.9	98.1	73.7	216.8	111.6	59.8	100.1	70.0	**95.7**
VH+E	5.7	100.9	568.4	258.8	278.1	139.5	217.5	361.4	280.7	189.5	143.9	272.8	207.0	584.2	305.3	164.9	280.7	200.9	**267.9**
SSR rank[1]		17	2			16		3			15			1	4	14			
VH+E rank		17	2			16		3			15			1	4	14			

[1] Rankings of SSR and days of VH+E show the position of the changes for a particular model relative to those for other models, from 1 (highest) to 17 (lowest).

For the 2080s at Dunedin Aero (Table 16, bottom), somewhat similar trends are found for the models that produce the greatest projected increases in fire danger. The IPCM4 model still ranks 1st in terms of the highest increases in SSR (217%, to 5.39 from the current 1.70) and days of VH+E (584%, or an extra 33.3 days to 39.0 days/season). It shows an even greater temperature increase (+18.2%, or 2.96°C) from the 2050s, which offsets smaller decreases in average fire season relative humidity (-0.8%) and rainfall (-27.9%) and, in this instance, reduced (-2.4%) rather then increased wind speed (see Table 16). The CGMR model also still ranks second for the 2080s, with greater decreases in rainfall (-28.2%) and this time also humidity (-0.8%), and a significantly higher temperature increase (+16.9%, 2.75°C), resulting in greater increases in fire climate severity (201% and 568%, respectively for SSR and days of VH+E) than for the 2050s. However, in a slight change from the 2050s, instead of the MIHR model ranking 3rd in terms of increases in SSR (and 4th for VH+E), it only ranked 4th for the 2080s due to a greater potential wind speed decrease (-3.1%) and continued rainfall increase (+3.4%), despite having the highest projected increase in temperature of any of the models (see Table 16). The 3rd ranking for the 2080s was instead taken by the GFCM20 model, which showed a decrease in average fire season rainfall (of -10.2%) in place of the increase seen for the MIHR model.

In general, the opposite trends were seen in the weather elements for the models that produced the lowest increases in fire climate severity. For example, at Dunedin Aero (Table 16), the BCM2 model produced the lowest overall increases in fire climate severity for both the 2050s and 2080s due to alignment in the changes in the other weather elements on reducing fire danger, and offsetting the increases due to higher projected temperatures. For the 2050s, the BCM2 model projected increases in fire season relative humidity (+0.7%) and rainfall (+9.1%), and reduced wind speeds (-3.9%) from current climate for the 1990s, as well as only moderately increased temperatures (+10.9%, or 1.77°C) compared with other models, which combined to produce only minor increases in SSR (22%) and the number of days of VH+E fire danger (69%) (see Table 16, top). Despite a higher projected temperature increase (+18.1% or 2.94°C) for the 2080s (see Table 16, bottom), a greater increase in rainfall (+26.1%, or an extra 100mm on average over the fire season), plus increased humidity (+0.5%) and decreased wind speeds (-5.4%), again resulted in only small increases in SSR (37%) and days of VH+E (101%) (although in the latter case, this still represents a doubling from 5.7 to 11.5 days/season).

For the 2050s, the MPEH5 and GIAOM models produced the next lowest increases in fire climate severity (of 50% and 132%, and 49% and 149%, for SSR and days of VH+E for each model, respectively) (see Table 16, top). These two models projected the lowest increases in average temperature (+4.1% or 0.66°C, and 4.4% or 0.72°C, respectively) and higher rainfall (+11.9% and +14.5%) that offset the effects of slight decreases in relative humidity (-0.1% and -0.9%) and increased wind speeds (+1.6% and +1.2%). However, in a change for the 2080s, the ECHOG and GIEH models replaced MPEH5 and GIAOM as the next lowest ranking models in terms of increases in fire season severity (see Table 16, bottom), due to alignment of the effects of all the weather elements on reducing fire danger and generally greater changes for ECHOG and GIEH. Like the MPEH5 and GIAOM models, ECHOG and GIEH had moderate to low projected increases in temperature of +15.0% (2.44°C) and +13.3% (2.15°C) (cf. +14.6%/2.37°C and +9.7%/1.57°C for MPEH5 and GIAOM, respectively), plus increased rainfall of +7.4% and +1.4% (cf. +6.1% and 18.8%). However, the ECHOG and GIEH models had significantly higher projected decreases in wind speed (-5.4% and -11.3%) compared to MPEH and GIAOM (-1.0% and -0.8%), that resulted in their lower rankings for fire climate severity for the 2080s.

While illustrating the linkages between changes in future climate and fire climate severity from the downscaled global models, these examples for the Dunedin Aero (DNA) station also demonstrate the complexities in the interactions between the projected changes in the weather elements and resulting fire danger. These are only further exacerbated by climatic season and monthly changes contained within the models that are not apparent from fire season (or annual) averages, as well as the possible influence of interannual variability (i.e. from one year to another), where averages may reflect the occurrence of just a few particularly severe months or seasons. Future analyses should therefore investigate changes for individual months and/or climatic seasons to better understand the effects of modelled monthly changes on fire danger. The variability between years for each projection period should also be quantified to better describe the effects of the projected weather changes on the potential range in fire climate severity, including the possible extremes.

Comparison with Previous Study

While the present study used updated scenario data and a wider range of global models from the IPCC's 4th Assessment (AR4), the results are in many cases comparable to those from the previous study of Pearce et al. (2005) based on the 3rd Assessment (AR3). That study considered changes in fire danger ratings and fire climate severity for the 2080s (representing 100-year changes from 1970-1999 to 2070-2099) for only two models (but with high-, mid- and low-range scenarios for each), based on projected changes in just temperature and rainfall, but for a wider range of station locations (52).

Weather changes

The Pearce et al. (2005) study determined average fire season temperature changes ranging from 0.47°C to 2.89°C under the Hadley (Low) and CSIRO (High) scenarios, and 0.52°C to 2.89°C for the full year. This compares with projected fire season changes for the 2080s of 1.02°C to 4.46°C from the 17 models used in the present analysis, and 1.42°C to 3.69°C. Therefore the current analysis considers a wider range in possible temperature changes than the 2005 study. This is partially due to the broader range of models used in the present analysis, but also the result of the use of variable monthly changes within each projection period in the present analysis (where temperatures changed by as much as 10°C from the baseline values in some months) rather than consistent changes for each individual month in all years in the Pearce et al. (2005) study.

Changes in average fire season rainfall varied from -35% to +18% (and -35% to +36% for full year) under Hadley (High) scenario in the 2005 study. This compares with average fire season changes of -48% to +88% (and -31% to +32% for the full year) in the present analysis. Therefore fire season rainfall was found to vary more widely than in the previous analysis, as a result of inclusion of the updated scenarios and broader range of models that, in particular, also include more marked seasonality in projected rainfall (and wind) patterns than was evident in the models used in the AR3 assessment.

As noted above, the Pearce et al. (2005) study did not consider wind speed and relative humidity changes, as was done in the present analysis. Therefore there will be differences in the resulting fire dangers due to the inclusion of these changes, which for the 2080s were:

- for relative humidity, average fire season decreases of -2.0% (relative to 1990s average RH) ranging to increases of +4.0% (and -2.8% to +2.6% for the full year); and
- for wind speed, average fire season decreases of -14.8 % ranging to increases of +5.6% (and -10.4% to +7.3%).

The greater fire season ranges of both these weather elements compared to full-year averages again highlight the seasonal variation in projected changes, with greater changes during fire season months (i.e. some or all of late spring, summer and early autumn) compared with months outside the fire season (i.e. some or all of late autumn, winter and early spring).

Fire climate severity changes

The weather changes outlined above for the Pearce et al. (2005) study resulted in projected changes for the SSR[6] averaged over fire season months of +0.7% to +57% (and +0.5% to +67% for the full year), under the Hadley (Low) and Hadley (High) scenarios, respectively. Of note was the lack of decreases in SSR found despite the broader range of sites. This contrasts with the present study, where fire season SSR values ranged from -37% to +217% (and -2% +245% for the full year), and a number of stations showed either no change or projected decreases in SSR.

For the number of days of VH+E Forest fire danger, the 2005 study projected average changes ranging from zero (no change) to +900% (for both the fire season and year), although the greatest changes were predicted for stations where the 1990s baseline fire climate was very close to zero (so that even minor increases to the number of projected days of VH+E resulted in very high relative changes). The greatest average fire season increase when these anomalous changes were excluded was +138%. Again, there were no locations where the number of days of VH+E fire danger was projected to decrease, so that results contrasted with those from the present study where the projected number of days of VH+E for the fire season ranged from -57% to +713% (and -57% to 600% for the full year). In absolute terms, the greatest projected changes in the number of days of VH+E fire danger over the fire season were 23.4 days/season (at

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[6] described in the Pearce et al. (2005) study based on the average Cumulative Daily Severity Rating (CDSR), obtained by summing the DSR values for each day over the fire season and averaging these totals over the number of fire seasons. When differences between projection periods are expressed as a percentage change, the result is the same as using the average SSR (the average of the daily values over each fire season, averaged over the number of fire seasons) used in the present study.

Gisborne, GSA) in the Pearce et al. (2005) study and 40.7 days/season (at Wellington, WNA) for the present analysis (or 25.0 days/year (again, at GSA) and 45.8 days/year (again, at WNA), for the full year respectively).

The differences between the ranges in the projected changes for these two fire climate severity measures for the two studies and, in particular, for the lack of decreases in the 2005 study, was due to the much greater number of models used in the present analysis, with their broader range and more marked seasonality in projected changes in the weather elements used to determine fire climate severity.

Areas of the country depicting changes

Of the stations included in the present analysis, those that showed the greatest changes (all increases) for SSR in the 2005 study were Kaikoura (KIX), Gisborne (GSA), Tauranga (TGA), Rotorua (ROA) and, in some instances, Dargaville (DAR) and Taupo (APA), predominantly under the Hadley (High) scenario but also, to a lesser extent, under the CSIRO (High) scenario. Queenstown (QNA), Invercargill (NVA) and Dunedin Aero (DNA), as well as Hokitika (HKA) and Westport (WSA), showed the lowest changes in SSR under the Hadley (Low) and, also to a lesser extent, CSIRO (Low) scenarios. For the number of days of VH+E Forest fire danger, the stations from the 2005 study to show the greatest changes were again ROA, KIX and APA, along with DAR, GSA and, in this case, also Wanganui (WUA), under both the Hadley (High) and CSIRO (High) scenarios. Again QNA, NVA and DNA, along with Wellington (WNA) and Christchurch Aero (CHA), showed the lowest changes in number of days of VH+E, under the Hadley-(Low) and -(Mid) and CSIRO (Low) scenarios.

This again contrasts with the findings from the present analysis where Kaikoura (KIX) but also Dunedin Aero (DNA) were clearly the two stations to show the greatest increases in fire climate severity. Taupo (APA), and to a lesser extent, Rotorua (ROA) and Tauranga (TGA) did show some increases in fire danger, but only under the most extreme model scenarios. Wanganui (WUA) and Wellington (WNA) were locations for which significant increases were projected by a greater number of models, as to a lesser extent was also Paraparaumu (PPA). Again, in a significant divergence from the previous study, where significant increases were found, Gisborne (GSA) showed only minor increases or decreases under most models in the present analysis. Similarly, Dargaville (DAR) showed decreases under several models in the current study (as did Kaitaia (KX), which was not included in the 2005 study). Invercargill (NVA), on the other hand, was one of the stations to show the lowest changes in the 2005 study, but was projected to have increased fire climate severity under many of the models in the present analysis.

In simplest terms, based on the findings from the present study and the 12-model averages from MfE (2008), the areas most likely to exhibit the greatest potential increases in fire climate severity are eastern areas (e.g. coastal Marlborough and Canterbury, and from the results of the present study, potentially also coastal Otago) and in the north of the North Island (especially Northland), where there is potential for “decreasing annual average rainfall” and an “increasing risk of dry periods or drought’ due to projected increases in westerly winds in winter and spring. This could result in increases in fire danger that are carried through into summer months, producing higher fire climate severity on average. Decreased westerly winds in summer and autumn that produce drier conditions in the west of the North Island could also produce increased fire danger in this area in the latter part of the fire season and also, on average, a more sever fire climate. At the other end of the fire danger spectrum, the projected increase in westerly winds during winter and spring would potentially result in more rainfall in the west of both islands, and therefore lower fire dangers in these areas at the start of the fire season. This could potentially result in reduced fire season severity. Similarly, the projected decrease in westerly winds during summer and autumn could produce rainfall increases in Gisborne and Hawkes Bay, reducing summer fire dangers and average fire climate severity in this region.

However, it is important to note that seasonal changes can in some instances be the opposite of the annual changes, and there will also continue to be significant year-to-year variability between individual fire seasons, so that some fire seasons may exhibit significantly higher faire dangers, and others significantly lower, that indicated by any average projected increase or decrease in overall fire climate severity.

Fire Season Length

A number of studies have highlighted the potential for fire season length to increase with climate change, through fire seasons starting earlier and/or finishing later (e.g. Street 1989, Wotton & Flannigan 2003). Pearce et al. (2005) suggested several possible approaches to defining the fire season, including using Monthly Severity Rating (MSR) values greater than 3.0 to indicate months with high to very high fire behaviour potential (after Stocks et al. 1998), or months where the average number of days of VH+E Forest fire danger is greater than 1.0. However, they did not investigate these fully for a wide range of New Zealand station locations to determine their validity.

Examples using both these approaches for two stations (Gisborne, GSA; and Christchurch, CHA) are illustrated in Tables 17-20. For Gisborne, the MSR method (Table 17) fails to pick up all of the months currently recognised as being part of the fire season, by excluding October and April. It is also not sufficiently discriminating between different GCMs, with about half of the 17 models adding the month of October for the 2050s, and all but one (HADCM3) picking up October for the 2080s. The HADCM3 model in fact show a reduction in fire season length for the 2080s, due to lower MSR values in October and November, while the IPCM4 model is the only one to suggest a possible increase in fire season length with higher MSR values extending beyond March into April. Results for Christchurch (Table 19) are only slightly better, with two models for the 2050s (GIEH and MIHR) showing extension into April, and HADCM3 again showing potential for the fire season to begin as early as August (although MSR values in October fall below the threshold). For Christchurch in the 2080s, an increased number of models show higher MSR values extending into April, and HADCM3 is again the only model to show elevated MSR values prior to October (and again, potentially extending back into August).

Table 17. Changes in average fire season length with climate change for the 2050s (top) and 2080s (bottom) for Gisborne (GSA) using Monthly Severity Rating (MSR) thresholds. Shaded cells indicate the fire season period where the average MSR consistently exceeds 3.0, a threshold identified for high to very high fire behaviour potential (after Stocks et al. 1998).

2050 GSA MSR

Model	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**	**Seas**
Actual	**8.13**	**5.01**	**3.21**	**2.12**	**1.04**	**0.23**	**0.15**	**0.44**	**0.92**	**2.37**	**3.97**	**6.04**	**2.80**	**4.41**
BCM2	9.19	5.72	3.65	2.62	1.33	0.38	0.20	0.55	1.15	2.74	4.84	7.22	**3.29**	5.14
CGMR	10.05	6.67	3.47	2.36	1.16	0.34	0.22	0.66	1.44	3.10	4.97	7.02	**3.44**	5.38
CNCM3	8.85	5.20	3.67	2.28	1.29	0.37	0.23	0.65	1.43	3.24	4.77	6.71	**3.22**	4.97
CSMK3	9.02	5.95	3.94	2.23	1.09	0.31	0.23	0.56	1.16	2.87	4.28	6.50	**3.17**	4.97
ECHOG	9.31	6.30	3.99	2.09	1.15	0.33	0.20	0.64	1.35	3.25	5.08	6.99	**3.38**	5.29
FGOALS	9.03	5.24	3.37	2.19	1.13	0.27	0.19	0.60	1.26	3.00	4.40	6.44	**3.09**	4.82
GFMC20	9.27	5.81	3.65	2.53	1.47	0.37	0.25	0.66	1.31	2.95	5.07	7.40	**3.39**	5.25
GFMC21	8.80	5.13	3.38	2.27	1.25	0.33	0.24	0.65	1.56	3.15	5.13	7.01	**3.24**	4.99
GIAOM	9.25	5.50	3.30	2.23	1.25	0.30	0.20	0.63	1.34	2.89	4.22	6.69	**3.14**	4.88
GIEH	9.28	5.46	3.85	2.97	1.55	0.33	0.24	0.76	1.27	3.15	4.84	7.40	**3.42**	5.29
HADCM3	9.38	5.52	3.05	1.92	1.09	0.72	1.19	2.44	2.53	2.13	2.88	5.58	**3.20**	4.36
HADGEM	9.39	6.37	4.18	2.46	1.05	0.24	0.20	0.60	1.20	2.82	5.13	7.03	**3.38**	5.34
IPCM4	10.21	6.33	4.19	2.63	1.48	0.35	0.25	0.69	1.17	3.13	5.58	7.68	**3.63**	5.69
MIHR	9.34	6.06	3.99	2.71	1.45	0.40	0.21	0.62	1.44	2.88	4.62	6.77	**3.36**	5.20
MIMR	8.67	5.49	3.49	2.18	1.02	0.34	0.18	0.58	1.26	3.10	4.91	7.22	**3.20**	5.02
MPEH5	8.83	6.38	3.42	2.52	1.27	0.35	0.20	0.68	1.55	2.94	4.90	6.72	**3.30**	5.10
MRCGCM	9.26	6.03	3.62	2.43	1.56	0.41	0.22	0.64	1.34	3.16	4.63	6.52	**3.31**	5.10
Average	**9.24**	**5.83**	**3.66**	**2.39**	**1.27**	**0.36**	**0.27**	**0.74**	**1.40**	**2.97**	**4.72**	**6.88**	**3.30**	**5.10**

2080 GSA MSR

Model	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**	**Seas**
Actual	**8.13**	**5.01**	**3.21**	**2.12**	**1.04**	**0.23**	**0.15**	**0.44**	**0.92**	**2.37**	**3.97**	**6.04**	**2.80**	**4.41**
BCM2	9.18	5.88	3.55	2.40	1.24	0.37	0.22	0.59	1.27	3.23	5.24	7.39	**3.37**	5.27
CGMR	10.84	7.11	3.73	2.44	1.54	0.46	0.30	0.70	1.48	3.46	5.84	7.67	**3.79**	5.87
CNCM3	9.52	5.66	3.76	2.47	1.38	0.36	0.22	0.68	1.55	3.40	5.22	7.26	**3.45**	5.34
CSMK3	9.43	5.76	4.02	2.47	1.30	0.34	0.25	0.66	1.30	3.17	4.81	6.85	**3.36**	5.22
ECHOG	9.49	6.41	3.80	2.49	1.40	0.35	0.24	0.69	1.36	3.16	5.13	7.20	**3.47**	5.38
FGOALS	8.88	5.29	3.43	2.55	1.25	0.30	0.22	0.60	1.29	3.13	4.95	7.07	**3.24**	5.05
GFMC20	9.78	6.31	3.95	2.71	1.54	0.45	0.27	0.69	1.52	3.60	5.42	7.43	**3.63**	5.60
GFMC21	8.85	4.63	3.05	2.25	1.20	0.33	0.26	0.67	1.43	3.22	5.50	7.53	**3.24**	5.02
GIAOM	9.30	5.82	3.29	2.23	1.23	0.32	0.20	0.63	1.30	3.02	4.55	6.95	**3.23**	5.03
GIEH	8.47	5.25	3.46	2.45	1.22	0.32	0.21	0.63	1.20	3.13	4.71	6.43	**3.12**	4.85
HADCM3	9.17	6.54	3.35	1.76	0.98	0.67	0.99	2.77	2.94	2.48	2.74	5.06	**3.28**	4.44
HADGEM	9.48	6.03	4.14	2.51	1.16	0.32	0.24	0.60	1.33	3.40	5.47	7.55	**3.51**	5.52
IPCM4	10.71	7.04	5.06	3.06	1.74	0.55	0.29	0.72	1.43	3.45	5.52	8.34	**3.98**	6.18
MIHR	9.78	6.90	4.21	2.87	1.49	0.40	0.29	0.75	1.54	3.12	5.22	7.70	**3.68**	5.69
MIMR	8.66	5.73	3.46	2.11	1.10	0.30	0.25	0.68	1.39	3.62	5.39	7.38	**3.33**	5.20
MPEH5	10.23	6.60	3.76	2.41	1.44	0.32	0.25	0.80	1.68	3.63	5.52	7.70	**3.69**	5.70
MRCGCM	10.10	6.06	3.52	2.55	1.43	0.42	0.28	0.77	1.44	3.00	4.57	7.05	**3.42**	5.27
Average	**9.52**	**6.06**	**3.74**	**2.45**	**1.33**	**0.39**	**0.29**	**0.80**	**1.50**	**3.25**	**5.05**	**7.21**	**3.46**	**5.33**

Table 18. Changes in average fire season length with climate change for the 2050s (top) and 2080s (bottom) for Gisborne (GSA) 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 consistently exceed 1.0 per month (after Pearce et al. 2005).

2050 GSA VH+E

Model	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**	**Seas**
Actual	**11.1**	**5.6**	**3.3**	**2.1**	**0.4**	**0**	**0**	**0**	**0.2**	**1.4**	**3.4**	**7.3**	**34.7**	34.1
BCM2	12.3	6.4	4.1	2.7	0.7	0	0	0	0.3	2.2	4.9	9.0	**42.3**	41.3
CGMR	13.3	7.6	3.8	2.3	0.4	0	0	0	0.4	2.8	5.6	9.1	**45.1**	44.3
CNCM3	12.0	6.0	4.0	2.2	0.4	0	0	0	0.7	3.0	5.1	8.5	**41.6**	40.6
CSMK3	11.7	6.4	4.2	2.0	0.3	0.1	0	0	0.3	2.4	4.1	8.0	**39.2**	38.6
ECHOG	12.2	7.5	4.5	1.8	0.4	0	0	0	0.4	2.7	5.1	8.7	**43.2**	42.4
FGOALS	12.1	5.8	3.2	1.9	0.3	0.1	0	0	0.4	2.4	4.1	8.0	**38.0**	37.3
GFMC20	12.2	6.5	4.0	2.5	1.2	0.1	0	0	0.4	2.2	5.9	9.4	**44.1**	42.5
GFMC21	11.6	5.5	3.7	2.2	0.6	0	0	0.1	0.7	2.8	5.5	8.7	**41.1**	39.8
GIAOM	12.3	6.0	3.5	2.2	0.3	0	0	0.1	0.4	2.4	3.7	8.5	**39.2**	38.5
GIEH	12.6	6.4	4.5	3.2	1.2	0	0	0.1	0.4	2.4	4.6	9.2	**44.4**	42.8
HADCM3	12.9	6.1	3.3	1.9	0.5	0	0	2.1	2.2	1.6	1.7	7.1	**39.3**	34.6
HADGEM	13.3	7.5	5.1	2.4	0.8	0	0	0	0.2	1.9	5.9	8.1	**45.0**	44.0
IPCM4	13.4	6.8	5.0	2.8	1.2	0	0	0	0.2	2.8	6.3	10.3	**48.7**	47.3
MIHR	12.6	7.1	4.6	2.7	0.7	0.1	0	0	0.5	2.8	4.8	8.7	**44.3**	43.1
MIMR	11.6	6.2	3.6	2.1	0.3	0.1	0	0	0.4	2.6	5.1	8.9	**40.6**	39.9
MPEH5	12.1	7.5	3.9	2.7	0.9	0	0	0	0.6	2.9	4.8	8.5	**43.7**	42.3
MRCGCM	12.6	6.4	3.6	2.4	0.9	0.1	0	0	0.4	2.9	4.4	8.0	**41.4**	40.1
Average	**12.4**	**6.5**	**4.0**	**2.3**	**0.6**	**0.02**	**0**	**0.1**	**0.5**	**2.5**	**4.8**	**8.6**	**42.4**	**41.1**

2080 GSA VH+E

Model	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**	**Seas**
Actual	**11.1**	**5.6**	**3.3**	**2.1**	**0.4**	**0**	**0**	**0**	**0.2**	**1.4**	**3.4**	**7.3**	**34.7**	34.1
BCM2	12.0	6.5	3.8	2.2	0.4	0.1	0	0	0.2	3.0	5.6	8.7	**42.3**	41.7
CGMR	14.9	8.0	4.0	2.5	1.1	0.1	0	0	0.5	3.5	7.1	9.9	**51.3**	49.7
CNCM3	12.9	6.5	4.2	2.6	0.8	0	0	0	0.6	3.3	6.0	8.9	**45.7**	44.3
CSMK3	12.7	6.7	4.5	2.6	0.8	0	0	0	0.3	2.9	4.8	8.2	**43.4**	42.4
ECHOG	12.9	7.3	4.1	2.5	1.1	0	0	0	0.4	2.7	5.5	9.4	**45.8**	44.3
FGOALS	12.0	5.9	3.5	2.5	0.6	0	0	0	0.2	2.8	5.4	8.7	**41.3**	40.6
GFMC20	13.5	6.4	4.4	2.7	0.9	0.1	0	0	0.4	3.8	6.4	9.6	**48.0**	46.7
GFMC21	12.5	5.4	3.2	2.3	0.6	0.1	0	0	0.4	3.2	6.3	9.6	**43.4**	42.4
GIAOM	12.7	6.7	3.5	2.2	0.7	0	0	0	0.5	2.7	4.3	8.6	**41.7**	40.5
GIEH	11.5	6.1	3.7	2.4	0.6	0.1	0	0	0.1	3.0	4.8	8.1	**40.2**	39.4
HADCM3	12.4	7.1	3.7	1.6	0.2	0	0.2	2.1	2.9	2.1	1.8	5.6	**39.4**	34.1
HADGEM	12.6	6.5	4.8	2.4	0.3	0.1	0	0	0.3	3.6	6.3	9.0	**45.7**	45.1
IPCM4	15.0	8.4	5.9	2.8	1.0	0.2	0	0	0.6	3.6	6.0	11.0	**54.2**	52.5
MIHR	13.0	7.9	4.9	3.0	0.8	0	0	0	0.7	2.5	5.9	9.9	**48.3**	46.9
MIMR	11.7	6.6	3.8	2.0	0.6	0.1	0	0	0.5	3.5	6.1	8.6	**43.3**	42.2
MPEH5	13.9	7.8	4.0	2.5	1.0	0	0	0.2	0.7	3.7	6.1	9.5	**49.0**	47.2
MRCGCM	13.7	6.6	4.2	2.6	0.8	0	0	0	0.5	2.9	4.3	8.7	**44.1**	42.9
Average	**12.9**	**6.8**	**4.1**	**2.4**	**0.7**	**0.03**	**0.01**	**0.1**	**0.6**	**3.1**	**5.4**	**8.9**	**45.1**	**43.7**

Table 19. Changes in average fire season length with climate change for the 2050s (top) and 2080s (bottom) for Christchurch (CHA) using Monthly Severity Rating (MSR) thresholds. Shaded cells indicate the fire season period where the average MSR consistently exceeds 3.0, a threshold identified for high to very high fire behaviour potential (after Stocks et al. 1998).

2050 CHA MSR

Model	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**	**Seas**
Actual	**8.73**	**7.96**	**4.66**	**2.32**	**1.06**	**0.30**	**0.18**	**0.61**	**1.56**	**3.90**	**4.93**	**6.80**	**3.56**	**5.60**
BCM2	9.62	8.65	5.63	2.94	1.42	0.44	0.28	0.71	1.75	4.09	5.74	7.44	**4.04**	6.29
CGMR	10.82	9.88	5.31	2.68	1.26	0.43	0.28	1.20	2.52	4.78	5.92	8.50	**4.44**	6.83
CNCM3	9.76	7.84	5.79	2.55	1.17	0.44	0.32	0.98	2.04	4.88	5.36	7.58	**4.04**	6.25
CSMK3	8.70	8.48	6.45	2.75	1.18	0.38	0.37	0.89	1.84	4.12	5.17	8.37	**4.04**	6.29
ECHOG	10.05	10.25	5.99	2.93	1.31	0.48	0.34	1.04	1.95	4.80	6.05	8.08	**4.41**	6.86
FGOALS	9.30	7.83	4.99	2.76	1.32	0.35	0.22	0.80	2.00	4.94	5.32	7.49	**3.93**	6.09
GFMC20	10.02	9.30	4.56	2.81	1.40	0.40	0.32	0.98	2.24	4.51	5.81	8.35	**4.20**	6.46
GFMC21	8.71	8.09	4.68	2.81	1.22	0.38	0.28	0.92	2.25	4.65	6.04	8.40	**4.02**	6.19
GIAOM	10.14	8.73	4.66	2.52	1.18	0.36	0.22	0.77	2.15	4.74	5.04	7.39	**3.97**	6.16
GIEH	9.50	8.15	5.80	3.13	1.44	0.40	0.25	0.98	1.94	4.76	6.03	8.57	**4.23**	6.56
HADCM3	10.34	8.18	3.86	1.75	0.97	0.71	1.22	3.13	3.31	2.90	3.90	6.57	**3.89**	5.35
HADGEM	9.23	8.96	5.92	2.72	1.07	0.30	0.25	1.05	2.04	4.46	5.29	6.97	**4.00**	6.21
IPCM4	10.13	8.71	5.56	2.95	1.51	0.59	0.31	0.82	1.83	4.47	6.25	8.38	**4.27**	6.63
MIHR	9.25	8.94	5.65	3.03	1.50	0.45	0.27	0.79	1.97	3.90	5.27	7.29	**4.00**	6.17
MIMR	8.65	7.96	4.74	2.85	1.11	0.39	0.21	0.61	1.92	4.65	6.02	7.47	**3.86**	6.04
MPEH5	8.85	10.46	4.56	2.63	1.12	0.40	0.19	0.78	2.06	4.47	5.64	7.09	**3.99**	6.21
MRCGCM	9.61	8.74	5.05	2.78	1.27	0.44	0.38	0.94	1.92	4.81	5.65	7.44	**4.07**	6.29
Average	**9.57**	**8.77**	**5.25**	**2.74**	**1.26**	**0.43**	**0.33**	**1.02**	**2.10**	**4.47**	**5.56**	**7.73**	**4.08**	**6.29**

2080 CHA MSR

Model	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**	**Seas**
Actual	**8.73**	**7.96**	**4.66**	**2.32**	**1.06**	**0.30**	**0.18**	**0.61**	**1.56**	**3.90**	**4.93**	**6.80**	**3.56**	**5.60**
BCM2	9.92	9.11	5.08	3.08	1.34	0.38	0.29	0.83	2.22	4.88	6.46	7.95	**4.27**	6.63
CGMR	13.14	10.98	5.97	3.11	1.72	0.50	0.33	1.10	2.57	5.19	7.48	9.50	**5.11**	7.90
CNCM3	10.35	8.69	5.39	2.96	1.29	0.57	0.29	1.01	2.43	4.91	5.90	7.97	**4.29**	6.59
CSMK3	9.81	8.72	6.10	2.90	1.24	0.42	0.28	1.21	2.10	4.41	5.98	8.29	**4.27**	6.59
ECHOG	10.74	10.20	6.74	3.37	1.43	0.46	0.36	0.97	2.27	4.83	5.99	8.34	**4.62**	7.16
FGOALS	9.33	8.13	5.07	3.15	1.39	0.40	0.29	0.82	1.96	4.78	5.88	7.98	**4.08**	6.32
GFMC20	10.16	8.94	4.92	3.25	1.47	0.51	0.36	1.06	2.70	5.07	5.91	8.52	**4.39**	6.67
GFMC21	8.49	7.90	4.61	2.96	1.23	0.46	0.36	0.78	2.22	4.33	6.77	8.44	**4.03**	6.21
GIAOM	9.95	8.90	4.58	2.52	1.39	0.39	0.25	1.07	2.24	4.80	5.18	7.47	**4.04**	6.19
GIEH	8.46	8.27	5.51	2.80	1.29	0.36	0.25	0.78	1.97	4.97	5.56	7.05	**3.92**	6.08
HADCM3	9.76	10.28	4.83	2.33	0.79	0.72	1.14	3.97	4.22	4.42	3.26	6.53	**4.32**	5.89
HADGEM	10.35	7.95	5.79	2.77	1.16	0.44	0.35	0.89	2.07	4.86	5.02	6.96	**4.04**	6.24
IPCM4	11.53	10.42	7.74	3.17	2.05	0.62	0.35	0.92	2.07	5.03	5.97	9.04	**4.89**	7.55
MIHR	9.23	10.65	6.17	3.56	1.52	0.38	0.27	0.98	2.52	5.22	6.38	7.89	**4.53**	6.99
MIMR	8.17	7.99	5.25	2.71	1.30	0.41	0.28	0.75	1.99	4.78	5.63	7.66	**3.89**	6.02
MPEH5	9.89	9.29	5.55	2.89	1.52	0.35	0.25	0.97	2.18	4.62	6.24	7.63	**4.26**	6.57
MRCGCM	11.09	9.66	5.88	3.09	1.61	0.43	0.33	1.00	1.97	4.36	5.95	8.17	**4.44**	6.87
Average	**10.02**	**9.18**	**5.60**	**2.98**	**1.40**	**0.46**	**0.35**	**1.12**	**2.33**	**4.79**	**5.86**	**7.96**	**4.32**	**6.62**

Table 20. Changes in average fire season length with climate change for the 2050s (top) and 2080s (bottom) for Christchurch (CHA) 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 consistently exceed 1.0 per month (after Pearce et al. 2005).

2050 CHA VH+E

Model	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**	**Seas**
Actual	**10.3**	**7.5**	**4.8**	**2.0**	**0.5**	**0**	**0**	**0**	**0.8**	**3.2**	**4.7**	**7.5**	**40.9**	39.7
BCM2	10.9	8.9	5.7	2.6	0.8	0.2	0.1	0.1	0.8	3.3	5.9	8.3	**47.2**	45.4
CGMR	12.8	10.3	5.7	2.1	0.6	0.2	0	0.3	1.6	4.7	6.3	10.0	**54.4**	51.7
CNCM3	10.7	7.6	6.2	2.2	0.6	0.1	0.1	0.1	1.1	4.2	5.2	8.7	**46.6**	44.7
CSMK3	10.5	8.7	6.5	2.4	0.6	0.1	0.1	0	0.9	3.7	5.2	9.3	**47.9**	46.2
ECHOG	11.4	11.5	6.5	2.9	0.8	0.3	0.1	0.1	1.0	4.2	5.5	8.8	**52.8**	50.6
FGOALS	10.5	7.9	4.7	2.4	0.7	0	0	0.1	1.0	3.9	4.9	8.1	**43.9**	42.2
GFMC20	11.2	9.3	4.7	2.1	0.8	0.1	0	0.2	1.1	3.2	5.7	9.7	**47.8**	45.7
GFMC21	10.5	8.3	5.1	2.4	0.6	0.1	0	0.2	1.4	4.0	5.8	8.6	**46.7**	44.5
GIAOM	11.0	8.0	4.7	2.0	0.7	0.2	0	0.1	1.3	4.4	4.5	8.4	**45.1**	42.9
GIEH	10.5	8.4	5.8	2.8	0.8	0.1	0	0.2	1.3	4.1	5.9	9.5	**49.2**	46.9
HADCM3	11.1	7.7	3.8	1.3	0.4	0.2	0.1	2.4	2.8	3.1	3.7	6.8	**43.2**	37.4
HADGEM	11.5	8.9	6.0	2.4	0.6	0	0	0.3	1.1	4.3	4.7	7.4	**47.0**	45.1
IPCM4	11.4	9.1	5.8	2.7	1.0	0.3	0.1	0.1	1.0	4.7	6.2	9.4	**51.4**	49.1
MIHR	10.4	9.0	6.0	2.4	1.0	0.1	0.1	0.1	1.4	3.5	4.9	7.9	**46.4**	43.9
MIMR	9.9	7.9	4.6	2.6	0.6	0	0	0	1.1	4.4	6.1	8.0	**45.0**	43.4
MPEH5	10.0	10.5	4.3	1.8	0.7	0.1	0	0.1	1.1	3.7	5.1	7.9	**45.1**	43.2
MRCGCM	11.2	9.0	5.9	2.5	0.7	0.2	0	0	1.4	4.5	5.1	8.5	**49.1**	46.6
Average	**10.9**	**8.9**	**5.4**	**2.3**	**0.7**	**0.1**	**0.04**	**0.2**	**1.2**	**4.0**	**5.3**	**8.5**	**47.5**	**45.2**

2080 CHA VH+E

Model	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**	**Seas**
Actual	**10.3**	**7.5**	**4.8**	**2.0**	**0.5**	**0**	**0**	**0**	**0.8**	**3.2**	**4.7**	**7.5**	**40.9**	39.7
BCM2	11.6	9.0	5.2	2.8	0.7	0	0	0.1	1.2	4.7	6.3	9.2	**50.6**	48.6
CGMR	15.3	11.4	6.2	2.7	1.3	0.1	0	0	1.7	5.2	7.7	10.7	**62.3**	59.0
CNCM3	11.8	9.1	5.6	2.4	0.8	0.3	0	0	1.4	5.1	6.0	8.8	**51.3**	48.7
CSMK3	11.3	8.7	5.9	2.5	0.7	0.1	0	0.2	1.4	3.7	6.1	9.8	**50.1**	47.8
ECHOG	13.1	11.3	7.4	2.9	0.9	0	0.1	0.3	1.6	4.1	6.7	9.8	**58.0**	55.2
FGOALS	11.0	8.1	5.0	2.8	0.8	0.1	0.1	0.2	1.0	3.8	5.9	8.4	**47.0**	44.9
GFMC20	12.0	9.4	5.1	3.1	1.0	0.2	0.1	0.1	2.0	4.9	6.2	9.6	**53.3**	50.1
GFMC21	10.5	7.5	4.7	2.6	0.8	0.2	0	0.1	1.4	4.1	6.5	9.7	**47.8**	45.5
GIAOM	11.6	8.8	4.5	2.0	0.8	0.1	0	0.2	1.6	3.8	4.7	8.3	**46.3**	43.6
GIEH	9.7	8.2	5.6	2.5	0.6	0	0	0.1	1.1	4.2	5.8	8.1	**45.8**	44.0
HADCM3	10.6	9.7	5.0	1.7	0.4	0.2	0.2	3.0	3.8	4.6	2.8	6.5	**48.1**	40.7
HADGEM	11.1	8.2	5.9	2.3	0.6	0.1	0.1	0	1.3	3.6	4.7	8.5	**46.2**	44.2
IPCM4	13.4	10.8	7.7	2.7	1.3	0.3	0	0.1	1.2	4.4	5.8	10.3	**57.8**	54.9
MIHR	10.3	10.5	6.2	2.9	0.7	0.1	0.1	0.1	1.7	4.4	6.3	9.0	**52.0**	49.4
MIMR	9.4	8.0	5.5	2.3	0.7	0	0	0.1	1.0	4.5	5.5	8.8	**45.4**	43.7
MPEH5	11.8	9.6	5.6	2.1	1.1	0.1	0	0.2	1.1	3.9	6.3	8.3	**49.9**	47.4
MRCGCM	13.1	10.0	6.1	2.6	0.9	0.2	0	0.1	1.0	4.0	5.9	8.9	**52.7**	50.6
Average	**11.6**	**9.3**	**5.7**	**2.5**	**0.8**	**0.1**	**0.02**	**0.3**	**1.5**	**4.3**	**5.8**	**8.9**	**50.8**	**48.1**

The VH+E Forest fire danger method appears to do better at describing the current (October-April) fire season at both stations (Tables 18 & 20), with several different models showing the potential for future fire seasons to extend into May and, in the case of the HADCM3 model, to also start in August. At Christchurch (Table 20), this approach also has the majority of models showing the possibility of the fire season starting in September as opposed to October as currently.

In reality, however, individual fire seasons vary widely in severity from year to year in response to interannual variability (e.g. El Nino/Southern Oscillation events), and can vary significantly from the average. For example, investigation of individual fire seasons for Christchurch (CHA) using the MSR >3.0 threshold (Table 21) shows that fire seasons under both current and future climate can vary in length from just a few months to many months, including months considered outside the current fire season. If anything, it appears from this albeit cursory investigation that fire season length may vary even more widely under future climate than at present.

However, use of these approaches with AR4 model data shows less promise than at the time of the Pearce et al. (2005) study, and suggests limited potential for widespread use across the country. Of the 20 stations included in the present analysis, only 3-4 of the stations with the most severe fire climates had months in either their current record or future projections that reached the MSR >3.0 thresholds. While more stations had months in which the average number of days of VH+E Forest fire danger exceeded the threshold of 1.0 day/month, these were still limited to the moderate to severe fire climates and many other locations with low current or future projected fire severity would fail to reach either of these thresholds. Hence, alternative methods, such as the minimum monthly temperature approach (with temperatures >7.2°C, after Simard et al. 1989) also suggested by Pearce et al. (2005) need to be found that better define the current fire season length for the range of New Zealand locations, as well as potential future changes with climate change.

Modelling Approaches

The present study included a number of advances over the previous analysis of Pearce et al. (2005) with the aim of improving estimates of potential changes in fire danger under future climate. These included the use of a broader range of models in an effort to better capture the range of possible outcomes, as well the potential for greater variability in future climate (such as increased likelihood of extremes). It also included all of the important weather variables, including humidity and wind speed, as well as improved estimates of temperature and rainfall changes. However, some issues were still encountered (e.g. with the limited number of station locations, and use of VCSN and RCM data). Further improvements could therefore be made in modelling approaches that could result in still better estimates of fire danger with climate change.

Efforts to utilise Virtual Climate Station Network (VCSN) gridded data to increase the number of locations and improve spatial coverage of estimated changes proved unsuccessful. Fire dangers calculated using VCSN data were not sufficiently representative of current fire climate, due to lower mean daily

Table 21. Changes in individual fire season length for Christchurch (CHA) using Monthly Severity Rating (MSR) thresholds under current climate (top) and for the 2050s from the HADCM3 model (bottom) Shaded cells indicate the fire season period where the average MSR consistently exceeds 3.0, a threshold identified for high to very high fire behaviour potential (after Stocks et al. 1998).

1990 CHA MSR Actual

Model	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Seas
1980	3.33	7.35	0.48	0.20	0.55	0.03	0.20	0.90	7.10	12.74	5.13	5.31	**3.60**	4.93
1981	13.59	13.32	3.69	1.88	2.35	0.01	0.26	0.06	1.17	1.69	2.17	9.82	**4.12**	6.55
1982	23.70	27.02	10.73	0.81	0.56	0.36	0.30	1.73	1.37	3.18	14.13	5.90	**7.36**	12.06
1983	15.72	7.53	14.07	6.16	0.59	0.18	0.06	1.15	2.16	0.97	6.24	3.74	**4.87**	7.79
1984	5.01	2.89	1.30	3.87	1.10	2.16	0.06	1.79	1.39	5.94	6.42	5.42	**3.11**	4.42
1985	20.88	9.35	3.36	5.82	2.36	0.41	0.75	0.65	3.20	2.77	4.00	1.01	**4.52**	6.73
1986	5.21	3.83	0.93	1.73	1.92	0.36	0.12	0.09	0.40	0.65	1.81	6.50	**1.96**	2.95
1987	8.78	6.88	0.33	2.15	1.00	0.46	0.16	0.16	1.88	2.20	1.46	3.02	**2.35**	3.52
1988	6.99	4.43	4.35	2.96	3.58	0.64	0.53	0.84	2.68	25.25	10.42	14.83	**6.49**	9.99
1989	3.44	3.73	4.95	1.17	0.01	0.06	0.16	0.13	0.12	0.37	4.56	4.96	**1.96**	3.31
1990	7.38	6.76	4.70	4.42	1.65	0.27	0.20	0.07	0.55	2.54	2.12	12.29	**3.57**	5.76
1991	6.49	3.77	3.58	1.63	0.52	0.33	0.13	1.00	0.79	3.11	1.33	2.47	**2.09**	3.20
1992	5.00	6.26	11.94	1.19	0.37	0.02	0.12	0.14	0.04	0.20	1.73	1.65	**2.39**	3.99
1993	3.77	2.11	2.91	0.44	0.13	0.29	0.18	0.82	0.56	7.65	3.65	0.31	**1.91**	3.00
1994	1.75	2.27	0.92	2.22	0.66	0.03	0.01	1.06	3.11	1.03	8.95	6.26	**2.34**	3.34
1995	8.58	5.84	6.56	1.21	0.71	0.03	0.08	0.53	0.56	.33	4.36	15.70	**3.72**	6.12
1996	7.71	12.35	1.95	2.42	0.43	0.03	0.00	0.05	1.30	2.06	4.78	8.15	**3.40**	5.56
1997	2.46	1.73	2.38	1.28	0.87	0.02	0.20	0.69	0.79	2.99	11.59	20.03	**3.77**	6.12
1998	15.24	22.66	12.45	3.71	0.58	0.21	0.04	0.15	1.56	0.85	2.70	5.82	**5.39**	8.94
1999	9.61	9.10	1.68	1.12	1.19	0.07	0.06	0.22	0.54	1.43	1.06	2.81	**2.37**	3.79
Average	**8.73**	**7.96**	**4.66**	**2.32**	**1.06**	**0.30**	**0.18**	**0.61**	**1.56**	**3.90**	**4.93**	**6.80**	**3.56**	**5.60**

2050 CHA MSR HADCM3

Model	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Seas
2040	6.63	7.14	0.20	0.20	0.91	0.08	1.83	3.09	9.79	9.93	3.95	6.68	**4.19**	4.96
2041	20.66	13.65	2.89	1.69	2.82	0.05	1.39	1.06	4.29	1.55	2.30	11.24	**5.27**	7.69
2042	29.14	23.81	7.56	0.54	0.64	1.21	2.26	6.47	2.77	3.34	12.33	4.87	**7.82**	11.55
2043	17.88	6.75	7.56	3.05	0.59	1.01	0.64	6.50	4.89	0.71	6.80	3.92	**5.02**	6.68
2044	5.21	3.06	0.77	2.29	1.17	3.88	1.25	7.15	1.79	4.79	5.67	6.51	**3.63**	4.06
2045	25.71	10.30	2.26	3.16	1.83	0.97	3.05	3.83	4.88	1.92	3.58	1.13	**5.20**	6.86
2046	6.02	2.69	1.09	0.95	2.51	0.69	0.99	0.63	1.09	0.91	1.80	7.90	**2.28**	3.07
2047	9.78	9.07	0.31	1.04	0.95	0.95	1.12	0.69	4.57	2.01	1.64	3.64	**2.94**	3.88
2048	8.13	4.49	2.64	1.58	2.63	1.20	3.34	2.99	5.20	11.81	8.74	11.00	**5.33**	6.96
2049	5.02	3.44	3.43	0.46	0.03	0.36	1.22	0.83	0.38	0.21	3.53	5.70	**2.05**	3.12
2050	9.10	6.15	4.83	5.04	1.74	0.89	1.59	1.32	1.39	2.27	1.68	11.84	**3.99**	5.86
2051	7.44	3.03	3.20	1.91	0.54	0.86	1.35	4.68	2.08	2.42	1.54	2.80	**2.66**	3.21
2052	4.98	6.69	12.32	0.70	0.23	0.19	0.92	1.11	0.12	0.11	1.25	1.52	**2.51**	3.93
2053	3.66	2.67	2.58	0.12	0.07	0.72	0.80	4.24	2.80	7.76	4.32	0.19	**2.50**	3.06
2054	1.26	2.87	0.88	1.73	0.71	0.03	0.35	3.99	6.79	0.95	6.25	4.95	**2.55**	2.68
2055	9.11	6.72	4.80	0.67	0.22	0.10	0.74	6.31	2.33	0.10	1.48	12.50	**3.76**	5.07
2056	7.24	12.84	1.94	2.35	0.10	0.11	0.04	0.47	2.74	1.88	3.19	7.15	**3.30**	5.15
2057	3.00	2.32	2.41	1.01	0.31	0.11	0.59	3.80	1.93	2.88	6.14	19.92	**3.73**	5.44
2058	17.82	25.99	13.72	5.13	0.73	0.54	0.35	1.68	4.24	0.73	1.58	4.36	**6.28**	9.75
2059	9.09	10.04	1.89	1.34	0.73	0.28	0.51	1.83	2.04	1.68	0.32	3.61	**2.74**	3.95
Average	**10.34**	**8.18**	**3.86**	**1.75**	**0.97**	**0.71**	**1.22**	**3.13**	**3.31**	**2.90**	**3.90**	**6.57**	**3.89**	**5.35**

estimates of temperature and wind speed, and significantly higher rainfall and number of rain-days when rainfall was recorded. Similar issues also affected Regional Climate Model (RCM) estimates, so that this approach was also not able to be used. Considerable additional research would be required to derive relationships between estimates of weather inputs provided by VCSN or RCM data and current climate; however, this should be considered as part of any future study to increase the spatial coverage to provide improved estimates of changes in fire danger with climate change.

The lack of station locations with observations covering the current climate baseline period (1980-1999 in this instance) was a key issue identified during the study. This is particularly problematic for fire danger estimation, where specific daily (1200 noon NZST) weather observations are required. This is further exacerbated by the preference to only use sites with long-term records in the order of 20-30 years. In the present study, these restrictions limited the number of station locations to just 20. However, observations at many of the fire weather stations for which data are archived by the National Rural Fire Authority began in the early 1990s, so that the use of a slightly different baseline period (e.g. from 1990- or 1995-2010) could significantly increase the number of sampling locations that could be used (potentially to around 70-80 sites). This would greatly improve the validity of the estimates derived, and the ability to interpolate changes to other locations across the country.

Like the majority of other New Zealand climate change studies undertaken to date, the present study used a statistical downscaling technique (Mullan et al. 2001) to downscale General Circulation Model (GCM) changes to provide the local detail 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, dynamic 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 and fire danger, and recent international studies are increasingly using this approach (e.g. Wotton et al. 1998, Flannigan et al. 2001, MfE 2008). While it was not possible (in the timeframe of this project) to rectify issues identified with current RCM model outputs for use in fire studies, this approach warrants further investigation. This RCM approach has the scientific advantage that it is more firmly based on atmospheric physics but requires substantially more computing power than statistical downscaling. 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, 1999), and any further advances in this area should be considered in future studies of changes in fire danger with climate change.

The previous study (Pearce et al. 2005) only considered the effects of changes in temperature and rainfall on future fire dangers as, at that time, possible changes in relative humidity and wind speed – the other key weather variables required to calculate fire danger – under future climate change scenarios were not well understood or could not readily be downscaled from GCM output. While changes in these variables were able to be adequately estimated for inclusion in the present study, they can both now be readily derived from standard RCM outputs.

Relative humidity is a critical factor in fire danger rating, due to its influence on fuel moisture, ignition potential, rate of combustion and fire spread, and it has been found, both here and in other studies (e.g. Beer et al. 1988), to be the most significant weather parameter affecting fire danger. Increased wind speeds would also almost certainly lead to a general increase in fire dangers in the majority of model scenarios. Therefore, any future investigation of the effects of climate change should incorporate more accurate estimates of changes in wind speed and relative humidity (as well as temperature and rainfall), preferably obtained through RCM modelling, to provide more accurate of predictions of likely changes in fire danger.

CONCLUSION

Down-scaled climate changes for the New Zealand region from 17 IPCC 4th Assessment global climate models for the A1B emissions scenario were applied to daily fire weather time-series for 20 station locations to provide improved estimates of the potential effects of climate change on New Zealand’s fire danger. This included monthly changes in temperature and rainfall, as well as wind speed and relative humidity, for two projection periods – the 2050s (2040-2059) and 2080s (2070-2089). The study sought to improve on estimates provided by the only previous study of climate change effects on fire danger (Pearce et al. 2005), which included (high-, mid- and low-range) scenarios for the 2080s of just temperature and rainfall from only two global models.

Results indicate that fire risk, as described by two fire climate severity measures – the Seasonal Severity Rating (SSR) and number of days of Very High and Extreme (VH+E) Forest fire danger – is likely to increase significantly from current levels in many parts of the country as a result of increases in temperature or wind speed, and lower rainfall or humidity. The areas most likely to show increases are the east and south of the South Island, especially coastal Otago and Marlborough and southeastern Southland, and the west of the North Island (particularly around Wanganui). There is also potential under the most extreme model scenarios across the lower North Island and into the Bay of Plenty. However, unlike the previous study, other eastern areas such as the Christchurch and Gisborne did not show significantly increased fire potential.

Fire danger in other areas may remain unchanged, or in fact decrease by the 2080s, due mainly to significant increases in rainfall. These areas include the West Coast of the South Island and western areas of the North Island such as Taranaki where fire dangers are already low, and East Cape and the Coromandel. Potential also exists for decreases in fire danger in Northland, Southland and parts of Canterbury under some models.

Changes indicated in the present study were generally greater than those of the 2005 study, but also varied more widely between climate models due to the greater range in projected changes, especially seasonal differences in rainfall and temperature. While many models showed continued increases through to the 2080s, a feature of several models was for fire danger to increase more rapidly to the 2050s, and then to stabilise or decrease by the 2080s, due to greater predicted increases in rainfall (especially during the fire season for the latter projection period.

Although not investigated in detail here, study results and those from the previous study by Pearce et al. (2005) indicate that changes in overall fire climate severity are also associated with significant changes in the contributing fire danger ratings. These in turn indicate that, in addition to the overall changes in fire climate severity, predominantly in the form of increases in most parts of the country, fire managers can expect:

- longer fire seasons in some parts of the country;
- increased drought frequency, and associated increases in fuel drying;
- easier ignition and, therefore, potentially 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, more prolonged mop-up, increased resource requirements and more difficult fire suppression.

This study incorporates several significant improvements over the previous analysis, which only included (high-, mid- and low-range) scenarios of temperature and rainfall from just two climate models for the 2080s. The present study utilised down-scaled daily changes for wind speed and relative humidity as well as temperature and rainfall from 17 global models for two projection periods (the 2050s and 2080s), in an effort to better capture future climate variability and a wider range of possible future climate outcomes. While it was only possible to base estimates of changes on results from a limited number of (just 20) sites (due to issues with data availability for the 1990s baseline period and alternative data sources), the study still provides improved estimates of the potential effects of climate change on New Zealand’s fire danger. However, further improvements could still be made through use of Regional Climate Models and/or an increase in the number of sampling locations, thereby improving the validity of the estimates derived and the ability to interpolate changes to other locations across the country.

However, through the use of improved climate models, modelling approaches and outputs not previously available, this study has substantially extended previous work to provide a more comprehensive and up-to-date evaluation of future fire climate and likely impacts. The results provide a significant advance on those from the previous analysis, and highlight the likelihood of increased fire risk in many regions of New Zealand with climate change. This improved knowledge will assist fire management agencies, landowners and communities to better develop appropriate future fire management and mitigation strategies.

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APPENDICES

Appendix 1 – Full year averages (over all months, Jan-Dec) of changes in fire climate severity measures estimated from 17 Global Climate Models, and comparisons with current climate for the 1990s (1980-1999) for:

Table A1.1 – Annual Severity Rating (ASR) for the 2050s (2040-2059)
Table A1.2 – Days of VH+E Forest fire danger for the 2050s (2040-2059)

Table A1.3 – Annual Severity Rating (ASR) for the 2080s (2070-2089)
Table A1.4 – Days of VH+E Forest fire danger for the 2050s (2040-2059)

Appendix 2 – Full year averages (over all months, Jan-Dec) of changes in weather elements estimated from 17 Global Climate Models, and comparisons with current climate for the 1990s (1980-1999) for:

Table A2.1 – Change in temperature (°C) for the 2050s (2040-2059)
Table A2.2 – Change in rainfall (%) for the 2050s (2040-2059)
Table A2.3 – Change in relative humidity (%) for the 2050s (2040-2059)
Table A2.4 – Change in wind speed (km/h) for the 2050s (2040-2059)

Table A2.5 – Change in temperature (°C) for the 2080s (2070-2089)
Table A2.6 – Change in rainfall (%) for the 2080s (2070-2089)
Table A2.7 – Change in relative humidity (%) for the 2080s (2070-2089)
Table A2.8 – Change in wind speed (km/h) for the 2080s (2070-2089)

Table A1.1. Average Annual Severity Rating (ASR) over all months (Jan-Dec) estimated for the 2050s (2040-2059) from 17 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	Actual	Models for 2050s – Annual Severity Rating (ASR)																	Model avg.
		BCM2	CGMR	CNCM3	CSMK3	ECHOG	FGOALS	GFCM20	GFCM21	GIAOM	GIEH	HADCM3	HADGEM	IPCM4	MIHR	MIMR	MPEH5	MRCGCM	
KX	**17.9**	1.67	1.65	1.47	1.00	1.58	1.03	1.40	1.63	0.81	1.66	2.45	1.43	1.23	2.25	1.74	0.78	1.20	**1.47**
KX	**0.93**	1.04	1.19	1.08	1.10	1.05	1.10	1.15	1.05	1.12	1.11	1.30	1.24	1.37	1.17	0.98	1.26	1.20	**1.15**
DAR	**0.53**	0.63	0.74	0.64	0.66	0.62	0.65	0.70	0.63	0.64	0.67	0.77	0.73	0.79	0.69	0.61	0.72	0.70	**0.68**
COR	**0.59**	0.65	0.68	0.64	0.63	0.68	0.62	0.65	0.63	0.63	0.64	0.63	0.67	0.65	0.61	0.60	0.63	0.65	**0.64**
AKL	**1.14**	1.33	1.45	1.33	1.32	1.34	1.35	1.43	1.28	1.37	1.41	1.52	1.53	1.64	1.45	1.24	1.57	1.47	**1.41**
TGA	**1.10**	1.33	1.43	1.25	1.25	1.36	1.22	1.38	1.28	1.27	1.39	1.36	1.40	1.45	1.24	1.25	1.39	1.36	**1.33**
ROA	**0.56**	0.67	0.72	0.64	0.65	0.69	0.62	0.69	0.65	0.64	0.72	0.70	0.71	0.73	0.64	0.63	0.71	0.68	**0.68**
GSA	**2.80**	3.29	3.44	3.22	3.17	3.38	3.09	3.39	3.24	3.14	3.42	3.20	3.38	3.63	3.36	3.20	3.30	3.31	**3.30**
APA	**0.58**	0.72	0.76	0.68	0.68	0.76	0.66	0.76	0.69	0.67	0.77	0.74	0.78	0.80	0.68	0.67	0.75	0.76	**0.73**
NPA	**0.41**	0.47	0.54	0.47	0.49	0.50	0.48	0.49	0.48	0.47	0.52	0.60	0.54	0.56	0.51	0.44	0.52	0.50	**0.50**
WUA	**0.78**	0.99	1.08	0.99	0.96	0.96	1.03	1.12	1.05	1.01	1.10	1.26	1.15	1.25	1.14	0.99	1.23	1.15	**1.09**
PPA	**0.74**	0.89	1.02	0.94	0.92	0.93	0.93	1.00	0.95	0.92	1.00	1.15	0.98	1.23	1.10	0.91	1.04	1.03	**1.00**
WNA	**2.04**	2.60	3.15	2.76	2.87	2.48	3.17	3.21	2.97	3.05	2.88	4.04	3.15	4.29	3.51	2.72	3.39	3.30	**3.15**
NSA	**1.28**	1.45	1.66	1.50	1.43	1.46	1.50	1.56	1.50	1.50	1.56	1.65	1.57	1.74	1.55	1.38	1.61	1.54	**1.54**
WSA	**0.16**	0.18	0.19	0.17	0.18	0.21	0.17	0.19	0.18	0.17	0.19	0.20	0.19	0.18	0.18	0.18	0.19	0.19	**0.19**
HKA	**0.10**	0.12	0.13	0.11	0.12	0.13	0.11	0.12	0.11	0.11	0.12	0.14	0.12	0.12	0.12	0.11	0.12	0.12	**0.12**
KIX	**1.12**	1.49	1.96	1.90	1.99	1.53	1.93	2.34	1.95	1.99	1.67	2.84	1.81	3.22	2.54	1.70	2.14	2.17	**2.07**
CHA	**3.56**	4.04	4.44	4.05	4.04	4.41	3.93	4.20	4.02	3.97	4.23	3.89	4.00	4.27	4.00	3.86	3.99	4.07	**4.08**
QNA	**0.89**	1.04	1.05	0.99	1.03	1.10	0.95	1.07	1.04	0.95	1.06	1.02	1.07	0.99	0.95	0.98	1.02	1.05	**1.02**
DNA	**1.17**	1.47	2.64	2.11	2.32	1.95	2.03	2.40	2.40	1.97	2.15	2.52	2.01	3.43	2.57	2.11	1.93	2.25	**2.25**
NVA	**0.37**	0.46	0.59	0.45	0.49	0.56	0.44	0.53	0.50	0.46	0.55	0.54	0.50	0.55	0.50	0.46	0.51	0.48	**0.50**
Avg.	**1.04**	**1.24**	**1.44**	**1.30**	**1.32**	**1.30**	**1.30**	**1.42**	**1.33**	**1.30**	**1.36**	**1.50**	**1.38**	**1.64**	**1.43**	**1.25**	**1.40**	**1.29**	**1.36**

Table A1.2. Average number of days/year of Very High and Extreme (VH+E) Forest fire danger for all months (Jan-Dec) estimated for the 2050s (2040-2059) from 17 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	Actual	Models for 2050s – Days/year of VH+E Fire Danger																	Model avg.
		BCM2	CGMR	CNCM3	CSMK3	ECHOG	FGOALS	GFCM20	GFCM21	GIAOM	GIEH	HADCM3	HADGEM	IPCM4	MIHR	MIMR	MPEH5	MRCGCM	
KX	**17.9**	1.67	1.65	1.47	1.00	1.58	1.03	1.40	1.63	0.81	1.66	2.45	1.43	1.23	2.25	1.74	0.78	1.20	**1.47**
KX	**5.9**	7.1	9.3	7.4	8.1	7.6	6.3	8.4	6.2	7.5	7.8	8.8	9.7	11.4	9.4	6.4	10.0	9.2	**8.3**
DAR	**2.2**	2.5	3.6	2.7	3.2	2.5	2.8	3.5	2.7	2.9	2.9	3.8	4.1	3.5	2.9	2.4	3.3	3.3	**3.1**
COR	**1.5**	2.2	2.6	2.1	1.9	2.3	1.7	2.2	2.1	2.4	2.2	2.2	1.9	2.1	1.8	1.9	1.7	2.5	**2.1**
AKL	**8.3**	11.3	13.0	10.1	10.5	11.2	11.1	12.9	9.8	10.9	12.1	12.7	16.1	16.4	12.1	9.7	16.0	12.7	**12.3**
TGA	**7.7**	11.0	11.8	8.6	9.4	10.7	8.6	10.8	9.5	9.9	11.2	9.0	12.3	11.3	9.0	10.2	11.2	10.2	**10.2**
ROA	**1.5**	2.5	3.3	1.9	2.8	2.4	2.1	2.9	1.9	2.1	2.8	3.1	2.9	2.5	2.0	2.6	2.8	2.8	**2.5**
GSA	**34.7**	42.2	45.1	41.6	39.2	43.2	38.0	44.1	41.1	39.2	44.4	39.3	45.0	48.7	44.3	40.6	43.7	41.4	**42.4**
APA	**2.2**	3.3	4.5	3.2	3.1	4.4	3.1	4.4	2.9	3.2	3.6	2.9	4.3	4.3	3.0	3.6	4.0	4.0	**3.6**
NPA	**1.1**	0.9	1.7	1.1	1.1	1.8	1.3	1.3	1.1	1.1	1.6	1.8	1.9	1.7	1.4	1.3	1.4	1.3	**1.4**
WUA	**2.6**	5.0	6.4	4.0	4.6	4.1	5.2	6.5	5.3	4.8	6.3	7.1	7.6	7.1	6.2	5.3	7.5	6.1	**5.8**
PPA	**2.0**	2.6	4.6	3.1	3.8	3.4	3.4	3.7	3.1	3.1	4.1	4.8	4.1	5.2	5.1	2.9	4.8	3.8	**3.8**
WNA	**16.8**	26.6	36.0	26.6	28.4	23.2	34.5	35.7	29.5	32.4	29.1	46.8	37.0	54.5	40.0	28.3	35.9	38.1	**34.2**
NSA	**9.0**	11.9	14.6	11.9	11.1	11.5	12.3	12.8	12.1	11.3	12.6	13.6	12.9	16.0	12.2	10.9	14.2	12.9	**12.6**
WSA	**0**	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0	**0.0**
HKA	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0.0**
KIX	**6.5**	10.2	16.6	15.1	16.2	10.1	16.6	22.1	17.0	16.9	12.4	29.2	14.8	33.7	25.8	12.5	19.3	18.8	**18.1**
CHA	**40.9**	47.2	54.4	46.6	47.9	52.8	43.9	47.8	46.7	45.1	49.2	43.2	47.0	51.4	46.4	45.0	45.1	49.1	**47.5**
QNA	**5.8**	7.4	7.4	7.1	7.5	8.4	6.3	8.4	7.5	6.0	8.2	6.2	8.1	6.9	6.1	6.7	7.1	7.7	**7.2**
DNA	**6.1**	10.4	28.7	19.3	23.0	18.5	17.9	23.8	23.7	17.9	20.8	26.1	18.7	40.6	24.5	20.2	16.0	20.8	**21.8**
NVA	**0.4**	0.8	1.5	0.4	1.0	1.3	0.4	1.5	1.1	0.8	1.4	0.6	1.0	1.0	0.8	0.9	1.5	0.9	**1.0**
Avg.	**7.74**	**10.24**	**13.24**	**10.61**	**11.12**	**10.95**	**10.76**	**12.61**	**11.15**	**10.85**	**11.61**	**13.03**	**12.44**	**15.89**	**12.63**	**10.56**	**12.27**	**11.17**	**11.83**

Table A1.3. Average Annual Severity Rating (ASR) over all months (Jan-Dec) estimated for the 2080s (2070-2089) from 17 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	Actual	Models for 2080s – Annual Severity Rating (ASR)																	Model avg.
		BCM2	CGMR	CNCM3	CSMK3	ECHOG	FGOALS	GFCM20	GFCM21	GIAOM	GIEH	HADCM3	HADGEM	IPCM4	MIHR	MIMR	MPEH5	MRCGCM	
KX	**0.93**	1.03	1.34	1.11	1.18	0.91	1.14	1.22	0.99	1.08	0.91	1.44	1.20	1.46	1.18	0.94	1.29	1.13	**1.15**
DAR	**0.53**	0.62	0.87	0.67	0.74	0.58	0.68	0.76	0.62	0.62	0.55	0.85	0.70	0.89	0.70	0.57	0.76	0.71	**0.70**
COR	**0.59**	0.70	0.75	0.67	0.67	0.71	0.66	0.67	0.64	0.62	0.58	0.68	0.64	0.70	0.65	0.60	0.65	0.69	**0.66**
AKL	**1.14**	1.33	1.67	1.36	1.46	1.24	1.40	1.57	1.19	1.35	1.14	1.73	1.42	1.89	1.54	1.20	1.57	1.40	**1.44**
TGA	**1.10**	1.31	1.51	1.27	1.38	1.37	1.24	1.43	1.18	1.23	1.12	1.42	1.40	1.62	1.34	1.20	1.51	1.35	**1.35**
ROA	**0.56**	0.66	0.81	0.65	0.71	0.68	0.64	0.71	0.61	0.62	0.57	0.72	0.72	0.84	0.70	0.61	0.77	0.68	**0.69**
GSA	**2.80**	3.37	3.79	3.45	3.36	3.47	3.24	3.62	3.24	3.23	3.12	3.27	3.51	3.98	3.67	3.33	3.69	3.42	**3.46**
APA	**0.58**	0.71	0.86	0.68	0.76	0.80	0.66	0.80	0.63	0.65	0.62	0.76	0.79	0.94	0.75	0.64	0.84	0.75	**0.74**
NPA	**0.41**	0.49	0.63	0.49	0.56	0.48	0.50	0.54	0.44	0.46	0.42	0.65	0.51	0.64	0.53	0.40	0.56	0.54	**0.52**
WUA	**0.78**	0.98	1.25	1.09	1.11	0.89	1.07	1.24	0.93	0.96	0.86	1.35	1.14	1.52	1.21	0.91	1.28	1.09	**1.11**
PPA	**0.74**	0.92	1.22	1.05	1.02	0.92	1.00	1.20	0.91	0.93	0.89	1.26	1.03	1.52	1.23	0.93	1.15	1.04	**1.07**
WNA	**2.04**	2.51	3.17	3.07	3.02	2.25	3.22	4.10	2.60	2.92	2.31	4.48	2.91	4.71	3.64	2.68	3.83	2.99	**3.20**
NSA	**1.28**	1.47	1.82	1.56	1.56	1.39	1.55	1.64	1.40	1.42	1.28	1.86	1.57	1.82	1.56	1.29	1.66	1.54	**1.55**
WSA	**0.16**	0.19	0.21	0.19	0.20	0.23	0.18	0.20	0.18	0.18	0.18	0.22	0.20	0.22	0.20	0.18	0.20	0.21	**0.20**
HKA	**0.10**	0.13	0.14	0.12	0.13	0.14	0.12	0.13	0.11	0.11	0.11	0.15	0.13	0.14	0.13	0.12	0.13	0.13	**0.13**
KIX	**1.12**	1.50	2.41	1.98	2.17	1.29	2.14	3.06	1.80	2.03	1.46	3.14	1.86	3.36	2.48	1.80	2.34	1.94	**2.16**
CHA	**3.56**	4.27	5.11	4.29	4.27	4.62	4.08	4.39	4.03	4.04	3.92	4.32	4.04	4.89	4.53	3.89	4.26	4.44	**4.32**
QNA	**0.89**	1.14	1.18	1.06	1.10	1.28	1.01	1.05	1.10	0.94	1.01	1.10	1.07	1.16	1.08	0.99	1.09	1.15	**1.09**
DNA	**1.17**	1.70	3.59	2.55	2.78	1.90	2.23	3.55	2.49	2.17	1.89	3.08	2.26	4.04	2.76	2.16	2.58	2.21	**2.58**
NVA	**0.37**	0.52	0.76	0.53	0.53	0.67	0.51	0.59	0.49	0.48	0.49	0.62	0.50	0.76	0.58	0.45	0.55	0.60	**0.57**
Avg.	**1.04**	**1.28**	**1.65**	**1.39**	**1.44**	**1.29**	**1.36**	**1.62**	**1.28**	**1.30**	**1.17**	**1.65**	**1.38**	**1.85**	**1.52**	**1.24**	**1.54**	**1.35**	**1.43**

Table A1.4. Average number of days/year of Very High and Extreme (VH+E) Forest fire danger for all months (Jan-Dec) estimated for the 2080s (2070-2089) from 17 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	Actual	Models for 2080s – Days/year of VH+E Fire Danger																	Model avg.
		BCM2	CGMR	CNCM3	CSMK3	ECHOG	FGOALS	GFCM20	GFCM21	GIAOM	GIEH	HADCM3	HADGEM	IPCM4	MIHR	MIMR	MPEH5	MRCGCM	
KX	**5.9**	6.3	11.1	7.4	8.9	4.9	7.7	7.9	6.4	8.3	5.8	10.9	8.9	11.8	8.5	6.3	10.2	7.7	**8.1**
DAR	**2.2**	2.5	5.2	2.7	3.4	1.9	2.6	4.0	2.6	2.8	2.1	4.3	3.2	4.3	3.2	2.2	3.7	3.8	**3.2**
COR	**1.5**	2.3	3.4	2.2	2.3	2.9	2.1	2.5	2.2	1.5	1.5	2.4	1.9	2.6	2.0	1.4	2.1	2.5	**2.2**
AKL	**8.3**	11.4	18.5	11.0	12.8	9.8	11.2	13.9	7.9	11.0	8.5	16.3	11.5	20.1	13.8	8.9	15.0	10.6	**12.5**
TGA	**7.7**	10.1	13.2	9.5	10.6	10.6	8.7	11.0	7.6	9.7	7.8	9.3	11.3	13.5	10.2	9.1	13.2	10.3	**10.3**
ROA	**1.5**	2.5	4.3	2.1	3.0	2.2	1.9	2.8	1.9	2.0	1.4	2.6	3.3	4.4	2.7	2.1	4.5	2.6	**2.7**
GSA	**34.7**	42.3	51.3	45.7	43.4	45.8	41.3	48.0	43.4	41.7	40.2	39.4	45.7	54.2	48.3	43.3	49.0	44.1	**45.1**
APA	**2.2**	3.7	5.3	2.9	3.5	4.4	2.7	3.9	2.5	2.8	2.7	3.4	4.2	6.0	4.1	2.9	4.9	3.3	**3.7**
NPA	**1.1**	1.5	2.5	1.6	2.0	1.2	1.5	0.9	0.9	0.9	1.1	1.6	1.7	2.1	1.6	0.5	2.4	1.6	**1.5**
WUA	**2.6**	4.3	7.5	5.6	5.9	3.2	5.0	6.6	4.0	4.0	3.1	7.7	6.2	12.5	6.4	3.3	8.8	4.7	**5.8**
PPA	**2.0**	2.7	6.6	4.0	4.9	2.9	3.6	5.2	3.1	2.8	2.9	5.7	4.2	12.1	6.3	3.0	5.9	4.2	**4.7**
WNA	**16.8**	24.2	38.3	32.7	33.1	20.7	35.4	51.2	26.0	29.7	21.1	52.3	31.7	62.6	42.0	26.9	46.1	28.1	**35.4**
NSA	**9.0**	11.8	17.2	12.8	12.4	10.9	12.1	13.1	10.8	10.5	9.6	16.2	13.2	17.0	13.2	9.8	15.1	12.3	**12.8**
WSA	**0**	0	0	0	0.1	0.2	0	0	0	0	0	0	0	0.1	0.1	0	0	0.1	**0.0**
HKA	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0.0**
KIX	**6.5**	10.1	23.8	15.2	18.0	7.7	18.2	29.6	14.3	17.6	8.7	33.0	14.3	33.5	24.0	13.1	21.0	15.9	**18.7**
CHA	**40.9**	50.6	62.3	51.3	50.1	58.0	47.0	53.3	47.8	46.3	45.8	48.1	46.2	57.8	52.0	45.4	49.9	52.7	**50.8**
QNA	**5.3**	9.4	9.9	8.0	9.0	12.1	7.3	7.9	8.8	5.9	7.1	7.5	8.3	9.9	8.0	7.5	8.5	9.4	**8.5**
DNA	**6.1**	13.0	44.1	26.4	29.9	16.7	21.1	39.7	26.8	21.1	16.0	33.3	22.0	49.2	29.1	20.3	26.8	21.2	**26.8**
NVA	**0.4**	1.0	2.5	1.0	1.2	2.8	0.8	1.0	0.5	0.7	0.7	0.9	0.9	2.8	0.9	0.6	1.2	1.7	**1.2**
Avg.	**7.71**	**10.47**	**16.34**	**12.08**	**12.70**	**10.92**	**11.49**	**15.10**	**10.85**	**10.95**	**9.28**	**14.73**	**11.91**	**18.81**	**13.80**	**10.31**	**14.40**	**12.01**	**12.71**

Table A2.1. Average change in temperature (°C) for all months (Jan-Dec) estimated for the 2050s (2040-2059) from 17 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Actual** (°C)	**Models for 2050s – Change in Temperature** (°C)																	**Model avg.**
		BCM2	**CGMR**	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**17.9**	1.67	1.65	1.47	1.00	1.58	1.03	1.40	1.63	0.81	1.66	2.45	1.43	1.23	2.25	1.74	0.78	1.20	**1.47**
DAR	**17.7**	1.79	1.75	1.57	1.08	1.67	1.11	1.48	1.75	0.86	1.78	2.64	1.55	1.27	2.39	1.85	0.82	1.28	**1.57**
COR	**17.6**	1.51	1.52	1.25	0.91	1.44	0.87	1.20	1.48	0.64	1.48	2.08	1.33	0.93	1.90	1.54	0.62	0.98	**1.28**
AKL	**17.4**	1.63	1.62	1.41	0.92	1.49	0.95	1.30	1.52	0.75	1.54	2.26	1.33	1.15	2.10	1.63	0.73	1.12	**1.38**
TGA	**17.2**	1.42	1.42	1.23	0.81	1.38	0.81	1.19	1.36	0.65	1.37	1.95	1.16	1.09	1.90	1.49	0.68	1.00	**1.23**
ROA	**15.4**	1.44	1.44	1.25	0.83	1.40	0.84	1.21	1.39	0.67	1.39	2.00	1.19	1.11	1.94	1.52	0.69	1.02	**1.25**
GSA	**17.8**	1.49	1.50	1.31	0.87	1.45	0.88	1.27	1.44	0.70	1.46	2.11	1.24	1.16	2.03	1.58	0.73	1.08	**1.31**
APA	**13.9**	1.41	1.42	1.21	0.80	1.38	0.80	1.18	1.35	0.63	1.35	1.90	1.15	1.08	1.88	1.48	0.67	0.98	**1.22**
NPA	**15.9**	1.76	1.76	1.50	1.06	1.67	1.05	1.44	1.72	0.80	1.73	2.50	1.52	1.20	2.30	1.82	0.78	1.21	**1.52**
WUA	**16.1**	1.55	1.54	1.36	0.92	1.48	0.94	1.30	1.51	0.74	1.53	2.25	1.31	1.16	2.09	1.62	0.73	1.12	**1.36**
PPA	**15.4**	1.72	1.78	1.54	1.06	1.70	1.05	1.51	1.71	0.82	1.74	2.45	1.44	1.35	2.38	1.86	0.85	1.25	**1.54**
WNA	**15.2**	1.75	1.77	1.57	1.09	1.68	1.10	1.51	1.74	0.86	1.78	2.59	1.51	1.32	2.41	1.86	0.84	1.28	**1.57**
NSA	**15.5**	1.80	1.77	1.58	1.10	1.69	1.13	1.49	1.77	0.87	1.80	2.68	1.58	1.26	2.41	1.87	0.82	1.29	**1.58**
WSA	**14.6**	1.62	1.61	1.36	0.97	1.53	0.95	1.30	1.58	0.72	1.58	2.27	1.41	1.06	2.08	1.66	0.69	1.09	**1.38**
HKA	**14.2**	1.47	1.48	1.29	0.90	1.40	0.91	1.23	1.45	0.70	1.48	2.14	1.28	1.04	1.97	1.54	0.67	1.04	**1.29**
KIX	**13.8**	1.79	1.80	1.63	1.14	1.70	1.17	1.56	1.80	0.92	1.85	2.74	1.56	1.36	2.51	1.91	0.88	1.34	**1.63**
CHA	**14.9**	1.71	1.72	1.47	1.07	1.61	1.05	1.40	1.70	0.79	1.72	2.48	1.52	1.11	2.23	1.77	0.74	1.17	**1.48**
QNA	**11.6**	1.74	1.79	1.45	1.09	1.67	1.03	1.40	1.74	0.74	1.75	2.42	1.56	1.05	2.21	1.80	0.71	1.12	**1.49**
DNA	**13.4**	1.83	1.93	1.69	1.24	1.78	1.24	1.64	1.90	0.93	1.98	2.79	1.63	1.38	2.60	2.00	0.90	1.37	**1.70**
NVA	**12.4**	1.88	2.01	1.69	1.25	1.84	1.22	1.66	1.94	0.90	2.00	2.75	1.66	1.35	2.60	2.04	0.89	1.34	**1.71**
Avg.	15.4	**1.65**	**1.66**	**1.44**	**1.00**	**1.58**	**1.01**	**1.38**	**1.62**	**0.77**	**1.65**	**2.37**	**1.42**	**1.18**	**2.21**	**1.73**	**0.76**	**1.16**	**1.45**

Table A2.2. Average change in rainfall (%) for all months (Jan-Dec) estimated for the 2050s (2040-2059) from 17 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Actual** (mm)	**Models for 2050s – Change in Rainfall** (%)																	**Model avg.**
		BCM2	**CGMR**	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**1331**	6	-7	-10	-5	8	-3	-7	-1	-6	-1	16	13	-20	-3	9	-10	-8	**-1.8**
DAR	**1169**	7	-6	-8	-5	9	0	-8	0	-3	1	12	14	-20	-2	12	-6	-8	**-0.6**
COR	**1891**	3	-3	2	2	0	4	2	4	4	6	9	7	-3	11	9	0	2	**3.4**
AKL	**1101**	8	-5	-8	-1	10	-2	-5	2	-4	1	12	12	-20	0	14	-7	-9	**-0.1**
TGA	**1181**	4	-4	-11	-2	6	-3	-12	2	-5	-1	18	8	-21	0	12	-9	-11	**-1.7**
ROA	**1363**	5	-7	-10	-5	9	-1	-10	-2	-5	-2	12	8	-21	0	10	-9	-9	**-2.2**
GSA	**986**	3	-2	-9	-5	3	2	-10	10	-2	-2	11	19	-19	1	12	-7	-7	**-0.2**
APA	**995**	4	-6	-10	-1	7	0	-11	4	-5	-1	22	7	-23	0	10	-9	-10	**-1.2**
NPA	**1427**	6	-6	-9	-2	7	2	-7	1	-3	0	12	12	-20	2	15	-6	-6	**-0.1**
WUA	**1126**	6	-5	-7	-1	10	0	-8	3	-5	0	21	17	-22	-2	13	-9	-6	**0.2**
PPA	**1030**	7	-6	-7	-3	9	1	-5	4	-3	1	15	12	-17	4	15	-6	-7	**0.8**
WNA	**953**	11	-3	-10	-8	18	-9	-14	5	-10	-7	32	13	-31	-12	12	-11	-12	**-2.1**
NSA	**1078**	5	1	-6	-1	16	-1	0	8	-2	10	8	17	-18	6	17	-3	-4	**3.1**
WSA	**2247**	-2	-11	-1	-1	-10	9	0	-1	5	-1	15	6	-4	8	2	3	1	**1.0**
HKA	**2916**	1	-10	-4	-3	-6	5	-1	0	5	-2	13	9	-9	7	3	3	-1	**0.5**
KIX	**781**	22	-6	-10	-16	29	-9	-7	14	-7	-9	16	18	-30	-16	11	6	-7	**-0.1**
CHA	**625**	0	-12	-1	-4	-5	2	-1	-1	3	0	7	8	-7	4	5	0	3	**0.1**
QNA	**837**	-2	-5	6	4	-8	10	4	5	10	11	25	5	4	13	9	7	7	**6.0**
DNA	**726**	8	-10	-9	-16	10	-4	-11	6	2	-6	6	25	-26	-3	15	1	-11	**-1.4**
NVA	**1149**	-2	-6	1	3	-13	8	5	5	7	4	24	6	-2	12	5	6	2	**3.9**
Avg.	**1245**	**4.9**	**-6.0**	**-6.0**	**-3.6**	**5.4**	**0.6**	**-5.3**	**3.4**	**-1.3**	**0.0**	**15.2**	**11.7**	**-16.4**	**1.4**	**10.5**	**-3.3**	**-4.9**	**0.38**

Table A2.3. Average change in relative humidity (actual %) for all months (Jan-Dec) estimated for the 2050s (2040-2059) from 17 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Actual** (%)	**Models for 2050s – Change in Relative Humidity (%)**																	**Model avg.**
		BCM2	**CGMR**	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**71**	0.1	0.2	0.7	0.0	0.4	0.0	0.6	0.7	-0.1	0.5	-0.7	-0.2	1.1	1.5	1.5	0.7	0.4	**0.43**
DAR	**71**	0.1	0.2	0.6	-0.1	0.4	0.0	0.5	0.7	-0.1	0.4	-0.6	0.0	0.9	1.4	1.4	0.7	0.4	**0.40**
COR	**70**	0.2	0.4	0.8	0.1	0.4	0.3	0.7	0.7	0.2	0.5	0.1	0.1	1.2	1.5	1.2	0.8	0.6	**0.59**
AKL	**71**	0.0	0.1	0.2	-0.4	0.2	-0.5	0.0	0.2	-0.5	0.0	-1.5	-0.4	0.3	0.5	1.1	0.2	-0.2	**-0.04**
TGA	**68**	0.0	0.2	0.7	0.1	0.3	0.1	0.7	0.6	0.0	0.6	-0.4	-0.3	1.3	1.6	1.5	0.7	0.6	**0.48**
ROA	**70**	0.0	0.2	0.8	0.1	0.4	0.1	0.7	0.7	0.0	0.6	-0.5	-0.3	1.3	1.6	1.6	0.7	0.6	**0.51**
GSA	**63**	-0.2	-0.1	0.0	-0.2	0.0	-0.3	0.0	0.1	-0.3	0.0	-0.8	-0.3	0.1	0.2	0.5	0.0	-0.1	**-0.08**
APA	**70**	0.0	0.2	0.8	0.1	0.3	0.1	0.8	0.7	0.1	0.6	-0.5	-0.3	1.3	1.7	1.6	0.8	0.6	**0.51**
NPA	**76**	0.2	0.2	0.7	-0.1	0.3	0.1	0.6	0.7	0.0	0.4	-0.4	0.0	1.0	1.4	1.4	0.7	0.4	**0.45**
WUA	**72**	-0.2	-0.2	-0.3	-0.5	0.1	-0.8	-0.3	0.0	-0.7	-0.3	-1.7	-0.6	-0.1	-0.1	0.8	-0.2	-0.4	**-0.32**
PPA	**71**	-0.2	-0.5	-0.7	-0.5	-0.2	-0.8	-0.7	-0.5	-0.6	-0.6	-1.2	-0.4	-0.8	-1.0	-0.2	-0.7	-0.6	**-0.60**
WNA	**71**	-0.1	-0.1	-0.2	-0.5	0.2	-0.7	-0.2	0.0	-0.6	-0.3	-1.6	-0.4	-0.1	0.0	0.7	-0.1	-0.4	**-0.26**
NSA	**68**	0.1	0.2	0.6	0.0	0.3	0.0	0.5	0.6	0.0	0.4	-0.4	-0.1	1.0	1.3	1.3	0.6	0.4	**0.41**
WSA	**74**	0.3	0.4	0.9	0.2	0.4	0.4	0.8	0.8	0.3	0.6	0.3	0.1	1.2	1.6	1.2	0.8	0.7	**0.64**
HKA	**74**	0.1	0.3	0.9	0.0	0.3	0.2	0.7	0.8	0.1	0.5	-0.2	0.0	1.3	1.7	1.5	0.9	0.6	**0.57**
KIX	**69**	0.0	0.1	-0.2	-0.4	0.3	-0.6	-0.1	0.1	-0.6	-0.2	-1.5	-0.2	-0.2	-0.1	0.6	0.0	-0.4	**-0.21**
CHA	**63**	-0.1	0.0	0.4	-0.3	0.1	0.0	0.3	0.4	-0.1	0.0	-0.8	-0.1	0.8	1.0	0.9	0.7	0.2	**0.19**
QNA	**63**	0.4	0.7	1.1	0.5	0.6	0.6	1.1	0.9	0.5	0.9	0.8	0.4	1.5	1.9	1.2	1.1	0.9	**0.89**
DNA	**67**	0.0	-0.4	-0.8	-0.9	0.0	-1.0	-0.9	-0.4	-0.9	-0.8	-2.0	-0.3	-1.0	-1.1	-0.1	-0.6	-0.9	**-0.71**
NVA	**72**	0.5	0.1	0.1	-0.7	0.5	-0.5	-0.1	0.4	-0.5	-0.2	-1.2	0.2	0.1	0.5	1.2	0.2	-0.2	**0.02**
Avg.	**70**	**0.06**	**0.10**	**0.35**	**-0.17**	**0.26**	**-0.16**	**0.29**	**0.41**	**-0.19**	**0.18**	**-0.74**	**-0.16**	**0.61**	**0.86**	**1.03**	**0.40**	**0.16**	**0.19**

Table A2.4. Average change in wind speed (km/h) for all months (Jan-Dec) estimated for the 2050s (2040-2059) from 17 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Actual** (km/h)	**Models for 2050s – Change in Wind Speed (km/h)**																	**Model avg.**
		BCM2	**CGMR**	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**20.9**	-0.51	-0.99	-0.11	-0.24	-0.85	0.17	-0.29	-0.57	0.28	-0.34	0.41	-0.32	0.12	-0.12	-0.46	0.10	0.26	**-0.20**
DAR	**14.4**	-0.29	-0.69	-0.11	-0.10	-0.58	0.12	-0.20	-0.34	0.20	-0.20	0.24	-0.14	-0.03	-0.17	-0.29	-0.03	0.15	**-0.14**
COR	**17.6**	-0.33	-0.79	-0.11	-0.27	-0.64	0.09	-0.27	-0.42	0.17	-0.29	0.34	-0.18	-0.05	-0.11	-0.32	0.02	0.11	**-0.18**
AKL	**21.2**	-0.24	-0.64	-0.12	-0.14	-0.31	0.10	-0.15	-0.29	0.18	-0.16	0.03	-0.15	0.00	0.01	-0.10	0.03	0.11	**-0.11**
TGA	**18.2**	0.05	-0.44	-0.30	-0.35	-0.06	-0.12	-0.30	-0.37	-0.03	-0.32	-0.18	-0.06	-0.30	-0.30	-0.20	-0.15	-0.14	**-0.21**
ROA	**16.0**	-0.06	-0.58	-0.26	-0.30	-0.29	-0.04	-0.33	-0.36	0.02	-0.31	-0.03	-0.05	-0.27	-0.24	-0.24	-0.08	-0.08	**-0.21**
GSA	**17.9**	0.11	-0.31	-0.35	-0.12	0.12	-0.10	-0.20	-0.32	-0.04	-0.12	-0.22	-0.09	-0.35	-0.21	0.00	-0.21	-0.09	**-0.15**
APA	**16.6**	0.07	-0.36	-0.27	-0.34	-0.02	-0.12	-0.25	-0.33	-0.05	-0.30	-0.24	-0.07	-0.30	-0.26	-0.15	-0.13	-0.14	**-0.19**
NPA	**21.3**	-0.40	-0.86	-0.15	-0.08	-0.75	0.17	-0.26	-0.42	0.18	-0.20	0.34	-0.20	-0.03	-0.10	-0.34	0.01	0.17	**-0.17**
WUA	**21.3**	-0.13	-0.46	-0.09	-0.13	-0.21	0.10	-0.10	-0.27	0.15	-0.14	0.02	-0.13	-0.01	0.07	-0.06	0.08	0.08	**-0.07**
PPA	**21.1**	-0.19	-0.48	-0.08	-0.10	-0.33	0.12	-0.09	-0.27	0.18	-0.12	0.13	-0.18	0.06	0.09	-0.10	0.11	0.14	**-0.07**
WNA	**29.9**	-0.53	-0.99	-0.08	-0.15	-0.88	0.26	-0.22	-0.48	0.37	-0.28	0.48	-0.34	0.20	0.07	-0.39	0.21	0.30	**-0.14**
NSA	**16.2**	-0.43	-0.76	-0.08	-0.29	-0.74	0.16	-0.25	-0.40	0.24	-0.34	0.16	-0.16	0.04	-0.10	-0.41	0.08	0.10	**-0.19**
WSA	**16.2**	-0.50	-0.75	0.06	-0.36	-0.77	0.20	-0.17	-0.40	0.24	-0.40	0.37	-0.22	0.22	0.13	-0.37	0.35	0.21	**-0.13**
HKA	**16.6**	0.07	-0.36	-0.27	-0.34	-0.02	-0.12	-0.25	-0.33	-0.05	-0.30	-0.24	-0.07	-0.30	-0.26	-0.15	-0.13	-0.14	**-0.19**
KIX	**17.4**	-0.42	-0.75	0.00	-0.15	-0.74	0.11	-0.22	-0.38	0.25	-0.26	0.49	-0.22	0.17	-0.03	-0.38	0.08	0.24	**-0.13**
CHA	**18.7**	-0.49	-0.55	-0.02	-0.08	-0.52	0.11	0.05	-0.47	0.32	-0.09	0.31	-0.53	0.54	0.02	-0.31	0.13	0.40	**-0.07**
QNA	**12.6**	-0.46	-0.65	0.06	-0.13	-0.77	0.21	-0.18	-0.26	0.24	-0.19	0.46	-0.16	0.16	-0.03	-0.35	0.09	0.21	**-0.10**
DNA	**17.5**	-0.50	-0.74	0.05	-0.27	-0.81	0.19	-0.14	-0.36	0.25	-0.35	0.36	-0.22	0.25	-0.09	-0.48	0.23	0.22	**-0.14**
NVA	**21.1**	-0.58	-0.11	0.66	0.22	-0.36	0.45	0.52	0.23	0.51	0.37	0.93	-0.36	0.96	0.60	0.06	0.39	0.63	**0.30**
Avg.	18.6	**-0.29**	**-0.61**	**-0.08**	**-0.19**	**-0.48**	**0.10**	**-0.16**	**-0.34**	**0.18**	**-0.22**	**0.21**	**-0.19**	**0.05**	**-0.05**	**-0.25**	**0.06**	**0.14**	**-0.12**

Table A2.5. Average change in temperature (°C) for all months (Jan-Dec) estimated for the 2080s (2070-2089) from 17 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Actual** (°C)	**Models for 2080s – Change in Temperature (°C)**																	**Model avg.**
		BCM2	**CGMR**	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**17.9**	2.71	2.59	2.33	1.42	2.39	1.75	2.40	2.24	1.69	1.90	3.25	2.40	2.70	3.74	2.90	2.19	2.28	**2.41**
DAR	**17.7**	2.90	2.75	2.47	1.54	2.54	1.88	2.55	2.39	1.80	2.03	3.51	2.59	2.83	3.98	3.08	2.33	2.44	**2.57**
COR	**17.6**	2.43	2.34	1.99	1.29	2.23	1.52	2.03	2.03	1.41	1.74	2.70	2.14	2.23	3.25	2.59	1.85	1.99	**2.10**
AKL	**17.4**	2.65	2.53	2.25	1.32	2.25	1.62	2.22	2.11	1.57	1.77	3.01	2.23	2.53	3.50	2.71	2.04	2.13	**2.26**
TGA	**17.2**	2.31	2.21	1.97	1.17	2.08	1.41	1.99	1.93	1.40	1.59	2.57	1.96	2.35	3.19	2.48	1.84	1.89	**2.02**
ROA	**15.4**	2.35	2.25	2.01	1.19	2.11	1.45	2.03	1.96	1.44	1.62	2.64	2.00	2.40	3.25	2.52	1.88	1.93	**2.06**
GSA	**17.8**	2.44	2.34	2.10	1.24	2.18	1.52	2.14	2.03	1.51	1.69	2.79	2.09	2.50	3.38	2.62	1.97	2.02	**2.15**
APA	**13.9**	2.29	2.21	1.95	1.16	2.09	1.39	1.96	1.92	1.38	1.59	2.51	1.94	2.33	3.16	2.47	1.82	1.87	**2.00**
NPA	**15.9**	2.85	2.73	2.39	1.50	2.56	1.80	2.45	2.37	1.72	2.01	3.28	2.51	2.74	3.87	3.04	2.24	2.36	**2.50**
WUA	**16.1**	2.52	2.41	2.17	1.31	2.23	1.61	2.22	2.09	1.57	1.76	2.98	2.21	2.54	3.49	2.70	2.04	2.11	**2.23**
PPA	**15.4**	2.80	2.78	2.44	1.47	2.57	1.80	2.56	2.37	1.76	2.02	3.23	2.45	2.92	3.96	3.09	2.31	2.36	**2.52**
WNA	**15.2**	2.85	2.78	2.48	1.52	2.55	1.87	2.60	2.38	1.81	2.04	3.44	2.55	2.90	3.99	3.10	2.35	2.43	**2.57**
NSA	**15.5**	2.92	2.78	2.49	1.56	2.57	1.91	2.58	2.42	1.82	2.06	3.56	2.63	2.84	4.01	3.11	2.35	2.47	**2.59**
WSA	**14.6**	2.61	2.50	2.17	1.38	2.36	1.64	2.22	2.17	1.55	1.85	2.98	2.30	2.46	3.52	2.78	2.03	2.15	**2.27**
HKA	**14.2**	2.38	2.30	2.03	1.27	2.14	1.55	2.12	1.99	1.48	1.70	2.83	2.13	2.34	3.29	2.57	1.92	2.01	**2.12**
KIX	**13.8**	2.92	2.84	2.56	1.58	2.57	1.97	2.73	2.43	1.89	2.10	3.66	2.65	2.98	4.11	3.17	2.44	2.52	**2.65**
CHA	**14.9**	2.75	2.67	2.31	1.50	2.49	1.80	2.42	2.30	1.67	1.99	3.26	2.49	2.60	3.75	2.96	2.17	2.31	**2.44**
QNA	**11.6**	2.79	2.74	2.30	1.52	2.60	1.78	2.39	2.36	1.64	2.05	3.13	2.50	2.56	3.77	3.02	2.14	2.31	**2.45**
DNA	**13.4**	2.97	3.02	2.63	1.67	2.72	2.07	2.90	2.53	1.95	2.25	3.72	2.76	3.07	4.26	3.34	2.53	2.61	**2.76**
NVA	**12.4**	3.03	3.11	2.64	1.70	2.85	2.06	2.89	2.61	1.93	2.31	3.62	2.78	3.07	4.31	3.42	2.52	2.62	**2.79**
Avg.	**15.4**	**2.67**	**2.59**	**2.28**	**1.42**	**2.40**	**1.72**	**2.37**	**2.23**	**1.65**	**1.90**	**3.13**	**2.37**	**2.65**	**3.69**	**2.88**	**2.15**	**2.24**	**2.37**

Table A2.6. Average change in rainfall (%) for all months (Jan-Dec) estimated for the 2080s (2070-2089) from 17 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	Actual (mm)	**Models for 2080s – Change in Rainfall** (%)																	Model avg.
		BCM2	CGMR	CNCM3	CSMK3	ECHOG	FGOALS	GFCM20	GFCM21	GIAOM	GIEH	HADCM3	HADGEM	IPCM4	MIHR	MIMR	MPEH5	MRCGCM	
KX	**642**	14	-10	-12	-8	1	-6	-15	-2	6	0	14	8	-26	-6	14	-11	-4	**-2.4**
DAR	**564**	13	-8	-10	-6	2	-3	-16	-3	6	2	13	12	-24	-3	14	-7	1	**-1.0**
COR	**963**	3	-2	-1	1	0	4	10	2	13	5	12	15	-3	10	15	8	7	**5.7**
AKL	**562**	16	-7	-8	-5	7	-2	-12	3	5	5	18	11	-22	0	17	-9	-1	**0.9**
TGA	**655**	13	-9	-7	-5	-1	1	-18	3	2	0	24	7	-28	-5	12	-12	-2	**-1.5**
ROA	**733**	13	-8	-9	-8	0	1	-17	-1	6	1	19	8	-25	-5	12	-11	-4	**-1.7**
GSA	**517**	12	-8	-9	-6	-1	-1	-17	3	2	-1	17	14	-24	-8	11	-8	1	**-1.4**
APA	**562**	16	-8	-8	-6	-1	2	-18	6	1	5	27	8	-26	-4	10	-12	-1	**-0.5**
NPA	**785**	14	-8	-9	-4	2	-2	-11	-1	7	3	15	7	-20	2	14	-4	-2	**0.2**
WUA	**607**	14	-10	-12	-8	1	-6	-15	-2	6	0	14	8	-26	-6	14	-11	-4	**-2.4**
PPA	**562**	13	-5	-5	-3	5	1	-9	3	5	5	22	13	-18	3	17	-3	1	**2.6**
WNA	**491**	21	-9	-6	-5	24	-6	-26	3	0	-1	26	8	-30	-11	9	-11	-4	**-1.1**
NSA	**556**	17	-3	-7	-6	10	0	-7	4	9	10	14	15	-22	3	22	-4	0	**3.2**
WSA	**1234**	-1	-14	-2	-4	-14	5	0	-2	7	-1	25	10	-6	6	4	3	0	**0.8**
HKA	**1690**	5	-15	-5	-7	-10	3	-4	-4	7	-2	19	9	-11	6	6	3	-1	**-0.1**
KIX	**403**	26	-7	0	1	31	-13	-27	1	0	2	12	11	-32	-16	13	-5	1	**-0.2**
CHA	**321**	2	-12	-4	-6	-11	2	3	-5	9	-2	23	8	-5	2	8	6	3	**1.2**
QNA	**480**	2	-5	4	-3	-11	12	14	5	14	10	34	11	6	17	13	18	10	**8.8**
DNA	**448**	16	-30	-13	-16	1	-13	-20	-8	2	-6	4	10	-29	-3	8	-4	-8	**-6.4**
NVA	**693**	0	-10	2	-2	-18	8	5	1	11	4	38	9	-1	14	11	12	2	**5.1**
Avg.	673	**11.4**	**-9.4**	**-6.0**	**-5.2**	**0.9**	**-0.7**	**-10.0**	**0.3**	**5.8**	**1.9**	**19.5**	**10.1**	**-18.5**	**-0.3**	**12.2**	**-3.1**	**-0.4**	0.49

Table A2.7. Average change in relative humidity (actual %) for all months (Jan-Dec) estimated for the 2080s (2070-2089) from 17 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	Actual (%)	Models for 2080s – Change in Relative Humidity (%)																	Model avg.
		BCM2	CGMR	CNCM3	CSMK3	ECHOG	FGOALS	GFCM20	GFCM21	GIAOM	GIEH	HADCM3	HADGEM	IPCM4	MIHR	MIMR	MPEH5	MRCGCM	
KX	**71**	0.3	0.1	1.1	-0.2	0.6	0.0	1.0	1.5	0.8	2.0	-0.9	0.5	1.6	2.0	2.2	1.3	0.3	**0.85**
DAR	**71**	0.3	0.1	1.0	-0.2	0.6	0.0	0.8	1.4	0.7	1.8	-0.9	0.6	1.4	1.9	2.0	1.2	0.3	**0.76**
COR	**70**	0.4	0.5	1.2	0.1	0.5	0.5	1.3	1.1	0.9	1.4	0.2	0.8	1.8	2.0	1.8	1.4	0.6	**0.96**
AKL	**71**	0.0	-0.3	0.5	-0.6	0.4	-0.7	-0.1	1.0	0.2	1.5	-2.1	-0.2	0.5	0.8	1.4	0.4	-0.3	**0.16**
TGA	**68**	0.2	0.2	1.2	-0.2	0.5	0.1	1.4	1.4	1.1	2.0	-0.4	0.5	1.9	2.0	2.1	1.5	0.4	**0.93**
ROA	**70**	0.3	0.2	1.2	-0.2	0.6	0.1	1.4	1.5	1.1	2.1	-0.5	0.5	2.0	2.1	2.2	1.6	0.5	**0.98**
GSA	**63**	-0.2	-0.4	0.1	-0.4	0.0	-0.4	-0.1	0.4	0.2	0.7	-1.0	-0.2	0.2	0.2	0.6	0.2	-0.2	**0.00**
APA	**70**	0.2	0.2	1.2	-0.2	0.5	0.2	1.4	1.5	1.1	2.1	-0.4	0.6	2.0	2.1	2.2	1.6	0.5	**0.98**
NPA	**76**	0.3	0.1	1.0	-0.2	0.6	0.1	0.9	1.4	0.7	1.8	-0.7	0.7	1.5	2.0	2.0	1.3	0.4	**0.82**
WUA	**72**	-0.3	-0.8	-0.1	-0.8	0.2	-0.9	-0.6	0.6	0.0	1.1	-2.3	-0.6	-0.1	0.0	0.8	-0.1	-0.6	**-0.26**
PPA	**71**	-0.4	-1.0	-0.8	-0.6	-0.2	-1.0	-1.4	-0.3	-0.6	-0.1	-1.7	-0.9	-1.2	-1.3	-0.5	-0.9	-0.8	**-0.80**
WNA	**71**	-0.1	-0.6	-0.1	-0.7	0.3	-0.8	-0.7	0.6	-0.1	1.0	-2.3	-0.4	-0.1	0.2	0.9	-0.1	-0.5	**-0.21**
NSA	**68**	0.3	0.1	1.0	-0.2	0.6	0.1	0.9	1.3	0.7	1.7	-0.6	0.6	1.4	1.8	1.9	1.2	0.4	**0.78**
WSA	**74**	0.5	0.5	1.3	0.1	0.6	0.5	1.4	1.2	1.0	1.5	0.5	0.9	1.8	2.2	1.9	1.5	0.7	**1.06**
HKA	**74**	0.3	0.1	1.3	-0.1	0.5	0.3	1.3	1.5	0.9	1.9	-0.4	0.8	1.9	2.3	2.2	1.6	0.5	**0.99**
KIX	**69**	-0.1	-0.3	-0.1	-0.5	0.5	-0.8	-0.7	0.6	-0.3	0.8	-2.3	-0.3	-0.2	0.2	0.9	-0.1	-0.5	**-0.18**
CHA	**63**	0.0	-0.3	0.6	-0.4	0.1	-0.1	0.3	0.8	0.4	1.1	-1.2	0.3	1.0	1.3	1.3	0.8	0.0	**0.35**
QNA	**63**	0.8	1.1	1.5	0.5	0.9	0.9	2.0	1.3	1.1	1.4	1.1	1.2	2.4	2.6	2.0	1.8	1.1	**1.40**
DNA	**67**	-0.2	-1.1	-0.9	-0.9	0.0	-1.3	-2.1	-0.1	-0.9	-0.1	-2.8	-1.0	-1.5	-1.2	-0.4	-1.2	-1.0	**-0.97**
NVA	**72**	0.8	-0.4	0.4	-0.5	0.7	-0.6	-0.8	1.2	0.1	1.3	-1.8	0.3	0.2	1.2	1.6	0.3	-0.1	**0.23**
Avg.	**70**	**0.18**	**-0.10**	**0.63**	**-0.31**	**0.44**	**-0.18**	**0.39**	**1.00**	**0.46**	**1.36**	**-1.03**	**0.24**	**0.92**	**1.22**	**1.45**	**0.76**	**0.08**	**0.44**

Table A2.8. Average change in wind speed (km/h) for all months (Jan-Dec) estimated for the 2080s (2070-2089) from 17 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Actual** (km/h)	**Models for 2080s – Change in Wind Speed (km/h)**																	**Model avg.**
		BCM2	**CGMR**	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**20.9**	-0.68	-1.22	-0.35	-0.39	-1.57	0.01	-0.18	-0.95	0.14	-0.80	0.90	-0.31	-0.23	-0.62	-0.95	-0.02	-0.20	**-0.44**
DAR	**14.4**	-0.39	-0.81	-0.26	-0.18	-0.99	0.02	-0.11	-0.59	0.13	-0.46	0.62	-0.18	-0.24	-0.46	-0.62	-0.05	-0.09	**-0.27**
COR	**17.6**	-0.44	-0.95	-0.23	-0.28	-1.12	0.01	-0.21	-0.72	0.09	-0.56	0.79	-0.16	-0.33	-0.53	-0.72	-0.08	-0.14	**-0.33**
AKL	**21.2**	-0.30	-0.83	-0.20	-0.26	-0.69	0.01	-0.06	-0.55	0.12	-0.32	0.39	-0.19	-0.23	-0.21	-0.34	0.04	-0.09	**-0.22**
TGA	**18.2**	0.06	-0.66	-0.36	-0.33	-0.32	-0.26	-0.61	-0.55	-0.21	-0.41	-0.10	-0.34	-0.63	-0.44	-0.40	-0.36	-0.26	**-0.36**
ROA	**16.0**	-0.12	-0.81	-0.36	-0.30	-0.62	-0.17	-0.52	-0.59	-0.16	-0.43	0.12	-0.25	-0.60	-0.47	-0.52	-0.29	-0.24	**-0.37**
GSA	**17.9**	0.24	-0.45	-0.33	-0.27	-0.10	-0.15	-0.34	-0.46	0.00	-0.16	0.03	-0.34	-0.52	-0.31	-0.14	-0.25	-0.11	**-0.22**
APA	**16.6**	0.09	-0.57	-0.33	-0.31	-0.22	-0.25	-0.57	-0.49	-0.21	-0.35	-0.14	-0.33	-0.54	-0.37	-0.34	-0.34	-0.25	**-0.33**
NPA	**21.3**	-0.53	-1.05	-0.31	-0.24	-1.32	0.03	-0.14	-0.74	0.14	-0.57	0.87	-0.20	-0.38	-0.57	-0.76	-0.05	-0.10	**-0.35**
WUA	**21.3**	-0.13	-0.63	-0.11	-0.24	-0.58	0.02	-0.05	-0.51	0.12	-0.27	0.35	-0.17	-0.24	-0.13	-0.26	0.03	-0.09	**-0.17**
PPA	**21.1**	-0.24	-0.61	-0.13	-0.22	-0.70	0.03	0.00	-0.52	0.13	-0.30	0.49	-0.19	-0.16	-0.15	-0.30	0.04	-0.08	**-0.17**
WNA	**29.9**	-0.75	-1.18	-0.27	-0.36	-1.68	0.11	0.00	-0.91	0.19	-0.71	1.14	-0.28	-0.24	-0.47	-0.85	0.09	-0.16	**-0.37**
NSA	**16.2**	-0.58	-0.98	-0.20	-0.38	-1.38	0.07	-0.21	-0.69	0.04	-0.64	0.64	-0.29	-0.37	-0.47	-0.80	-0.03	-0.26	**-0.38**
WSA	**16.2**	-0.75	-1.01	-0.10	-0.39	-1.44	0.10	-0.11	-0.75	0.04	-0.70	0.84	-0.12	-0.18	-0.29	-0.75	0.08	-0.27	**-0.34**
HKA	**14.2**	-0.48	-0.71	-0.10	-0.24	-1.00	0.11	-0.09	-0.46	0.06	-0.41	0.63	-0.04	-0.20	-0.24	-0.53	0.06	-0.14	**-0.22**
KIX	**17.4**	-0.59	-0.79	-0.17	-0.21	-1.21	0.07	-0.03	-0.56	0.12	-0.57	0.88	-0.16	-0.09	-0.47	-0.71	0.01	-0.13	**-0.27**
CHA	**18.7**	-0.54	-0.47	-0.01	-0.26	-1.19	0.08	0.36	-0.65	0.42	-0.62	1.04	-0.53	0.45	-0.39	-0.73	0.19	0.00	**-0.17**
QNA	**12.6**	-0.68	-0.78	-0.12	-0.18	-1.31	0.13	0.04	-0.47	0.13	-0.50	0.92	-0.10	-0.11	-0.42	-0.76	0.07	-0.16	**-0.25**
DNA	**17.5**	-0.74	-0.93	-0.14	-0.27	-1.43	0.06	-0.11	-0.63	0.04	-0.76	0.67	-0.16	-0.07	-0.52	-0.92	0.05	-0.24	**-0.36**
NVA	**21.1**	-0.62	0.20	0.74	0.15	-0.64	0.56	1.38	0.20	0.75	0.09	1.55	0.32	1.11	0.37	-0.09	0.81	0.42	**0.43**
Avg.	**18.5**	**-0.41**	**-0.76**	**-0.17**	**-0.26**	**-0.97**	**0.03**	**-0.08**	**-0.58**	**0.10**	**-0.47**	**0.63**	**-0.20**	**-0.19**	**-0.36**	**-0.57**	**0.00**	**-0.13**	**-0.26**