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

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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 2040s, 2030-2049; and 2090s, 2080-2099) were estimated using monthly changes in weather inputs (temperature, humidity, wind speed and rainfall). These changes were obtained from downscaling of 16 global climate models for the A1B emissions scenario from the IPCC's 4th Assessment applied to 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. This is primarily the result of increases in temperature and decreases in rainfall, although higher wind speed and lower humidity will also contribute to higher future fire danger. The areas most likely to increase from current levels are the east and south of the South Island, especially coastal Otago, 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 2090s, 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.

The occurrence of the changes indicated in these locations would see the areas of elevated fire danger under current climate in Canterbury, Gisborne, Marlborough and Central Otago/South Canterbury expand along the east coast of both islands to include coastal Otago, Wellington and Hawkes Bay by the 2040s, and to develop further in Marlborough, Hawkes Bay and Wairarapa by the 2090s. Fire dangers in Wanganui, the Bay of Plenty and Northland would also increase. However, despite significant percentage increases in Southland, south Taranaki and the Coromandel, fire climate severity in these areas would increase but still remain comparatively low relative to other parts of the country.

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 2090s, a feature of several models was for fire danger to increase more rapidly to the 2040s, and then to stabilise or decrease by the 2090s. This levelling off is due to greater predicted increases in rainfall (especially during fire season months) in these climate models 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 could expect longer fire seasons in some parts of the country, increased drought frequency, an increased number of fires and greater areas burned, and increased fire suppression costs and damages.

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 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:

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Client Report No.	18087 (Output No. 47055)
Products investigated	Fire and climate change
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GLOSSARY OF ABBREVIATIONS

Abbreviation	**Definition**
AR3	IPCC 3rd Assessment Report (2001)
AR4	IPCC 4th Assessment Report (2007)
CGMR	Canadian Centre for Climate Modelling and Analysis, Canada [CCMA_CGCM3.1] model – *an example model predicting high-range climate changes*
CSIRO	Commonwealth Scientific & Industrial Research Organisation, Australia
DSR	Daily Severity Rating component of the FWI System
ECHOG	Meteorological Institute of the University of Bonn, Korea Meteorological Administration (KMA), and Model and Data Group, Germany/Korea [MIUB_ECHO-G] model – *an example model predicting mid-range climate changes*
ENSO	El Niño – Southern Oscillation
FWI System	Fire Weather Index System
GCM	Global Circulation Model, sometimes referred to as Global Climate Model
IPCC	Intergovernmental Panel on Climate Change
MAF	Ministry of Agriculture & Forestry, NZ
MfE	Ministry for the Environment, NZ
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] model – *an example model predicting low-range climate changes*
NCEP	National Centre for Environmental Prediction, USA
NIWA	National Institute of Water & Atmospheric Research, NZ
NZFDRS	New Zealand Fire Danger Rating System
NZMS	New Zealand Meteorological Service (MetService)
NZST	New Zealand Standard Time
RCM	Regional Climate Model
SLMACC	Sustainable Land Management and Climate Change Plan
SRES	IPCC Special Report on the Emissions Scenarios
SSR	Seasonal Severity Rating (average DSR over fire season)
VCSN	Virtual Climate Station Network
VH+E	Very High & Extreme (Forest) fire danger

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 (Intergovernmental Panel on 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, Fire Weather Index (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 just 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 affect 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 Global 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 El Nino/Southern Oscillation) 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 2040s (50 years into the future, i.e. 2030-2049) and 2090s (100 years into the future, i.e. 2080-2099) 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 (i.e. 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 2040s and 2090s 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 scenarios (from the IPCC’s Special Report on Emissions Scenarios, SRES), 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.

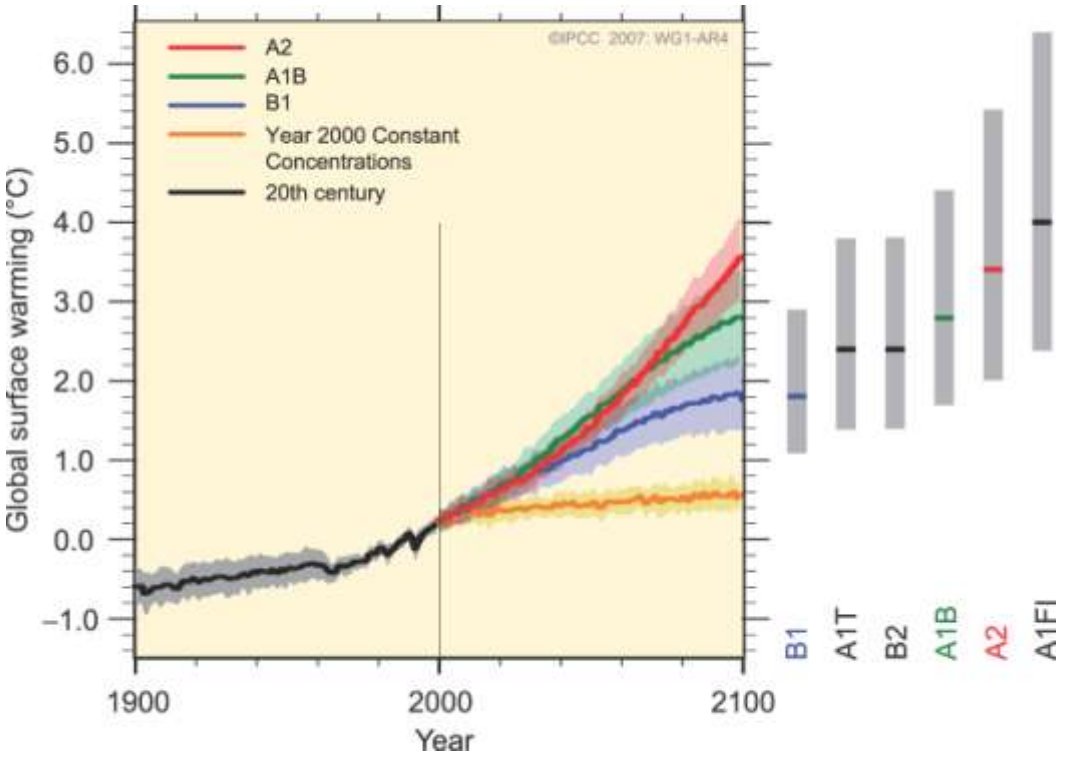

Figure 1. IPCC multi-model temperature projections for selected scenarios. The grey bars to the right show the range in global warming for the scenarios used in MfE (2008).
Note: Solid lines are multi-model global averages of surface warming (relative to 1980-1999) for scenarios B1, A1B and A2, shown 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 GCMs 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, by comparison of predictions for a 30-year (i.e. 1970-1999) base period with gridded observational data from National Centre for Environmental Prediction (NCEP) re-analysis (Kalnay et al. 1996), found that 5 of the 17 models (including 3 with considerably coarser resolution) 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 GCMs (plus additional information provided from a regional climate model), with model changes 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 (11 of which were used in the present study[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 (see Table 1). The range for each variable reflects not only the range of greenhouse gas futures represented by the six SRES scenarios, but also the range of climate model predictions for individual emission scenarios. Since the production of the MfE (2008) report, downscaling has also been undertaken for an additional 6 GCMs (5 of which were used in the present study), 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 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.

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[1] Only 11 of the 12 models used in MfE (2008), and 5 of the 6 additional models downscaled for NZ (by NIWA), were used in the present study, with changes for the NCAR (NCAR_CCSM30) and BCM2 (BCCR_BCM2.0) models, respectively, not available due to issues with GCM data coverage or problems resolving the downscaled projections for these models.

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.**
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]	2.20	0.97	**0.71**	2.16	**2.07**
BCM2	*Bjerknes Centre for Climate Research, Norway [BCCR_BCM2.0]*					
NCAR	*National Centre for Atmospheric Research, USA [NCAR_CCSM30]*	*2.71*	*1.57*	*1.19*	*2.63*	*2.11*

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. Models indicated in italics (BCM2 & NCAR) were not used in the present study (see footnote 1, on previous page)

- 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%.

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

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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

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 delivered in time for this analysis, although it is doubtful they would have provided suitable output for analysis in any event.

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). Temperature and wind speed 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. Most of the differences in values of VCSN versus actual data could be attributed to the different observation times. In the case of daily rainfall, the differences were generally small as VCSN estimates comprise 24-hour totals to 9am compared with 12 noon for station fire weather observations. Relative humidity estimates in the VCSN data are also based on 9am observations, so they were generally significantly higher (moister) than the 12 noon station fire weather observations. Temperature estimates from the VCSN data are a daily mean derived from the maximum and minimum temperatures for the day, so were generally lower compared with the 12 noon station fire weather observations. Similarly, as a result of being averaged from daily wind run measurements, VCSN 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 SSR values close to zero in all cases. This was only exacerbated when model climate changes were applied which predicted increased rainfall and relative humidity values.

While it may have been possible with more time to derive statistical relationships between the VCSN data and actual climate, it was not possible to do this in the time available and the validity of such an approach is also questionable. It was therefore not possible to realise the intended benefits from the expanded VCSN gridded dataset at the time of this analysis.

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 (mainly airport locations) (Table 2), albeit providing reasonable spatial coverage across the country as well as recognised climate/fire climate regions (Figure 2).

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 2040s (2030-2049) and 2090s (2080-2099).

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).

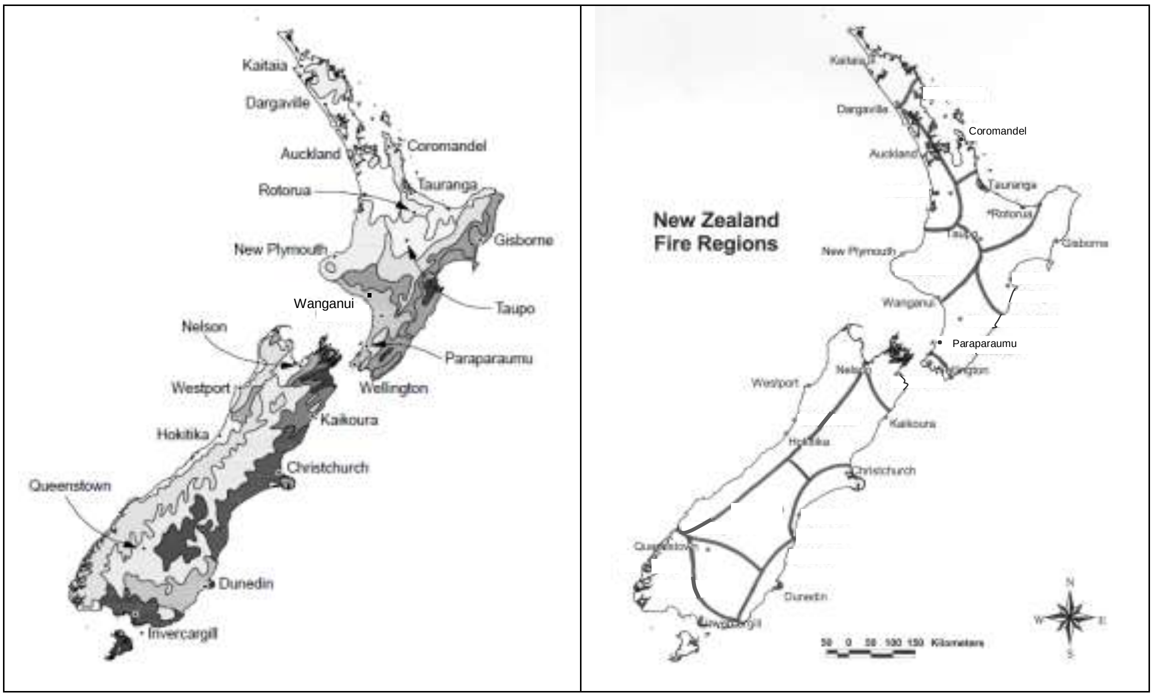


Figure 2. Locations of fire weather stations used in the current analysis, shown in relation to: (a) New Zealand climate regions (after NZMS 1983), and (b) New Zealand fire climate regions (after Heydenrych and Salinger 2002).

Application of Climate Offsets

Changes from current climate (i.e. “offsets”) projected for each of the weather elements from GCM downscaling for the two future climate periods (2040s and 2090s) were applied to the weather observations from each of the 20 stations’ current (1980-1999) daily time series. These offsets were obtained from the downscaled estimates for the VCSN grid point closest to each weather station location by either subtracting (for temperature) or dividing (for humidity, wind speed and rainfall) the VCSN estimates for the future projection periods (2040s or 2090s) from/by the VCSN estimates for the current baseline period (1990s) derived. Application of these offsets to actual daily station observations resulted in what were considered more valid values of weather elements for future fire climate, without the anomalous values observed in the modelled VCSN datasets, yet still retaining the extremes (of high wind speed, low humidity, and low and high temperatures) contained within the daily fire weather station datasets but 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 global climate 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. In doing so, this captures the month-to-month variability simulated by the GCMs in the projections, thereby taking consideration of changing distributions (beyond mean shifts) and potential for increased future climate variability.

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 33 scenarios for each of the 20 station locations (i.e., current 1990s climate, plus 16 models for both of the 2040s and 2090s).

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 was then compared using the estimates from the different GCMs, including both individual model estimates as well as the average across all 16 models investigated. Use of the multi-model average is a recognised way of describing the "best estimate" from consensus of the widely varying models being compared, although it is also usual to include the likely range in possible outcomes across all models since no one model is more likely than any other (Meehl et al. 2007, MfE 2008). Hence, to help illustrate the range of possible outcomes, model averages were also contrasted with examples of individual models producing low, mid and high-range changes. Projected regional changes were also mapped to illustrate potential changes across the country, again using the 16 model averages, plus these examples of low, mid and high-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 are likely to occur.

Mapping of Spatial Changes

Maps of projected changes in fire danger were produced by interpolating the changes predicted at each of the 20 station locations. Maps were produced using ESRI's® ArcGIS software, with "surfaces" being fitted through the data to describe the spatial pattern of changes in fire climate across the country. Several spatial interpolation techniques available within the ArcGIS Geostatistical Analyst extension were tested (including Inverse Distance Weighting, thin-plate splines and kriging/ cokriging). However, ultimately the cokriging technique was favoured, as this allowed inclusion of additional surface prediction variables (e.g. elevation), as well as comparison of fitted model accuracy using surface error estimates plus the semivariogram statistical output produced as part of this method. Cokriging had also previously been found to be the most accurate method for interpolating New Zealand's current fire climate severity (Pearce et al. 2011). Final maps were produced through cokriging, using station location (latitude/longitude) and elevation as surface prediction variables, as well as the fitted surface for current fire climate severity (for fire season DSR and number of days of VH+E fire danger) derived from data for 77 station locations by Pearce et al. (2011). The inclusion of the latter significantly improved the prediction of potential changes at locations remote from the sampled station sites, although caution should still be applied when interpreting the maps for these locations due to the interpolation being based on such a relatively small number of data points (only 20 stations).

RESULTS AND DISCUSSION

Changes in Fire Danger

Estimated changes in fire danger during fire season months (October-April) using the two fire climate severity measures for the 2040s and 2090s are presented in the figures and tables that follow. (Changes averaged over the full calendar year are also included in Appendix 1). Tables 3 & 4 and Figures 3 & 4 illustrate the projected changes from current (1990s) fire climate for the 2040s, and Tables 5 & 6 and Figures 5 & 6 changes for the 2090s. The tables and figures presented here illustrate changes in fire climate severity from current climate (as a % change) averaged across the fire season, whereas the tables included in Appendices 1-2 compare actual estimates of the fire climate severity measures from the 16 GCMs with the overall model average and current (actual) climate for fire season months (Appendix 1) or the full calendar year (Appendix 2).

In addition to the 16 model average, Figures 3 & 4 also include maps illustrating changes predicted by an individual mid-range model (ECHOG), as well as low- (MIMR) and high-range (CGMR) models. The changes projected by these models, which are no more or less likely to occur than any other model, are included to illustrate the range and variability in possible outcomes. In particular, this includes projections of fire climate severity from the more extreme models containing some of the lowest and highest changes in the contributing climate variables. However, by averaging the changes predicted across a range of structurally different models, the overall 16 model average provides the “best estimate” of potential future fire climate severity, and one that is certainly an advance over consideration of just one or two individual models.

Note that caution should be applied when interpreting percentage changes, as small percentage changes (both increases and decreases) at locations with high existing fire climate severity can result in significant changes in fire danger compared with much larger percentage changes at stations with lower fire climate severities. Some caution should also be applied when interpreting the changes depicted in the maps provided, particularly for locations other than those investigated, due to the limited number of stations on which the interpolation is based. To overcome this limitation, every effort has been made to improve the accuracy of the spatial interpolation, in this case by using the cokriging methodology including elevation and current fire climate severity as additional predictors of future fire danger. So despite the 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.

When projected changes were mapped across the country (see Figures 3 & 4), the greatest changes were generally found in the east of the South Island, and lower North Island. Whereas the South Island typically showed a clear east-west trend (with increases in the east, and little or no change or possible decreases in the west), the pattern in the North Island was more often south-north (with the greatest increases in the south and smaller changes in the north). However, under some models, more east-west changes across the North Island were apparent.

Projected changes for the 2040s

For fire season Seasonal Severity Rating (SSR) in the 2040s (Table 3), model projections for the 20 stations showed changes of -2% to 148%, with an average increase of 26% across all 16 models. These changes correspond to changes in SSR of -0.1 to 3.0 points, and an average increase of 0.41 points (see Appendix 1). Projected increases were greatest under the IPCM4 model (average 43%, or 0.73 points), and lowest under the CNCM3 model (average 15% or 0.25 points). The HADCM3 model was the only model to show decreases in SSR to 2040, although these were few (only 2 stations) and small at -1% or -0.01 points (from 0.94 to 0.93) for Coromandel (COR), and -2% or -0.1 points (from 5.60 to 5.50) at Christchurch Aero (CHA). Projected increases in SSR were greatest at Dunedin Aero (DNA), averaging 78% or 1.33 points, followed by Kaikoura (KIX) (69% or 1.06 points) and Wellington Aero (WNA) (46% or 1.46 points); and lowest at COR (8% or 0.08 points), CHA (12% or 0.66 points) and Queenstown Aero (QNA) (13% or 0.18 points).

For the 16 model average for SSR (Figure 3a), the spatial pattern of changes shows the greatest potential increases (50-85%) in coastal Otago and Marlborough, resulting from the increases projected for the Dunedin Aero (DNA) and Kaikoura (KIX) stations (Table 3). Lower yet still significant increases of 40-50% are indicated for Wellington (based on Wellington Aero, WNA) and 30-40% for the lower North Island (based on the responses of Paraparaumu, PPA, and Wanganui, WUA). However, large areas of little or no change (0-10%) are also indicated by the 16 model average on the South Island’s West Coast and North Island’s East Cape, where there is also some potential for slight decreases (-5% to -10%) in SSR.

By comparison, the low model example (Figure 3b), which is based on the MIMR model which illustrated some of the lowest overall changes (see Tables 3-6), showed the potential for even greater increases (70-100%) in coastal Otago and Marlborough. However, increases (of 25-50%) were predicted for a smaller area of the lower North Island, and much greater areas of little or no change were also predicted under this model, including the South Island’s West Coast and across the majority of the North Island. No decreases were determined for any stations under this model (Table 3), but their potential is indicated for East Cape and the West Coast by the interpolation of the station changes.

The mid range model example (Figure 3c), which is based on the ECHOG model, extended the area of highest potential increase in SSR (50-70%) from coastal Otago into Southland (based on the response of Invercargill, NVA; see Table 3). However, lower increases (40-50%) were projected for Kaikoura (KIX) under this model. With the exception of southern Fiordland which showed potential for little or no change, the remainder of the country, including the entire North Island, showed only small increases (of 10-40%) in SSR.

In contrast, the high-range model example (Figure 3d), illustrated using the CGMR model which consistently produced the highest increases of all the models (see Tables 3-6), showed the potential for significantly higher SSR values across much of the country. Again the greatest increases, in this instance of 70-150%, were in coastal Otago (Dunedin Aero, DNA) and Marlborough (Kaikoura, KIX).

Table 3. Projected changes (%) in average Seasonal Severity Rating (SSR) over fire season months (Oct-Apr) estimated for the 2040s (2030-2049) from 16 Global Climate Models, and comparison with current SSR for the 1990s (1980-1999).

Station Code	**Current SSR**	**Models for 2040s – % change in Seasonal Severity Rating (SSR)**																**Avg. change (%)**
		CGMR	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**1.51**	26	10	13	17	13	21	18	13	14	15	22	35	31	11	28	16	**18.8**
DAR	**0.95**	36	13	20	25	20	27	31	19	25	16	25	40	34	15	33	16	**24.8**
COR	**0.94**	12	4	6	15	6	12	14	6	9	-1	15	9	6	3	7	7	**8.2**
AKL	**1.86**	27	11	13	23	18	25	14	17	21	18	21	35	29	9	26	20	**20.3**
TGA	**1.73**	25	11	13	22	10	16	21	12	18	1	21	24	21	13	22	17	**16.7**
ROA	**0.90**	28	12	15	21	14	20	19	12	22	8	23	24	24	12	25	15	**18.5**
GSA	**4.41**	20	13	8	18	11	16	15	11	16	1	20	22	17	13	16	14	**14.3**
APA	**0.92**	27	14	16	27	12	22	21	14	24	5	28	28	23	14	30	22	**20.4**
NPA	**0.62**	21	10	21	19	17	27	17	13	22	14	22	35	32	10	26	17	**20.1**
WUA	**1.22**	32	20	21	28	25	27	22	25	25	25	36	55	49	23	46	32	**30.6**
PPA	**1.15**	29	18	15	27	19	29	19	19	23	20	24	47	50	22	27	23	**25.6**
WNA	**3.21**	54	25	30	25	40	56	26	41	29	57	38	94	69	41	58	46	**45.5**
NSA	**2.05**	27	9	9	17	14	16	12	12	12	17	14	26	20	12	24	16	**16.1**
WSA	**0.23**	21	10	17	27	8	17	20	9	17	3	21	13	19	9	20	16	**15.6**
HKA	**0.14**	21	6	18	21	8	16	19	13	21	7	22	10	20	9	15	13	**14.9**
KIX	**1.54**	93	37	59	46	57	87	54	51	36	79	46	143	96	80	73	62	**68.6**
CHA	**5.60**	17	9	10	16	7	17	12	10	17	-2	14	17	15	10	6	12	**11.7**
QNA	**1.43**	16	7	12	25	9	17	25	4	17	1	22	10	7	5	11	14	**12.8**
DNA	**1.70**	112	49	63	62	66	113	71	66	62	74	54	148	106	86	62	52	**77.9**
NVA	**0.58**	36	15	25	61	21	44	37	25	44	10	32	38	35	19	16	28	**30.4**
Avg.	**1.63**	**34.0**	**15.0**	**20.2**	**27.2**	**19.8**	**31.3**	**24.3**	**19.6**	**23.7**	**18.3**	**26.0**	**42.6**	**35.2**	**20.9**	**28.5**	**22.8**	**25.6**
Rank*	-	*3*	*16*	*12*	*6*	*13*	*4*	*8*	*14*	*9*	*15*	*7*	*1*	*2*	*11*	*5*	*10*	-

* where rank 1 = highest % change, 16 = lowest % change.

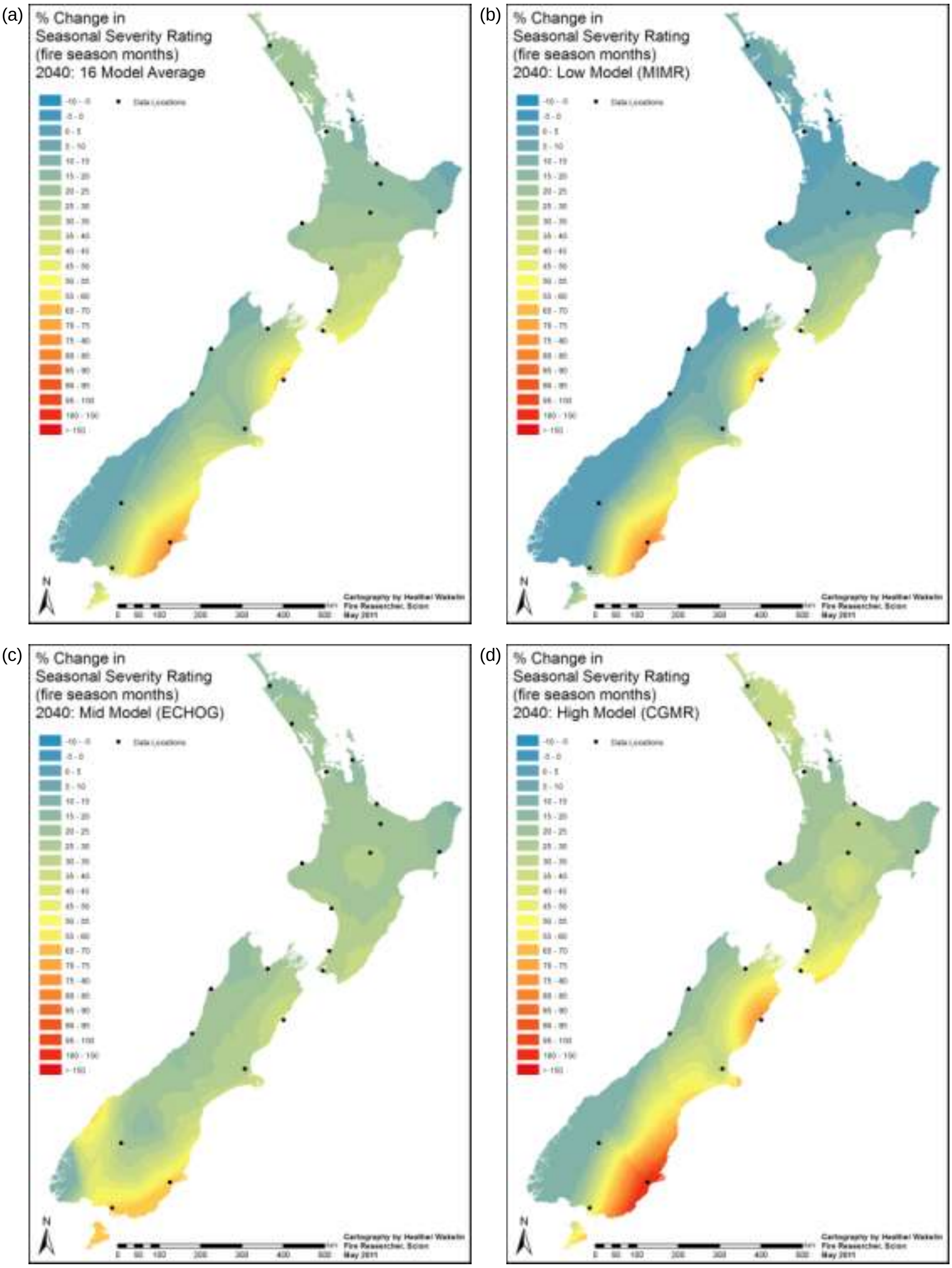


Figure 3. Changes (%) in the average Seasonal Severity Rating (SSR) over fire season months (Oct-Apr) from current climate to the 2040s (2030-2049) for: (a) the average of all 16 models investigated; (b) an example low-range model (MIMR); (c) an example mid-range model (ECHOG); and (d) an example high-range model (CGMR).

For this high-range model (Figure 3d), increases in SSR of 50-70% were indicated over the lower North Island based on the response of Wellington (WNA) (Table 3). Most of the remainder of the North Island showed potential for increases of 20-50%, with values near the higher end of this range in Northland and the central North Island. In the South Island, the West Coast (Hokitika, HKA, and Westport, WSA) region is again expected to show little or no change from current SSR values under this CGMR model (see Table 3).

Changes projected for the average number of days of Very High and Extreme (VH+E) forest fire danger, when expressed on a percentage basis, were generally higher than (about 2.5 times) those estimated for the SSR. However, although the values of these projected changes were higher, the spatial patterns of changes (Figure 4) were similar to those found for the SSR for the same (2040s) projection period (see Figure 3). Again, care should be taken when interpreting percentage changes, as small percentage increases at stations with high existing fire climate severity can result in significantly more days of VH+E fire danger compared with much larger percentage increases at stations with lower fire climate severities.

Changes in the number of days of VH+E fire danger each fire season (Table 4) ranged from -19% to 421%, with an average increase of 64% across all stations and models. These values correspond with decreases of 1.4 days of VH+E per fire season, up to increases of 34.7 days/season, and an average of 3.6 extra days per season of VH+E (see Appendix 1). Changes were again greatest under the IPCM4 model (average 107%, or an extra 6.5 days/season), and lowest under the CNCM3 model (average 32%, or 1.9 days/season). Decreases from current values for 2040 were again observed under the HADCM3 model (of -3% or -1.4 days/season at Christchurch Aero, CHA, and -9% or -0.5 days/season at Queenstown Aero, QNA), and also under GIAOM (-5% or -0.1 day/season at New Plymouth Aero, NPA) and GFCM21 (-10% or -0.2 days/season also at NPA). The greatest increases in the number of days of VH+E fire danger over the fire season were observed at Dunedin Aero (DNA) (average 220%, or 12.6 more days/season), followed by Kaikoura (KIX) (134% or 8.4 more days/season) and Invercargill Aero (NVA) (129% or an extra 0.5 days/season). The lowest increases were observed at Christchurch Aero (13% or 5.4 more days/season) and Gisborne Aero (GSA) (19% or 6.6 more days/season).

In the case of the 16 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 2040s (see Figure 3d), with the areas of greatest increases (100-200%) 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 (50-70%) 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 possible decreases (up to -20%) were projected. In the South Island, the Christchurch and West Coast regions showed little or no change, and the potential for some decreases (of up to -10%) based on the lack of changes in VH+E fire danger observed at Hokitika (HKA) and Westport (WSA) (Table 4).

Table 4. Projected changes (%) in the average number of days/season of Very High and Extreme (VH+E) Forest fire danger for fire season months (Oct-Apr) estimated for the 2040s (2030-2049) from 16 Global Climate Models, and comparison with the current number of days/season of VH+E for the 1990s (1980-1999).

Station Code	Current VH+E (days)	Models for 2040s – % change in number of days/fire season of VH+E fire danger																Avg. change (%)
		CGMR	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**5.9**	50	12	41	48	12	44	43	16	31	56	48	74	68	30	77	24	**42.1**
DAR	**2.7**	77	9	60	47	40	42	68	43	49	68	38	85	64	30	64	34	**51.2**
COR	**1.5**	57	23	40	73	13	73	70	23	37	47	60	47	7	20	30	47	**41.7**
AKL	**8.3**	64	16	24	56	36	67	25	40	49	59	49	80	64	17	65	48	**47.4**
TGA	**7.7**	56	14	29	41	14	23	32	12	22	16	21	38	36	27	32	25	**27.4**
ROA	**1.5**	133	37	87	93	43	80	40	17	113	103	77	100	103	43	100	47	**76.0**
GSA	**34.1**	27	20	12	27	15	20	21	15	22	5	22	29	25	14	21	17	**19.4**
APA	**2.2**	91	32	50	91	36	45	52	32	86	43	48	93	75	48	70	66	**59.9**
NPA	**1.1**	5	14	48	0	29	105	-19	-5	38	38	29	67	86	19	67	43	**35.1**
WUA	**2.6**	120	65	88	120	90	96	61	80	88	124	127	214	182	100	196	124	**117.2**
PPA	**2.0**	77	77	97	136	59	118	31	41	97	113	90	141	231	67	79	92	**96.6**
WNA	**16.8**	128	42	69	54	85	114	58	94	54	116	82	207	144	87	118	95	**96.6**
NSA	**8.9**	67	24	27	45	38	45	26	25	28	51	32	57	42	39	53	41	**40.1**
WSA	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0.0**
HKA	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0.0**
KIX	**6.3**	173	44	111	81	114	176	98	98	71	195	105	271	173	148	152	130	**133.8**
CHA	**39.7**	22	8	15	20	6	19	17	10	20	-3	16	18	18	11	6	13	**13.5**
QNA	**5.7**	35	6	32	53	15	33	46	0	32	-9	41	28	12	7	23	20	**23.4**
DNA	**5.7**	324	139	189	161	193	325	204	187	173	232	145	421	261	242	196	133	**220.3**
NVA	**0.4**	138	50	175	325	125	275	88	88	125	63	150	175	150	25	38	75	**128.9**
Avg.	**7.6**	**82.1**	**31.6**	**59.7**	**73.6**	**48.2**	**85.0**	**47.9**	**40.8**	**56.8**	**65.8**	**58.9**	**107.3**	**87.1**	**48.7**	**69.4**	**53.6**	**63.5**
Rank*	-	*4*	*16*	*8*	*5*	*13*	*3*	*14*	*15*	*10*	*7*	*9*	*1*	*2*	*12*	*6*	*11*	-

* where rank 1 = highest % change, 16 = lowest % change.

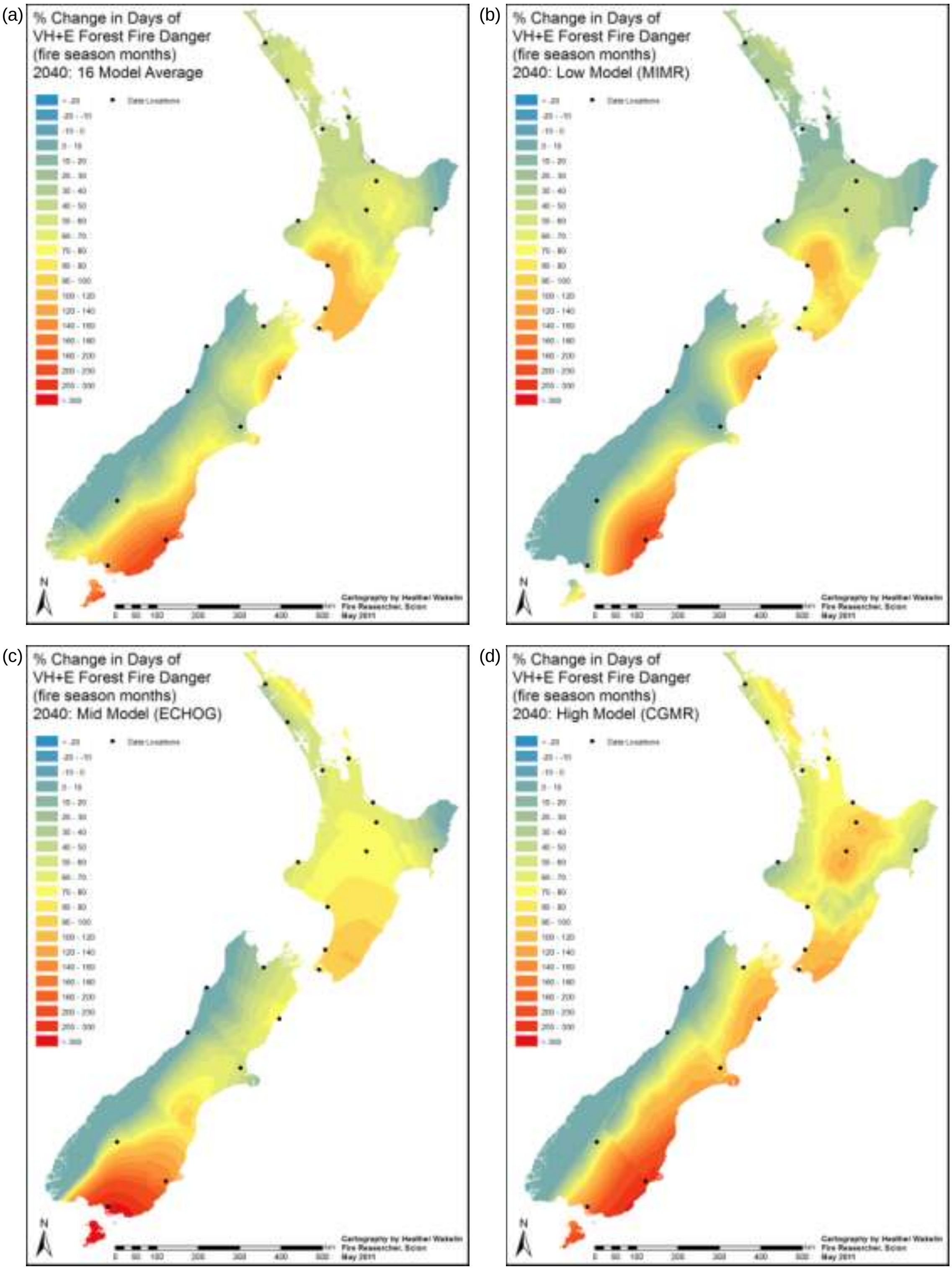


Figure 4. Changes (%) in the average number of days/year of Very High and Extreme (VH+E) Forest Fire Danger over fire season months (Oct-Apr) from current climate to the 2040s (2030-2049) for: (a) the average of all 16 models investigated; (b) an example low-range model (MIMR); (c) an example mid-range model (ECHOG); and (d) an example high-range model (CGMR).

The mid-range model example (again, based on ECHOG) for VH+E fire danger for the 2040s (Figure 4c) showed a somewhat different pattern to any of the previous models, due to a much greater range in projected changes. These were greatest (up to 350%) along the south coast of the South Island due to the response of Invercargill Aero (NVA) under this model (see Table 4). Increases around Kaikoura (KIX) were also less marked, as was the effect of lower changes around Christchurch Aero (CHA) typically seen for other models, although the general pattern across the South Island was still east-west. In the North Island, the pattern was generally south-north, with increases of 120% in the greater Wellington region decreasing to 60% in the Auckland region. However, the pattern was more east-west north of Auckland, with increases of up to 100% in the east decreasing to <40% for western Northland due to the responses of Dargaville (DAR) and Kaitaia (KX) under this ECHOG model. Similarly, for the East Coast region, changes trend down to little or no change (<20%) due to the response of Gisborne Aero (GSA), with the possibility of decreases (of -10% to -20%) in the number of days of VH+E for East Cape.

The high-range model example (illustrated using the CGMR model that projected the highest overall increases), indicated the potential for significantly increased numbers of days of VH+E fire danger right across the country for the 2040s (Figure 4d). In the South Island, only the West Coast and Fiordland were projected to show little or no increase (0-10%) in the potential frequency of VH+E fire weather days. The greatest increases were again predicted around coastal Otago (>250%) and Marlborough/North Canterbury (100-150%). For the North Island, the greatest increases are predicted for the greater Wellington/Wairarapa region (100-140%), central North Island/Bay of Plenty (80-140%) and eastern Northland (80-120%). Only western Taranaki (based on New Plymouth Aero, NPA) showed little or no change (10-20%) in the number of days of VH+E fire danger for this model scenario.

Projected changes for the 2090s

Fire season SSR values for the 2090s (Table 5) ranged from -6% to 247%, with an average increase of 32% across all models and stations, and as such were generally higher than comparable values for the 2040s (see Table 3). These projected changes correspond to changes in SSR of -0.2 to 4.4 points, and an average increase of 0.52 points (see Appendix 1). Predicted increases were greatest under the IPCM4 model (average 79%, or 1.30 points), but lowest under the GIEH model (average 11% or 0.18 points). Decreases in SSR to 2090 were observed under the GIEH, MIMR, GFCM21 and ECHOG models, although these were small (at -1% to -6%) and seen for just a few stations (most frequently, Kaitaia, KX), with the largest decrease (-6% or -0.19 points) at Wellington Aero (WNA) under the ECHOG model. Projected increases in SSR were greatest at the same stations as for the 2040s: Dunedin Aero (DNA), averaging 102% or 1.73 points, followed by Kaikoura (KIX) (76% or 1.16 points) and Wellington Aero (WNA) (50% or 1.61 points); and lowest at COR (11% or 0.11 points), CHA (18% or 1.02 points) and Nelson Aero (NSA) (18% or 0.38 points).

Spatial changes in fire climate severity projected for the 2090s were somewhat similar to those found for the 2040s (see Figures 5 & 6, cf. Figures 3 & 4).

However, they also demonstrated somewhat different spatial patterns due to the greater variability between individual model projections for this longer range time period. Changes under several of the models were less clearly east-west across the South Island, whereas in the North Island they were more generally south-north. These differences are likely due to the greater variability in rainfall projections, and increased latitudinal influence on temperature increases within the downscaled GCMs by the 2090s.

The 16 model average for fire season SSR values in the 2090s (Figure 5a) showed a very similar spatial pattern to the 2040s (see Figure 3a), although values for the 2090s were higher. Projected increases were greatest for the coastal areas of Otago (>100%) and Marlborough (up to 80%), again based on the responses of Dunedin Aero (DNA) and Kaikoura (KIX) to the various GCMs (see Table 5). Increases were lowest for Christchurch Aero (CHA) (<20%), with areas of little or no change also indicated for southern Westland/Fiordland and northwest Nelson in the South Island, and East Cape and the Coromandel Peninsula in the North Island. With the exception of Wellington/Wairarapa where increases of up to 60% were predicted, increases across the rest of the North Island were generally around 20-50% for the 16-model average.

The low-range model example for 2090s SSR (illustrated using MIMR) (Figure 5b), was also similar to the low-range model of SSR for the 2040s (see Figure 3b), although values were generally slightly lower for the 2090s, likely due to the higher rainfall predicted for this projection period under this model. The coastal areas around Dunedin Aero (DNA) and Kaikoura (KIX) were the only areas to show the potential for significant increases in SSR (40-70%) for this period, with changes over the lower North Island projected to increase only slightly (<40%). Remaining areas, including the upper North Island, Nelson and inland mid-Canterbury areas, and West Coast (especially Fiordland) were projected to remain the same or possibly decrease (by up to -10%) based on modelled changes for stations in or close to these regions (see Table 5). [The area of more significant increases indicated for southern Fiordland is likely an anomaly resulting from the interpolation methodology, and SSR values in this region are also more likely to remain the same or possibly also decrease slightly].

Projected changes in SSR for the 2090s mid-range model example (illustrated by the ECHOG model) (Figure 5c) show a somewhat different pattern to SSR changes under the same model for the 2040s (see Figure 3c). Across the South Island, values follow a more south-north trend, with the greatest increases (up to 70%) predicted in the south around Invercargill Aero (NVA), and extending up into central and coastal Otago due to the influence of changes for Queenstown Aero (QNA) and Dunedin Aero (DNA) (see Table 5). In the northern South Island, and across most of the North Island, SSR values for the 2090s are predicted to remain the same or increase only slightly (up to 30%). However, there is potential for slightly greater increases (up to 50%) for the East Cape region, and for decreases (of up to -10%) at each end of the North Island (Wellington/southern Wairarapa, and the Far North) in SSR for the 2090s under this mid-range model.

Table 5. Projected changes (%) in average Seasonal Severity Rating (SSR) over fire season months (Oct-Apr) estimated for the 2090s (2080-2099) from 16 Global Climate Models, and comparison with current SSR for the 1990s (1980-1999).

Station Code	**Current SSR**	**Models for 2090s – % change in Seasonal Severity Rating (SSR)**																**Model avg. (%)**
		CGMR	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**1.51**	46	11	27	0	21	35	-1	11	-2	30	20	64	23	-3	30	14	**20.3**
DAR	**0.95**	58	16	35	17	31	45	13	16	5	26	28	72	28	1	38	23	**28.4**
COR	**0.94**	31	8	13	21	12	17	9	5	-1	3	8	21	8	0	9	15	**11.2**
AKL	**1.86**	45	14	25	5	25	33	3	13	-2	24	21	66	27	0	31	19	**21.8**
TGA	**1.73**	40	10	26	25	13	34	8	12	3	0	30	51	17	2	26	18	**19.7**
ROA	**0.90**	50	11	27	21	16	30	10	11	1	8	33	54	21	2	27	18	**21.2**
GSA	**4.41**	37	17	18	24	19	30	12	12	9	0	29	45	28	14	29	20	**21.5**
APA	**0.92**	54	13	33	29	16	39	11	12	1	3	38	69	21	3	34	22	**24.8**
NPA	**0.62**	55	12	31	6	23	33	3	8	6	30	22	63	30	-2	26	17	**22.7**
WUA	**1.22**	63	23	37	9	34	55	7	20	9	39	43	94	51	10	52	23	**35.5**
PPA	**1.15**	60	28	33	14	31	50	13	21	19	37	33	107	62	21	45	28	**37.6**
WNA	**3.21**	60	35	50	-6	56	77	14	41	14	74	42	138	74	24	67	41	**50.1**
NSA	**2.05**	41	13	19	3	21	31	6	9	0	25	19	51	24	-1	23	13	**18.5**
WSA	**0.23**	45	16	26	39	20	30	10	7	7	18	23	43	26	13	23	30	**23.6**
HKA	**0.14**	47	13	25	27	23	23	10	5	6	22	23	42	28	6	16	27	**21.6**
KIX	**1.54**	81	71	78	3	89	119	31	61	27	89	44	202	111	44	97	63	**75.6**
CHA	**5.60**	44	15	18	27	18	21	10	10	10	5	10	41	21	8	15	20	**18.2**
QNA	**1.43**	40	16	21	42	16	29	22	4	13	12	19	26	17	13	16	29	**21.0**
DNA	**1.70**	172	81	94	49	120	152	89	70	61	85	62	247	126	61	98	62	**101.8**
NVA	**0.58**	104	27	42	74	41	64	31	21	30	25	36	95	48	17	37	47	**46.1**
Avg.	**1.63**	**58.6**	**22.5**	**33.9**	**21.4**	**32.3**	**47.3**	**15.6**	**18.5**	**10.7**	**27.9**	**29.2**	**79.5**	**39.6**	**11.7**	**37.0**	**27.5**	**32.1**
Rank*	-	*2*	*11*	*6*	*12*	*7*	*3*	*14*	*13*	*16*	*9*	*8*	*1*	*4*	*15*	*5*	*10*	-

* where rank 1 = highest % change, 16 = lowest % change.

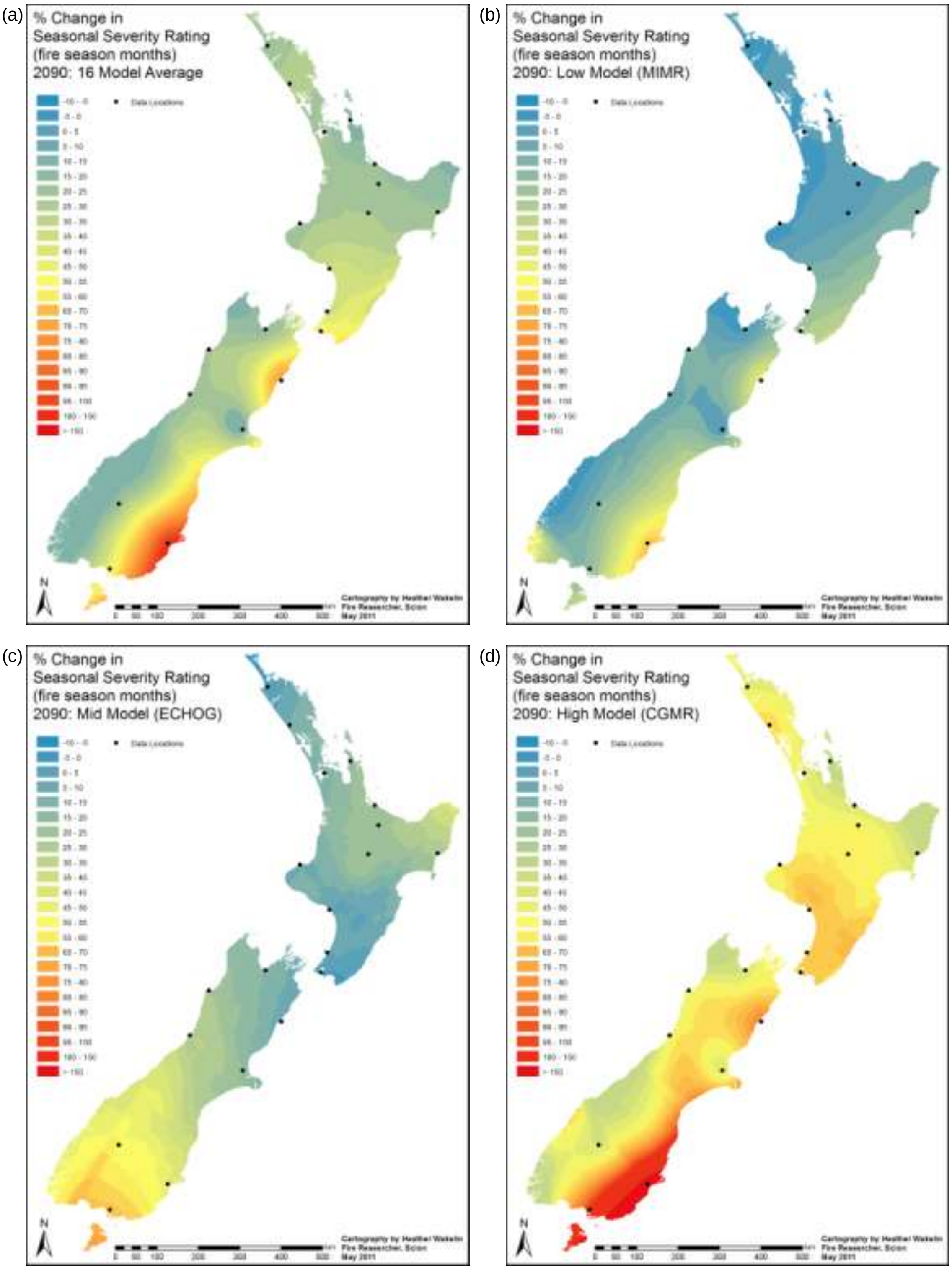


Figure 5. Changes (%) in the average Seasonal Severity Rating (SSR) over fire season months (Oct-Apr) from current climate to the 2090s (2080-2099) for: (a) the average of all 16 models investigated; (b) an example low-range model (MIMR); (c) an example mid-range model (ECHOG); and (d) an example high-range model (CGMR).

The high-range model example for SSR for the 2090s (based on CGMR) (Figure 5d) shows a more similar pattern to its 2040s counterpart (see Figure 3d), but with significantly higher increases projected across the entire country. Peak increases of greater than 150% were still centred on coastal Otago, but extended inland and across eastern Southland due to the changes estimated for Dunedin (DNA) and Invercargill Aero (NVA) (Table 5). Lower but still significant increases (of 60-80%) were again also indicated for coastal Marlborough (Kaikoura, KIX) plus inland Canterbury, and the lower North Island extending to Wanganui and into Taranaki based on projected changes for Wanganui Aero (WUA) and New Plymouth Aero (NPA) (see Table 5). Increases of 50-70% also extended across the central North Island and through western parts of Auckland and Northland. Remaining areas (on the South Island's West Coast, in northwest Nelson, East Cape and Coromandel), which typically showed little or no change or even possible decreases under other models, all showed potential increases of 30-40% in SSR for the 2090s under this most extreme model.

Projected changes in the average number of days of VH+E fire danger during the 2090s, expressed on a percentage basis, were generally greater than (about 1.3 times) those for VH+E fire danger class frequency for the 2040s, and were also higher than (typically about twice) those for the SSR for the same (2090s) projection period. However, although the values of these projected changes were higher, the spatial patterns of changes (Figure 6) were for the most part similar to those for VH+E fire danger class frequency for the 2040s (see Figure 4), and to those for SSR for the 2090s projection period (see Figure 5). Again, care should be taken when interpreting percentage changes, due to the influence in real terms (i.e. on the increased number of days of VH+E fire danger) of small percentage increases at stations with high existing fire climate severity compared with much larger percentage increases at stations with lower fire climate severities.

Changes in the number of days of VH+E fire danger each fire season for the 2090s (Table 6) varied the widest of any of the climate severity measures and projection periods investigation, ranging from -24% to 676%, with an average increase of 79% across all stations and models. These values correspond with decreases of 0.6 days of VH+E per fire season, up to increases of 47.8 days/ season, and an average of 4.4 extra days per season of VH+E (see Appendix 1). Changes were again greatest under the IPCM4 model (average 209%, or an extra 11.2 days/season), and lowest under the GIEH model (average 27%, or 1.6 days/ season). Decreases in the number of days of VH+E from current values were observed under the GIEH model (up to -18% or -0.4 days/season at Taupo Aero, APA), ECHOG (-24% or -0.3 days/season at New Plymouth Aero, NPA), GFCM21 (-11% or -0.6 days/season at Kaitaia, KX), as well as GIAOM (-10% or -0.1 days/ season also at NPA) and MIMR (-6% or -0.2 days/season at Dargaville, DAR). Auckland Aero (AKL) was the station to show decreases most often, along with NPA, KX and APA. The greatest increases in the number of days of VH+E fire danger over the fire season were observed at Dunedin Aero (DNA) (average 290%, or 16.5 more days/ season), followed by Invercargill Aero (NVA) (222% or an extra 0.9 days/season), Paraparaumu (PPA) (142% or 2.8 more days/season) and Kaikoura (KIX) (142% or 8.9 more days/season). Stations on the West Coast (Westport Aero, WSA, and Hokitika Aero, HKA) exhibited no change (from the current 0 days/season of VH+E), while the lowest increases were observed at

Christchurch Aero (CHA) (22% or 8.6 more days/season), Gisborne Aero (GSA) (29% or 9.8 more days/season) and Tauranga (TGA) (32% or 2.4 extra days/season).

The pattern of spatial changes for the 16 model average of days of VH+E fire danger for the 2090s (Figure 6a) showed a very similar pattern to that for the 2040s (see Figure 4a), particularly over the South Island. The greatest increases were again focussed around coastal Otago/Southland (>250%) and Kaikoura (up to 120%), decreasing east to west down to no change along the West Coast. In the North Island, the area of highest increases in the south had higher values (up to 160% in Wairarapa) for the 2090s and extended further to the north (>70% at Taupo Aero, APA). Otherwise, values north of Auckland (40-60%) and for East Cape (up to -10%) were the same as for the 2040s.

The spatial pattern of changes for the 2090s low-range model (based on MIMR) for VH+E fire danger (Figure 6b) was somewhat similar to that for its 2040s counterpart (Figure 4b) over the South Island, but more variable in the north. However, the areas of greatest increases in the south around Dunedin Aero (DNA) (up to 200%) and Kaikoura (KIX) (up to 90%) were more localised with lower values than for the 2040s. The area of little or no change (0-10%) in the southwest was also reduced to immediately around Queenstown Aero (QNA), with areas of increases (of 20-50%) extending further to the west. [Again, the area of greater indicated increases in the far southwest is likely an anomaly of the interpolation method]. In the North Island, the area of highest increases (up to 100%) is restricted to immediately around Paraparaumu (PPA), with scattered areas of slightly lower increases (of 70-90%) across the lower part of the North Island (due to lower projected increases for Wanganui Aero (WUA) and Wellington Aero (WNA) (see Table 6 cf. Table 4). Projected increases across the remainder of the North Island were also generally lower for the 2090s compared with the 2040s low-range model.

The 2090s 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 120% over the entire lower South Island, based on large projected increases at Invercargill (NVA) (>300%), Dunedin Aero (DNA) (>140%) and Queenstown (QNA) (100%) (see Table 6). Increases of greater than 80% are also predicted for the central and eastern North Island based on modelled changes for Rotorua Aero (ROA) and Taupo Aero (APA). Interestingly, there are also significant areas of little or no change indicated under this mid-range model, presumably as a result of increased rainfalls for the 2090s, in Northland, Auckland, Taranaki, Manawatu, Wellington/Wairarapa, Marlborough, South Canterbury and Westland based on the lack of projected changes in the number of days of VH+E at stations in these areas (see Table 6).

The VH+E high-range model example for the 2090s (based on the CGMR model) (Figure 6d) potentially depicts close to the worst-case scenario for changes in fire danger across New Zealand from the present analysis. It portrays significant increases (>100%) in the frequency of severe fire danger days across much of the country, including increases of >250% in Otago/Southland (based on changes for

Table 6. Projected changes (%) in the average number of days/season of Very High and Extreme (VH+E) Forest fire danger for fire season months (Oct-Apr) estimated for the 2090s (2080-2099) from 16 Global Climate Models, and comparison with the current number of days/season of VH+E for the 1990s (1980-1999).

Station Code	**Current VH+E (days)**	**Models for 2090s – % change in number of days/fire season of VH+E fire danger**																**Avg. change (%)**
		CGMR	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**5.9**	108	6	49	-3	32	68	-11	24	9	89	38	137	56	2	56	24	42.6
DAR	**2.7**	140	23	70	19	57	92	34	40	6	98	30	149	53	-6	100	43	59.2
COR	**1.5**	120	13	53	73	30	77	73	40	-3	17	23	80	13	7	27	67	44.4
AKL	**8.3**	118	24	59	-1	60	60	10	18	-7	85	32	166	53	-3	68	53	49.7
TGA	**7.7**	77	14	34	51	14	52	11	22	3	7	38	83	24	5	45	24	31.6
ROA	**1.5**	223	47	77	110	50	100	20	40	10	67	77	137	87	27	100	50	76.3
GSA	**34.1**	49	23	24	31	23	43	18	14	13	0	40	60	38	17	38	26	28.6
APA	**2.2**	168	2	73	82	18	95	20	52	-18	36	82	175	50	-2	75	30	58.7
NPA	**1.1**	129	0	67	-24	19	62	5	-10	19	100	52	162	95	5	67	10	47.3
WUA	**2.6**	273	51	143	22	80	200	25	76	16	204	145	376	153	45	184	67	128.8
PPA	**2.0**	287	69	126	21	82	164	23	67	59	226	95	531	228	95	141	67	142.5
WNA	**16.8**	117	73	106	-4	113	167	33	86	27	142	90	285	136	53	141	89	103.4
NSA	**8.9**	89	29	45	15	38	82	21	24	11	61	44	108	56	1	49	35	44.2
WSA	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
HKA	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
KIX	**6.3**	141	125	156	7	162	227	61	106	48	200	82	387	196	75	182	113	141.6
CHA	**39.7**	52	14	21	37	21	29	13	8	12	5	17	44	22	11	14	24	21.6
QNA	**5.7**	81	22	35	97	28	72	38	3	30	18	35	54	30	18	37	64	41.4
DNA	**5.7**	498	230	262	142	356	429	274	204	164	239	165	676	343	191	288	175	**289.7**
NVA	**0.4**	663	38	188	475	63	300	150	100	150	150	163	563	88	38	175	250	221.9
Avg.	**7.6**	**166.6**	**40.1**	**79.3**	**57.4**	**62.3**	**116.0**	**41.0**	**45.7**	**27.4**	**87.2**	**62.4**	**208.6**	**86.1**	**28.8**	**89.3**	**60.5**	**78.7**
Rank*	**-**	*2*	*14*	*7*	*11*	*9*	*3*	*13*	*12*	*16*	*5*	*8*	*1*	*6*	*15*	*4*	*10*	-

* where rank 1 = highest % change, 16 = lowest % change.

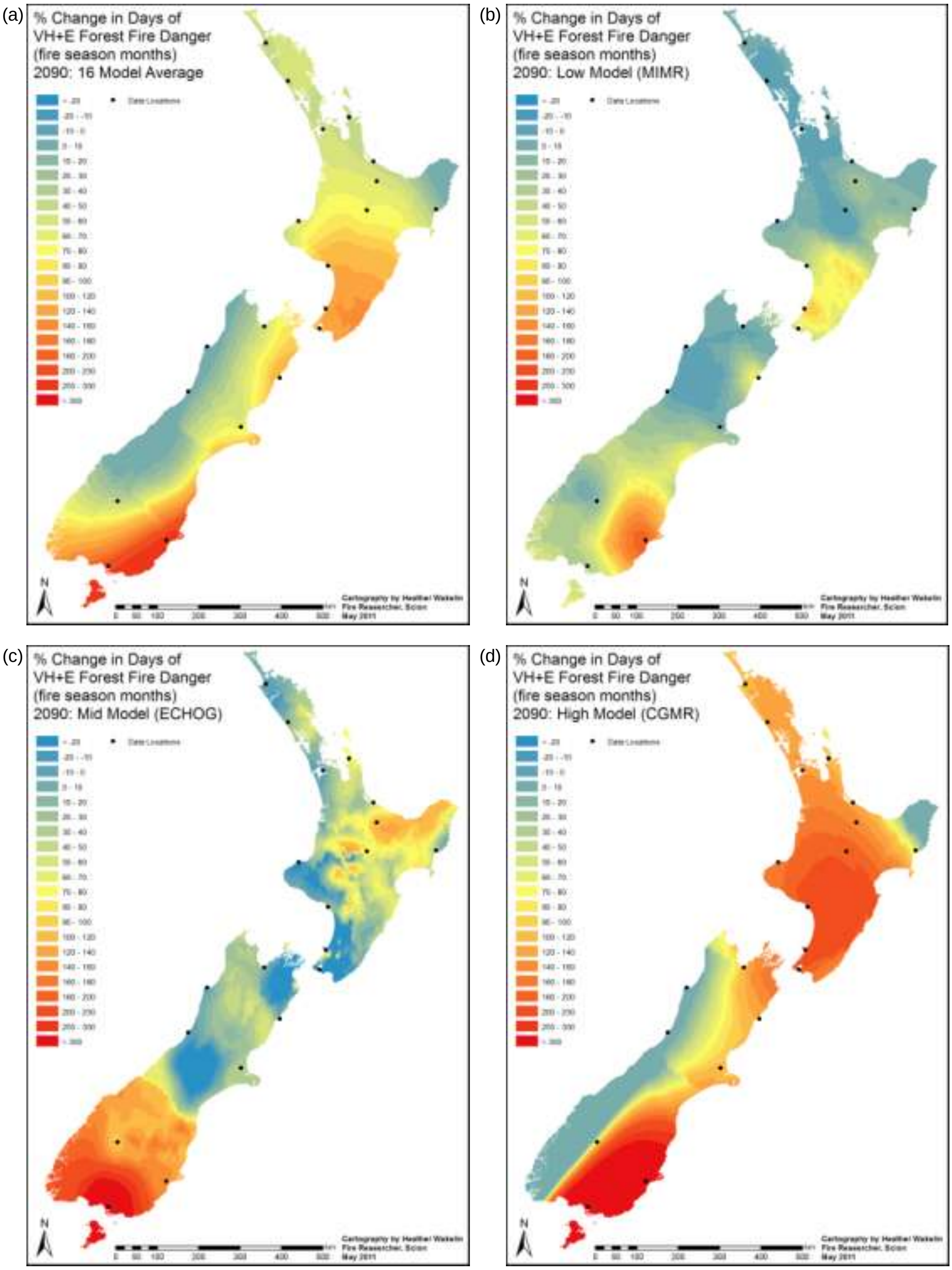


Figure 6. Changes (%) in the average number of days/year of Very High and Extreme (VH+E) Forest Fire Danger over fire season months (Oct-Apr) from current climate to the 2090s (2080-2099) for: (a) the average of all 16 models investigated; (b) an example low-range model (MIMR); (c) an example mid-range model (ECHOG); and (d) an example high-range model (CGMR).

Dunedin Aero, DNA, and Invercargill Aero, NVA) and the lower North Island (Wanganui Aero, WUA, Paraparaumu, PPA, and Wellington Aero, WNA) (see Table 6). Only the South Island's West Coast (based on Hokitika, HKA and Westport, WSA) and East Cape of the North Island (based on Gisborne Aero, GSA) show little or no change in potential number of days of VH+E under this extreme model. Changes of greater than 100% (indicated in Figure 6 by the areas of dark orange and red) represent a potential doubling, and greater than 200% a trebling (indicated by the areas of darkest red), of the number of days of VH+E forest fire danger thereby indicating very significant increases in fire climate severity by the 2090s under this model scenario.

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 and North Islands currently with moderately elevated fire danger (see Figures 7-10), such as Dunedin Aero (DNA), Kaikoura (KIX) and Wellington Aero (WNA), but interestingly not Christchurch Aero (CHA) or Gisborne (GSA). 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), as well as in eastern Northland. Other possible areas are those where fire dangers are currently low, but changes in future climate would result in significant increases in relative fire danger (i.e. as a % of current fire danger) at those locations. The latter would therefore include western areas of the North Island (e.g. Wanganui, WUA), and the south of the South Island (e.g. Invercargill, NVA).

Increases in these locations would see the current areas of elevated fire danger (Figures 11a & 12a) in Canterbury, Gisborne, Marlborough and Central Otago/ South Canterbury extend along the east coast of both islands to include coastal Otago, Wellington and Hawkes Bay by the 2040s (Figures 11b & 12b), and to develop further in Marlborough, Hawkes Bay and Wairarapa by the 2090s (Figures 11c & 12c). Fire dangers in Wanganui, the Bay of Plenty and Northland would also increase. However, despite significant percentage increases in Southland, south Taranaki and the Coromandel, fire climate severity in these areas would increase but still remain comparatively low relative to other parts of the country.

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, plus Figures 11 & 12) 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, but only under some model scenarios.

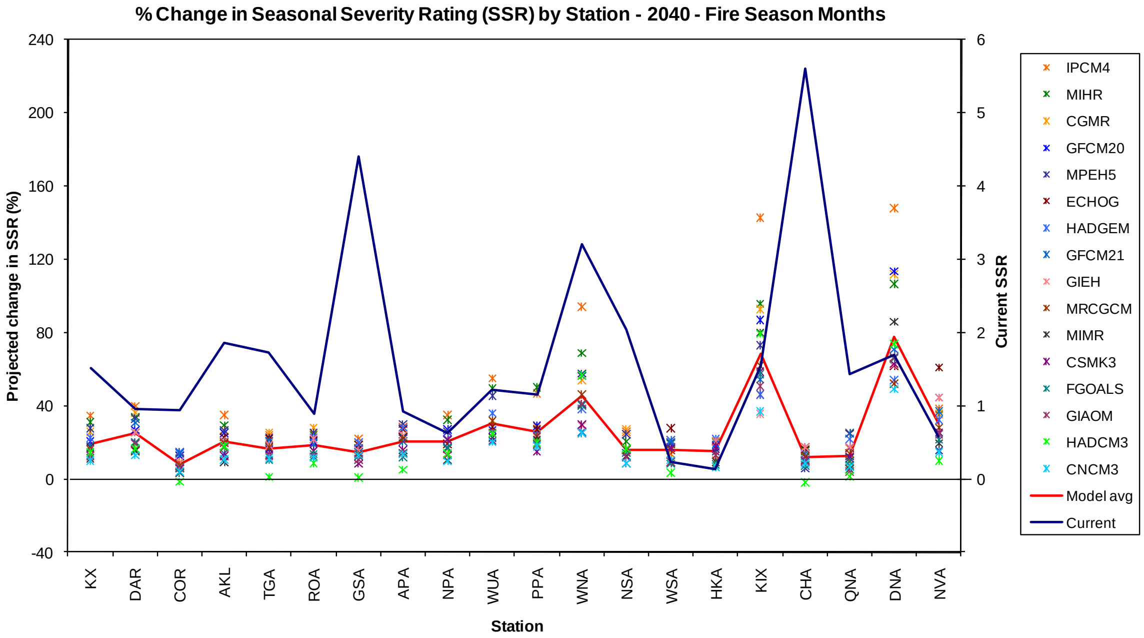


Figure 7. Range of projected changes (%) in Seasonal Severity Rating (SSR) for fire season months (Oct-Apr) for the 2040s (2030-2049) from 16 Global Climate Models for locations across New Zealand. The 16 model average and current SSR values are also shown for comparison.

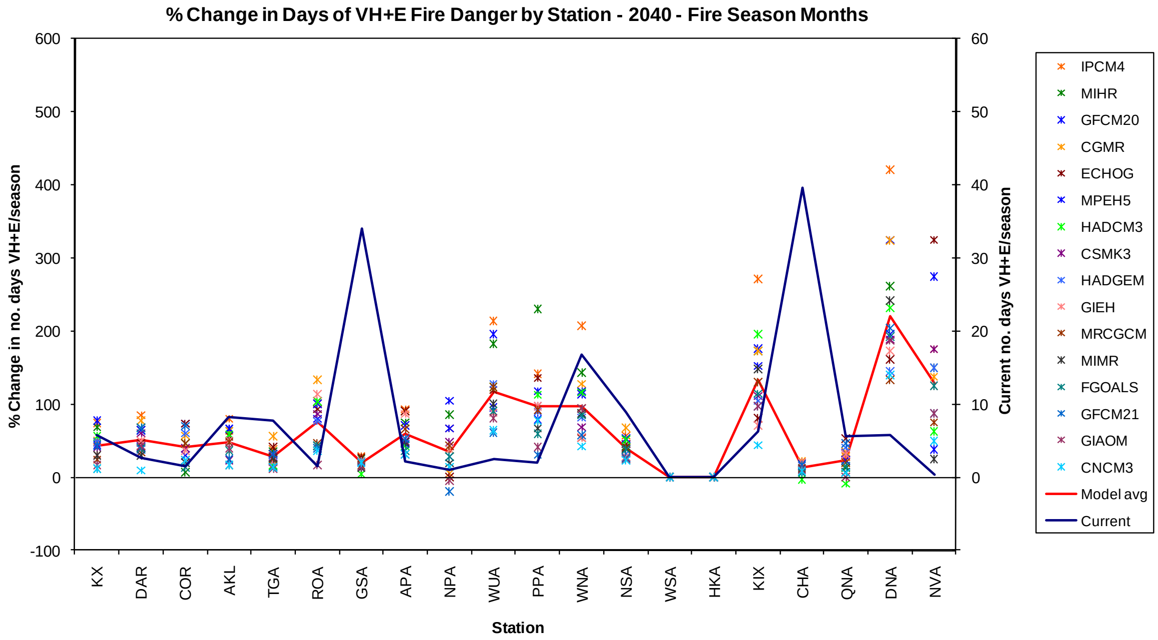


Figure 8. Range of projected changes (%) in the number of days/year of Very High and Extreme (VH+E) Forest fire danger during fire season months (Oct-Apr) for the 2040s (2030-2049) from 16 Global Climate Models for locations across New Zealand. The 16 model average and current number of days of VH+E fire danger are also shown for comparison.

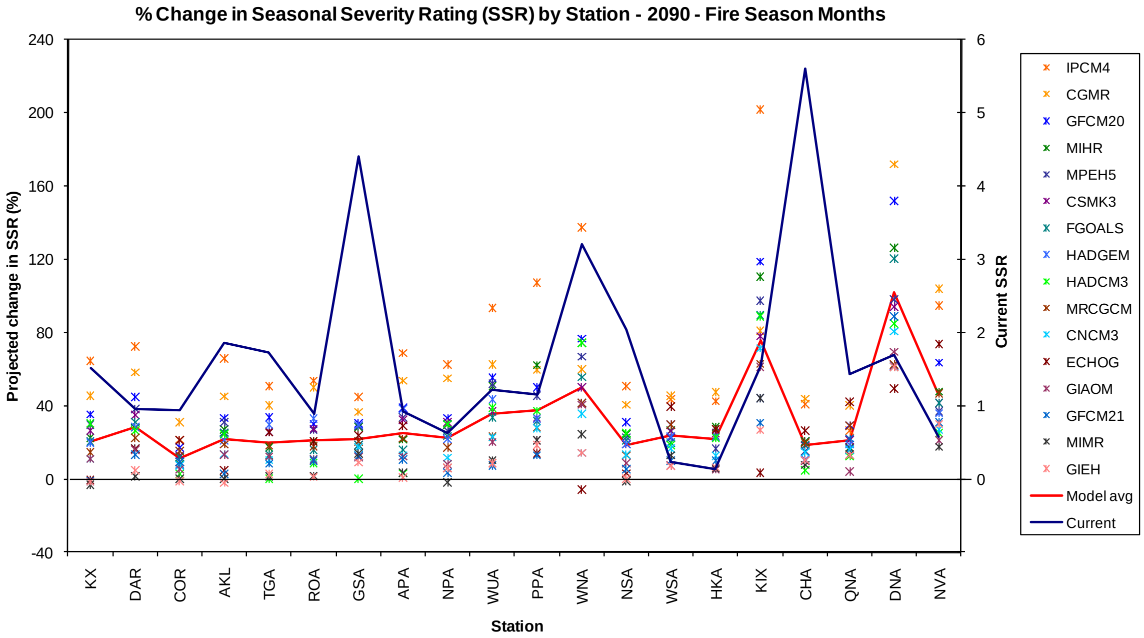


Figure 9. Range of projected change (%) in Seasonal Severity Rating (SSR) for fire season months (Oct-Apr) for the 2090s (2080-2099) from 16 Global Climate Models for locations across New Zealand. The 16 model average and current values of SSR are also shown for comparison.

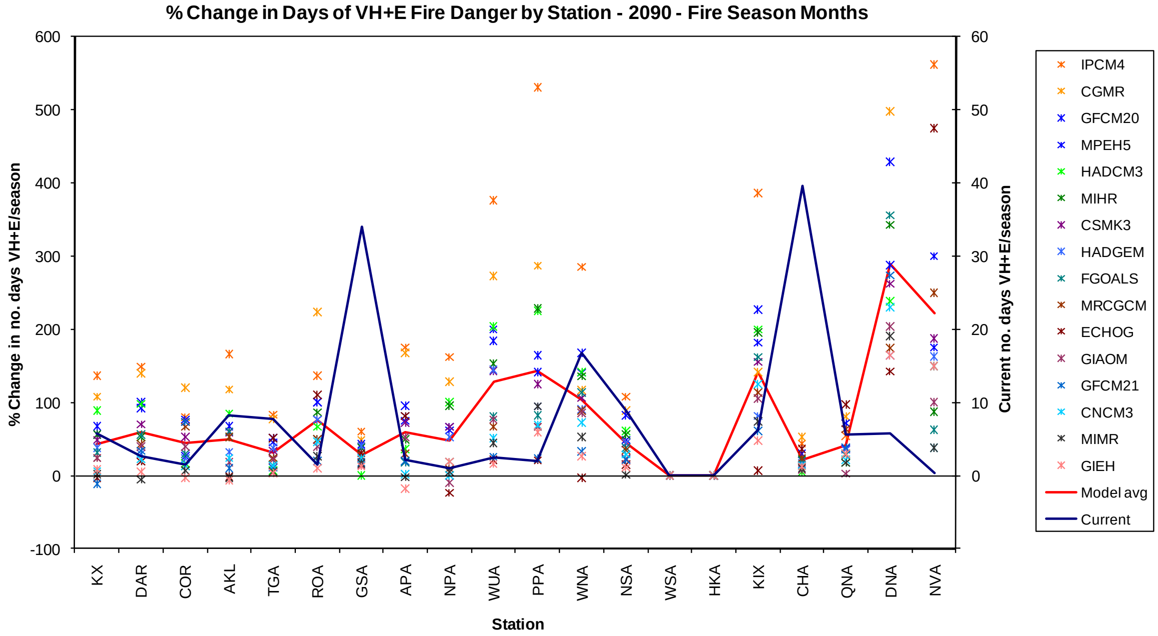
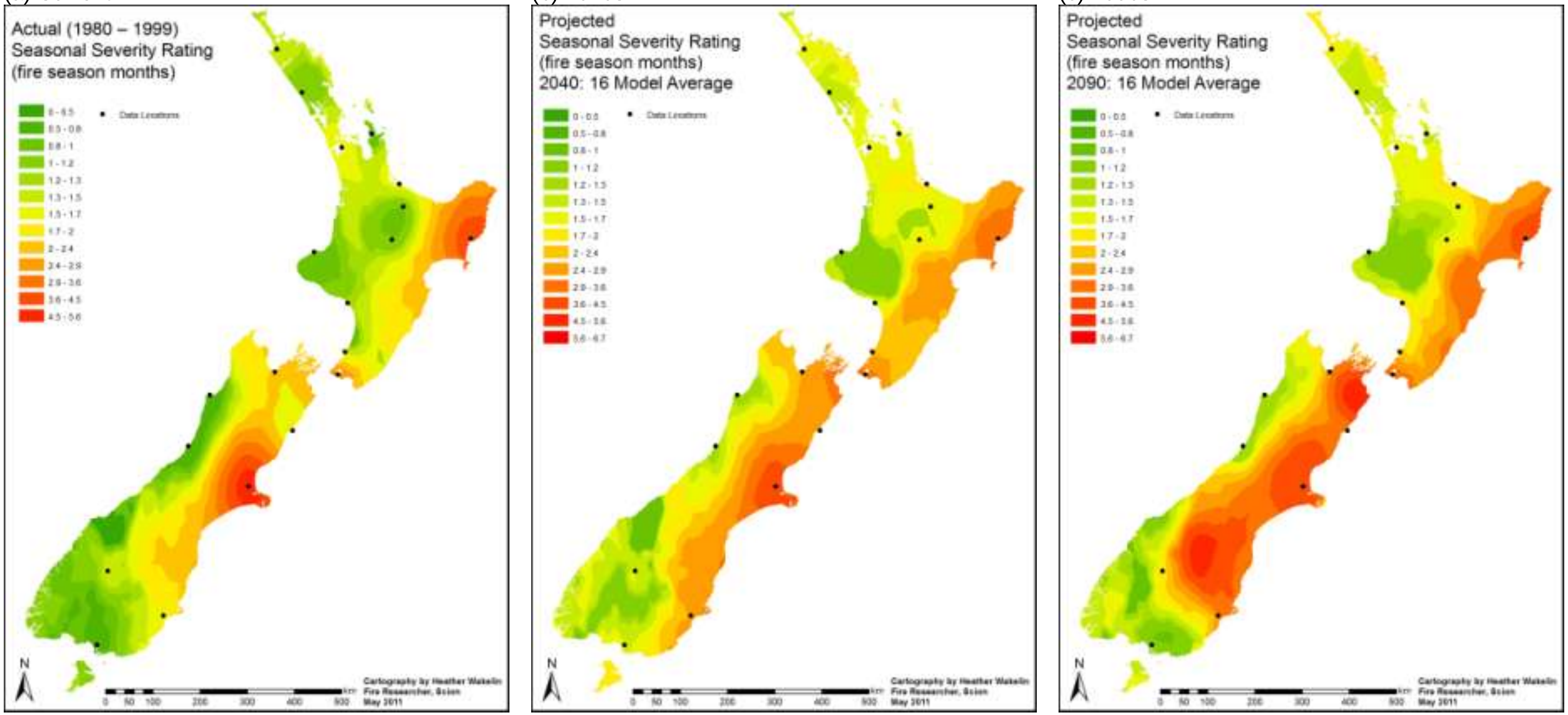


Figure 10. Range of projected changes (%) in the number of days/year of Very High and Extreme (VH+E) Forest fire danger during fire season months (Oct-Apr) for the 2090s (2080-2099) from 16 Global Climate Models for locations across New Zealand. The 16 model average and current number of days of VH+E fire danger are also shown for comparison.

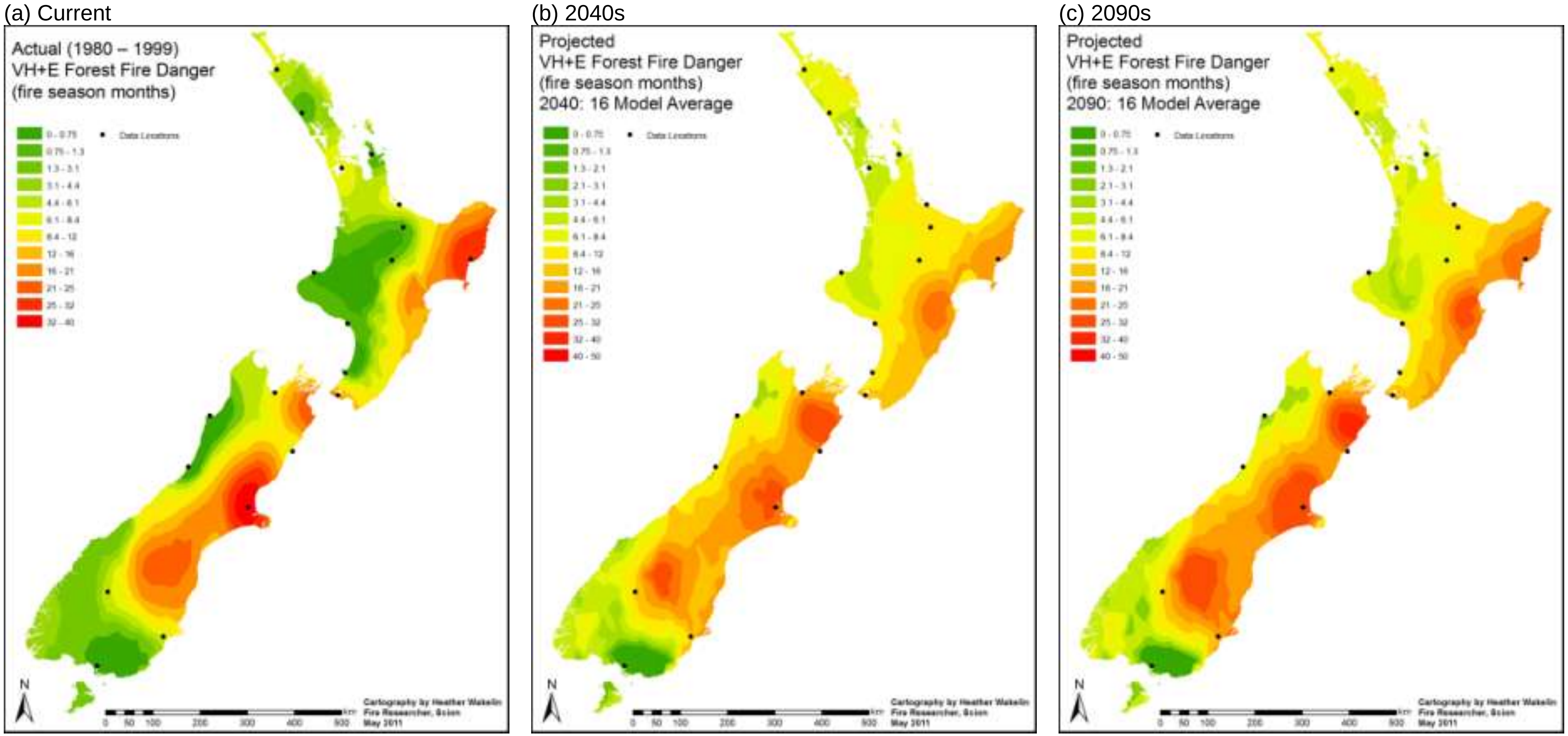


(a) Current

(b) 2040s

(c) 2090s

Figure 11. Pattern of projected changes in Seasonal Severity Rating (SSR) over fire season months (Oct-Apr) from (a) current climate, to (b) the 2040s (2030-2049), to (c) the 2090s (2080-2099), based on the overall average of the 16 GCMs investigated.



(a) Current

(b) 2040s

(c) 2090s

Figure 12. Pattern of projected 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 (a) current climate, to (b) the 2040s (2030-2049), to (c) the 2090s (2080-2099), based on the overall average of the 16 GCMs investigated.

In terms of future changes in fire climate severity, the impacts on the potential number of days of Very High and Extreme (VH+E) fire danger are arguably more intuitive than those for Seasonal Severity Rating (SSR). These are summarised for fire season months for both the 2040s and 2090s in Table 7 (in addition to Figure 12).

For the 2040s, changes for both the 16 model average and individual models are in the majority of cases positive, indicating likely increases in fire danger from current levels (albeit small in some cases or, in the case of Hokitika (HKA), no change). However, small negative changes (i.e. decreases) in fire danger class frequency are possible at some stations (e.g. Christchurch Aero, CHA; Queenstown, QNA; and New Plymouth, NPA) under the least extreme models. Average changes for the 2090s from the 16 models are again exclusively positive, however many more stations indicate possible decreases in fire danger (negative changes) for the lowest of the individual models.

As noted previously, caution needs to be applied when interpreting percentage changes in fire danger, as the greatest percentage increases can be indicated at stations where the current fire danger is negligible (i.e. Westport, WSA), so that any increase (in this case of 0.1 to 0.2 days/season, or 1 day every 5-10 fire seasons) is significant. Another station to indicate similarly significant percentage changes was Invercargill Aero (NVA), where the average increase for the 2040s of 129% suggests an additional 0.5 days/season (from the current 0.4 to 0.9 days/ season), and the maximum projected increase of 325% an extra 1.3 days (to 1.7 days/season). Even greater increases are possible for the 2090s, with an average 222% increase (or +0.9 days to 1.3 days/season) and maximum 663% (or +2.7 days to 3.1 days/season).

Coromandel (COR) and New Plymouth Aero (NPA) show somewhat significant percentage increases for the 16 model average (44-50%), but more significant maximum possible increases (120-162%), in the potential number of days of VH+E for the 2090s. However, these relatively large percentage increases translate to only small increases in the actual number of days of VH+E (on average, an extra 0.5-0.7 days; and maximum of 1.7-1.8 days/season). Predicted increases for Dargaville (DAR) and Taupo Aero (APA) for the 2090s are similar (average 59%, maximum 149-175%), although the projected changes in the number of days of VH+E are slightly larger (on average, and extra 1.3-1.6 days/season, maximum 3.9-4.0 days/season), while those for Kaitaia (KX) and Auckland (AKL) are larger again (average 43-50% for 2.5-4.1 extra days/season, maximum 137-166% for 8.0-13.7 days/season). In the latter case, these maximum projected changes for the 2090s represent significant increases from current climate (from 5.9 up to 13.9 days/season for KX, and from 8.3 up to 22.0 days/season for AKL) due to the moderately low current fire danger.

Wanganui (WUA) and Paraparaumu (PPA) showed similar trends for both the 2040s and 2090s, but with more significant increases projected for the 2090s. Average increases of 117% and 129% at WUA (corresponding to an extra 3.0 and 3.3 days/season) increase the number of days of VH+E from the current 2.6 days/season to 5.5 and 5.8 days/ season, for the 2040s and 2090s respectively. The even larger maximum possible increases of 214% and 376% (+5.5 and +9.6

days/season) potentially mean up to 8.0 and 12.2 days/season. For PPA, the average increases of 97% and 142% (+1.9 and +2.8 days/season) potentially increase the number of days of VH+E from the current 2.0 days/ season to 3.8 and 4.7 days/season, with maximum increases of 231% and 531% (+4.5 and +10.4 days/season) extending this to a possible 6.5 days/season for the 2040s and 12.3 days/season by the 2090s.

However, some of the most significant increases were where the greatest percentage increases also corresponded to a much higher number of days of VH+E fire danger. This occurred at Kaikoura (KIX), Wellington Aero (WNA) and Dunedin Aero (DNA). For KIX, average increases of 134% and 142% mean the potential for an additional 8.4 and 8.9 days/season (up from the current 6.3 days, to 14.7 and 15.2 days/season for the 2040s and 2090s, respectively). Maximum possible increases of 271% and 387% highlight the potential for even greater increases in the VH+E fire danger class frequency, by as many as 17.1 and 24.4 days (to 23.4 days/season for the 2040s, and 30.7 days/season by the 2090s) under the most severe models. Similarly, WNA shows 16 model average increases of 97% and 103%, or an extra 16.2 and 17.3 days/season (from the current 16.8 days to 32.9 and 34.1 days/season), with maximum increases of 207% and 285% or an extra 34.7 and 47.8 days/season (to 51.5 and 64.6 days season for the 2040s and 2090s). In the latter case, this would result in WNA having one of the, if not the, most severe fire climates in the country (and higher than Christchurch Aero’s 60.5 days/season of VH+E for the 2090s). But DNA shows the greatest potential percentage increases. From the 16 model averages, increases of 220% and 290% correspond to 12.6 and 16.5 more days of VH+E (from the current 5.7 days to 18.3 and 22.2 days/season) for the 2040s and 2090s. Even greater possible increases are indicated for DNA by the most extreme models, of 421% and 676% or an additional 24.0 and 38.6 days (up to 29.7 and 44.3, from the current 5.7 days/season). These are very dramatic potential increases in the likelihood of days of VH+E fire danger on which any fires would be difficult, if not impossible to control.

In contrast, low percentage increases at Gisborne Aero (GSA) and Christchurch Aero (CHA) correspond to what is still a significant number of additional days of VH+E fire danger, due to their comparatively high current fire danger levels. Average increases of 19% and 29% for GSA correspond to increases of 6.6 and 9.8 days/season (from 34.1 days, to 40.7 and 43.9 days/season for the 2040s and 2090s, respectively), and maximum increases of 29% and 60% translating to an additional 9.9 and 20.5 days (to 44.0 and 54.6 days/season). Average increases of 13% and 22% at CHA correspond to increases of 5.4 and 8.6 days/season (from the current 39.7 days, to 45.1 and 48.3 days/season), with maximum possible increases of 22% and 52% meaning a possible additional 8.7 and 20.8 days (to 48.4 and 60.5 days/season). So while demonstrating smaller potential percentage increases than many other locations, these projected increases would still see these areas continue to have some of the more severe fire climates in the country (see Figure 12).

Table 7. Changes in the number of days of Very High and Extreme (VH+E) Forest fire danger for the 2040s (2030-2049) and 2090s (2080-2099) from current levels (1980-1999) projected from 16 GCMs at 20 station locations across New Zealand.

Station Code	Number of days/fire season of VH+E Fire Danger												
	Current VH+E (days/ season)	Models for 2040s						Models for 2090s					
		Model average	Model range	Average change	Model range	Average change	Model range	Model average	Model range	Average change	Model range	Average change	Model range
		(days/season		(no. days)		(%)		(days/season)		(no. days)		(%)	
KX	**5.9**	**8.3**	(6.6 – 10.4)	2.5	(0.7 – 4.5)	42	(12 – 77)	**8.3**	(5.2 – 13.9)	2.5	(-0.6 – 8.0)	43	(-11 – 137)
DAR	**2.7**	**4.0**	(2.9 – 4.9)	1.4	(0.3 – 2.3)	51	(9 – 85)	**4.2**	(2.5 – 6.6)	1.6	(-0.2 – 4.0)	59	(-6 – 149)
COR	**1.5**	**2.1**	(1.6 – 2.6)	0.6	(0.1 – 1.1)	42	(7 – 73)	**2.2**	(1.5 – 3.3)	0.7	(-0.1 – 1.8)	44	(-3 – 120)
AKL	**8.3**	**12.2**	(9.6 – 14.9)	3.9	(1.4 – 6.6)	47	(16 – 80)	**12.4**	(7.7 – 22.0)	4.1	(-0.6 – 13.7)	50	(-7 – 166)
TGA	**7.7**	**9.8**	(8.6 – 12.1)	2.1	(0.9 – 4.4)	27	(12 – 56)	**10.1**	(8.0 – 14.1)	2.4	(0.3 – 6.4)	32	(3 – 83)
ROA	**1.5**	**2.6**	(1.8 – 3.5)	1.1	(0.3 – 2.0)	76	(17 – 133)	**2.6**	(1.7 – 4.9)	1.1	(0.2 – 3.4)	76	(10 – 223)
GSA	**34.1**	**40.7**	(35.7 – 44.0)	6.6	(1.6 – 9.9)	19	(5 – 29)	**43.9**	(34.2 – 54.6)	9.8	(0.0 – 20.5)	29	(0 – 60)
APA	**2.2**	**3.5**	(2.9 – 4.3)	1.3	(0.7 – 2.1)	60	(32 – 93)	**3.5**	(1.8 – 6.1)	1.3	(-0.4 – 3.9)	59	(-18 – 175)
NPA	**1.1**	**1.4**	(0.9 – 2.2)	0.4	(-0.2 – 1.1)	35	(-19 – 105)	**1.5**	(0.8 – 2.8)	0.5	(-0.3 – 1.7)	47	(-24 – 162)
WUA	**2.6**	**5.5**	(4.1 – 8.0)	3.0	(1.6 – 5.5)	117	(61 – 214)	**5.8**	(3.0 – 12.2)	3.3	(0.4 – 9.6)	129	(16 – 376)
PPA	**2.0**	**3.8**	(2.6 – 6.5)	1.9	(0.6 – 4.5)	97	(31 – 231)	**4.7**	(2.4 – 12.3)	2.8	(0.4 – 10.4)	142	(21 – 531)
WNA	**16.8**	**32.9**	(23.9 – 51.5)	16.2	(7.1 – 34.7)	97	(42 – 207)	**34.1**	(16.2 – 64.6)	17.3	(-0.6 – 47.8)	103	(-4 – 285)
NSA	**8.9**	**12.4**	(11.0 – 14.8)	3.5	(2.1 – 6.0)	40	(24 – 67)	**12.8**	(9.0 – 18.4)	3.9	(0.1 – 9.6)	44	(1 – 108)
WSA	**0**	**0.01**	(0 – 0.1)	0.01	(0 – 0.1)	0	(0 – 1000+)	**0.03**	(0 – 0.2)	0.03	(0 – 0.2)	0	(0 – 2000+)
HKA	**0**	**0**	0	0	0	0	0	**0**	0	0	0	0	0
KIX	**6.3**	**14.7**	(9.1 – 23.4)	8.4	(2.8 – 17.1)	134	(44 – 271)	**15.2**	(6.8 – 30.7)	8.9	(0.5 – 24.4)	142	(7 – 387)
CHA	**39.7**	**45.1**	(38.4 -48.4)	5.4	(-1.4 – 8.7)	13	(-3 – 22)	**48.3**	(41.8 – 60.5)	8.6	(2.1 – 20.8)	22	(5 – 52)
QNA	**5.7**	**7.0**	(5.2 – 8.7)	1.3	(-0.5 – 3.0)	23	(-9 – 53)	**8.0**	(5.8 – 11.2)	2.3	(0.1 – 5.5)	41	(3 – 97)
DNA	**5.7**	**18.3**	(13.3 – 29.7)	12.6	(7.6 – 24.0)	220	(133 – 421)	**22.2**	(13.8 – 44.3)	16.5	(8.1 – 38.6)	290	(142 – 676)
NVA	**0.4**	**0.9**	(0.5 – 1.7)	0.5	(0.1 – 1.3)	129	(25 – 325)	**1.3**	(0.6 – 3.1)	0.9	(0.2 – 2.7)	222	(38 – 663)
Avg.	**7.6**	**11.3**	**(0 – 51.5)**	**3.6**	**(-1.4 – 34.7)**	**64**	**(-19 – 1000)**	**12.1**	**(0 – 64.6)**	**4.4**	**(-0.6 – 47.8)**	**79**	**(-24 – 2000)**

Trends in rates of change in fire danger

What is apparent from detailed scrutiny of the changes projected for fire season severity in Tables 3-7 (and Appendices 1 & 2) is that not all models show fire dangers continuing to increase at all station locations beyond the 2040s to the 2090s. For some models and at some locations, fire climate severity exhibited a tendency to peak by the 2040s and then remain at about the same level for the 2090s. This trend can be seen in the pattern of changes in projected values for both SSR and days of VH+E fire danger for the 2040s and 2090s compared to current values (Figures 11 & 12), although was more evident for days of VH+E. For example, the 16 model averages for the projected number of days of VH+E remain the same from the 2040s to the 2090s for the majority of stations in the upper North Island (see Table 7), and increase only slightly (by 1-2 days/season) for most of the remaining stations.

For individual models, this lack of ongoing increases was clearly apparent at Kaikoura (KIX) for the CGMR model, where the fire season SSR and number of days of VH+E fire danger increased significantly to the 2040s (by 93% and 173%, respectively) (Tables 3 & 4), but then stayed the same or decreased slightly by the 2090s (81% and 141%) (Tables 5 & 6), indicating little change or a slight decrease between the two projection periods. Kaikoura (KIX) also showed a similar tendency under the GIAOM and HADCM3 models, as did Dunedin (DNA) under the GIEH and HADCM3 models. Some locations and models also showed a greater decrease in fire climate severity from the 2040s to 2090s. An example of this was Dunedin Aero (DNA) under the MIMR model, where SSR increased by 86% and VH+E by 242% to the 2040s, but only 61% and 191% to the 2090s, indicating decreases of -25% for SSR and -51% for VH+E from the 2040s to the 2090s. Wellington (WNA) under ECHOG, and again Kaikoura (KIX) under a number of models including ECHOG, GFCM21 and MIMR, also showed 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 16 models and station locations, the number of days of VH+E fire danger during the fire season is projected to increase by 64% from current values for the 2040s and 79% for the 2090s, but only 15% (based on current values) from the 2040s to the 2090s (see Table 7). There was obviously much variability between models in these rates of change, although model ranges (with the exception of Westport, WSA) for the 1990s to 2040s period (-19% to +421%) were less variable than those for the 2040s to 2090s (-115% to +525%). In real terms, these average changes correspond to an average increase of 3.6 days/season of VH+E fire danger from the 1990s to 2040s (range -1 to +35 days/season), and just 0.8 days/season for the 2040s to 2090s (range -10 to +15 days/season). The rates of change in SSR for the two projection periods varied less, at 26% for the 1990s to 2040s (and 32% for 1990s to 2090s), and 6% from the 2040s to 2090s, although the ranges in these rates between models were just as variable at -2% to +148% for the 1990s to 2040s, and -43% to +99% for the 2040s to 2090s.

Variation Between Models

The individual Global Circulation Models (GCMs) are varied representations of the climate system with different model sensitivities, rates of warming and interannual variability derived from differences in modelling resolution and the way they each 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 differing estimates of the climate changes that influence fire danger.

In general terms, the influence of each of the GCMs on future fire dangers falls into one of three broad categories of models (although this is dependent on the magnitude and seasonality of climatic changes projected by each model across the country, particularly for rainfall and temperature):

1. Models that result in increases in fire danger to the 2040s, and which continue to show increases to the 2090s due to increasingly sever climate – models in this category include IPCM4, CGMR and GFCM20.
2. Models that produce increases in fire danger to the 2040s, but then remain relatively constant to the 2090s due to higher projected rainfall (especially during summer, and that may cause fire dangers at some individual stations to decrease) – models in this category include MIHR, HADGEM and GIAM; the MPEH5, HADCM3, FGOALS, and to a lesser extent MRGCM, CSMK3 and CNCM3 models are somewhat intermediate between type 2 and type 1 above, possibly due to offsetting of rainfall decreases.
3. Models that produce increases in fire danger to the 2040s, but decreases from the 2040s to the 2090s due to much higher projected rainfall that causes fire dangers at several stations to decrease – models in this category include ECHOG, GFCM21, GIEH and MIMR.

The magnitude, seasonality and spatial pattern of projected changes in climate across the country combine to influence the changes in fire danger at individual stations, and therefore the overall ranking of each model in terms of its ability to bring about significant changes in future fire climate severity. Of the 16 GCMs investigated (see Figures 7-10, and Figures 13-14), the IPCM4 model consistently produced the greatest overall increases in fire danger under future climate, averaging 43% and 79% across the 20 stations for SSR, and 107% and 209% for the number of days of VH+E fire danger, for fire season months for the 2040s and 2090s, respectively (with similar values for the full year; see Appendix 2). It was closely followed by the CGMR model (with 34% and 59% increases for SSR, and 82% and 167% for VH+E for fire season months). For this reason, this model was chosen as an example for illustrating potential changes from the more extreme high-range models in Figures 3-6(b). The GFCM20 model ranked the next highest of the models, with changes continuing to increase strongly from the 2040s to

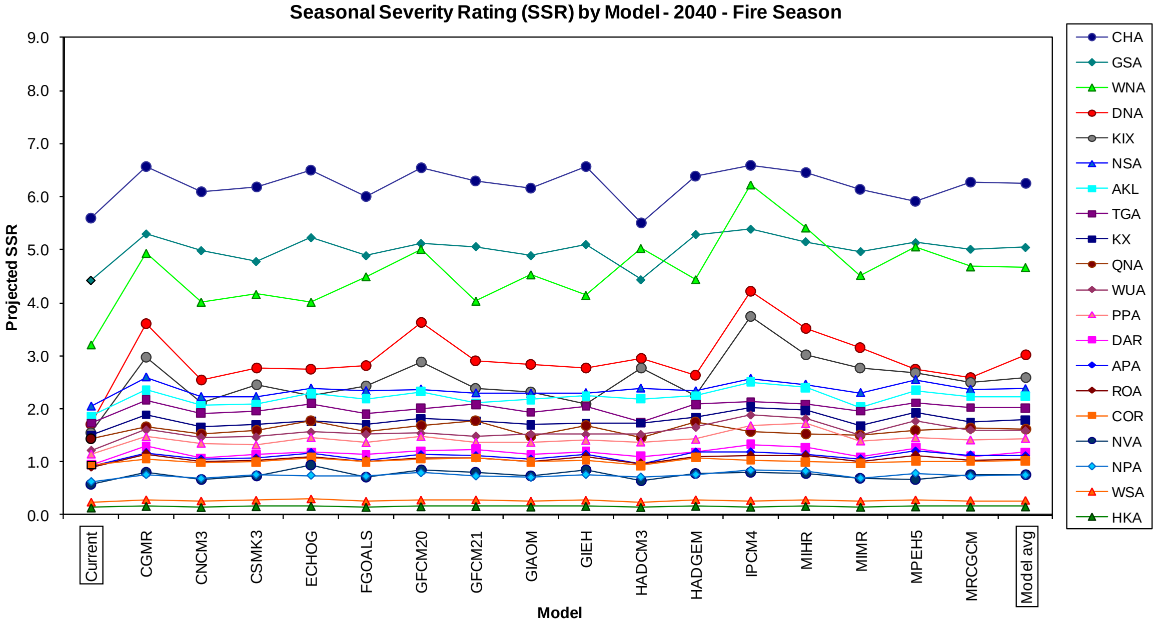
2090s. This was followed by the MIHR model which showed little change from the 2040s to 2090s, and by the MPEH5 model which produced higher fire dangers for the 2090s compared to the 2040s.

The HADCM3 model, which ranked mid-range (6th of the 16 models) in terms of overall changes in fire danger, showed only slight increases from the 2040s to 2090s due to predicted decreases in fire danger for the 2040s at several stations, while the HADGEM model which ranked 7th showed little change between the two projection periods. Changes for the CSMK3 model were also mid range, but were comparatively lower for the 2040s resulting in it slipping to 12th of the 16 models, compared with 7th for the 2090s and 8th overall. Changes for the ECHOG model were also consistently in the middle of the ranges projected by the 16 models (see Figures 7-10, and Figures 13-14), so it was therefore chosen to illustrate potential changes for mid-range models in Figures 3-6(c), and comparison with the 16 model average (Figures 3-6(a)). However, projected increases for this model were lower for the 2090s than for the 2040s (21% cf. 27% for fire season SSR, and 57% cf. 74% for VH+E) due to predicted decreases in fire danger under this model for the 2090s at several stations. This resulted in it slipping to 11th of the 16 models for the 2090s, compared with 7th for the 2040s and 9th overall. Changes for the MRCGCM model were similar for the 2040s and 2090s, whereas those for FGOALS were slightly higher for the 2090s than the 2040s. However, this resulted in the FGOALs model rising to 9th of the 16 models for the 2090s, compared with 15th for the 2040s and 11th overall.

Changes for the GFCM21 model overall ranked near the lower end of the 16 models investigated (12th), but ranked higher for the 2040s (10th) due to higher projected increases for the 2040s compared with the 2090s, where it ranked lower (14th) as a result of predicted decreases at one station (Kaitaia, KX). However, the 15th ranked GIAOM model showed little change in projected increases from the 2040s to the 2090s. In comparison, the GIEH model predicted lower increases in SSR and days of VH+E fire danger for the 2090s compared with the 2040s, due to projected decreases at a number of stations under this model. The MIMR model was the GCM that consistently produced some of the lowest changes in fire danger (see Figures 7-10, and Figures 13-14), so it was selected as an example to illustrate the potential changes for these low-range models in Figures 3-6(d). However, it also showed lower increases for the 2090s (12% and 29% for SSR and VH+E, respectively) than for the 2040s (21% and 49%) as a result of predicted decreases in fire danger at several stations for the 2090s, so that it ranked slightly higher (13th) for the 2040s compared to 15th for 2090s and overall. The CNCM3 model produced slightly higher increases for the 2090s (22% and 40%) compared to the 2040s (15% and 32%), resulting in it ranking higher (12th) for this later projection period but last overall of the 16 models investigated (based on full year and fire season rankings for both projection periods).

Apart from the HADCM3 model noted above, the GFCM21 and GIAOM models were the only other models to show decreases in fire danger for the 2040s (see Figures 7 & 8). Several different models produced decreases in fire danger over the full projection period to the 2090s (see Figures 9 & 10), albeit relatively minor (generally of less than -10%), including the GIEH, ECHOG, MIMR and, to a lesser extent, GFCM21 and GIAOM models. The greatest decreases for the 2090s were under the ECHOG (-24% at New Plymouth, NPA) and GIEH (-18% at Taupo Aero, APA) models. The greater number of projected decreases in fire danger for the 2090s (than the 2040s) also reinforces the tendency for fire dangers to decrease from the 2040s to the 2090s at several stations under some models and, overall, certainly to increase less than the much more rapid increase projected from the current climate baseline to the 2040s.

(a)



(b)

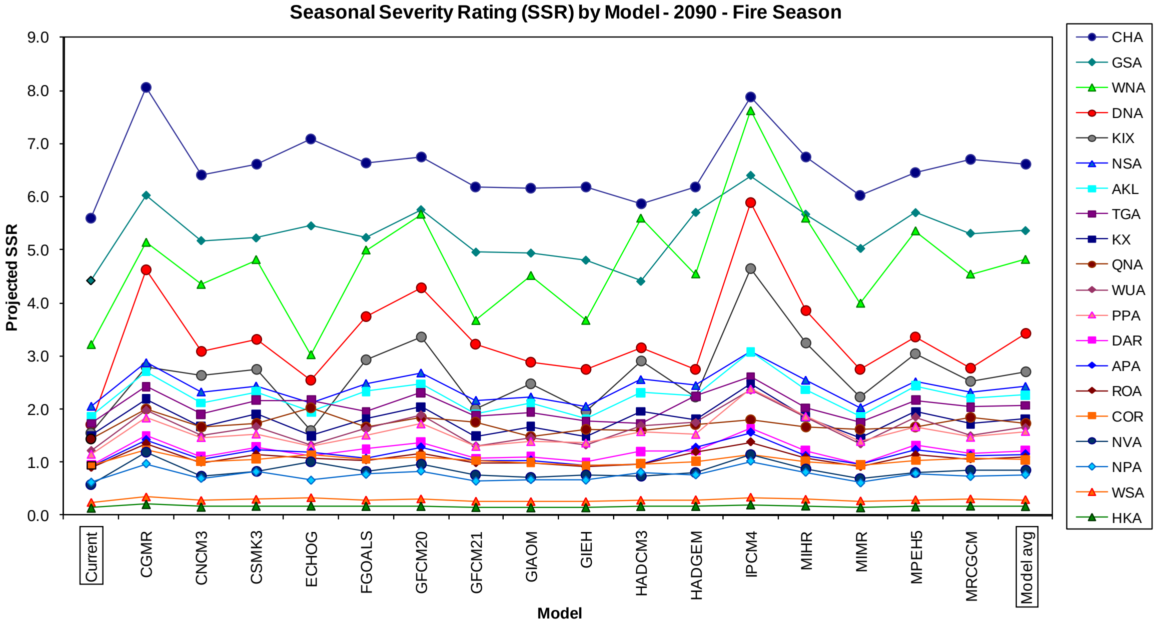
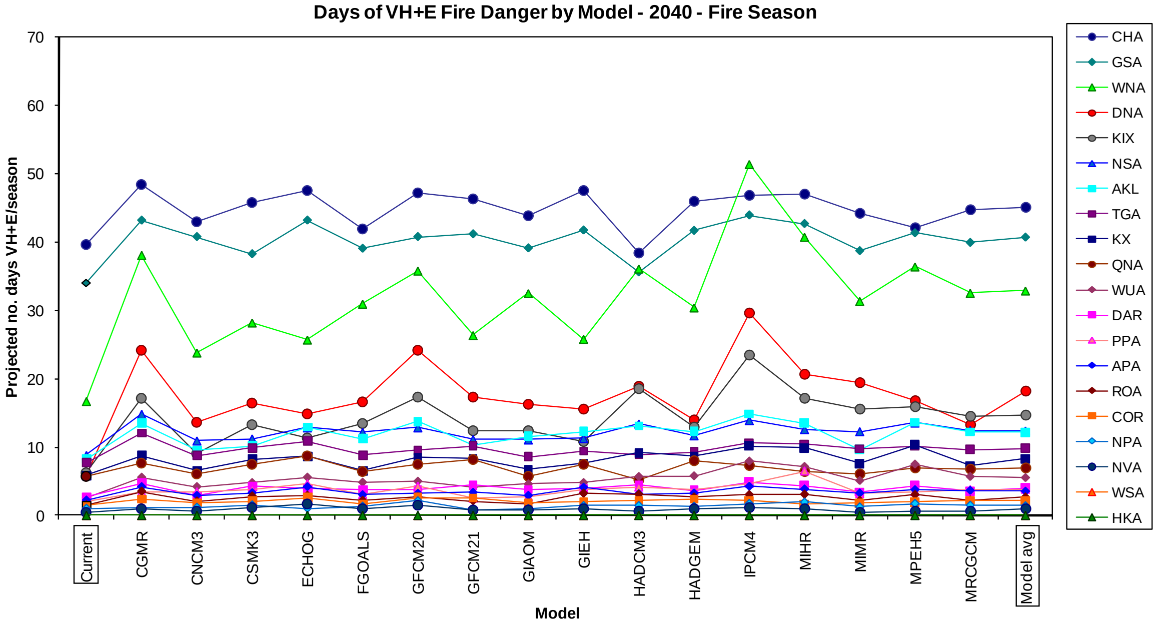


Figure 13. Range in average values of the Seasonal Severity Rating (SSR) over fire season months (Oct-Apr) projected by 16 Global Climate Models for locations across New Zealand for: (a) the 2040s (2030-2049), and (b) the 2090s (2080-2099).

(a)



(b)

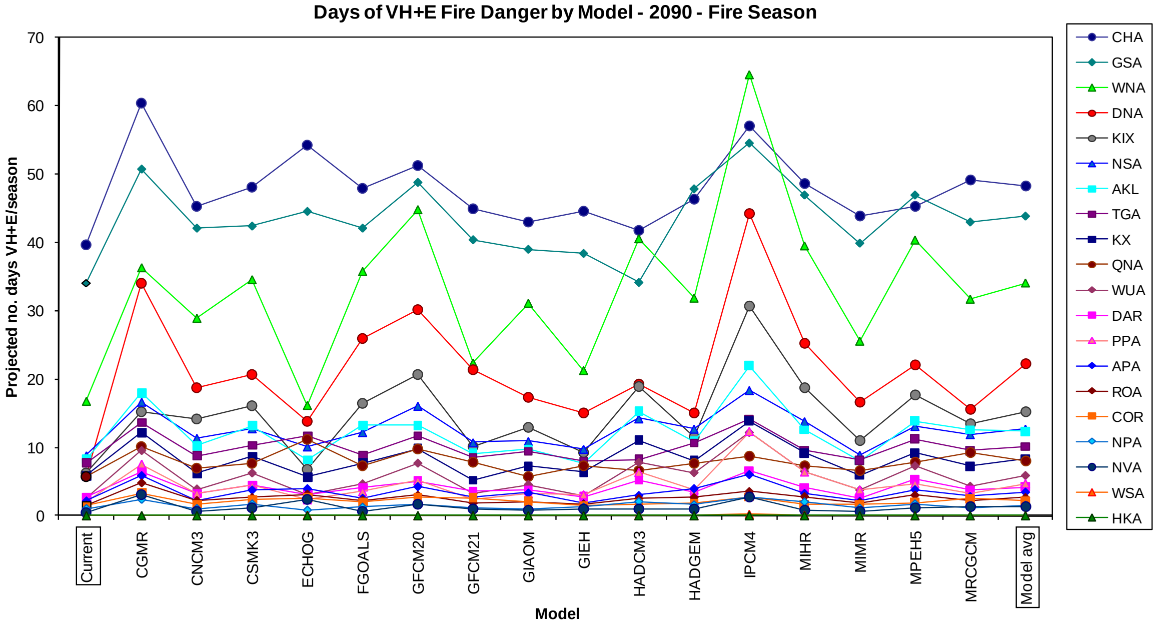


Figure 12. Range in average number of days of Very High and Extreme (VH+E) Forest fire danger during fire season months (Oct-Apr) projected by 16 Global Climate Models for locations across New Zealand for: (a) the 2040s (2030-2049), and (b) the 2090s (2080-2099).

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 higher fire danger by increasing the rate of evaporation and drying of vegetation fuels. Stronger 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 them, 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 increase only 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 2090s).

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)[3].

A sensitivity analysis to determine the relative importance of projected weather changes on fire danger (Scion, unpublished) found that the fire climate severity measures were most sensitive to changes in relative humidity, followed by temperature and wind speed, and then rainfall. 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%)

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

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% for each element 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. 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 2040s and 2090s are shown in Appendix 3. Full year changes are also included in Appendix 4. These changes agree reasonably 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 and projection periods. For example, the mean annual temperature increase (for all months) across all 16 models at the 20 station locations investigated here was 1.16°C for the 2040s and 2.52°C for the 2090s (see Appendix 4), 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 change (i.e. decrease) by -0.47% for the 2040s and -0.16% for the 2090s (see Appendix 4), compared with changes of up to +/-20% (MfE 2008).

Fire season averages, at least for temperature, could be expected to be higher than these mean annual estimates, since the fire season months (October-April) encompass the (normally) warmest period of the year and exclude the (normally) cooler winter months. However, the average fire season temperature increases across all models and station locations (0.99°C for the 2040s and 2.35°C for the 2090s; Appendix 3) were lower than the annual averages (1.16°C and 2.52°C), indicating greater increases in temperature over winter months within the majority of models compared with during the fire season. Averaged over all models, temperature increases were generally lower in the north of the country and highest in the south, although average fire season changes varied considerably between models and station locations. These ranged from a -0.01°C decrease (for Taupo (APA) under HADCM3) to 2.08°C increase (for Dunedin (DNA) and Invercargill (NVA) under MIHR) for the 2040s, and increases of 1.07°C (again, at Taupo (APA) under HADCM3) to 5.02°C (also Invercargill (NVA) under MIHR) for the 2090s. Variation in the projected monthly changes was even greater, ranging from decreases of 5.74°C to increases of 11.59°C. Of the downscaled GCMs, the MIHR model showed some of greatest increases for both the 2040s and 2090s, whereas the HADCM3 model projected some of the highest increases for full year averages but lowest for fire season averages. The CSMK3 and GIAOM models showed some of the lowest increases for both 2040s and 2090s, whereas the MPEH5 model only projected lower increases for the 2040s.

The average fire season changes for rainfall across all models and locations were higher than for the full year, with increases of 3.3% and 6.4% projected for the 2040s and 2090s, respectively (see Appendix 3) (cf. -0.47% and -0.16% for the full year). 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, these average changes varied greatly been models and station sites, ranging from a 70% increase in rainfall (at Wellington (WNA) under HADCM3) to a 47% decrease (Kaikoura (KIX) under IPCM4) for the 2040s, and a 94% increase (Wellington Aero (WNA) under HADCM3) to a 47% decrease (Dunedin Aero (DNA) under IPCM4) for the 2090s. In the South Island, higher decreases were generally projected for the west than for the east, whereas in the North Island greater decreases were generally projected for the south and lower decreases (or higher increases) in the north. The IPCM4 model consistently projected the highest decreases in rainfall for both the 2040s and 2090s, along with the CNCM3 model but only for the 2040s. The CSMK3 model projected some of the highest decreases for the 2090s, but greatest increases (or lowest decreases) for the 2040s. The MIMR model predicted some of the highest increases for the 2090s. However, the HADCM3 model consistently projected the greatest increases in rainfall for both the 2040s and 2090s.

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 were considerably smaller. Average changes across all 16 models and 20 station locations were slightly higher (by 0.2-0.4%) for fire season months than for the full year (see Appendices 3 & 4), but were more variable between models and stations for the full year (+/-3% cf. +/-2%). Overall changes for fire season relative humidity were also greater for the 2090s (0.9% increase) than for the 2040s (0.3% increase). However, these again varied widely, from a 0.9% decrease (at Dunedin Aero (DNA) under MIHR) to a 1.6% increase (for Hokitika (HKA) under MIHR) for the 2040s, and from a 1.2% decrease (again, at Dunedin Aero (DNA) under MIHR) to a 2.9% increase (at Invercargill (NVA) under MIMR) for the 2090s (Appendix 3). When averaged across all 20 stations, humidity decreases were greatest under the HADCM3 model, and HADGEM for the 2040s and CGMR for the 2090s. The greatest increases in humidity occurred under the MIMR model, followed by the MIHR and/or GIEH models. No obvious pattern was discernable for changes in relative humidity across the country. Despite the negligible average changes, the more variable monthly changes of +/-20% did result in considerable variation in daily values for relative humidity throughout the projection periods. Hence, these changes would have contributed to changes in the calculated values of the FWI System components on a daily basis, and therefore to the resulting fire climate severity measures.

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 were even smaller. Average changes across models and stations for fire season months (Appendix 3) were however lower than for the full year (see Appendix 4), by around 1% (0.1-0.2 km/h) with greater differences projected for the 2090s than the 2040s. This again reinforces the seasonality in projected zonal 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 2040s and 2090s, average fire season wind speeds were projected to decrease by 0.1 km/h (-1%) and 0.4 km/h (-2%), respectively. This again varied widely between models and locations, from -1.0 km/h (-3%) (Wellington (WNA) under ECHOG) to +0.8 km/h (3%) (at Invercargill (NVA) under IPCM4) for the 2040s, and -2.6 km/h (-8%) (again, at Wellington (WNA) under ECHOG) to +0.9 km/h (4%) (also at Invercargill (NVA) under IPCM4) for the 2090s (Appendix 3). Again, no obvious pattern of changes in wind speed was discernable across the country. Wind speed increases were greatest under the HADCM3 and MPEH5 models, while the greatest decreases occurred under the ECHOG model for both the 2040s and 2090s. Again, monthly and therefore daily changes in wind speed were in many instances much larger (up to +/-30 km/h), so that these would certainly have contributed to changes in the calculated daily values of the FWI System components and fire climate severity measures that are not readily apparent in the overall model changes.

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 2090s of 1.07°C to 5.02°C from the 16 models used in the present analysis, and 1.29°C to 4.89°C for the full year. 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 more than 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 -47% to +94% (and -41% to +38% for full year) under Hadley (High) scenario in the 2005 study. This compares with average fire season changes of -28% to +65% (and -22% to +23% 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 2090s were:

- for relative humidity, average fire season decreases of -1.2% (relative to 1990s average RH) ranging to increases of +2.9% (and -2.8% to +2.9% for the full year); and
- for wind speed, average fire season decreases of -14.4% ranging to increases of +4.4% (and -10.0% to +7.3% for the full year).

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[4] 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 -6% to +247% (and -1% +285% 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 in the previous study 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 -24% to +676% (and -24% to +826% for the full year) (excluding Westport, WSA). In absolute terms, the greatest projected changes in the number of days of VH+E fire danger

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[4] 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 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.

over the fire season were 23.4 days/season (at Gisborne, GSA) in the Pearce et al. (2005) study and 47.8 days/season (at Wellington, WNA) for the present analysis (or 25.0 days/year (again, at GSA) and 53.1 days/year (again, at WNA), for the full year respectively). In contrast, GSA increased by a maximum of 20.5 days/season (22.6 days/year) under the IPCM4 model, and 8.3 days/season (9.0 days/year) under the CSMK3 model comparable to the CSIRO model from Pearce et al. (2005) study, and zero days/season (no change) (and 4.7 days/year) under the HADCM3 model comparable to the Hadley model.

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 predominantly 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. 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. As a result, some fire seasons may exhibit significantly higher fire dangers, and others significantly lower, than indicated by any average projected increase or decrease in overall fire climate severity.

The use of the high- and low-range scenarios in the 2005 study, based on applying multiplication factors (of 1.255 for high, and 0.476 for low) to the temperature and rainfall offsets to generate the IPCC extremes, would also have been a factor in producing greater changes for the high-range models in the 2005 study compared to the equivalent (mid-range) models used here.

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 two of the stations to show the greatest increases in fire climate severity. Tauranga (TGA), and to a lesser extent, Taupo (APA)and Rotorua (ROA) did show some increases in fire danger, but only under the more 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 divergence from the previous study, where significant increases were found at Gisborne (GSA), this station showed only minor increases under most models in the present analysis. Similarly, Dargaville (DAR) and Auckland (AKL) 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 significantly increased fire climate severity under many of the models in the present analysis.

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 were investigated for several stations as part of the present analysis. The MSR method failed to pick up all of the months currently recognised as being part of the fire season, by excluding October and April. It was also not sufficiently discriminating between different GCMs, with about half of the 16 models adding the month of October for the 2040s, and few if any picking up October for the 2090s. In fact, some models showed a reduction in fire season length for the 2090s, due to lower MSR values in October and November. Only a few models suggested possible increases in fire season length with higher MSR values extending beyond March into April for either of the 2040s or 2090s. The VH+E Forest fire danger method appeared to do better at describing the current (October-April) fire season, with several different models showing the potential for future fire seasons to extend into May. This approach also had a number of models showing the possibility of the fire season starting in September and, in at least one case, in August.

In reality, however, individual fire seasons vary widely in severity from year to year in response to interannual variability (e.g. ENSO events), and can vary significantly from the average. For example, the investigation of individual fire seasons using the MSR >3.0 threshold showed 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 appeared 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 in future.

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 estimates of temperature and wind speed, and higher relative humidity. 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 16 global climate models for the A1B emissions scenario from the IPCC's 4th Assessment 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 2040s (2030-2049) and 2090s (2080-2099). 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 some parts of the country. This is primarily the result of increases in temperature and decreases in rainfall, although higher wind speed and lower humidity also contribute to higher future fire danger. 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 Christchurch and Gisborne did not show significantly increased fire potential. Fire danger in other areas may remain unchanged, or in fact decrease by the 2090s, 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 in these locations would see the areas of elevated fire danger under current climate in Canterbury, Gisborne, Marlborough and Central Otago/South Canterbury extend along the east coast of both islands to include coastal Otago, Wellington and Hawkes Bay by the 2040s, and to develop further in Marlborough, Hawkes Bay and Wairarapa by the 2090s. Fire dangers in Wanganui, the Bay of Plenty and Northland would also increase. However, despite significant percentage increases in Southland, south Taranaki and the Coromandel, fire climate severity in these areas would increase but still remain comparatively low relative to other parts of the country.

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 2090s, a feature of several models was for fire danger to increase more rapidly to the 2040s, and then to stabilise or decrease by the 2090s, 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 could contribute to longer fire seasons in some parts of the country, increased drought frequency, a greater number of fires and increased fire suppression costs and damages.

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 16 global models for two projection periods (the 2040s and 2090s), 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 – <u>Fire season averages</u> (over months Oct-Apr) of changes in fire climate severity measures estimated from 16 Global Climate Models, and comparisons with current climate for the 1990s (1980-1999) for:

Table A1.1. Average **Seasonal Severity Rating (SSR) over fire season months (Oct-Apr) estimated for the 2040s (2030-2049)** from 16 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	Current SSR	Models for 2040s – Seasonal Severity Rating (SSR)																Model avg.
		CGMR	CNCM3	CSMK3	ECHOG	FGOALS	GFCM20	GFCM21	GIAOM	GIEH	HADCM3	HADGEM	IPCM4	MIHR	MIMR	MPEH5	MRCGCM	
KX	**1.51**	1.89	1.65	1.70	1.76	1.70	1.82	1.77	1.70	1.72	1.73	1.84	2.03	1.97	1.67	1.93	1.75	**1.79**
DAR	**0.95**	1.29	1.07	1.14	1.19	1.14	1.20	1.24	1.13	1.19	1.11	1.19	1.33	1.27	1.10	1.26	1.10	**1.18**
COR	**0.94**	1.06	0.98	1.00	1.08	1.00	1.06	1.07	1.00	1.03	0.93	1.08	1.03	1.00	0.97	1.01	1.01	**1.02**
AKL	**1.86**	2.36	2.06	2.09	2.28	2.19	2.33	2.12	2.18	2.24	2.19	2.24	2.51	2.40	2.03	2.35	2.23	**2.24**
TGA	**1.73**	2.17	1.92	1.95	2.10	1.90	2.01	2.09	1.94	2.04	1.74	2.08	2.13	2.08	1.96	2.11	2.02	**2.02**
ROA	**0.90**	1.15	1.00	1.03	1.09	1.02	1.08	1.07	1.00	1.09	0.97	1.10	1.11	1.11	1.01	1.12	1.03	**1.06**
GSA	**4.41**	5.30	4.99	4.78	5.23	4.89	5.12	5.06	4.89	5.10	4.44	5.29	5.39	5.15	4.97	5.13	5.01	**5.04**
APA	**0.92**	1.17	1.05	1.07	1.17	1.03	1.13	1.11	1.05	1.14	0.97	1.18	1.18	1.14	1.06	1.20	1.13	**1.11**
NPA	**0.62**	0.76	0.68	0.76	0.74	0.73	0.79	0.73	0.70	0.76	0.71	0.76	0.84	0.82	0.69	0.78	0.73	**0.75**
WUA	**1.22**	1.61	1.46	1.47	1.57	1.52	1.54	1.49	1.52	1.52	1.52	1.65	1.89	1.82	1.50	1.77	1.60	**1.59**
PPA	**1.15**	1.48	1.35	1.32	1.46	1.37	1.48	1.37	1.37	1.41	1.38	1.43	1.69	1.73	1.40	1.46	1.42	**1.44**
WNA	**3.21**	4.94	4.02	4.16	4.01	4.50	5.01	4.04	4.53	4.14	5.03	4.44	6.23	5.42	4.52	5.06	4.68	**4.67**
NSA	**2.05**	2.60	2.23	2.23	2.39	2.34	2.37	2.30	2.29	2.30	2.39	2.34	2.57	2.46	2.30	2.55	2.37	**2.38**
WSA	**0.23**	0.28	0.26	0.27	0.30	0.25	0.27	0.28	0.26	0.27	0.24	0.28	0.27	0.28	0.26	0.28	0.27	**0.27**
HKA	**0.14**	0.17	0.15	0.17	0.17	0.15	0.16	0.17	0.16	0.17	0.15	0.17	0.16	0.17	0.15	0.16	0.16	**0.16**
KIX	**1.54**	2.97	2.11	2.44	2.25	2.42	2.88	2.38	2.32	2.09	2.76	2.25	3.74	3.02	2.77	2.67	2.49	**2.60**
CHA	**5.60**	6.58	6.08	6.18	6.51	6.00	6.56	6.29	6.16	6.56	5.50	6.38	6.58	6.45	6.14	5.92	6.28	**6.26**
QNA	**1.43**	1.66	1.53	1.60	1.78	1.56	1.67	1.79	1.49	1.68	1.45	1.74	1.57	1.53	1.51	1.59	1.63	**1.61**
DNA	**1.70**	3.61	2.54	2.77	2.76	2.83	3.63	2.91	2.83	2.76	2.96	2.62	4.22	3.51	3.16	2.76	2.59	**3.03**
NVA	**0.58**	0.79	0.67	0.73	0.94	0.71	0.84	0.80	0.73	0.84	0.64	0.77	0.81	0.79	0.70	0.68	0.75	**0.76**
Avg.	**1.63**	**2.19**	**1.89**	**1.94**	**2.04**	**1.96**	**2.15**	**2.00**	**1.96**	**2.00**	**1.94**	**2.04**	**2.36**	**2.21**	**1.99**	**2.09**	**2.01**	**2.05**
Rank*	-	*3*	*16*	*12*	*6*	*13*	*4*	*8*	*14*	*9*	*15*	*7*	*1*	*2*	*11*	*5*	*10*	-

* where rank 1 = highest % change, 16 = lowest % change.

Table A1.2. Average number of **days/year of Very High and Extreme (VH+E) Forest fire danger for fire season months (Oct-Apr) estimated for the 2040s (2030-2049)** from 16 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Current VH+E**	**Models for 2040s – Days/fire season of VH+E Fire Danger**																**Model avg.**
		CGMR	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**5.9**	8.8	6.6	8.3	8.7	6.6	8.5	8.4	6.8	7.7	9.2	8.7	10.2	9.9	7.6	10.4	7.3	**8.3**
DAR	**2.7**	4.7	2.9	4.3	3.9	3.7	3.8	4.5	3.8	4.0	4.5	3.7	4.9	4.4	3.5	4.4	3.6	**4.0**
COR	**1.5**	2.4	1.9	2.1	2.6	1.7	2.6	2.6	1.9	2.1	2.2	2.4	2.2	1.6	1.8	2.0	2.2	**2.1**
AKL	**8.3**	13.5	9.6	10.2	12.9	11.3	13.8	10.3	11.6	12.3	13.1	12.3	14.9	13.5	9.7	13.7	12.2	**12.2**
TGA	**7.7**	12.1	8.8	9.9	10.9	8.8	9.5	10.2	8.6	9.4	9.0	9.3	10.7	10.5	9.8	10.2	9.7	**9.8**
ROA	**1.5**	3.5	2.1	2.8	2.9	2.2	2.7	2.1	1.8	3.2	3.1	2.7	3.0	3.1	2.2	3.0	2.2	**2.6**
GSA	**34.1**	43.2	40.8	38.3	43.2	39.1	40.8	41.2	39.2	41.8	35.7	41.7	44.0	42.7	38.8	41.4	40.0	**40.7**
APA	**2.2**	4.2	2.9	3.3	4.2	3.0	3.2	3.4	2.9	4.1	3.2	3.3	4.3	3.9	3.3	3.8	3.7	**3.5**
NPA	**1.1**	1.1	1.2	1.6	1.1	1.4	2.2	0.9	1.0	1.5	1.5	1.4	1.8	2.0	1.3	1.8	1.5	**1.4**
WUA	**2.6**	5.6	4.2	4.8	5.6	4.9	5.0	4.1	4.6	4.8	5.7	5.8	8.0	7.2	5.1	7.6	5.7	**5.5**
PPA	**2.0**	3.5	3.5	3.9	4.6	3.1	4.3	2.6	2.8	3.9	4.2	3.7	4.7	6.5	3.3	3.5	3.8	**3.8**
WNA	**16.8**	38.2	23.9	28.3	25.8	31.0	35.9	26.4	32.6	25.9	36.2	30.5	51.5	40.8	31.4	36.5	32.6	**32.9**
NSA	**8.9**	14.8	11.0	11.3	12.9	12.2	12.9	11.2	11.1	11.3	13.4	11.7	13.9	12.6	12.3	13.6	12.5	**12.4**
WSA	**0**	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0.1	0	**0.01**
HKA	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
KIX	**6.3**	17.2	9.1	13.3	11.4	13.5	17.4	12.5	12.5	10.8	18.6	12.9	23.4	17.2	15.7	15.9	14.5	**14.7**
CHA	**39.7**	48.4	43.0	45.8	47.6	42.0	47.3	46.4	43.9	47.5	38.4	46.0	47.0	47.0	44.2	42.1	44.7	**45.1**
QNA	**5.7**	7.6	6.0	7.5	8.7	6.5	7.5	8.3	5.7	7.5	5.2	8.0	7.3	6.4	6.1	7.0	6.8	**7.0**
DNA	**5.7**	24.2	13.7	16.5	14.9	16.7	24.2	17.4	16.4	15.6	19.0	14.0	29.7	20.6	19.5	16.9	13.3	**18.3**
NVA	**0.4**	1.0	0.6	1.1	1.7	0.9	1.5	0.8	0.8	0.9	0.7	1.0	1.1	1.0	0.5	0.6	0.7	**0.9**
Avg.	**7.6**	**12.7**	**9.6**	**10.6**	**11.2**	**10.4**	**12.1**	**10.6**	**10.4**	**10.7**	**11.1**	**10.9**	**14.1**	**12.5**	**10.8**	**11.7**	**10.8**	**11.3**
Rank*	**-**	*4*	*16*	*8*	*5*	*13*	*3*	*14*	*15*	*10*	*7*	*9*	*1*	*2*	*12*	*6*	*11*	**-**

* where rank 1 = highest % change, 16 = lowest % change.

Table A1.3. Average **Seasonal Severity Rating (SSR) over fire season months (Oct-Apr) estimated for the 2090s (2080-2099)** from 16 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Current SSR**	**Models for 2090s – Seasonal Severity Rating (SSR)**																**Model avg.**
		CGMR	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**1.51**	2.19	1.67	1.91	1.50	1.82	2.04	1.49	1.67	1.48	1.96	1.81	2.47	1.85	1.46	1.95	1.72	**1.81**
DAR	**0.95**	1.50	1.11	1.28	1.11	1.24	1.37	1.07	1.10	0.99	1.20	1.22	1.64	1.22	0.96	1.31	1.16	**1.22**
COR	**0.94**	1.23	1.01	1.06	1.14	1.05	1.11	1.03	0.99	0.93	0.97	1.01	1.14	1.02	0.94	1.03	1.08	**1.05**
AKL	**1.86**	2.70	2.11	2.32	1.95	2.33	2.48	1.91	2.11	1.82	2.31	2.25	3.08	2.36	1.86	2.44	2.21	**2.26**
TGA	**1.73**	2.42	1.91	2.17	2.17	1.96	2.31	1.87	1.94	1.77	1.73	2.24	2.60	2.02	1.75	2.17	2.04	**2.07**
ROA	**0.90**	1.35	0.99	1.14	1.08	1.04	1.17	0.98	0.99	0.90	0.97	1.19	1.38	1.08	0.91	1.13	1.06	**1.09**
GSA	**4.41**	6.03	5.17	5.22	5.45	5.23	5.75	4.96	4.94	4.81	4.41	5.70	6.40	5.67	5.03	5.70	5.31	**5.36**
APA	**0.92**	1.42	1.04	1.22	1.19	1.07	1.28	1.02	1.04	0.93	0.95	1.28	1.56	1.12	0.95	1.23	1.13	**1.15**
NPA	**0.62**	0.97	0.70	0.82	0.66	0.77	0.83	0.64	0.67	0.66	0.81	0.76	1.02	0.81	0.61	0.79	0.73	**0.77**
WUA	**1.22**	1.98	1.50	1.67	1.32	1.63	1.89	1.31	1.46	1.32	1.69	1.75	2.36	1.84	1.34	1.85	1.50	**1.65**
PPA	**1.15**	1.84	1.47	1.53	1.31	1.51	1.72	1.30	1.39	1.36	1.58	1.53	2.38	1.87	1.39	1.67	1.47	**1.58**
WNA	**3.21**	5.14	4.35	4.81	3.02	4.99	5.67	3.66	4.51	3.67	5.60	4.54	7.62	5.60	3.99	5.36	4.54	**4.82**
NSA	**2.05**	2.88	2.32	2.43	2.11	2.48	2.68	2.16	2.23	2.05	2.56	2.44	3.08	2.54	2.02	2.51	2.31	**2.43**
WSA	**0.23**	0.34	0.27	0.29	0.33	0.28	0.30	0.26	0.25	0.25	0.28	0.29	0.34	0.30	0.26	0.29	0.30	**0.29**
HKA	**0.14**	0.21	0.16	0.18	0.18	0.17	0.17	0.15	0.15	0.15	0.17	0.17	0.20	0.18	0.15	0.16	0.18	**0.17**
KIX	**1.54**	2.79	2.64	2.74	1.59	2.92	3.37	2.01	2.48	1.95	2.91	2.22	4.65	3.24	2.22	3.04	2.51	**2.70**
CHA	**5.60**	8.06	6.42	6.62	7.09	6.64	6.75	6.18	6.17	6.17	5.88	6.19	7.89	6.76	6.03	6.46	6.71	**6.63**
QNA	**1.43**	2.01	1.65	1.73	2.03	1.66	1.85	1.75	1.49	1.61	1.60	1.70	1.80	1.67	1.62	1.66	1.85	**1.73**
DNA	**1.70**	4.63	3.08	3.30	2.54	3.75	4.29	3.22	2.89	2.74	3.15	2.76	5.90	3.85	2.74	3.37	2.76	**3.44**
NVA	**0.58**	1.19	0.74	0.83	1.02	0.83	0.96	0.77	0.71	0.76	0.73	0.79	1.14	0.86	0.69	0.80	0.86	**0.85**
Avg.	**1.63**	**2.54**	**2.02**	**2.16**	**1.94**	**2.17**	**2.40**	**1.89**	**1.96**	**1.82**	**2.07**	**2.09**	**2.93**	**2.29**	**1.85**	**2.25**	**2.07**	**2.15**
Rank*	-	*2*	*11*	*7*	*13*	*6*	*3*	*14*	*12*	*16*	*9*	*8*	*1*	*4*	*15*	*5*	*10*	-

* where rank 1 = highest % change, 16 = lowest % change.

Table A1.4. Average number of **days/year of Very High and Extreme (VH+E) Forest fire danger for fire season months (Oct-Apr) estimated for the 2090s (2080-2099)** from 16 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Current VH+E**	**Models for 2090s – Days/fire season of VH+E Fire Danger**																**Model avg.**
		CGMR	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**5.9**	12.2	6.2	8.7	5.7	7.7	9.8	5.2	7.3	6.4	11.1	8.1	13.9	9.2	6.0	9.2	7.3	**8.3**
DAR	**2.7**	6.4	3.3	4.5	3.2	4.2	5.1	3.6	3.7	2.8	5.3	3.5	6.6	4.1	2.5	5.3	3.8	**4.2**
COR	**1.5**	3.3	1.7	2.3	2.6	2.0	2.7	2.6	2.1	1.5	1.8	1.9	2.7	1.7	1.6	1.9	2.5	**2.2**
AKL	**8.3**	18.0	10.3	13.2	8.2	13.2	13.2	9.1	9.8	7.7	15.3	10.9	22.0	12.6	8.0	13.9	12.6	**12.4**
TGA	**7.7**	13.7	8.8	10.3	11.7	8.8	11.7	8.6	9.4	8.0	8.3	10.7	14.1	9.6	8.1	11.2	9.6	**10.1**
ROA	**1.5**	4.9	2.2	2.7	3.2	2.3	3.0	1.8	2.1	1.7	2.5	2.7	3.6	2.8	1.9	3.0	2.3	**2.6**
GSA	**34.1**	50.8	42.1	42.4	44.6	42.1	48.8	40.4	39.0	38.4	34.2	47.9	54.6	47.0	39.9	47.0	43.0	**43.9**
APA	**2.2**	5.9	2.3	3.8	4.0	2.6	4.3	2.7	3.4	1.8	3.0	4.0	6.1	3.3	2.2	3.9	2.9	**3.5**
NPA	**1.1**	2.4	1.1	1.8	0.8	1.3	1.7	1.1	1.0	1.3	2.1	1.6	2.8	2.1	1.1	1.8	1.2	**1.5**
WUA	**2.6**	9.5	3.9	6.2	3.1	4.6	7.7	3.2	4.5	3.0	7.8	6.3	12.2	6.5	3.7	7.3	4.3	**5.8**
PPA	**2.0**	7.6	3.3	4.4	2.4	3.6	5.2	2.4	3.3	3.1	6.4	3.8	12.3	6.4	3.8	4.7	3.3	**4.7**
WNA	**16.8**	36.3	28.9	34.6	16.2	35.8	44.8	22.4	31.1	21.3	40.6	31.9	64.6	39.5	25.6	40.4	31.7	**34.1**
NSA	**8.9**	16.7	11.4	12.8	10.2	12.3	16.1	10.8	11.0	9.8	14.3	12.8	18.4	13.9	9.0	13.2	12.0	**12.8**
WSA	**0**	0	0	0	0.1	0	0	0	0	0	0.1	0	0.2	0.1	0	0	0	**0.03**
HKA	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
KIX	**6.3**	15.2	14.2	16.1	6.8	16.5	20.6	10.2	13.0	9.3	18.9	11.5	30.7	18.7	11.0	17.8	13.5	**15.2**
CHA	**39.7**	60.5	45.3	48.1	54.3	47.9	51.4	45.0	43.0	44.7	41.8	46.3	57.2	48.6	43.9	45.4	49.2	**48.3**
QNA	**5.7**	10.2	6.9	7.7	11.2	7.3	9.7	7.8	5.8	7.4	6.7	7.7	8.7	7.4	6.7	7.8	9.3	**8.0**
DNA	**5.7**	34.1	18.8	20.7	13.8	26.0	30.2	21.3	17.4	15.1	19.3	15.1	44.3	25.3	16.6	22.1	15.7	**22.2**
NVA	**0.4**	3.1	0.6	1.2	2.3	0.7	1.6	1.0	0.8	1.0	1.0	1.1	2.7	0.8	0.6	1.1	1.4	**1.3**
Avg.	**7.6**	**15.5**	**10.5**	**12.1**	**10.2**	**11.9**	**14.4**	**9.9**	**10.4**	**9.2**	**12.0**	**11.4**	**18.9**	**13.0**	**9.6**	**12.8**	**11.3**	**12.1**
Rank*	**-**	*2*	*11*	*6*	*13*	*8*	*3*	*14*	*12*	*16*	*7*	*9*	*1*	*4*	*15*	*5*	*10*	**-**

* where rank 1 = highest % change, 16 = lowest % change.

Appendix 2 – __Full year averages__ (over all months, Jan-Dec) of changes in fire climate severity measures estimated from 16 Global Climate Models, and comparisons with current climate for the 1990s (1980-1999) for:

Table A2.1. Average **Annual Severity Rating (ASR) over all months (Jan-Dec) estimated for the 2040s (2030-2049)** from 16 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Current ASR**	**Models for 2040s – Annual Severity Rating (ASR)**																**Model avg.**
		CGMR	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**0.93**	1.18	1.06	1.08	1.09	1.06	1.14	1.14	1.08	1.07	1.33	1.15	1.28	1.25	1.04	1.22	1.14	**1.14**
DAR	**0.58**	0.80	0.68	0.71	0.74	0.71	0.75	0.79	0.72	0.74	0.83	0.73	0.83	0.80	0.68	0.80	0.70	**0.75**
COR	**0.59**	0.66	0.61	0.62	0.67	0.62	0.66	0.67	0.63	0.64	0.63	0.67	0.64	0.62	0.60	0.63	0.63	**0.64**
AKL	**1.14**	1.45	1.29	1.30	1.41	1.36	1.45	1.34	1.37	1.38	1.62	1.38	1.57	1.50	1.26	1.48	1.41	**1.41**
TGA	**1.10**	1.39	1.25	1.25	1.34	1.23	1.30	1.36	1.26	1.31	1.41	1.33	1.39	1.34	1.25	1.38	1.33	**1.32**
ROA	**0.56**	0.72	0.63	0.64	0.68	0.64	0.68	0.67	0.64	0.68	0.72	0.68	0.70	0.69	0.62	0.70	0.66	**0.67**
GSA	**2.80**	3.38	3.19	3.05	3.33	3.12	3.27	3.28	3.17	3.26	3.24	3.33	3.45	3.33	3.16	3.29	3.25	**3.26**
APA	**0.58**	0.74	0.67	0.67	0.74	0.65	0.72	0.71	0.67	0.72	0.77	0.74	0.75	0.72	0.66	0.76	0.73	**0.71**
NPA	**0.41**	0.50	0.47	0.51	0.49	0.48	0.53	0.49	0.48	0.50	0.62	0.51	0.56	0.55	0.45	0.52	0.50	**0.51**
WUA	**0.79**	1.05	0.99	0.97	1.02	1.00	1.04	1.02	1.03	0.99	1.28	1.09	1.25	1.22	0.97	1.19	1.09	**1.07**
PPA	**0.74**	0.97	0.91	0.89	0.96	0.90	0.99	0.94	0.93	0.92	1.13	0.93	1.12	1.16	0.91	0.99	0.97	**0.98**
WNA	**2.04**	3.18	2.68	2.87	2.59	2.95	3.42	2.80	3.05	2.71	4.09	2.94	4.15	3.62	2.93	3.39	3.13	**3.16**
NSA	**1.28**	1.63	1.43	1.43	1.50	1.48	1.51	1.48	1.46	1.45	1.69	1.48	1.65	1.58	1.45	1.61	1.51	**1.52**
WSA	**0.16**	0.19	0.17	0.18	0.20	0.17	0.18	0.19	0.17	0.18	0.20	0.19	0.18	0.18	0.17	0.18	0.18	**0.18**
HKA	**0.10**	0.12	0.11	0.12	0.12	0.11	0.12	0.12	0.12	0.12	0.14	0.12	0.11	0.12	0.11	0.11	0.12	**0.12**
KIX	**1.12**	2.14	1.64	2.07	1.64	1.88	2.20	1.99	1.89	1.59	3.01	1.72	3.02	2.40	2.08	2.11	1.95	**2.08**
CHA	**3.56**	4.25	3.94	4.00	4.15	3.86	4.22	4.07	4.01	4.18	3.96	4.08	4.18	4.16	3.94	3.82	4.06	**4.05**
QNA	**0.87**	1.03	0.94	0.98	1.09	0.96	1.03	1.09	0.92	1.03	0.96	1.08	0.96	0.94	0.93	0.97	1.00	**0.99**
DNA	**1.17**	2.53	1.90	2.15	1.93	1.98	2.61	2.30	2.16	1.92	2.75	1.91	3.05	2.73	2.25	2.08	1.92	**2.26**
NVA	**0.37**	0.52	0.44	0.47	0.60	0.45	0.55	0.52	0.48	0.54	0.53	0.49	0.51	0.51	0.45	0.44	0.48	**0.50**
Avg.	**1.04**	**1.42**	**1.25**	**1.30**	**1.32**	**1.28**	**1.42**	**1.35**	**1.31**	**1.30**	**1.54**	**1.33**	**1.57**	**1.47**	**1.30**	**1.38**	**1.34**	**1.37**
Rank*	**-**	*4*	*16*	*12*	*10*	*15*	*5*	*7*	*11*	*14*	*2*	*9*	*1*	*3*	*13*	*6*	*8*	**-**

* where rank 1 = highest, 16 = lowest.

Table A2.2. Average number of **days/year of Very High and Extreme (VH+E) Forest fire danger for all months (Jan-Dec) estimated for the 2040s (2030-2049)** from 16 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Current VH+E**	**Models for 2040s – Days/year of VH+E Fire Danger**																**Model avg.**
		CGMR	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**5.9**	8.8	6.6	8.3	8.7	6.6	8.5	8.4	6.8	7.7	9.3	8.7	10.2	9.9	7.6	10.4	7.4	**8.3**
DAR	**2.7**	4.7	2.9	4.3	3.9	3.7	3.8	4.5	3.8	4.0	4.6	3.7	4.9	4.4	3.5	4.4	3.6	**4.0**
COR	**1.5**	2.4	1.9	2.1	2.6	1.7	2.6	2.6	1.9	2.1	2.2	2.4	2.2	1.6	1.8	2.0	2.2	**2.1**
AKL	**8.3**	13.5	9.6	10.3	12.9	11.3	13.8	10.4	11.6	12.3	13.8	12.3	14.9	13.5	9.7	13.7	12.4	**12.2**
TGA	**7.7**	12.2	8.8	9.9	11.0	8.8	9.7	10.3	8.8	9.4	9.6	9.3	10.9	10.5	9.8	10.4	9.8	**9.9**
ROA	**1.5**	3.6	2.1	2.8	2.9	2.2	2.7	2.1	1.8	3.2	3.1	2.7	3.1	3.1	2.2	3.0	2.2	**2.7**
GSA	**34.7**	44.2	41.7	39.0	44.1	40.0	41.4	42.3	40.3	42.6	40.0	42.2	44.8	43.9	39.9	42.0	41.6	**41.9**
APA	**2.2**	4.2	2.9	3.3	4.2	3.0	3.2	3.4	2.9	4.1	3.3	3.3	4.3	3.9	3.3	3.8	3.7	**3.5**
NPA	**1.1**	1.1	1.2	1.6	1.1	1.4	2.2	0.9	1.0	1.5	1.6	1.4	1.8	2.0	1.3	1.8	1.5	**1.4**
WUA	**2.6**	5.6	4.3	4.8	5.6	4.9	5.3	4.3	4.9	4.8	6.9	6.0	8.1	7.3	5.1	7.9	6.0	**5.7**
PPA	**2.0**	3.5	3.5	3.9	4.6	3.1	4.3	2.6	2.8	3.9	4.5	3.7	4.7	6.5	3.3	3.5	3.9	**3.9**
WNA	**16.8**	38.4	24.2	29.8	26.2	32.1	39.0	29.1	33.8	26.2	46.8	31.9	54.7	43.0	31.7	38.4	34.2	**34.9**
NSA	**9.0**	14.9	11.1	11.5	12.9	12.5	13.1	11.5	11.3	11.5	14.3	11.9	14.2	12.9	12.5	13.7	12.8	**12.6**
WSA	**0**	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0.1	0	**0.01**
HKA	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
KIX	**6.5**	18.8	10.4	18.5	12.0	16.5	20.4	17.0	15.5	11.9	32.5	14.8	30.4	21.5	18.9	19.5	17.4	**18.5**
CHA	**40.9**	50.9	45.4	47.9	49.3	44.0	49.5	48.4	46.0	49.3	43.6	47.5	48.6	49.0	45.9	43.8	46.6	**47.2**
QNA	**5.7**	7.6	6.0	7.5	8.7	6.5	7.5	8.3	5.7	7.5	5.2	8.0	7.3	6.4	6.1	7.0	6.8	**7.0**
DNA	**6.1**	26.7	15.8	20.3	16.8	18.1	28.2	22.4	20.3	16.7	29.2	16.8	35.2	27.3	22.0	20.1	15.6	**21.9**
NVA	**0.4**	1.0	0.6	1.1	1.7	0.9	1.5	0.8	0.8	0.9	0.9	1.0	1.1	1.0	0.5	0.6	0.7	**0.9**
Avg.	**7.8**	**13.1**	**9.9**	**11.3**	**11.5**	**10.9**	**12.8**	**11.4**	**11.0**	**11.0**	**13.6**	**11.4**	**15.1**	**13.4**	**11.2**	**12.3**	**11.4**	**11.9**
Rank*	**-**	*4*	*16*	*11*	*7*	*15*	*5*	*8*	*13*	*14*	*2*	*10*	*1*	*3*	*12*	*6*	*9*	**-**

* where rank 1 = highest, 16 = lowest.

Table A2.3. Average **Annual Severity Rating (ASR) over all months (Jan-Dec) estimated for the 2090s (2089-2099)** from 16 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	Current ASR	Models for 2090s – Annual Severity Rating (ASR)																Model avg.
		CGMR	CNCM3	CSMK3	ECHOG	FGOALS	GFCM20	GFCM21	GIAOM	GIEH	HADCM3	HADGEM	IPCM4	MIHR	MIMR	MPEH5	MRCGCM	
KX	**0.93**	1.37	1.09	1.23	0.95	1.16	1.33	0.96	1.06	0.93	1.45	1.17	1.59	1.17	0.93	1.28	1.14	**1.18**
DAR	**0.58**	0.93	0.71	0.81	0.70	0.78	0.89	0.69	0.69	0.62	0.90	0.78	1.04	0.77	0.61	0.84	0.75	**0.78**
COR	**0.59**	0.77	0.64	0.67	0.71	0.66	0.69	0.64	0.62	0.58	0.67	0.64	0.72	0.64	0.59	0.65	0.68	**0.66**
AKL	**1.14**	1.67	1.34	1.48	1.23	1.47	1.59	1.22	1.32	1.13	1.70	1.43	1.94	1.48	1.16	1.57	1.42	**1.45**
TGA	**1.10**	1.55	1.26	1.41	1.39	1.28	1.50	1.22	1.25	1.14	1.41	1.47	1.71	1.32	1.14	1.45	1.37	**1.37**
ROA	**0.56**	0.84	0.64	0.72	0.68	0.66	0.74	0.62	0.62	0.57	0.73	0.76	0.87	0.68	0.57	0.73	0.68	**0.69**
GSA	**2.80**	3.86	3.37	3.40	3.48	3.37	3.76	3.22	3.17	3.08	3.25	3.64	4.17	3.68	3.23	3.71	3.47	**3.49**
APA	**0.58**	0.89	0.67	0.78	0.75	0.69	0.82	0.65	0.66	0.60	0.76	0.81	1.00	0.72	0.61	0.80	0.74	**0.75**
NPA	**0.41**	0.64	0.48	0.56	0.45	0.52	0.57	0.44	0.46	0.44	0.70	0.53	0.69	0.55	0.42	0.54	0.51	**0.53**
WUA	**0.79**	1.30	1.06	1.14	0.92	1.09	1.35	0.90	0.98	0.88	1.41	1.19	1.61	1.23	0.91	1.31	1.06	**1.15**
PPA	**0.74**	1.21	1.02	1.04	0.89	1.01	1.20	0.90	0.94	0.90	1.29	1.03	1.61	1.27	0.93	1.18	1.03	**1.09**
WNA	**2.04**	3.36	3.05	3.48	2.13	3.27	4.17	2.55	3.08	2.44	4.63	3.13	5.15	3.75	2.68	3.84	3.21	**3.37**
NSA	**1.28**	1.81	1.52	1.57	1.34	1.60	1.73	1.40	1.42	1.30	1.84	1.59	1.99	1.63	1.29	1.65	1.51	**1.57**
WSA	**0.16**	0.23	0.19	0.20	0.22	0.19	0.20	0.17	0.17	0.17	0.23	0.20	0.22	0.20	0.18	0.19	0.20	**0.20**
HKA	**0.10**	0.15	0.12	0.13	0.13	0.13	0.13	0.12	0.11	0.11	0.16	0.13	0.14	0.13	0.11	0.12	0.13	**0.13**
KIX	**1.12**	2.13	2.29	2.47	1.34	2.12	3.14	1.71	2.03	1.49	3.27	1.83	3.79	2.50	1.78	2.65	2.13	**2.29**
CHA	**3.56**	5.17	4.19	4.34	4.59	4.29	4.45	4.06	3.99	3.97	4.32	4.05	5.07	4.38	3.91	4.19	4.34	**4.33**
QNA	**0.87**	1.24	1.03	1.06	1.24	1.03	1.13	1.07	0.92	0.99	1.09	1.05	1.11	1.03	1.00	1.02	1.13	**1.07**
DNA	**1.17**	3.27	2.49	2.92	1.93	2.67	3.59	2.59	2.16	1.95	2.96	2.19	4.49	2.88	2.06	2.75	2.17	**2.69**
NVA	**0.37**	0.77	0.50	0.55	0.66	0.54	0.64	0.51	0.48	0.50	0.62	0.53	0.74	0.57	0.46	0.54	0.56	**0.57**
Avg.	**1.04**	**1.66**	**1.38**	**1.50**	**1.29**	**1.43**	**1.68**	**1.28**	**1.31**	**1.19**	**1.67**	**1.41**	**1.98**	**1.53**	**1.23**	**1.55**	**1.41**	**1.47**
Rank*	**-**	*4*	*11*	*7*	*13*	*8*	*2*	*14*	*12*	*16*	*3*	*10*	*1*	*6*	*15*	*5*	*9*	**-**

* where rank 1 = highest, 16 = lowest.

Table A2.4. Average number of **days/year of Very High and Extreme (VH+E) Forest fire danger for all months (Jan-Dec) estimated for the 2090s (2089-2099)** from 16 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Current VH+E**	**Models for 2090s – Days/year of VH+E Fire Danger**																**Model avg.**
		CGMR	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**5.9**	12.2	6.2	8.7	5.7	7.7	9.8	5.2	7.3	6.4	11.2	8.1	13.9	9.2	6.0	9.2	7.3	**8.4**
DAR	**2.7**	6.4	3.3	4.5	3.2	4.2	5.1	3.6	3.7	2.8	5.7	3.5	6.6	4.1	2.5	5.4	3.8	**4.3**
COR	**1.5**	3.3	1.7	2.3	2.6	2.0	2.7	2.6	2.1	1.5	1.8	1.9	2.7	1.7	1.6	1.9	2.5	**2.2**
AKL	**8.3**	18.0	10.3	13.2	8.2	13.3	13.3	9.3	9.8	7.8	16.1	11.0	22.1	12.6	8.1	14.0	12.6	**12.5**
TGA	**7.7**	13.8	8.9	10.5	11.7	8.9	11.8	8.7	9.5	8.1	9.7	11.0	14.4	9.6	8.1	11.4	9.6	**10.3**
ROA	**1.5**	4.9	2.2	2.7	3.2	2.3	3.0	1.8	2.1	1.7	2.6	2.7	3.6	2.8	1.9	3.0	2.3	**2.7**
GSA	**34.7**	52.0	43.3	43.6	45.2	43.4	51.0	41.4	39.9	39.1	39.4	48.9	57.2	48.4	40.6	48.8	44.0	**45.4**
APA	**2.2**	5.9	2.3	3.8	4.0	2.6	4.3	2.7	3.4	1.8	3.3	4.0	6.1	3.3	2.2	3.9	2.9	**3.5**
NPA	**1.1**	2.4	1.1	1.8	0.8	1.3	1.7	1.1	1.0	1.3	2.5	1.7	2.8	2.1	1.1	1.8	1.3	**1.6**
WUA	**2.6**	9.6	4.4	6.4	3.2	4.7	8.8	3.3	4.5	3.1	9.4	6.5	12.8	6.6	3.9	7.8	4.6	**6.2**
PPA	**2.0**	7.6	3.4	4.4	2.4	3.6	5.3	2.4	3.3	3.2	6.9	3.8	12.5	6.6	3.8	5.0	3.4	**4.8**
WNA	**16.8**	37.2	31.9	40.1	16.7	36.4	52.2	23.5	32.7	22.0	54.1	34.3	69.8	41.9	26.2	45.0	34.8	**37.4**
NSA	**9.0**	16.9	11.7	13.0	10.2	12.6	16.6	11.1	11.2	10.0	15.8	13.2	19.2	14.2	9.0	13.6	12.3	**13.1**
WSA	**0**	0	0	0	0.1	0	0	0	0	0	0.1	0	0.2	0.1	0	0	0	**0.03**
HKA	**0**	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0	**0.01**
KIX	**6.5**	17.7	20.2	23.5	8.2	18.2	31.4	13.0	16.4	10.0	35.0	14.0	40.5	22.4	13.6	24.8	18.4	**20.4**
CHA	**40.9**	63.8	47.5	51.0	56.7	50.3	54.6	47.3	44.7	46.5	49.2	49.0	59.9	51.2	46.2	47.5	51.4	**51.0**
QNA	**5.7**	10.2	6.9	7.7	11.2	7.3	9.7	7.8	5.8	7.4	6.9	7.7	8.7	7.4	6.7	7.8	9.3	**8.0**
DNA	**6.1**	39.5	24.9	30.6	17.0	29.1	42.0	27.7	21.0	17.0	31.3	19.5	56.0	30.6	19.4	28.9	20.4	**28.4**
NVA	**0.4**	3.1	0.6	1.2	2.3	0.7	1.6	1.0	0.8	1.0	1.3	1.1	2.7	0.8	0.6	1.1	1.4	**1.3**
Avg.	**7.8**	**16.2**	**11.5**	**13.4**	**10.6**	**12.4**	**16.2**	**10.7**	**10.9**	**9.5**	**15.1**	**12.1**	**20.6**	**13.8**	**10.1**	**14.0**	**12.1**	**13.1**
Rank*	**-**	*3*	*11*	*7*	*14*	*8*	*2*	*13*	*12*	*16*	*4*	*10*	*1*	*6*	*15*	*5*	*9*	**-**

* where rank 1 = highest, 16 = lowest.

Appendix 3 – Fire season averages (over months Oct-Apr) of changes in weather elements estimated from 16 Global Climate Models, and comparisons with current climate for the 1990s (1980-1999) for:

Table A3.1. Average change in **temperature (°C) for fire season months (Oct-Apr) estimated for the 2040s (2030-2049)** from 16 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Current (°C)**	**Models for 2040s – Change in Fire Season Temperature (°C)**																**Model avg.**
		CGMR	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**20.0**	1.26	0.98	0.73	1.11	0.81	0.99	1.35	0.73	1.41	0.13	1.25	1.00	1.82	1.33	0.32	0.85	**1.00**
DAR	**20.3**	1.34	1.02	0.80	1.16	0.87	1.03	1.44	0.77	1.52	0.19	1.35	1.03	1.93	1.42	0.32	0.91	**1.07**
COR	**19.7**	1.16	0.83	0.76	1.02	0.71	0.83	1.24	0.59	1.28	0.19	1.17	0.73	1.51	1.14	0.20	0.75	**0.88**
AKL	**19.8**	1.18	0.93	0.68	1.05	0.75	0.94	1.27	0.69	1.31	0.10	1.17	0.95	1.69	1.24	0.31	0.80	**0.94**
TGA	**19.6**	1.08	0.88	0.60	1.02	0.67	0.89	1.17	0.63	1.16	0.00	1.05	0.91	1.53	1.12	0.30	0.73	**0.86**
ROA	**18.1**	1.10	0.89	0.61	1.03	0.68	0.90	1.18	0.64	1.19	0.01	1.07	0.92	1.56	1.14	0.30	0.74	**0.87**
GSA	**20.5**	1.14	0.92	0.63	1.06	0.71	0.93	1.22	0.67	1.24	0.03	1.10	0.96	1.64	1.19	0.31	0.78	**0.91**
APA	**16.5**	1.08	0.87	0.61	1.03	0.66	0.88	1.16	0.62	1.15	-0.01	1.04	0.90	1.51	1.10	0.29	0.73	**0.85**
NPA	**18.0**	1.34	1.00	0.83	1.19	0.84	1.01	1.44	0.74	1.49	0.17	1.34	0.96	1.84	1.37	0.29	0.89	**1.05**
WUA	**18.4**	1.17	0.92	0.67	1.05	0.75	0.93	1.26	0.69	1.30	0.09	1.16	0.95	1.69	1.23	0.31	0.80	**0.94**
PPA	**17.5**	1.34	1.04	0.77	1.22	0.83	1.06	1.40	0.78	1.48	0.09	1.27	1.10	1.91	1.40	0.33	0.91	**1.06**
WNA	**17.4**	1.34	1.03	0.78	1.17	0.86	1.04	1.42	0.78	1.52	0.16	1.31	1.07	1.94	1.42	0.32	0.91	**1.07**
NSA	**18.2**	1.36	1.02	0.82	1.16	0.88	1.03	1.46	0.77	1.54	0.21	1.36	1.02	1.94	1.43	0.31	0.91	**1.08**
WSA	**16.6**	1.23	0.91	0.78	1.09	0.77	0.91	1.32	0.66	1.37	0.17	1.24	0.85	1.66	1.24	0.25	0.81	**0.95**
HKA	**16.3**	1.12	0.84	0.68	0.98	0.71	0.85	1.19	0.63	1.27	0.16	1.11	0.84	1.58	1.17	0.25	0.75	**0.88**
KIX	**16.0**	1.37	1.03	0.79	1.15	0.89	1.05	1.43	0.81	1.58	0.22	1.33	1.10	2.02	1.48	0.33	0.94	**1.10**
CHA	**17.8**	1.30	0.93	0.84	1.11	0.83	0.93	1.39	0.70	1.49	0.26	1.31	0.87	1.78	1.33	0.23	0.86	**1.01**
QNA	**14.9**	1.35	0.93	0.92	1.17	0.83	0.93	1.43	0.68	1.51	0.28	1.36	0.81	1.74	1.33	0.19	0.87	**1.02**
DNA	**16.2**	1.44	1.02	0.88	1.20	0.92	1.05	1.46	0.82	1.68	0.31	1.36	1.08	2.08	1.54	0.27	0.98	**1.13**
NVA	**14.9**	1.49	1.04	0.94	1.28	0.93	1.07	1.52	0.81	1.71	0.31	1.41	1.06	2.07	1.55	0.25	1.00	**1.15**
Avg.	**17.8**	**1.26**	**0.95**	**0.76**	**1.11**	**0.79**	**0.96**	**1.34**	**0.71**	**1.41**	**0.15**	**1.24**	**0.96**	**1.77**	**1.31**	**0.28**	**0.85**	**0.99**
Rank*	**-**	*5*	*10*	*13*	*7*	*12*	*8*	*3*	*14*	*2*	*16*	*6*	*9*	*1*	*4*	*15*	*11*	**-**

* where rank 1 = greatest increase, 16 = lowest increase (decrease).

Table A3.2. Average change in **rainfall (%) for fire season months (Oct-Apr) estimated for the 2040s (2030-2049)** from 16 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Current (mm)**	**Models for 2040s – Change in Fire Season Rainfall (%)**																**Model avg.**
		CGMR	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**642**	-1	-5	12	9	7	-8	1	-6	-1	38	9	-22	-7	9	-3	4	**2.3**
DAR	**567**	4	-4	10	8	8	-2	0	-3	0	38	7	-20	2	10	-4	3	**3.6**
COR	**963**	-2	1	7	-10	9	-1	-3	-1	8	33	-1	-4	7	9	4	0	**3.5**
AKL	**562**	5	-4	11	11	11	-4	3	0	2	50	7	-22	0	13	-4	3	**5.1**
TGA	**655**	1	-5	19	7	8	-4	0	-1	0	31	11	-24	1	13	-6	-1	**3.0**
ROA	**733**	3	-7	12	2	8	-6	0	-2	-1	49	10	-22	0	10	-7	-1	**2.9**
GSA	**517**	8	-3	13	17	7	-5	-3	-6	-5	42	10	-19	-1	11	-5	2	**4.1**
APA	**562**	1	-8	14	6	6	-8	3	-4	-2	64	12	-20	-2	9	-7	3	**4.2**
NPA	**781**	-2	-4	20	8	7	-5	-1	-2	1	43	7	-18	3	11	-1	-2	**4.0**
WUA	**607**	-3	-7	18	11	5	-4	3	-1	-1	61	8	-24	1	8	-5	0	**4.3**
PPA	**562**	0	-5	17	6	6	-7	-2	0	1	50	8	-17	5	10	-1	-2	**4.3**
WNA	**491**	-3	-6	21	23	3	-10	0	1	-7	70	15	-38	-5	-1	-10	1	**3.3**
NSA	**556**	2	-6	21	10	11	-5	-2	-2	-2	34	9	-22	-1	13	-5	-2	**3.2**
WSA	**1234**	-6	-2	4	-16	4	-6	-7	1	-1	39	-1	-5	7	6	6	-2	**1.4**
HKA	**1690**	-6	-1	7	-11	5	-3	-3	3	-1	26	3	-7	5	8	6	-1	**1.9**
KIX	**403**	-8	-3	17	34	12	4	2	11	-12	39	24	-47	-14	9	-8	3	**3.8**
CHA	**321**	-4	-2	5	-10	5	-2	-3	1	-2	25	-1	-6	5	2	7	-3	**1.1**
QNA	**480**	-1	2	8	-13	4	-1	0	4	9	31	-1	0	16	9	11	1	**4.8**
DNA	**448**	-7	5	6	16	21	0	-12	-7	-6	10	28	-24	-13	17	15	-1	**3**
NVA	**693**	-5	2	4	-18	7	-6	-6	2	4	37	0	-2	12	7	12	-3	**3.0**
Avg.	**673**	**-1.2**	**-3.1**	**12.3**	**4.5**	**7.7**	**-4.3**	**-1.4**	**-0.7**	**-0.9**	**40.5**	**8.1**	**-18.1**	**1.0**	**9.3**	**-0.3**	**0.0**	**3.3**
Rank*	**-**	*5*	*3*	*15*	*11*	*12*	*2*	*4*	*7*	*6*	*16*	*13*	*1*	*10*	*14*	*8*	*9*	**-**

* where rank 1 = greatest decrease, 16 = lowest decrease (highest increase).

Table A3.3. Average change in relative **humidity (actual %) for fire season months (Oct-Apr) estimated for the 2040s (2030-2049)** from 16 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Current (%)**	**Models for 2040s – Change in Fire Season Relative Humidity (%)**																**Model avg.**
		CGMR	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**69**	0.1	0.7	-0.1	0.4	0.1	0.8	0.4	0.0	0.4	0.9	-0.2	1.0	1.4	1.4	0.6	0.4	**0.51**
DAR	**69**	0.1	0.7	0.0	0.4	0.1	0.7	0.4	0.0	0.3	0.9	-0.2	0.8	1.3	1.3	0.6	0.3	**0.47**
COR	**69**	0.2	0.6	-0.1	0.3	0.2	0.6	0.3	0.2	0.4	0.7	-0.1	1.0	1.3	1.1	0.6	0.4	**0.47**
AKL	**68**	-0.2	0.4	0.0	0.4	-0.1	0.6	0.3	-0.2	0.1	0.6	-0.2	0.4	0.7	0.9	0.3	0.1	**0.25**
TGA	**66**	0.0	0.6	-0.2	0.3	0.1	0.9	0.3	0.2	0.5	0.7	-0.4	1.1	1.5	1.5	0.5	0.4	**0.50**
ROA	**67**	0.0	0.7	-0.2	0.3	0.1	0.9	0.3	0.2	0.5	0.7	-0.4	1.2	1.6	1.5	0.6	0.4	**0.52**
GSA	**60**	-0.2	0.1	-0.1	0.1	-0.1	0.3	0.1	-0.1	0.0	0.3	-0.2	0.2	0.3	0.5	0.1	0.0	**0.09**
APA	**67**	0.0	0.6	-0.2	0.3	0.1	0.9	0.3	0.2	0.5	0.8	-0.4	1.2	1.6	1.5	0.6	0.4	**0.51**
NPA	**75**	0.1	0.7	-0.1	0.3	0.1	0.7	0.4	0.0	0.3	0.9	-0.1	0.9	1.4	1.3	0.6	0.4	**0.50**
WUA	**69**	-0.3	0.2	0.0	0.3	-0.2	0.4	0.2	-0.3	0.0	0.3	-0.3	0.1	0.2	0.6	0.1	-0.1	**0.08**
PPA	**70**	-0.4	-0.2	0.0	0.0	-0.3	0.0	0.0	-0.4	-0.3	-0.2	-0.1	-0.6	-0.7	-0.2	-0.2	-0.3	**-0.24**
WNA	**68**	-0.1	0.3	0.1	0.4	-0.2	0.4	0.2	-0.3	-0.1	0.4	-0.1	0.0	0.2	0.6	0.2	0.0	**0.11**
NSA	**66**	0.1	0.6	-0.1	0.3	0.1	0.7	0.4	0.0	0.3	0.8	-0.2	0.9	1.2	1.2	0.5	0.3	**0.46**
WSA	**74**	0.2	0.7	-0.1	0.3	0.2	0.7	0.4	0.2	0.5	0.8	-0.1	1.0	1.5	1.2	0.6	0.4	**0.52**
HKA	**75**	0.1	0.8	-0.1	0.3	0.2	0.7	0.4	0.1	0.4	1.1	-0.2	1.1	1.6	1.5	0.8	0.4	**0.57**
KIX	**70**	0.0	0.3	0.2	0.5	-0.1	0.2	0.2	-0.4	-0.1	0.3	0.0	-0.1	0.0	0.4	0.1	0.0	**0.11**
CHA	**59**	-0.1	0.6	-0.2	0.2	0.0	0.4	0.1	-0.1	-0.1	0.8	-0.2	0.7	0.9	0.9	0.6	0.2	**0.30**
QNA	**58**	0.4	0.7	0.0	0.4	0.3	0.6	0.4	0.4	0.6	0.6	0.1	1.1	1.4	1.0	0.5	0.5	**0.56**
DNA	**64**	-0.3	0.1	0.2	0.4	-0.2	0.0	0.1	-0.5	-0.5	-0.2	0.2	-0.7	-0.8	-0.2	0.0	-0.3	**-0.18**
NVA	**69**	0.1	0.8	0.2	0.7	0.1	0.7	0.7	-0.3	0.0	0.5	0.5	0.2	0.6	0.9	0.6	0.2	**0.40**
Avg.	**68**	**-0.01**	**0.49**	**-0.03**	**0.34**	**0.03**	**0.56**	**0.28**	**-0.06**	**0.18**	**0.58**	**-0.14**	**0.57**	**0.86**	**0.93**	**0.41**	**0.21**	**0.33**
Rank*	**-**	*4*	*11*	*3*	*9*	*5*	*12*	*8*	*2*	*6*	*14*	*1*	*13*	*15*	*16*	*10*	*7*	**-**

* where rank 1 = greatest decrease, 16 = lowest decrease (highest increase).

Table A3.4. Average change in **wind speed (km/h) for fire season months (Oct-Apr) estimated for the 2040s (2030-2049)** from 16 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Current (km/h)**	**Models for 2040s – Change in Fire Season Wind Speed (km/h)**																**Model avg.**
		CGMR	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**21.1**	-0.49	-0.13	-0.61	-0.88	0.01	-0.21	-0.63	0.01	-0.33	-0.25	-0.40	0.30	0.05	-0.14	0.39	-0.33	**-0.23**
DAR	**14.3**	-0.36	-0.16	-0.22	-0.59	0.05	-0.20	-0.36	-0.01	-0.12	-0.15	-0.20	0.12	-0.02	-0.11	0.19	-0.21	**-0.15**
COR	**18.5**	-0.47	-0.18	-0.50	-0.64	-0.02	-0.18	-0.43	0.03	-0.25	0.12	-0.32	0.06	0.03	-0.06	0.19	-0.26	**-0.18**
AKL	**22.0**	-0.28	-0.08	-0.32	-0.34	0.06	-0.11	-0.39	0.06	-0.12	0.04	-0.08	0.11	0.10	0.11	0.17	-0.09	**-0.07**
TGA	**18.9**	-0.25	-0.03	-0.22	0.00	0.00	-0.08	-0.22	-0.05	-0.23	-0.05	0.17	-0.19	-0.22	-0.10	0.11	-0.07	**-0.09**
ROA	**16.2**	-0.32	-0.07	-0.25	-0.25	0.02	-0.17	-0.29	-0.08	-0.24	0.10	0.07	-0.16	-0.17	-0.08	0.14	-0.12	**-0.12**
GSA	**19.0**	-0.18	-0.10	-0.06	0.11	0.06	-0.01	-0.19	0.01	0.01	-0.15	0.23	-0.17	-0.16	0.09	-0.05	0.00	**-0.03**
APA	**17.2**	-0.19	0.01	-0.21	0.07	0.01	-0.05	-0.20	-0.05	-0.22	-0.05	0.17	-0.19	-0.21	-0.06	0.11	-0.04	**-0.07**
NPA	**21.6**	-0.47	-0.21	-0.37	-0.81	0.03	-0.26	-0.49	-0.03	-0.17	-0.06	-0.26	0.15	-0.01	-0.05	0.25	-0.26	**-0.19**
WUA	**22.8**	-0.29	-0.05	-0.30	-0.22	0.08	-0.09	-0.37	0.06	-0.10	0.12	-0.03	0.09	0.10	0.16	0.21	-0.03	**-0.04**
PPA	**21.7**	-0.29	-0.06	-0.30	-0.35	0.03	-0.10	-0.38	0.05	-0.12	0.10	-0.13	0.17	0.13	0.11	0.21	-0.08	**-0.06**
WNA	**31.3**	-0.61	-0.14	-0.56	-1.03	0.03	-0.27	-0.71	0.04	-0.30	0.04	-0.45	0.40	0.16	0.02	0.42	-0.30	**-0.20**
NSA	**19.5**	-0.49	-0.16	-0.58	-0.88	-0.01	-0.27	-0.53	0.00	-0.33	0.04	-0.38	0.18	0.01	-0.10	0.28	-0.29	**-0.22**
WSA	**17.9**	-0.50	-0.02	-0.77	-0.86	-0.02	-0.20	-0.60	0.01	-0.53	0.39	-0.49	0.26	0.21	-0.05	0.53	-0.30	**-0.19**
HKA	**16.0**	-0.37	-0.08	-0.44	-0.66	0.01	-0.20	-0.36	0.00	-0.25	0.29	-0.32	0.13	0.10	0.00	0.26	-0.20	**-0.13**
KIX	**17.9**	-0.45	-0.14	-0.48	-0.81	-0.07	-0.17	-0.40	0.03	-0.27	-0.07	-0.41	0.26	0.09	-0.13	0.22	-0.21	**-0.19**
CHA	**20.8**	-0.37	-0.14	-0.64	-0.62	-0.05	0.05	-0.48	0.29	-0.13	-1.01	-0.59	0.76	0.17	-0.06	0.22	-0.24	**-0.18**
QNA	**14.4**	-0.39	-0.16	-0.44	-0.89	0.00	-0.25	-0.46	0.00	-0.24	0.07	-0.53	0.24	0.06	-0.11	0.20	-0.30	**-0.20**
DNA	**18.9**	-0.37	-0.03	-0.59	-0.85	-0.02	-0.26	-0.47	0.00	-0.40	-0.20	-0.51	0.36	0.03	-0.26	0.43	-0.34	**-0.22**
NVA	**22.8**	-0.19	-0.09	-0.42	-0.53	0.00	0.17	-0.19	0.37	0.14	0.08	-0.94	0.79	0.70	0.22	0.15	-0.07	**0.01**
Avg.	**19.6**	**-0.37**	**-0.10**	**-0.41**	**-0.55**	**0.01**	**-0.14**	**-0.41**	**0.04**	**-0.21**	**-0.03**	**-0.27**	**0.18**	**0.06**	**-0.03**	**0.23**	**-0.19**	**-0.14**
Rank*	**-**	*13*	*8*	*15*	*16*	*5*	*9*	*14*	*4*	*11*	*6*	*12*	*2*	*3*	*7*	*1*	*10*	**-**

* where rank 1 = greatest increase, 16 = lowest increase (greatest decrease).

Table A3.5. Average change in **temperature (°C) for fire season months (Oct-Apr) estimated for the 2090s (2080-2099)** from 16 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Current (°C)**	**Models for 2090s – Change in Fire Season Temperature (°C)**																**Model avg.**
		CGMR	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**20.0**	2.74	2.27	1.56	2.28	1.96	2.23	2.38	1.52	2.17	1.48	2.51	2.96	4.40	3.00	2.29	2.42	**2.39**
DAR	**20.3**	2.91	2.40	1.68	2.40	2.10	2.35	2.54	1.59	2.33	1.63	2.69	3.09	4.70	3.19	2.42	2.59	**2.54**
COR	**19.7**	2.50	1.93	1.47	2.20	1.68	1.89	2.22	1.27	2.00	1.30	2.33	2.47	3.81	2.69	1.93	2.20	**2.12**
AKL	**19.8**	2.59	2.14	1.47	2.18	1.81	2.09	2.24	1.43	2.02	1.36	2.37	2.80	4.10	2.82	2.15	2.27	**2.24**
TGA	**19.6**	2.40	1.98	1.34	2.12	1.59	1.93	2.05	1.34	1.81	1.10	2.15	2.64	3.68	2.58	1.97	2.05	**2.05**
ROA	**18.1**	2.43	2.02	1.36	2.13	1.62	1.96	2.08	1.36	1.84	1.14	2.19	2.69	3.75	2.63	2.01	2.09	**2.08**
GSA	**20.5**	2.52	2.09	1.40	2.17	1.70	2.04	2.15	1.41	1.92	1.21	2.26	2.78	3.92	2.72	2.09	2.17	**2.16**
APA	**16.5**	2.40	1.97	1.34	2.14	1.56	1.91	2.05	1.33	1.80	1.07	2.15	2.63	3.64	2.57	1.95	2.04	**2.03**
NPA	**18.0**	2.91	2.33	1.68	2.50	2.01	2.28	2.55	1.55	2.31	1.53	2.68	3.02	4.54	3.16	2.33	2.56	**2.50**
WUA	**18.4**	2.57	2.13	1.46	2.17	1.80	2.08	2.22	1.43	2.00	1.34	2.34	2.79	4.08	2.80	2.14	2.25	**2.22**
PPA	**17.5**	2.94	2.38	1.63	2.50	2.00	2.37	2.49	1.62	2.28	1.43	2.62	3.22	4.57	3.16	2.39	2.51	**2.51**
WNA	**17.4**	2.91	2.39	1.64	2.39	2.09	2.37	2.50	1.61	2.32	1.58	2.65	3.15	4.67	3.17	2.42	2.55	**2.53**
NSA	**18.2**	2.93	2.40	1.69	2.40	2.13	2.36	2.57	1.60	2.36	1.67	2.72	3.09	4.74	3.21	2.43	2.62	**2.56**
WSA	**16.6**	2.67	2.12	1.55	2.31	1.83	2.07	2.35	1.40	2.12	1.40	2.47	2.72	4.13	2.89	2.12	2.35	**2.28**
HKA	**16.3**	2.43	1.96	1.39	2.03	1.72	1.94	2.11	1.31	1.94	1.32	2.23	2.56	3.86	2.64	1.98	2.14	**2.10**
KIX	**16.0**	2.94	2.43	1.66	2.33	2.19	2.43	2.53	1.64	2.39	1.70	2.69	3.20	4.85	3.23	2.48	2.61	**2.58**
CHA	**17.8**	2.80	2.20	1.63	2.33	1.99	2.18	2.47	1.45	2.29	1.58	2.61	2.82	4.43	3.04	2.22	2.49	**2.41**
QNA	**14.9**	2.90	2.19	1.70	2.51	1.97	2.17	2.57	1.44	2.37	1.54	2.70	2.81	4.41	3.11	2.19	2.54	**2.44**
DNA	**16.2**	3.06	2.41	1.72	2.40	2.27	2.49	2.61	1.65	2.55	1.78	2.77	3.24	4.99	3.34	2.49	2.68	**2.65**
NVA	**14.9**	3.18	2.44	1.79	2.60	2.26	2.51	2.72	1.66	2.63	1.74	2.88	3.29	5.02	3.43	2.50	2.75	**2.71**
Avg.	**17.8**	**2.74**	**2.21**	**1.56**	**2.31**	**1.91**	**2.18**	**2.37**	**1.48**	**2.17**	**1.44**	**2.50**	**2.90**	**4.31**	**2.97**	**2.22**	**2.39**	**2.35**
Rank*	**-**	*4*	*10*	*14*	*8*	*13*	*11*	*7*	*15*	*12*	*16*	*5*	*3*	*1*	*2*	*9*	*6*	**-**

* where rank 1 = greatest increase, 16 = lowest increase.

Table A3.6. Average change in **rainfall (%) for fire season months (Oct-Apr) estimated for the 2090s (2080-2099)** from 16 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Current (mm)**	**Models for 2090s – Change in Fire Season Rainfall (%)**																**Model avg.**
		CGMR	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**642**	2	-2	4	8	-1	-14	9	9	9	72	10	-34	8	31	0	9	7.5
DAR	**567**	-5	-3	-1	3	4	-14	13	9	12	64	6	-34	12	33	0	12	7.0
COR	**963**	-12	-1	-2	-19	4	-1	6	6	16	40	3	-13	24	18	5	4	4.9
AKL	**562**	4	1	0	10	3	-13	24	6	15	74	10	-32	15	35	-3	11	10.1
TGA	**655**	-3	-3	-3	7	3	-12	15	6	12	66	9	-35	11	34	-2	11	7.3
ROA	**733**	-3	-3	-7	5	6	-15	14	4	11	81	3	-34	8	33	-5	10	6.8
GSA	**517**	4	-3	-5	-2	9	-18	11	0	5	68	0	-33	8	32	2	11	5.6
APA	**562**	-1	1	-3	8	9	-16	19	3	14	86	4	-35	11	33	-9	11	8.5
NPA	**781**	-4	-2	-6	0	-1	-8	8	6	14	60	9	-31	17	32	2	8	6.5
WUA	**607**	6	3	-4	16	2	-9	17	8	14	81	4	-28	11	32	-4	16	10.3
PPA	**562**	-1	1	-5	3	1	-12	10	8	16	74	7	-28	19	33	1	13	8.8
WNA	**491**	21	-2	-1	42	-6	-16	15	7	12	94	11	-32	-7	25	-9	20	11.0
NSA	**556**	3	-4	-2	5	3	-10	16	7	12	68	9	-34	14	27	-5	9	7.4
WSA	**1234**	-20	3	-10	-32	5	-10	-5	4	0	58	-4	-18	19	11	5	-3	0.2
HKA	**1690**	-17	3	-9	-25	0	-8	-2	6	-1	51	2	-21	19	14	6	1	1.3
KIX	**403**	28	2	1	52	-12	-18	9	14	6	70	33	-28	-12	37	-1	28	13.0
CHA	**321**	-12	2	-14	-29	-1	-2	-6	4	0	42	1	-15	14	18	4	-3	0.3
QNA	**480**	-13	6	-6	-30	5	9	-6	6	11	43	2	-7	27	15	12	0	4.6
DNA	**448**	-12	-8	-5	1	-17	-10	-1	16	1	47	35	-47	3	43	4	1	3
NVA	**693**	-20	5	-8	-33	6	-1	-5	5	10	58	2	-16	25	15	7	-3	2.9
Avg.	673	**-2.7**	**-0.2**	**-4.3**	**-0.6**	**1.1**	**-9.8**	**8.1**	**6.7**	**9.5**	**64.9**	**7.9**	**-27.7**	**12.3**	**27.5**	**0.6**	**8.3**	**6.4**
Rank*	**-**	*4*	*6*	*3*	*5*	*8*	*2*	*11*	*9*	*13*	*16*	*10*	*1*	*14*	*15*	*7*	*12*	**-**

* where rank 1 = greatest decrease, 16 = lowest decrease (highest increase).

Table A3.7. Average change in **relative humidity (actual %) for fire season months (Oct-Apr) estimated for the 2090s (2080-2099)** from 16 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Current (%)**	**Models for 2090s – Change in Fire Season Relative Humidity (%)**																**Model avg.**
		CGMR	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**69**	-0.2	1.6	0.0	1.1	0.0	1.4	1.8	1.2	2.3	0.7	0.9	1.8	2.4	2.7	1.8	0.6	**1.27**
DAR	**69**	-0.2	1.5	0.1	1.1	0.0	1.3	1.8	1.0	2.0	0.7	0.9	1.6	2.3	2.5	1.7	0.6	**1.18**
COR	**69**	0.2	1.3	0.1	0.5	0.4	1.3	1.2	1.0	1.4	0.7	0.8	1.8	2.3	1.9	1.5	0.6	**1.06**
AKL	**68**	-0.5	1.1	-0.1	1.4	-0.6	0.7	1.6	0.9	1.9	0.1	0.5	0.9	1.1	2.2	1.2	0.4	**0.79**
TGA	**66**	-0.3	1.7	-0.1	0.7	0.2	1.5	1.6	1.3	2.2	0.7	0.6	2.0	2.5	2.5	1.9	0.6	**1.22**
ROA	**67**	-0.2	1.7	-0.1	0.8	0.2	1.5	1.6	1.3	2.3	0.7	0.6	2.0	2.6	2.6	2.0	0.6	**1.28**
GSA	**60**	-0.5	0.5	-0.2	0.4	-0.3	0.3	0.7	0.4	0.9	0.1	0.1	0.4	0.5	1.0	0.6	0.1	**0.31**
APA	**67**	-0.3	1.7	-0.1	0.7	0.2	1.5	1.6	1.3	2.3	0.7	0.6	2.0	2.6	2.5	2.0	0.6	**1.25**
NPA	**75**	-0.1	1.6	0.1	1.0	0.1	1.3	1.7	1.1	2.0	0.8	1.0	1.7	2.4	2.6	1.7	0.6	**1.23**
WUA	**69**	-0.7	0.8	-0.1	1.3	-0.9	0.3	1.3	0.6	1.5	-0.2	0.2	0.3	0.3	1.7	0.8	0.2	**0.46**
PPA	**70**	-0.7	-0.2	-0.1	0.6	-0.9	-0.6	0.3	-0.2	0.1	-0.5	-0.2	-0.9	-1.2	0.0	-0.3	-0.2	**-0.32**
WNA	**68**	-0.5	0.7	0.0	1.4	-0.8	0.3	1.3	0.5	1.3	-0.2	0.5	0.3	0.3	1.7	0.7	0.2	**0.48**
NSA	**66**	-0.1	1.5	0.1	0.9	0.1	1.2	1.6	1.1	1.9	0.6	0.8	1.6	2.2	2.4	1.6	0.6	**1.13**
WSA	**74**	0.2	1.5	0.1	0.5	0.6	1.4	1.3	1.1	1.6	0.9	0.9	1.8	2.6	2.1	1.7	0.7	**1.20**
HKA	**75**	-0.2	1.7	0.0	0.8	0.2	1.6	1.8	1.2	2.2	0.9	1.0	2.0	2.8	2.8	2.0	0.6	**1.34**
KIX	**70**	-0.2	0.5	0.2	1.7	-0.9	0.2	1.2	0.4	1.1	-0.4	0.7	0.3	0.1	1.6	0.4	0.2	**0.44**
CHA	**59**	-0.5	1.0	-0.1	0.5	-0.2	0.8	1.1	0.7	1.2	0.5	0.6	1.0	1.4	1.8	1.2	0.2	**0.71**
QNA	**58**	0.7	1.3	0.3	0.6	0.8	1.5	1.1	1.0	1.3	0.8	0.9	2.1	2.6	1.8	1.5	0.8	**1.19**
DNA	**64**	-0.5	0.0	0.1	1.6	-1.2	-0.6	0.7	-0.1	0.2	-0.8	0.3	-0.9	-1.2	0.6	-0.2	0.0	**-0.12**
NVA	**69**	0.0	1.6	0.6	2.4	-0.5	0.9	2.3	1.0	1.7	0.4	1.6	0.9	1.6	2.9	1.5	1.0	**1.23**
Avg.	**68**	**-0.22**	**1.16**	**0.04**	**1.00**	**-0.18**	**0.88**	**1.38**	**0.84**	**1.57**	**0.35**	**0.66**	**1.15**	**1.51**	**2.00**	**1.26**	**0.44**	**0.87**
Rank*	**-**	*1*	*11*	*3*	*9*	*2*	*8*	*13*	*7*	*15*	*4*	*6*	*10*	*14*	*16*	*12*	*5*	**-**

* where rank 1 = greatest decrease, 16 = lowest decrease (highest increase).

Table A3.8. Average change in **wind speed (km/h) for fire season months (Oct-Apr) estimated for the 2090s (2080-2099)** from 16 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Current (km/h)**	**Models for 2090s – Change in Fire Season Wind Speed (km/h)**																**Model avg.**
		CGMR	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**21.1**	-1.38	-0.13	-0.79	-2.24	0.07	-0.29	-1.23	-0.08	-0.85	0.34	-1.11	-0.58	-0.30	-0.88	-0.02	-0.75	**-0.64**
DAR	**14.3**	-0.92	-0.13	-0.47	-1.45	0.10	-0.27	-0.71	-0.10	-0.41	0.24	-0.71	-0.48	-0.12	-0.52	-0.02	-0.41	**-0.40**
COR	**18.5**	-1.16	-0.12	-0.63	-1.62	0.09	-0.28	-0.84	-0.12	-0.57	0.58	-0.85	-0.60	-0.17	-0.70	-0.01	-0.56	**-0.47**
AKL	**22.0**	-0.84	-0.03	-0.45	-1.06	0.19	-0.08	-0.66	0.10	-0.29	0.44	-0.52	-0.40	0.10	-0.17	0.09	-0.32	**-0.24**
TGA	**18.9**	-0.52	-0.11	-0.22	-0.15	-0.09	-0.19	-0.43	-0.03	-0.41	0.20	-0.17	-0.61	-0.31	-0.11	-0.12	-0.14	**-0.21**
ROA	**16.2**	-0.76	-0.13	-0.32	-0.67	-0.03	-0.26	-0.52	-0.09	-0.44	0.38	-0.30	-0.70	-0.24	-0.24	-0.12	-0.24	**-0.29**
GSA	**19.0**	-0.42	-0.01	-0.22	-0.01	0.08	-0.06	-0.35	0.15	-0.04	0.25	-0.16	-0.53	-0.04	0.12	-0.03	0.05	**-0.08**
APA	**17.2**	-0.39	-0.07	-0.19	-0.01	-0.11	-0.13	-0.37	0.00	-0.38	0.15	-0.10	-0.52	-0.30	-0.06	-0.11	-0.11	**-0.17**
NPA	**21.6**	-1.29	-0.18	-0.57	-1.95	0.14	-0.32	-0.95	-0.09	-0.51	0.44	-0.92	-0.67	-0.11	-0.66	-0.02	-0.53	**-0.51**
WUA	**22.8**	-0.79	0.01	-0.42	-0.86	0.19	-0.01	-0.63	0.13	-0.25	0.48	-0.42	-0.35	0.19	-0.06	0.15	-0.29	**-0.18**
PPA	**21.7**	-0.81	-0.02	-0.46	-1.09	0.16	-0.07	-0.66	0.08	-0.31	0.47	-0.52	-0.33	0.11	-0.20	0.07	-0.33	**-0.24**
WNA	**31.3**	-1.63	-0.15	-0.86	-2.63	0.22	-0.36	-1.36	-0.02	-0.81	0.67	-1.22	-0.66	-0.06	-0.79	0.05	-0.77	**-0.65**
NSA	**19.5**	-1.37	-0.18	-0.70	-2.15	0.13	-0.42	-1.08	-0.09	-0.76	0.49	-1.03	-0.59	-0.25	-0.88	-0.04	-0.73	**-0.60**
WSA	**17.9**	-1.35	-0.11	-0.76	-2.18	0.10	-0.25	-1.16	-0.06	-0.97	0.79	-0.95	-0.43	-0.11	-0.78	0.05	-0.85	**-0.56**
HKA	**16.0**	-1.02	-0.10	-0.50	-1.60	0.11	-0.19	-0.72	-0.07	-0.51	0.60	-0.70	-0.42	-0.03	-0.54	0.04	-0.52	**-0.39**
KIX	**17.9**	-1.02	-0.16	-0.53	-1.85	0.03	-0.27	-0.87	-0.10	-0.66	0.25	-0.92	-0.36	-0.27	-0.84	0.02	-0.60	**-0.51**
CHA	**20.8**	-0.79	-0.01	-0.76	-1.89	0.16	0.00	-1.25	0.24	-0.74	-0.37	-1.39	0.27	-0.25	-1.04	0.18	-0.68	**-0.52**
QNA	**14.4**	-1.09	-0.14	-0.54	-2.07	0.14	-0.36	-0.89	-0.12	-0.63	0.44	-1.02	-0.42	-0.16	-0.91	-0.01	-0.67	**-0.53**
DNA	**18.9**	-1.14	-0.18	-0.65	-2.11	-0.02	-0.33	-1.02	-0.13	-0.94	0.06	-0.99	-0.35	-0.41	-1.02	-0.08	-0.78	**-0.63**
NVA	**22.8**	-0.36	0.19	-0.48	-1.68	0.56	0.29	-0.55	0.33	0.00	0.35	-1.01	0.89	0.74	-0.56	0.47	-0.48	**-0.08**
Avg.	**19.6**	**-0.95**	**-0.09**	**-0.53**	**-1.46**	**0.11**	**-0.19**	**-0.81**	**0.00**	**-0.52**	**0.36**	**-0.75**	**-0.39**	**-0.10**	**-0.54**	**0.03**	**-0.49**	**-0.40**
Rank*	**-**	*15*	*5*	*11*	*16*	*2*	*7*	*14*	*4*	*10*	*1*	*13*	*8*	*6*	*12*	*3*	*9*	**-**

* where rank 1 = greatest increase, 16 = lowest increase (greatest decrease).

Appendix 4 – <u>Full year averages</u> (over all months, Jan-Dec) of changes in weather elements estimated from 16 Global Climate Models, and comparisons with current climate for the 1990s (1980-1999) for:

Table A4.1. Average change in **temperature (°C) for all months (Jan-Dec) estimated for the 2040s (2030-2049)** from 16 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Current (°C)**	**Models for 2040s – Change in Mean Annual Temperature (°C)**																**Model avg.**
		CGMR	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**17.9**	1.43	1.12	0.75	1.17	0.88	1.13	1.40	0.84	1.39	2.08	1.17	0.96	1.79	1.29	0.48	0.93	**1.18**
DAR	**18.1**	1.53	1.19	0.83	1.24	0.95	1.19	1.50	0.90	1.50	2.25	1.27	0.99	1.90	1.37	0.49	0.99	**1.26**
COR	**17.6**	1.31	0.96	0.70	1.06	0.78	0.94	1.25	0.68	1.25	1.75	1.09	0.70	1.46	1.11	0.33	0.77	**1.01**
AKL	**17.4**	1.33	1.05	0.69	1.10	0.81	1.05	1.31	0.78	1.29	1.92	1.09	0.90	1.67	1.21	0.45	0.86	**1.09**
TGA	**17.2**	1.20	0.94	0.59	1.02	0.71	0.95	1.17	0.69	1.14	1.63	0.95	0.85	1.50	1.09	0.41	0.76	**0.98**
ROA	**15.4**	1.22	0.96	0.60	1.04	0.73	0.97	1.19	0.71	1.16	1.67	0.97	0.86	1.53	1.12	0.43	0.78	**1.00**
GSA	**17.8**	1.27	1.00	0.63	1.08	0.76	1.02	1.24	0.75	1.22	1.77	1.01	0.91	1.61	1.16	0.45	0.82	**1.04**
APA	**13.9**	1.20	0.93	0.58	1.03	0.70	0.94	1.16	0.68	1.13	1.59	0.94	0.83	1.48	1.09	0.41	0.75	**0.96**
NPA	**15.9**	1.51	1.15	0.80	1.24	0.92	1.14	1.47	0.84	1.46	2.11	1.25	0.92	1.80	1.33	0.45	0.94	**1.21**
WUA	**16.1**	1.32	1.04	0.69	1.10	0.81	1.05	1.30	0.78	1.28	1.90	1.07	0.91	1.66	1.20	0.45	0.86	**1.09**
PPA	**15.4**	1.52	1.17	0.78	1.28	0.90	1.21	1.47	0.89	1.45	2.06	1.18	1.05	1.89	1.37	0.54	0.97	**1.23**
WNA	**15.2**	1.53	1.20	0.82	1.26	0.94	1.22	1.50	0.91	1.49	2.21	1.23	1.04	1.93	1.38	0.53	1.00	**1.26**
NSA	**15.5**	1.54	1.20	0.84	1.25	0.96	1.20	1.52	0.90	1.52	2.29	1.29	0.99	1.91	1.38	0.49	1.00	**1.27**
WSA	**14.6**	1.39	1.04	0.74	1.13	0.84	1.03	1.34	0.75	1.34	1.92	1.15	0.81	1.62	1.21	0.39	0.85	**1.10**
HKA	**14.2**	1.28	0.98	0.69	1.04	0.78	0.99	1.24	0.73	1.24	1.82	1.04	0.81	1.56	1.13	0.40	0.81	**1.04**
KIX	**13.8**	1.57	1.24	0.87	1.27	0.98	1.27	1.55	0.96	1.56	2.35	1.27	1.08	2.02	1.43	0.56	1.05	**1.32**
CHA	**14.9**	1.49	1.12	0.83	1.19	0.91	1.11	1.45	0.82	1.46	2.11	1.25	0.85	1.75	1.29	0.42	0.92	**1.19**
QNA	**11.7**	1.54	1.11	0.85	1.24	0.92	1.10	1.47	0.79	1.49	2.04	1.28	0.78	1.69	1.29	0.37	0.90	**1.18**
DNA	**13.4**	1.68	1.28	0.96	1.36	1.03	1.34	1.63	1.00	1.66	2.41	1.33	1.08	2.09	1.48	0.58	1.10	**1.38**
NVA	**12.4**	1.73	1.28	0.97	1.41	1.04	1.33	1.66	0.98	1.69	2.35	1.36	1.03	2.06	1.50	0.54	1.08	**1.38**
Avg.	**15.4**	**1.43**	**1.10**	**0.76**	**1.17**	**0.87**	**1.11**	**1.39**	**0.82**	**1.39**	**2.01**	**1.16**	**0.92**	**1.75**	**1.27**	**0.46**	**0.91**	**1.16**
Rank*	**-**	*3*	*10*	*15*	*7*	*13*	*9*	*4*	*14*	*5*	*1*	*8*	*11*	*2*	*6*	*16*	*12*	**-**

* where rank 1 = greatest increase, 16 = lowest increase (decrease).

Table A4.2. Average change in **rainfall (%) for all months (Jan-Dec) estimated for the 2040s (2030-2049)** from 16 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Current (mm)**	**Models for 2040s – Change in Mean Annual Rainfall (%)**																**Model avg.**
		CGMR	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**1331**	1	-11	1	5	1	-9	-7	-10	1	4	11	-17	-8	5	-13	-8	**-3.4**
DAR	**1186**	4	-11	3	5	3	-4	-6	-7	3	2	9	-17	-3	5	-11	-7	**-2.0**
COR	**1891**	3	0	7	0	7	5	0	2	7	9	5	-1	8	6	4	1	**4.0**
AKL	**1101**	5	-8	2	7	5	-5	-4	-5	3	7	11	-18	-4	7	-10	-7	**-0.9**
TGA	**1181**	1	-11	7	3	3	-5	-6	-6	2	3	12	-21	-4	7	-12	-9	**-2.2**
ROA	**1363**	-1	-12	4	-1	4	-6	-7	-6	0	7	13	-18	-4	6	-12	-9	**-2.5**
GSA	**986**	5	-10	6	7	3	-5	-8	-6	0	3	10	-17	-3	5	-11	-5	**-1.6**
APA	**995**	-1	-11	6	2	2	-8	-4	-7	0	17	13	-18	-5	4	-12	-7	**-1.9**
NPA	**1426**	-1	-7	9	6	4	-3	-6	-6	2	9	10	-15	-1	6	-7	-8	**-0.6**
WUA	**1126**	-1	-8	5	5	4	-5	-5	-3	-1	15	13	-19	-3	4	-11	-8	**-1.2**
PPA	**1030**	1	-7	8	4	5	-2	-6	-4	3	11	11	-14	0	7	-7	-8	**0.1**
WNA	**951**	-1	-8	3	15	3	-11	-11	-7	-4	18	18	-27	-10	0	-20	-11	**-3.3**
NSA	**1078**	2	-12	11	6	7	-6	-8	-5	1	2	12	-19	-6	9	-13	-11	**-1.9**
WSA	**2247**	-6	-3	5	-9	4	0	-4	1	1	14	3	-2	6	5	5	0	**1.2**
HKA	**2916**	-5	-3	5	-6	4	1	-3	-1	-1	9	4	-5	5	6	3	-1	**0.6**
KIX	**781**	4	-8	-4	18	7	-6	-8	-5	-10	13	24	-33	-17	5	-18	-12	**-2.9**
CHA	**625**	-5	-4	2	-5	6	0	-3	0	0	7	0	-1	5	2	8	-3	**0.6**
QNA	**837**	-1	4	11	-7	6	7	7	5	9	24	4	2	16	8	13	5	**7.1**
DNA	**726**	-3	-6	-3	11	13	-4	-17	-11	-8	-7	27	-21	-15	9	3	-7	**-2.4**
NVA	**1149**	-3	1	6	-10	6	3	0	2	7	20	5	1	12	6	11	1	**4.2**
Avg.	**1246**	**-0.1**	**-6.8**	**4.7**	**2.7**	**4.8**	**-3.2**	**-5.3**	**-3.9**	**0.7**	**9.3**	**10.8**	**-14.0**	**-1.5**	**5.6**	**-5.5**	**-5.7**	**-0.47**
Rank*	**-**	*9*	*2*	*12*	*11*	*13*	*7*	*5*	*6*	*10*	*15*	*16*	*1*	*8*	*14*	*4*	*3*	**-**

* where rank 1 = greatest decrease, 16 = lowest decrease (highest increase).

Table A4.3. Average change in **relative humidity (actual %) for all months (Jan-Dec) estimated for the 2040s (2030-2049)** from 16 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Current (%)**	**Models for 2040s – Change in Mean Annual Relative Humidity (%)**																**Model avg.**
		CGMR	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**71**	0.1	0.4	-0.3	0.4	0.0	0.7	0.3	0.0	0.4	-0.9	-0.2	0.9	1.3	1.3	0.7	0.1	**0.32**
DAR	**71**	0.0	0.4	-0.3	0.3	0.0	0.5	0.3	-0.1	0.3	-0.8	-0.1	0.7	1.2	1.2	0.6	0.1	**0.28**
COR	**70**	0.2	0.6	-0.1	0.4	0.2	0.7	0.4	0.3	0.4	0.0	0.0	1.0	1.4	1.0	0.8	0.4	**0.48**
AKL	**71**	-0.2	-0.1	-0.5	0.2	-0.3	0.2	-0.1	-0.4	0.0	-1.7	-0.4	0.2	0.4	0.8	0.1	-0.4	**-0.13**
TGA	**68**	0.1	0.5	-0.2	0.4	0.0	0.8	0.3	0.2	0.5	-0.6	-0.3	1.1	1.5	1.3	0.8	0.2	**0.40**
ROA	**70**	0.1	0.5	-0.2	0.4	0.0	0.9	0.4	0.2	0.5	-0.6	-0.3	1.1	1.6	1.3	0.8	0.2	**0.42**
GSA	**63**	-0.2	-0.1	-0.2	0.0	-0.2	0.1	-0.1	-0.2	0.0	-0.9	-0.3	0.1	0.2	0.4	0.0	-0.2	**-0.09**
APA	**70**	0.1	0.5	-0.2	0.4	0.0	0.9	0.4	0.2	0.5	-0.6	-0.3	1.1	1.6	1.3	0.8	0.3	**0.43**
NPA	**76**	0.1	0.5	-0.3	0.3	0.1	0.6	0.3	0.0	0.3	-0.6	-0.1	0.8	1.2	1.2	0.7	0.2	**0.32**
WUA	**72**	-0.4	-0.3	-0.6	0.0	-0.4	-0.1	-0.3	-0.6	-0.1	-1.9	-0.5	-0.2	-0.1	0.5	-0.2	-0.6	**-0.36**
PPA	**71**	-0.5	-0.6	-0.4	-0.3	-0.4	-0.5	-0.5	-0.6	-0.4	-1.3	-0.3	-0.7	-0.9	-0.3	-0.7	-0.6	**-0.57**
WNA	**71**	-0.3	-0.2	-0.5	0.1	-0.3	-0.1	-0.3	-0.6	-0.2	-1.8	-0.3	-0.2	-0.1	0.5	-0.1	-0.5	**-0.31**
NSA	**68**	0.1	0.4	-0.2	0.3	0.1	0.6	0.3	0.0	0.3	-0.6	-0.1	0.8	1.2	1.1	0.6	0.2	**0.31**
WSA	**74**	0.2	0.6	0.0	0.4	0.2	0.7	0.5	0.3	0.5	0.2	0.1	1.0	1.5	1.1	0.8	0.4	**0.53**
HKA	**74**	0.1	0.6	-0.2	0.3	0.1	0.7	0.4	0.1	0.4	-0.4	-0.1	1.1	1.6	1.3	0.9	0.3	**0.45**
KIX	**69**	-0.2	-0.2	-0.4	0.2	-0.3	-0.2	-0.2	-0.6	-0.2	-1.6	-0.1	-0.3	-0.2	0.3	-0.1	-0.4	**-0.28**
CHA	**63**	-0.2	0.3	-0.4	0.1	-0.1	0.3	0.0	-0.2	-0.1	-1.0	-0.1	0.6	0.9	0.8	0.6	0.0	**0.11**
QNA	**62**	0.5	0.9	0.2	0.6	0.4	0.9	0.7	0.6	0.6	0.7	0.3	1.2	1.7	1.1	1.0	0.7	**0.76**
DNA	**67**	-0.5	-0.7	-0.7	-0.2	-0.5	-0.8	-0.6	-1.0	-0.6	-2.1	-0.2	-0.9	-1.3	-0.3	-0.7	-0.9	**-0.75**
NVA	**72**	-0.2	0.0	-0.7	0.2	-0.1	-0.1	-0.1	-0.7	-0.1	-1.5	0.2	0.0	0.2	0.8	-0.1	-0.4	**-0.17**
Avg.	**69.7**	**-0.05**	**0.21**	**-0.31**	**0.23**	**-0.07**	**0.33**	**0.10**	**-0.16**	**0.15**	**-0.90**	**-0.16**	**0.47**	**0.73**	**0.84**	**0.37**	**-0.05**	**0.11**
Rank*	**-**	*6*	*10*	*2*	*11*	*5*	*12*	*8*	*4*	*9*	*1*	*3*	*14*	*15*	*16*	*13*	*7*	**-**

* where rank 1 = greatest decrease, 16 = lowest decrease (highest increase).

Table A4.4. Average change in **wind speed (km/h) for all months (Jan-Dec) estimated for the 2040s (2030-2049)** from 16 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Current (km/h)**	**Models for 2040s – Change in Mean Annual Wind Speed (km/h)**																**Model avg.**
		CGMR	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**20.9**	-0.6	-0.1	-0.1	-0.7	-0.1	-0.1	-0.4	0.1	-0.3	0.5	-0.3	0.3	0.2	-0.2	0.3	0.1	**-0.08**
DAR	**14.2**	-0.4	-0.2	0.1	-0.5	0.0	-0.1	-0.2	0.1	-0.1	0.3	-0.1	0.1	0.1	-0.1	0.1	0.0	**-0.05**
COR	**17.6**	-0.5	-0.1	-0.2	-0.5	-0.1	-0.1	-0.3	0.1	-0.2	0.4	-0.2	0.1	0.1	-0.1	0.1	0.0	**-0.09**
AKL	**21.2**	-0.3	-0.2	-0.1	-0.2	0.0	0.0	-0.2	0.1	-0.1	0.1	-0.1	0.1	0.2	0.0	0.1	0.0	**-0.04**
TGA	**18.2**	-0.3	-0.3	-0.2	-0.1	-0.1	-0.3	-0.3	-0.2	-0.2	-0.2	0.0	-0.2	-0.3	-0.2	-0.1	-0.1	**-0.20**
ROA	**16.0**	-0.4	-0.2	-0.2	-0.3	-0.1	-0.2	-0.3	-0.1	-0.2	0.0	0.0	-0.1	-0.2	-0.2	-0.1	-0.1	**-0.17**
GSA	**17.9**	-0.2	-0.4	-0.1	0.0	0.0	-0.1	-0.2	-0.1	0.0	-0.3	0.0	-0.2	-0.2	-0.1	-0.2	-0.1	**-0.13**
APA	**16.6**	-0.3	-0.2	-0.2	0.0	-0.1	-0.2	-0.3	-0.2	-0.2	-0.3	0.0	-0.2	-0.2	-0.2	-0.1	-0.1	**-0.18**
NPA	**21.6**	-0.5	-0.2	0.0	-0.6	0.0	-0.1	-0.3	0.1	-0.1	0.4	-0.1	0.2	0.1	-0.1	0.2	0.1	**-0.06**
WUA	**21.6**	-0.3	-0.2	-0.1	-0.1	0.0	0.0	-0.2	0.1	-0.1	0.1	-0.1	0.1	0.2	0.0	0.2	0.1	**-0.03**
PPA	**21.0**	-0.3	-0.1	0.0	-0.2	0.0	0.0	-0.2	0.1	-0.1	0.2	-0.1	0.2	0.2	0.0	0.2	0.1	**-0.01**
WNA	**29.8**	-0.6	-0.1	0.0	-0.8	0.0	0.0	-0.3	0.2	-0.2	0.6	-0.2	0.4	0.3	-0.1	0.4	0.1	**-0.02**
NSA	**16.2**	-0.5	-0.1	-0.2	-0.6	0.0	-0.1	-0.3	0.1	-0.3	0.3	-0.2	0.2	0.1	-0.1	0.2	-0.1	**-0.10**
WSA	**16.2**	-0.5	0.1	-0.3	-0.6	0.0	-0.1	-0.3	0.1	-0.4	0.5	-0.2	0.3	0.3	0.0	0.4	0.0	**-0.05**
HKA	**14.2**	-0.4	0.0	-0.1	-0.4	0.0	-0.1	-0.2	0.1	-0.2	0.4	-0.2	0.2	0.2	0.0	0.2	0.0	**-0.03**
KIX	**17.4**	-0.5	0.0	-0.1	-0.6	0.0	0.0	-0.2	0.1	-0.2	0.6	-0.2	0.3	0.2	-0.1	0.2	0.1	**-0.03**
CHA	**18.7**	-0.3	-0.1	-0.1	-0.4	0.0	0.2	-0.2	0.5	-0.1	0.4	-0.5	0.7	0.3	-0.1	0.3	0.2	**0.05**
QNA	**12.5**	-0.4	0.0	-0.1	-0.6	0.0	0.0	-0.2	0.1	-0.2	0.6	-0.3	0.3	0.2	-0.1	0.2	0.0	**-0.02**
DNA	**17.5**	-0.4	0.1	-0.2	-0.6	0.0	-0.1	-0.2	0.1	-0.3	0.5	-0.3	0.4	0.2	-0.2	0.4	0.0	**-0.05**
NVA	**21.1**	0.0	0.5	0.2	-0.1	0.2	0.6	0.3	0.7	0.2	1.1	-0.5	0.9	0.9	0.2	0.6	0.4	**0.39**
Avg.	**18.5**	**-0.38**	**-0.09**	**-0.10**	**-0.40**	**-0.01**	**-0.04**	**-0.23**	**0.10**	**-0.17**	**0.31**	**-0.17**	**0.20**	**0.14**	**-0.08**	**0.19**	**0.03**	**-0.05**
Rank*	**-**	*15*	*10*	*11*	*16*	*7*	*8*	*14*	*5*	*13*	*1*	*12*	*2*	*4*	*9*	*3*	*6*	**-**

* where rank 1 = greatest increase, 16 = lowest increase (greatest decrease).

Table A4.5. Average change in **temperature (°C) for all months (Jan-Dec) estimated for the 2090s (2080-2099)** from 16 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Current (°C)**	**Models for 2090s – Change in Mean Annual Temperature (°C)**																**Model avg.**
		CGMR	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**17.9**	2.84	2.41	1.61	2.31	1.97	2.58	2.45	1.75	2.10	3.29	2.57	2.94	4.25	2.99	2.43	2.44	**2.56**
DAR	**18.1**	3.02	2.56	1.73	2.45	2.12	2.75	2.62	1.86	2.25	3.55	2.77	3.08	4.52	3.18	2.57	2.61	**2.73**
COR	**17.6**	2.57	2.06	1.42	2.12	1.71	2.17	2.21	1.45	1.92	2.73	2.30	2.41	3.67	2.65	2.00	2.14	**2.22**
AKL	**17.4**	2.66	2.25	1.49	2.17	1.82	2.39	2.29	1.62	1.95	3.05	2.39	2.76	3.97	2.81	2.25	2.27	**2.38**
TGA	**17.2**	2.44	2.04	1.31	2.02	1.59	2.12	2.07	1.45	1.75	2.62	2.12	2.56	3.58	2.57	2.02	2.03	**2.14**
ROA	**15.4**	2.48	2.08	1.34	2.05	1.63	2.17	2.10	1.48	1.79	2.69	2.16	2.61	3.65	2.61	2.06	2.07	**2.19**
GSA	**17.8**	2.57	2.17	1.40	2.12	1.71	2.29	2.19	1.56	1.86	2.83	2.26	2.72	3.81	2.72	2.17	2.16	**2.28**
APA	**13.9**	2.43	2.02	1.29	2.03	1.56	2.09	2.05	1.43	1.74	2.56	2.09	2.54	3.55	2.56	1.99	2.01	**2.12**
NPA	**15.9**	3.00	2.48	1.67	2.46	2.03	2.62	2.58	1.77	2.23	3.32	2.70	2.97	4.39	3.13	2.44	2.53	**2.64**
WUA	**16.1**	2.64	2.24	1.48	2.16	1.81	2.39	2.27	1.62	1.94	3.02	2.37	2.76	3.95	2.79	2.25	2.26	**2.37**
PPA	**15.4**	3.03	2.52	1.67	2.50	2.02	2.73	2.58	1.83	2.22	3.27	2.64	3.17	4.46	3.18	2.55	2.53	**2.68**
WNA	**15.2**	3.03	2.56	1.72	2.46	2.10	2.79	2.62	1.87	2.25	3.48	2.73	3.15	4.53	3.19	2.60	2.60	**2.73**
NSA	**15.5**	3.05	2.58	1.75	2.46	2.15	2.78	2.65	1.88	2.28	3.60	2.81	3.09	4.56	3.20	2.60	2.64	**2.76**
WSA	**14.6**	2.75	2.25	1.53	2.25	1.85	2.37	2.37	1.60	2.04	3.01	2.47	2.67	3.99	2.86	2.20	2.31	**2.41**
HKA	**14.2**	2.52	2.11	1.43	2.05	1.74	2.27	2.18	1.53	1.88	2.86	2.28	2.54	3.73	2.64	2.11	2.15	**2.25**
KIX	**13.8**	3.09	2.65	1.80	2.49	2.21	2.94	2.69	1.96	2.32	3.69	2.84	3.24	4.68	3.26	2.73	2.69	**2.83**
CHA	**14.9**	2.92	2.39	1.67	2.37	2.02	2.59	2.53	1.73	2.21	3.29	2.67	2.81	4.26	3.03	2.38	2.49	**2.59**
QNA	**11.7**	3.00	2.38	1.68	2.47	2.01	2.55	2.59	1.69	2.27	3.16	2.70	2.76	4.26	3.08	2.32	2.49	**2.59**
DNA	**13.4**	3.26	2.71	1.91	2.62	2.31	3.11	2.83	2.03	2.49	3.73	2.96	3.32	4.85	3.40	2.83	2.80	**2.95**
NVA	**12.4**	3.36	2.73	1.92	2.74	2.30	3.08	2.89	2.01	2.55	3.64	2.99	3.32	4.89	3.47	2.79	2.82	**2.97**
Avg.	**15.4**	**2.83**	**2.36**	**1.59**	**2.31**	**1.93**	**2.54**	**2.44**	**1.70**	**2.10**	**3.17**	**2.54**	**2.87**	**4.18**	**2.97**	**2.36**	**2.40**	**2.52**
Rank*	**-**	*5*	*11*	*16*	*12*	*14*	*7*	*8*	*15*	*13*	*2*	*6*	*4*	*1*	*3*	*10*	*9*	**-**

* where rank 1 = greatest increase, 16 = lowest increase.

Table A4.6. Average change in **rainfall (%) for all months (Jan-Dec) estimated for the 2090s (2080-2099)** from 16 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Current (mm)**	**Models for 2090s – Change in Mean Annual Rainfall (%)**																**Model avg.**
		CGMR	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**1331**	-1	-12	-10	1	-6	-15	-9	2	4	21	6	-30	-2	13	-14	-4	**-3.5**
DAR	**1169**	-4	-13	-12	0	-4	-12	-6	5	6	13	6	-29	1	16	-11	-2	**-2.7**
COR	**1891**	-4	1	0	0	3	13	6	13	12	14	11	-4	18	16	11	8	**7.5**
AKL	**1101**	1	-9	-10	3	-1	-12	4	3	10	20	6	-28	5	18	-12	-2	**-0.4**
TGA	**1181**	-3	-11	-12	1	-3	-14	-3	2	6	22	5	-31	0	17	-12	-2	**-2.3**
ROA	**1363**	-5	-11	-12	-2	-1	-16	-3	1	8	25	0	-31	0	16	-16	-4	**-3.2**
GSA	**986**	-2	-10	-10	-5	2	-14	-3	-1	2	17	2	-25	0	15	-10	-4	**-2.9**
APA	**995**	-3	-9	-10	-1	1	-16	1	0	10	30	0	-32	2	16	-19	-5	**-2.1**
NPA	**1427**	-3	-9	-11	-1	-4	-8	-4	5	10	20	9	-26	5	18	-7	-1	**-0.4**
WUA	**1331**	4	-4	-10	5	-1	-8	2	3	8	26	5	-22	2	16	-13	-1	**0.8**
PPA	**1030**	-2	-6	-10	0	-3	-10	-2	5	12	25	7	-24	8	21	-7	0	**0.9**
WNA	**953**	5	-8	-17	17	-7	-23	-5	-7	7	32	4	-32	-11	11	-24	-5	**-3.9**
NSA	**1078**	0	-13	-12	0	-2	-14	-4	1	8	22	6	-28	1	12	-15	-3	**-2.5**
WSA	**2247**	-16	1	-4	-14	3	2	-3	10	0	29	7	-9	11	9	8	0	**2.0**
HKA	**2916**	-14	-2	-8	-11	-1	-2	-4	9	0	25	9	-13	10	10	5	1	**0.8**
KIX	**781**	10	-6	-18	22	-13	-28	-14	-9	-2	18	16	-33	-10	14	-27	0	**-5.0**
CHA	**625**	-9	1	-7	-8	-1	5	-6	10	-2	22	7	-7	7	12	13	-1	**2.2**
QNA	**837**	-6	7	3	-8	5	26	5	15	11	33	14	3	23	16	26	11	**11.5**
DNA	**726**	-15	-16	-19	1	-16	-21	-15	2	-5	14	17	-41	-2	20	-9	-6	**-6.9**
NVA	**1149**	-13	5	-3	-15	6	12	1	13	8	38	11	-5	17	14	16	4	**6.8**
Avg.	**1256**	**-4.1**	**-6.2**	**-9.6**	**-0.6**	**-2.3**	**-7.7**	**-3.0**	**4.2**	**5.7**	**23.4**	**7.3**	**-22.2**	**4.3**	**15.0**	**-5.9**	**-0.8**	**-0.16**
Rank*	**-**	*6*	*4*	*2*	*10*	*8*	*3*	*7*	*11*	*13*	*16*	*14*	*1*	*12*	*15*	*5*	*9*	**-**

* where rank 1 = greatest decrease, 16 = lowest decrease (highest increase).

Table A4.7. Average change in **relative humidity (actual %) for all months (Jan-Dec) estimated for the 2090s (2080-2099)** from 16 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	**Current (%)**	**Models for 2090s – Change in Mean Annual Relative Humidity (%)**																**Model avg.**
		CGMR	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**71**	-0.1	1.2	-0.1	0.9	-0.2	1.0	1.6	1.0	2.1	-0.9	0.5	1.7	2.2	2.4	1.5	0.4	**0.94**
DAR	**71**	-0.2	1.1	-0.1	0.9	-0.2	0.9	1.5	0.8	1.8	-0.9	0.5	1.4	2.1	2.2	1.3	0.3	**0.84**
COR	**70**	0.3	1.3	0.3	0.8	0.3	1.4	1.3	1.0	1.4	0.2	0.8	1.9	2.3	1.9	1.6	0.7	**1.09**
AKL	**71**	-0.6	0.4	-0.7	0.6	-1.0	-0.2	0.9	0.3	1.5	-2.1	-0.3	0.4	0.8	1.7	0.3	-0.3	**0.11**
TGA	**68**	-0.1	1.3	0.0	0.8	-0.1	1.4	1.5	1.2	2.0	-0.5	0.4	2.0	2.3	2.3	1.8	0.4	**1.05**
ROA	**70**	-0.1	1.4	0.0	0.9	-0.1	1.4	1.6	1.2	2.1	-0.5	0.4	2.0	2.4	2.5	1.8	0.5	**1.10**
GSA	**63**	-0.5	0.2	-0.4	0.2	-0.5	-0.1	0.4	0.2	0.7	-1.0	-0.3	0.2	0.2	0.7	0.2	-0.2	**0.00**
APA	**70**	-0.1	1.4	0.0	0.9	-0.1	1.5	1.6	1.3	2.1	-0.5	0.4	2.1	2.4	2.4	1.9	0.5	**1.11**
NPA	**76**	-0.1	1.2	-0.1	0.9	-0.1	1.0	1.5	0.9	1.8	-0.7	0.6	1.6	2.2	2.3	1.4	0.4	**0.91**
WUA	**72**	-0.9	-0.1	-0.9	0.4	-1.3	-0.8	0.5	0.0	1.1	-2.3	-0.7	-0.3	-0.2	1.0	-0.3	-0.6	**-0.34**
PPA	**71**	-0.9	-0.8	-0.8	-0.3	-1.1	-1.5	-0.5	-0.6	-0.1	-1.7	-1.0	-1.4	-1.5	-0.5	-1.2	-0.8	**-0.93**
WNA	**71**	-0.7	0.0	-0.8	0.5	-1.1	-0.8	0.5	-0.1	1.0	-2.3	-0.5	-0.3	0.0	1.1	-0.3	-0.6	**-0.28**
NSA	**68**	-0.1	1.1	0.0	0.8	-0.1	1.0	1.4	0.9	1.7	-0.6	0.5	1.5	2.0	2.1	1.3	0.4	**0.87**
WSA	**74**	0.3	1.4	0.3	0.8	0.4	1.5	1.4	1.1	1.5	0.5	0.9	1.9	2.4	2.1	1.8	0.8	**1.20**
HKA	**74**	-0.1	1.4	0.0	0.9	0.1	1.3	1.6	1.1	1.9	-0.4	0.8	2.0	2.6	2.5	1.8	0.5	**1.12**
KIX	**69**	-0.4	-0.1	-0.7	0.7	-1.0	-0.8	0.4	-0.3	0.8	-2.2	-0.3	-0.3	0.0	1.0	-0.5	-0.4	**-0.26**
CHA	**63**	-0.5	0.7	-0.3	0.4	-0.3	0.4	0.9	0.5	1.0	-1.2	0.3	1.0	1.4	1.6	0.9	0.0	**0.42**
QNA	**62**	0.9	1.6	0.7	1.2	0.9	2.1	1.6	1.3	1.4	1.1	1.3	2.5	2.9	2.2	2.1	1.2	**1.56**
DNA	**67**	-0.98	-0.90	-1.24	0.03	-1.50	-2.21	-0.55	-0.97	-0.14	-2.75	-0.95	-1.76	-1.52	-0.18	-1.77	-1.03	**-1.15**
NVA	**72**	-0.4	0.6	-0.7	0.9	-0.8	-0.8	1.0	0.1	1.3	-1.7	0.3	0.1	1.2	2.0	-0.1	0.0	**0.18**
Avg.	**69.7**	**-0.27**	**0.71**	**-0.28**	**0.66**	**-0.39**	**0.38**	**1.00**	**0.54**	**1.36**	**-1.03**	**0.18**	**0.91**	**1.31**	**1.68**	**0.78**	**0.09**	**0.48**
Rank*	**-**	*4*	*10*	*3*	*9*	*2*	*7*	*13*	*8*	*15*	*1*	*6*	*12*	*14*	*16*	*11*	*5*	**-**

* where rank 1 = greatest decrease, 16 = lowest decrease (highest increase).

Table A4.8. Average change in **wind speed (km/h) for all months (Jan-Dec) estimated for the 2090s (2080-2099)** from 16 Global Climate Models, and comparison with current climate for the 1990s (1980-1999).

Station Code	Current (km/h)	Models for 2090s – Change in Mean Annual Wind Speed (km/h)																Model avg.
		CGMR	**CNCM3**	**CSMK3**	**ECHOG**	**FGOALS**	**GFCM20**	**GFCM21**	**GIAOM**	**GIEH**	**HADCM3**	**HADGEM**	**IPCM4**	**MIHR**	**MIMR**	**MPEH5**	**MRCGCM**	
KX	**20.9**	-1.3	-0.2	-0.2	-1.4	-0.1	0.0	-0.9	0.2	-0.7	1.1	-0.5	-0.3	-0.5	-0.8	0.2	-0.3	**-0.36**
DAR	**14.2**	-0.8	-0.2	-0.1	-0.9	0.0	0.0	-0.5	0.1	-0.4	0.7	-0.3	-0.3	-0.3	-0.5	0.1	-0.2	**-0.22**
COR	**17.6**	-1.1	-0.2	-0.2	-1.0	0.0	-0.1	-0.6	0.1	-0.5	0.8	-0.4	-0.3	-0.4	-0.7	0.1	-0.3	**-0.30**
AKL	**21.2**	-0.7	-0.2	-0.1	-0.6	0.0	0.1	-0.5	0.2	-0.2	0.5	-0.3	-0.3	-0.1	-0.2	0.1	-0.2	**-0.16**
TGA	**18.2**	-0.6	-0.4	-0.4	-0.3	-0.3	-0.5	-0.7	-0.2	-0.4	0.0	-0.4	-0.7	-0.5	-0.3	-0.4	-0.3	**-0.39**
ROA	**16.0**	-0.8	-0.4	-0.3	-0.6	-0.2	-0.4	-0.7	-0.1	-0.4	0.2	-0.3	-0.7	-0.4	-0.4	-0.3	-0.3	**-0.38**
GSA	**17.9**	-0.4	-0.4	-0.2	-0.1	-0.2	-0.3	-0.6	0.0	-0.1	0.1	-0.4	-0.6	-0.3	-0.1	-0.4	-0.1	**-0.25**
APA	**16.6**	-0.5	-0.4	-0.3	-0.2	-0.3	-0.5	-0.6	-0.2	-0.4	-0.1	-0.3	-0.6	-0.4	-0.3	-0.4	-0.2	**-0.36**
NPA	**21.6**	-1.2	-0.2	-0.1	-1.3	0.0	0.0	-0.7	0.2	-0.5	1.0	-0.4	-0.4	-0.4	-0.7	0.1	-0.2	**-0.29**
WUA	**21.6**	-0.7	-0.1	-0.2	-0.5	0.0	0.1	-0.5	0.2	-0.2	0.4	-0.3	-0.2	0.0	-0.2	0.1	-0.2	**-0.14**
PPA	**21.0**	-0.7	-0.1	-0.1	-0.6	0.0	0.1	-0.5	0.2	-0.3	0.6	-0.3	-0.2	-0.1	-0.2	0.1	-0.1	**-0.13**
WNA	**29.8**	-1.3	-0.2	-0.2	-1.6	0.1	0.2	-0.9	0.3	-0.6	1.3	-0.5	-0.2	-0.3	-0.7	0.3	-0.3	**-0.29**
NSA	**16.2**	-1.1	-0.1	-0.3	-1.3	0.1	-0.1	-0.7	0.1	-0.6	0.7	-0.4	-0.3	-0.4	-0.7	0.1	-0.4	**-0.34**
WSA	**16.2**	-1.2	0.0	-0.3	-1.3	0.1	0.1	-0.7	0.1	-0.8	0.8	-0.3	-0.1	-0.2	-0.6	0.3	-0.4	**-0.27**
HKA	**14.2**	-0.9	0.0	-0.1	-0.9	0.1	0.1	-0.4	0.1	-0.4	0.6	-0.2	-0.2	-0.1	-0.4	0.2	-0.2	**-0.17**
KIX	**17.4**	-0.9	-0.1	-0.1	-1.2	0.0	0.1	-0.5	0.2	-0.5	1.0	-0.3	0.0	-0.4	-0.7	0.3	-0.2	**-0.21**
CHA	**18.7**	-0.6	0.0	-0.1	-1.0	0.1	0.4	-0.6	0.4	-0.5	1.1	-0.7	0.5	-0.3	-0.7	0.5	-0.1	**-0.11**
QNA	**12.5**	-0.9	0.0	-0.1	-1.2	0.2	0.1	-0.4	0.2	-0.5	0.9	-0.3	-0.1	-0.3	-0.6	0.3	-0.3	**-0.18**
DNA	**17.5**	-1.0	-0.1	-0.2	-1.4	0.1	0.0	-0.6	0.1	-0.8	0.7	-0.3	0.0	-0.4	-0.8	0.2	-0.3	**-0.30**
NVA	**21.1**	0.0	0.8	0.3	-0.5	0.7	1.4	0.5	0.8	0.1	1.4	0.1	1.4	0.6	-0.1	1.3	0.2	**0.56**
Avg.	**18.5**	**-0.83**	**-0.12**	**-0.16**	**-0.89**	**0.01**	**0.04**	**-0.55**	**0.16**	**-0.44**	**0.69**	**-0.34**	**-0.18**	**-0.25**	**-0.49**	**0.15**	**-0.22**	**-0.21**
Rank*	**-**	*15*	*6*	*7*	*16*	*5*	*4*	*14*	*2*	*12*	*1*	*11*	*8*	*10*	*13*	*3*	*9*	**-**

* where rank 1 = greatest increase, 16 = lowest increase (greatest decrease).