Fire Technology Transfer Note

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Describing New Zealand's fire climate:
Part I – Fire danger climatology analyses

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Introduction

Weather (and climate)[1] is a key component of the fire environment, and an essential determinant of fire behaviour and fire danger. While it is recognised that New Zealand does not have one of the worst fire climates in the world, each year seasonal weather conditions contribute to elevated fire dangers and an associated increase in the risk of wildfires in most parts of the country. In particular, strong winds, high temperatures, low humidity and seasonal drought can combine to produce dangerous fire weather situations. Unlike many other parts of the world where more stable continental climates prevail, problem fire weather can also occur at almost any time of the year due to New Zealand's milder, maritime environment. To effectively manage this risk, fire managers therefore require a good appreciation of the severity of fire weather and fire danger conditions for their locale.

With the support of the New Zealand Fire Service Commission's (NZFSC) Contestable Research Fund, together with the Foundation for Research Science and Technology (FRST) and NZ rural fire sector stakeholders, staff from Ensis (formerly Forest Research) have developed a database of daily fire weather and fire danger records for a network of more than 120 weather stations located across the country. The database comprises data from the National Rural Fire Authority's (NRFA) network of fire weather monitoring stations, together with that for a number of additional Meteorological Service of NZ (MetService) and National Institute of Water and Atmospheric Research (NIWA) stations. The database has formed the basis for a series of analyses comparing the severity of fire climates in different parts of the country, predicting the severity of fire seasons, and for projecting the likely effect of climate change on future fire dangers. The first of two *Fire Technology Transfer Note* (FTTN) newsletters, this FTTN (No. 32) describes these analyses together with some of the results and future directions. A second FTTN (No. 33) describes related research undertaken by other research providers, such as the NIWA and MetService, with input from Ensis.

Background

Assessment of the effect of fire weather (and other fire environment factors of fuels and topography) on potential fire occurrence and fire behaviour is assisted by the use of the New Zealand Fire Danger Rating System (NZFDRS) (Fig. 1a) which is, in turn, based on the Canadian Forest Fire Danger Rating System. The NZFDRS is used by New Zealand fire authorities for a range of fire management activities, and also to inform the public of prevailing fire danger conditions.

[1] *Weather* describes the state of the atmosphere surrounding the earth at a particular point in time over a given region, whereas *climate* is the "average weather" obtained by integrating or summarising weather data over a longer time period to describe the typical weather conditions an area might expect to experience (Sturman and Tapper 1996).

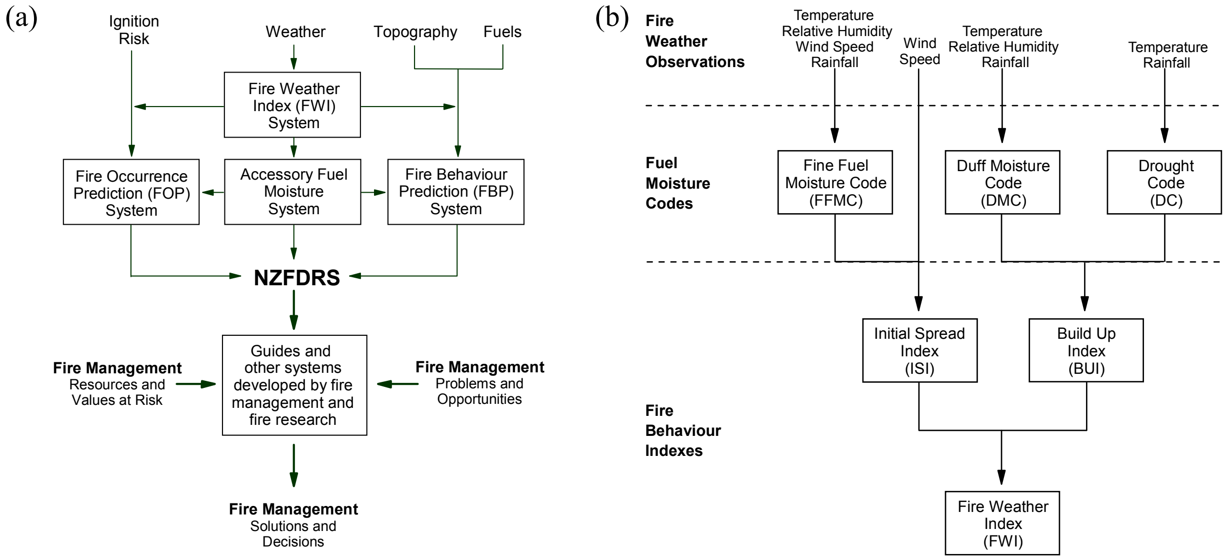


Figure 1. Simplified structure diagrams for: **(a)** the New Zealand Fire Danger Rating System (NZFDRS), illustrating the linkage to fire management actions (Fogarty *et al.* 1998); and **(b)** the Fire Weather Index (FWI) System (Anon. 1993).

The development of the NZFDRS has been described by Fogarty *et al*. (1998) and Anderson (2005, 2006). The Fire Weather Index (FWI) subsystem (Fig. 1b) of the NZFDRS provides numerical ratings of relative ignition potential and fire behaviour based solely on weather data (Van Wagner 1987). Daily noon local standard time observations of temperature, relative humidity, wind speed, and 24-hour accumulated rainfall, collected by a network of automatic weather stations (Fig. 2), are used to compute values of the three fuel moisture codes and three fire behaviour indexes. Although these may be determined from tables (e.g., Anon. 1993), they are usually obtained by computer calculation (Van Wagner and Pickett 1985). The archiving of historical records of daily fire weather and FWI data make it possible to undertake climatological analyses of current, past, and even future, fire danger.

While production of climatologies for the standard weather elements are commonplace (e.g., NZMS 1983*a*, NIWA 2006), analyses of fire danger are much less routine (e.g., Nikleva 1973, Tapper *et al.* 1993) and few examples of New Zealand fire climate studies exist despite a clear need being expressed for such research (Valentine 1978, Alexander 1992). In trialling the FWI System prior to its introduction, Valentine (1978) compared fire season climatologies for British Columbia and New Zealand, and Cooper and Ashley-Jones (1987) used fire danger class frequencies to investigate the economics of fire prevention activities. In the pre-cursor to the more recent research, Pearce (1996) produced a fire climatology for 20 weather stations, presenting long-term average and extreme values for both weather inputs and fire danger components for each station based on the example of Simard and Valenzuela (1972). While the emphasis was on describing fire danger in various parts of the country using the climate regions of NZMS (1983*b*), the study also compared fire climates in different parts of the country using measures of fire season severity based on the FWI System. Pearce's (1996) database was extended in 1998 to investigate the potential impact of the 1997/98 El Nino event on regional fire dangers (Anon. 1998, Pearce 1998), and in 2001 to further illustrate the use of severity ratings to compare and predict fire season conditions (Majorhazi and Pearce 2001)[2]. The Pearce (1996) data was also used by Pearce and Hawke (1999) to determine the length of data record required for further fire climatology analyses.

The rationale for developing and maintaining a database of fire weather and fire danger ratings is evidenced by the vast array of studies and associated fire management applications illustrated in the international literature. A significant number of these studies have used fire climatologies in an

[2] Comparative analyses of seasonal severity in New Zealand's fire climate have been continued by Majorhazi (2003).

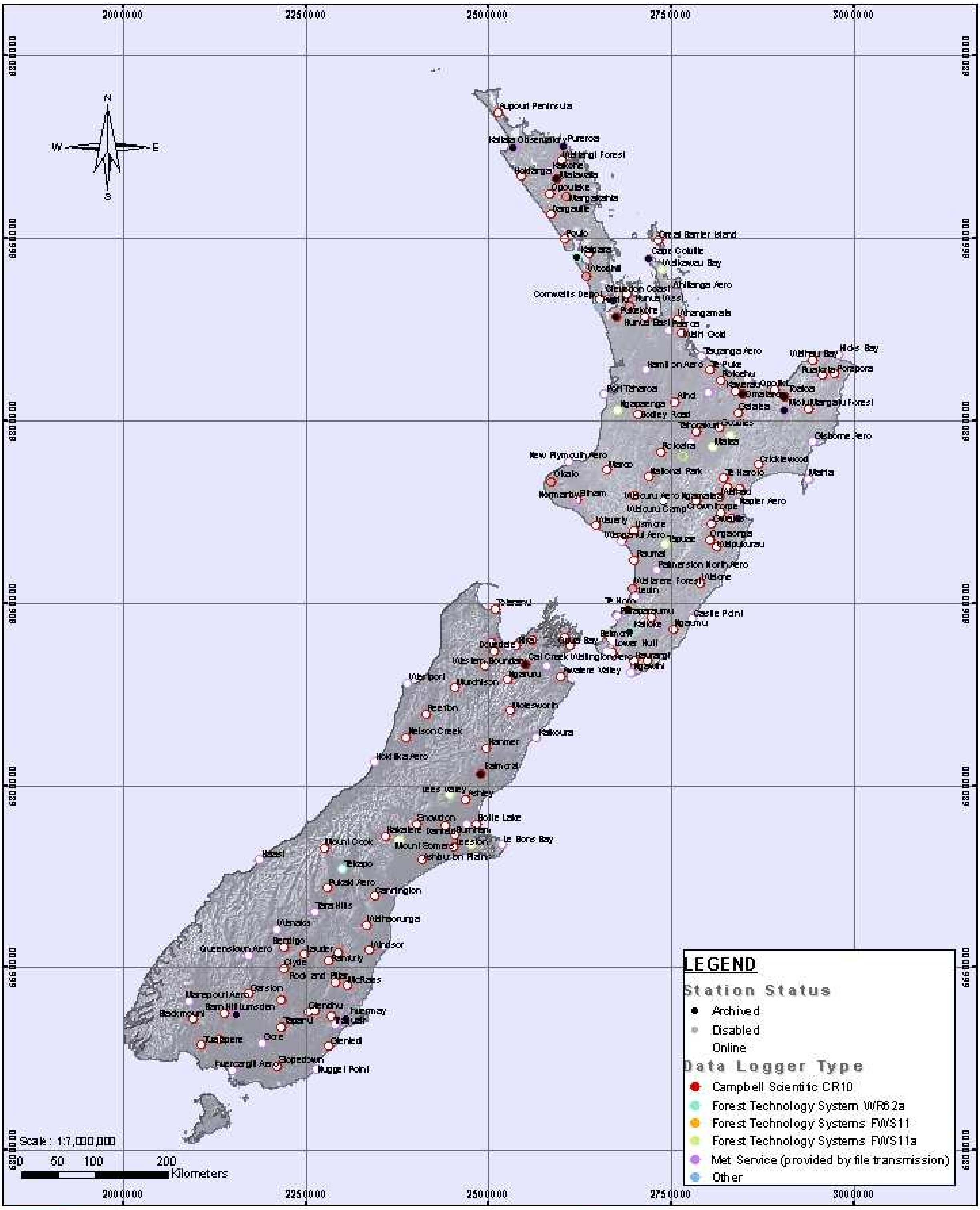


Figure 2. Weather stations comprising the National Rural Fire Authority's (NRFA) fire weather monitoring network.

effort to describe fire activity (e.g., Cheney 1976, Haines *et al*. 1980, Harrington *et al*. 1983). However, fire danger climatologies have also been used to describe seasonal trends in fire danger (McAlpine 1990), compare the severity of fire seasons and weather station locations (Stocks 1971, Harvey *et al*. 1986), determine length of fire season (Wotton and Flannigan 1993), define fire climate regions (Simard 1973, Stocks 1978), and to define impacts of El Nino-Southern Oscillation events (Williams 1998) and past and present climate change (Stocks *et al*. 1998, Flannigan *et al*. 2001, Williams *et al*. 2001). Perhaps most importantly, fire climatologies have been used to develop systems to support fire management activities, including prevention (OMNR 1989, Borger 1997), preparedness (Gray and Janz 1985, Fogarty and Smart 1994), fire suppression (Andrews *et al*. 1998, Fogarty and Slijepcevic 1998), and prescribed fire planning (Andrews and Bradshaw 1990).

Ensis Research on New Zealand's Fire Climate

Over the past few years, a major effort has been made to improve description of New Zealand's fire climate, supported by the New Zealand Fire Service Commission's (NZFSC) Contestable Research Fund. A key part of this research has been the development of a database of long-term fire weather and fire danger records for fire weather stations across the country. This includes data for stations on the National Rural Fire Authority's (NRFA) fire weather monitoring network (see Fig. 2), as well as additional Meteorological Service of New Zealand (MetService) and National Insitute of Water and Atmospheric Research (NIWA) stations.

1. Fire danger climatology database and summaries of long-term averages and extremes (Pearce *et al.* 2003)

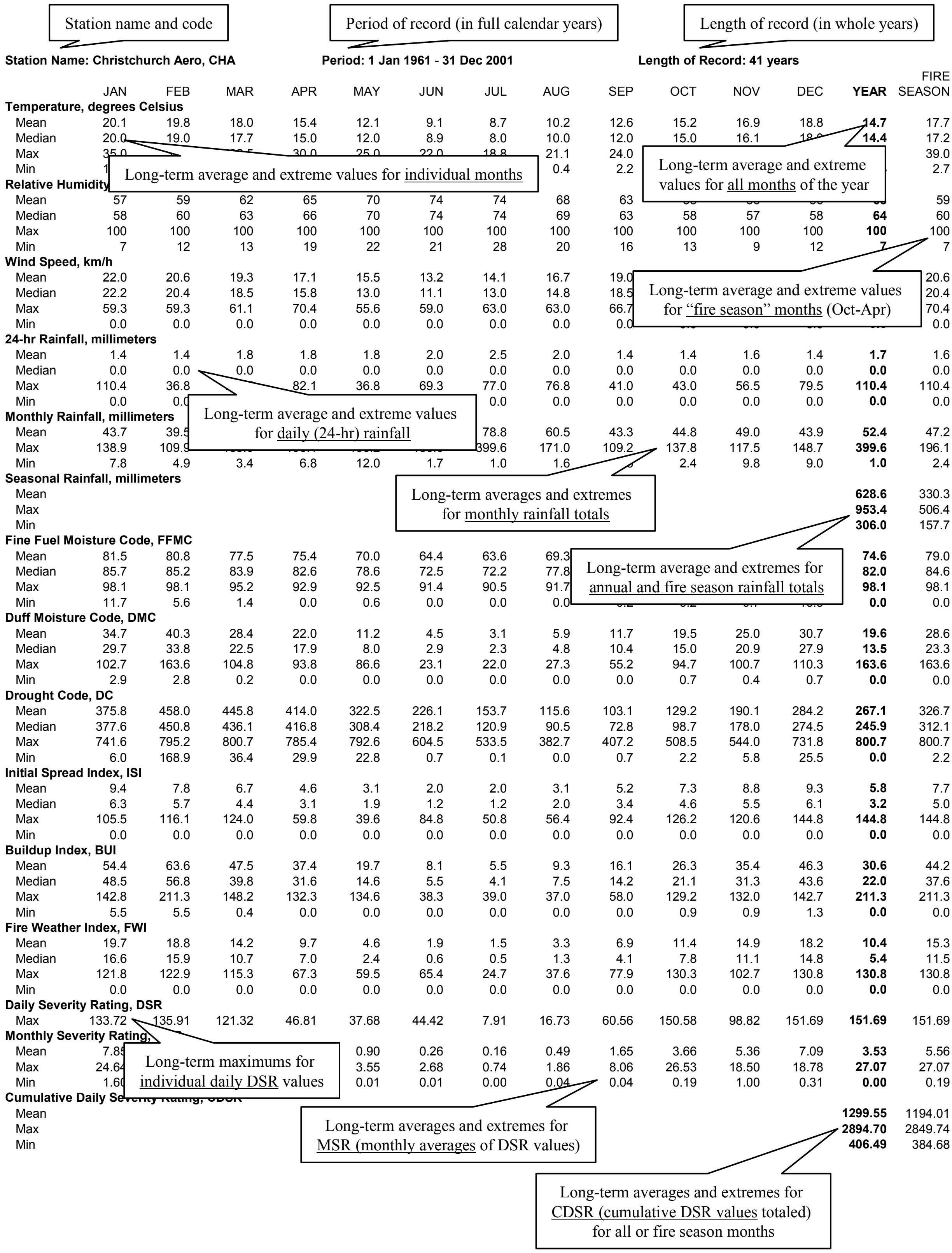
In 2003, in an effort to improve knowledge on the fire climate of New Zealand, the Pearce (1996) study was upgraded as part of the NZFSC-funded project "Fire Danger Climatology Analyses and Tools" (Pearce *et al*. 2003). The 1996 analysis was updated to include more recent data, and extended to include a greater number of available weather stations. The study comprised three main steps:

- compilation of a database of continuous daily fire weather records for each weather station by replacing missing or erroneous values with suitable data from appropriate substitute stations;
- recalculation of Fire Weather Index (FWI) System and fire danger class values from the completed weather input datasets; and
- statistical analysis of long-term average and extreme (min/max) values of weather and fire danger components for each weather station.

In total, some 20,000 weather values were substituted to complete the more than 535,000 records of weather and fire danger components for the 127 weather stations that had greater than 5 years of record available. The final number of stations for which datasets were completed and analysed was significantly higher than originally estimated (85-100). However, the data quality issues encountered highlight a number of issues relating to weather station maintenance, accuracy and completeness of data contained within the NRFA's fire weather archive, and the need for adequate quality control.

The principal output from the analysis was a summary table for each of the 127 stations containing the long-term average and extreme values of each of the weather and FWI System components summarised by month, fire season and year (Fig. 3). These summary tables also included fire danger class frequencies for Forest and Scrubland fuel types, by month, fire season and calendar year.

Summary statistics for each station were also used to identify the individual weather stations and geographic regions with the most severe fire climates. Stations in Marlborough and Canterbury demonstrated the highest values (Table 1) of the three fire climate severity measures evaluated – the Cumulative Daily Severity Rating (CDSR), and combined frequency of days falling into the VERY HIGH and EXTREME fire danger classes for Forest (VH+E FFDC) and Scrubland (VH+E SFDC). For individual station locations, three stations in Marlborough – Awatere Valley (AWV), Woodbourne Aero (WBA) (i.e., Blenheim) and Molesworth (MLX/MOL) – had the most severe fire climates, with Christchurch Aero (CHA) in Canterbury and Castle Point (CPX) in Wairarapa the other two stations in the top 5; the latter more likely due to the windiness of the site, compared to seasonal dryness as the principal factor at the other locations. At the other end of the scale, the 7 stations with the least severe fire climates included Opouteke (OPO) in Northland, Marco (WHG) in Taranaki, Athol (ATH) in the Waikato, Waimarino Forest (WAF) in Wanganui/Manawatu, and all three stations – Westport (WSA), Hokitika Aero (HKA) and Haast (HTX) – from the South Island's West Coast. These stations are generally characterised by the highest annual rainfalls. [See Table 5 (pages 19-22) in Pearce *et al*. (2003) for the full list of fire climate severity rankings for individual weather stations].



Station Name: Christchurch Aero, CHA **Period: 1 Jan 1961 - 31 Dec 2001** **Length of Record: 41 years**

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	**YEAR**	FIRE SEASON
Temperature, degrees Celsius														
Mean	20.1	19.8	18.0	15.4	12.1	9.1	8.7	10.2	12.6	15.2	16.9	18.8	**14.7**	17.7
Median	20.0	19.0	17.7	15.0	12.0	8.9	8.0	10.0	12.0	15.0	16.1	[illegible]	**14.4**	17.2
Max	35.0	[illegible]	[illegible]	30.0	25.0	22.0	18.8	21.1	24.0	[illegible]	[illegible]	[illegible]	[illegible]	39.0
Min	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.4	2.2	[illegible]	[illegible]	[illegible]	[illegible]	2.7
Relative Humidity														
Mean	57	59	62	65	70	74	74	68	63	[illegible]	[illegible]	[illegible]	[illegible]	59
Median	58	60	63	66	70	74	74	69	63	58	57	58	**64**	60
Max	100	100	100	100	100	100	100	100	100	100	100	100	**100**	100
Min	7	12	13	19	22	21	28	20	16	13	9	12	**7**	7
Wind Speed, km/h														
Mean	22.0	20.6	19.3	17.1	15.5	13.2	14.1	16.7	19.0	[illegible]	[illegible]	[illegible]	[illegible]	20.6
Median	22.2	20.4	18.5	15.8	13.0	11.1	13.0	14.8	18.5	[illegible]	[illegible]	[illegible]	[illegible]	20.4
Max	59.3	59.3	61.1	70.4	55.6	59.0	63.0	63.0	66.7	[illegible]	[illegible]	[illegible]	[illegible]	70.4
Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	[illegible]	[illegible]	[illegible]	[illegible]	0.0
24-hr Rainfall, millimeters														
Mean	1.4	1.4	1.8	1.8	1.8	2.0	2.5	2.0	1.4	1.4	1.6	1.4	**1.7**	1.6
Median	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0
Max	110.4	36.8	[illegible]	82.1	36.8	69.3	77.0	76.8	41.0	43.0	56.5	79.5	**110.4**	110.4
Min	0.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0
Monthly Rainfall, millimeters														
Mean	43.7	39.5	[illegible]	[illegible]	[illegible]	[illegible]	78.8	60.5	43.3	44.8	49.0	43.9	**52.4**	47.2
Max	138.9	109.9	[illegible]	[illegible]	[illegible]	[illegible]	399.6	171.0	109.2	137.8	117.5	148.7	**399.6**	196.1
Min	7.8	4.9	3.4	6.8	12.0	1.7	1.0	1.6	[illegible]	2.4	9.8	9.0	**1.0**	2.4
Seasonal Rainfall, millimeters														
Mean													**628.6**	330.3
Max													**953.4**	506.4
Min													**306.0**	157.7
Fine Fuel Moisture Code, FFMC														
Mean	81.5	80.8	77.5	75.4	70.0	64.4	63.6	69.3	[illegible]	[illegible]	[illegible]	[illegible]	**74.6**	79.0
Median	85.7	85.2	83.9	82.6	78.6	72.5	72.2	77.8	[illegible]	[illegible]	[illegible]	[illegible]	**82.0**	84.6
Max	98.1	98.1	95.2	92.9	92.5	91.4	90.5	91.7	[illegible]	[illegible]	[illegible]	[illegible]	**98.1**	98.1
Min	11.7	5.6	1.4	0.0	0.6	0.0	0.0	0.0	[illegible]	[illegible]	[illegible]	[illegible]	**0.0**	0.0
Duff Moisture Code, DMC														
Mean	34.7	40.3	28.4	22.0	11.2	4.5	3.1	5.9	11.7	19.5	25.0	30.7	**19.6**	28.6
Median	29.7	33.8	22.5	17.9	8.0	2.9	2.3	4.8	10.4	15.0	20.9	27.9	**13.5**	23.3
Max	102.7	163.6	104.8	93.8	86.6	23.1	22.0	27.3	55.2	94.7	100.7	110.3	**163.6**	163.6
Min	2.9	2.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.4	0.7	**0.0**	0.0
Drought Code, DC														
Mean	375.8	458.0	445.8	414.0	322.5	226.1	153.7	115.6	103.1	129.2	190.1	284.2	**267.1**	326.7
Median	377.6	450.8	436.1	416.8	308.4	218.2	120.9	90.5	72.8	98.7	178.0	274.5	**245.9**	312.1
Max	741.6	795.2	800.7	785.4	792.6	604.5	533.5	382.7	407.2	508.5	544.0	731.8	**800.7**	800.7
Min	6.0	168.9	36.4	29.9	22.8	0.7	0.1	0.0	0.7	2.2	5.8	25.5	**0.0**	2.2
Initial Spread Index, ISI														
Mean	9.4	7.8	6.7	4.6	3.1	2.0	2.0	3.1	5.2	7.3	8.8	9.3	**5.8**	7.7
Median	6.3	5.7	4.4	3.1	1.9	1.2	1.2	2.0	3.4	4.6	5.5	6.1	**3.2**	5.0
Max	105.5	116.1	124.0	59.8	39.6	84.8	50.8	56.4	92.4	126.2	120.6	144.8	**144.8**	144.8
Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0
Buildup Index, BUI														
Mean	54.4	63.6	47.5	37.4	19.7	8.1	5.5	9.3	16.1	26.3	35.4	46.3	**30.6**	44.2
Median	48.5	56.8	39.8	31.6	14.6	5.5	4.1	7.5	14.2	21.1	31.3	43.6	**22.0**	37.6
Max	142.8	211.3	148.2	132.3	134.6	38.3	39.0	37.0	58.0	129.2	132.0	142.7	**211.3**	211.3
Min	5.5	5.5	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.9	1.3	**0.0**	0.0
Fire Weather Index, FWI														
Mean	19.7	18.8	14.2	9.7	4.6	1.9	1.5	3.3	6.9	11.4	14.9	18.2	**10.4**	15.3
Median	16.6	15.9	10.7	7.0	2.4	0.6	0.5	1.3	4.1	7.8	11.1	14.8	**5.4**	11.5
Max	121.8	122.9	115.3	67.3	59.5	65.4	24.7	37.6	77.9	130.3	102.7	130.8	**130.8**	130.8
Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0
Daily Severity Rating, DSR														
Max	133.72	135.91	121.32	46.81	37.68	44.42	7.91	16.73	60.56	150.58	98.82	151.69	**151.69**	151.69
Monthly Severity Rating, [illegible]														
Mean	7.85	[illegible]	[illegible]	[illegible]	0.90	0.26	0.16	0.49	1.65	3.66	5.36	7.09	**3.53**	5.56
Max	24.64	[illegible]	[illegible]	[illegible]	3.55	2.68	0.74	1.86	8.06	26.53	18.50	18.78	**27.07**	27.07
Min	[illegible]	[illegible]	[illegible]	[illegible]	0.01	0.01	0.00	0.04	0.04	0.19	1.00	0.31	**0.00**	0.19
Cumulative Daily Se[illegible]														
Mean													**1299.55**	1194.01
Max													**2894.70**	2849.74
Min													**406.49**	384.68

Figure 3. Example of summary output table containing summary statistics for weather elements and FWI System components, with descriptive comments on statistics and format.

The compilation of a comprehensive database of daily fire weather and fire danger information for 127 of the 179 weather stations for which data was available was the other major output from the analysis. This database was an essential component of the subsequent research being conducted by Ensis (and also NIWA and MetService, see FTTN 33). The database also provides an extremely useful tool for fire managers to make more informed fire management decisions on prevention, preparedness, and prescribed burning activities.

Table 1. Ranking of regional fire climate severity based on stations included in the fire climatology analysis, using the average of rankings for long-term mean Cumulative Daily Severity Rating (CDSR) and number of days of VERY HIGH and EXTREME (VH+E) fire danger class for Forest (FFDC) and Scrubland (SFDC). The average length of record (years) and annual rainfall (mm) for each region are also included for comparative purposes.

No.	Region	No. Stations	Length of Record (years)	CDSR	VH+E FFDC (days)	VH+E SFDC (days)	Annual Rainfall (mm)	Rank CDSR	Rank FFDC	Rank SFDC	Average Rank
1	Canterbury	10	10.4	900	21.8	234.2	741	1	1	3	1.7
2	Marlborough	7	11.4	795	21.1	237.7	1101	2	2	2	2.0
3	Otago	10	11.3	762	16.1	223.8	677	3	3	6	4.0
4	South Cant'y	4	9.3	636	14.6	228.2	667	5	4	5	4.7
5	Eastern	13	9.2	579	14.3	231.3	1383	6	5	4	5.0
6	Wellington	4	23.3	435	6.8	248.2	1070	8	7	1	5.3
7	Wairarapa	7	7.7	745	13.3	216.2	1213	4	6	8	6.0
8	Nelson	4	15.8	576	5.2	211.1	1255	7	8	10	8.3
9	Northland	10	11.8	285	4.7	217.8	1374	11	10	7	9.3
10	Wang/Man	13	9.8	306	4.9	205.1	1126	10	9	11	10.0
11	CNI	13	12.8	284	4.6	211.9	1493	12	11	9	10.7
12	Southland	9	11.7	346	3.3	181.8	1106	9	12	15	12.0
13	Auckland	9	9.9	209	2.2	194.8	1297	13	13	13	13.0
14	Waikato	6	10.8	180	1.7	191.2	1712	14	14	14	14.0
15	Taranaki	5	10.8	157	0.9	196.7	1447	15	15	12	14.0
16	West Coast	3	25.3	44	0.0	135.0	2900	16	16	16	16.0
	South Island	**47**	**12.3**	**644**	**13.5**	**213.7**	**1026**				
	North Island	**80**	**11.1**	**359**	**6.4**	**212.7**	**1346**				
	National	**127**	**11.5**	**463**	**9.0**	**212.9**	**1228**				

2. Prediction of fire season severity (Pearce and Moore 2004)

As part of a second NZFSC-funded project, "Prediction of Fire Season Severity", Ensis developed an analytical tool for predicting fire season severity based on data from past seasons contained in the fire climatology database (Pearce and Moore 2004). This was achieved by conducting statistical analyses on measures of fire season severity – such as Cumulative Daily Severity Ratings (CDSR), Drought Code (DC) and Buildup Index (BUI) – for a subset of 7 weather stations with long-term fire climate records. Two contrasting analytical approaches were investigated:

(1) analyses of statistical similarity between fire season trend curves, as the basis for identifying the historical season most similar to current conditions; and

(2) fitting of parametric functions that characterise the general shape of fire season trend curves, and use of derived function descriptors to predict intermediate as well as fire season end values.

The 7 stations were all airport (MetService) stations that had been used in previous analyses, and were therefore easily updated and had the greatest number of years of record available (>30 years) for comparative analyses and parametric curve fitting. They also provided good geographic spread across the country and represented the range of fire season severities identified by Pearce *et al*. (2003) in the previous study.

Both approaches were found to be effective at grouping seasons with similar fire severity as determined through CDSR. The similarity approach (1) was better for grouping seasons according to BUI and DC as neither of these two indices had temporal patterns that could be easily modelled with a parametric function. The parametric curve fitting method (2) successfully modelled overall fire season severity as measured through CDSR and, more importantly, also proved successful in predicting seasonal severity 1-2 months ahead.

In this parametric curve fitting method, the sigmoidal growth trend in the CDSR for each year of record (see Fig. 4) was fitted using a Chapman-Richards function (which is widely used to model monotonic growth; Draper and Smith 1998), and then annual relationships substituted with a non-linear mixed effects model in which time was treated as a fixed effect and fire season was treated as a random effect. In other words, the manner in which CDSR increases with time since July 1st was assumed to be constant (i.e., fixed) between fire seasons, but the maximum value that it reaches at the end of the fire season was assumed to vary between fire seasons (i.e., it was random).

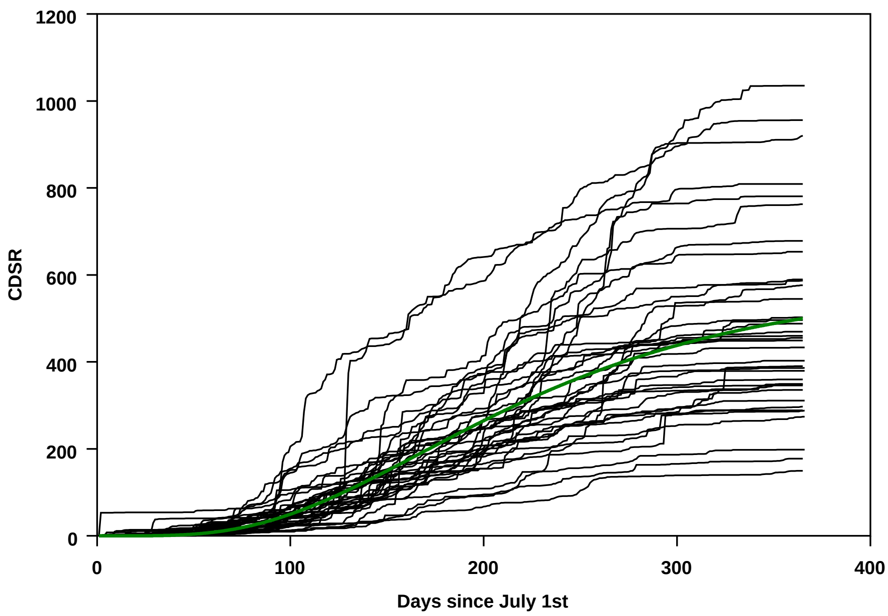


Figure 4. Growth in Cumulative Daily Severity Rating (CDSR) with days since July 1st for data from all fire seasons recorded at Dunedin Aero, where the solid green line corresponds to a fitted average growth curve.

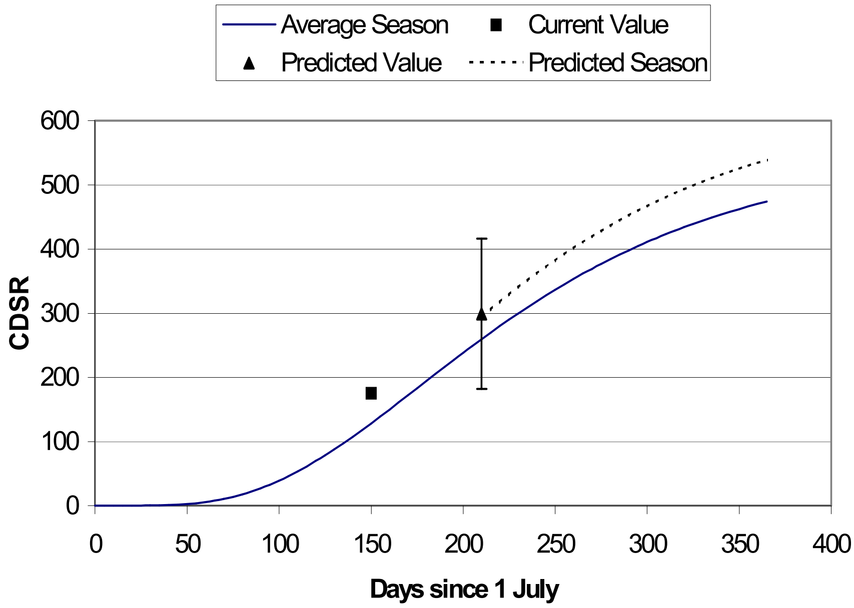


Figure 5. Graphical representation of the method for predicting CDSR at future dates into the fire season based on the current value.

A Microsoft Excel™-based spreadsheet package encompassing this parametric curve fitting approach was developed (see Fig. 5) and, while still requiring further development and testing before it can be used operationally, in particular validation for a broader range of station locations, this does offer promise as a means of predicting future trends in fire season severity.

The other significant finding of this study related to annual trends in fire danger index components and potential fire season start dates. Typically, the starting date for the fire season is cited as October 1st when, in fact, actual fire season start date varies from year to year and between regions with seasonal conditions. October 1st is also commonly used as the starting point for cumulative fire danger ratings, such as the CDSR. Normalised values of the BUI and DSR were used to identify average minimum values of these indices (Fig. 6) which indicate that a more logical starting date for such cumulative ratings is in fact July 1st (or around Julian day 182). However, further investigation is still required to identify appropriate criteria and values for both fire season start and end dates, which are likely to be more variable from region to region, and season to season.

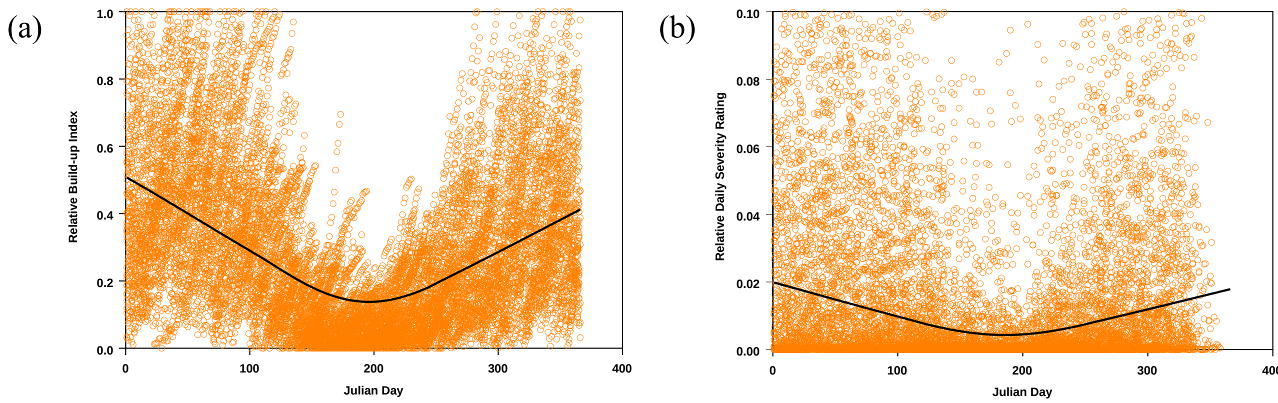


Figure 6. Seasonal trends in normalised values of: **(a)** relative Build-up Index (BUI); and **(b)** relative Daily Severity Rating (DSR), for the Dunedin Aero weather station. The solid line corresponds to a smoothing function fitted to the data.

3. Impact of climate change on future fire danger (Pearce *et al.* 2005)

A third NZFSC-funded project, “Impact of Climate Variability and Change on Seasonal Fire Danger”, documenting the impact of climate change on future fire danger, was conducted jointly by Ensis and NIWA during 2004/05 (Pearce *et al*. 2005).

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 (e.g., Pinol *et al*. 1998, Flannigan *et al*. 2001, De Groot *et al*. 2003). The main objective of this study was to determine likely changes in fire danger under actual scenarios of climate change for New Zealand. The research applied regional climate change scenarios for the 2080s to the long-term weather records for individual stations in the fire danger climatology database.

The climatology database was updated to include data to 31 December 2004, and 52 stations providing good spatial coverage were then selected for analysis of the effects of climate change based on 11 or more unbroken calendar years of data (i.e., 10 complete fire seasons). This length of record included a fairly representative period of climate. Two General Circulation Models (GCMs), CSIRO and Hadley, with contrasting spatial patterns of climate change were used to investigate the effects on fire danger. GCM model outputs were “downscaled”, using a statistical technique developed for New Zealand by NIWA (Mullan *et al*. 2001), to provide mean monthly offsets for temperature and rainfall that were used to recreate daily fire weather and fire danger records for each station. High, low, and mid-range scenarios of climate change were generated for each model.

Summary statistics of weather inputs, FWI System components and fire danger class frequencies (*cf*. Fig. 3) were calculated for each station for the range of scenarios. This included mean values of temperature, rainfall, Fine Fuel Moisture Code (FFMC), Build Up Index (BUI), Cumulative Daily Severity Rating (CDSR), and number of days of Very High plus Extreme (VH+E) Forest fire danger. Annual differences were compared to those for fire season months when most fires are expected to occur. The main findings were:

- Changes in temperature and rainfall followed the original patterns in offset values for each scenario. Temperature changes of +0.5 to +2.4 ºC were significantly higher than current climate for all but the Hadley low extreme scenario. Rainfall changes were more variable. The Hadley model scenarios resulted in reductions of -15% to -35% (-100 to -330 mm) in annual rainfalls for stations in Northland, Bay of Plenty and eastern parts of both the North and South Islands, and increases of +10% to +25% (+80 to +800 mm) for stations from the West Coast and Southland. Changes in rainfall under the CSIRO scenarios were not significant, apart from a 12% increase (+70 to +80 mm) at Invercargill.
- Increased FFMC values occurred in most places under both the Hadley and CSIRO high extreme and mid-range scenarios, in particular in the Auckland, Bay of Plenty, Gisborne, Wellington and coastal Canterbury areas (Fig. 7a). However, average changes were small at less than +2 to +3 points. Small decreases in FFMC (up to -0.5 points) were obtained for some stations in the southern South Island under the Hadley model. Similarly, significant increases in BUI (up to +20 points, or +60%) were found from the Bay of Plenty and central (Wellington/Nelson) regions under both the Hadley and CSIRO model scenarios, while stations in north and east of the North Island and east of the South Island increased significantly under only the Hadley model scenarios (Fig. 7b). Stations in the west and south showed increases solely under the CSIRO model, as a result of drier winters and wetter springs in the south and west under this model.
- Significantly higher CDSR values (Fig. 7c) and more days of VH+E Forest fire danger (Fig. 7d) were found for stations in the east of both islands, the Bay of Plenty and central (Wellington/ Nelson) regions under both the Hadley and CSIRO high extreme and mid-range scenarios. In several cases (e.g., Gisborne, Napier and Christchurch Aeros), average CDSR values increased

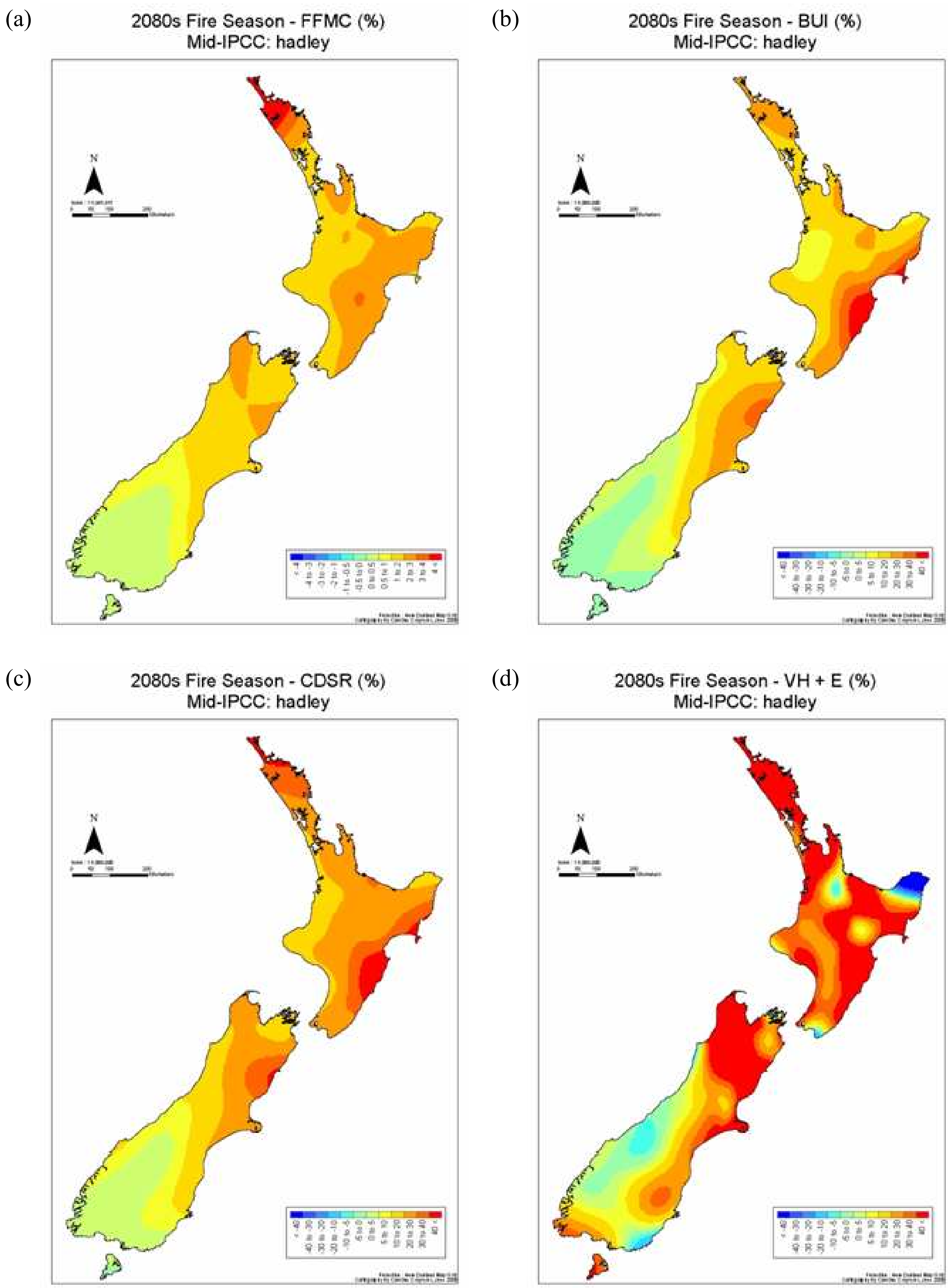


Figure 7. Potential changes (%) in future fire dangers for the 2080s, averaged over fire season months for the Hadley mid-range climate change scenario: **(a)** Fine Fuel Moisture Code (FFMC); **(b)** Buildup Index (BUI); **(c)** Cumulative Daily Severity Rating (CDSR)/Seasonal Severity Rating (SSR); and **(d)** average number of days of Very High and Extreme (VH+E) Forest fire danger.

by more than 300-580 points (25-65%), and the total number of days of VH+E Forest fire danger by more than 20 days (>50%). Smaller, but still statistically significant, increases in CDSR (10-110 points, or 15-25%) were found under the CSIRO high extreme scenario for stations in the west of both islands and south of the South Island. Several stations (typically those in the south and west with low or no existing fire danger) showed little or no change in CDSR or VH+E Forest fire danger but, in one case (Tara Hills under the Hadley high extreme scenario), showed a very slight decrease in VH+E fire danger.

- Observational evidence from changes in mean monthly temperatures, FFMC and Monthly Severity Rating (MSR) values, and VH+E Forest fire danger class frequencies under the model scenarios does suggest that fire season length could well be extended, by both starting earlier and/or finishing later, in many parts of the country. However, no adequate method exists to properly test this result.
- Given New Zealand's maritime climate any subtle changes in relative humidity (RH), which was not modelled, are unlikely to have any significant effect on future fire dangers. However, indicative wind speed increases from global climate models almost certainly suggest further increases in future fire dangers. Modelled changes in the mean westerly wind component across New Zealand show an increase of about 10% of its current value over the next 50 years, with a mid-range projection of 60% by the 2080s. This will increase the Initial Spread Index (ISI) value; and result in increased drying, and therefore higher FFMC values and subsequent ISI and FWI values. The general trend is expected to be a further increase in future fire weather severity.

Results from this study indicate that under future fire climate New Zealand <u>is</u> likely to experience more severe fire weather and fire danger (see Fig. 7), especially in the Bay of Plenty, east of both islands and central (Wellington/Nelson) regions. This will result in increased fire risk including:

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

It is possible that some of this risk might be offset by increased rainfall in some parts of the country (e.g., southern South Island). The indications of possible future fire activity and increased suppression and management requirements associated with climate change highlighted within this study will enable New Zealand rural fire authorities to make more informed fire management decisions on fire prevention and preparedness activities now and in the future.

A similar study identifying possible changes in fire weather under future climate change scenarios for south-eastern Australia was recently produced (Hennessy *et al*. 2005). It also predicts the potential for significant changes in fire weather, with frequencies of Very High or Extreme fire weather days increasing by 4-25% by 2020 and 15-70% by 2050 if model projections are correct.

Future Directions

An extension of the NZFSC Contestable Research Fund project "Prediction of Fire Weather and Associated Fire Danger" has just been approved for funding in 2006/07. To be conducted jointly by NIWA and Ensis, this new project aims to further investigate the impacts of seasonal, annual and decadal climate variability on fire danger (in addition to continuing research to improve regional fire danger forecasts, including development of new methods for forecasting fire danger from two to four weeks ahead for fire climate regions; see FTTN 33).

This research proposes to analyse the effects of two of the main factors contributing to interannual variability, the El Niño-Southern Oscillation (ENSO) and Interdecadal Pacific Oscillation (IPO), using the weather records for individual stations contained in the fire danger climatology database. Long-term fire weather records will be updated to include data for recent seasons, and current fire danger climatologies re-computed for the existing 127 weather stations, and any additional stations with sufficient length of record. Severity ratings and fire danger class frequencies will be calculated for each station for composites of El Niño/La Niña seasons, and before and after 1977 to determine IPO changes. Fire danger climatologies will be compared to those under current fire climate to predict potential impacts on regional fire danger and seasonal severity for patterns of current climate variability. Results from this research will improve understanding of the potential effects of seasonal to decadal climate variability for assessment of fire climate and fire danger trends. This will enable rural fire authorities to make more informed fire management decisions on fire prevention, preparedness and suppression activities.

A project to develop a geo-spatial database of fire climate and associated mapping tools has also been initiated by Ensis Bushfire Research. This involves linking the fire climate database with a Geographical Information System (GIS), as the basis for production of maps depicting spatial variation in fire weather and fire danger across the country. It is planned to produce maps of daily or long-term average/extreme fire weather (temperature, relative humidity, wind speed and 24-hour rainfall) and fire danger (FWI System codes and indices, severity ratings, and fire danger classes) for any summary period (i.e., month, fire season or year), all within the GIS (currently only ArcGIS). To allow this, a number of tools are being developed, including ArcGIS projects for calculating fire danger indices and fire climate statistics, and investigation of appropriate spatial interpolation methods for mapping fire weather and climate.

Once completed, there are opportunities to also link the spatial fire climate information with a number of other applications, such as fuel type mapping to enable production of fuel load maps (e.g., for fuel types where available fuel load is dependent on BUI; see FTTN 30 (Opperman and Coquerel 2005)) and Wildfire Threat Analysis. In both these cases, linkages with the spatial fire climatology have the advantage of being able to create and depict any weather or climate scenario, as opposed to the single fire climate scenario currently contained within the New Zealand Wildfire Threat Analysis System (NZWTAS) (NRFA 2005).

Conclusion

Considerable research on describing and predicting New Zealand's fire climate has been undertaken in recent years by scientists from Ensis (in conjunction with NIWA and MetService), through support from the NZFSC's Contestable Research Fund, the Foundation for Research Science and Technology (FRST) and rural fire sector stakeholders. A key element of this has been the development of a fire climatology database of daily fire weather and fire danger information for weather station locations across the country. This database has provided the basis for a number of subsequent studies, including comparison of the severity of fire climates in different parts of the country, prediction of the severity of fire seasons, and projection of likely effects of climate change on future fire dangers. Further work on the effects of ENSO and decadal fluctuations on fire danger, and a geospatial database and mapping of fire climate, is either underway or planned to commence in the next few months. Several of the analyses and applications described here (e.g., fire season severity prediction tool, fire season start and end dates) require further research, while a focal point for future work also lies in developing these into tools for operational use and implementation.

It is planned to continue to update the fire climatology database at regular intervals to enable further research on improving description of New Zealand's fire climate to be undertaken. The research is therefore providing results that can be utilised immediately, as well as a platform from which future research can be built. It is contributing to an increased awareness of seasonal fire danger trends, improved regional fire danger forecasts, and prediction of fire season severity and climate change effects. By indicating potential fire behaviour and suppression requirements, both in the short-term and into the future, it is enabling rural fire authorities to make more informed fire management decisions, leading to more effective and efficient use of resources and, ultimately, a reduction in the incidence and consequences of rural fires.

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