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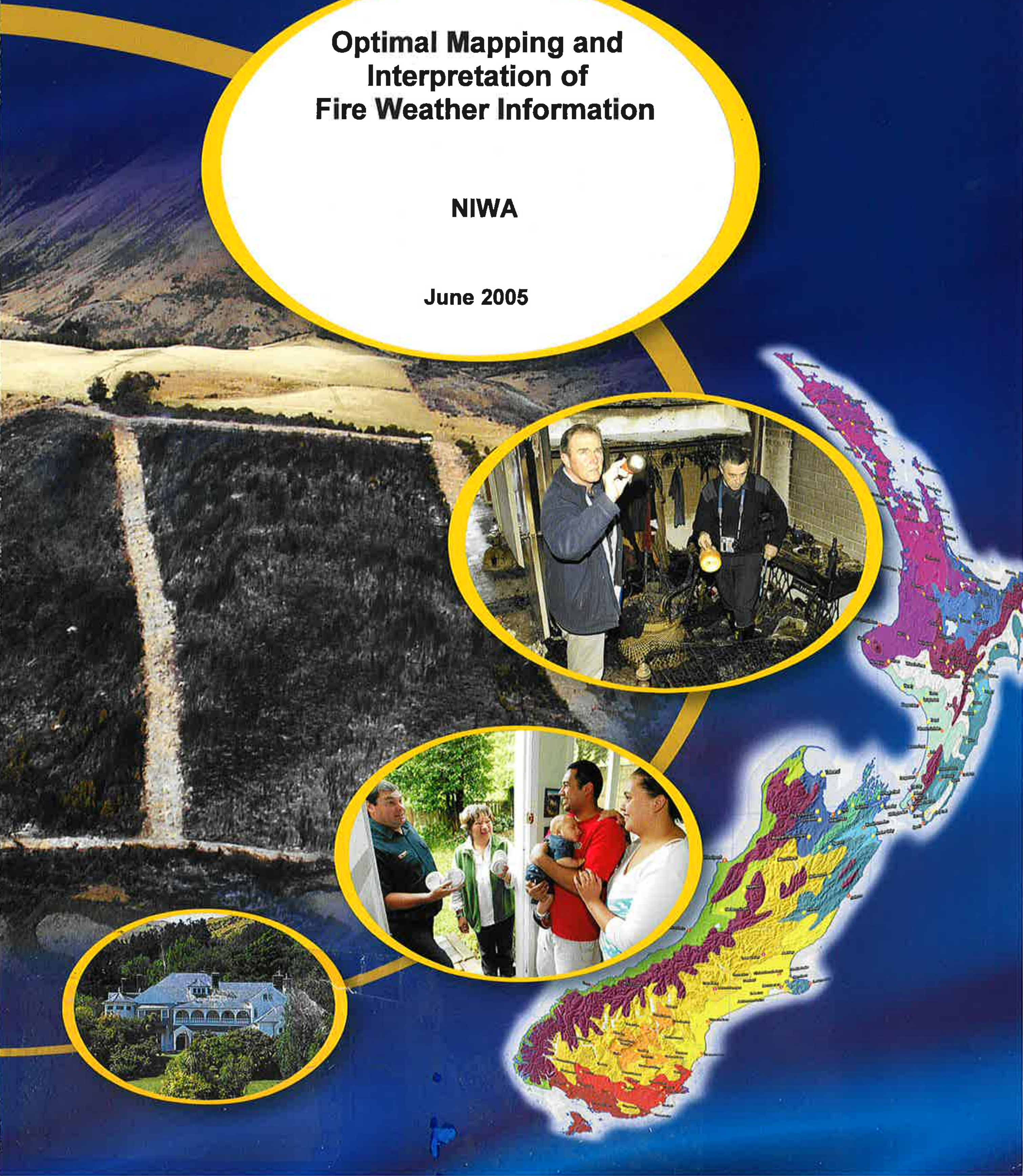
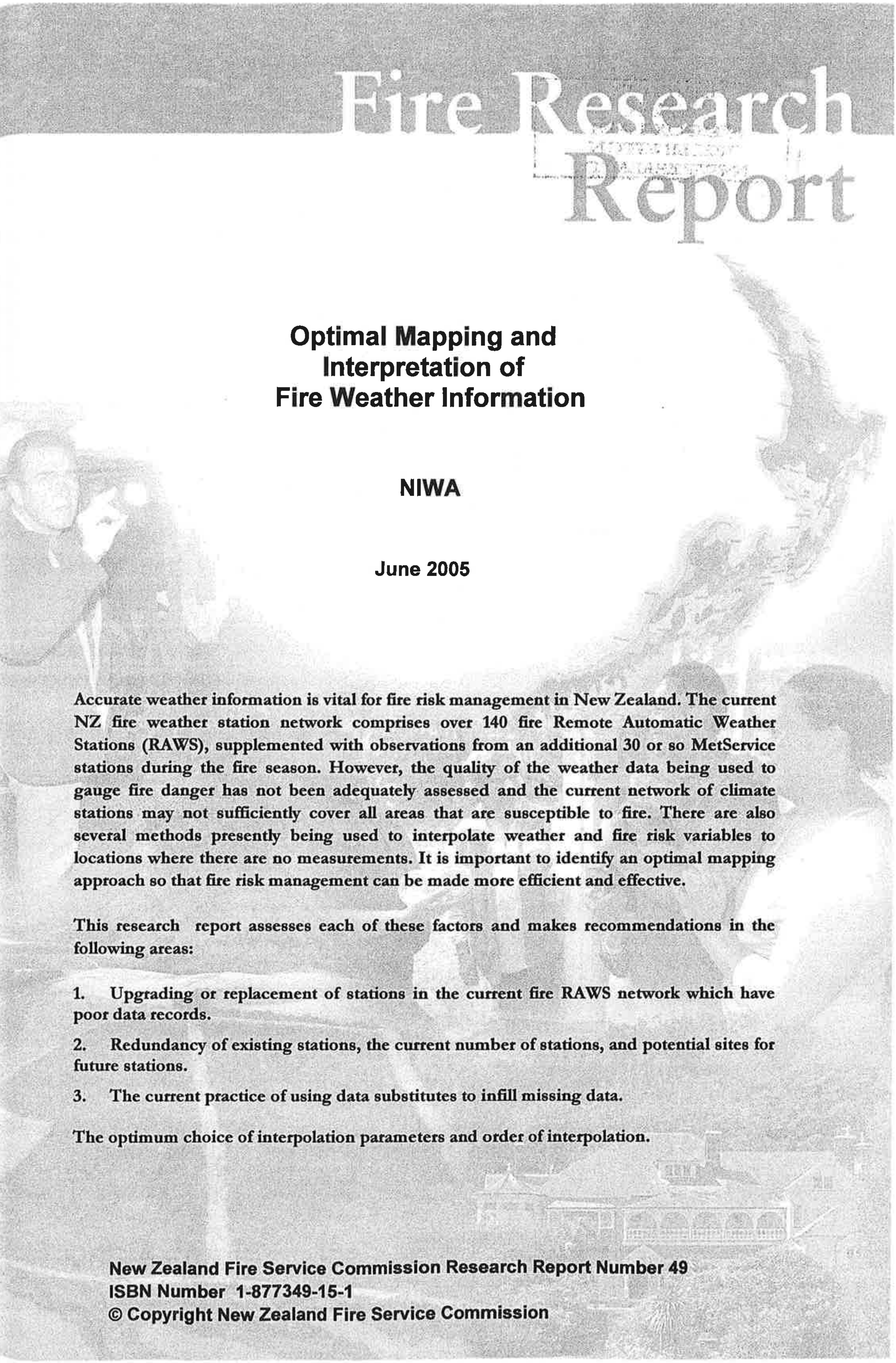
Fire Research Report



Optimal Mapping and Interpretation of Fire Weather Information

NIWA

June 2005



Fire Research Report

Optimal Mapping and Interpretation of Fire Weather Information

NIWA

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Accurate weather information is vital for fire risk management in New Zealand. The current NZ fire weather station network comprises over 140 fire Remote Automatic Weather Stations (RAWS), supplemented with observations from an additional 30 or so MetService stations during the fire season. However, the quality of the weather data being used to gauge fire danger has not been adequately assessed and the current network of climate stations may not sufficiently cover all areas that are susceptible to fire. There are also several methods presently being used to interpolate weather and fire risk variables to locations where there are no measurements. It is important to identify an optimal mapping approach so that fire risk management can be made more efficient and effective.

This research report assesses each of these factors and makes recommendations in the following areas:

1. Upgrading or replacement of stations in the current fire RAWS network which have poor data records.
2. Redundancy of existing stations, the current number of stations, and potential sites for future stations.
3. The current practice of using data substitutes to infill missing data.

The optimum choice of interpolation parameters and order of interpolation.

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NIWA Client Report: WLG2005-1
30 June 2005

NIWA Project: NZF03301 / YEAR2

Final Report: Optimal Mapping and Interpretation of Fire Weather Information

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Prepared for

New Zealand Fire Service

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1. Introduction

Accurate weather information is vital for fire risk management in New Zealand. The current NZ fire weather station network comprises over 140 fire Remote Automatic Weather Stations (RAWS), supplemented with observations from an additional 30 or so MetService stations during the fire season. However, the quality of the weather data being used to gauge fire danger has not been adequately assessed and the current network of climate stations may not sufficiently cover all areas that are susceptible to fire. Also, there are several methods presently being used to interpolate weather and fire risk variables to locations where there are no measurements. It is important to identify the advantages and disadvantages of the different mapping approaches so that fire risk management can be made more efficient and effective.

The following tasks have been performed over the period 1 July 2003 – 30 June 2005, to address the above issues:

1. Analysis of time series plots of historical fire RAWS data to check for periods of long data gaps and for spurious (or “erroneous”) values.

2. Examination of histograms of the data, checking for extreme outliers and anomalously skewed data records.

3. Checking of the historical fire RAWS data against nearby NIWA or MetService automatic weather stations to identify poor-quality data.

4. A detailed literature review of spatial interpolation scheme comparison studies, and advice to NZFS on whether the currently used scheme, thin plate smoothing spline interpolation, should be maintained or replaced.

5. Identification of the relative importance of each climate station in the current RAWS network for the purpose of spatial interpolation of the four climate parameters used to assess fire risk (i.e. rainfall, relative humidity, temperature, and wind speed).

6. Analysis of the accuracy of spatially interpolating these four climate parameters by comparison of interpolated values to actual values at climate stations not included in the current fire RAWS network.

7. Calculation of the root mean square error at each climate station in the current RAWS network for the four climate parameters used to assess fire risk comparing data from the pre-assigned substitute stations, used to infill missing data, to actual data.

8. Calculation of the root mean square errors again; comparing data interpolated using a spline model, as a potential method for infilling missing data, to the actual data.

9. Analysis of the effect of a square root transformation, bivariate spline interpolation, and alternate covariates (a 1951–80 mean annual rainfall surface for rainfall and relative humidity interpolation, and a daily temperature range surface for wind speed interpolation) on the root mean square errors.

10. Reporting on the likelihood of reducing the interpolation error associated with mapping the Fire Weather Index (FWI) by interpolating the index, rather than its component weather variables.

Recommendations are made on the following matters:

1. Upgrading or replacement of stations in the current fire RAWS network which have poor data records.

2. Redundancy of existing stations, the current number of stations, and potential sites for future stations.

3. The current practice of using data substitutes to infill missing data.

4. The optimum choice of interpolation parameters and order of interpolation.

2. Station Data Quality Analysis

The goal of this stage of the study was to “Analyse the quality and reliability of climate data from the existing fire RAWS network”. This involved the completion of tasks 1 – 3, described in section 1. Work was completed on this stage of the study during the period 1 July 2003 – 15 December 2003, and results were presented in the Milestone 1 progress report submitted to NZFS in December 2003.

2.1 Data and Analysis

Hourly climate data from all the fire climate stations (121 stations nationwide) from 1996 to September 2003 were compressed and burned onto a CD by Mr. Karl Majorhazi, NZFS, and sent to NIWA in an easily readable form in September 2003. These data have been read into a special table in NIWA’s National Climate Database which is accessible only by project personnel.

Spatial interpretation of unchecked historical data may result in misleading patterns, due to the influence of poor quality data. Three analysis stages were implemented to identify poor quality data. These were: 1. Identification of extreme data outliers; 2. Visual inspection of time series plots; and 3. Use of regression analyses. For stage 1, histograms of the data were produced to identify extreme outliers (e.g. Figure 1). Cut off values were chosen, beyond which data were considered to be of poor quality and were deleted. These cut offs were:

- Temperature: -30 °C to 50 °C
- RH: 0% to 100%
- Wind speed: 0 km/hr to 100 km/hr
- Rainfall: 0 mm/hr to 100 mm/hr

For stage 2, time series plots like the example shown for Aupouri Peninsula (Figure 2) were produced for every fire RAWS. Data of obviously poor quality were identified by visually inspecting these plots and were deleted. On Figure 2, obvious periods of poor data quality can be seen (e.g. for RH, wind speed, and rainfall the period between June and mid-September 1996).

Finally, for stage 3, regressions of mean daily temperature, minimum daily RH, mean daily wind speed, and daily total rainfall at each fire RAWS against the contemporary data at the nearest NIWA or MetService operated automatic weather station were performed. The regression plots highlight significant outliers which are then identified on the time series plots. If the outliers are suspected to be data of poor quality they are deleted. Figure 3 shows example regression plots for Aupouri Peninsula versus Cape Reinga AWS.

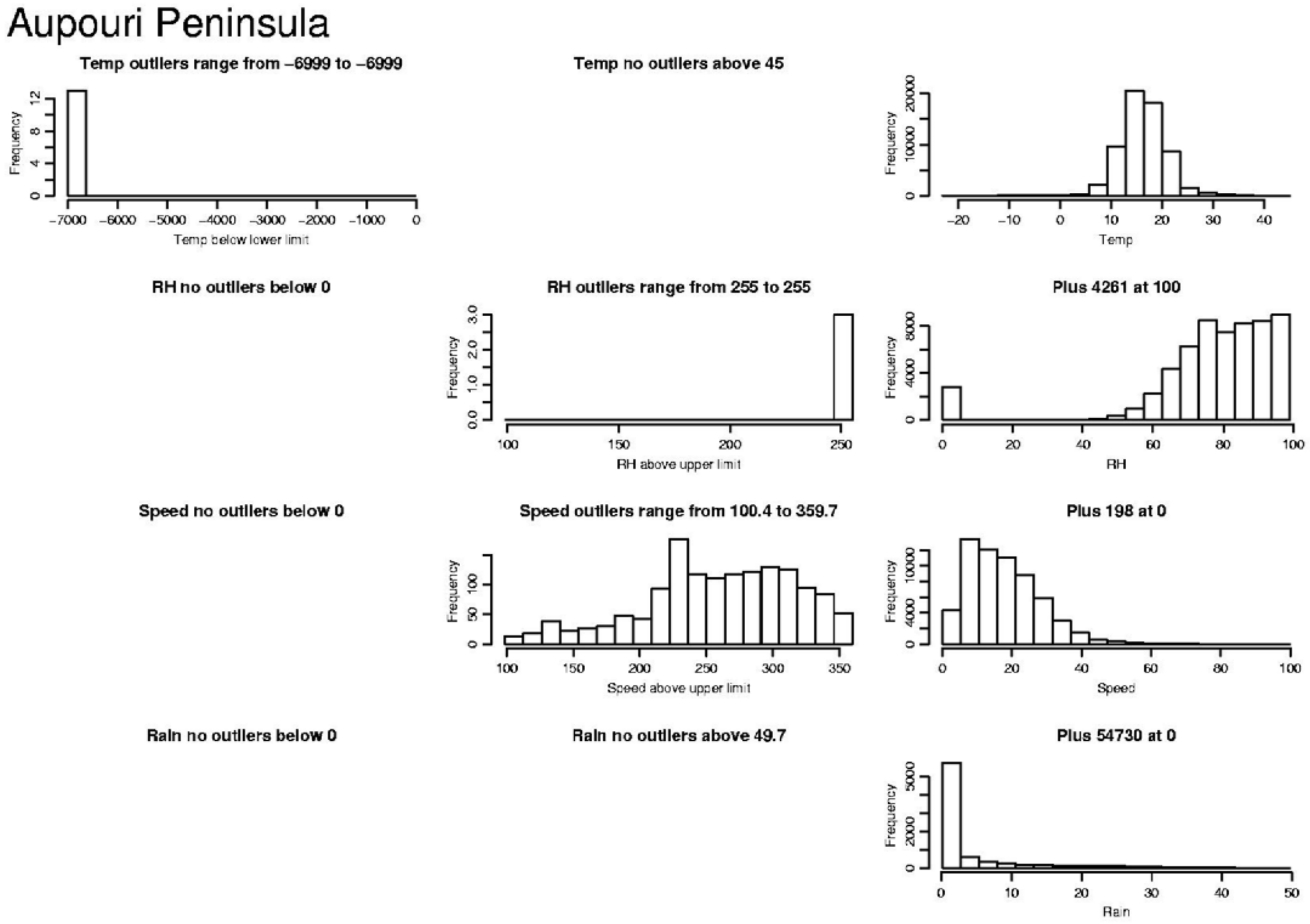

Figure 1: Histogram plots of temperature, RH, wind speed, and rainfall outliers for Aupouri Peninsula.

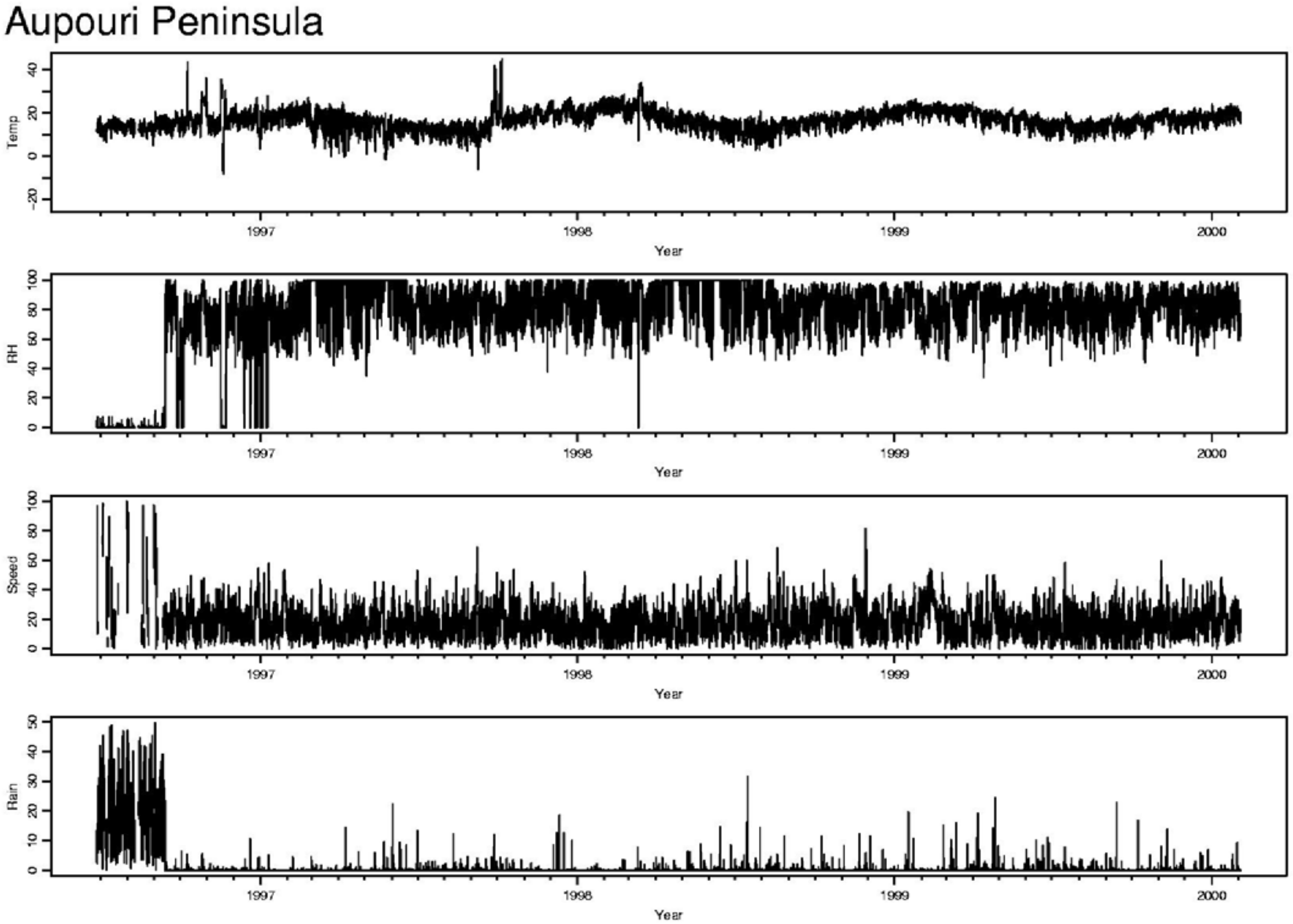

Figure 2: Time series plots of hourly temperature, RH, wind speed, and rainfall for Aupouri Peninsula.

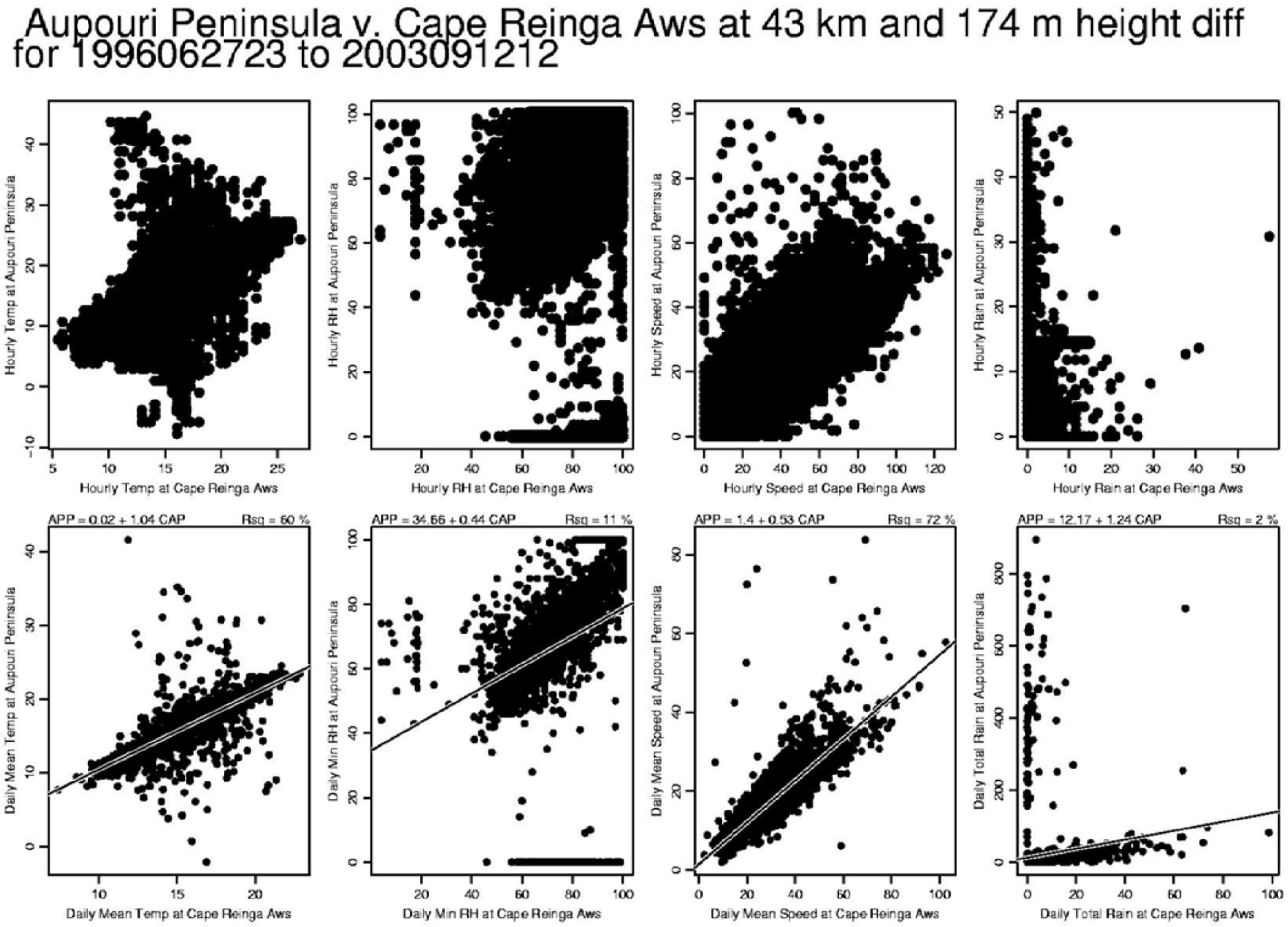

Figure 3: Regression plots of hourly and daily temperature, RH, wind speed, and rainfall for Aupouri Peninsula versus Cape Reinga AWS.

Figures 4 – 7 show the effects of the quality checking on the numbers of days of temperature, rainfall, relative humidity, and wind speed data respectively, for each of the fire RAWS encompassing data up to the end of 2002, the last complete year of data. In each plot, the height of the red bar represents the theoretical number of days of data for the particular station, based on its start and end dates. The height of the blue bar represents the actual number of days of “good quality” data (i.e. after all the deletions from the quality checking analyses have been made).

From Figures 4 – 7, it can be seen that there are some stations that have historically had very few days of data (e.g. CLY, Clyde, which only has data for a few months in 1999), some stations that have a lot of data of poor quality (e.g. TEK, Tekapo), some stations that have generally good data with the exception of one data type (e.g. HNW, Hunua West, which recorded temperature data of poor quality for most of 2000-2002 inclusive, although the rainfall, relative humidity, and wind speed data during this period were generally good), and some stations that have very good data records for all variables (e.g. RFP, Rimutaka Forest Park).

Figures 8 – 11 are the same plots as Figures 4 – 7, but for the period January – September, 2003. This period was separated from the “historical” period, 1996 – 2002, in order to assess the “current” data quality. From these Figures it can be seen that most of the stations have complete records for this 9-month period (where the red bar is completely obscured by the blue bar). This suggests that most of the “current” data are of relatively good quality. There are some “historical” stations which have no data during this period (e.g. BUR, Burnham) and some stations which have been disabled during the period (e.g. HOK, Hokianga). Stations with sizeable red bars (e.g. WTF, Waitarere Forest temperature and relative humidity data) should be looked at closely to determine the cause of the currently poor data quality.

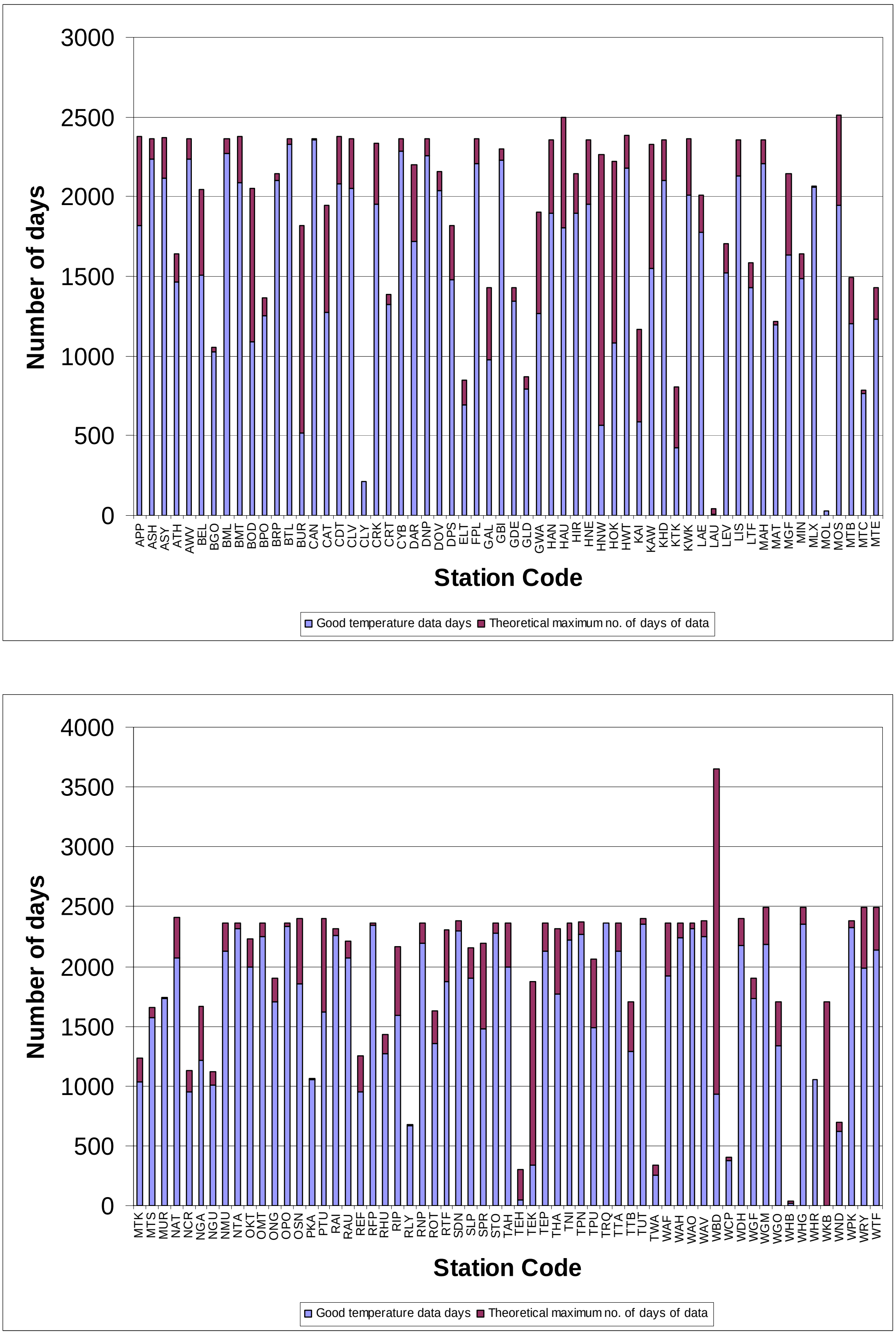

Figure 4: The theoretical number of days of temperature data (based on the start and end dates, red bars) for each fire RAWS up to the end of 2002 and number of days of temperature data of good quality (blue bars).

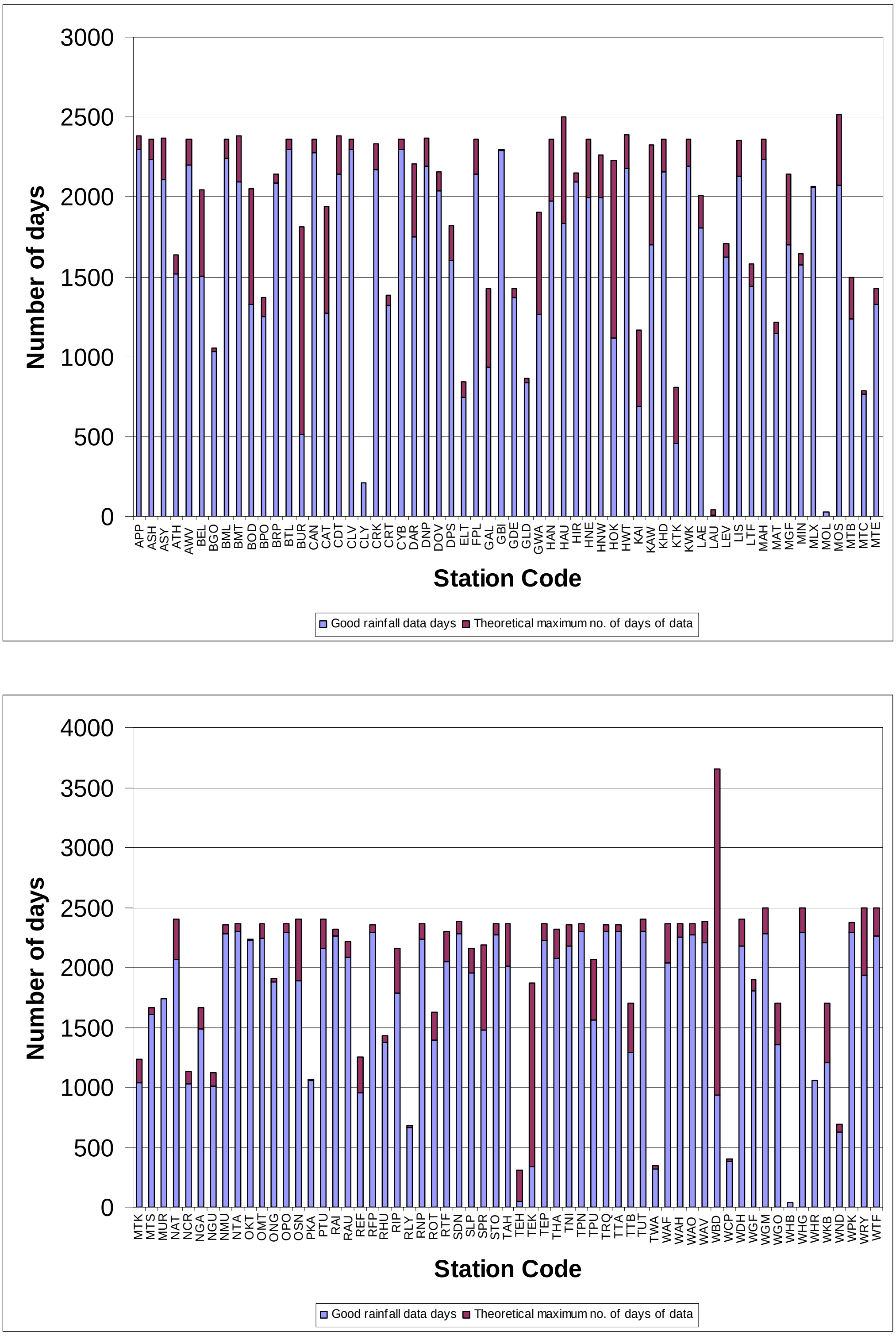

Figure 5: The theoretical number of days of rainfall data (based on the start and end dates, red bars) for each fire RAWS up to the end of 2002 and number of days of rainfall data of good quality (blue bars).

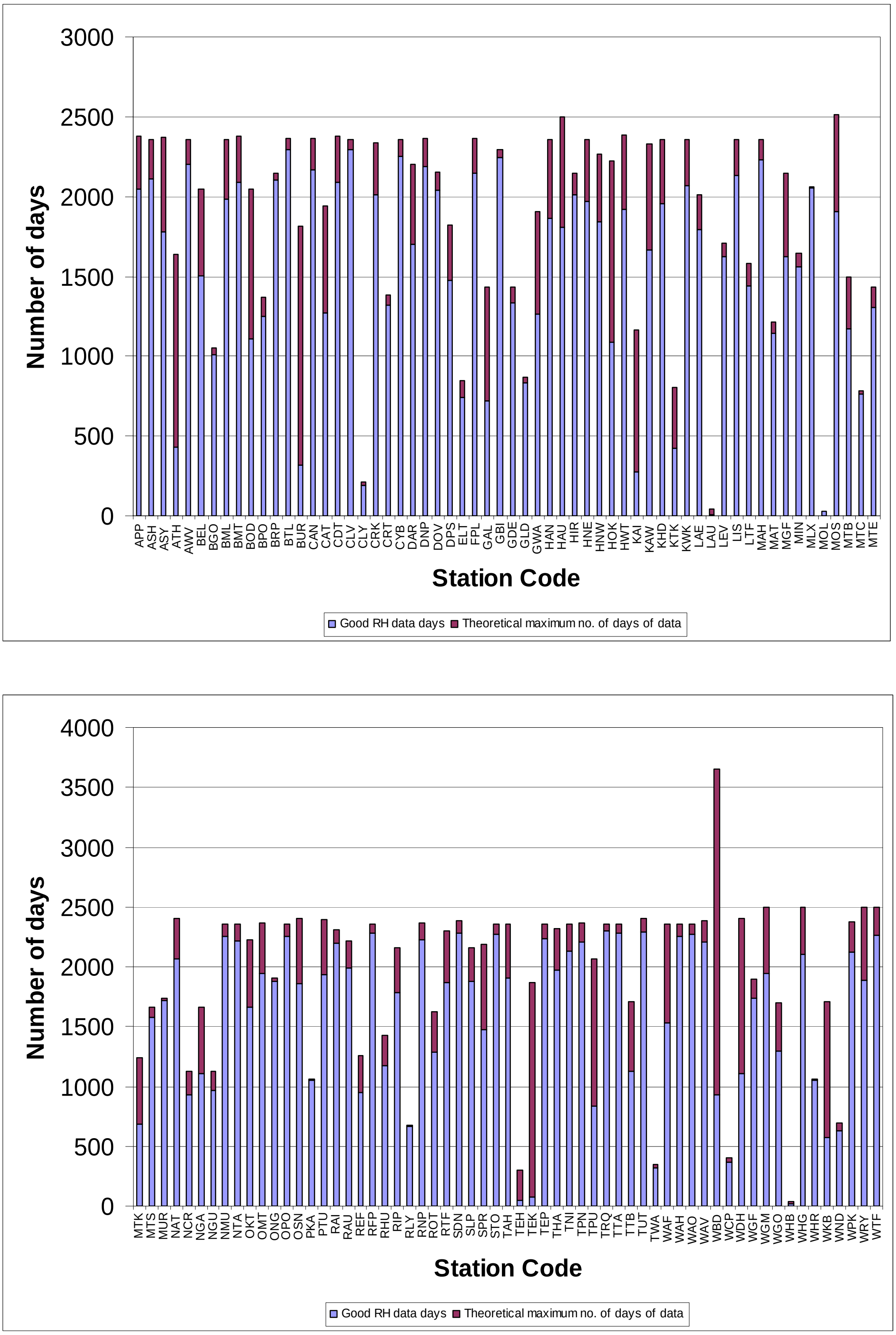

Figure 6: The theoretical number of days of relative humidity data (based on the start and end dates, red bars) for each fire RAWS up to the end of 2002 and number of days of relative humidity data of good quality (blue bars).

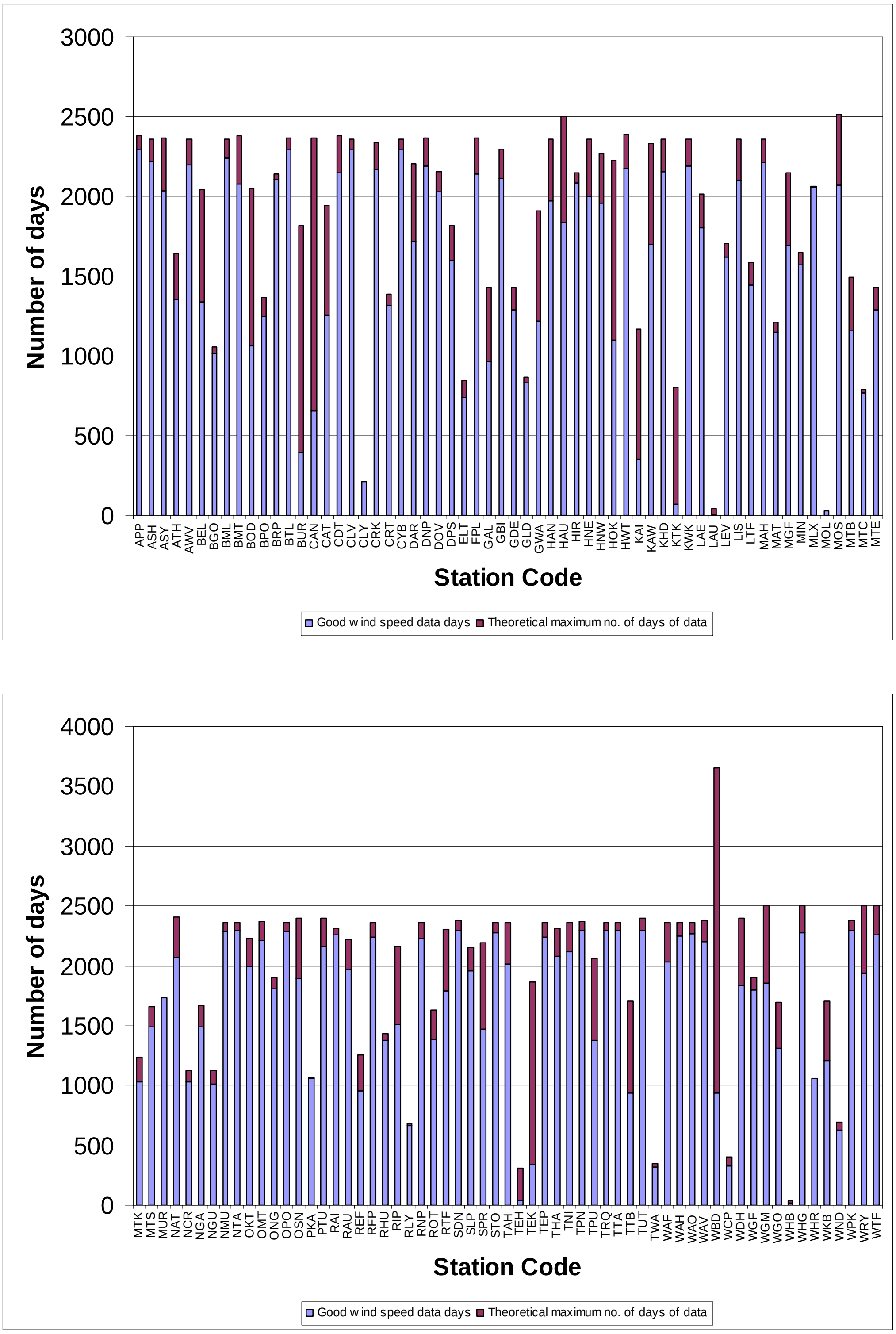

Figure 7: The theoretical number of days of wind speed data (based on the start and end dates, red bars) for each fire RAWS up to the end of 2002 and number of days of wind speed data of good quality (blue bars).

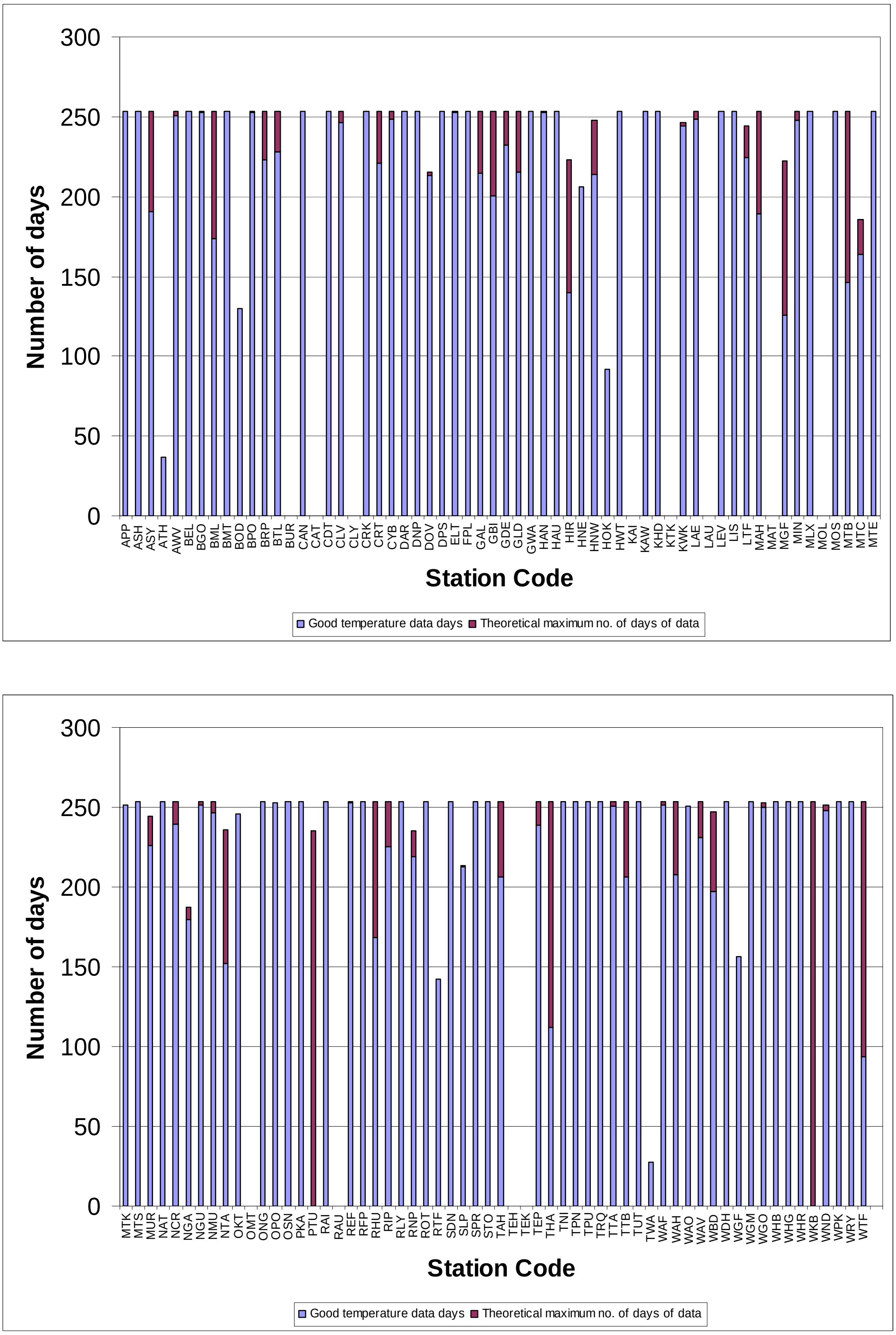

Figure 8: The theoretical number of days of temperature data (based on the start and end dates, red bars) for each fire RAWS for January – September 2003 and number of days of temperature data of good quality (blue bars).

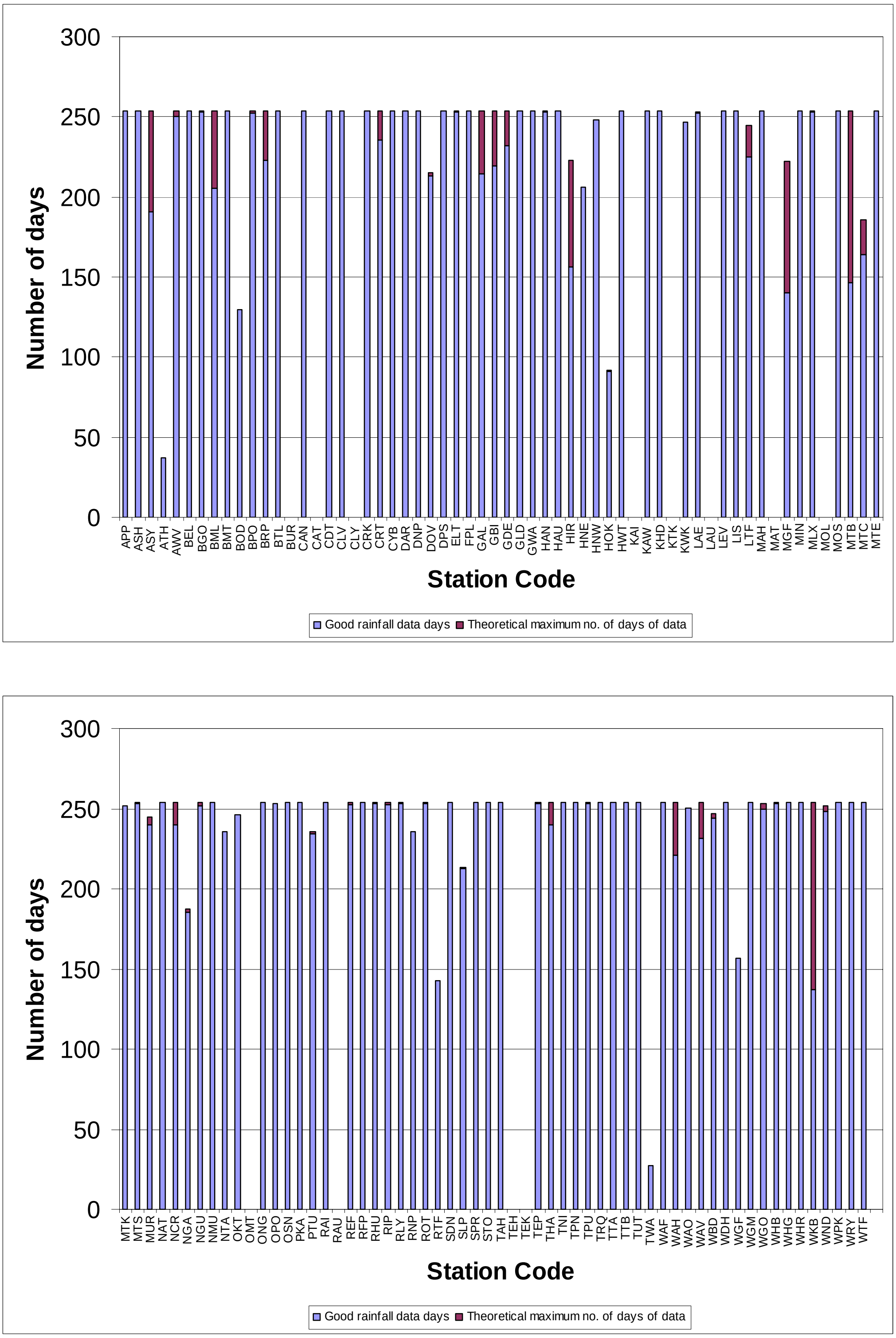

Figure 9: The theoretical number of days of rainfall data (based on the start and end dates, red bars) for each fire RAWS for January – September 2003 and number of days of rainfall data of good quality (blue bars).

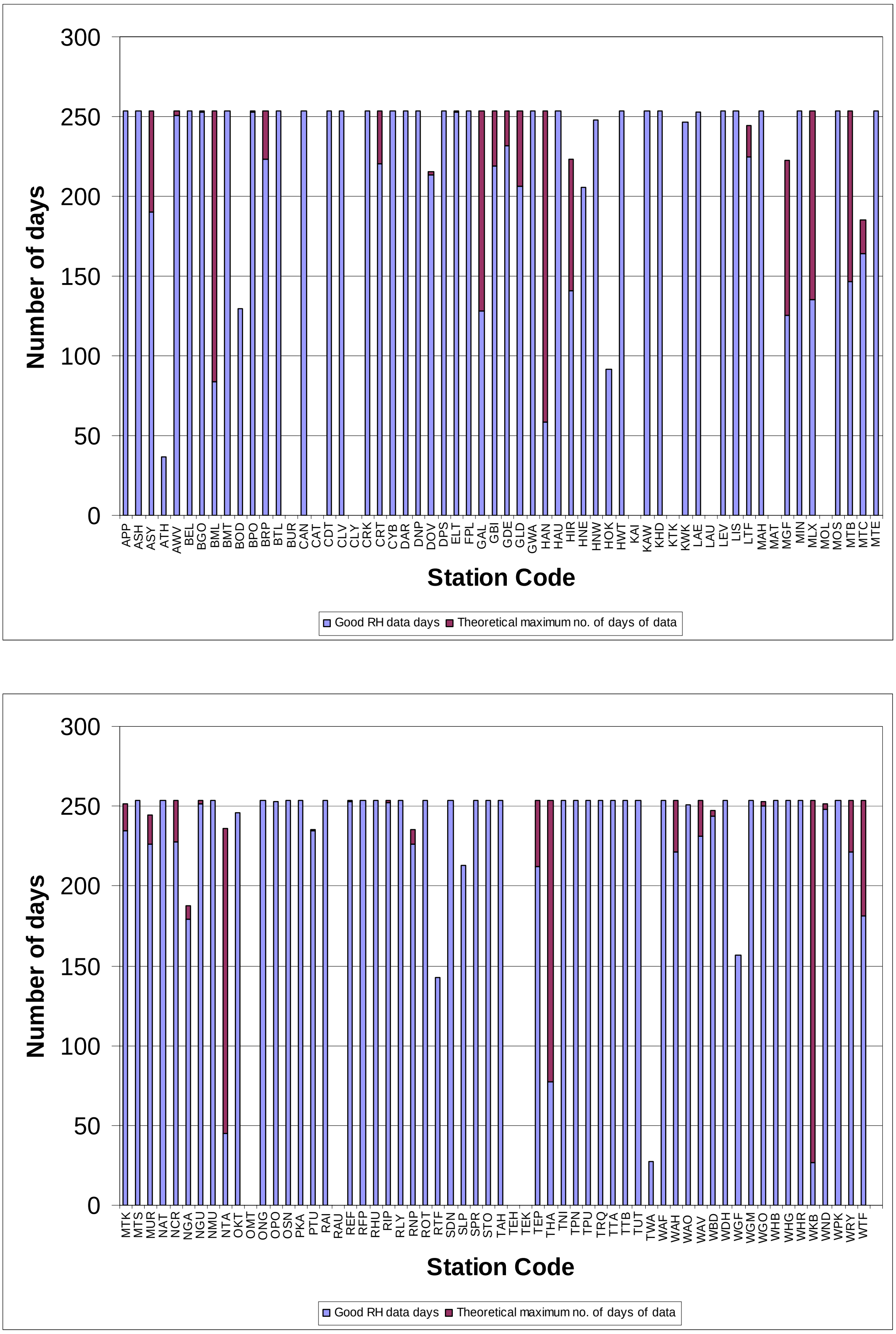

Figure 10: The theoretical number of days of relative humidity data (based on the start and end dates, red bars) for each fire RAWS for January – September 2003 and number of days of rainfall data of good quality (blue bars).

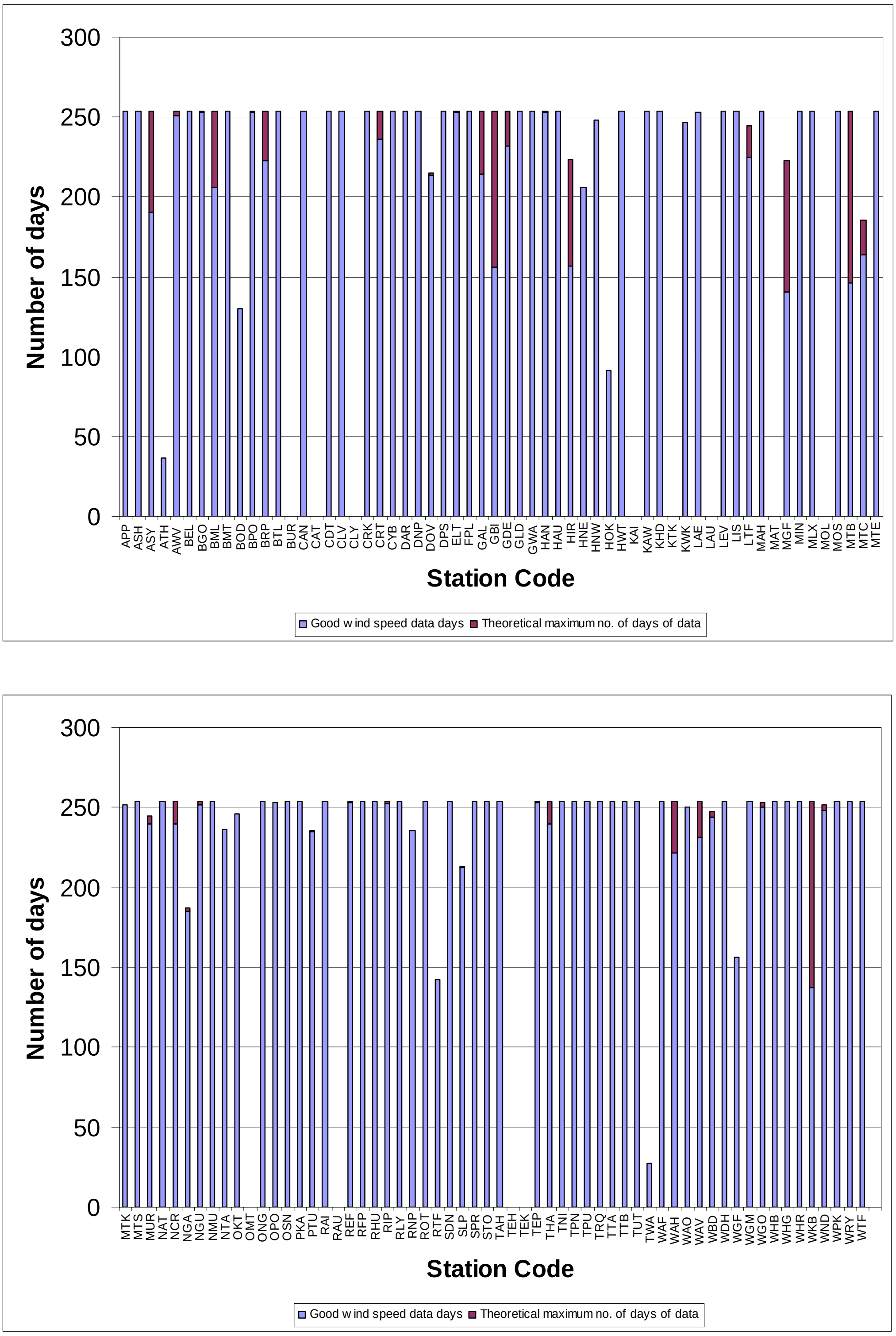

Figure 11: The theoretical number of days of wind speed data (based on the start and end dates, red bars) for each fire RAWS for January – September 2003 and number of days of rainfall data of good quality (blue bars).

2.2 Recommendations

Spatial interpretation of the unchecked historical data may result in misleading patterns, due to the influence of poor quality data. It is understood that NZFS will use historical fire climate maps as a basis of comparison with present day maps (i.e. the production of seasonal anomalies from the long-term average). Thus, it is vital that the historical average conditions are correctly interpreted.

Lists of data deletions up to and including September 2003 for each climate element based on the quality checking analysis were sent to NZFS in January 2004. These lists are described in Appendix 9.1. It is recommended that NZFS use a revised dataset, after making these data deletions, for all of their historical analyses of New Zealand fire climate. For data collected since September 2003, it is recommended that NZFS perform a similar three stage quality checking routine as described in section 2.

3. Literature Review of Interpolation Methods

There are a number of spatial interpolation techniques currently being used to map climate and fire parameters throughout the world. The most common methods are linear interpolation, polynomial interpolation, thin-plate smoothing spline interpolation, kriging, and cokriging. This literature review of comparison studies (see the bibliography, section 8, for a list of the studies reviewed) identifies the advantages and disadvantages of the several schemes. Based on this review, a recommendation was made to the NZFS regarding the applicability of their currently-used scheme, thin plate smoothing spline interpolation. This work involved the completion of task 4, described in section 1. Work was completed on this stage of the study during the period 1 July 2004 – 15 December 2004, and results were presented in the Literature Review report submitted to NZFS in December 2004.

In the following sections, simpler interpolation schemes are reviewed first, followed by the more sophisticated methods. For all the methods, the hypothetical example shown in Figure 12 is used as a reference. Mathematical representations of the methods are not described here. For this information, the reader is referred to the original studies listed in the bibliography.

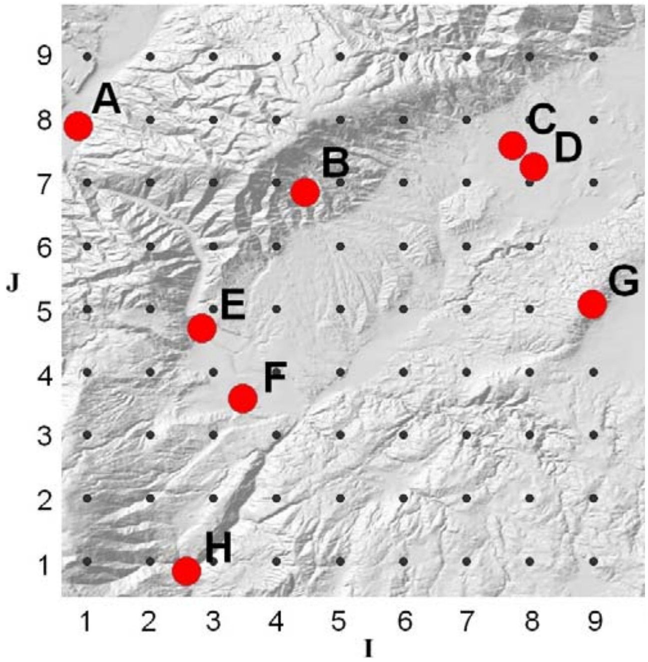

Figure 12: A hypothetical example showing the location of climate stations (red dots, A–H) from which data are interpolated onto a regular 9 by 9 point grid (black dots).

3.1 Nearest Neighbour

This is a very simple method in which grid point values are assigned the value at the station nearest them. For example, grid point i=4, j=6 (where i is the x-axis numeral and j is the y-axis numeral) shown in Figure 12 would be assigned the value at station B, while grid point i=4, j=5 would be assigned the value at station E.

There are obvious problems with this method when there are no "nearby" stations, such as in the bottom right corner of Figure 12. In all the comparison studies reviewed, this method was least accurate for estimating values away from their recording location. Nevertheless, this simplistic method is currently used by NZFS for filling in gaps in station records caused by instrument or other failures.

3.2 Inverse Distance Weighting (IDW)

This method is similar to nearest neighbour, except that the grid values are a weighted average of the values from nearby climate stations. The weights are equal to the inverse of the distance between the grid point and the stations. For example, the value at grid point i=7, j=7 (Figure 12) would be an average of the values at stations B, C, D, and G (given an *a priori* search radius of 3 grid squares), with more weight given to the values at stations C and D due to closer proximity to the grid point. Once again, there are problems using this method in data-sparse areas (although, to a certain extent this is a problem with all interpolation schemes).

Both nearest neighbour and IDW can be significantly improved by including topographical effects. For example, an environmental lapse rate (–6.5 °C/km) can be applied to temperature values at the stations before the interpolation is performed. Then, after the interpolation, the grid values can be transformed back by re-applying the lapse rate. This normalising technique standardises the temperature data with respect to elevation, resulting in a more accurate interpolation of 'like' data.

3.3 Trend Surface Analysis

These methods involve fitting one function, i.e. a statistical trend or hyper-surface, to all the data within a study area. The simplest of these surfaces is a linear trend, such as an environmental lapse rate. More complicated surfaces are usually a power or trigonometric series polynomial, with the number of terms in the polynomial equation determining the complexity of the surface. For some studies, a polynomial trend surface will perform well, as shown in Boyer (1984) and Collins (2004). However, critics argue that computation time can be excessive – depending on the complexity of the equation – and that, in general, global equations are not appropriate at medium to larger-sized data sets. Gower (1973) states, "… when fitting the topography of the Northwest Highlands one would not be influenced by what happens in the South Downs."

3.4 Thin Plate Laplacian Smoothing Spline (LSS)

Hutchinson (1991 and 1995) and Hutchinson and Gessler (1994) describe this method in detail and compare it with several other interpolation schemes. A good description of the method is its similarity to draping a rubberised blanket over the data, where the stiffness of the rubber can be manipulated to either closely fit the station data or more smoothly cover the entire area (achieved through manipulation of the signal to noise ratio). Alternatively, and often ideally, the optimum amount of smoothing can be set by minimizing the generalised cross validation error.

A significant advantage of the method is that it can accommodate several covariates (other than location variables, i.e. latitude and longitude or easting and northing) to aid the interpolation. Such covariates are usually topographic (e.g. elevation, slope, aspect, distance from the coast etc.); however, any spatially-complete dataset can be used (e.g. satellite-derived cloud cover used for interpolating rainfall data). A disadvantage of the method is its reliance on a dense network of stations covering all aspects of the topography being mapped. Often there are very few or no stations at high elevation locations (see Figure 12 for a typical example) meaning the interpolation is dependent upon the relationships developed at lower elevation stations, which may not hold true for high elevation areas. This is particularly problematic for the interpolation of rainfall, which is often underestimated at high elevations.

3.5 Kriging and Cokriging

Kriging consists of three steps: (1) an examination of the variation of data values depending upon their distances apart (constructing a sample semivariogram); (2) fitting a theoretical model (a model semivariogram) to these relationships; and (3) using the model to calculate the weights for a particular set of neighbouring points and computing the interpolated value (Phillips *et al.*, 1992). Cokriging involves calculating additional semivariograms for other correlated variables (such as elevation) and cross-semivariograms for their interactions to help make the estimate.

Kriging (and in particular cokriging) often produces reliable interpolations, particularly when the data density is high. Comparisons with other methods show that kriging often results in lower interpolation errors, thus it is considered to be a useful technique and has been used widely (Phillips *et al*., 1992). A significant disadvantage of the method is that it requires an initial estimation of the covariance structure (i.e. the semivariogram) by determining the nugget variance (the variance at zero distance), the sill (the variance to which the semivariogram asymptotically rises), and the range (the distance at which the sill or some predetermined fraction of the sill is reached).

3.6 Comparison of Methods

Each of the above methods has its applications and therefore there are no strict criteria for analysts to choose among technologies, *a priori*. Summarising the comparative studies reviewed here, we conclude that either polynomial interpolation, splines, or cokriging should be used for the purposes of interpolation of fire weather information for all of New Zealand. Each of these methods has the ability to include topographic variables such as elevation, which is consistently shown to improve the spatial prediction error. However, there is no consistent evidence to suggest that any one of these methods is better suited to this application compared with the others.

3.7 Recommendations

Based on these findings, our advice to the NZFS is that their currently-used scheme, thin plate smoothing spline interpolation (as described in Leathwick and Briggs, 2001), should be maintained. There is no consistent evidence, based on the above review of literature, that this technique is any less effective at estimating climate and/or fire variables at a national scale compared with any other method, given the current density and location of the fire RAWS.

4. Fire RAWS Network Analysis

The goal of this stage of the study was to "Analyse the current fire RAWS network, identify possible gaps, and define an optimal network". This involved the completion of tasks 5 and 6, described in section 1. Work was completed on this stage of the study during the period 16 December 2003 – 30 June 2004, and results were presented in the Milestone 2 progress report submitted to NZFS in June 2004.

4.1 Data and Methodology

For this part of the study, data covering the two years from September 2001 to August 2003 inclusive were analysed. These data were considered to be "current" (data for this project were originally supplied by NZFS in September 2003). Quality checking of NZFS stations with data covering this 2-year period (using the techniques described in section 2) identified 69 (of 140, i.e., only 50%) stations with good seasonal data records. These stations, and their number of seasons with good data records (out of a maximum of 8 seasons, where the seasons are: springs = September–November 2001 and 2002, summers = December–February 2001/02 and 2002/03, autumns = March–May 2002 and 2003, and winters = June–August 2002 and 2003) are listed in Table 1. The 43 climate stations operated by the New Zealand Meteorological Service (MetService) which were also included in the fire RAWS network during this 2-year period are shown in Table 2.

Average daily noon–noon rainfall and average noon-time temperature, relative humidity, and wind speed at the 112 stations listed in Tables 1 and 2 were calculated for each of the eight 3-month seasons (i.e. two years) from September 2001 through August 2003 inclusive. The noon hour is used by NZFS for all fire weather data analyses. Spatial interpolations were performed on these data for each season and each climate element using the software package "ANUspline" (Hutchinson, 2004), and the interpolation diagnostics were analysed to determine the relative importance of each station in the current fire RAWS network. ANUspline is currently used by NZFS for spatial interpolation of fire weather data.

Sixty-seven Automatic Weather Stations (AWS) and Electronic Weather Stations (EWS) situated around the country (operated by MetService and NIWA) were selected to be used as validation sites for the fire RAWS spatial interpolations. These stations are listed in Table 3. None of these validation stations are included in Table 2. Figure 13 shows the location of the NZFS and MetService fire RAWS and the validation sites.

Comparisons of interpolated to actual values at the validation sites were performed for each season and each climate element, where the data were not missing. These comparisons show where the fire RAWS network could be augmented, in order to increase the spatial interpolation accuracy of the four climate parameters used to assess fire risk.

In a later part of the analysis (section 4.3), stations from the existing RAWS network were left out of the interpolation procedure, to check for possible redundancies in the RAWS network.

Table 1: NZFS fire RAWS with good recent data records[1] during the period September 2001 – August 2003 (table continued on next page).

Station Acronym	Station Name	Number of seasons[1]
APP	Aupouri Peninsula	6
ASH	Ashburton Plains	6
AWV	Awatere Valley	8
BEL	Belmont	6
BGO	Bendigo	8
BMT	Blackmount	6
BPO	Big Pokororo	6
BRP	Bridge Pa	6
BTL	Bottle Lake	7
CAN	Cannington	8
CDT	Cornwallis Depot	8
CLV	Clevedon Coast	5
CRK	Cricklewood	8
CYB	Glenledi	8
DAR	Dargaville	7
DNP	Dansey Pass	8
DOV	Dovedale	5
DPS	Deep Stream	8
ELT	Eltham	7
FPL	Darfield	8
GLD	Glendhu	7
HAN	Hanmer	6
HAU	Haurangi	6
HWT	Holdsworth Station	4
KHD	Keneperu Head	6
KWK	Kaiwaka	7
LAE	Lauder	7
LEV	Lees Valley	8
LIS	Lismore	8
LTF	Lake Taupo Forest	7

MAH	Mahurangi	7
MIN	Minginui	7
MLX	Molesworth	6
MOS	Barn Hill	5
MTE	Matea	6
MTK	Motukarara	6
MTS	Mount Somers	8
NAT	National Park	8
NCR	Nelson Creek	5
NGU	Ngaruru	8
NMU	Ngaumu	8
OKT	Okato	8
ONG	Ongaonga	8
OPO	Opouteke	7
OSN	Opua Bay	7
PKA	Pukaki Aero	8
RAI	Rai Valley	5
REF	Reefton	8
RFP	Rimutaka Forest Park	8
RLY	Ranfurly	8
SDN	Snowdon	8
SLP	Slopedown	5
STO	Stony Creek	8
TNI	Totaranui	7
TPN	Tapanui	8
TRQ	Traquair	8
TTA	Toatoa	8
TTB	Titahi Bay	7
TUT	Tuatapere	8
WAH	Waihau	5
WAO	Waione	8
WAV	Waverly	5
WDH	Woodhill	7
WGM	Whangamata	8
WHG	Marco	8
WHR	Waihaorunga	8
WND	Windsor	6
WPK	Waipukurau	7
WRY	Wreys Bush	4

1 The eight seasons (i.e. two years) from September 2001 through August 2003 were chosen to represent the “current” period. Fire RAWS with good quality-checked data for at least four of the eight seasons have been selected for analysis.

Table 2: Climate stations operated by MetService which were included in the fire RAWS network during the period September 2001 – August 2003.

Station Acronym	**Station Name**	**Number of seasons**[1]
APA	Taupo Aero	6
CHA	Christchurch Aero	6
CPX	Castle Point	6
DNA	Dunedin Aero	6
GCE	Gore	6
GSA	Gisborne Aero	6
HIX	Hicks Bay	6
HKA	Hokitika Aero	6
HNA	Hamilton Aero	6
HTX	Haast	5
KIX	Kaikoura	6
KOE	Kaikohe	6
LBX	Le Bons Bay	6
LNX	Levin	6
MHX	Mahia	6
MOA	Manapouri Aero	6
MSX	East Taratahi	6
NGX	Nugget Point	6
NOE	Normanby	4
NPA	New Plymouth Aero	6
NRA	Napier Aero	6
NSA	Nelson Aero	6
NVA	Invercargill Aero	6
NWX	Ngawi	4
OUA	Oamaru Aero	6
PAX	Paeroa	6
PEX	Purerua	5
PMA	Palmerston North Aero	6
PPA	Paraparaumu	6
QNA	Queenstown Aero	6
ROA	Rotorua Aero	6
RUX	Waiouru Aero	6
TGA	Tauranga Aero	6
THE	Tara Hills	4
TUA	Timaru Aero	6
WBA	Woodbourne Aero	6
WFA	Wanaka	6
WKA	Whakatane Aero	6
WNA	Wellington Aero	6
WRA	Whangarei Aero	6
WSA	Westport	6
WTA	Whitianga Aero	6
WUA	Wanganui Aero	6

1 The eight seasons (i.e. two years) from September 2001 through August 2003 were chosen to represent the “current” period. No winter season data from these stations are used for real-time fire research purposes. Only stations with data for at least four of the eight seasons have been selected for analysis.

Table 3: List of the NIWA and MetService climate stations used as validation sites for the fire RAWS spatial interpolations (table continued on next page).

Agent number	Station name	Latitude	Longitude	Elevation (m)
1002	Cape Reinga AWS	-34.432	172.682	214
1056	Kerikeri EWS	-35.183	173.926	79
1340	Leigh 2	-36.273	174.796	27
1400	Whangaparaoa AWS	-36.606	174.835	89
1468	Auckland,Owairaka	-36.893	174.726	41
1905	Motu EWS	-38.286	177.530	488
1962	Auckland Aero	-37.007	174.789	33
2006	Pukekohe EWS	-37.208	174.863	82
3126	Wairoa, North Clyde	-39.017	177.413	15
3445	Wellington Aero	-41.322	174.804	43
3715	Wanganui,Spriggens Park EWS	-39.945	175.046	15
3798	Farewell Spit AWS	-40.547	173.000	3
3925	Reefton EWS	-42.117	171.860	198
4141	Puysegur Point AWS	-46.158	166.611	44
4395	Brothers Island AWS	-41.116	174.432	68
4424	Cape Campbell AWS	-41.730	174.276	2
4764	Winchmore EWS	-43.794	171.793	160
5535	Lauder EWS	-45.041	169.686	370
5823	Tiwai Point EWS	-46.587	168.376	5
5909	South West Cape AWS	-47.278	167.464	101
7340	Enderby Is AWS	-50.483	166.300	40
9533	Secretary Island AWS	-45.221	166.886	19
9654	Mokohinau AWS	-35.905	175.115	60
11234	Hanmer Forest EWS	-42.535	172.850	355
12328	North Shore, ARC	-36.786	174.736	20
12428	Te Puke EWS	-37.822	176.324	91
12429	Motueka, Riwaka EWS	-41.098	172.972	8
12430	Blenheim Research EWS	-41.498	173.963	4
12431	Clyde EWS	-45.207	169.313	171
12432	Turangi EWS	-38.995	175.812	375
12442	Paraparaumu EWS	-40.907	174.984	5
12444	Invercargill Aero 2 EWS	-46.419	168.329	0
12482	Manapouri, West Arm Jetty	-45.525	167.275	178
12616	Ruakura EWS	-37.780	175.313	40
12636	Waione EWS	-40.453	176.308	48
15752	Dunedin, Musselburgh EWS	-45.904	170.513	2
15876	Whakatu EWS	-39.610	176.912	5
16826	Murchison EWS	-41.805	172.324	185
17029	Wallaceville EWS	-41.135	175.052	56
17030	Matamata, Hinuera EWS	-37.874	175.735	85
17067	Kaitaia EWS	-35.135	173.262	85
17244	Rangiora EWS	-43.325	172.612	12
17603	Lincoln, Broadfield EWS	-43.627	172.470	18

17609	Darfield EWS	-43.496	172.150	190
17610	Snowdon EWS	-43.470	171.672	560
17838	Warkworth EWS	-36.435	174.667	72
18125	Mt Cook EWS	-43.736	170.096	765
18183	Kaitaia Aero EWS	-35.067	173.287	80
18234	Baring Head	-41.407	174.867	79
18309	Milford Sound AWS	-44.677	167.923	3
18437	Middlemarch EWS	-45.518	170.138	198
18464	Mt Ruapehu, Chateau EWS	-39.198	175.544	1097
18468	Awatere Valley, Dashwood EWS	-41.648	174.074	78
18593	Ranfurly EWS	-45.122	170.100	450
18594	Windsor EWS	-45.010	170.823	81
18603	Wreys Bush EWS	-46.029	168.110	112
21866	Kawerau EWS	-38.040	176.753	18
21937	Appleby 2 EWS	-41.319	173.095	18
21938	Martinborough EWS	-41.253	175.389	30
21963	Palmerston North EWS	-40.382	175.609	34
22719	Mangere EWS	-36.963	174.775	5
23849	Takaka EWS	-40.863	172.805	20
23872	Stratford EWS	-39.336	174.305	300
23899	Te Kuiti EWS	-38.333	175.153	61
23908	Toenepi EWS	-37.720	175.587	48
23934	Greymouth Aero EWS	-42.460	171.190	4
24120	Christchurch, Kyle St EWS	-43.531	172.607	6

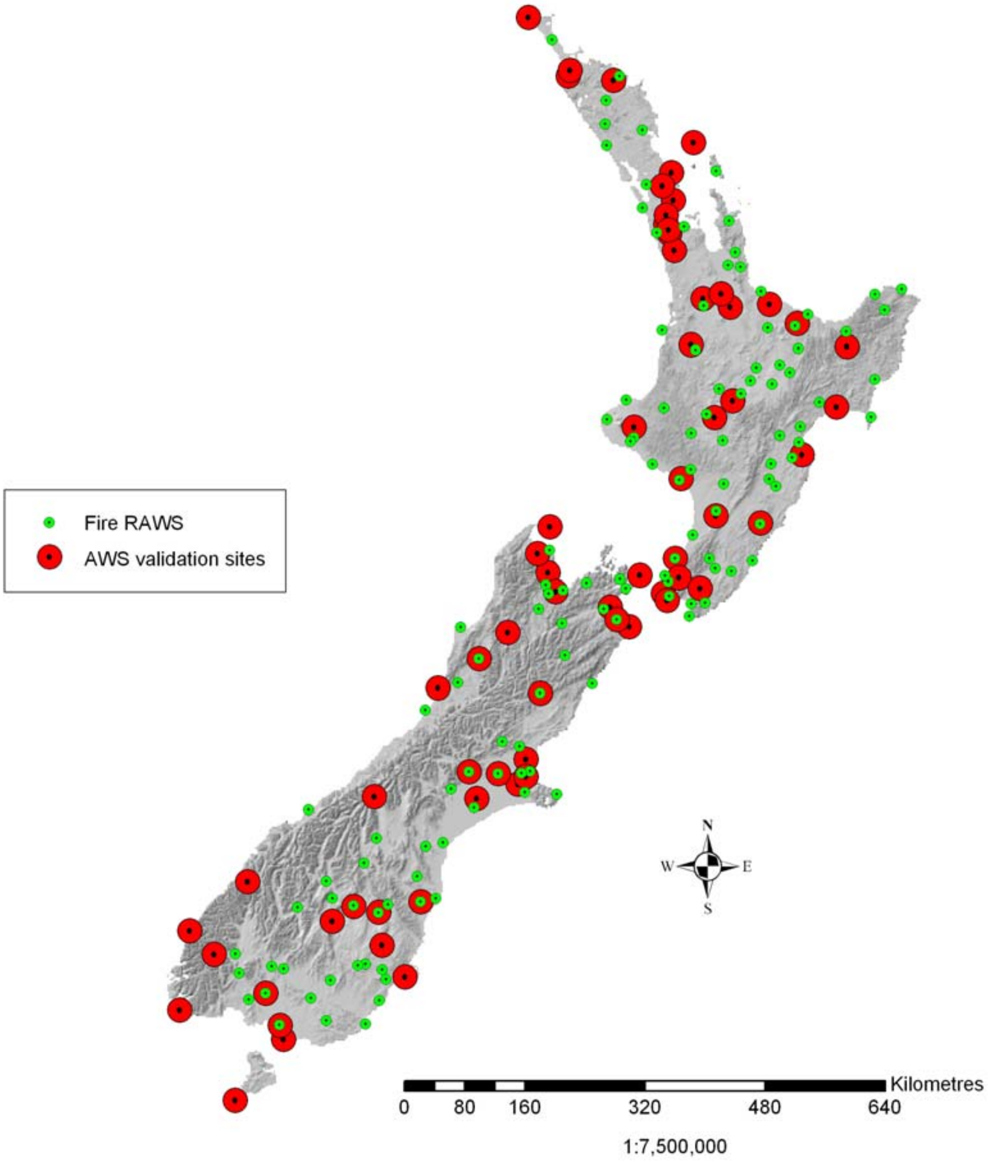

Figure 13: Location of NZFS and MetService fire RAWS with good data records during the period September 2001 – August 2003 (from Tables 1 and 2, small green circles) and the NIWA and MetService AWS and EWS validation sites (from Table 3, large red circles).

4.2 Determining the Relative Importance of the Fire RAWS

The ANUspline spatial interpolation software package can be used to produce diagnostics of the prediction standard error values at each of the input data locations. These standard errors are calculated from the difference between the interpolated value at the station location when data from that station are omitted from the interpolation, and the actual value at the station. The ANUspline program produces an optimum interpolated surface by minimising these standard errors through a process called generalised cross validation.

Stations with the largest standard errors are the most important for accurate spatial interpolation, as their removal has the largest impact on the error of the interpolated values. Thus, using the standard error values the input climate stations can be ranked in terms of their relative importance to the interpolation.

Each interpolation (eight seasons and four climate elements) produces different station rankings. This is due to the effect of missing data on the interpolations (most stations had missing data for at least one of the eight seasons – see Tables 1 and 2) and also due to the influence of different predominant weather patterns between seasons (i.e. spring 2001 may have been dry while spring 2002 may have been wet, in a particular area). In fact, the relative rank (absolute rank divided by the highest rank) for any station can vary significantly with season and element, as is shown in Figure 14 for the station AWV, Awatere Valley.

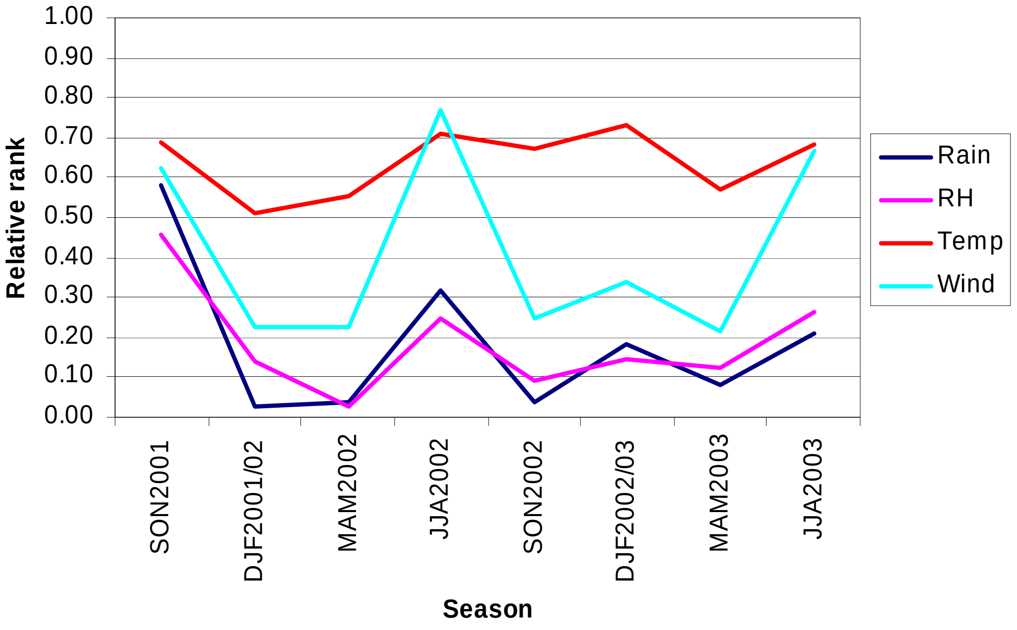

Figure 14: Relative rank (0 = lowest rank, 1 = highest rank) of station AWV (Awatere Valley) for each climate element and each season.

From Figure 14, it can be seen that temperature and wind data are quite important at this site (i.e. these variables have high relative ranks, particularly so for wind in the winter season when there were no data from any of the MetService stations) while rainfall and relative humidity data from this site are relatively unimportant for every season except spring 2001. Interestingly, there were no data from the nearby station at Opua Bay in spring 2001, while data were recorded there from summer 2001/02 onwards. All the spring 2001 relative ranks are high, highlighting the effect of missing data on the ranking.

Averaging the relative ranks across each season and climate element produces an overall rank for each fire RAWS. These average relative ranks are shown in Figure 15. The top ten ranked stations are HIX, Hicks Bay; APP, Aupouri Peninsula; PEX, Purerua; TTA, Toatoa; WTA, Whitianga Aero; KOE, Kaikohe; MHX, Mahia; HTX, Haast; WSA, Westport; and OKT, Okato. All of these stations are located in areas with a low density of stations. This is not surprising as without the data from these sites the interpolation is reliant on data from a large distance away; hence it is less likely to be accurate. Interestingly, seven of these top ten stations are MetService stations, indicating that the supplementation of the NZFS stations with MetService stations is vital.

The bottom ten ranked stations are RLY, Ranfurly; LAE, Lauder; DNP, Dansey Pass; WFA, Wanaka; THE, Tara Hills; BGO, Bendigo; CAN, Cannington; WHR, Waihaorunga; CHA, Christchurch Aero; and PKA, Pukaki Aero. All these stations are located in close proximity to each other – except for Christchurch Aero, which is close to another station: BTL, Bottle Lake. This strongly suggests that at least one of these stations is redundant, in terms of mapping the four climate parameters used to assess fire risk. It does not suggest that they are all redundant, as removing some will increase the importance of the others.

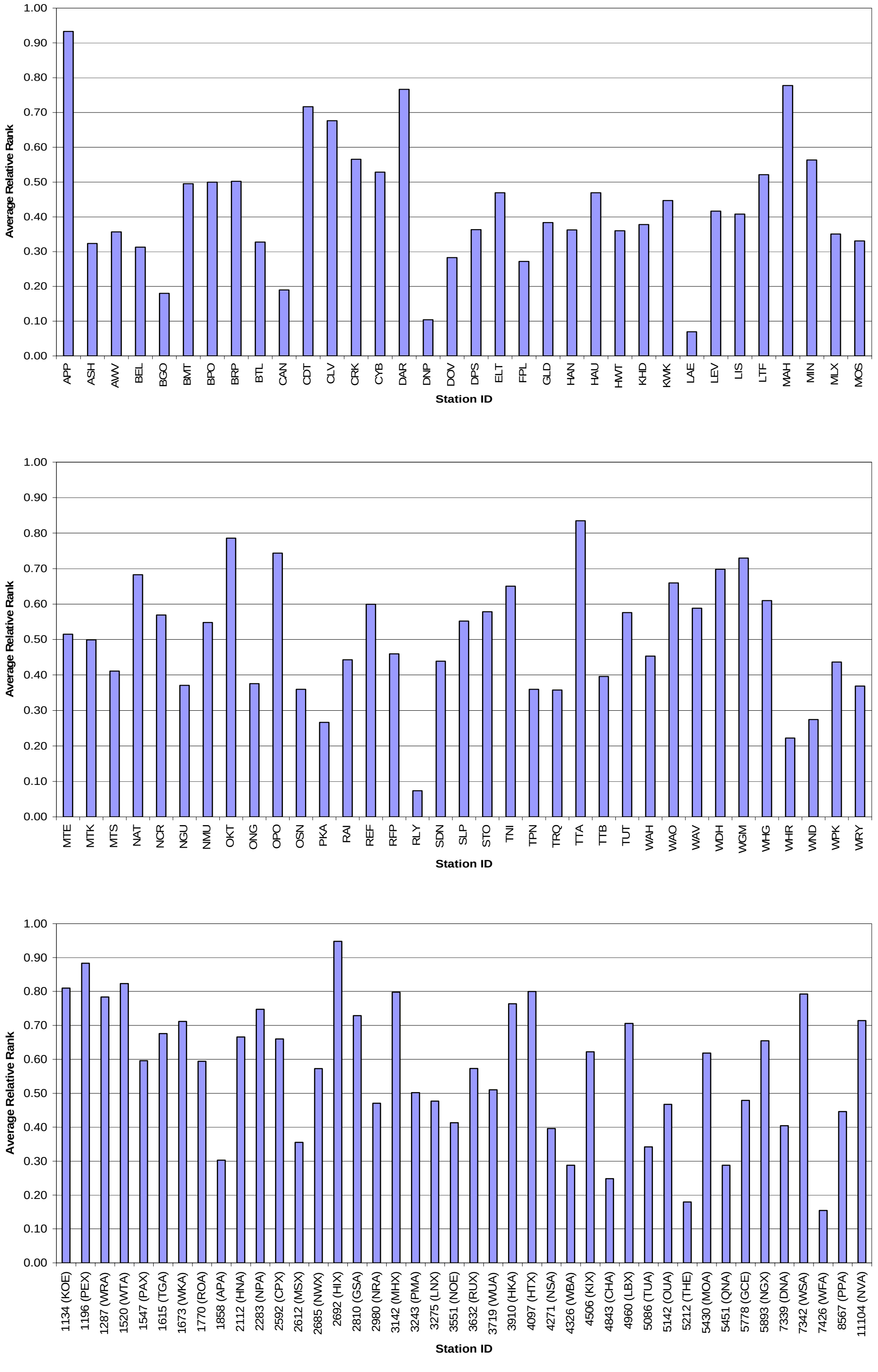

Figure 15: Average relative ranks for each fire RAWS (stations APP–MOS in top graph, stations MTE–WRY in middle graph, and MetService stations in bottom graph).

4.3 Analysing the Accuracy of the Fire RAWS Interpolations

Figure 13 shows the location of the fire RAWS and AWS and EWS validation sites used in this study. Data from the validation sites for each season were compared with the values interpolated to these sites from the fire RAWS data. As was shown in the previous section, the results vary according to season and climate element. In an attempt to aggregate the results, the daily absolute difference (absolute value of the interpolated value minus the actual value for each day) at each validation site was averaged over all eight seasons.

Maps of these average absolute differences for each climate element are shown as Figures 16 – 19. The validation sites have been colour coded so that validation site locations with a small average absolute difference between the interpolated values and the actual values are coloured blue, low-to-moderate differences are coloured light green, moderate differences are coloured dark green, moderate-to-high differences are coloured yellow, and large differences are coloured red. The colour scheme is the same for all the climate elements.

Figure 16 shows the results for rainfall. It can be seen that even the low average absolute differences are quite high (i.e. up to 30 mm). This result is not surprising, as rainfall varies markedly over relatively short distances in New Zealand due to the country’s complex terrain, which makes interpolation schemes less accurate. The stations with the largest difference are in the Southern Alps (Mt Cook) and south Westland, where there are no fire RAWS (presumably because the fire risk is minimal). However there are six stations (coloured yellow on Figure 16) with moderate-to-high average differences which are located in less remote areas. These stations are shown in Table 4. From Figure 16 it can also be seen that there is a cluster of stations in the Auckland – Waikato – Bay of Plenty area with moderate differences (60.1 mm – 120.0 mm). It is suggested that these locations and those in Table 4 may be good candidates for additions to the current fire RAWS network.

The results for relative humidity are shown as Figure 17. Most (all but 4 – which are all located in remote areas) of the validation sites have average absolute relative humidity differences less than 8.1%. This suggests that the current fire RAWS network is sufficient for the interpolation of relative humidity. Possible locations where the network could be augmented are the Auckland region and the far north.

Table 4: Validation stations with average absolute rainfall differences (the average over the eight seasons of the absolute value of the interpolated daily values minus the actual daily values) between 120 and 240mm.

Agent no.	Station name	Number of seasons	Average absolute difference (mm)
23872	Stratford EWS	5	121.8
21938	Martinborough EWS	8	121.8
9654	Mokohinau AWS	8	132.9
4395	Brothers Island AWS	7	160.7
18234	Baring Head	7	164.7
18464	Mt Ruapehu, Chateau EWS	8	193.4

Figure 18 shows the results for air temperature. As with relative humidity, the differences are generally low which suggests the current network is sufficient. The one area which is of possible concern is the Auckland region, where there are a cluster of stations with average differences between 0.9 and 1.6 °C.

Figure 19 shows the average absolute differences for wind speed at the AWS validation sites. The greatest differences are at locations where the wind speed is typically very high (e.g. Cape Reinga, Farewell Spit, Baring Head, Puysegur Point, and the southwest cape of Stewart Island). Otherwise, the average absolute differences are below 8.1 km/hr, which represents a fairly good result for interpolating wind speed.

4.4 Recommendations

It is suggested that if any stations are to be discontinued, the bottom ten ranked stations from the list of average relative ranks (i.e. RLY, LAE, DNP, WFA, THE, BGO, CAN, WHR, CHA, and PKA) should be looked at first. There is a clear indication that at least one of these neighbouring (but not CHA) stations is redundant.

It is strongly recommended that NZFS continue to supplement fire RAWS network data with data from the MetService stations listed in Table2. These data are of high quality and have been shown to rank highly in terms of their importance to the accurate spatial interpolation of fire weather elements.

Consideration should also be given to additional station locations to improve network coverage. Rainfall is the least accurately interpolated of the four climate elements used to assess fire risk, particularly at the locations shown in Table 4 and in the general Auckland – Waikato – Bay of Plenty area. MetService stations within this area which are not included in the current fire RAWS network (e.g. Mokohinau, Whangaparaoa, Owairaka, or Auckland Airport) or NIWA stations (e.g. Warkworth, Mangere, Pukekohe, Ruakura, Toenepi, Matamata, or Te Puke) should be considered for inclusion in the fire RAWS network in the future to improve rainfall, but also temperature and humidity, interpolation.

The Fire Service could also consider the possibility of including additional stations from the NIWA/MetService raingauge network to improve coverage in remote areas, such as the Southern Alps and south Westland.

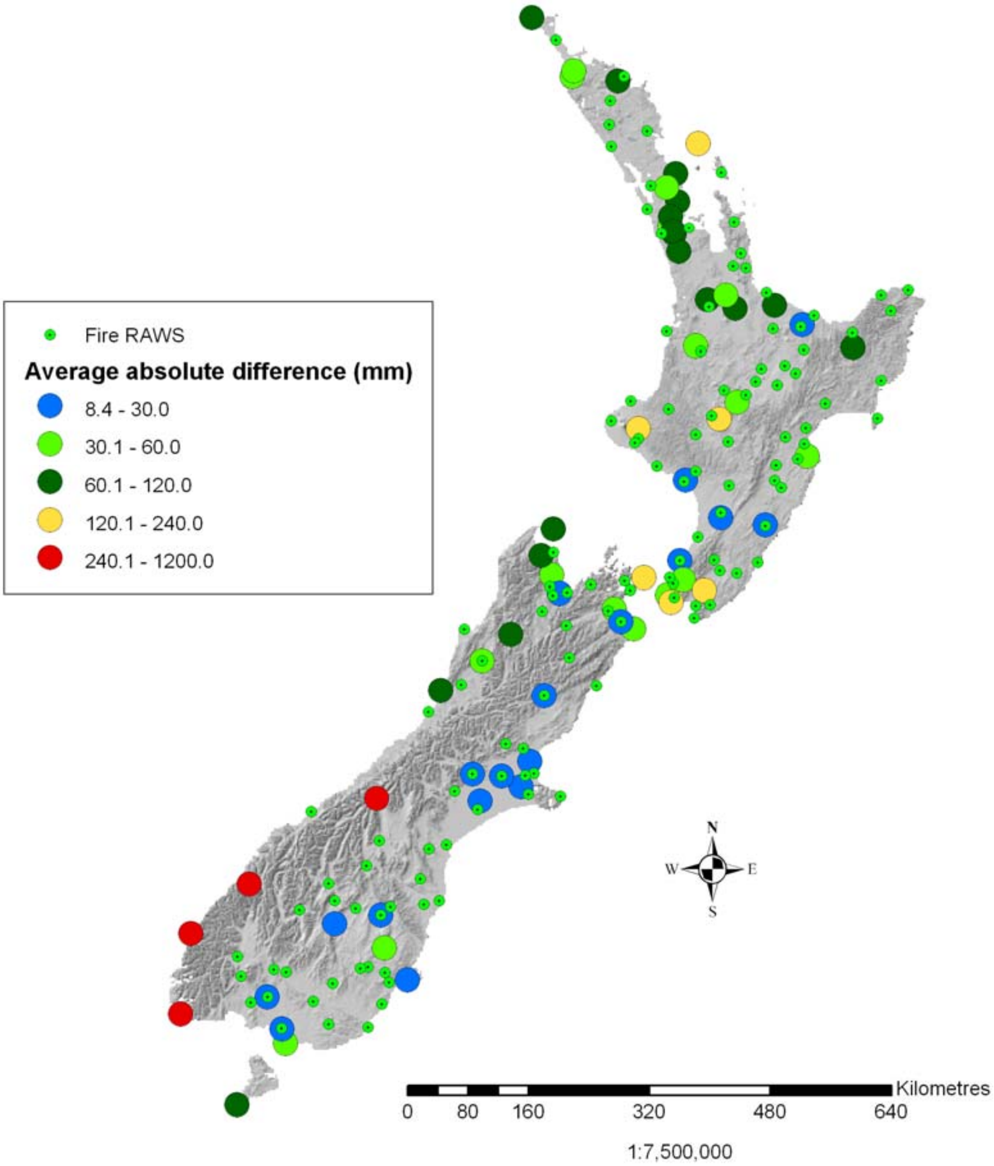

Figure 16: The average absolute difference (in millimetres) between average daily rainfall interpolated from the fire RAWS and measured at the AWS validation sites.

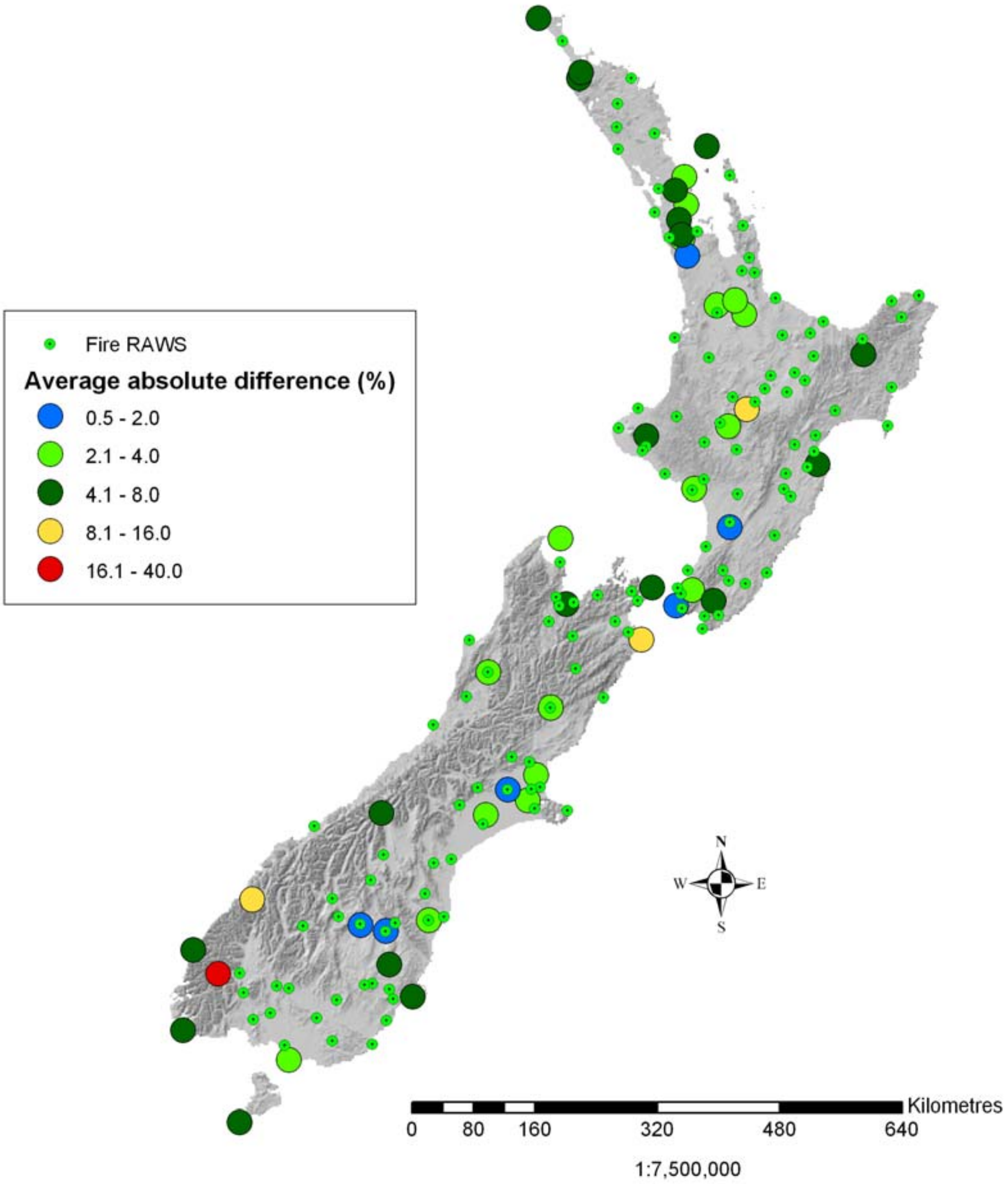

Figure 17: The average absolute difference (in percent) between average noon-time relative humidity interpolated from the fire RAWS and measured at the AWS validation sites.

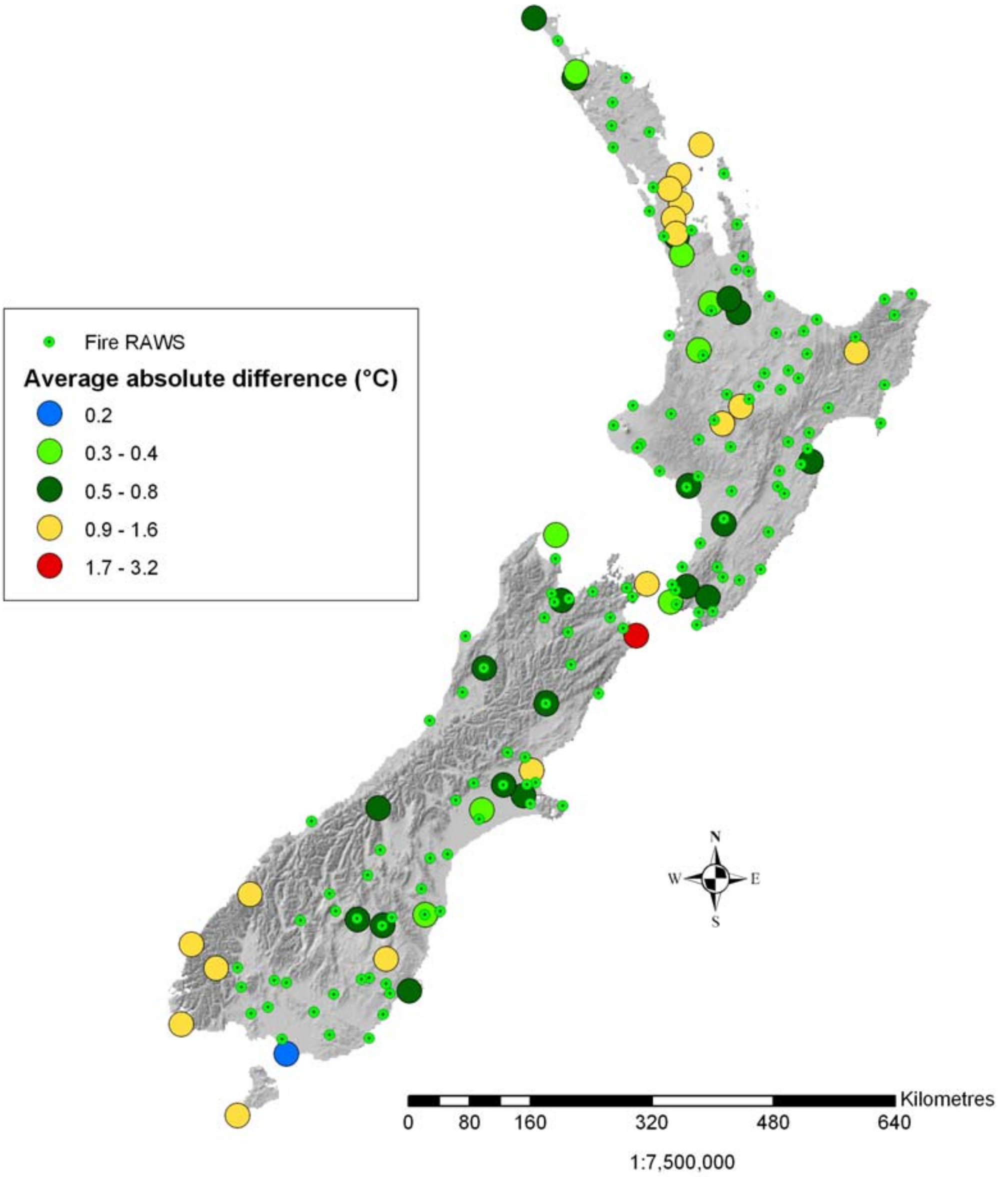

Figure 18: The average absolute difference (in degrees Celsius) between average noon-time air temperature interpolated from the fire RAWS and measured at the AWS validation sites.

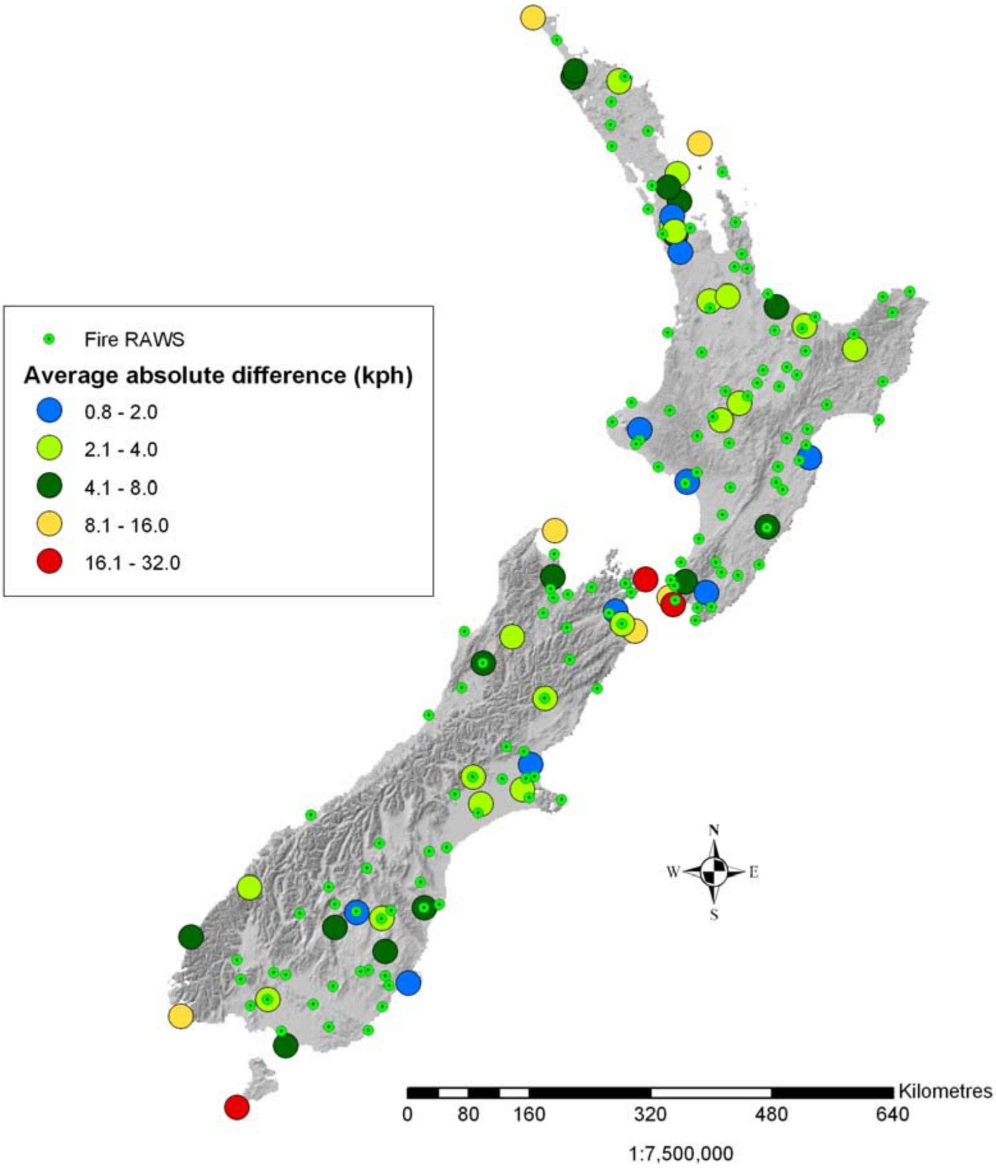

Figure 19: The average absolute difference (in kilometres per hour) between average noon-time wind speed interpolated from the fire RAWS and measured at the AWS validation sites.

5. Use of Data Substitutes

The goal of this stage of the study was to "Analyse the impact of the current practice of using data substitutes to replace missing data and compare errors from this approach with an interpolation approach". This involved the completion of tasks 7 and 8, described in section 1. Work was completed on this stage of the study during the period 1 July 2004 – 15 December 2004, and results were presented in the Milestone 3 progress report submitted to NZFS in December 2004.

5.1 Data and Methodology

Average daily noon–noon rainfall and average noon-time temperature, relative humidity, and wind speed at the stations listed in Tables 1 and 2 were calculated for the test period September 2001 through August 2003 inclusive. From the 112 stations listed in these Tables, a subset of 107 stations was identified as having "substitute" stations which also have good daily data records. The list of substitute stations, which are typically neighbouring stations, was provided by NZFS. It is the current practice of the NZFS to fill in missing daily data using data from the station's substitute. The purpose of this part of the analysis is to examine the errors associated with this methodology, by choosing days when there was no missing data, then comparing substituted data with actual data. These errors are then compared with the errors associated with using a spline interpolation of daily values to each station, rather than using substitutes.

For the test period September 2001 – August 2003, the number of days identified when there was no missing data at all the 107 fire RAWS and their substitutes was 290 (rainfall), 143 (temperature), 127 (relative humidity), and 274 (wind speed). For each of these days and for each station, pairs of data values were identified. These pairs were the actual data values at the station (i.e. the noon–noon rainfall total, and the noon-time temperature, relative humidity, and wind speed) and the equivalent data values from the substitute site. A 'sums of squares' analysis was performed on the data, and a root mean square error (RMSE) for each meteorological variable was calculated for each station. The magnitude of the RMSE is an indicator of the closeness of the data pairs. That is, locations with substitute data that are closely matched to the actual data will have a small RMSE, while locations with substitute and actual data that are poorly matched will have a large RMSE.

The thin plate smoothing spline interpolation approach for infilling missing data was tested using a "leave one out" methodology. This involved removing one station from the set, and interpolating the daily rainfall, noon-time temperature, relative humidity, and wind speed data from all the remaining stations to the omitted station’s location. This was repeated for each day, and then the RMSE was calculated from the estimated and actual values. The process was then repeated omitting each station in turn, yielding a RMSE for each meteorological variable for each of the 107 sites.

5.2 Root Mean Square Error Analysis

Figure 20 shows the rainfall RMSE for each station for both the substitute method (blue bars) and the interpolation method (red bars). It can be seen that the errors are typically larger (sometimes by a great deal) when the rainfall is estimated by interpolation compared with using a substitute. The very obvious exception is at station MIN “Minginui”, which has a substitute RMSE two orders of magnitude greater than the majority of the other sites. It is clear from this result that the substitute station for Minginui (i.e. TTA “Toatoa”) is a very poor match. Other than this station however, the results show that interpolation of daily rainfall does not improve on the current practice of using data substitutes. This is clearly shown in Figure 21, which is a plot of the difference between the RMSE (substitute) and the RMSE (interpolation). Positive differences indicate the interpolation method has a lower RMSE; negative differences indicate the substitute method has a lower RMSE.

However, Hutchinson (1998) concludes that because daily rainfall data are skewed (many more zero or near-zero observations than larger values) it is important to firstly apply a square root transformation to the data. Then the transformed values can be interpolated (and subsequently back-transformed). The software package ANUspline (developed by Hutchinson and currently used by NZFS) has an option for doing this transformation automatically. Thus, the present analysis of fire RAWS rainfall data was repeated using the square root transformation option. The results of this analysis are shown in Figures 22 (blue bars = no transformation, red bars = square root transformation) and 23.

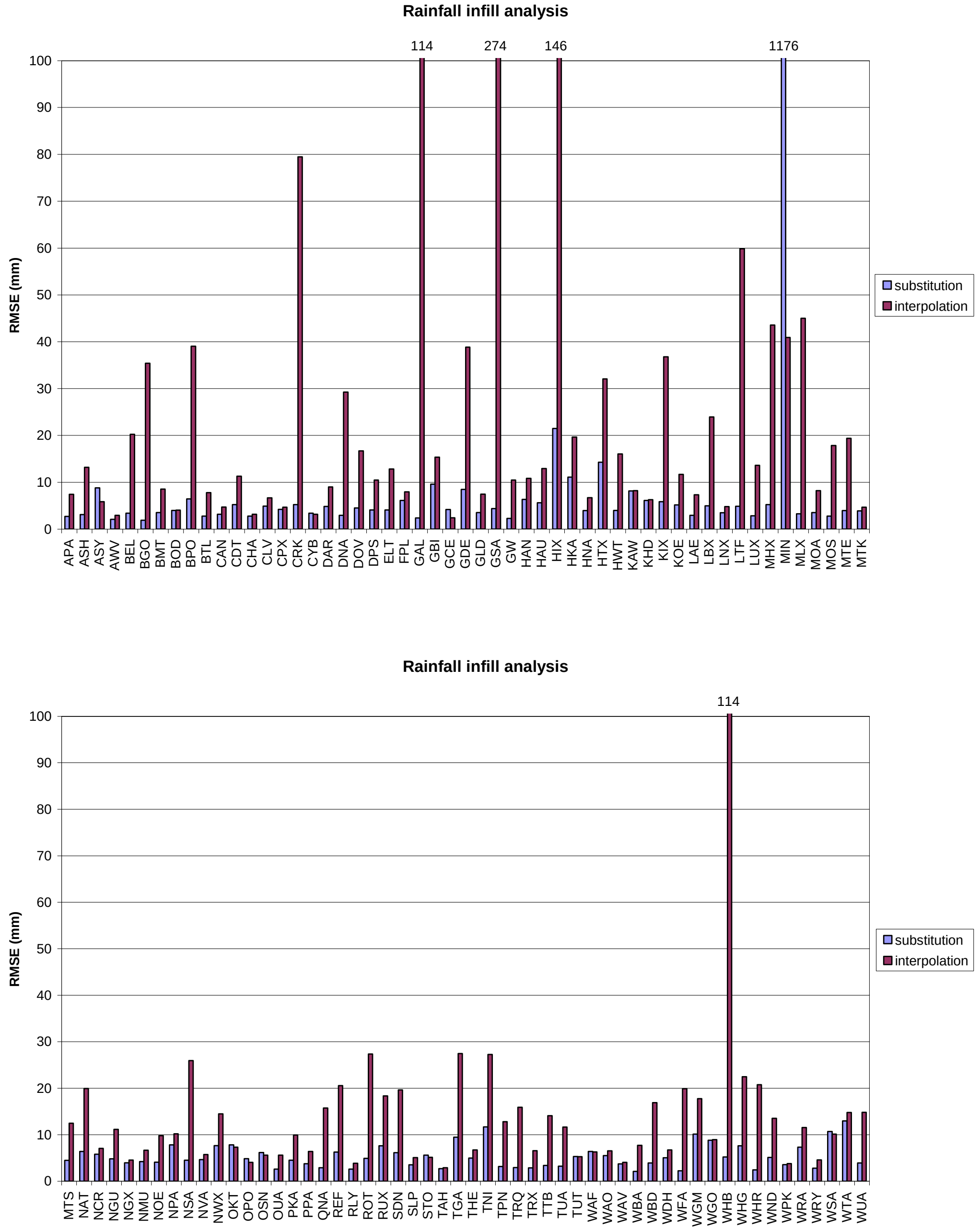

Figure 20: Root mean square error (RMSE) for the two rainfall infill methods, substitution and interpolation, for each of the 107 fire RAWS analysed. Numbers listed at the ends of bars indicate data values that exceed the axis limits.

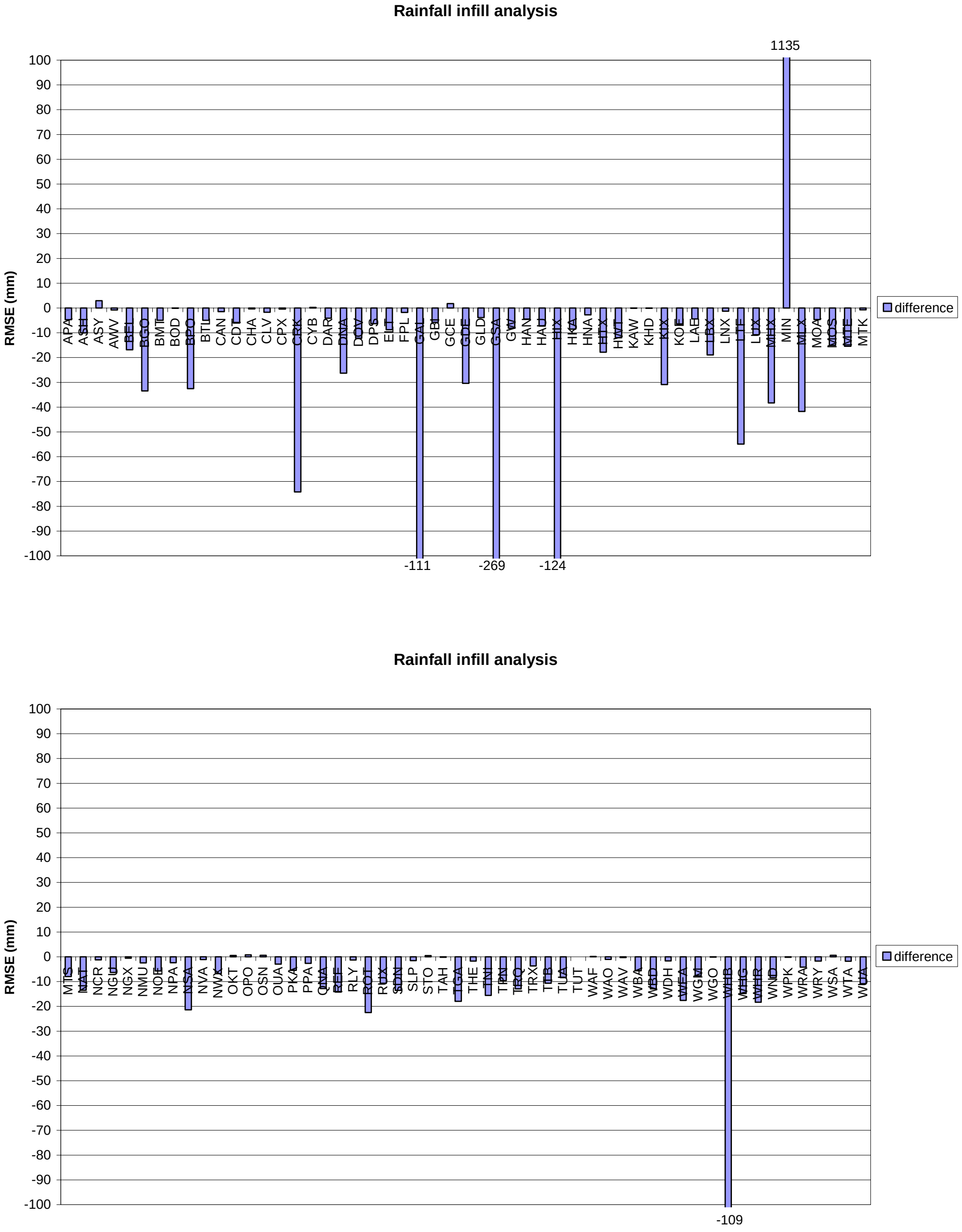

Figure 21: Rainfall root mean square error (RMSE) difference (substitute minus interpolation) for each of the 107 fire RAWS analysed. Numbers listed at the ends of bars indicate data values that exceed the axis limits.

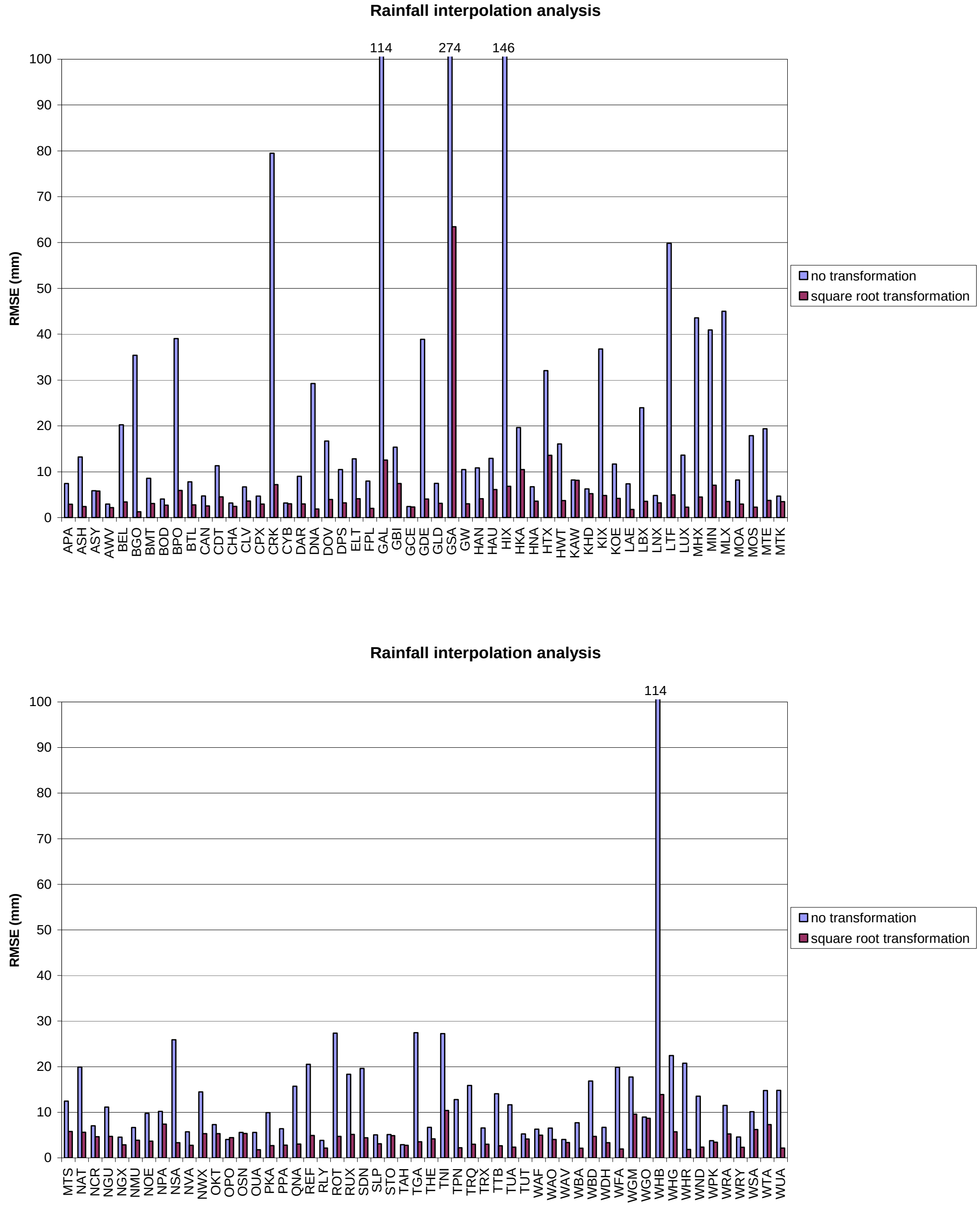

Figure 22: Root mean square error (RMSE) for the interpolation method with and without a square root transformation, for each of the 107 fire RAWS analysed. Numbers listed at the ends of bars indicate data values that exceed the axis limits.

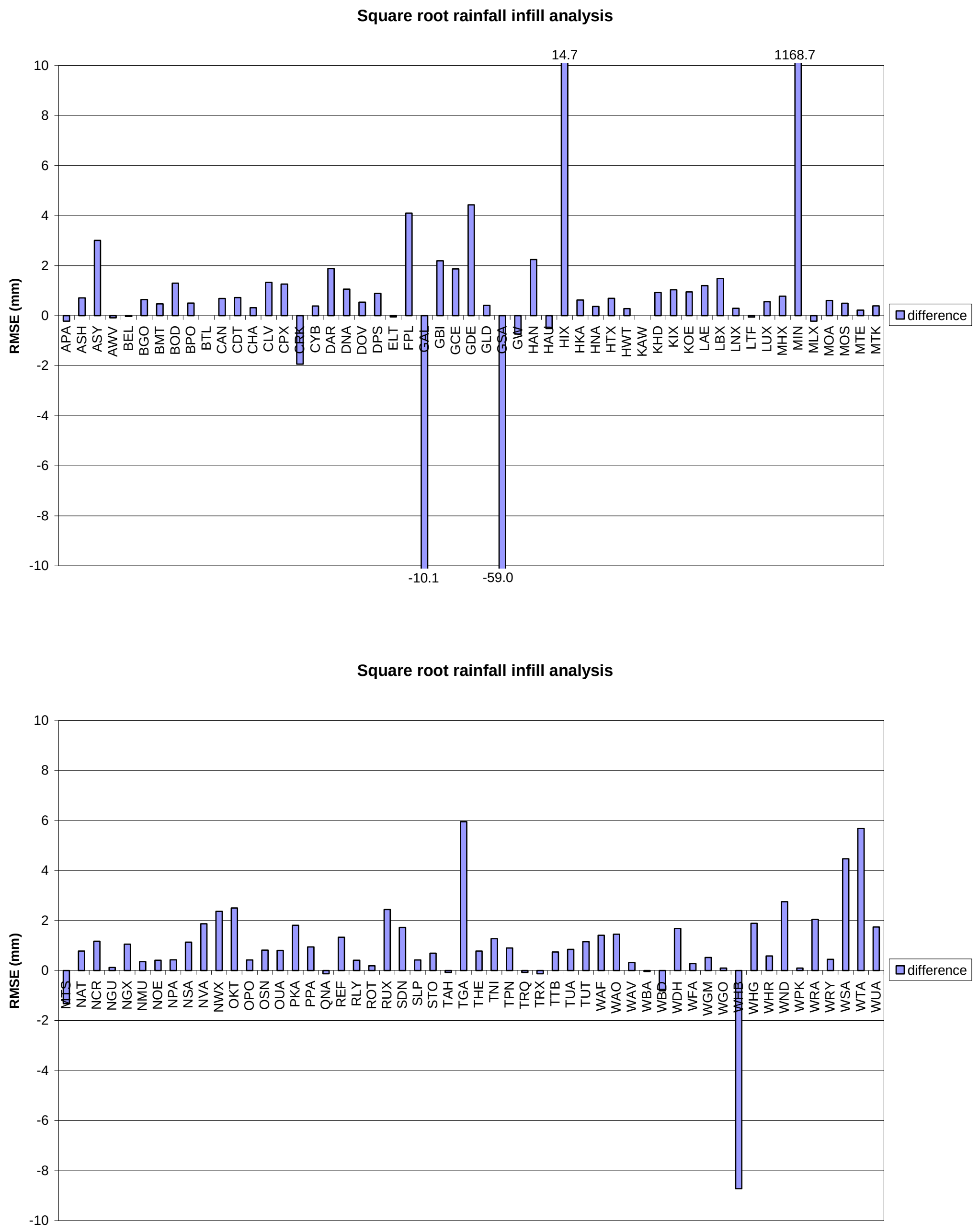

Figure 23: Rainfall root mean square error (RMSE) difference (substitute minus square root transformed interpolation), for each of the 107 fire RAWS analysed. Numbers listed at the ends of bars indicate data values that exceed the axis limits.

From Figure 22, it can be seen that using a square root transformation greatly improves the interpolation RMSE for daily rainfall. Also, when compared with the substitute RMSE (Figure 23), it is now clear that the transformed daily rainfall interpolations have a lower RMSE at almost all stations analysed, with a few exceptions. Figures 24 – 26 show the difference plots for temperature, relative humidity, and wind speed. These figures also show that for the majority of stations analysed, an interpolation approach results in a lower RMSE compared with using data substitutes. For relative humidity and wind speed a square root transformation was also performed (red bars), however there were no significant improvements over the untransformed values (blue bars).

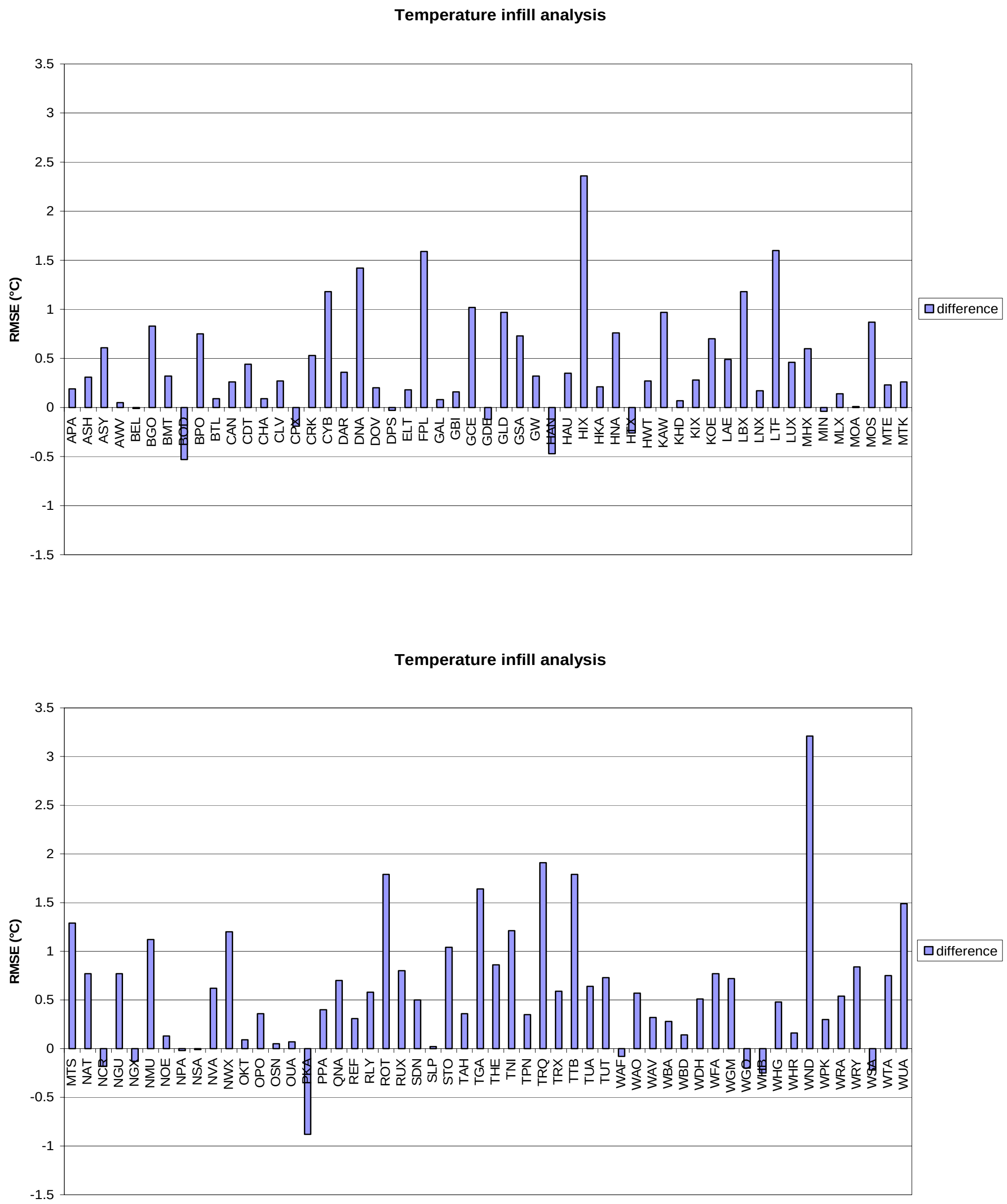

Figure 24: Temperature root mean square error (RMSE) difference (substitute minus interpolation) for each of the 107 fire RAWS analysed.

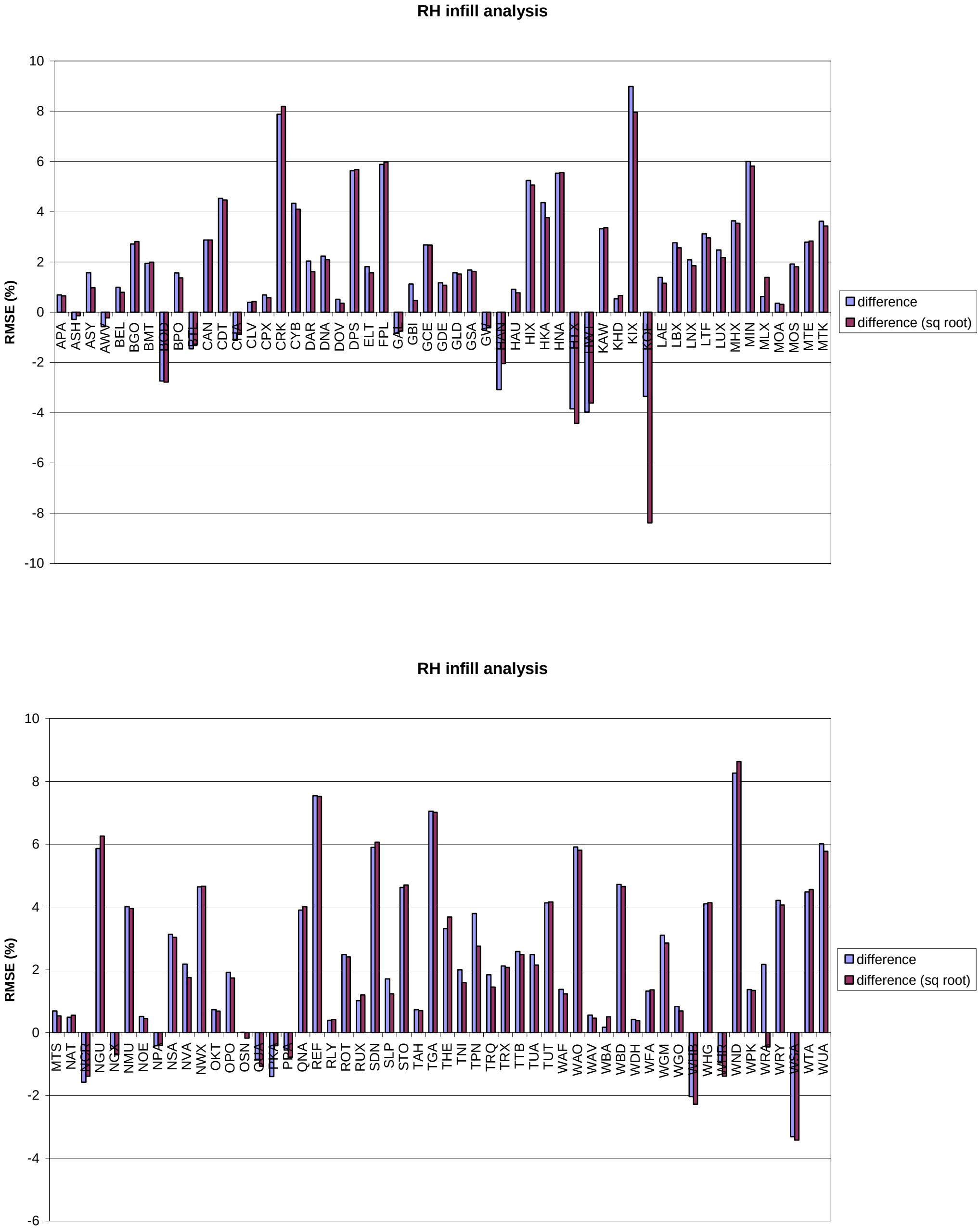

Figure 25: Relative Humidity root mean square error (RMSE) difference (substitute minus interpolation, and substitute minus square root transformed interpolation) for each of the 107 fire RAWS analysed.

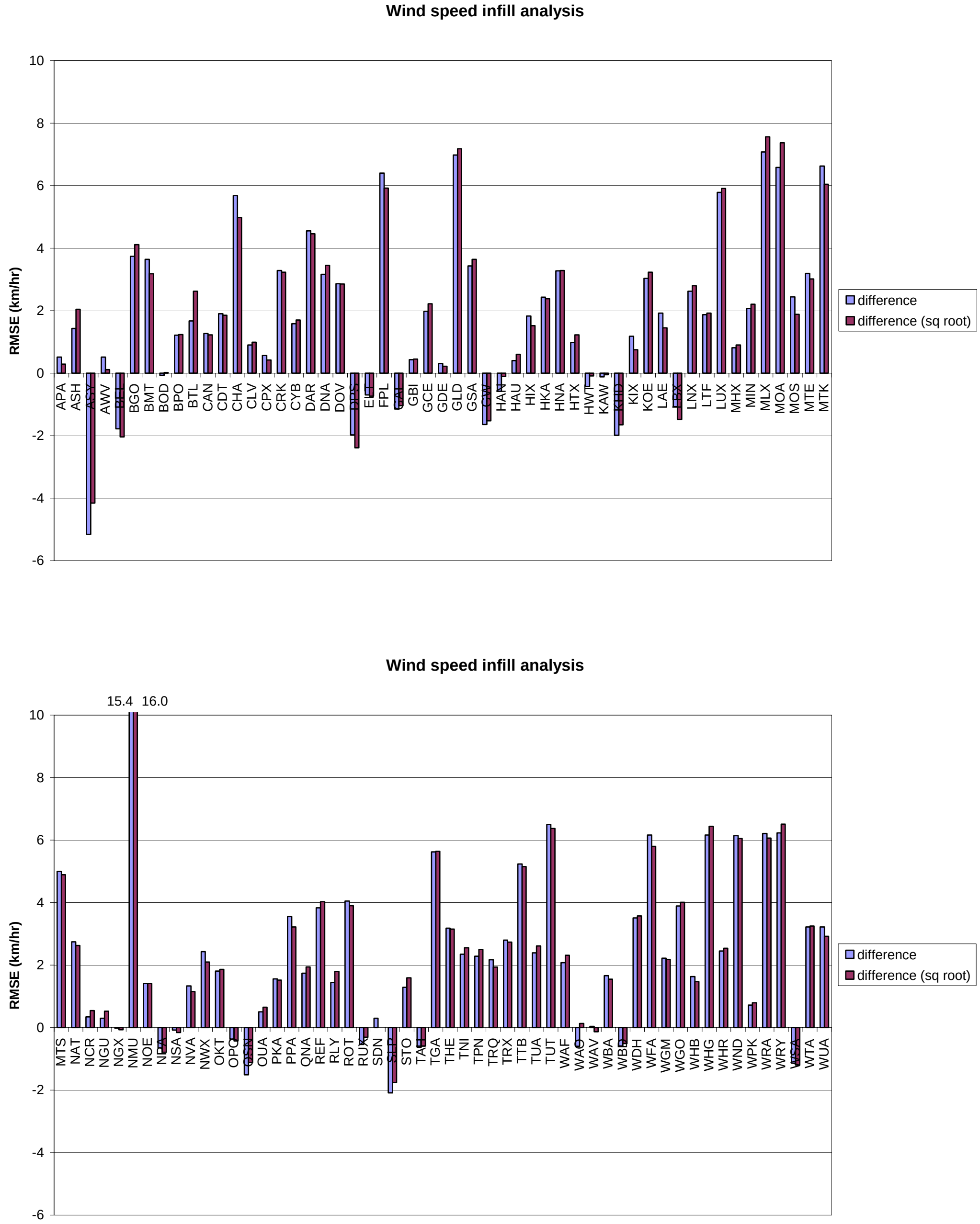

Figure 26: Wind speed root mean square error (RMSE) difference (substitute minus interpolation, and substitute minus square root transformed interpolation) for each of the 107 fire RAWS analysed. Numbers listed at the ends of bars indicate data values that exceed the axis limits.

5.3 Recommendations

The above results clearly show that an interpolation approach is better suited for filling in missing daily noon–noon rainfall and noon-time temperature, relative humidity, and wind speed data compared with a data substitutes approach. This result has also been shown in Canada by Flannigan and Wotton (1989). For rainfall, it is also clear that a square root transformation is needed before interpolating the values, followed by a back transformation. The ANUspline software package has this transformation option available.

In a few cases, the RMSE associated with the data substitute is lower than that associated with the interpolation (e.g. GSA, Gisborne Aero, for rainfall). Thus, an ideal approach would be to use the substitutes where they perform better, and use the interpolations everywhere else.

The performance of the interpolation approach would also likely be improved by increasing the accuracy of the interpolated surfaces through inclusion of additional MetService or NIWA stations (as recommended in the previous section). In the case of rainfall in particular, this could result in a significant improvement of the interpolation approach over the use of substitutes.

6. Optimum Interpolation Parameters

The goal of this stage of the study was to "Analyse methods to reduce interpolation error through statistical transformations, alternate spline covariates, and interpolation order". This involved the completion of tasks 9 and 10, described in section 1. Work was completed on this stage of the study during the period 16 December 2004 – 30 June 2005.

6.1 Data and Methodology

The daily datasets compiled for the work described in the previous section were re-used for this part of the analysis. As in the previous section, analyses of the RMSE before and after changes were made to the interpolation scheme were used here as indicators of improved interpolation accuracy. An early result, as shown in section 5.2 above, was the obvious reduction in daily rainfall interpolation error associated with the use of a square root transformation. No significant error reduction was achieved using a square root transformation for temperature, relative humidity, or wind speed data. Hence, a square root transformation was implemented in all the subsequent analyses of daily rainfall data in this section.

Currently, NZFS use a four-dimensional spline model to interpolate daily noon–noon rainfall and noon-time temperature, relative humidity, and wind speed. The four independent spline variables used are easting, northing, elevation, and topographic protection (the fourth variable is derived from a transformation of the digital elevation model and is designed to minimize the east-west transference of the interpolated field across the main divide, Leathwick, *pers. comm.*, 2005). In this stage of the analysis, different spline variables were experimented with and compared to the standard trivariate model (easting, northing, and elevation). It was not regarded as necessary to include topographic protection in this analysis. Any improvements over the standard trivariate model resulting from the inclusion of topographic protection can be replicated by adding it to any revised set of spline variables, should they be identified as producing significantly lower RMSE.

6.2 Alternate Spline Variables for Rainfall Interpolation

Hutchinson (1998) describes the use of a two-dimensional (or bivariate) thin plate smoothing spline model to interpolate daily rainfall values. The two independent spline variables used were easting and northing location variables. Thus, a similar bivariate spline model was experimented with here, and the RMSE values were calculated at each of the 107 fire RAWS stations analysed.

Also, preliminary work done by NIWA suggest that the interpolation of rainfall is improved when elevation above sea level is replaced with a 1951–80 mean annual rainfall surface as the third independent variable in a trivariate spline interpolation (Tait, *in prep*). This hypothesis was based on the observation that the 1951–80 map showed more realistic rainfall totals in the mountains (based on short-term observations, some high resolution Numerical Weather Prediction model runs, and observed river flows) than those produced from an elevation-based spline model.

The hand-drawn 1951–80 rainfall contour map (New Zealand Meteorological Service, 1985) was based on observations at climate stations, with an expert interpolation "by eye" of rainfall for locations with few or no observations (J. Sansom, NIWA, personal communication). This included most of the mountainous areas of the country, the remote areas of the southwest of the South Island, and some central North and South Island locations. Recently, the hand-drawn contours were digitised and converted into vectors, which were then interpolated onto a 1 km raster grid.

Figure 27 shows the results of the RMSE analysis for daily rainfall interpolation using three spline models: bivariate, trivariate (using elevation), and trivariate (using the 1951–80 mean annual rainfall surface). At almost all stations the RMSE for the bivariate model (red bars) is greater than the RMSE from the two trivariate models (yellow and aqua bars), with the two notable exceptions being station GSA, Gisborne Aero and GAL, Galatea.

The RMSE difference between the two trivariate models at all the stations is generally insignificant. This is likely due to the lack of high elevation stations in the sample – the 3 highest stations of the 107 fire RAWS analysed are all below 900 m (MLX, Molesworth, 881 m; NAT, National Park, 825 m; and RUX, Waiouru Aero, 821 m). The major differences between using elevation and the 1951–80 rainfall surface are expected to be at very high elevations.

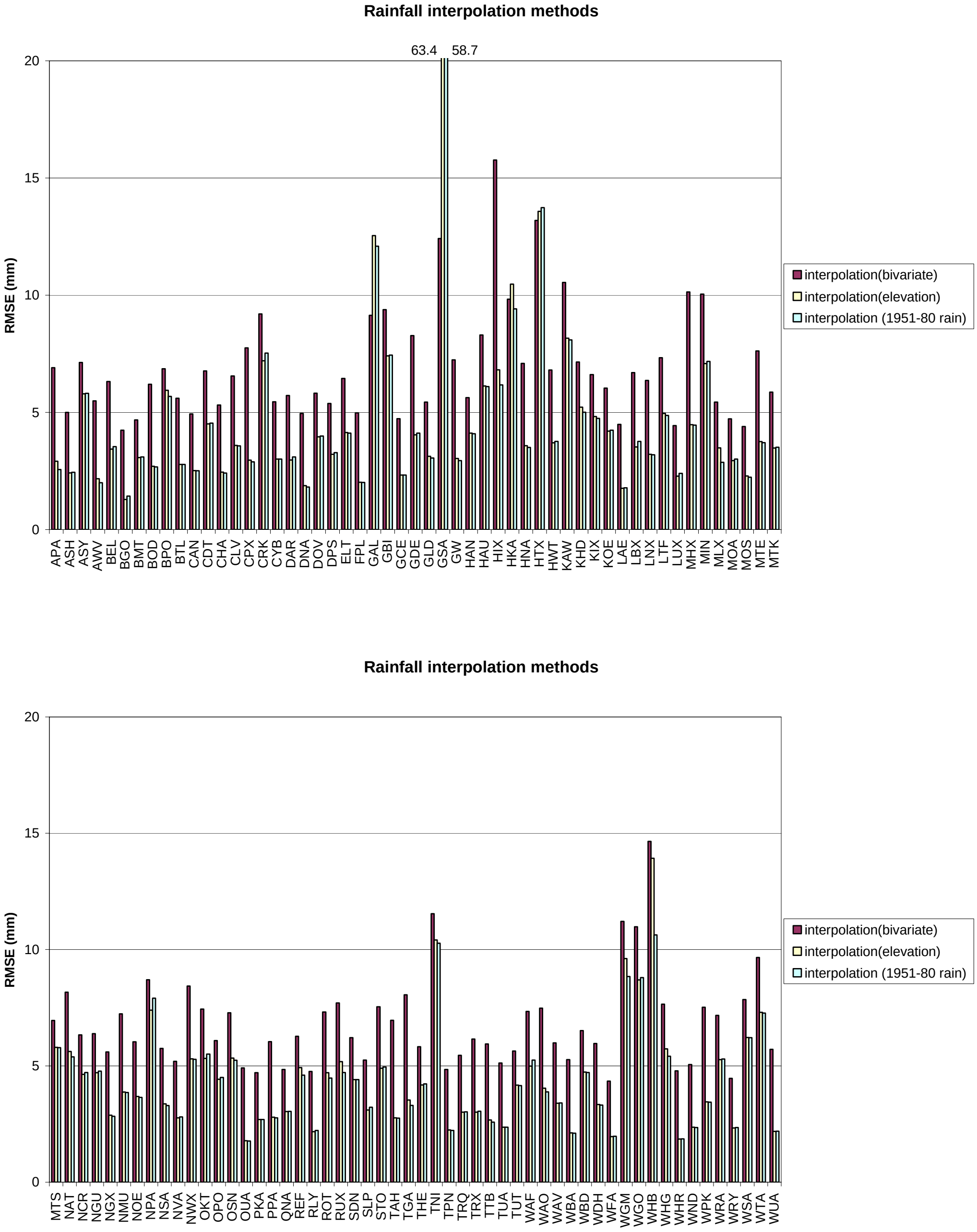

Figure 27: Root mean square error (RMSE) for three daily rainfall interpolation schemes: bivariate (easting and northing only), trivariate (easting, northing, and elevation), and trivariate (easting, northing, and the 1951–80 rainfall surface). The RMSE is shown for each of the 107 fire RAWS analysed. Numbers listed at the ends of bars indicate data values that exceed the axis limits.

6.3 Alternate Spline Variables for Relative Humidity Interpolation

The 1951–80 mean annual rainfall surface was also used as a third independent spline variable for the interpolation of daily noon-time relative humidity. However, as Figure 28 shows, this did not significantly improve the interpolation RMSE (blue bars) compared with using elevation (red bars).

6.4 Alternate Spline Variables for Wind Speed Interpolation

Recent work by NIWA suggests that the mean annual daily temperature range may be a useful variable for interpolating mean wind speed (Tait and Reid, *in prep*). This is because daily temperature range is inversely related to wind speed, i.e. locations which have high daily temperature ranges typically experience low wind speeds and vice versa. Thus, a mean annual daily temperature range surface was generated for the whole country using a trivariate spline model with variables of easting, northing, and elevation. Following this, a trivariate model using easting, northing, and daily temperature range was used to interpolate daily noon-time wind speed.

The comparison of wind speed RMSE between trivariate models using daily temperature range (blue bars) and elevation (red bars) is shown as Figure 29. It can be seen that using mean annual daily temperature range as a third independent variable does not significantly improve the RMSE, compared with elevation.

6.5 Alternate Spline Variables for Temperature Interpolation

No alternate spline variables were experimented with for the interpolation of daily temperature. This is because the three-variable combination of easting, northing, and elevation is generally accepted as being very good for interpolating air temperature (Hutchinson and Bischof, 1983; Laslett *et al*., 1987, Phillips *et al*., 1992).

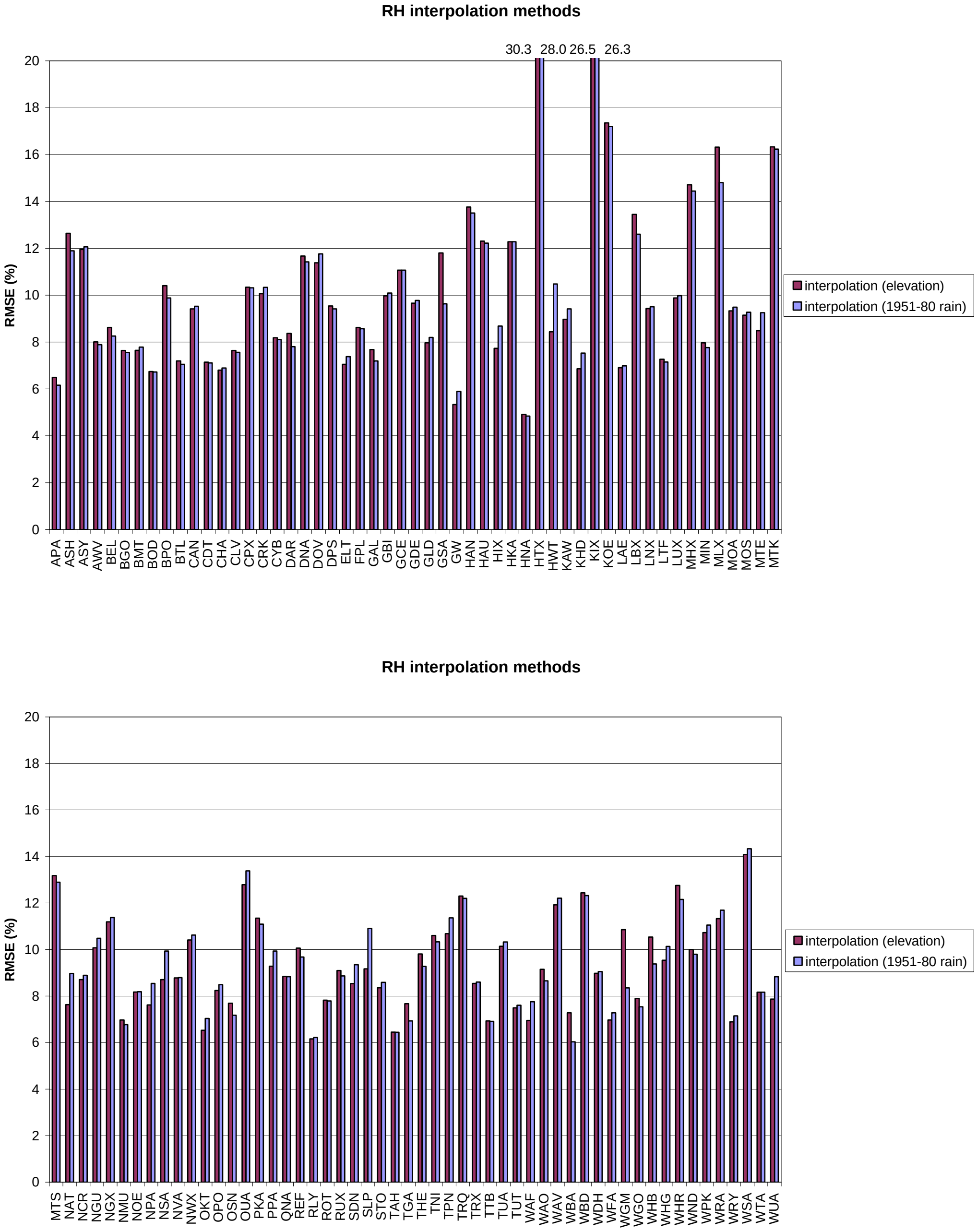

Figure 28: Root mean square error (RMSE) for two relative humidity interpolation schemes: trivariate (easting, northing, and elevation), and trivariate (easting, northing, and the 1951–80 rainfall surface). The RMSE is shown for each of the 107 fire RAWS analysed. Numbers listed at the ends of bars indicate data values that exceed the axis limits.

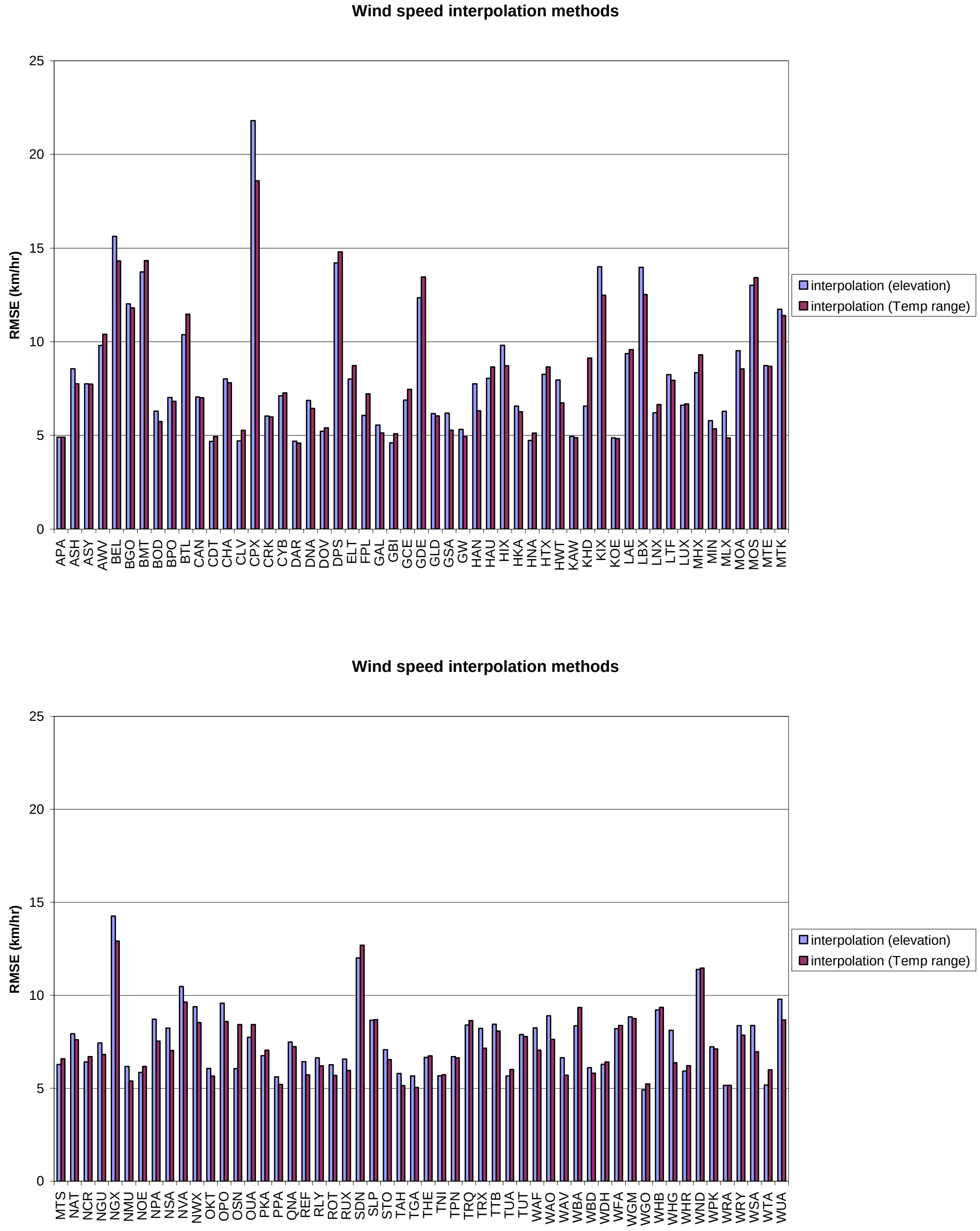

Figure 29: Root mean square error (RMSE) for two wind speed interpolation schemes: trivariate (easting, northing, and elevation), and trivariate (easting, northing, and daily temperature range). The RMSE is shown for each of the 107 fire RAWS analysed.

6.6 Order of Fire Weather Index Interpolation

The Fire Weather Index (FWI) and its components and derivatives are used by NZFS to assess the current and historical fire danger throughout New Zealand (National Rural Fire Authority, 2005). The six FWI parameters are currently calculated daily from the daily noon–noon rainfall and noon-time temperature, relative humidity, and wind speed data after these meteorological data have been interpolated from the fire RAWS onto a 2km grid covering the whole country. It is possible that a more accurate method may be to calculate the FWI parameters at the climate stations and then interpolate the FWI parameters to the grid.

This suggested approach is likely to reduce the overall error of estimating the FWI throughout the country, as there will be at least a four-fold reduction in the interpolation error (i.e. interpolating each of the four weather variables introduces four sources of interpolation error, which are additive, compared with one source of interpolation error if the FWI is calculated at the stations and then interpolated onto the grid. Additionally, the FWI value itself is also derived from intermediate components – FFMC, DMC, DC, ISI, and BUI – so that there are potentially up to 7 sources of error).

Flannigan and Wotton (1989) present the results of a detailed study of interpolation methods for forest fire danger rating in Canada. One of their results is the clear reduction in interpolation error by interpolating the FWI instead of the weather variables (see their Table 2, page 1062). The authors state that the reason for this result is the abnormally high error associated with the interpolation of daily rainfall, compared with the other three weather variables and the FWI system components. They conclude that this is due to the highly variable nature of summer precipitation in Canada.

Section 4.3 of this report shows that the spatial interpolation of daily rainfall in New Zealand also results in abnormally high interpolation errors, compared with the other three weather variables used to calculate the FWI. Summer rainfall in New Zealand, as it is in Canada, can also be highly variable over relatively short distances due to the country’s complex topography and the frequent summertime incidence of small-scale convective precipitation processes. Thus, it is logical that the Flannigan and Wotton (1989) result is also relevant in New Zealand, and that interpolation of FWI rather than of its weather components should be undertaken to reduce the interpolation error.

6.7 Recommendations

The four-dimensional spline model (with independent variables of easting, northing, elevation, and topographic protection) currently used by NZFS to interpolate daily noon–noon rainfall and noon-time temperature, relative humidity, and wind speed should be maintained. There is no evidence that using the 1951–80 mean annual rainfall surface or the mean annual daily temperature range surface as spline variables significantly improves the interpolation errors. Bilinear interpolation (using just easting and northing variables) results in consistently higher RMSE values.

For the spatial estimation of the FWI system values, it is strongly recommended that the daily indicies be calculated at the stations and then interpolated onto the 2 km grid, rather than the current practice of interpolating the daily weather variables and then calculating the FWI components at the grid resolution. This follows the results of Flannigan and Wotton (1989) in their Canadian study.

7. Summary of Recommendations

7.1 Data Quality

Spatial interpretation of unchecked historical weather data may result in misleading patterns, due to the influence of poor quality data. It is recommended that NZFS use a revised dataset, omitting the suggested data deletions provided and described in section 9.1, for all of their historical analyses of New Zealand fire climate. For data collected since September 2003, it is recommended that NZFS perform a similar three stage quality checking routine as described in section 2.

7.2 Fire RAWS Network

Generally, the more stations there are in the network the more accurate the spatial interpolations will be. However, it is suggested that if any stations are to be discontinued, the bottom ten ranked stations from the list of average relative ranks (i.e. RLY, LAE, DNP, WFA, THE, BGO, CAN, WHR, CHA, and PKA) should be looked at first. There is a clear indication that at least one of these neighbouring stations is redundant.

The interpolation of rainfall is the least accurate of the four climate elements used to assess fire risk, particularly at the locations shown in Table 3 and in the general Auckland – Waikato – Bay of Plenty area. MetService stations within this area which are not included in the current fire RAWS network (e.g. Mokohinau, Whangaparaoa, Owairaka, or Auckland Airport) or NIWA stations (e.g. Warkworth, Mangere, Pukekohe, Ruakura, Toenepi, Matamata, or Te Puke) should be considered for inclusion in the fire RAWS network in the future.

The Fire Service should also continue to supplement the fire RAWS network with data from MetService stations. Consideration should also be given to using additional stations from the NIWA/MetService raingauge network to improve the interpolation of rainfall.

7.3 Data Substitutes

An interpolation approach is clearly better suited for filling in missing daily noon–noon rainfall and noon-time temperature, relative humidity, and wind speed data compared with a data substitutes approach. This result has also been shown in Canada by Flannigan and Wotton (1989). It is strongly recommended that NZFS replace the current practice of using data substitutes in favour of estimating missing data from an interpolation of data from neighbouring sites. ANUspline should be used to perform these interpolations. For an ideal approach, data substitutes could still be used for the few cases where the RMSE was lower than that from interpolation if additional stations in these locations are not added to the network.

7.4 Interpolation Error Reduction

For daily rainfall, it is clear that a square root transformation is needed before interpolating the values, followed by a back transformation. The ANUspline software package has this option available. Otherwise, the four-dimensional spline model (with independent variables of easting, northing, elevation, and topographic protection) currently used by NZFS to interpolate daily noon–noon rainfall and noon-time temperature, relative humidity, and wind speed should be maintained.

For the spatial estimation of the FWI system components, it is strongly recommended that the daily index be calculated at the stations and then interpolated onto the 2 km grid, rather than the current practice of interpolating the daily weather variables and then calculating the FWIs at the grid resolution. This follows the results of Flannigan and Wotton (1989) in their Canadian study.

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10. Appendix

9.1 Lists of Quality Checked Data Deletions for each Climate Element

The files named “temperature_deletions.lst”, “rainfall_deletions.lst”, “rh_deletions.lst”, and “windspeed_deletions.lst” sent to NZFS in January 2004 list all the deletions made to each of the fire RAWS up to September 2003 based on the quality checking analysis described in section 2 of this report. For each file, the first column represents the station identifier code and the second column is the deleted day, depicted in the format “YYYYMMDD”.

For example, the first few lines of “temperature_deletions.lst” are:

```
APP                 19960926
APP                 19961001
APP                 19961002
APP                 19961003
APP                 19961004
```

where APP = the station code for Aupouri Peninsula and “19960926” = the date 26th September, 1996.