Climate Surfaces for New Zealand

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Contents

1. Summary

Although climate is frequently recognised as a major factor affecting both natural and managed ecosystems, analysis of its effects is frequently hampered by lack of readily available data, particularly at sites remote from climate stations. One solution to this problem is to fit mathematical surfaces to climate station data to allow interpolation at other sites. This report describes the fitting of such surfaces to long-run average climate station data for New Zealand, enabling prediction of monthly climate parameters (temperature, rainfall, solar radiation, humidity, vapour pressure deficit and wind) for any site whose location can be specified using New Zealand Map Grid coordinates and elevation (in metres).

Estimates from these surfaces, which are jointly owned by Landcare Research NZ Ltd and the Department of Conservation, will be made available at cost for research, teaching, or public administration. Estimates will be made available for commercial purposes at a cost to be negotiated on a case-by-case basis.

2. Introduction

Knowledge of climates is frequently important for understanding ecological systems, particularly in landscape-scale studies covering larger geographic areas. However, use of climatic data is often frustrated by the difficulty of estimating parameters for sites remote from climate stations. This report describes mathematical surfaces which enable prediction of a range of monthly climate parameters for any site in New Zealand, provided its location can be specified in terms of New Zealand Map Grid (NZMG) eastings and northings, and elevation. Surfaces cover the three main islands of New Zealand, and those smaller islands falling within the area covered by the New Zealand Map Grid coordinate ranges specified in Table 1. It excludes the Chatham Islands, which are not covered by the New Zealand Map Grid, and for which data are only readily available from one climate station.

Climate surfaces available at April 2002 provide mean monthly estimates of:

1. daily minimum temperature (°C);
2. daily average temperature (°C);
3. daily maximum temperature (°C);
4. total rainfall (mm);
5. daily solar radiation (MJ M^{-2} day^{-1});
6. daily 9 a.m. humidity (%);
7. daily 9 a.m. vapour pressure deficit (kPa);
8. average daily wind speed (km/hr).

Details of these surfaces, along with example maps derived from them, are provided below. Our intention is to make estimates from these surfaces widely available to facilitate development of a better understanding of the role of climate in ecological systems. Other surfaces , e.g., rain days, frost days, average annual minimum temperatures, etc., may be developed in the future if there is sufficient user-demand.

3. Surface development

3.1 Data

The majority of the climatic data used in the fitting of these surfaces was taken from publications of the former New Zealand Meteorological Service as listed for each climate surface. The majority of the data used covers either the period from 1950-1980 (temperature and rainfall), or all available records up until 1980 (all other parameters). Available monthly data was entered into a Paradox database for all climate stations falling within the NZMG limits specified in Table 1. To insure reliability, the annual average values were also entered for each climate parameter, and used to check automatically that monthly values had been entered correctly.

3.2 Surface fitting

All climate surfaces were developed using the ANUSPLIN suite of software (v. 4.1). This is an implementation of thin-plate smoothing splines produced by the Centre for Resource and Environmental Studies, ANU, Canberra, Australia, and designed for interpolation of climate parameters measured over an irregularly spaced network of stations (Hutchinson & Gessler 1994). The majority of surfaces were fitted as trivariate splines using NZMG easting and northing, and elevation in metres. Departures from this are noted below in the surface descriptions.

Table 1. Easting and northing limits used in development of climate surfaces for New Zealand.

NZMG	Lower limit	Upper limit
Easting	1 900 000	3 100 000
Northing	5 000 000	7 000 000

3.3 Availability of estimates

Landcare Research and the Department of Conservation jointly own the climate surfaces. Estimates can be provided outside these two organisations on the signing of a provision of data agreement. Where climate estimates are used for public administration, teaching, or research, charges will be made only to cover the work required to provide the estimates. Charges will be set on a case-by-case basis where climate estimates are to be used for commercial purposes.

4. The surfaces

Two measures of the standard errors are provided for each surface: the square root of the generalised cross validation, and the square root of the mean standard error. Neither is a completely satisfactory measure of the true surface errors, the first over-estimating and the second under-estimating the error (M. F. Hutchinson pers. comm.); the true standard error will lie somewhere between these two values.

4.1 Mean minimum temperature

Source: Temperature Normals 1951 to 1980, N.Z. Meteorological Service Miscellaneous Publication 183

No. of stations: 346

All stations were weighted equally, rather than by their length of record, as is commonly used for rainfall (Hutchinson 1995). Surface parameters for each month, shown in Table 2, indicate that standard errors are lower in summer than winter, reflecting the more uniform temperature conditions in these months.

Table 2. Monthly input data and surface characteristics for mean daily minimum temperature (°C).

Month	Mean	Range	Root GCV	Root MSE
January	11.5	4.7 - 16.7	0.77	0.38
February	11.6	5.3 - 17.4	0.86	0.41
March	10.6	4.2 - 17.2	0.85	0.36
April	8.1	1.3 - 15.5	0.93	0.33
May	5.4	-1.8 - 13.1	0.96	0.29
June	3.3	-4.0 - 11.4	0.99	0.26
July	2.7	-5.5 - 10.4	1.00	0.37
August	3.6	-4.0 - 10.5	0.87	0.32
September	5.2	-2.7 - 10.8	0.82	0.35
October	6.9	-0.8 - 11.9	0.74	0.34
November	8.5	1.1 - 13.7	0.74	0.35
December	10.4	3.2 - 14.9	0.74	0.35

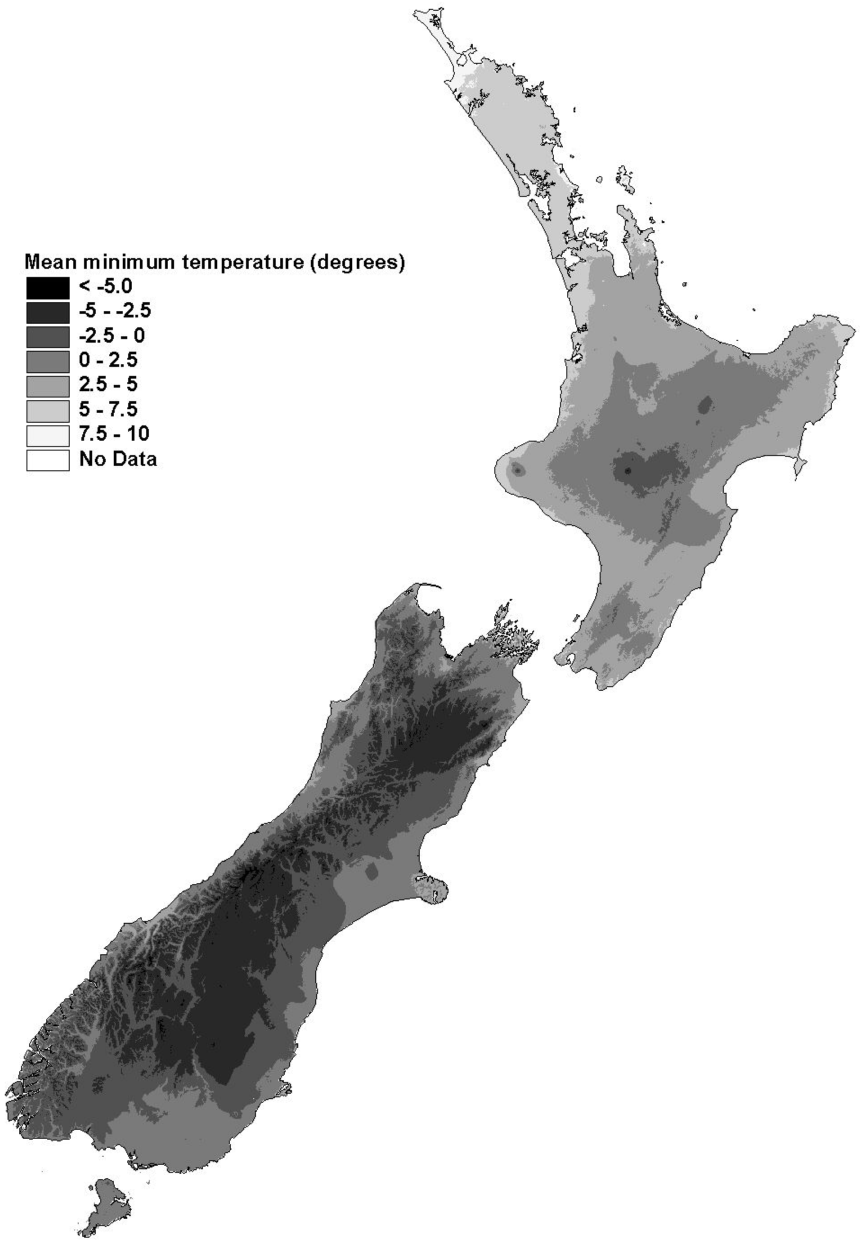

Fig. 1 Estimates, derived from the minimum temperature surface, of mean minimum temperature of the coldest month for points on a 1 km grid across New Zealand.

4.2 Mean maximum temperature

Source: Temperature Normals 1951 to 1980, N.Z. Meteorological Service Miscellaneous Publication 183

No. of stations: 346

This surface was also fitted with equally weighted station data. Standard errors were generally lower than for the minimum temperature surface, reflecting the lower variability in maximum as opposed to minimum temperatures. In contrast to the minimum temperature surface, standard errors were lower for winter months than for summer.

Table 3. Monthly input data and surface characteristics for mean daily maximum temperatures (°C).

Month	Mean	Range	Root GCV	Root MSE
January	21.9	12.8 - 25.5	0.63	0.29
February	22.0	13.9 - 25.6	0.60	0.28
March	20.5	11.4 - 24.7	0.52	0.24
April	17.6	8.3 - 21.8	0.44	0.21
May	14.3	4.8 - 19.3	0.38	0.18
June	11.8	2.5 - 17.1	0.35	0.15
July	11.2	1.4 - 16.2	0.34	0.15
August	12.4	2.0 - 16.8	0.38	0.18
September	14.4	3.4 - 17.7	0.46	0.22
October	16.4	5.9 - 19.7	0.53	0.25
November	18.3	8.5 - 22.0	0.59	0.28
December	20.3	11.6 - 23.9	0.61	0.27

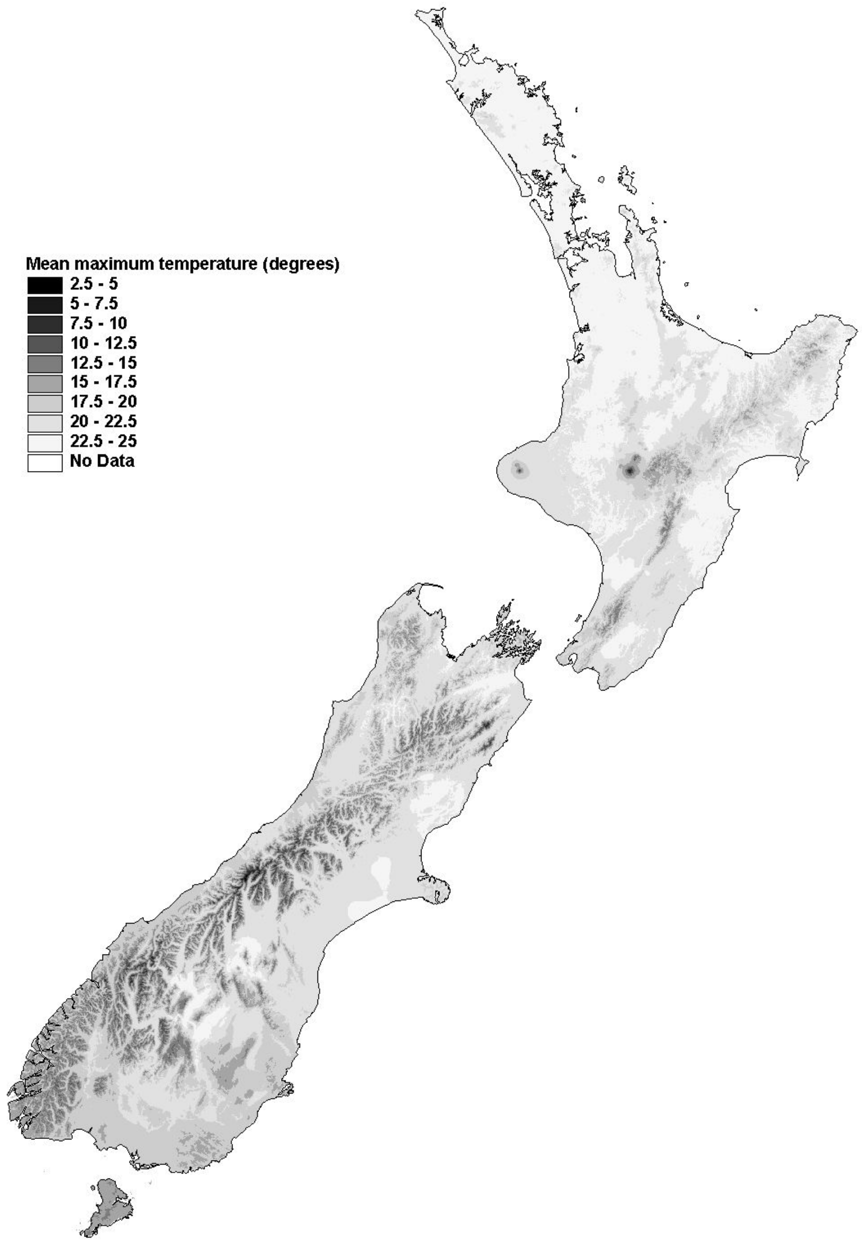

Fig. 2. Estimates, derived from the maximum temperature surface, of mean maximum temperature of the warmest month for points on a 1 km grid across New Zealand.

4.3 Mean daily temperature

Source: Temperature Normals 1951 to 1980, N.Z. Meteorological Service Miscellaneous Publication 183

No. of stations: 300

The mean daily temperature surface was fitted to data derived by averaging the daily minimum and maximum temperatures for the 300 stations for which both parameters were available. Stations were again weighted equally. The surface has standard errors that vary much less through the year than those for the minimum and maximum temperature surfaces.

Table 4. Monthly input data and surface characteristics for mean daily average temperature (°C).

Month	Mean	Range	Root GCV	Root MSE
January	16.7	8.8 - 20.1	0.49	0.22
February	16.8	9.6 - 20.6	0.51	0.22
March	15.5	7.8 - 20.1	0.49	0.21
April	12.9	5.1 - 17.9	0.52	0.23
May	9.9	1.9 - 15.4	0.56	0.27
June	7.5	-0.4 - 13.5	0.60	0.29
July	6.9	-1.4 - 12.7	0.58	0.28
August	8.0	-1.0 - 12.9	0.49	0.22
September	9.8	0.4 - 13.4	0.46	0.19
October	11.7	2.6 - 15.2	0.45	0.20
November	13.4	4.8 - 17.0	0.45	0.20
December	15.3	7.4 - 18.5	0.47	0.21

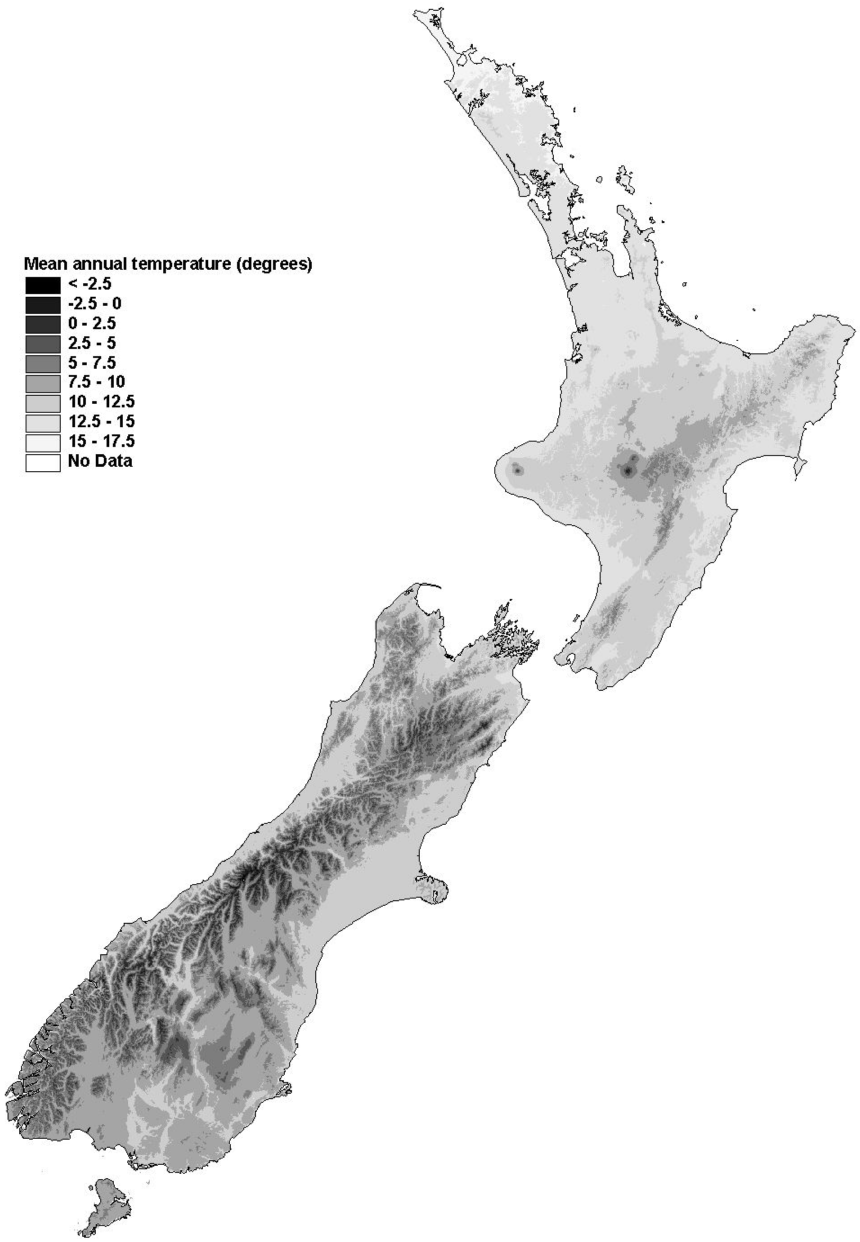

Fig. 3. Estimates, derived from the average temperature surface, of mean average temperature for points on a 1 km grid across New Zealand.

4.4 Rainfall

Source data: Rainfall Normals for New Zealand 1951 to 1980, N.Z. Meteorological Service Miscellaneous Publication 185, + misc. rain gauge records - see below for details.

No. of stations: 2202

The Meteorological Service publication used as a source of input data for this surface contains data for approx. 2500 stations. These include both those for which a complete record spanning all thirty years is available, and those for which records cover shorter periods of varying length. For the latter, 1950-1980 normals were calculated after estimations had been made for missing years, based on rainfall at surrounding stations. For these stations, a ranking indicating the correlation with surrounding stations as follows provides an indication of data quality:

1 = complete record with 6 or less months missing;

2 = incomplete record but R^2 with surrounding stations > 0.9;

3 = $0.8 < R^2 \leq 0.9$;

4 = $0.7 < R^2 \leq 0.8$;

5 = $0.6 < R^2 \leq 0.7$;

6 = $0.5 < R^2 \leq 0.6$;

7 = $R^2 \leq 0.5$;

8 = insufficient data for regression estimation in all months.

After initial trials indicated a paucity of data in very high rainfall, mountainous areas about and to the west of the South Island main divide, data for 21 storage rain gauges (Griffiths & McSaveney 1983) were added. These were divided into monthly amounts according to the proportions applying to the closest adjacent stations for which monthly data were available.

The final rainfall surface was fitted using the program SPLINB, which can accommodate much larger input datasets than SPLINA because of its use of knots, i.e., user-specified points to which the climate surface is tied. Stations with data quality ratings of 6 and above were selected, along with the storage rain-gauge sites, giving 2202 stations in all. Estimates of inter-annual variability in monthly rainfall were estimated from a surface fitted to monthly variance:mean data for 304 stations derived from New Zealand Meteorological Service (1979), and used as weights.

Predictions for DEM data from an initial trivariate spline using eastings, northings, and elevation, suggested that this was not adequately picking up the expected orographically-driven, west-east declines in rainfall. Addition of a variable indicating the predominant topographic sheltering, calculated from a digital elevation model (D. Giltrap, unpubl. data) gave a modest reduction in GCV, and a substantially better representation of the expected orographic patterns. This, however, requires calculation of the topographic sheltering for any sites for which rainfall estimates are subsequently required. To enable this, an additional trivariate spline surface was fitted to topographic protection data for 5000 DEM points using SPLINB with 1000 knots. This latter surface has a standard error of around 0.1 on a scale on which the majority of values lie between –3 and + 3. Where rainfall estimates are required for a set of independent points, values of the topographic protection variable are first derived from this latter surface, and the resulting output is then used to obtain rainfall estimates.

The surface was fitted with an initial set of 700 knots, selected using the program SELNOT. Extra knots were then added from those stations not already selected as knots, and which had high individual contributions to the generalised cross validation. These were added at around 50 a time, and the surface refitted, this procedure being repeated until the software limit of 1000 knots was reached. The final surface has a final monthly standard error of between 7 and 9 mm for most months (Table 5).

Table 5. Monthly input data and surface characteristics for mean monthly rainfall (mm).

Month	Mean	Range	Root GCV	Root MSE
January	101	35 - 1213	15.8	7.82
February	95	12 - 856	15.7	7.75
March	113	24 - 1061	16.0	7.94
April	120	28 - 939	15.3	7.59
May	135	25 - 962	18.2	9.02
June	130	12 - 718	15.6	7.74
July	132	14 - 716	17.1	8.48
August	130	19 - 809	18.0	8.94
September	113	17 - 928	16.1	8.02
October	117	31 - 1037	18.1	8.00
November	113	25 - 1143	16.4	8.14
December	118	35 - 903	16.8	8.31

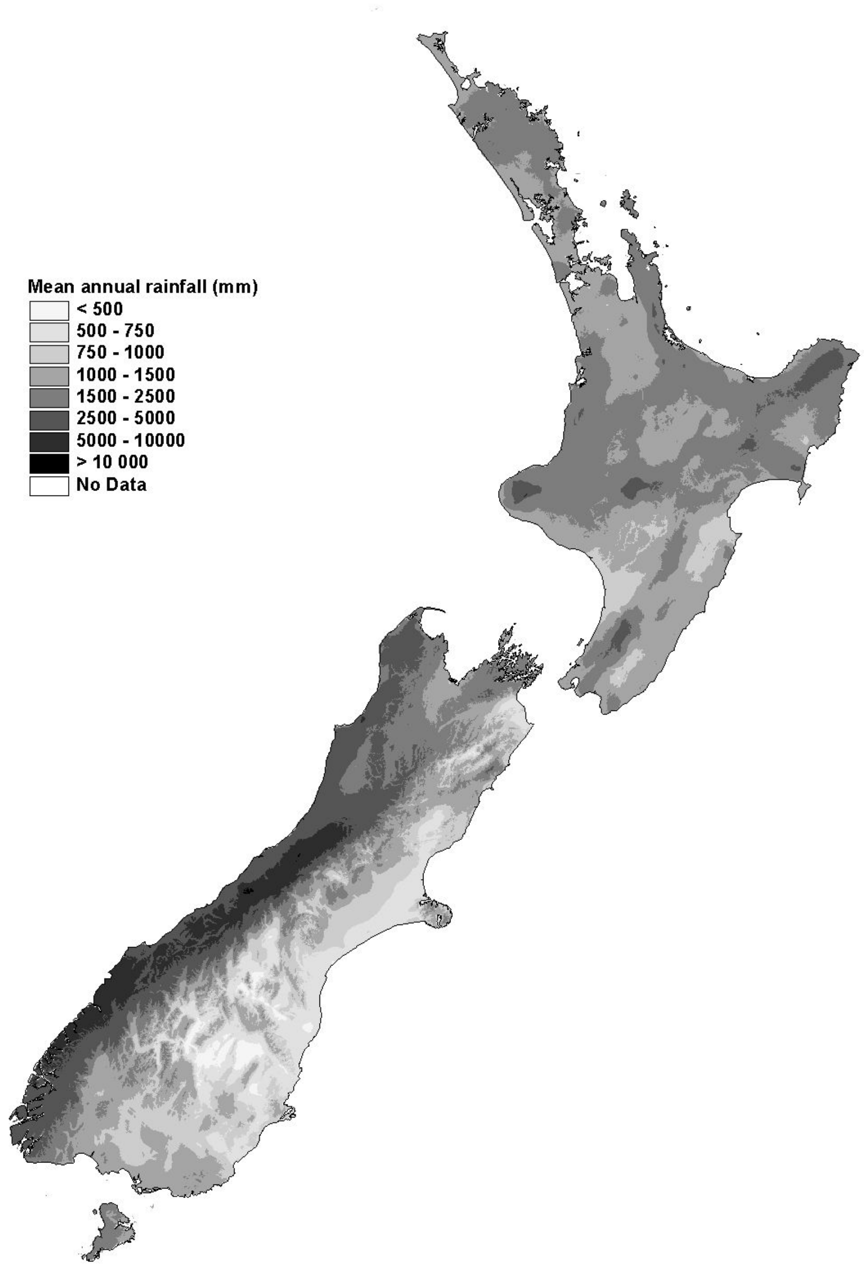

Fig. 4. Estimates, derived from the rainfall surface, of mean annual rainfall for points on a 1 km grid across New Zealand.

4.5 Nine a.m. humidity

Source: Summaries of Climatological Observations to 1980, N.Z. Meteorological Service Miscellaneous Publication 177.

No. of stations: 293

This surface was fitted using four predictor variables, easting, northing, elevation, and a variable indicating predominant topographic sheltering as described for the rainfall surface. Standard errors are between 2 and 3% in all months.

Table 6. Monthly input data and surface characteristics for mean daily 9 a.m. humidity (%).

Month	Mean	Range	Root GCV	Root MSE
January	73.4	54 - 92	3.68	1.82
February	76.2	56 - 94	3.57	1.77
March	78.9	63 - 94	3.15	1.57
April	81.9	65 - 95	3.22	1.61
May	83.9	65 - 95	3.23	1.61
June	85.1	66 - 96	3.28	1.61
July	85.5	67 - 96	3.28	1.61
August	83.2	65 - 94	3.32	1.66
September	78.4	63 - 93	3.15	1.57
October	73.9	54 - 93	3.37	1.68
November	72.7	52 - 90	3.98	1.93
December	72.9	55 - 90	3.68	1.82

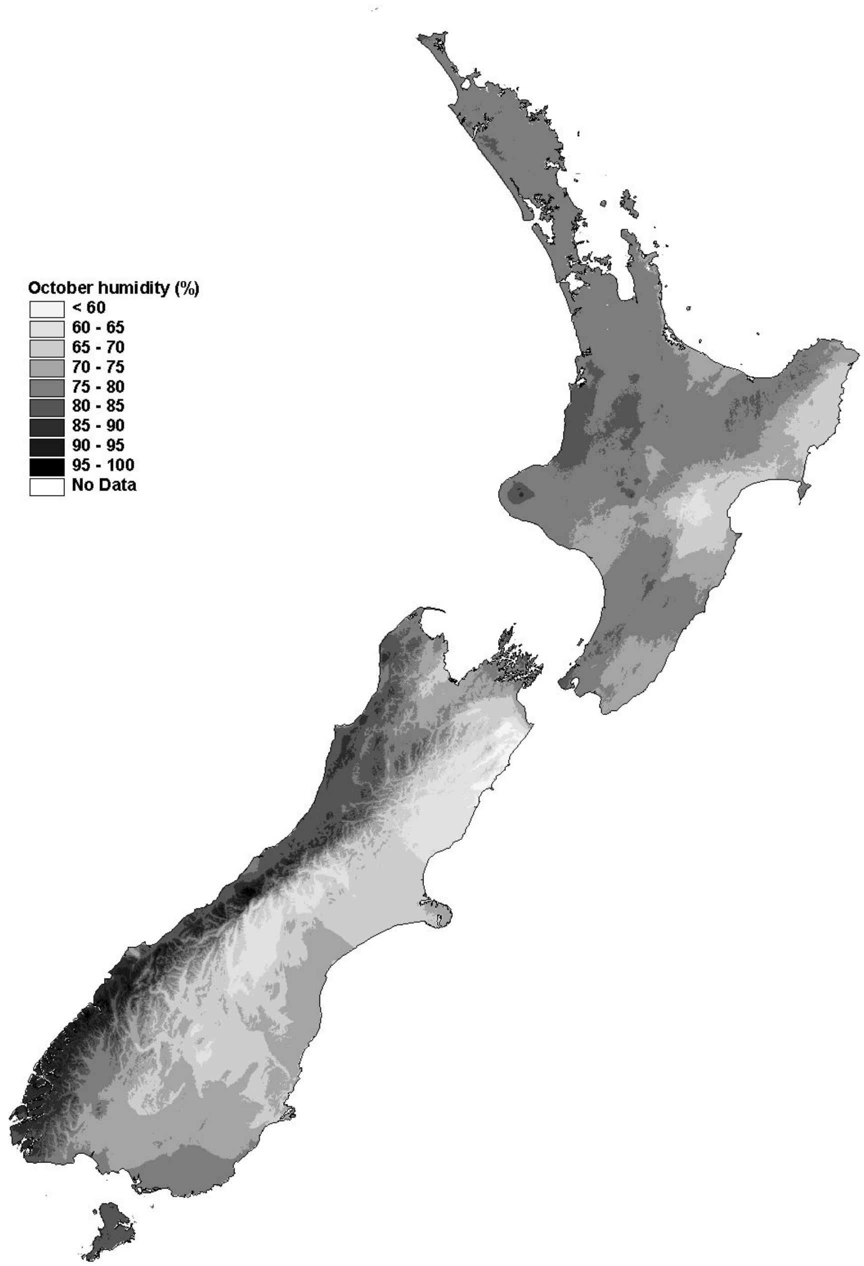

Fig. 5. Estimates, derived from the humidity surface, of October humidity for points on a 1 km grid across New Zealand.

4.5 Nine a.m. vapour pressure deficit

Source: Calculated from temperature and humidity data contained in Summaries of Climatological Observations to 1980, N.Z. Meteorological Service Miscellaneous Publication 177.

No. of stations: 287

Although relative humidity is the measure of the dryness of the air most commonly recorded, values strongly reflect the effects of variation in air temperature. To overcome this problem, monthly humidity data were converted to estimates of vapour pressure following the procedure described in (Jones 1994–pages 109-112). This first required estimation of the temperature at 0900 hours, the time at which humidity measurements are made, and this was calculated from the measured mean daily minimum and maximum temperatures for each month using a function that simulates the temperature course through the day (Goudriaan and van Laar 1994). The estimated temperature at 0900 hours was then used to calculate the saturation water vapour pressure (*e*), which indicates the maximum amount of water vapour able to be held in the air given its temperature. As the relative humidity (*RH*) indicates the percentage of this maximum that is actually occupied, the vapour pressure deficit (δe) can then be calculated as

$$\delta e = \frac{100 - RH}{100} \times e \, .$$

The surface was then fitted using a topographic protection variable as for rainfall and humidity. Standard errors vary from 0.02 in winter to 0.04 in summer.

Table 6. Monthly input data and surface characteristics for mean daily 9 a.m. vapour pressure deficit (kPa).

Month	Mean	Range	Root GCV	Root MSE
January	0.58	0.15–1.08	0.08	0.04
February	0.51	0.15–1.01	0.08	0.04
March	0.40	0.10–0.73	0.06	0.03
April	0.27	0.07–0.52	0.05	0.03
May	0.19	0.05–0.39	0.04	0.02
June	0.15	0.03–0.39	0.04	0.02
July	0.14	0.03–0.32	0.03	0.02
August	0.18	0.05–0.35	0.03	0.02
September	0.27	0.06–0.46	0.04	0.02
October	0.39	0.07–0.73	0.05	0.03
November	0.48	0.12–0.88	0.07	0.04
December	0.54	0.14–0.97	0.08	0.04

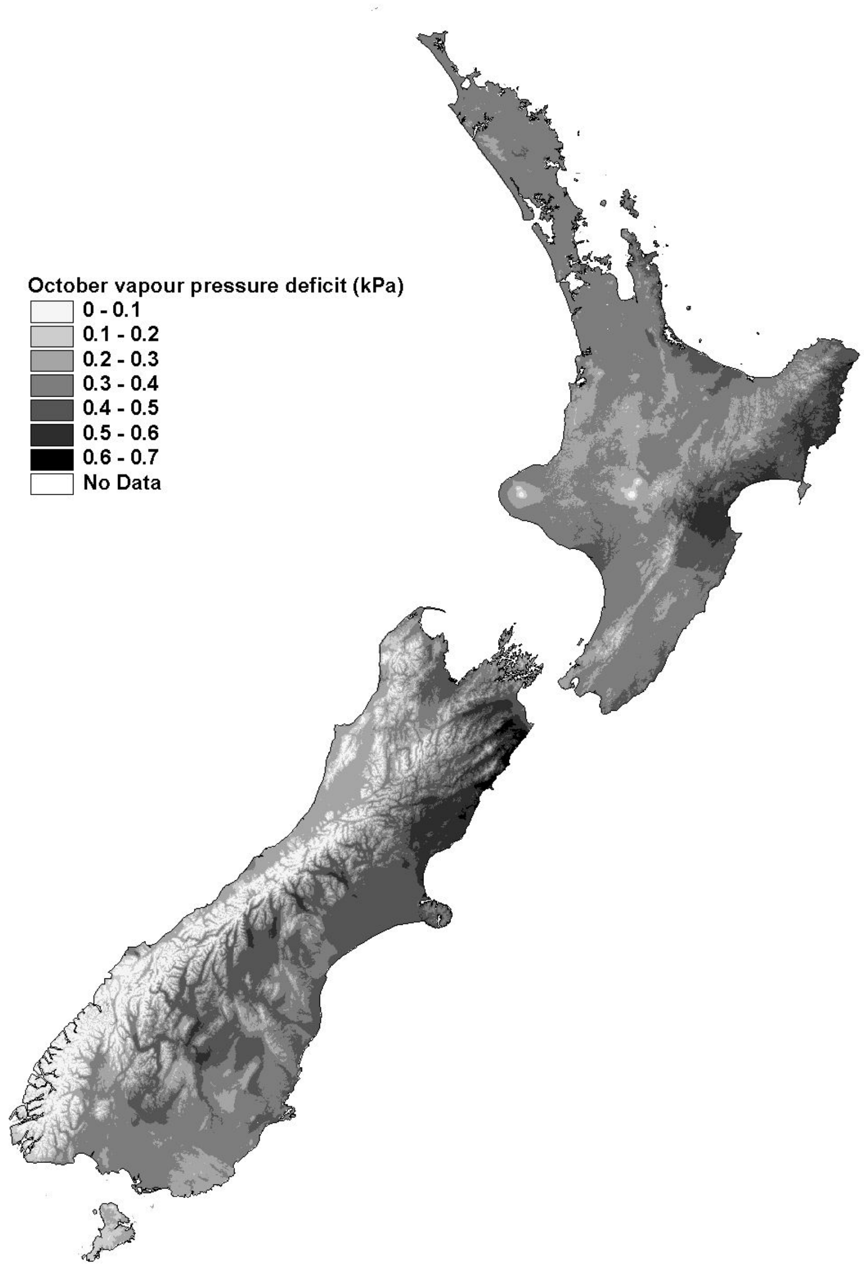

Fig. 5. Estimates for October derived from the vapour pressure deficit surface for points on a 1 km grid across New Zealand.

4.7 Solar radiation

Source data: Summaries of Climatological Observations to 1980, N.Z. Meteorological Service Miscellaneous Publication 177; Sunshine Normals 1941-1970. New Zealand Meteorological Service Miscellaneous Publication 150.

No. of stations: solar radiation – 21; sunshine hours – 97;

The solar radiation surface presented by far the most difficult technical challenges, given the relative paucity of measured data. The surface was developed in two stages to enable use of additional data from stations from which measurements of sunshine hours are available. Prediction of solar radiation from sunshine hours was based on the consistent relationship between

$$SR_{ratio} = \frac{SR_m}{SR_{xa}} \quad \text{and} \quad SS_{ratio} = \frac{SS_m}{SS_{max}}$$

where SR_m is measured solar radiation, SR_{xa} is extra-atmospheric solar radiation, SS_m is measured sunshine hours, and SS_{max} is maximum possible sunshine hours (see de Lisle, 1966). Values for SS_{max} and SR_{xa} were calculated using a purpose written FORTRAN program using standard solar geometry equations (e.g., Jones 1992); values of SS_{max} were adjusted for the hours for which the sun is above the 5° threshold at which Stokes-Campbell recorders become operative. Values of both SS_{max} and SS_m were also adjusted to take account of losses from horizon obstruction as described in N. Z. Met. Serv. Publ. 150. Separate monthly surfaces were then fitted predicting SR_{ratio} using easting, northing, and SS_{ratio} as spline variables, and with 18 data points. These surfaces were then used to predict SR_{ratio} for a further 80 sites for which sunshine data only was available, and SR_m was then predicted for these sites based on their calculated SR_{xa}. With the addition of four sites for which solar radiation alone was measured, this gave a total of 101 sites to be used for fitting a solar radiation surface.

Fitting of the solar radiation surface to these points was initially attempted using the same approach as that used by Hutchinson *et al.* (1984) and Mitchell (1991), i.e., using as a surrogate of cloudiness, a transformation of rainfall as a third spline variable. However, when this was found to give a substantial decrease in fit compared with a bivariate spline using eastings and northings alone, two other candidate variables were considered, mean daily temperature range (see Bristow & Campbell 1984), and mean 9 a.m. humidity (see Fitzpatrick & Nix 1970). The latter was found to have by far the higher correlation with solar radiation, and its addition to the bivariate surface gave a substantial improvement in fit. It did, however, reduce the number of available stations for surface fitting to 98, because humidity data is not available for all sites with measured solar radiation or sunshine hours. Standard errors are smaller in winter than summer months, ranging overall from c. 0.2-0.5 MJ M^{-2} day^{-1}.

Table 7. Monthly input data and surface characteristics for mean daily solar radiation (MJ m^{-2} day^{-1}).

Month	Mean	Range	Root GCV	Root MSE
January	22.7	20.0 - 25.3	0.68	0.33
February	19.8	17.4 - 23.2	0.70	0.35
March	15.0	12.4 - 17.2	0.45	0.23
April	10.6	7.9 - 12.6	0.35	0.17
May	7.07	4.6 - 8.9	0.32	0.16
June	5.58	3.6 - 7.4	0.20	0.10
July	6.31	4.2 - 8.6	0.23	0.12
August	8.89	7.1 - 11.1	0.23	0.11
September	13.0	11.2 - 15.0	0.28	0.08
October	17.4	14.8 - 19.7	0.59	0.25
November	21.3	19.4 - 23.5	0.67	0.33
December	23.1	20.7 - 25.3	0.69	0.29

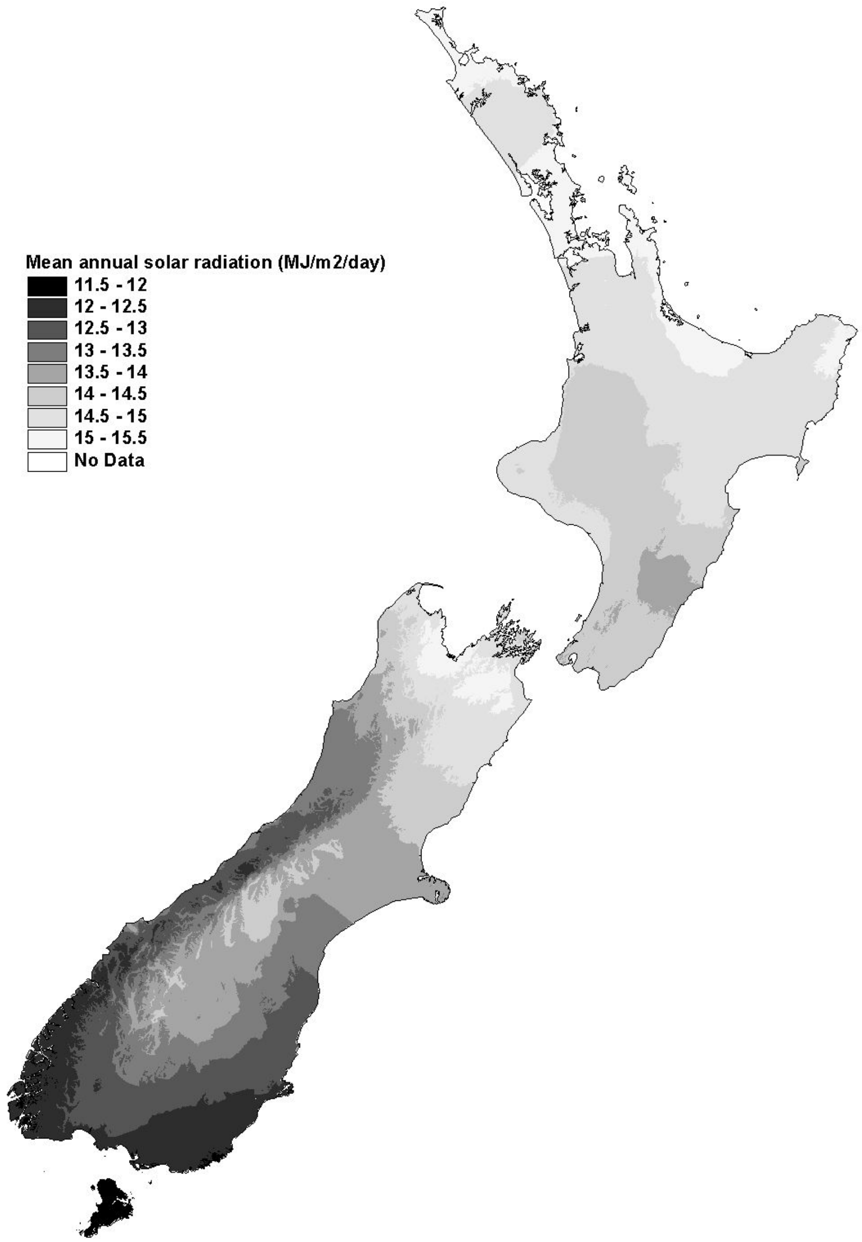

Fig. 6. Estimates, derived from the solar radiation surface, of mean annual solar radiation for points on a 1 km grid across New Zealand.

4.8 Wind

Source data: Summaries of Climatological Observations to 1980, N.Z. Meteorological Service Miscellaneous Publication 177 plus additional unpublished data.

No of stations: 270

The wind surface was fitted as a trivariate spline using eastings, northings and elevation. Both mean wind speeds and surface errors are highest in October and November.

Table 8. Monthly input data and surface characteristics for mean daily wind speed (km/hr).

Month	Mean	Range	Root GCV	Root MSE
January	13.5	4 - 36	5.26	2.63
February	12.6	4 - 35	5.01	2.50
March	12.3	3 - 33	4.92	2.45
April	11.7	3 - 35	4.60	2.27
May	11.9	3 - 33	4.85	2.41
June	11.4	2 - 36	4.47	2.21
July	11.6	2 - 37	4.77	2.37
August	12.3	3 - 35	4.65	2.31
September	13.7	4 - 34	5.38	2.68
October	14.6	5 - 40	5.69	2.84
November	14.5	5 - 38	5.53	2.75
December	13.8	4 - 34	5.38	2.69

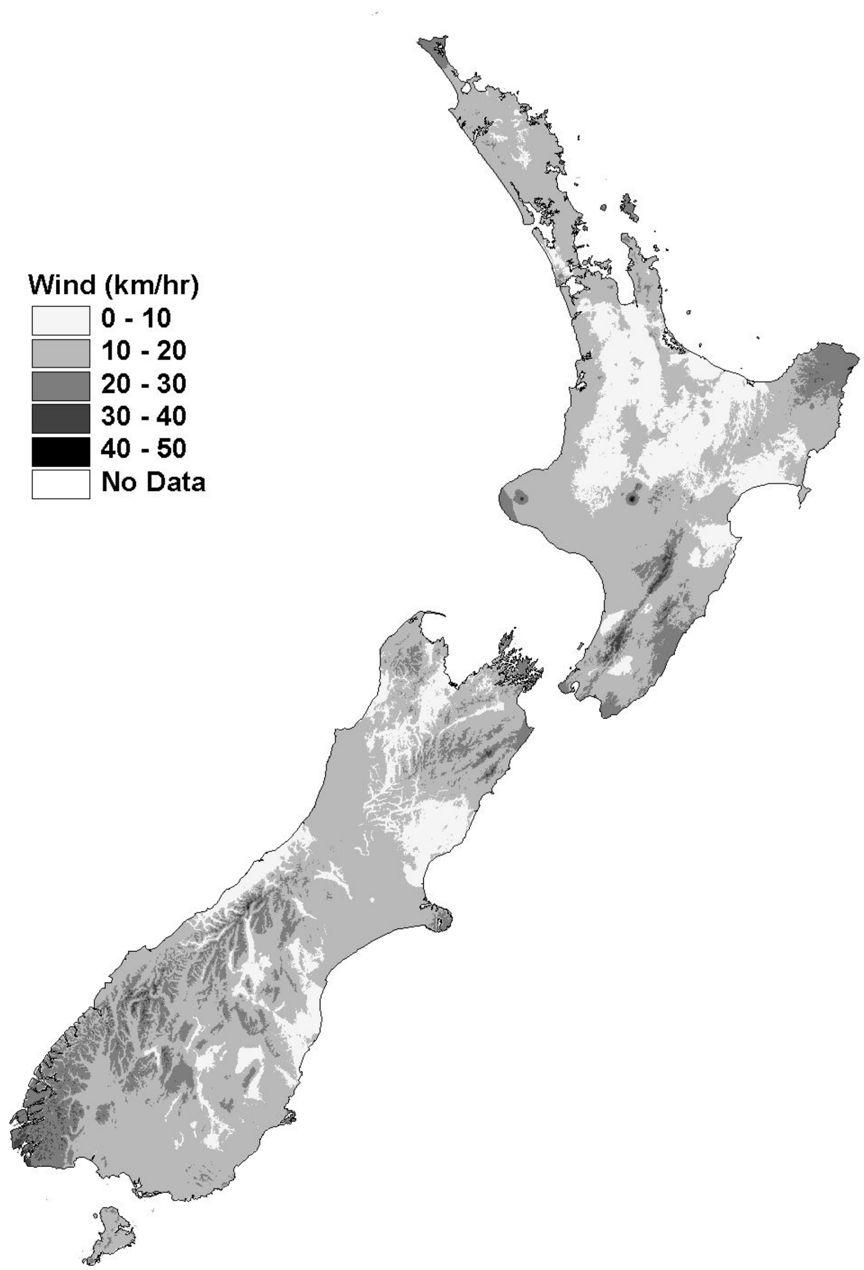

Fig. 7. Estimates, derived from the wind surface, of mean annual wind speed for points on a 1 km grid across New Zealand.

5. Acknowledgments

We are indebted to Anna Clarkson who earned herself a bottle of Baileys Irish Cream by her unerring accuracy in entering the climate station data to which the surfaces were fitted. David Giltrap generously provided data describing variation in topographic protection across New Zealand, and Mike Hutchinson assisted with a number of technical queries and checked the final surface summaries. Jake Overton provided helpful comment on an earlier draft of this documentation.

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