NIWA
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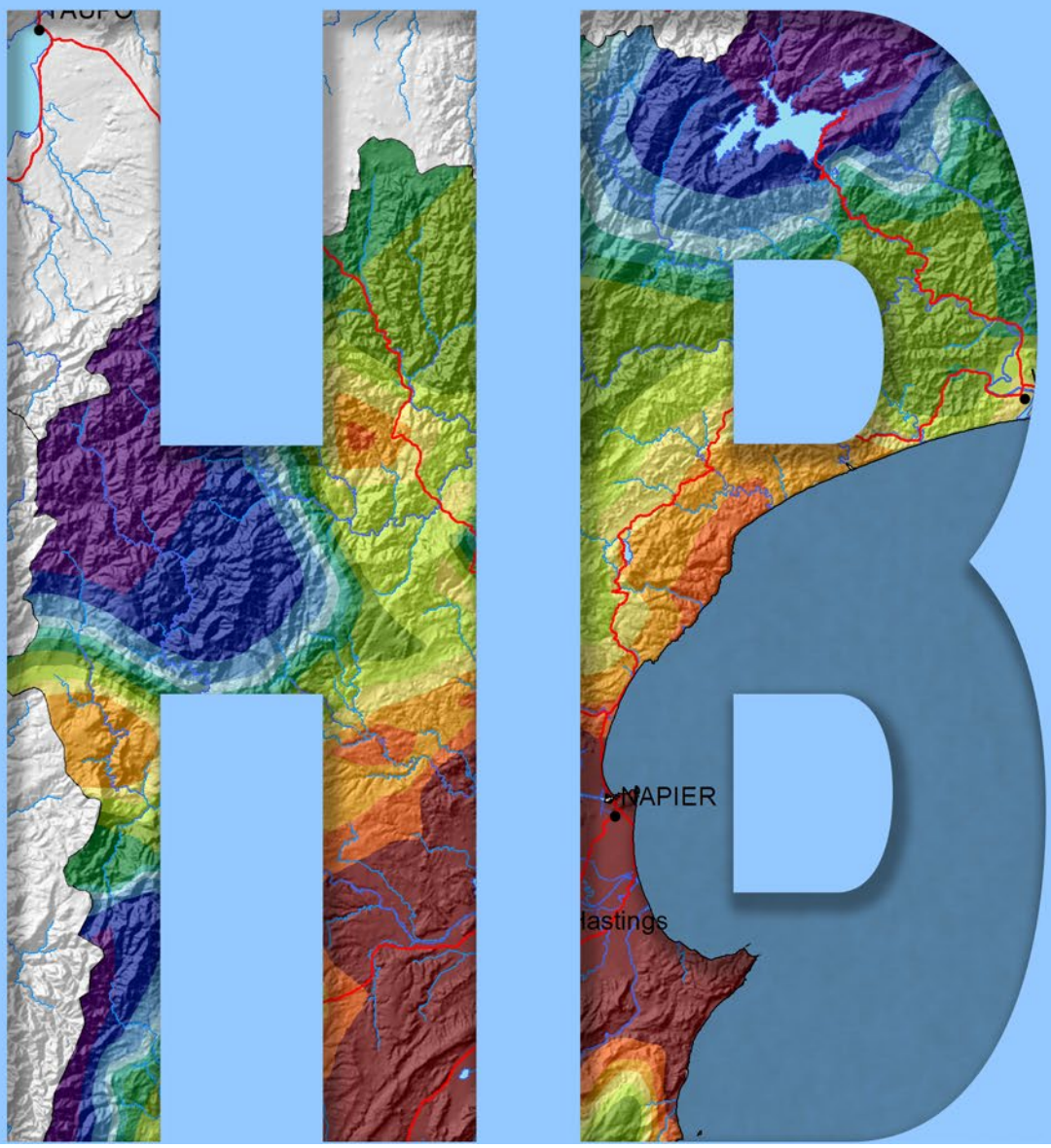
THE CLIMATE AND WEATHER OF HAWKE'S BAY

3rd edition

P.R. Chappell



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Note to Third Edition

This publication replaces the second edition of the New Zealand Meteorological Service Miscellaneous Publication 115 (5), written in 1987 by C.S. Thompson. It was considered necessary to update the second edition, incorporating more recent data and updated methods of climatological variable calculation.

THE CLIMATE AND WEATHER OF HAWKE'S BAY

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CONTENTS

SUMMARY 6

INTRODUCTION 7

TYPICAL WEATHER SITUATIONS IN HAWKE'S BAY 9

CLIMATIC ELEMENTS 15

- Wind 15
- Rainfall 18
  - Rainfall distribution 18
  - Rainfall frequency and intensity 21
  - Recent extreme events in Hawke's Bay 22
  - Periods of low rainfall 23
- Temperature 24
  - Sea surface temperature 24
  - Air temperature 24
  - Earth Temperatures 27
  - Frosts 28
- Sunshine and Solar Radiation 29
  - Sunshine 29
  - Solar radiation 30
  - UV (Ultra-violet radiation) 30
- Fog 31
- Severe convective storms 31
  - Thunderstorms 31
  - Hail 31
  - Tornadoes 31
  - Snow 32
- Sea swell and waves 32

DERIVED CLIMATOLOGICAL PARAMETERS 35

- Vapour pressure and relative humidity 35
- Evapotranspiration and soil water balance 36
- Drought in Hawke's Bay 38
- Degree-day totals 39

ACKNOWLEDGEMENTS 42

REFERENCES 42

SUMMARY

The climate of Hawke's Bay is influenced largely by the orography and the airstreams crossing New Zealand. It is a region of highly variable and sporadic rainfall, and large and occasionally sudden temperature variations. Hawke's Bay is a sunny region with most areas having over 2000 hours per year.

Hawke's Bay is less windy than many other coastal areas of New Zealand, experiencing a high frequency of very light winds. Consequently, a large number of frosts occur during the cooler months of the year. Much of the rain in Hawke's Bay occurs when the wind directions are predominantly easterly or southerly. Rainfall is extremely variable in spring and summer when westerly winds prevail over the country. In most years insufficient rainfall (dry spells) results in a total depletion of soil moisture to the extent that plant growth ceases. The high country areas of Hawke's Bay are exposed and gales occur frequently. Showers of snow are frequent during the winter months in cold southerly conditions.

INTRODUCTION

Hawke's Bay is situated on the eastern side of the North Island of New Zealand and derives its name from the large semi-circular Hawke Bay. Hawke's Bay extends from Cape Turnagain in the south to Mahia Peninsula in the northeast. In this publication Hawke's Bay is defined as the area shown in Figure 1, which is the region administered by Hawke's Bay Regional Council. Apart from the relatively flat Heretaunga Plains in which lie the principal urban areas of Napier and Hastings, and an inland plain (Takapau) to its southwest, most of Hawke's Bay is rolling hill country bounded on the west by the Huiarau, Kaweka, and Ruahine Ranges. The region also includes part of Waikaremoana National Park, in the north of the region.

Agriculture is the predominant economic activity of the region. This is mostly intensive sheep and beef farming along with viticulture, market gardening, orcharding, and the processing of horticultural cash crops.

All numbers given in the following tables are calculated from the 1981-2010 normal period (a normal is an average or estimated average over a standard 30-year period), unless otherwise stated.

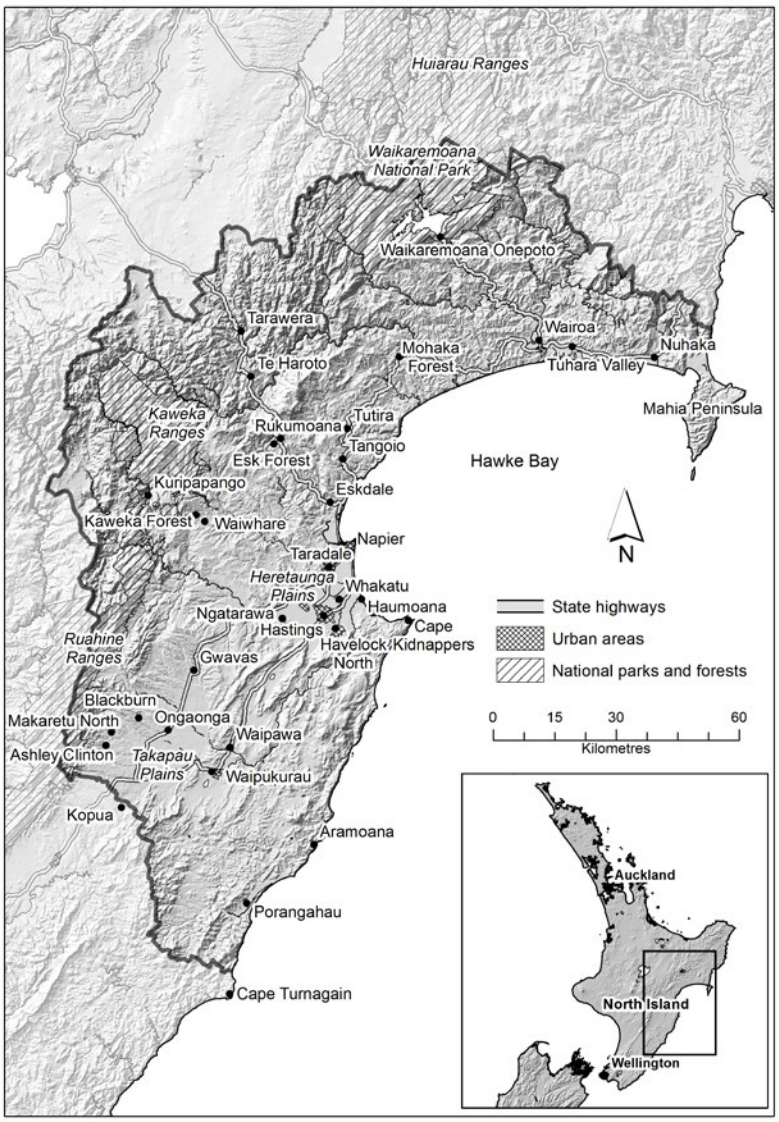


Figure 1. Map of Hawke's Bay region, with locations of places mentioned in the text, tables, and figures.

TYPICAL WEATHER SITUATIONS IN HAWKE'S BAY

A feature of the atmospheric circulation in the New Zealand region is the absence of semi-permanent anticyclones. Daily weather maps show a sequence of eastward-moving anticyclones, separated by troughs of low pressure or depressions. These large-scale synoptic features determine the broad climatic features in Hawke's Bay. The weather experienced in this region is influenced to a large extent by the mountain ranges in the west. When westerly winds blow across the region, the high country shelters the rest of Hawke's Bay and can result in high temperatures with dry conditions. In southerly and easterly situations the high country enhances precipitation as air masses are forced to ascend over the ranges. In extreme conditions heavy rain can lead to major flooding on the plains.

West to northwest airstreams

It is quite common in strong west or northwest airstreams for showers to fall on the western ranges while the rest of

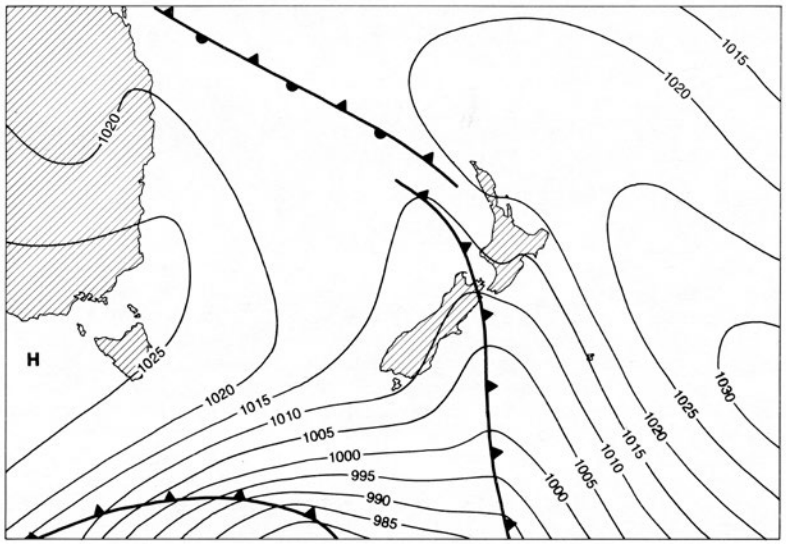


Figure 2. Mean sea level pressure analysis for 0000 hours on 29 April 1986.

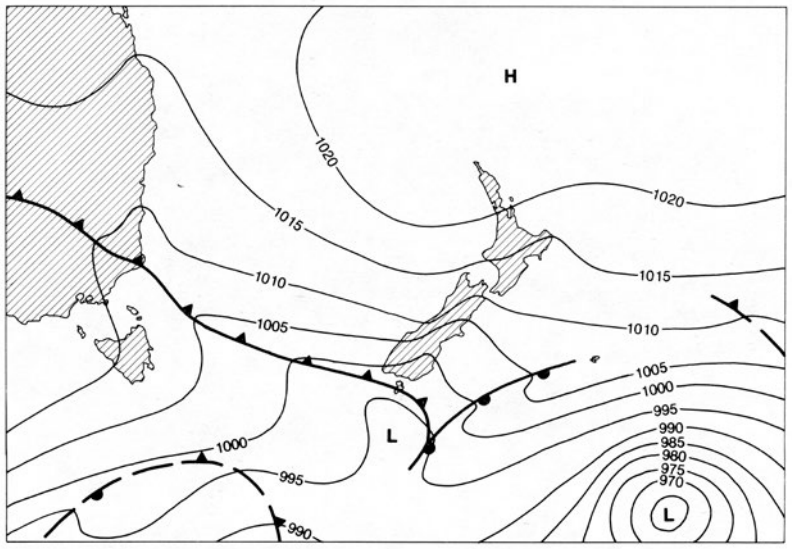


Figure 3. Mean sea level pressure analysis for 0000 hours on 3 October 1986.

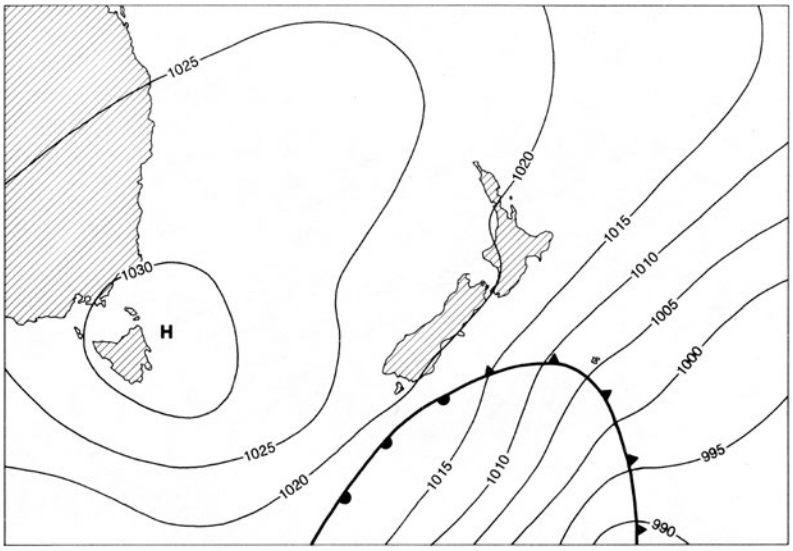


Figure 4. Mean sea level pressure analysis for 0000 hours on 9 June 1982.

Hawke's Bay experiences dry mild windy conditions. However, in situations where eastward-moving cold fronts are present between two anticyclones (Figure 2), brief periods of rain occur as the front crosses the region. The duration can vary from less than one hour to over six hours depending on the speed of the front. The amount of rainfall may also vary, from under 5 mm to over 20 mm depending on the intensity of the front. On most occasions, a rapid clearance follows and the wind will blow

from the westerly quarter. If the wind continues to blow southerly due to rising pressures over the east coast of the South Island, skies will become cloudy again accompanied by further rain and a large drop in temperature.

Figure 2 illustrates a situation where a strong northwest airstream lies over the North Island ahead of a weak cold front. The front crossed Hawke's Bay mid-morning on 29 April 1986, and was accompanied by scattered falls of rain which lasted no more than five hours. Many areas of the region recorded less than 5 mm, except further southwest outside the region where up to 10 mm fell. A southerly wind change accompanied the front but had died out by the middle of the afternoon as sea level pressures began to fall over the South Island ahead of the next cold front approaching Southland.

Westerly airstreams (Figure 3) may persist for several days, with orographic showers to the west of the main divide and continuing dry mild conditions in the east. Cloud above the Hawke's Bay and Wairarapa regions during these airstreams is generated by the forced ascent of the strong westerlies by the ranges.

South to southwest airstreams

When anticyclones or ridges of high pressure cover much of the Tasman Sea and pressures are low to the east of New Zealand, a southwest airstream tends to cover the country. This type of situation, although found all year round, is most common during winter and spring. Such occurrences usually last from one to three days, rarely longer. When an anticyclone is centred over southern New Zealand, a cold southerly airstream will flow over the North Island with showers from Cook Strait to East Cape. Southwesterly airstreams are associated with frequent showers, but if the surface wind flow

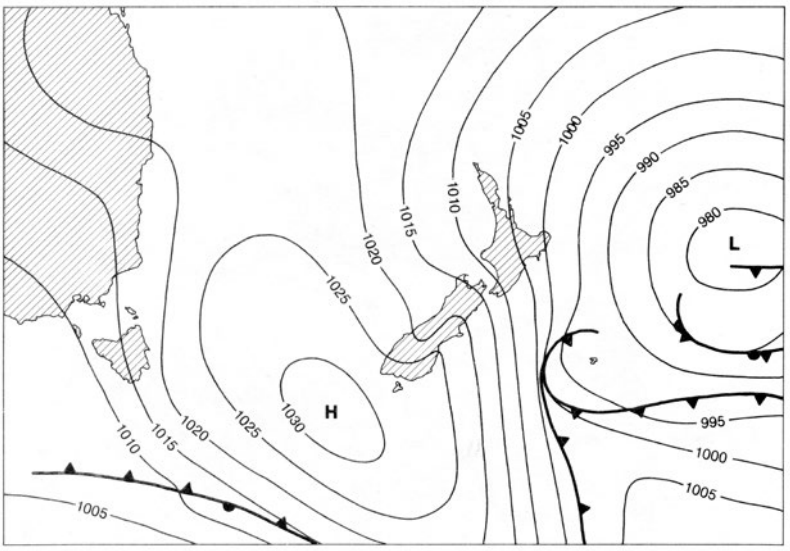


Figure 5. Mean sea level pressure analysis at 1200 hours on 2 July 1986.

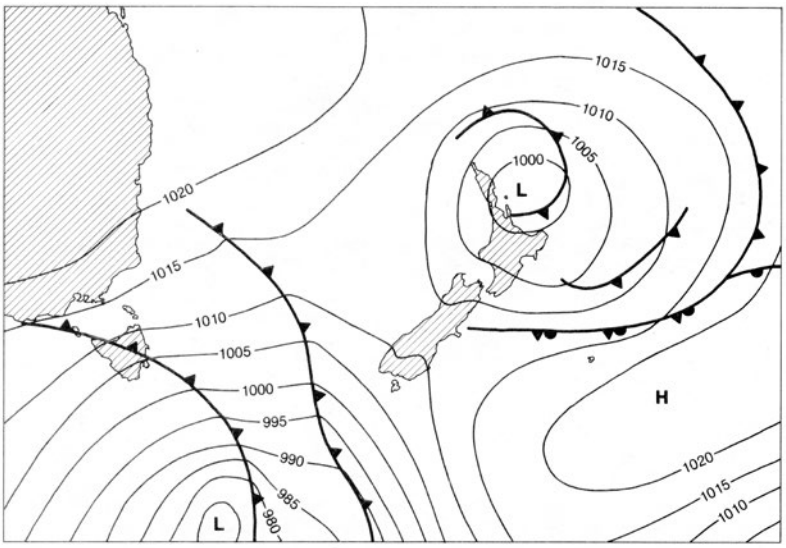


Figure 6. Mean sea level pressure analysis at 0000 hours on 22 July 1985.

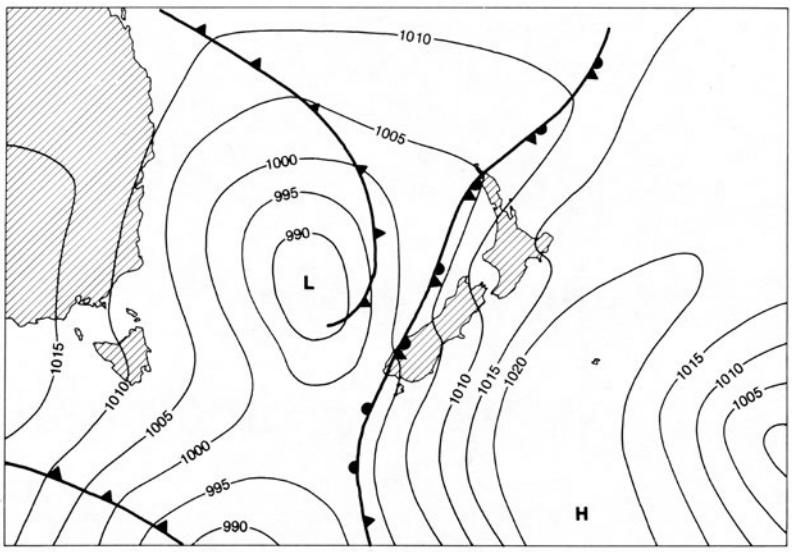


Figure 7. Mean sea level pressure analysis at 0000 hours on 21 June 1986.

is roughly parallel to the axis of New Zealand, Hawke's Bay will experience fine cool weather. Such a situation is illustrated in Figure 4. In these situations, it is common that the Tasman Sea and the oceans east of New Zealand are extensively covered by open celled cumulus cloud, but most of the North Island is cloud free being in the shadow of the South Island.

East to southeast airstreams

In Hawke's Bay, east to southeast airstreams are associated with a depression over or to the east of the North Island and an area of high pressure to the south of the country. Frequently the depressions form either in the Tasman Sea or in the tropics and then move southeast towards the North Island. Strong east or southeast winds blow across Hawke's Bay, and if any accompanying frontal zones become slow-moving heavy rain is likely. Two examples of this type of situation with strong winds and heavy rain are given in Figures 5 and 6. In both situations, many lowland areas measured over 25 mm of rain, and up to 75-90 mm in the mountainous regions. Gale force winds were also observed at Napier on 2 July 1986.

North to northeast airstreams

North to northeast airstreams are characterised by relatively mild and humid air masses which flow between a large anticyclone to the east of New Zealand and a low pressure area to the west. These situations may be slow moving when the anticyclone blocks the movement of the low pressure trough. For depressions moving southwards in the Tasman Sea, little rain falls on the eastern side of the main ranges. However, if the front is particularly active, rain falls both in the flow ahead of the front and also with the front.

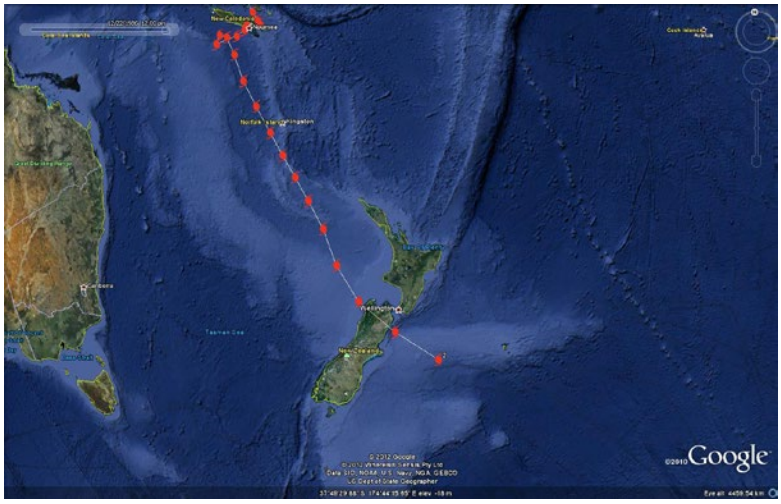


Figure 8a. Tropical cyclones which made landfall in New Zealand during December, 1970-2010. Source: Southwest Pacific Enhanced Archive of Tropical Cyclones (SPEArTC; Diamond et al., 2012).

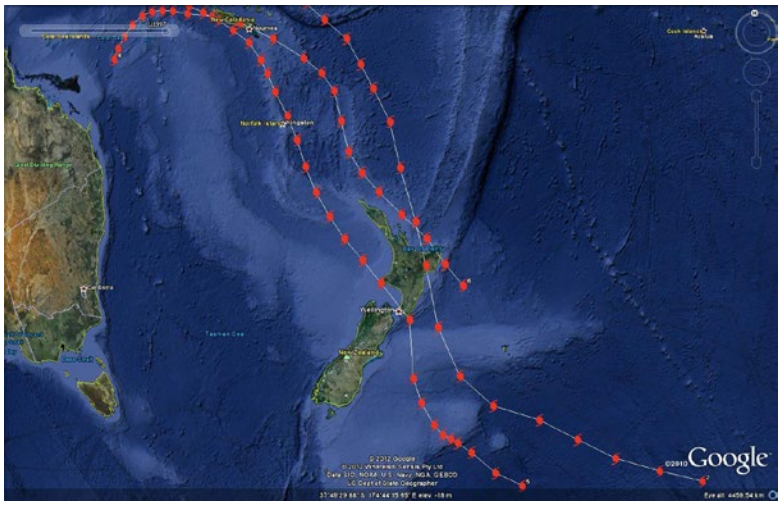


Figure 8b. Tropical cyclones which made landfall in New Zealand during January, 1970-2010. Source: SPEArTC (Diamond et al., 2012).

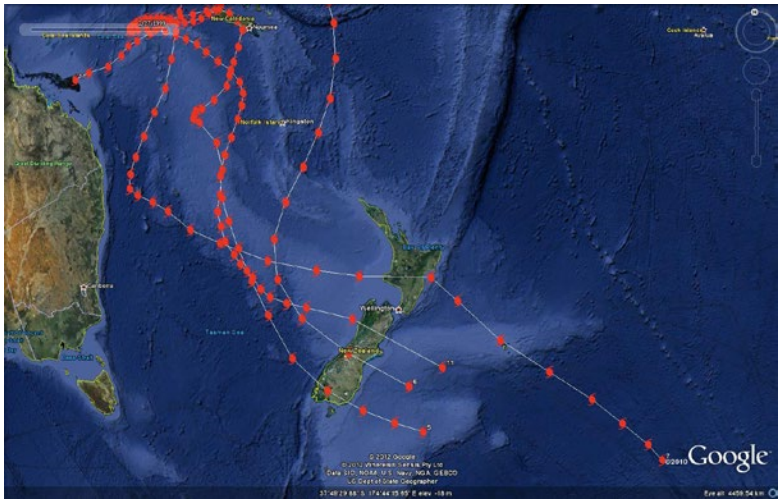


Figure 8c. Tropical cyclones which made landfall in New Zealand during February, 1970-2010. Source: SPEArTC (Diamond et al., 2012).

On 21 June 1986 (Figure 7) fresh to strong northeasterly winds and widespread light rain were observed in Hawke's Bay. An active frontal zone to the west of New Zealand crossed the North Island late in the day. It was followed by light west-north-west winds and a rapid clearance of cloud. An extensive area of low stratiform cloud was present over the seas to the east of the North Island. This phenomenon is a feature of such situations when mild humid air masses of subtropical origin are cooled by a cold sea, thus allowing the formation of stratiform cloud.

Cyclones of tropical origin

The tropical cyclone season in the southern hemisphere lasts from November to April. Originating in low latitudes within the cloud masses of the South Pacific Convergence Zone, tropical cyclones reaching northern New Zealand and still retaining true cyclonic characteristics, such as a warm core, are extremely rare. They are nevertheless accompanied by heavy rain and strong winds. Tracks of tropical cyclones which have made landfall in New Zealand between 1970 and 2010 are shown in Figure 8a-e. The passage of ex-tropical cyclone Giselle directly over Napier during the early hours of 10 April 1968 caused considerable damage to trees and buildings in Napier and Hastings. It was during this storm that the inter-island ferry Wahine sank in the entrance to Wellington harbour.

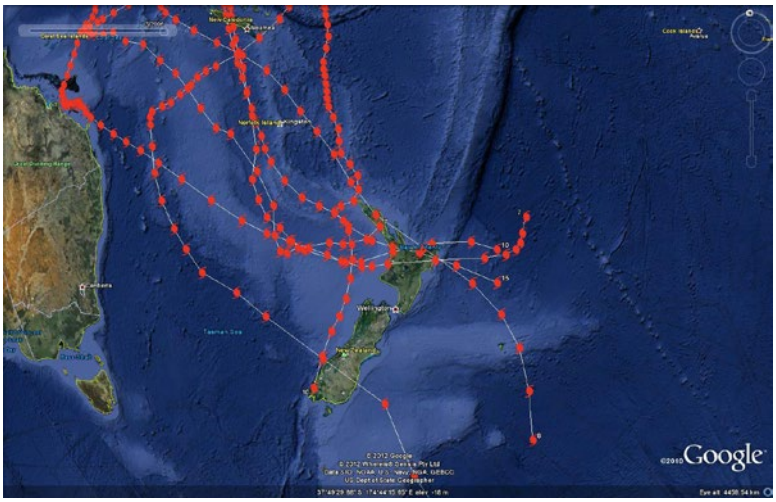


Figure 8d. Tropical cyclones which made landfall in New Zealand during March, 1970-2010. Source: SPEArTC (Diamond et al., 2012).

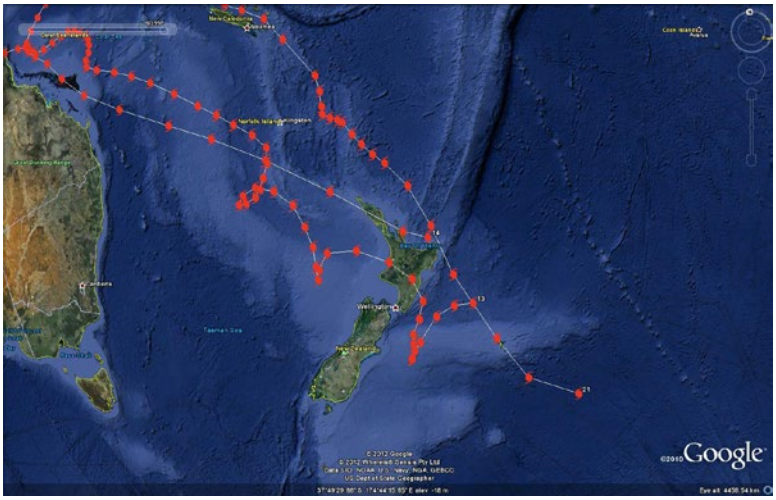


Figure 8e. Tropical cyclones which made landfall in New Zealand during April, 1970-2010. Source: SPEArTC (Diamond et al., 2012).

CLIMATIC ELEMENTS

Wind

The prevailing winds over New Zealand in the zone directly above the earth's surface are westerly, and they influence the general precipitation and temperature regimes of Hawke's Bay. Local winds in Hawke's Bay are largely influenced by the orography, and the region is less windy than many other coastal areas of New Zealand. Sheltering effects by the western ranges results in a high frequency of calm or very light winds. This effect is most pronounced at night-time and in winter under clear weather conditions. Havelock North, with its many orchards surrounded by tall shelter belts, has calm conditions most of the time. Throughout the region there is a tendency for the wind to be channelled along river valleys. Over central and southern Hawke's Bay the predominant directions are from the west or southwest along the Heretaunga and Takapau Plains. In the north the wind tends to blow most frequently from the north or northwest. Figure 9 shows mean annual wind frequencies of surface wind based on hourly observations from selected stations. Exposed sites such as Mahia have a higher percentage of strong winds than more sheltered sites, such as Whakatu.

Mean wind speed data (average wind speeds are taken over the 10 minute period preceding each hour) are available for several sites in Hawke's Bay, and these illustrate the several different wind regimes of the region (Table 1). Mahia, which is located on an exposed peninsula, is much windier throughout the year compared with Napier, which is located in the Hawke Bay embayment.

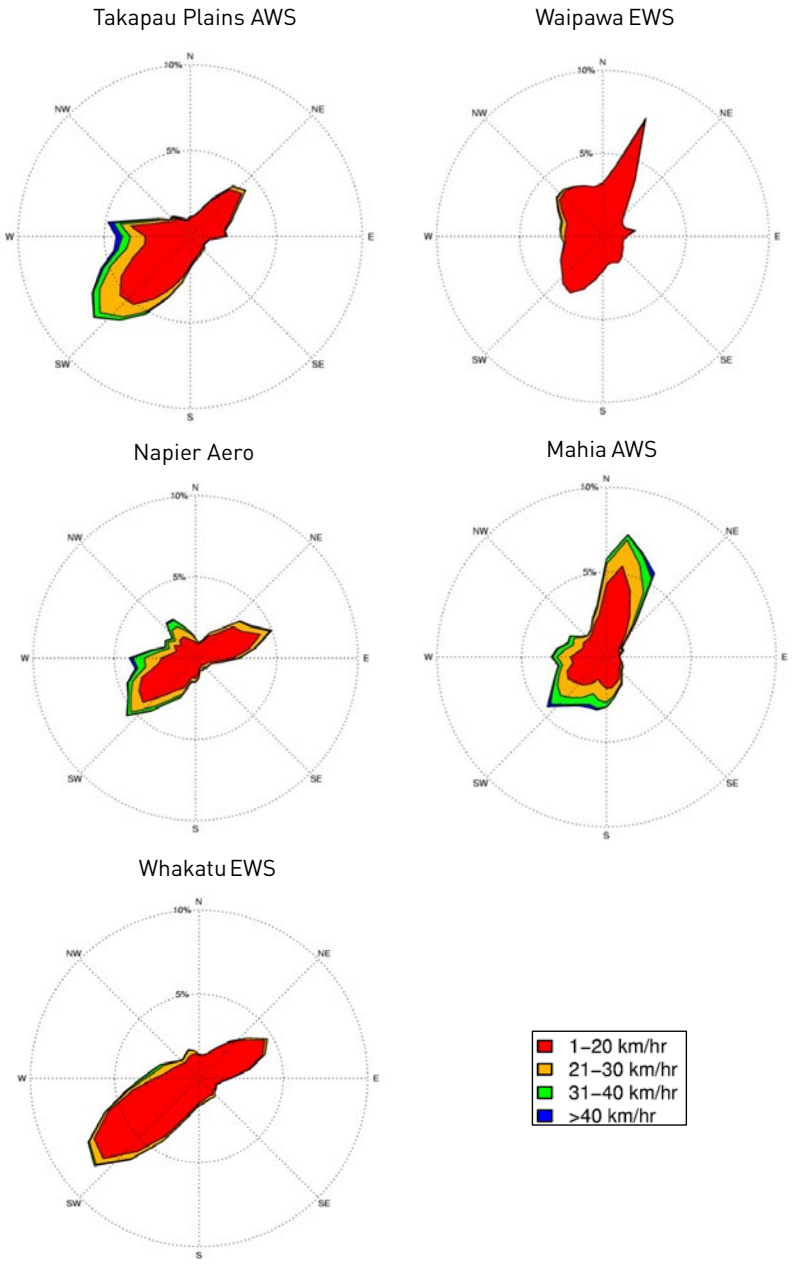


Figure 9. Mean annual wind frequencies (%) of surface wind directions from hourly observations at selected Hawke's Bay stations. The plots show the directions from which the wind blows, e.g. the dominant wind direction on the Takapau Plains is from the southwest.

Table 1. Mean monthly/annual wind speeds (km/hr) for Hawke's Bay sites, from all available data.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Mahia AWS	16.7	16.7	16.9	16.5	16.7	18.5	18.2	18.3	17.5	19.1	19.0	17.8	17.6
Napier Aero AWS	14.2	13.7	13.4	11.6	12.2	13.0	13.1	13.6	13.5	15.9	16.0	15.2	13.8
Whakatu EWS	10.8	11.7	10.7	9.2	9.8	11.1	10.8	11.7	11.6	13.0	12.5	11.9	11.2

In contrast, lighter winds are experienced at Whakatu, which is located slightly further inland, south of Napier. Note that other sites in the region do not have the minimum data requirements of 10 years of monthly data, to be able to be included in this table, hence data for only three sites are presented.

Spring is generally the windiest season throughout the region. Because of the relatively high frequency of light winds in lowland regions there is only a small seasonal variation, although winter and spring tend to be windier than other times of the year. Table 2 gives the seasonal proportion of strong and light winds as a percentage of the annual total. For example, of all strong winds recorded at Napier, 23% occurred in summer, 17% in autumn, 26% in winter and 34% in spring. In compiling this table a strong wind was defined as having a mean wind speed of at least 31 km/hr.

When pressure gradients are weak, well developed onshore sea breezes blow during the daytime in all seasons except winter. Sea breezes develop as a result of large temperature gradients between the land and sea. At times, especially during summer, the sea breeze at Hawke's Bay can penetrate inland for considerable distances up the Heretaunga and Takapau Plains. A sea breeze situation in Hawke's Bay is given in Figure 10 for noon on 31 January 1986. A sea breeze of 11 km/hr from the east had started at Napier Airport by 10 am. With clear skies and warm afternoon temperatures inland, the sea breeze blew all day reaching 37 km/hr from the north-east at 4 pm before moderating and dying out just before 11 pm.

Table 2. Seasonal percentages of strong or light winds (%) for Hawke's Bay sites, from all available data.

Location		Summer	Autumn	Winter	Spring
Mahia AWS	Strong	19	22	28	30
	Light	26	25	24	24
Napier Aero AWS	Strong	23	17	26	34
	Light	23	25	27	25
Whakatu EWS	Strong	21	14	21	44
	Light	26	24	24	25

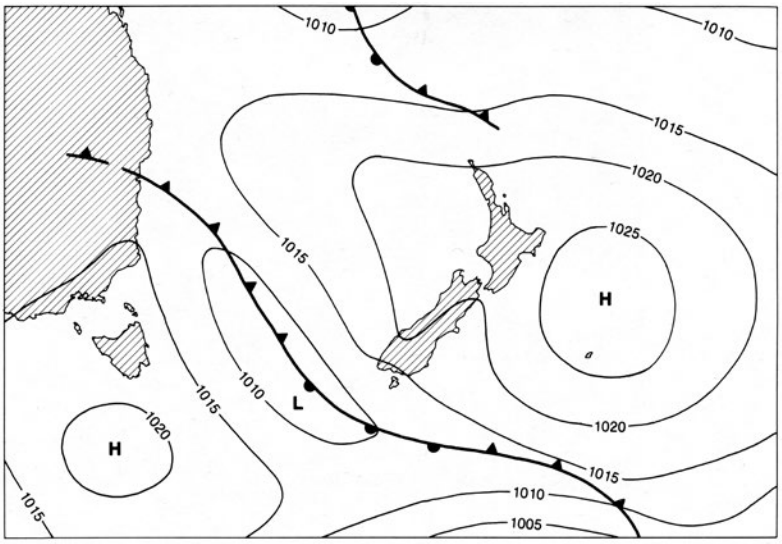


Figure 10. Mean sea level pressure analysis at 1200 on 31 January 1986.

Diurnal variation in wind speed is well-marked, with greatest wind speeds occurring in the early part of the afternoon. This is because at that time of day heating of the land surface is most intense and stronger winds aloft are brought down to ground level by turbulent mixing. Cooling at night generally restores a lighter wind regime. Table 3 gives average wind speeds at three-hourly intervals for selected stations.

High winds over 55 km/hr are relatively rare in many lowland areas, but are much more frequent in the mountain ranges and about exposed coasts such as Cape Kidnappers and the Mahia Peninsula. Such winds are recorded mostly from directions between northwest and southwest. Gusts of at least 63 km/hr are recorded at Napier on about 48 days each year, mostly from the west or northwest, and gusts over 96 km/hr occur on average one day each year (Table 4). In comparison, the more exposed site at Mahia experiences higher numbers of gust days, and Whakatu records fewer gust days than Napier.

In the mountain ranges of Hawke's Bay, high winds may occur for about 15% of the time. In strong pressure gradients, gales (i.e. mean speeds in excess of 63 km/hr) may blow for several days on end. During the periods when strong west or northwest airstreams flow across the North Island ranges, the strong turbulent winds descend to low levels and produce warm gusty and dry foehn winds.

Although gale force winds can occur in any month, they are most frequent in winter. The highest gust recorded in the region was 147 km/hr at Mahia on 15 July 1998. Maximum gusts recorded at different stations in the region are listed in Table 5.

Table 3. Average wind speed (km/hr) for selected hours.

Location	00	03	06	09	12	15	18	21
Mahia AWS	16	16	16	18	20	20	18	17
Napier Aero AWS	11	11	11	13	18	19	15	12
Whakatu EWS	9	8	8	11	15	17	13	9

Table 4. Average number of days per year with gusts exceeding 63 km/hr and 96 km/hr for selected stations.

Location	Gusts >63 km/hr	Gusts >96 km/hr
Mahia AWS	73	3
Napier Aero AWS	48	1
Whakatu EWS	26	0.3

Table 5. Highest ever recorded gusts at selected Hawke's Bay stations, from all available data.

Location	Gust (km/hr)	Direction (°)	Date
Mahia AWS	147	W	15/07/1998
Napier Aero AWS	105	W	22/10/1998
Whakatu EWS	101	WNW	13/12/2002

Rainfall

Rainfall distribution

Rainfall patterns in the region are closely related to elevation, and exposure to the predominant air flows (westerly, southwesterly, and northeasterly). The distribution of the Hawke's Bay region's median annual rainfall is shown in Figure 11. Areas with high annual rainfall over 2000 mm (Ruahine, Kaweka, and Huiarau Ranges) provide a stark contrast to areas which receive around less than 800 mm of rain per year, that is the area just north of Napier to south of Waipukurau, including the Heretaunga and Takapau Plains.

Meteorological systems bringing rain to Hawke's Bay are irregular, causing high rainfall variability both in time and space. Nearly all the rain is associated with cold fronts, and falls as showers of relatively short duration. Over 60% of the rainfall at Napier occurs when the wind is from the south or southeast, although some of the most intense falls are usually associated with northeast or easterly airstreams. In a study on rainfall and wind direction in Hawke's Bay, Coulter (1962) found that at all locations rainfall on the lowland areas was reduced in westerly-quarter winds because of sheltering by the ranges.

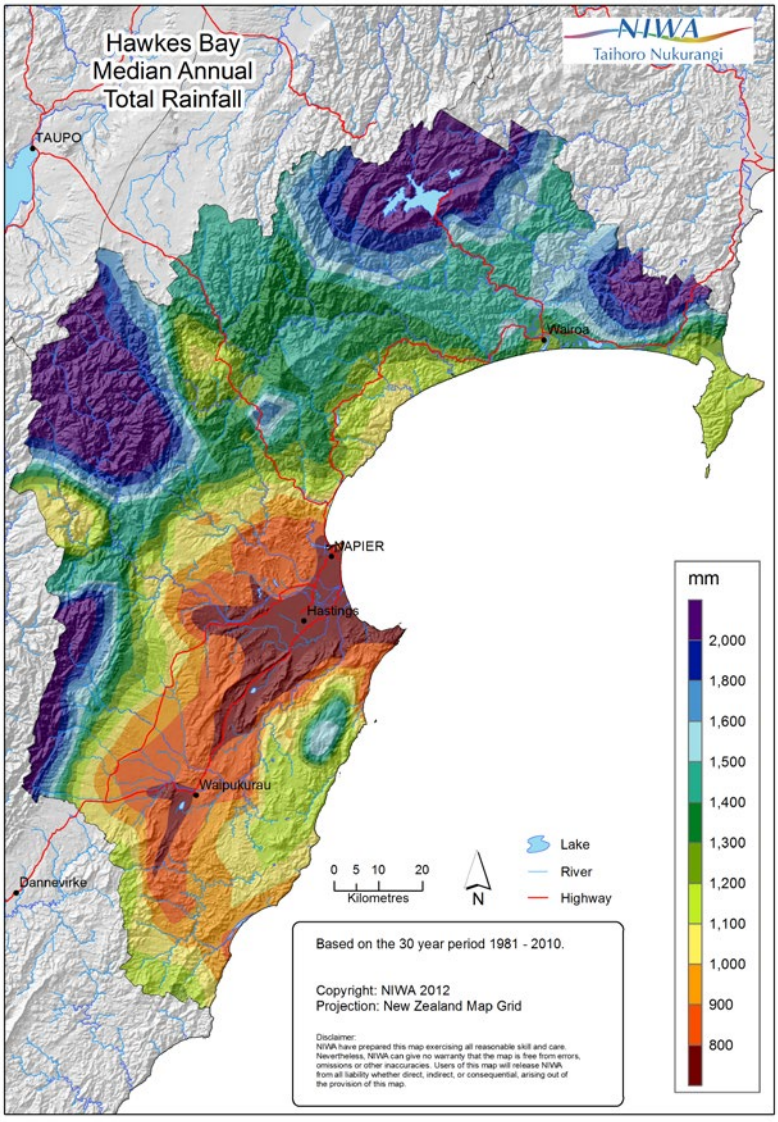


Figure 11. Hawke's Bay median annual total rainfall, 1981-2010.

Table 6. Monthly/annual rainfall normals (a; mm) and percentage of annual total for each month (b; %).

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Aramoana	62	79	83	88	96	115	121	99	77	80	63	51	1015
	6	8	8	9	9	11	12	10	8	8	6	5	
Ashley Clinton	79	114	120	107	96	102	141	101	110	104	115	86	1274
	6	9	9	8	8	8	11	8	9	8	9	7	
Blackburn	68	94	112	94	78	82	121	81	100	77	98	71	1074
	6	9	10	9	7	8	11	8	9	7	9	7	
Gwavas	73	81	85	85	74	94	130	76	76	79	70	75	998
	7	8	8	9	7	9	13	8	8	8	7	8	
Kaweka Forest	97	114	125	103	94	88	147	91	102	91	113	115	1279
	8	9	10	8	7	7	11	7	8	7	9	9	
Makaretu North	98	109	107	111	107	120	157	112	120	113	107	111	1370
	7	8	8	8	8	9	11	8	9	8	8	8	
Mohaka Forest	71	71	194	100	133	123	148	126	157	103	68	71	1365
	5	5	14	7	10	9	11	9	11	8	5	5	

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Napier Aero AWS	67	61	50	79	76	90	112	54	49	71	56	59	823
	8	7	6	10	9	11	14	7	6	9	7	7	
Napier Nelson Pk	47	54	67	68	75	82	109	61	58	60	52	54	786
	6	7	8	9	10	10	14	8	7	8	7	7	
Ngatarawa	46	55	59	59	57	72	96	54	50	52	48	59	707
	6	8	8	8	8	10	14	8	7	7	7	8	
Ongaonga	67	70	73	75	69	83	108	68	67	70	63	67	879
	8	8	8	8	8	9	12	8	8	8	7	8	
Rukumoana 2	81	122	179	115	105	111	185	108	105	114	113	83	1421
	6	9	13	8	7	8	13	8	7	8	8	6	
Tangoio	62	77	176	137	83	92	148	103	103	97	59	76	1213
	5	6	14	11	7	8	12	9	9	8	5	6	
Tuhara Valley	53	106	157	159	156	142	134	106	129	83	121	55	1402
	4	8	11	11	11	10	10	8	9	6	9	4	
Tutira	96	84	165	117	99	103	171	113	118	71	96	72	1304
	7	6	13	9	8	8	13	9	9	5	7	6	
Wairoa, North Clyde EWS	80	94	114	128	122	123	134	99	89	89	76	69	1216
	7	8	9	11	10	10	11	8	7	7	6	6	
Waiwhare	91	97	101	89	86	99	139	85	82	85	79	94	1124
	8	9	9	8	8	9	12	8	7	8	7	8	

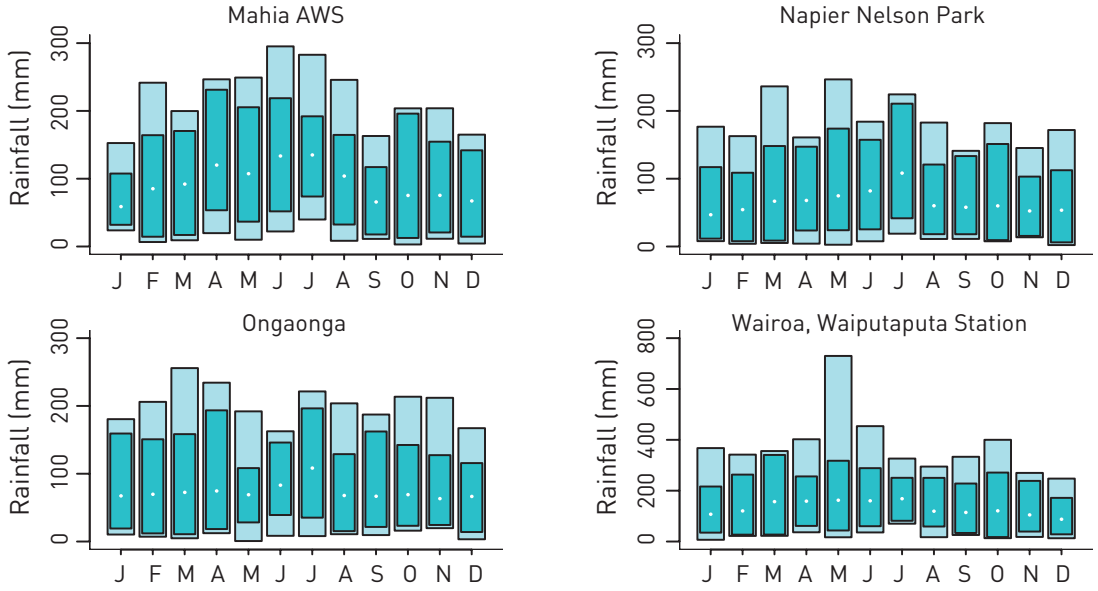
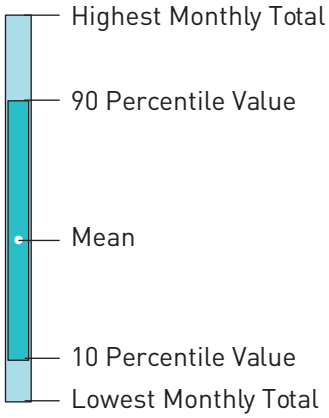


Figure 12. Monthly variation in rainfall for selected Hawke's Bay stations.



Seasonal influences on rainfall distribution are also quite well defined. Table 6 lists monthly rainfall normals and percentage of annual total for selected stations. This table shows a clearly defined winter rainfall maximum. The proportion of annual rainfall that is recorded in the winter months from June to August is fairly consistent across the Hawke's Bay region at 29%, but the proportion of rainfall recorded in the summer months from December to February ranges from 15%

at Tuhara Valley to 26% at Kaweka Forest. Throughout Hawke's Bay there is a seasonal variation with a winter maximum and a spring or early summer minimum. In spring and summer westerlies tend to predominate, and consequently the winds are warm and dry.

The distribution of monthly rainfall is shown in Figure 12. The 10th percentile, 90th percentile, and mean rainfall values for each month are shown along with maximum and minimum recorded values for several stations.

Rainfall variability over longer periods is indicated by rainfall deciles, as given in Table 7. The 10th percentile values show the accumulated rainfalls that will normally be exceeded in nine out of ten years, while the 90th percentile values indicate the accumulated falls that will normally be exceeded in only one year in ten. The table includes periods from one month to twelve months; each period over one month begins with the month stated. For example, using the table for Napier, for three months it can be seen that in the three month period beginning in April, 92 mm or more of rainfall can be expected in nine years in ten, while a total of 342 mm or more should occur in only one year in ten.

Table 7. Rainfall deciles for consecutive months.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Napier Nelson Park												
1 month												
10th	12	8	9	24	24	25	42	18	18	9	16	6
90th	117	109	148	147	174	157	211	121	133	151	103	112
3 months												
10th	75	60	77	92	117	132	126	73	85	87	64	50
90th	290	289	344	342	394	388	329	272	283	263	266	266
6 months												
10th	213	286	286	299	282	297	265	172	208	171	180	218
90th	570	596	633	602	651	585	506	510	509	448	469	518
12 months												
10th	548	576	559	523	554	611	555	570	533	512	528	507
90th	997	986	949	973	992	1034	1001	955	992	988	1012	973
Ongaonga												
1 month												
10th	19	12	11	18	28	39	35	15	22	23	24	14
90th	159	151	158	193	108	146	196	129	162	142	127	116
3 months												
10th	82	85	104	137	141	172	137	87	120	130	98	98
90th	340	383	377	339	363	366	338	329	317	306	319	325
6 months												
10th	281	345	341	345	293	353	320	265	265	243	248	269
90th	586	620	609	591	639	577	545	594	648	601	583	563
12 months												
10th	666	704	650	685	701	665	639	674	680	664	691	682
90th	1030	1032	1122	1083	1076	1051	1053	1077	1052	1068	1037	1016
Wairoa, North Clyde EWS												
1 month												
10th	32	23	18	47	32	54	73	24	23	14	20	14
90th	254	204	242	250	225	214	197	209	170	264	176	162
3 months												
10th	118	151	103	207	252	215	161	149	118	148	82	76
90th	516	527	514	526	540	610	543	535	492	439	368	409
6 months												
10th	446	506	494	461	471	442	366	252	312	287	153	148
90th	960	970	1006	957	1059	1020	867	828	891	865	898	893
12 months												
10th	944	893	917	907	992	991	1041	938	-	785	1051	1004
90th	1779	1691	1681	1724	1714	1591	1560	1605	-	1769	1853	1855

Rainfall frequency and intensity

Rain day frequency increases towards the high country, with over 160 days in the foothills of the ranges. The frequency of rain days is greatest during winter months (about 30% of total) and least in summer (20% of total). Rain is frequently heavier and more intense in the high country than elsewhere. Napier receives heavy rains (over 25 mm) on about seven days per year, whereas Kaweka Forest records 13 days per year with rainfall totals over 25mm.

The average number of days each year on which 0.1 mm or more of rain is recorded varies from around 125 days around Napier and the Heretaunga Plains, to over 160 days in the south of the region (Ashley Clinton and Blackburn). The Heretaunga Plains also generally exhibit the lowest number of wet days in the region, with less than 90 wet days recorded there on average, compared with 137 in Ashley Clinton and Makaretu North). The 0.1 mm rain days and 1 mm wet days show similar geographic variability. Table 8 lists the average number of days per month with 0.1 mm and 1 mm of rain for selected stations.

Heavy rainfalls can occur in Hawke's Bay with southerly and easterly flows, as well as when ex-tropical depressions pass near the region. Intense rainfalls also occur with thunderstorms. In Table 9, maximum short period rainfalls for periods of 10 minutes to 72 hours with calculated return periods are given for several stations. Also listed in this table are the maximum rainfalls expected in 2, 5, 10, 20, and 50 years. Depth-duration frequency tables for Hawke's Bay locations are available from NIWA's High Intensity Rainfall Design System (HIRDS). HIRDS uses the index-frequency method to calculate rainfall return periods. For more information on methods and to use the tool, see www.hirds.niwa.co.nz.

Table 8. Average monthly rain days and wet days for Hawke's Bay region; a: 0.1 mm rain day, b: 1 mm wet day.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Aramoana	a	8	7	9	10	11	12	13	12	10	10	9	7	119
	b	6	6	8	8	10	11	11	11	9	9	7	6	102
Ashley Clinton	a	12	11	13	13	15	16	17	18	16	16	15	13	176
	b	9	9	10	10	11	13	13	14	13	13	12	10	137
Blackburn	a	12	11	13	13	14	15	16	16	17	15	13	13	167
	b	9	8	10	10	10	10	12	12	12	10	10	9	123
Gwavas	a	9	9	10	10	11	12	13	12	11	11	10	9	126
	b	7	7	8	8	9	10	11	10	9	9	8	8	104
Kaweka Forest	a	11	11	12	12	13	12	14	14	13	13	13	11	150
	b	9	9	9	10	10	10	11	11	10	10	10	9	119
Makaretu North	a	12	11	13	13	13	12	15	15	15	14	13	13	159
	b	10	9	11	10	11	11	13	13	13	12	12	11	137
Napier Aero AWS	a	9	9	10	10	11	12	13	11	11	11	9	10	125
	b	7	6	7	7	7	8	9	7	7	8	6	7	87
Napier Nelson Pk	a	8	8	10	10	11	12	13	12	11	11	9	9	124
	b	6	6	7	7	8	9	9	8	7	8	6	7	88
Ngatarawa	a	8	8	9	9	11	13	13	13	11	10	9	10	127
	b	6	6	7	7	8	9	9	8	8	7	7	7	89
Ongaonga	a	9	9	10	10	12	13	14	13	13	12	11	10	134
	b	7	7	8	8	9	10	11	10	9	9	8	8	103
Rukumoana 2	a	9	9	10	10	10	13	12	12	11	11	10	9	127
	b	8	9	9	9	9	11	10	11	10	10	9	8	113
Wairoa, North Clyde EWS	a	12	11	12	14	14	15	17	15	13	13	12	12	159
	b	8	8	9	10	10	11	13	10	9	8	9	8	112
Waiwhare	a	9	9	9	9	10	11	10	11	11	11	10	10	120
	b	8	8	8	8	8	10	9	9	9	9	8	8	102

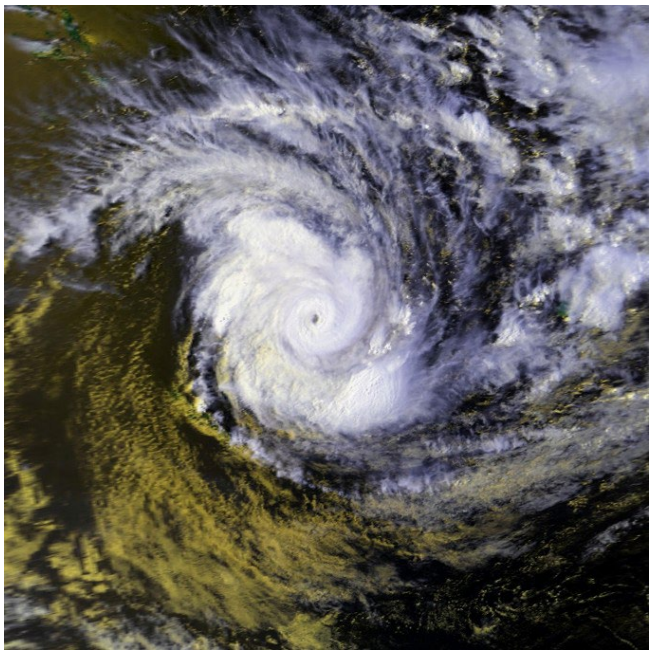
Table 9. Maximum recorded short period rainfalls and calculated return periods from HIRDS.

Location		10min	20min	30min	1hr	2hrs	6hrs	12hrs	24hrs	48hrs	72hrs
Napier Nelson Park	a	21	41	52	65	68	69	69	103	118	142
	b	100+	100+	100+	100+	100+	17	5	7	4	5
	c	5	8	10	15	21	37	52	74	93	106
	d	7	10	13	21	29	50	70	99	123	140
	e	9	13	17	26	36	61	85	119	149	169
	f	11	16	21	32	44	74	103	143	178	203
	g	14	21	27	42	57	95	131	180	225	256
Waipukurau Aero	a	16	21	23	25	39	48	64	110	142	153
	b	29	20	29	5	11	5	7	27	25	18
	c	8	11	13	18	24	37	49	65	84	97
	d	10	14	17	24	31	47	62	80	103	119
	e	12	17	21	30	38	56	72	92	118	137
	f	15	21	25	36	45	65	83	104	135	156
	g	19	27	32	46	57	80	99	124	159	185
Wairoa, North Clyde EWS	a	11.6	17.4	23.3	39.1	70.6	126.8	175.7	213.5	235.5	241.7
	b	13	14	17	29	82	100+	96	52		
	c	7	10	13	19	27	47	66	93	115	130
	d	9	14	17	25	35	61	86	121	149	169
	e	11	16	20	30	42	73	102	144	178	201
	f	13	19	24	36	50	86	121	170	210	238
	g	16	24	30	45	63	107	151	211	261	295

a: highest fall recorded (mm)
b: calculated return period of a (years)
c: max fall calculated with ARI 2 years (mm)
d: max fall calculated with ARI 5 years (mm)
e: max fall calculated with ARI 10 years (mm)
f: max fall calculated with ARI 20 years (mm)
g: max fall calculated with ARI 50 years (mm)

Recent extreme events in Hawke's Bay

Hawke's Bay has experienced numerous extreme weather events, with significant damage and disruption caused by flooding and high winds. The events listed below are some of the most severe events to have affected the Hawke's Bay region between 1980 and 2013.



6-10 March 1988: Ex-tropical cyclone Bola affected most regions in the North Island, including Hawke's Bay, bringing widespread damage with combinations of heavy rain, flooding, high winds, and heavy seas. In the Hawke's Bay region, two people drowned during the storm. A Civil Defence Emergency (CDE) was in place in different parts of the region from the 8th to the 17th. Significant portions of farmland were affected by flooding, river erosion, and landslides/gullies. State Highway (SH) 2 between Wairoa and Napier was blocked and damaged by flooding and slips. Wairoa's main bridge collapsed, splitting the town in two and destroying the town's water supply. Many roads and

bridges in the area were impassable, and hundreds of people were evacuated due to flooding.

1-3 June 1997: A deep low pressure system moved down the North Island and stalled near Mahia Peninsula. A very strong southeast flow developed due to a ridge of high pressure over southern New Zealand, which caused gales and heavy swells in the Hawke's Bay. Heavy rain caused flooding and slips in the region, closing SH 2 between Wairoa and Napier. There were numerous power outages in the region, and a CDE was declared for Northern Hawke's Bay on the 2nd and 3rd. All schools in that part of the region were closed. High winds felled trees, downing power lines, and roofs were lifted. 166 people were evacuated in Nuhaka where flash flooding occurred.

7-10 December 2001: Thunderstorms brought heavy rain and flooding to the Hawke's Bay region on the 9th. It was estimated to be a 100-year rainfall event in Napier and Hastings city centres. The rain caused damage to apricot crops, roofs, and some shop stock. Urban stormwater drains were overwhelmed by the rain and there was widespread surface flooding in central Napier, Hastings, and Havelock North. A roof of a department store partly collapsed, damaging hundreds of thousands of dollars' worth of stock.

17-24 June 2006: A depression lay to the northeast of the North Island, causing a very strong, cold southeast flow over the Hawke's Bay region. On the 18th, heavy snow fell to 500 m, causing hundreds of motorists to be stranded. Numerous state highways in the region were closed, with SH 5 from Taupo to Eskdale covered with snow 50 cm deep. There were numerous power cuts to homes and farms in the high country. Heavy rain also caused slips which closed some roads.

29 July-1 August 2008: This storm affected the country only a few days after another intense storm. In the Hawke's Bay region, surface flooding and slips forced the closure of some roads and railway lines. Residents in central Hawke's Bay were told to boil their drinking water for a week due to contamination fears caused by the flooding. High winds closed the Napier-Taihape Road, and caused tree fall and building damage. Some schools were also closed due to the flooding. Numerous beachfront houses at Haumoana were damaged by high seas.

24-31 May 2010: A front caused heavy rain and high seas in the Hawke's Bay region. The shoreline at Te Awanga was undermined and the motor camp had to relocate some cabins further inland. Streets were flooded in suburban areas on the Heretaunga Plains, and some roads were closed. In central Napier, slips caused some homes to be evacuated.

Periods of low rainfall

Periods of fifteen days or longer with less than 1 mm of rain on any day are referred to as 'dry spells'. Dry spells are common in Hawke's Bay during late spring, summer, and early autumn. There is an average of 3.5 such periods each year in Napier, 2.6 in Ongaonga, and 1.7 in Wairoa. The average duration of a dry spell is about 19 days. The longest recent dry spell between three key sites in Hawke's Bay (Napier Nelson Park, Wairoa Waiputaputa Station, and Ongaonga) was 40 days recorded in Napier, from 4 April to 13 May 1986. During this dry spell, 20 consecutive days were without any rain. The longest recent dry spell in in Ongaonga was also 40 days, during both 2 May 2007 and 10 June 2007 and 7 February 2013 to 18 March 2013 (28 and 26 consecutive dry days during these periods, respectively). In Wairoa, the longest recent dry spell was 27 days from 3 to 29 November 1994, of which all days were without any rain.

Some long dry spells are interspersed with only a few days where more than 1 mm of rain fell on each day. For example, from 4 February 1989 there was a 33-day dry spell, followed by one day with 2.7 mm of rain, followed by another 33-day dry spell, followed by one day with 1.5 mm of rain, which was followed by a 17-day dry spell. The rain on the intervening days was very minimal, and this 83-day period recorded only 9.4 mm of rain.

Temperature

Sea surface temperature

Monthly mean sea surface temperature off the coast of Hawke's Bay is compared with mean air temperature for Napier in Figure 13. There is about a four week lag between the minima of land and sea temperatures, with air temperatures being cooler than sea surface temperatures from March to October. Figure 14 shows the mean sea surface temperatures for the New Zealand region for February and August, which are the warmest and coolest months with respect to sea surface temperatures.

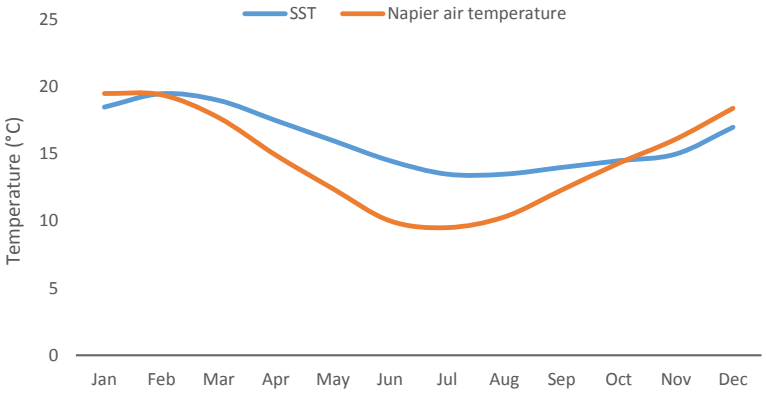


Figure 13. Mean monthly land (Napier Nelson Park) and sea surface temperatures (off the coast of Hawke's Bay).

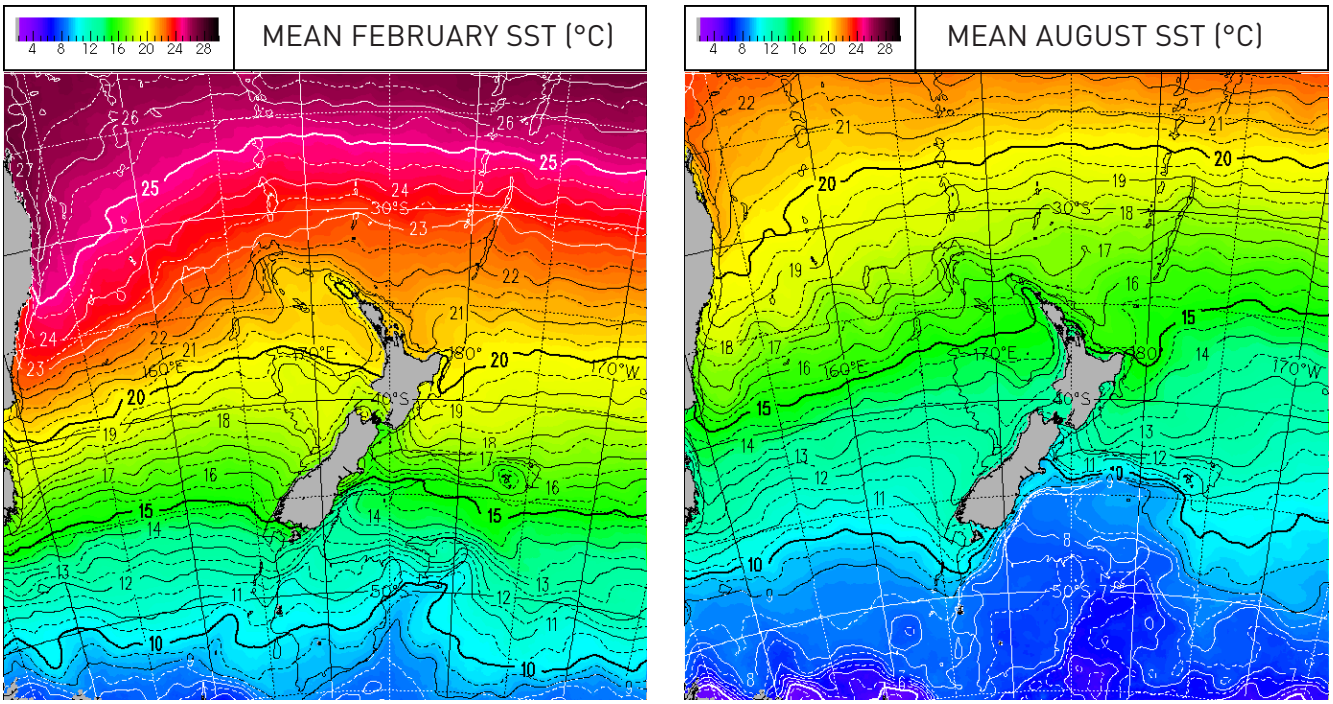
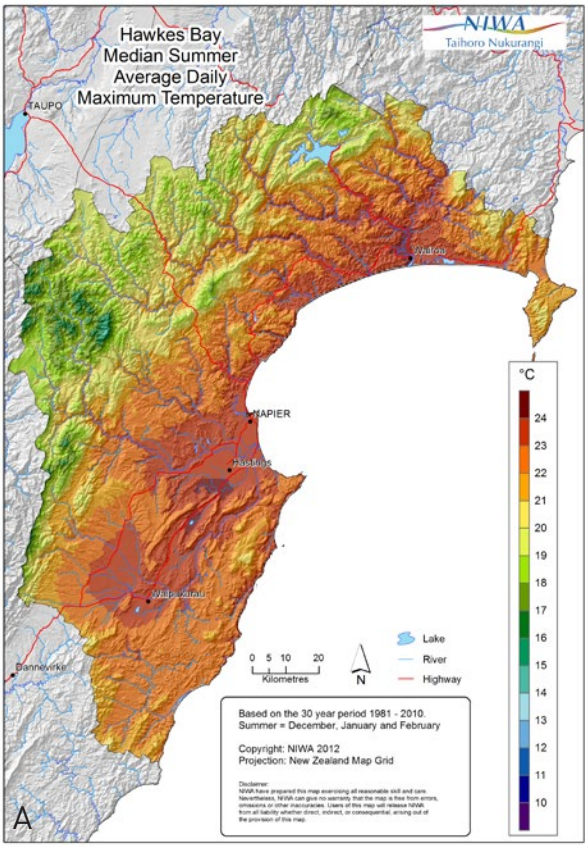


Figure 14. Monthly mean sea surface temperatures (°C) for: a) February; b) August, based on the years 1993–2002. Source: NIWA SST Archive, Uddstrom and Oien (1999).

Air temperature

In general, the Heretaunga and Takapau Plains experience warm afternoon temperatures of at least 23°C in summer (Figure 15a), and cold winter night temperatures of 3-5°C (Figure 15b). Along the coast, maximum temperatures are higher than in the hill country. Minimum temperatures are also warmer than further inland due to the modifying influences of Hawke Bay and the Pacific Ocean. Figure 16 shows that median annual average temperature in the Hawke's Bay region varies with elevation. Low-lying areas around the coast and Heretaunga Plains have a median annual temperature of around 13.5°C, whereas the inland ranges experience median annual temperatures of about 8°C. Air temperatures decrease with height above sea level by about 0.6°C for each 100 m increase in elevation. In elevated areas, the cooler conditions mean that temperatures will often fall below freezing, especially during the winter. Further, the daily variation in temperature decreases as the altitude increases. Figure 17 gives the monthly

temperature regime (highest recorded, mean monthly maximum, mean daily maximum, mean, mean daily minimum, mean monthly minimum, and lowest recorded) for selected sites in Hawke's Bay.



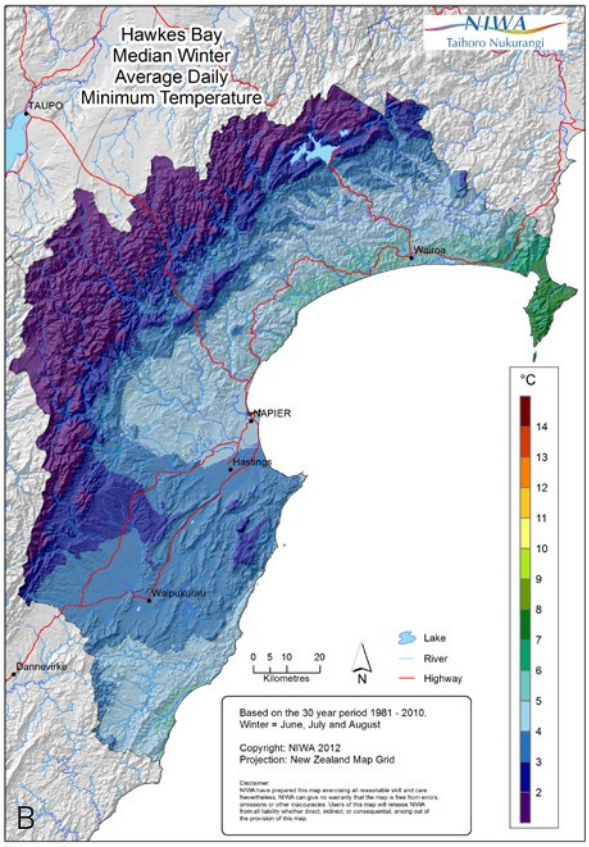


Figure 15. a) Left: Hawke's Bay median summer average daily maximum temperature; b) Right: Hawke's Bay median winter average daily minimum temperature.

Hawke's Bay, like other regions east of the main ranges, can experience sudden and large temperature changes (Figure 18). Daily temperature ranges are larger than are found in western areas of New Zealand (Table 10). The daily range of temperature, i.e. the difference between the maximum and the minimum, is smaller at the coast (e.g. Napier and Wairoa) than in sheltered inland areas (e.g. Waipukurau). However, in the ranges the daily variation is also influenced by cloudiness and elevation; the higher the elevation and cloudier the conditions, the smaller the temperature range (e.g. Waikaremoana).

The diurnal temperature range for Napier is moderate. Table 11 and Figure 19 show mean hourly temperatures for Napier for January and July.

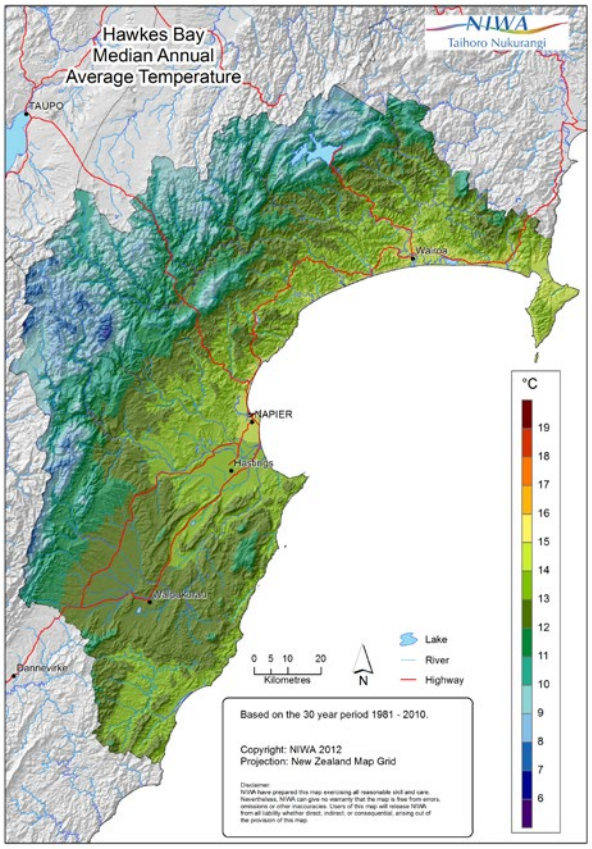


Figure 16. Hawke's Bay median annual average temperature, 1981-2010.

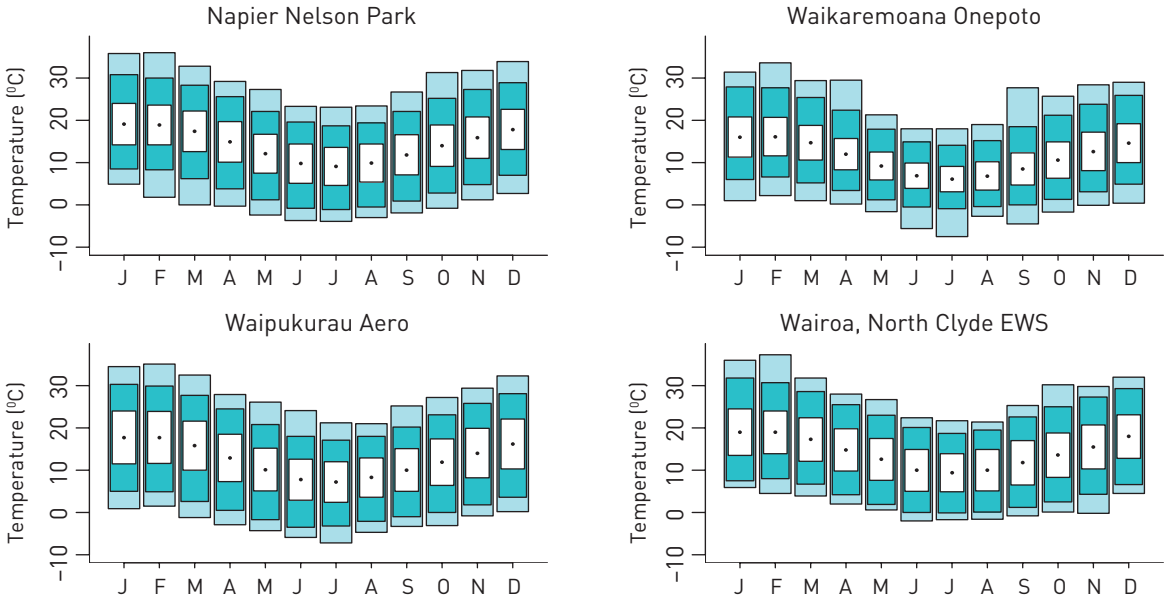
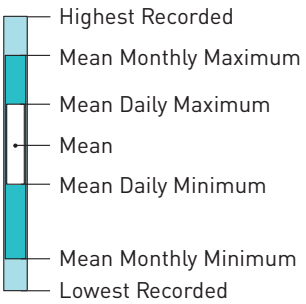


Figure 17. Monthly variation in air temperatures for selected Hawke's Bay stations.



The highest maximum temperature measured in the region to date is 38.0°C, recorded at Wairoa on 11 January 1979. The extreme minimum temperature of -11.6°C was recorded at Kuripapango in the Kaweka Range in June 1958. These extreme temperatures compare to national extremes of 42.4°C and -25.6°C.

Table 10. Average daily temperature range (Tmax - Tmin, °C) for Hawke's Bay sites.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Napier Nelson Pk	9.9	9.6	10	10	10	9.9	9.5	9.8	10	9.8	9.7	9.5	9.8
Waikaremoana Onepoto	10.2	9.7	9.2	7.6	6.7	6.4	6.1	7.1	8.1	9	9.5	9.2	8.2
Waipukurau Aero	12.6	11.8	11.2	11.3	10.4	9.9	9.4	9.5	10	10.8	11.1	11.4	10.8
Wairoa, North Clyde EWS	10.6	10.2	10.2	9.8	10	9.8	9.2	9.6	10	9.8	10.4	10.2	10

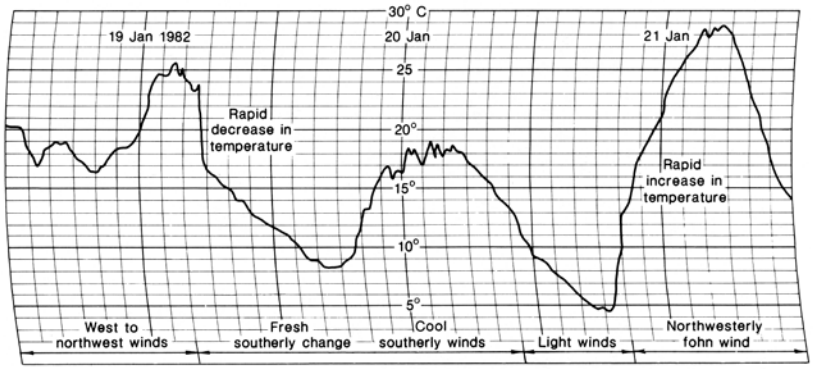


Figure 18. Thermogram trace 19-21 January 1982 at Havelock North showing large and sudden temperature changes.

With the prevailing wind direction over New Zealand being westerly, high temperatures resulting from the dry foehn winds in the lowland areas are not uncommon, and summertime temperatures frequently rise above 25°C. Wairoa has an average of 50 days each year when the maximum temperature exceeds 25°C. At Mahia, Naiper, Waipukurau, and Whakatu, the respective values are 13, 44, 40, and 34 days per year.

Table 11. Mean hourly temperatures at Napier Nelson Park for January and July.

hrs	00	01	02	03	04	05	06	07	08	09	10	11
January	16.5	16.1	15.6	15.3	15.1	14.7	15.6	17.4	19.0	20.1	20.8	21.3
July	8.1	8.1	7.9	7.5	7.5	7.5	7.1	7.3	7.5	8.6	10.5	11.7
hrs	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
January	21.6	21.8	21.9	21.7	21.5	21.1	20.5	19.7	18.7	18.1	17.5	16.9
July	12.3	12.7	12.9	12.7	12.3	11.2	10.0	9.6	9.2	8.8	8.7	8.4

Earth Temperatures

Earth (soil) temperatures are measured once daily at 9 am at several Hawke's Bay locations. Earth temperatures are measured at varying depths and are important, amongst other things, for determining the growth and development of plants. Different plants have different rooting depths and as such, earth temperatures are routinely monitored at 10, 20, 30, 50, and 100 cm depths. Table 12 lists mean monthly earth temperatures for a number of standard depths.

In the Hawke's Bay region, earth temperatures, like air temperatures, vary spatially. The sites at higher elevations, such as Waipukurau, exhibit cooler 9 am earth temperatures than sites at lower elevations, such as Napier. Figure 20 shows how earth temperatures change throughout the year at Napier, compared with air temperature. The temperature cycle for 100 cm depth is more dampened and lagged than at shallower depths.

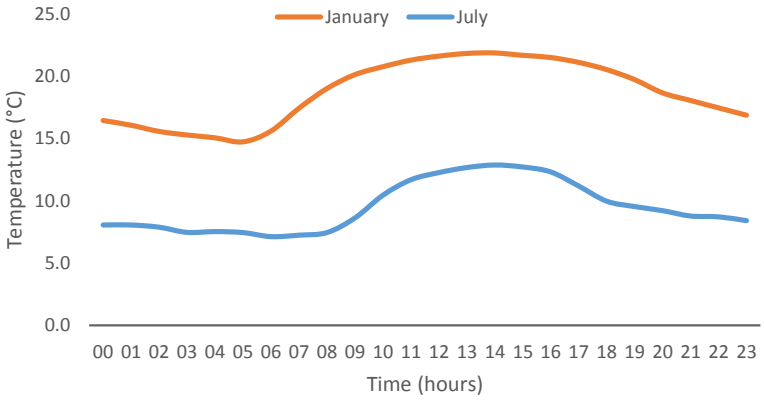


Figure 19. Mean hourly temperatures at Napier Nelson Park for January and July.

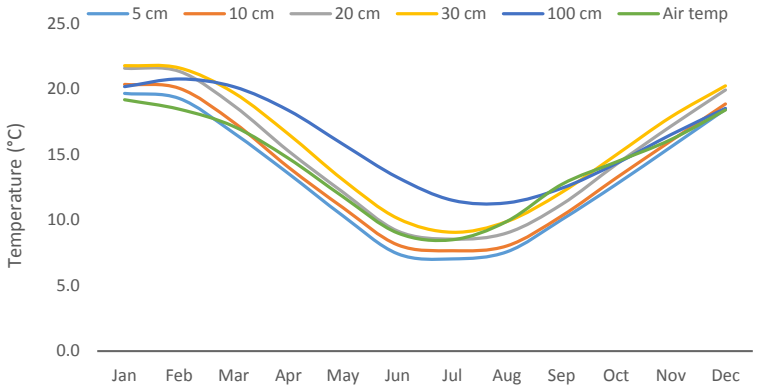


Figure 20. Average monthly 9 am earth temperatures for different depths and mean 9 am air temperature at Napier Nelson Park.

Table 12. Mean 9 am earth temperatures at different Hawke's Bay locations, with station elevations.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Havelock Nth D.S.I.R. 1 (9m)	5 cm	20.1	18.8	16.2	11.7	7.9	5.2	4.6	6.0	9.2	13.3	16.9	19.3	12.4
	10 cm	19.4	18.7	16.3	12.3	8.7	6.1	5.4	6.7	9.0	12.4	15.7	18.1	12.4
	20 cm	20.7	20.4	18.2	14.4	10.7	7.8	6.9	8.2	10.5	13.5	16.8	19.2	13.9
	30 cm	21.1	20.8	18.8	15.2	11.6	8.8	7.7	8.9	11.1	14.1	17.2	19.5	14.6
	100 cm	18.5	19.1	18.6	16.9	14.4	12.0	10.4	10.3	11.4	13.2	15.3	17.1	14.8
Napier Nelson Pk (2m)	5 cm	19.7	19.3	16.6	13.6	10.3	7.4	7.0	7.6	10.0	12.7	15.6	18.5	13.2
	10 cm	20.4	20.1	17.4	14.0	10.9	8.1	7.7	8.0	10.3	13.2	16.0	18.9	13.8
	20 cm	21.6	21.3	18.7	15.3	12.1	9.2	8.5	9.0	11.2	14.2	17.2	19.9	14.9
	30 cm	21.8	21.6	19.7	16.6	13.1	10.1	9.1	9.9	12.1	15.0	17.9	20.2	15.6
	100 cm	20.2	20.8	20.2	18.4	15.8	13.2	11.5	11.3	12.4	14.3	16.5	18.5	16.1
Waipukurau Aero (137m)	10cm	18.6	18.1	15.7	12.3	9.0	6.5	5.6	6.6	8.8	11.9	15.0	17.3	12.1
	20cm	19.3	19.2	17.0	13.7	10.5	7.9	6.9	7.7	9.7	12.3	15.2	17.6	13.1
	30cm	19.6	19.6	17.7	14.7	11.5	8.9	7.7	8.5	10.3	12.8	15.6	18.0	13.7
Whakatu (6m)	5 cm	19.4	18.1	16.1	13.0	8.7	6.0	5.5	7.0	10.5	13.5	16.1	18.9	12.7
	10 cm	19.0	18.5	16.2	12.9	9.2	6.6	6.0	7.0	9.7	12.7	15.3	18.0	12.6
	20 cm	20.3	20.2	18.1	14.9	11.2	8.6	7.7	8.6	10.8	13.8	16.5	19.0	14.1
	30 cm	20.6	20.5	18.5	15.5	12.1	9.5	8.6	9.3	11.4	14.2	16.9	19.3	14.7
	100 cm	18.4	19.0	18.6	17.0	14.8	12.5	11.0	10.8	11.7	13.4	15.3	17.0	14.9

Frosts

Frost is a local phenomenon and its frequency of occurrence can vary widely over very small areas. Areas most likely to be subjected to frost are flat areas, where air is not able to drain away on calm nights, and valleys, where cold air is likely to drift from higher areas.

There are two types of frost recorded. Air frosts occur when air temperature measured in a screen by a thermometer 1.3 m above the ground falls below 0°C. Ground frosts are recorded when the air temperature 2.5 cm above a clipped grass surface falls to -1.0°C or lower. Both types of frost are common in the Hawke's Bay region in the cooler months. Table 13 lists for selected sites the mean daily grass minimum and extreme grass minimum temperatures and the average number of days each month with ground and air frosts. Data on air temperatures (mean daily, monthly minima, and extreme minima) can be obtained from Figure 17.

Table 13. Occurrences of frosts and grass minimum temperatures in Hawke's Bay.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Kaweka Forest	a	9.4	9.3	7.5	4.9	2.7	1.7	0.5	1.1	1.7	4.0	6.0	7.9	4.7
	b	-1.2	-0.9	-2.0	-3.0	-4.0	-9.0	-8.7	-6.0	-7.6	-2.7	-2.6	-1.5	
	c	0	0	0	1	2	6	8	7	3	1	0	0	30
	d	0	0	0	0	0	1	1	1	0	0	0	0	3
Napier Nelson Pk	a	12.5	12.7	10.7	7.9	5.2	2.8	2.4	2.8	4.7	6.9	8.9	11.6	7.4
	b	2.3	0.2	-1.2	-2.5	-3.6	-7.2	-6.4	-6.4	-6.1	-3.5	-4.2	1.0	
	c	0	0	0	0	2	6	7	6	2	1	0	0	24
	d	0	0	0	0	0	2	3	2	1	0	0	0	8
Porangahau 2	a	10.5	10.6	8.9	5.8	3.6	2.1	1.3	1.7	2.9	5.0	7.4	9.3	5.7
	b	-1.1	0.6	-2.4	-3.0	-5.1	-6.9	-7.1	-6.7	-5.3	-4.5	-1.8	-2.4	
	c	0	0	0	1	4	8	10	9	6	2	0	0	40
	d	0	0	0	0	0	1	2	1	0	0	0	0	4
Waipukurau Aero	a	8.4	8.9	7.9	4.4	2.6	1.0	0.3	1.1	2.4	3.8	5.6	7.4	4.5
	b	-4.0	-1.1	-5.2	-5.0	-7.1	-12.0	-9.8	-7.6	-5.6	-5.4	-4.2	-3.4	
	c	1	0	0	2	6	10	12	10	6	4	1	1	52
	d	0	0	0	0	3	6	7	4	2	0	0	0	22
Wairoa, North Clyde EWS	a	11.2	12.0	10.0	7.4	5.0	2.4	2.6	2.4	3.8	5.6	7.9	10.3	6.7
	b	0.9	2.0	0.5	-1.7	-3.5	-5.6	-5.0	-5.2	-6.0	-3.0	-2.0	0.0	
	c	0	0	0	0	1	7	6	6	2	1	0	0	23
	d	0	0	0	0	0	1	1	1	0	0	0	0	2

a: mean daily grass minimum (°C)
b: lowest grass minimum recorded (°C)
c: average number of ground frosts per month
d: average number of air frosts per month

Sunshine and Solar Radiation

Sunshine

The extensive sheltering by the western high country from the prevailing westerly winds, makes much of Hawke's Bay a very sunny region (Figure 21). Bright sunshine hours are highest at and near the coast (more than 2200 hours recorded annually in these areas), and sunshine totals decline further inland. Increased cloudiness in the high country reduces the amount of sunshine, and less than 1850 hours per year are common in the Ruahine Ranges. Figure 22 shows the monthly mean, maximum, and minimum recorded bright sunshine hours for selected sites in Hawke's Bay.

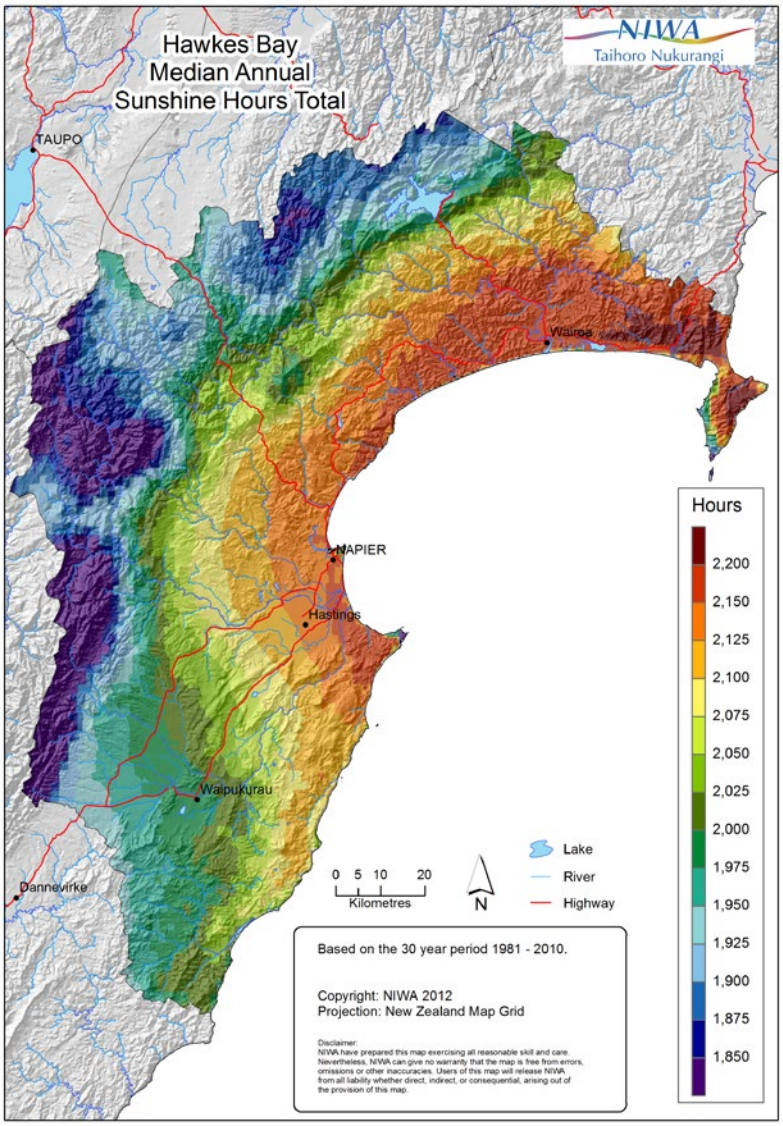


Figure 21. Median annual sunshine hours for Hawke's Bay, 1981-2010.

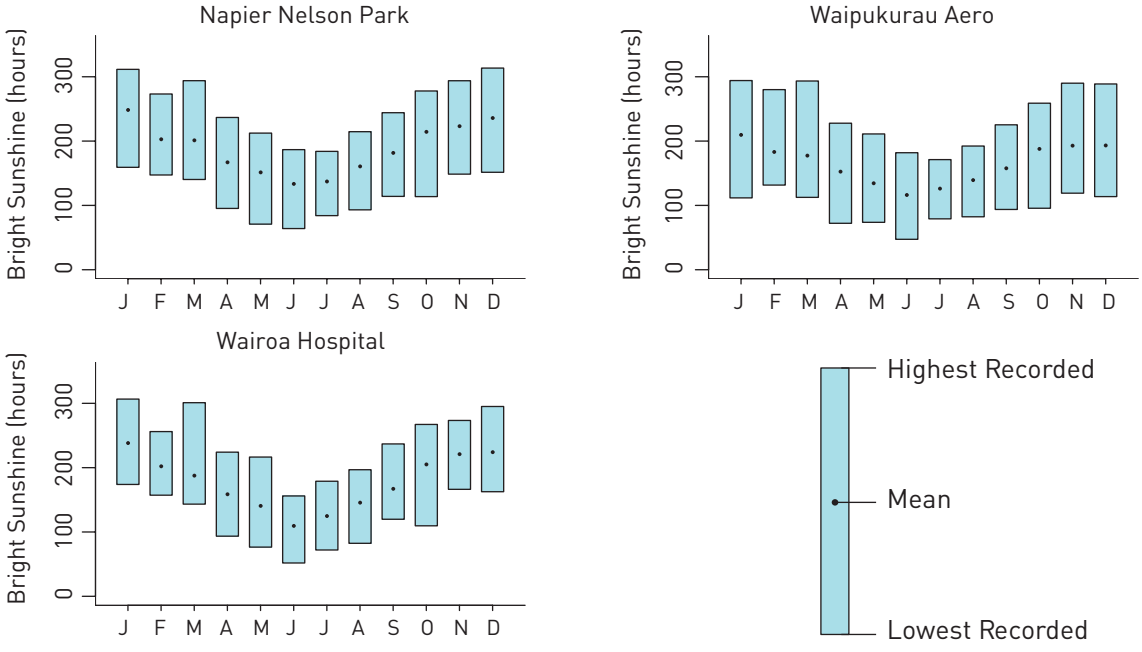


Figure 22. Mean, highest, and lowest recorded monthly bright sunshine hours for selected sites in Hawke's Bay.

Solar radiation

Solar radiation records are available for a number of sites in Hawke's Bay, but only a few sites have a long record (>10 years). Solar radiation is presented for Mahia, Napier, and Whakatu. Insolation is at a maximum in December and January and a minimum in June. Table 14 shows mean daily solar radiation (global) for each month for these three sites.

Table 14. Mean daily global solar radiation (MJ/m²/day) for Hawke's Bay sites.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Mahia AWS	22.2	18.8	14.9	10.5	7.5	6.0	6.4	9.4	13.7	18.0	21.1	22.2	14.2
Napier Aero AWS	22.9	19.4	15.8	11.2	7.9	6.4	6.8	9.9	14.0	18.5	21.7	22.8	14.8
Whakatu EWS	23.4	20.2	15.9	11.1	7.5	6.0	6.4	9.6	14.1	18.8	22.0	23.1	14.8

UV (Ultra-violet radiation)

Ultra-violet radiation (UV) measurements are not available for any stations in the Hawke's Bay region. Figure 23 shows an example of a UV forecast for Napier, and indicates the levels of UV and times of the day where sun protection is required.

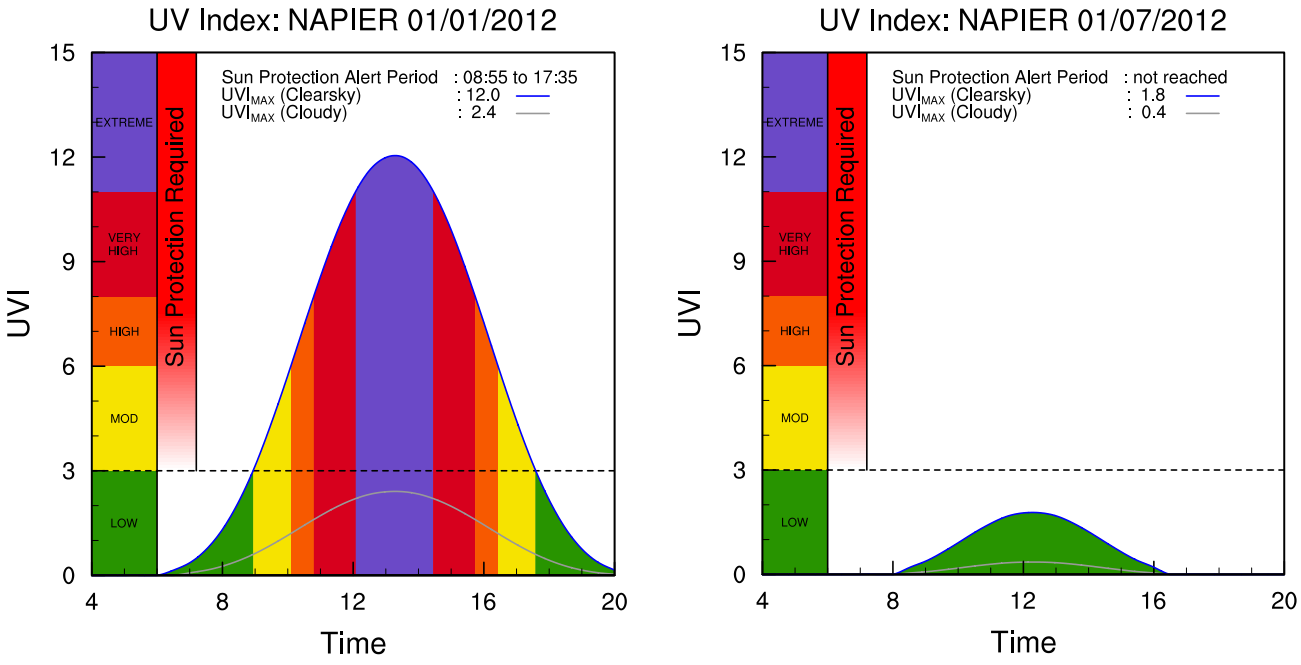


Figure 23. UV Index forecast for Napier, January and July. Source: https://www.niwa.co.nz/our-services/online-services/uv-and-ozone

Fog

The most common type of fog in the Hawke's Bay region is radiation fog, formed when the air cools to its dew-point on clear nights, allowing the water vapour in the air to condense. Fogs also sometimes form when the humidity of the air near the ground has been raised by falling rain.

The frequency of fog varies widely over the Hawke's Bay region, ranging from an average of 36 days with fog per year at Waikaremoana to an average of once every four months in Esk Forest. Although fog can occur at any time of the year it is recorded most frequently between March and August. The average number of days per year with fog for selected stations in the Hawke's Bay region is listed in Table 15.

Table 15. Average number of days each year with thunder, fog, and hail, from all available data.

Location	Thunder	Fog	Hail
Esk Forest	3	3	1
Havelock Nth D.S.I.R. 1	3	12	1
Makaretu Research Station	3	8	0.7
Napier Nelson Pk	4	4	0.9
Waikaremoana Onepoto	2	36	1
Waipukurau Aero	8	34	1
Wairoa, Frasertown	0.2	4	0.5

Severe convective storms

Thunderstorms

In the Hawke's Bay region, thunderstorms occur throughout the year, and thunder has a maximum frequency in the late spring and summer months. Thunderstorms are usually associated with cold south or southwest airstreams, whereas summertime thunderstorms may result from strong surface heating in weak synoptic gradients, leading to intense cumuliform cloud development. Average annual frequencies for selected stations are given in Table 15, and range from eight in Waipukurau to only one every five years in Wairoa. At some of the stations, it is likely that not all thunderstorms are detected. The heavy rain, lightning, hail, wind squalls, and rare tornadoes which can occur with thunderstorms will sometimes cause severe local flooding, disruption of electrical and electronic equipment, and damage to trees, crops, and buildings.

Hail

There is no significant difference in days with hail throughout the region, the number of which are low (0.5-1 days per year). As with thunderstorms, an unknown number of hail falls will escape detection at some of the stations. Hail is most likely over the winter and spring months. Table 15 gives the average number of days per year on which hail is reported at selected stations.

One particularly severe hail event was on 8 October 1986. A hailstorm which was about 300m wide affected the Hastings and Taradale area and lasted about 10 minutes. Most of the hailstones were 10 mm in diameter, although some were up to 40 mm diameter. Fifty-seven fruit growers were affected, and 450 ha of pipfruit was badly damaged, plus grapes, kiwifruit, and berry crops. The total cost of damage was estimated at $39 million 2010 dollars. One strawberry grower said his strawberries had reduced from $7/kg to $1.70/kg due to hail damage.

Tornadoes

Tornadoes are rapidly rotating columns of air extending from the base of a cumulonimbus cloud, and have in New Zealand a damage path typically 10-20m wide and 1-5 km long. The small size (compared to tornadoes in the USA), their short lifetimes, and the sparse population of much of New Zealand must result in an unknown number of tornadoes not being reported.

Tornadoes are rare in the Hawke's Bay region. Only three damage-causing tornadoes are recorded in NIWA's Historical Weather Events Database (www.hwe.niwa.co.nz), two in 2008 and one in 2004. On 30 April 2004, a tornado tore its way across forest and farmlands between Te Haroto and Tarawera in the early morning. The tornado lasted for about ten minutes, and it uprooted trees, tore down fences, and brought down power lines. Windows were smashed on some properties and outdoor furniture was sent flying. SH 5 was closed due to power lines being brought down across the highway. About 100 homes lost power for a few hours following the tornado.

Snow

Snow showers may occur at any time of the year on the ranges surrounding Hawke's Bay in cold southerly airstreams, but snow to low levels is exceedingly rare; about one or two days every 10 years.

Widespread snow was reported to low levels over the east of the North Island on 21 June 1976 (Figure 24) when a deep depression lay just east of the North Island and a slow moving anticyclone over the southwest Tasman Sea extended a ridge over the seas to the south of the country. The strong cold southerlies between the high and low pressure areas brought heavy falls of snow to the ranges of Hawke's Bay from 20-25 June as the synoptic weather pattern remained static during this time.

More recently, a significant snow event occurred on 24-26 September 2000. A rapidly deepening low crossed the North Island and caused a very cold southerly flow over Hawke's Bay. This caused high winds, heavy rain, and snow as low as 250 m in the region. The storm cut power to 95,000 people on the night of the 25th. Numerous highways were closed due to snow and ice, which was up to 20 cm deep on the roads, as well as fallen trees. There were large lamb losses in the region due to the low temperatures.

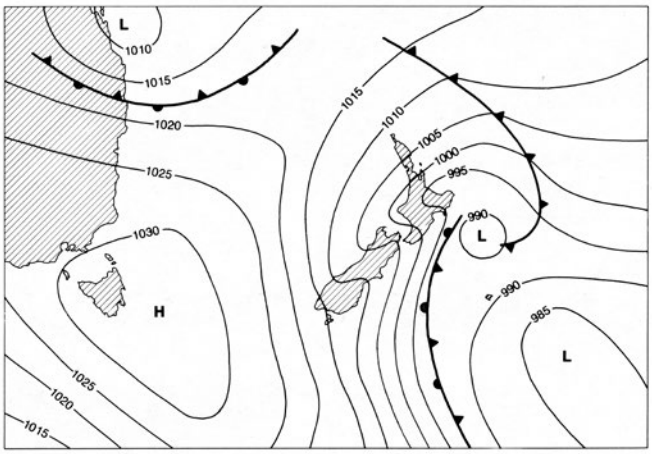


Figure 24. Mean sea level analysis for 0000 hours on 21 June 1976.

Sea swell and waves

The area of the Pacific Ocean which is bounded by the Hawke's Bay region is sheltered from the prevailing west to southwest swells of its latitude zone by the land mass of the North Island. Consequently high waves are less frequent than in corresponding western areas. Similarly it is protected from the cool ocean currents induced by the prevailing westerly winds. Thus waves from the southerly quarter are the most frequent (due to the region's exposure to the south). The prevailing easterly flow over the Pacific Ocean to the north of New Zealand produces a persistent easterly swell in the latitude of northern New Zealand, especially during the summer and autumn when the belt of southeasterly trade winds tends to lie further south than in other seasons. Of all swells observed, the frequency of those from one to two metres is 65%, while for those greater than two metres is 20% (Gorman et al., 2003). Most of the large southerly swells arriving in the Hawke's Bay region originate in the strong south-westerly wind zone that frequently exists between New Zealand and the Chatham Islands.

Table 16. Generated wave heights associated with specific wind speeds. Assumes a fetch length of 500 km with unlimited wind duration.

Wind speed (km/hr)	Associated wave height (m)
10	0.5
20	1
30	2
40	3
50	4
75	7
100	11
125	13+

Along some parts of the Hawke's Bay coast, particularly at Te Awanga and Haumoana, high seas associated with high tides can cause significant damage to beachfront properties. On 8-9 February 2008, heavy swells associated with ex-tropical cyclone Gene undermined some beachfront properties, flooded car parks, and left debris along the shoreline.

There is a known relationship between steady wind speed and wave heights over the open sea. The most probable wave heights for a given wind speed over a typical fetch length in New Zealand coastal waters of about 500 km are given in Table 16.

DERIVED CLIMATOLOGICAL PARAMETERS

Apart from elements such as temperature and rainfall which can be measured directly, it has been found that parameters computed from several elements, have some important uses especially in industry. Parameters which define the overall suitability of the climate for agriculture, horticulture, architectural and structural designs, and contracting, etc., are vapour pressure, relative humidity, evapotranspiration (leading to soil water balance), degree-days (thermal time), and rainfall extremes. Some of these parameters and their uses are discussed in the following paragraphs. Short-term high intensity rainfalls have been covered previously.

Vapour pressure and relative humidity

Vapour pressure and relative humidity are the two parameters most frequently used to indicate moisture levels in the atmosphere. Both are calculated from simultaneous dry and wet bulb thermometer readings, although a hygrograph may be used to obtain continuous humidity readings.

Vapour pressure is the part of total air pressure that results from the presence of water vapour in the atmosphere. It varies greatly with air masses from different sources, being greatest in warm air masses that have tropical origins and lowest in cold, polar-derived air masses. Vapour pressure can be important in determining the physiological response of organisms to the environment (very dry air, especially if there is a pre-existing soil moisture deficit, can cause or increase wilting in plants). Average 9 am vapour pressures for several stations are given in Table 17.

Relative humidity is quite high in all seasons, but there is a peak in winter, as shown in Table 18. The sites inland (Waipukurau and Wairoa) tend to have higher relative humidity than coastal sites.

Table 17 Mean monthly/annual 9 am vapour pressure (hPa) for selected Hawke's Bay sites.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Mahia Aws	15.6	16.2	14.8	13.6	11.9	10.1	9.8	9.7	10.5	11.2	12.2	14.5	12.5
Napier Nelson Pk	15.6	15.8	14.7	13.0	11.0	9.3	8.9	9.3	10.2	11.1	12.4	14.2	12.1
Waipukurau Aero	15.6	15.6	14.6	12.0	9.9	8.6	8.2	9.0	10.2	11.5	12.8	14.5	11.5
Wairoa, North Clyde EWS	15.5	16.1	14.5	13.1	11.1	9.3	9.3	9.6	10.9	11.1	12.6	14.4	12.3

Table 18. Mean monthly/annual 9 am relative humidity (%) for selected Hawke's Bay sites.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Mahia AWS	75	78	78	79	79	79	80	77	75	75	74	76	77
Napier Nelson Pk	70	74	75	77	79	80	80	76	69	67	68	67	73
Waipukurau Aero	77	84	84	84	84	85	84	84	81	78	78	78	82
Wairoa, North Clyde EWS	72	78	79	82	82	82	85	81	76	74	71	70	78

Evapotranspiration and soil water balance

Evapotranspiration is the process where water held in the soil is gradually released to the atmosphere through a combination of direct evaporation and transpiration from plants. A water balance can be calculated by using daily rainfalls and by assuming that the soil can hold a fixed amount of water with actual evapotranspiration continuing at the maximum rate until moisture depletion of the soil occurs. The calculation of water balance begins after a long dry spell when it is known that all available soil moisture is depleted or after a period of very heavy rainfall when the soil is completely saturated. Daily calculations are then made of moisture lost through evapotranspiration or replaced through precipitation. If the available soil water becomes insufficient to maintain evapotranspiration then a soil moisture

Table 19. Mean monthly/annual water balance summary for a soil moisture capacity of 150 mm.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Napier Nelson Pk	DE	107	65	44	15	3	1	0	0	1	39	74	98	449
	ND	22	15	13	8	3	1	0	0	0	11	17	20	111
	RO	0	0	2	2	17	39	68	25	14	5	1	0	174
	NR	0	0	0	0	1	4	6	3	1	0	0	0	16
Ngatarawa	DE	95	61	39	15	4	1	0	0	0	31	68	82	395
	ND	21	16	13	9	4	1	0	0	0	9	17	17	107
	RO	0	0	2	7	5	22	63	23	14	9	2	0	147
	NR	0	0	0	0	1	3	5	3	2	1	0	0	15
Ongaonga	DE	73	48	27	9	2	0	0	0	0	7	41	61	269
	ND	17	13	10	6	2	1	0	0	0	3	11	15	76
	RO	0	6	5	14	17	46	85	40	27	16	4	0	259
	NR	0	0	0	1	2	6	8	5	3	1	0	0	26
Tutira	DE	86	53	31	9	4	0	0	0	1	26	53	100	363
	ND	17	12	9	4	3	0	0	0	0	7	12	19	83
	RO	15	5	57	39	53	51	141	54	68	8	10	0	500
	NR	0	0	1	2	3	6	6	4	2	0	0	0	25
Wairoa, Waiputaputa Stn	DE	52	34	16	1	0	0	0	0	0	5	26	50	184
	ND	11	8	5	1	0	0	0	0	0	2	6	11	45
	RO	12	25	51	79	104	132	154	74	58	50	19	9	767
	NR	1	1	3	4	6	9	11	7	4	2	1	0	48

DE is the average amount of soil moisture deficit in mm
ND is the average number of days per month on which a soil moisture deficit occurs
RO is the average amount of runoff in mm
NR is the average number of days per month on which runoff occurs

deficit occurs and irrigation becomes necessary to maintain plant growth. Runoff occurs when the rainfall exceeds the soil moisture capacity (assumed to be 150 mm for most New Zealand soils). The Hawke's Bay region is relatively well served by frequent rainfalls in winter, but due to high evapotranspiration and a minimum of rainfall, irrigation or watering is usually necessary from late spring to early autumn.

Mean monthly and annual water balance values are given in Table 19, for a number of sites in Hawke's Bay. It can be seen from this table that sites on or near the Heretaunga Plains (Napier and Ngatarawa) have about 95 days between November and April when there is insufficient soil moisture to maintain plant growth without irrigation, but only 43 days in Wairoa. There is adequate moisture available to maintain plant growth between June and September. Figure 25 shows region-wide variability in days of soil moisture deficit per year.

Potential evapotranspiration (PET) has been calculated for Mahia and Napier using the Penman method (Penman, 1948). The monthly mean, minimum, and maximum PET values are listed in Table 20. These values were calculated from all available data.

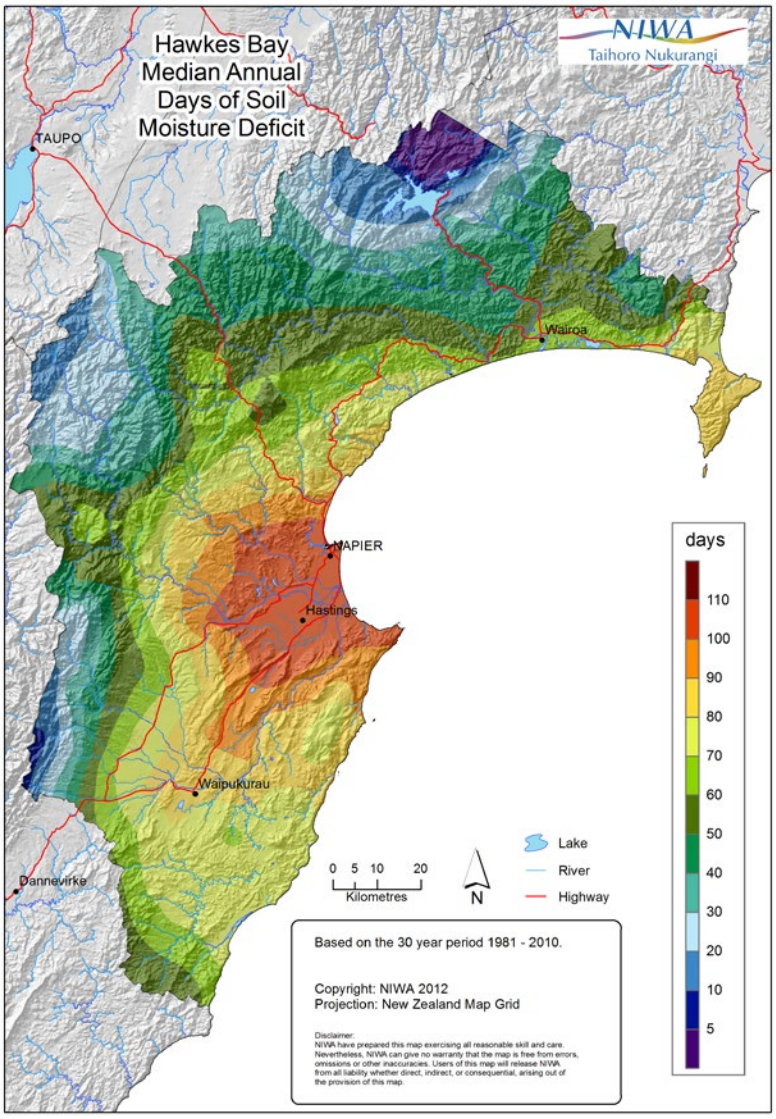


Figure 25. Hawke's Bay median annual days of soil moisture deficit, 1981-2010

Table 20. Penman calculated maximum, mean, and minimum monthly potential evapotranspiration (mm), as well as total mean annual PET.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Mahia AWS	Max	184	154	125	74	60	45	48	63	94	147	166	183	
	Mean	151	117	99	61	44	35	36	52	76	112	132	145	88
	Min	91	87	61	47	31	24	26	40	63	96	85	101	
Napier Nelson Park	Max	175	135	118	72	50	32	39	55	88	151	159	191	
	Mean	152	117	97	57	35	24	27	43	69	107	126	150	84
	Min	121	95	75	39	25	17	18	32	53	78	96	118	

Drought in Hawke's Bay

The Hawke's Bay region experienced a major drought between November 1997 and June 1998. Severe soil moisture deficits (more than 130 mm of deficit) were present in the region. Numerous locations in the region experienced extremely low rainfall during the drought, with Napier recording only 6 mm of rain in December 1997, 10% of normal December rainfall. During October to December 1997, constant strong winds, low humidity, and high temperatures acted to significantly reduce soil moisture. Figure 26 shows the soil moisture deficits reached at Napier Nelson Park over the drought period, compared to normal soil moisture deficit conditions for the same time of year (soil moisture deficit from October to July averaged from 1981-2010).

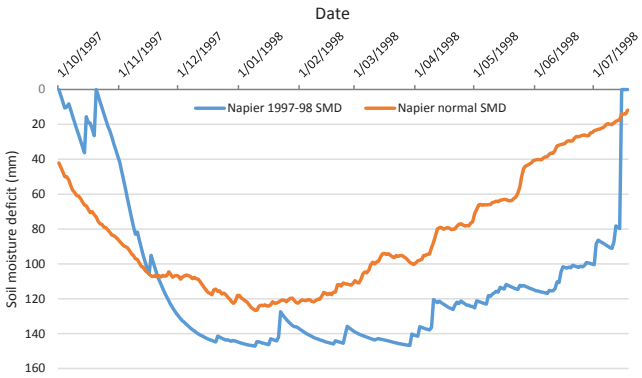


Figure 26. Soil moisture deficit at Napier Nelson Park during the November 1997 to June 1998 drought, compared with normal soil moisture deficit conditions for the same time of year at Napier Nelson Park (1981-2010).

The Hawke's Bay region also experienced major droughts in 2002-03, for three consecutive years from 2006-07 to 2008-09, and during the summer and early autumn of 2012-13. Between September 2012 and March 2013, only 39% of normal rainfall for that period was recorded in Napier (155 mm), and 47% of normal rainfall for September to March was recorded in Ongaonga (225 mm). Wairoa was a little better off, with 68% of normal rainfall for that period (419 mm). Much of the region was suffering from extreme soil moisture deficits (more than 130 mm of deficit), which meant that pasture growth had ceased (Figure 27). The dry conditions meant that farmers had to dry off cattle early and sell off stock. The stock feed situation remained very low in drought-stricken areas, and the price of feed significantly increased. Based on one measure of drought severity (the Potential Evapotranspiration Deficit) the 2012-13 drought was the worst drought to hit the central Hawke's Bay region since 1945-46. At the time of writing (June 2013), economic costs due to the 2012-13 drought across the North Island and Westland were estimated at a minimum of $1.6 billion.

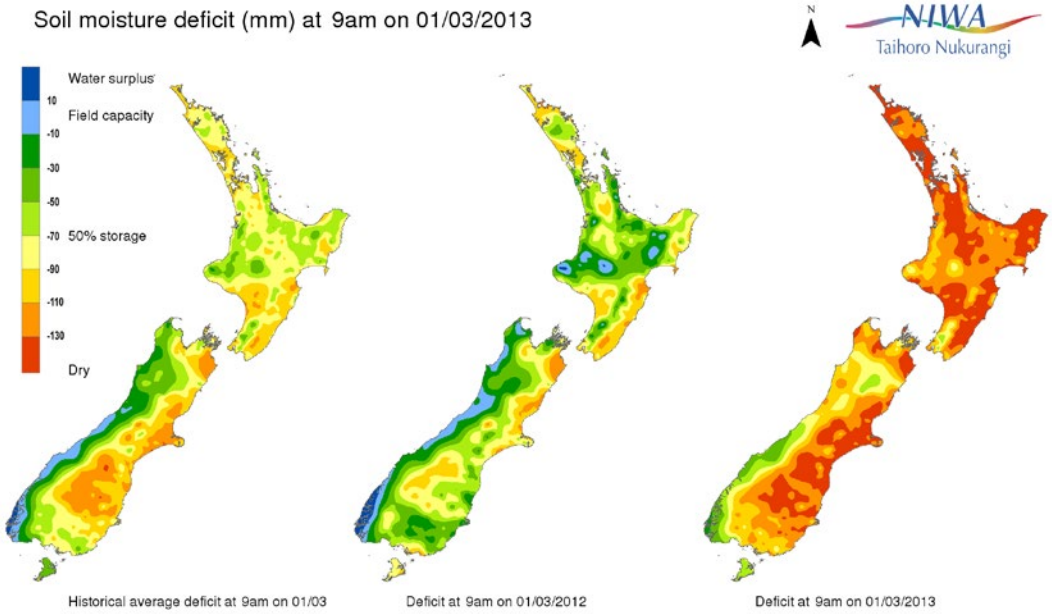


Figure 27. Soil moisture deficit as at 1 March 2013 (right hand map). Areas of extreme soil moisture deficit (more than 130 mm of soil moisture deficit) are shown in red, and areas of significant soil moisture deficit (more than 110 mm of soil moisture deficit) are shown in dark orange. Normal soil moisture deficit conditions for the time of year are given in the left hand figure, and the middle figure shows soil moisture deficit conditions as at 1 March 2012.

Degree-day totals

The departure of mean daily temperature above a base temperature which has been found to be critical to the growth or development of a particular plant is a measure of the plant's development on that day. The sum of these departures then relates to the maturity or harvestable state of the crop. Thus, as the plant grows, updated estimates of harvest time can be made. These estimates have been found to be very valuable for a variety of crops with different base temperatures. Degree-day totals indicate the overall effects of temperature for a specified period, and can be applied to agricultural and horticultural production. Growing degree-days express the sum of daily temperatures above a selected base temperature that represent a threshold of plant growth. Table 21 lists the monthly totals of growing degree-day totals above base temperatures of 5°C and 10°C for sites in the Hawke's Bay region.

Table 21. Average growing degree-day totals above base 5°C and 10°C for selected Hawke's Bay sites.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Kopua[1]	5°C	375	340	319	228	164	95	80	99	151	206	247	332	2635
	10°C	220	200	164	85	37	11	6	9	31	66	102	177	1109
Mahia Aws	5°C	408	377	372	298	249	173	160	167	207	255	290	367	3323
	10°C	253	236	217	149	97	38	24	30	62	103	140	212	1560
Napier Nelson Pk	5°C	451	406	394	300	229	150	137	163	219	288	332	417	3485
	10°C	296	264	239	151	80	32	23	35	77	135	182	262	1776
Wairoa, North Clyde EWS	5°C	435	395	380	289	233	150	136	154	205	263	317	404	3362
	10°C	280	254	225	139	81	28	18	26	64	111	167	249	1643

[1]Kopua is in the Manawatu-Wanganui Region, just south of the boundary with Hawke's Bay region. There were no Hawke's Bay stations in the south of the region with degree-day data, hence Kopua was used.

Table 22. Average cooling (CDD) and heating (HDD) degree-day totals with base 18°C for selected Hawke's Bay sites.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Kopua	CDD	21	19	8	0	0	0	0	0	0	0	1	9	58
	HDD	50	45	92	162	239	298	327	307	239	197	144	80	2180
Mahia AWS	CDD	33	30	14	3	0	0	0	0	0	1	4	17	100
	HDD	28	20	45	95	154	217	244	236	184	149	104	53	1526
Napier Nelson Pk	CDD	64	52	29	7	1	0	0	0	1	5	14	44	218
	HDD	17	14	38	97	175	240	266	240	171	120	72	31	1482
Wairoa, North Clyde EWS	CDD	55	47	24	5	1	0	0	0	0	2	10	38	182
	HDD	23	18	46	107	171	240	268	249	185	142	83	37	1569

Cooling and heating degree days are measurements that reflect the amount of energy that is required to cool or heat buildings to a comfortable base temperature, which in this case is 18°C. Table 22 shows that the number of cooling degree days reach a peak in summer in Hawke's Bay, where there is a higher demand for energy to cool building interiors to 18°C. Conversely, heating degree days reach a peak in winter, where the demand for energy to heat buildings to 18°C is highest. Figure 28 shows region-wide variability in the number of heating degree days per year. The number of heating degree days tends to be lower in low elevation coastal areas, compared with areas further inland and at higher elevations.

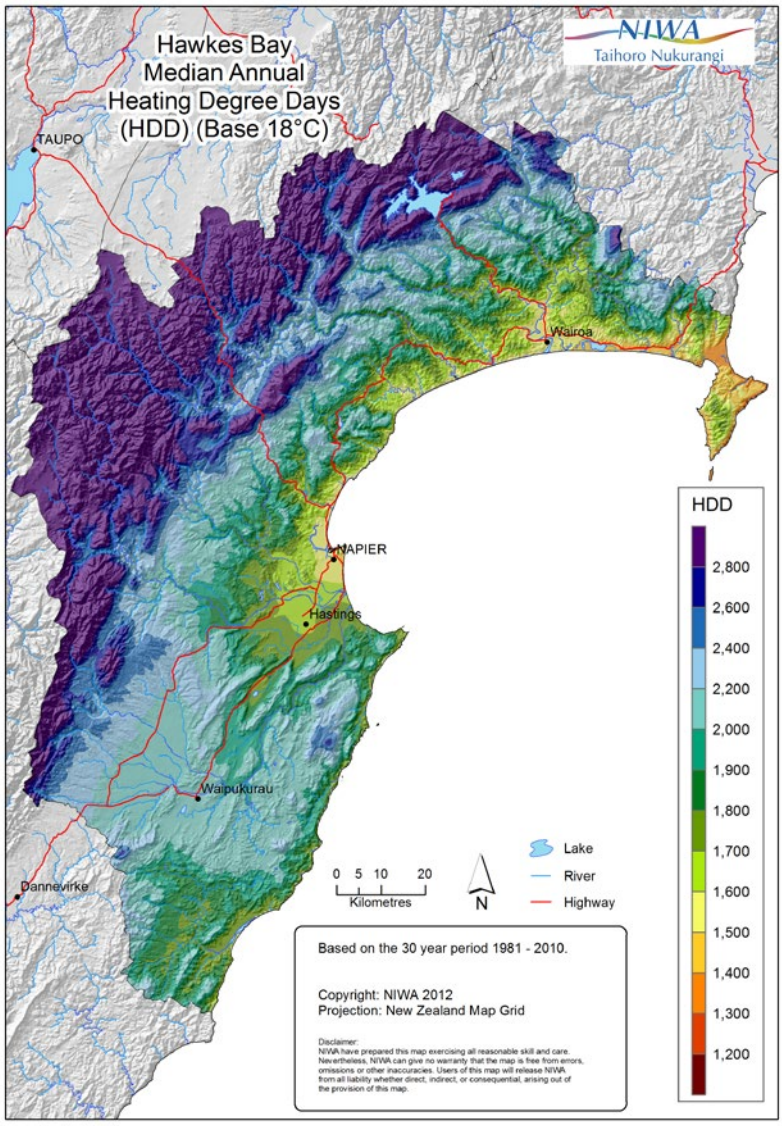


Figure 28. Median annual heating degree days for Hawke's Bay, 1981-2010.

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