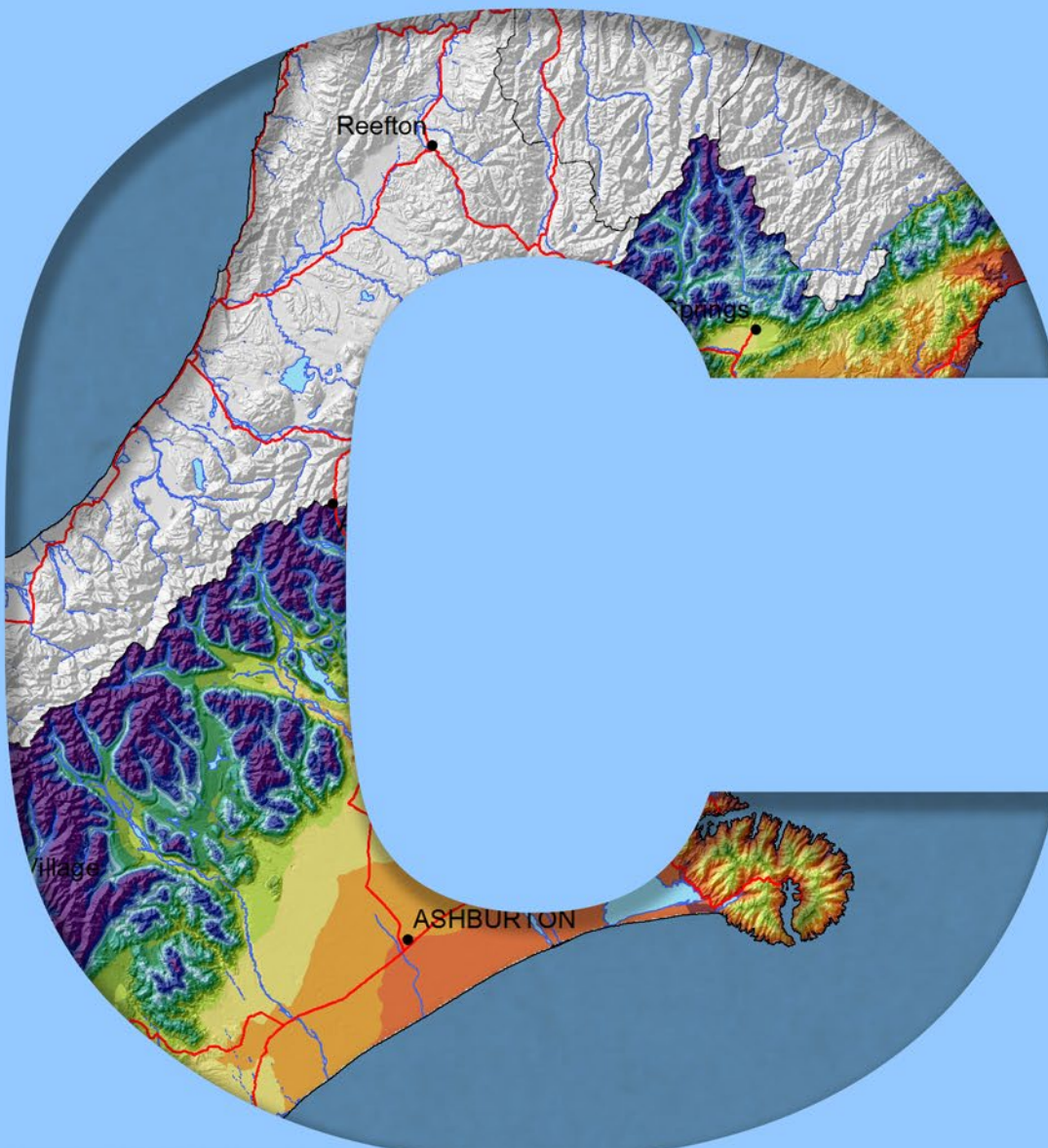


THE CLIMATE AND WEATHER OF CANTERBURY

2nd edition

G. R. Macara



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Note to Second Edition

This publication replaces the first edition of New Zealand Meteorological Service Miscellaneous Publication 115 (17), written in 1987 by A. P. Ryan. It was considered necessary to update the first edition, incorporating more recent data and updated methods of climatological variable calculation.

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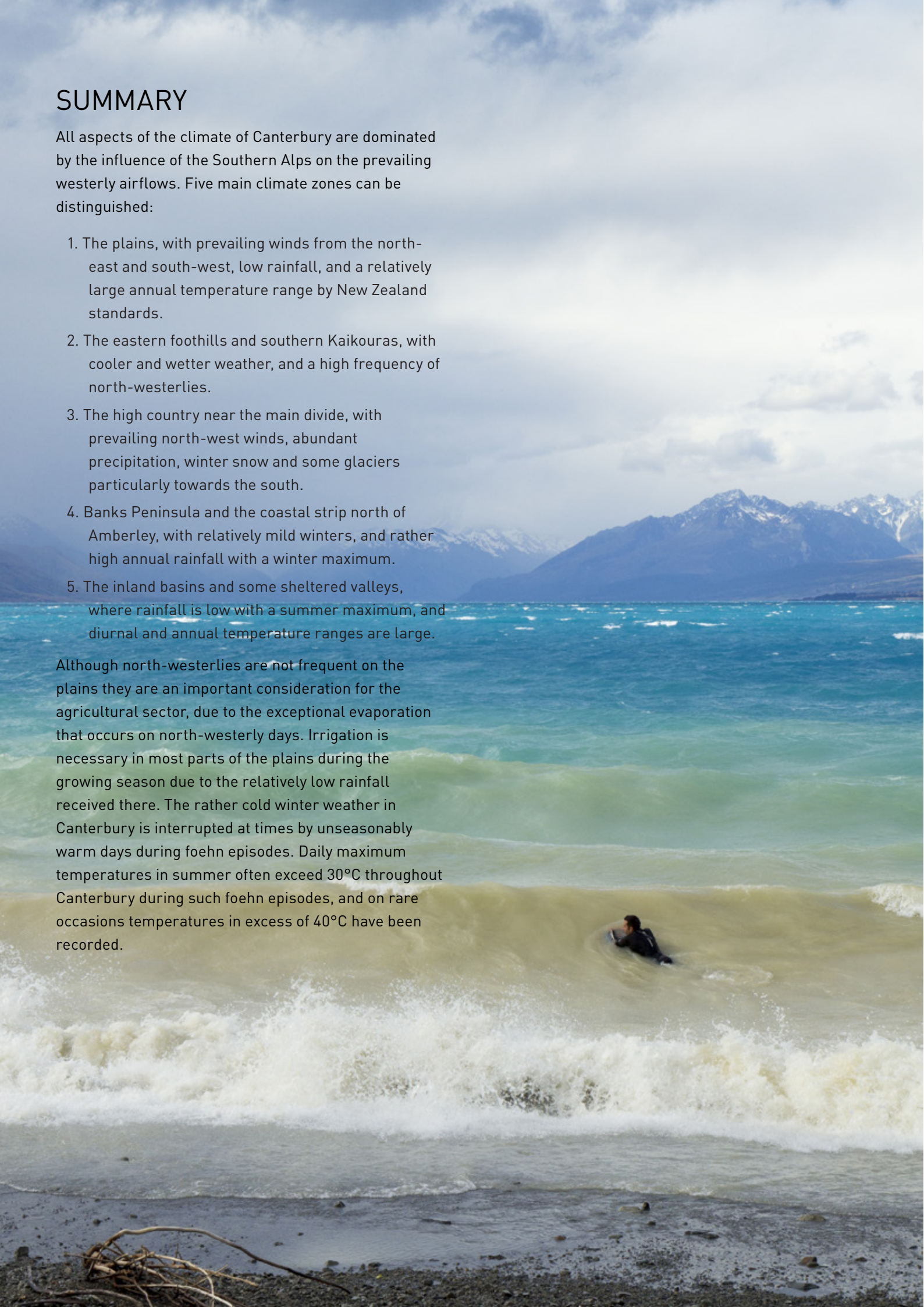


SUMMARY

All aspects of the climate of Canterbury are dominated by the influence of the Southern Alps on the prevailing westerly airflows. Five main climate zones can be distinguished:

1. The plains, with prevailing winds from the north-east and south-west, low rainfall, and a relatively large annual temperature range by New Zealand standards.
2. The eastern foothills and southern Kaikouras, with cooler and wetter weather, and a high frequency of north-westerlies.
3. The high country near the main divide, with prevailing north-west winds, abundant precipitation, winter snow and some glaciers particularly towards the south.
4. Banks Peninsula and the coastal strip north of Amberley, with relatively mild winters, and rather high annual rainfall with a winter maximum.
5. The inland basins and some sheltered valleys, where rainfall is low with a summer maximum, and diurnal and annual temperature ranges are large.

Although north-westerlies are not frequent on the plains they are an important consideration for the agricultural sector, due to the exceptional evaporation that occurs on north-westerly days. Irrigation is necessary in most parts of the plains during the growing season due to the relatively low rainfall received there. The rather cold winter weather in Canterbury is interrupted at times by unseasonably warm days during foehn episodes. Daily maximum temperatures in summer often exceed 30°C throughout Canterbury during such foehn episodes, and on rare occasions temperatures in excess of 40°C have been recorded.



INTRODUCTION

New Zealand spans latitudes 34 to 47 degrees south, and so lies within the Southern Hemisphere temperate zone. In this zone, westerly winds at all levels of the atmosphere move weather systems, which may also be either decaying or developing, eastwards over New Zealand giving great variability to its weather. These prevailing westerlies sometimes abate, and air from either tropical or polar regions may reach New Zealand with heavy rainfalls or cold showery conditions, respectively. The main divide of the Southern Alps acts as a barrier to the prevailing westerlies and has a profound effect on the climate of Canterbury, separating New Zealand's wettest region (the West Coast) from considerably drier regions east of the main divide.

The Canterbury region (Figure 1) is bounded in the east by the coast, and in the west by the main divide which reaches 3,724 m at the summit of Mount Cook. The coastal plain extends from Waimate to Waipara. The plains slope gently upwards to reach 150-200 m in the north, but where they are broadest in mid-Canterbury, the foot of the ranges lies at 350-400 m. Banks Peninsula lies to the east of the general run of the coast, and rises to 919 m at Mt Herbert.

Apart from on Banks Peninsula, the region's rivers drain eastwards to the coast. There are two types of river system, which respond differently to rainfall events. The catchments of the major rivers extends to the main divide, and the rivers typically penetrate the foothills through deep gorges. River flows gauged at the plains may be very high when there is a heavy rainfall event along the divide, even though there may be little or no rainfall recorded on the plains at the time. Other rivers rise on the eastern flanks of the foothills, and their flow regimes may differ considerably from the major rivers. Some of the glacial lakes in the western

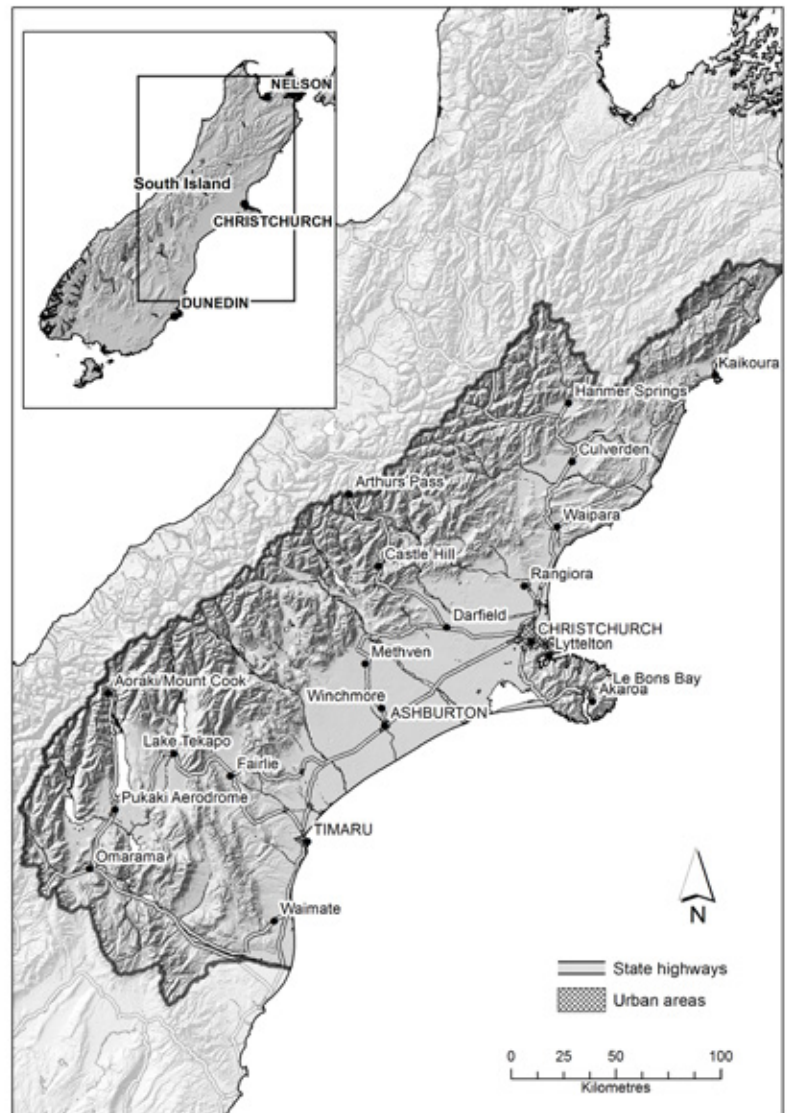


Figure 1. Map of the Canterbury region, showing the places mentioned in this publication.

high country are large enough to influence the local climate. The unique colour of these lakes is derived from the suspended sediment (rock flour) sourced from the glaciated areas occurring along and near the main divide.

Note that 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. Also note that all data for Christchurch are recorded at the airport, unless otherwise stated.



TYPICAL WEATHER SITUATIONS IN CANTERBURY

New Zealand lies in the zone of mid-latitude westerlies where a succession of depressions (lows) and subtropical anticyclones (highs) generally progress eastwards over the country. Often, a trough of low pressure separates two highs, and it usually contains a frontal system, which extends into one or more lows on the southern side of the highs. As the highs move east, New Zealand experiences a regular weather sequence, which has a period of about a week. Whilst this pattern provides the basic framework of the day-to-day weather, the succession is frequently interrupted.

In anticyclonic conditions the weather in Canterbury is generally fine, but it is often cloudy in winter if winds are onshore. Approaching troughs of low pressure are commonly preceded by extensive high cloud, but significant precipitation east of the main divide is rare at the frontal passage unless it becomes slow-moving. Orographic influences on the weather in Canterbury are very strong. Westerly airflows bring rainfall and cloudiness along the main divide, but reduced rainfall and increased sunshine hours farther east. Conversely, an easterly airflow often results in rainfall and cloudiness for the east coast and plains, but reduced rainfall and increased sunshine hours farther west. Because of the orographic influence, both the pressure and airflow patterns can be strongly disturbed in Canterbury causing, for example, a lee wave depression.

Easterly-quarter airflows

Surface south-easterlies are very rare, except for sea breezes south of Banks Peninsula, and where the flow is channeled by valleys. Usually, there is an anticyclone to the south or east of New Zealand (Figure 2), and an inversion at about 1000-2000 m which prevents significant convection. However, in winter the freezing level may lie below the inversion, and in the more southerly flows there are frequent light showers. Otherwise, the typical cloud is stratus with a low base and periods of drizzle. Sea fog also occurs, especially between late-spring and early-autumn. The low cloud does not penetrate inland of the foothills, and it usually clears during the day, except in winter or when there is also a sheet of upper-level cloud.

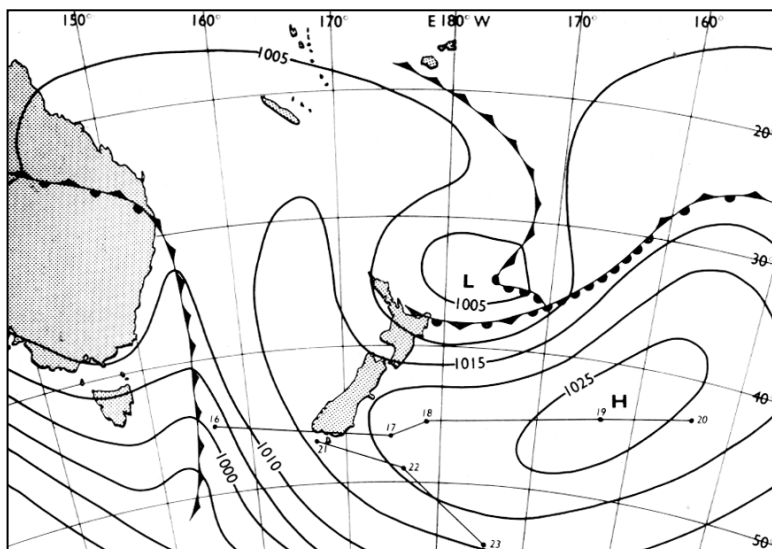


Figure 2. Mean sea level pressure analysis for 1200 hrs NZST on 19 November 1960.

Southerly-quarter airflows

These cold airflows have travelled over relatively warm sea and they are unstable. When the flow is anticyclonic, there is extensive low stratus and cumulus cloud, with frequent light showers. Cloud generally clears west of the Seaward Kaikoura Range and the eastern foothills, but it occasionally penetrates into the southern basins. With cyclonic flow (Figure 3), convection is stronger, and significant snowfalls may occur to low elevations, particularly in winter and spring. Summer convection on land is intensified by daytime heating, and heavy afternoon or early evening showers may develop. At the passage of an active cold front, the south or south-west winds may be very strong. Eventually, the flow turns to the west as a trailing ridge approaches. As this happens, Canterbury is progressively sheltered by the high ground farther south. The sheltering effect begins inland and spreads to the coast, so that showers now only form over the sea and on exposed headlands.

West-southwesterly airflows

In deep south-west flows associated with strong outbreaks of polar air, the wind is south-west over the whole region, except in some of the river gorges where winds are often channelled to north-west. The weather is mainly fine throughout Canterbury and showers only affect exposed coastal areas, mainly north of the Rakaia mouth. Showers do not penetrate far inland as these areas are sheltered by the mountains of Southland and Otago. In many cases, especially in spring and summer, south-westerlies are comparatively shallow. Such cases are often associated with minor frontal disturbances. The post-frontal air penetrates quickly north-east along the east coast, but only very slowly inland, where the winds remain north-west. However, when winds are not too strong and the flow ahead of the frontal

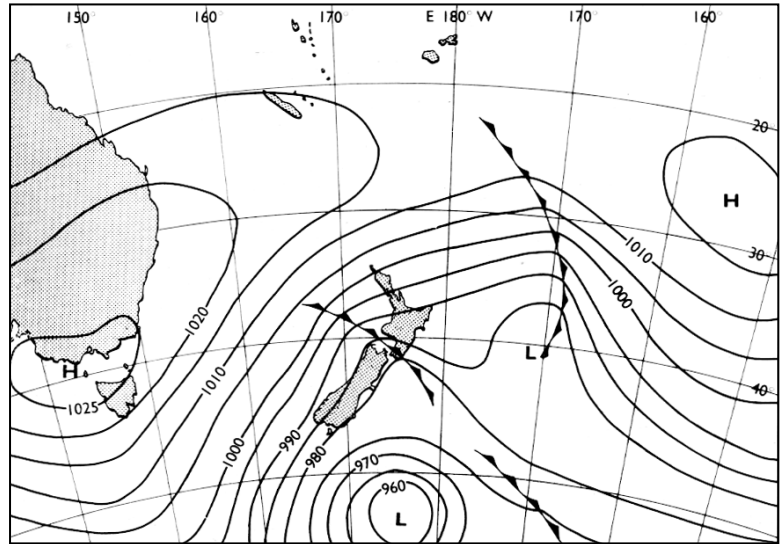


Figure 3. Mean sea level pressure analysis for 1800 hrs NZST on 26 April 1965.



disturbance is potentially unstable, the combination of daytime heating and frontal uplift may result in the formation of heavy convective storms.

Northwesterly airflows

When the undisturbed flow is light or moderate and stable (Figure 4), there is strong resistance to the ascent of air over the main divide. The flow is diverted around the northern end of the South Island, to return through Cook Strait and along the east coast of Canterbury as a north-easterly. With a strong unstable flow, there is little resistance to ascent over the main divide, and the wind is north-west throughout Canterbury.

The weather is usually fine eastward of the main divide, although convection occasionally occurs towards the east coast on summer afternoons, resulting in showers from high-base cumulus. There is strong diurnal variation in wind strength, especially in winter, when a nocturnal inversion often forms over the plains. In such conditions, places above the inversion (such as the hills of Banks Peninsula) experience relatively high temperatures while considerable frosts may be present on the plains. Often the warm north-westerlies reach the ground over the inland plains but rise over the cool north-east flow nearer the east coast. As a result, there can be a considerable difference between the air temperatures observed at these locations, with coastal temperatures at least several degrees lower than those inland.

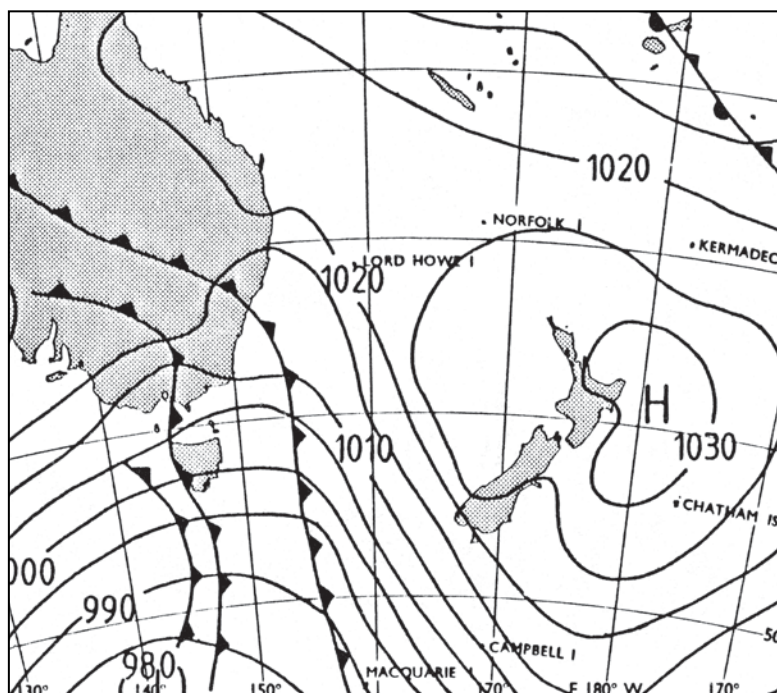


Figure 4. Mean sea level pressure analysis for 0000 hours NZST on 18 September 1982.



CLIMATIC ELEMENTS

Wind

Wind direction over New Zealand in the zone directly above the earth's surface may be interpreted from a mean sea level pressure (MSLP) map, following the general principle that in the Southern Hemisphere air flows in a clockwise direction around a depression (or a 'low'), and in an anticlockwise direction around an anticyclone (or a 'high'). As such, MSLP maps can be used to indicate the general wind direction at the earth's surface.

However, actual wind direction and speed at a particular locality is modified by the influence of friction and topography. Along the east coast of Canterbury the wind regime is complicated by a cool sea breeze from the easterly quarter, particularly in late-spring, summer and early-autumn. Sea breezes develop in Canterbury when synoptic-scale pressure gradients are weak (e.g. Figure 4), and are generated by air temperatures over land becoming higher than air temperatures over the sea. Figure 5 shows mean annual wind frequencies of surface wind based on hourly observations from selected Canterbury stations.

Mean wind speed data (average wind speeds are taken over the 10 minute period preceding each hour) are available for a number of sites in Canterbury, and these illustrate the several different wind regimes of the region (Table 1). Mean wind speeds are highest at coastal locations such as Le Bons Bay and Kaikoura, and lowest at the sheltered inland location of Hanmer Springs. There is notable variability in mean monthly wind speeds over the course of a year in Canterbury, where wind speeds are typically highest from around mid-spring (October) to mid-summer (January), and lowest from mid-autumn to mid-winter (April to August). This seasonality is observed across almost all of the Canterbury region, but is more pronounced at inland locations. Kaikoura is typically windier than most areas of

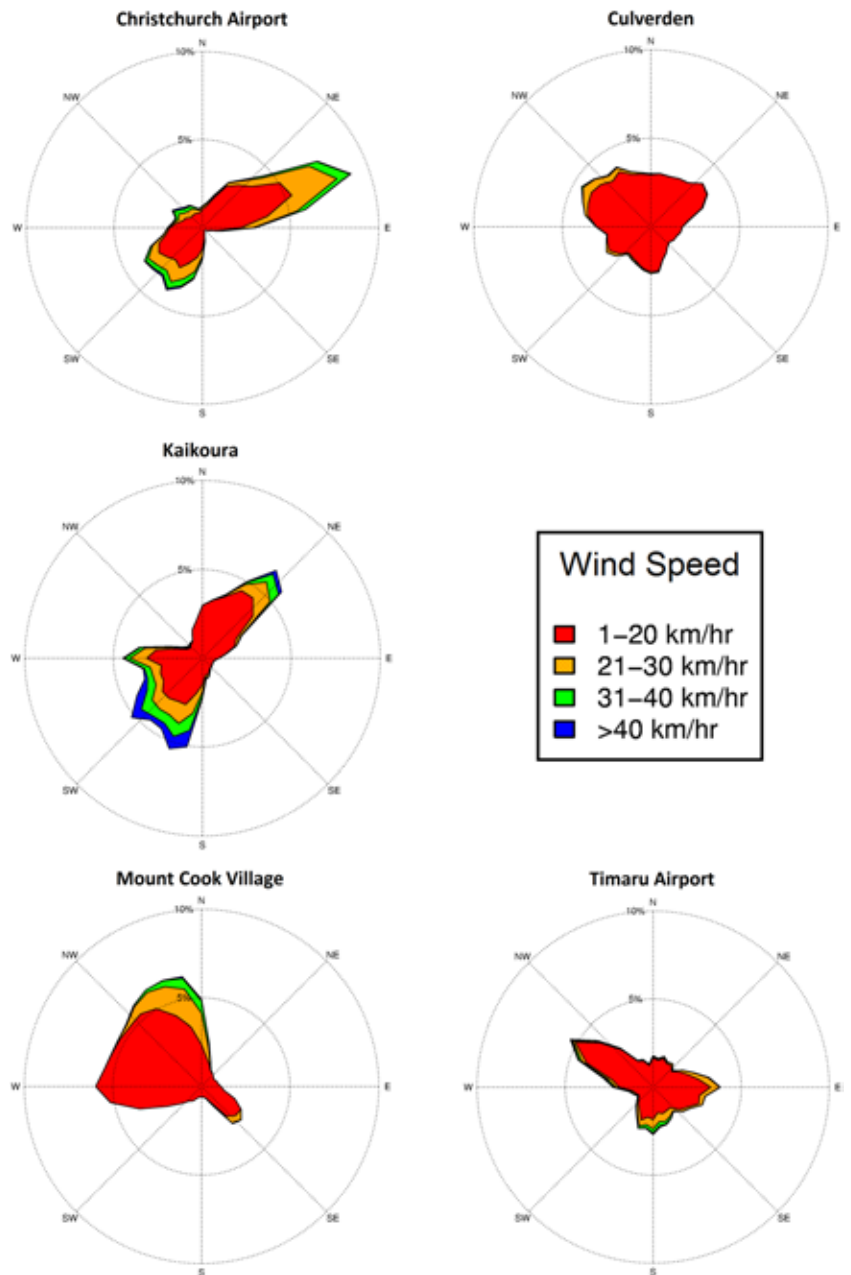


Figure 5. Mean annual wind frequencies (%) of surface wind directions from hourly observations at selected Canterbury stations. The plot shows the directions from which the wind blows, e.g. the dominant wind direction at Christchurch Airport is from the east-north-east.

Canterbury throughout the year, with this difference in mean wind speeds more prominent during the winter months.

Table 2 gives the seasonal distribution and frequency of occurrence of strong winds (defined as having a daily mean wind speed of greater than 30 km/hr). For example, of all strong winds recorded at Christchurch, 35% (seven strong wind days, on average) occur in spring. As a further example, Le Bons Bay and Rangiora share the same distribution of strong winds in autumn, with 26% of their respective annual strong winds being recorded in that season. However, Le Bons Bay has an average of 25 strong wind days in autumn, compared to just 1 in Rangiora. This highlights that although a similar seasonal distribution of strong winds may be observed between different locations

in Canterbury, the actual number of strong wind days per season at those locations may be considerably different. As shown in Tables 1 and 2, spring and summer are typically the windiest seasons throughout the region.

Diurnal variation in wind speed is well-marked, with highest wind speeds occurring mid-afternoon before decreasing overnight. This is because heating of the land surface is most intense during the day, 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 locations, whilst Figure 6 visually highlights the typical diurnal variation of wind speed observed at two of these sites.

Table 1. Mean monthly and annual wind speed (km/hr) for selected Canterbury locations, from all available data.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Le Bons Bay	23.0	22.2	23.0	22.1	22.2	23.7	21.1	22.0	24.3	24.1	23.7	23.5	22.9
Kaikoura	16.3	15.8	15.9	15.2	15.7	16.4	15.3	16.3	15.8	16.9	17.1	16.7	16.1
Lyttelton Harbour	18.1	17.2	16.4	14.0	14.1	13.6	13.1	14.8	16.0	17.4	17.7	18.3	15.9
Christchurch	17.3	16.3	14.9	13.0	12.2	11.1	11.4	12.8	14.4	15.9	16.6	17.1	14.4
Lake Tekapo	15.9	13.0	13.0	11.6	11.3	10.7	11.3	11.5	15.3	15.9	16.3	14.8	13.4
Darfield	13.7	13.4	13.3	11.6	11.7	12.1	11.3	12.0	14.3	14.4	14.6	14.5	13.1
Rangiora	11.6	10.7	10.0	8.8	9.3	9.1	8.7	10.0	10.9	11.4	11.4	11.8	10.3
Pukaki Aerodrome	13.4	10.7	10.3	8.9	8.5	6.6	7.7	8.3	11.5	12.4	12.7	12.5	10.3
Winchmore	11.4	10.3	10.2	9.0	9.0	8.2	8.4	9.5	11.5	11.7	12.0	11.7	10.3
Fairlie	11.0	8.4	8.8	8.3	9.9	9.4	10.4	9.2	11.1	11.0	10.5	9.6	9.8
Mt Cook Village	12.4	10.3	10.0	8.2	8.1	7.3	6.8	7.2	10.7	11.5	11.9	11.1	9.6
Timaru	10.4	9.7	9.4	8.3	8.2	8.4	8.2	8.6	9.7	10.9	10.8	10.5	9.4
Culverden	10.2	8.1	7.9	6.8	6.4	6.0	6.3	7.0	8.6	9.5	9.4	9.1	8.0
Hanmer Springs	7.7	6.9	6.8	5.7	5.9	5.5	5.2	6.0	8.1	8.5	8.4	8.2	6.9

Table 2. Seasonal distribution and frequency (mean number of days) of strong winds (daily mean wind speed > 30 km/hr) recorded at selected Canterbury locations, from all available data.

Location	Summer		Autumn		Winter		Spring		Annual Frequency
	Distribution	Frequency	Distribution	Frequency	Distribution	Frequency	Distribution	Frequency	
Le Bons Bay	22%	21	26%	25	25%	25	27%	27	98
Kaikoura	23%	9	24%	10	26%	10	27%	11	40
Christchurch	28%	6	21%	4	16%	3	35%	7	20
Lake Tekapo	28%	5	15%	2	18%	3	39%	7	17
Mt Cook Village	30%	3	20%	2	15%	1	35%	4	10
Darfield	26%	2	15%	1	18%	2	41%	4	9
Timaru	24%	1	17%	1	23%	1	36%	2	5
Rangiora	16%	1	26%	1	20%	1	38%	2	5
Hanmer Springs	27%	1	10%	0.3	13%	0.4	50%	1	3

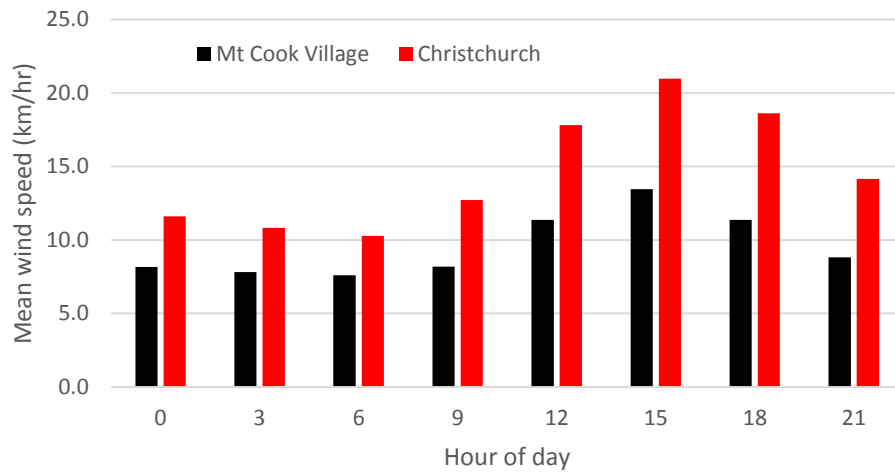


Figure 6. Mean wind speed at selected hours of the day for Christchurch and Mt Cook Village.

Table 3. Mean wind speed (km/hr) at three-hourly intervals of the day.

Location	0000	0300	0600	0900	1200	1500	1800	2100
Christchurch	11.6	10.8	10.3	12.7	17.8	21.0	18.6	14.2
Darfield	11.3	11.2	11.2	12.3	14.7	16.7	15.4	12.3
Hanmer Springs	5.5	5.5	5.4	5.6	8.1	9.9	8.9	6.4
Kaikoura	15.0	14.4	14.1	14.1	17.1	18.0	16.7	15.8
Lake Tekapo	12.4	11.7	11.4	11.4	13.4	16.5	16.4	13.8
Le Bons Bay	23.2	22.4	22.1	22.4	24.0	24.4	23.9	23.5
Mt Cook Village	8.2	7.8	7.6	8.2	11.4	13.5	11.4	8.8
Rangiora	8.3	7.8	7.7	8.8	12.6	14.8	12.8	9.6
Timaru	7.7	7.4	7.4	8.3	11.2	14.3	11.7	8.5

Photo: ©mychillybin.co.nz/Jeremy Town



Gusty winds are relatively infrequent throughout most lowland Canterbury locations, occurring more frequently in the mountain ranges and exposed coastal locations. Christchurch experiences an average of 52 days per year with wind gusts exceeding 61 km/hr, considerably less than Kaikoura where on average 97 such days per year are recorded (Table 4). Maximum gusts recorded at different locations in Canterbury are listed in Table 5. The highest gust recorded in the region (and for all New Zealand) was 250 km/hr, occurring at Mt John (near Lake Tekapo) on 18 April 1970 (<http://www.niwa.co.nz/education-and-training/schools/resources/climate/extreme>).

Table 4. Mean number of days per year with gusts exceeding 61 km/hr (33 knots) and 94 km/hr (50 knots) for selected locations.

Location	Days with gusts >61 km/hr	Days with gusts >94 km/hr
Christchurch	52	2
Darfield	43	1
Hanmer Springs	36	2
Kaikoura	97	17
Lake Tekapo	69	5
Mt Cook Village	108	15
Mt John	158	72
Rangiora	30	0.6
Timaru	34	2

Table 5. Highest recorded wind gusts at selected Canterbury locations, from all available data.

Location	Gust (km/hr)	Direction	Date
Christchurch (Airport)	172.4	WNW	01/08/1975
Darfield	116.6	NW	05/05/2014
Hanmer Springs	137.2	NW	28/03/2001
Kaikoura	194.8	WNW	01/08/1975
Lake Tekapo	122.4	WNW	13/10/2006
Mt Cook Village	177.8	N	21/02/2004
Mt John	250.0	NW	18/4/1970
Rangiora	116.6	NW	22/09/2002
Timaru	164.9	WNW	01/08/1975



Photo: ©mychillybin.co.nz/Jeremy Town

Rainfall

Rainfall distribution

Canterbury's median annual rainfall is shown in Figure 7, which clearly illustrates how rainfall is affected by topography and exposure to the main rain bearing airflows from the west. Rainfall is highest along the main divide which has both high elevation and western exposure. This is the result of orographic enhancement. Specifically, moisture-laden air masses passing over the Tasman Sea are forced to rise over the western ranges. As these air masses rise, they cool rapidly, causing the stored water vapour to condense, resulting in rainfall. The air masses continue eastwards, but they hold significantly less moisture once beyond the main divide. As a result, there is a marked decrease eastwards in median annual rainfall beyond the Canterbury high country. The inland basins of the MacKenzie Country are among the driest areas of New Zealand. Here, annual rainfall totals of below 500 mm are typically recorded. This is approximately ten times less than that which falls in nearby high elevation locations in the main divide. The inland basins typically aren't quite as dry as Central Otago, where annual rainfall totals below 400 mm are common.

Table 6 lists monthly rainfall normals and the percentage of annual total for selected locations. Many Canterbury locations observe a maximum of rainfall in late-autumn and winter. For example, Christchurch, Kaikoura and Akaroa receive 31%, 32% and 37% of their annual rainfall during winter respectively. Methven, Timaru, Waimate and Tara Hills receive a fairly even distribution of rainfall throughout the year, with a peak in December. Akaroa observes a notable summer rainfall minimum, with just 16% of annual rainfall falling from to December to February.

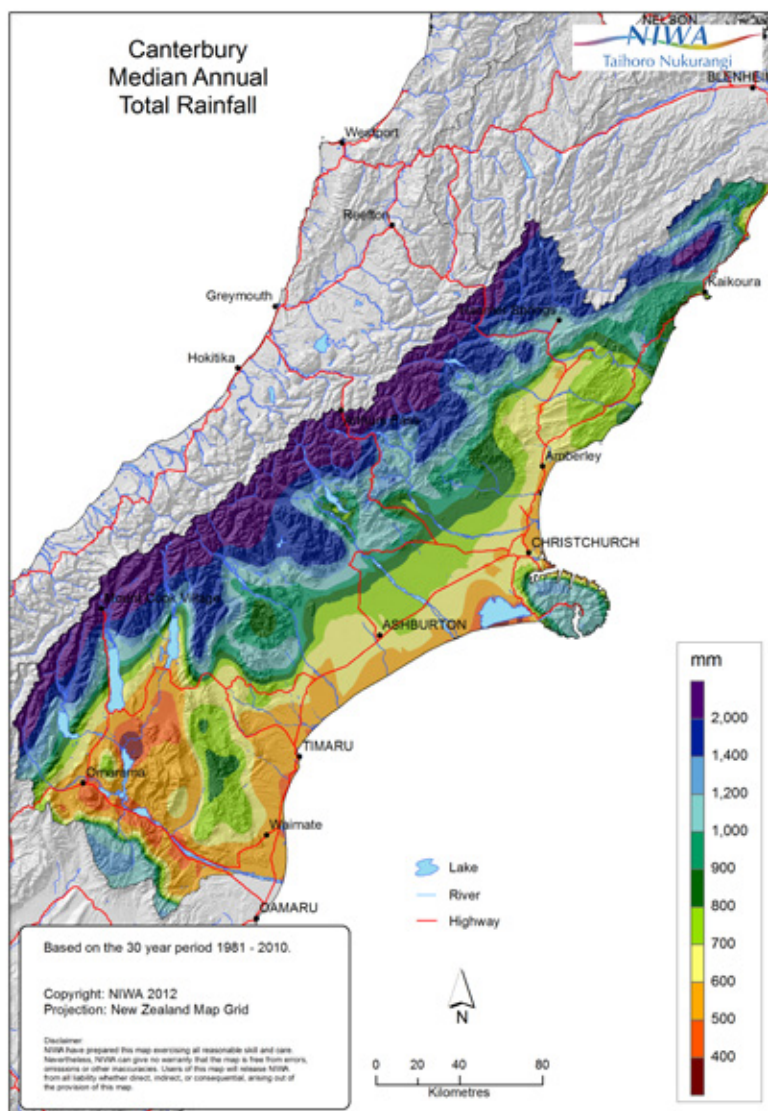


Figure 7. Canterbury median annual total rainfall, 1981–2010.

Table 6. Monthly and annual rainfall normal (a; mm), and monthly distribution of annual rainfall (b; %) at selected Canterbury locations, for the period 1981–2010.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Akaroa	a	51	53	68	67	92	101	131	123	70	82	70	63	969
	b	5	5	7	7	9	10	14	13	7	8	7	6	
Arthur's Pass	a	414	267	341	342	377	401	305	352	430	483	424	508	4642
	b	9	6	7	7	8	9	7	8	9	10	9	11	
Ashburton	a	53	53	57	49	63	57	64	62	48	59	59	57	681
	b	8	8	8	7	9	8	9	9	7	9	9	8	
Castle Hill Village	a	62	55	80	63	70	92	84	100	98	101	77	84	967
	b	6	6	8	6	7	9	9	10	10	10	8	9	
Christchurch	a	38	42	45	46	64	61	68	64	41	53	46	50	618
	b	6	7	7	7	10	10	11	10	7	9	7	8	
Culverden	a	28	44	47	57	46	50	58	53	32	48	63	52	576
	b	5	8	8	10	8	9	10	9	6	8	11	9	
Darfield	a	54	57	64	53	68	67	74	75	55	62	62	65	756
	b	7	8	8	7	9	9	10	10	7	8	8	9	
Kaikoura	a	39	52	59	56	57	75	92	67	57	63	59	47	721
	b	5	7	8	8	8	10	13	9	8	9	8	7	
Lake Tekapo	a	44	36	49	45	57	60	50	58	50	50	41	52	591
	b	7	6	8	8	10	10	8	10	9	8	7	9	
Methven	a	75	70	80	65	75	66	78	80	64	80	74	90	895
	b	8	8	9	7	8	7	9	9	7	9	8	10	
Mt Cook Village	a	423	260	380	344	365	322	265	301	345	416	367	497	4285
	b	10	6	9	8	9	8	6	7	8	10	9	12	
Rangiora	a	47	53	50	50	59	64	78	66	51	57	54	57	688
	b	7	8	7	7	9	9	11	10	7	8	8	8	
Tara Hills (Omarāma)	a	48	33	43	36	46	46	39	36	36	38	42	62	506
	b	9	7	8	7	9	9	8	7	7	8	8	12	
Timaru	a	48	52	48	38	47	39	46	44	37	50	50	52	550
	b	9	9	9	7	9	7	8	8	7	9	9	10	
Waimate	a	50	45	49	44	38	37	49	42	37	46	43	56	536
	b	9	8	9	8	7	7	9	8	7	9	8	11	
Waipara	a	58	41	45	56	36	53	54	63	63	39	60	52	620
	b	9	7	7	9	6	9	9	10	10	6	10	8	

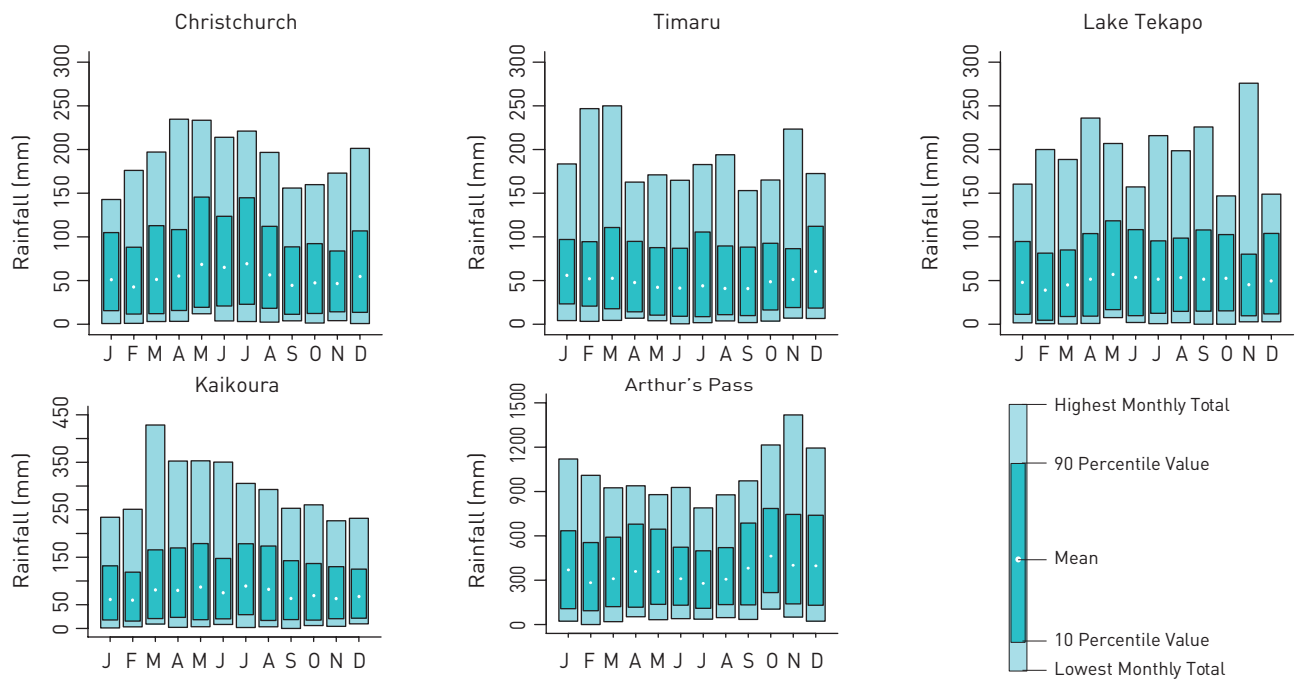


Figure 8. Monthly variation of rainfall for selected Canterbury locations from all available data.

The distribution of monthly rainfall is shown in Figure 8. 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 is further indicated by rainfall deciles, as given in Tables 7, 8 and 9. The 10th percentile values show the accumulated rainfalls that will normally be exceeded in nine out of ten years, whilst the 90th percentile values indicate the accumulated falls that will normally be exceeded in only one year in ten. The tables include periods from

one month to twelve months (annual), with each time period that is longer than one month beginning with the month stated. For example, using the table for Christchurch (Table 8), it can be seen that in the three month period beginning in January, 75 mm or more of rainfall can be expected in nine years in ten, while a total of 246 mm or more should occur, on average, in only one year in ten.

Table 7. Rainfall means and deciles at monthly, 3-monthly, 6-monthly, 9-monthly and annual intervals for Arthur's Pass from all available data.

Arthur's Pass		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1 month	90th	635	555	591	679	645	523	499	520	686	785	745	739
	Mean	370	283	310	359	358	310	279	307	382	463	401	398
	10th	107	93	121	117	137	131	110	135	133	216	140	131
3 months	90th	1449	1412	1484	1434	1348	1262	1420	1646	1769	1794	1857	1641
	Mean	966	954	1029	1028	941	897	966	1147	1254	1262	1159	1057
	10th	560	559	563	658	597	552	525	685	743	720	620	562
6 months	90th	2626	2561	2531	2598	2763	2893	2995	3051	3020	2825	2879	2806
	Mean	1993	1900	1924	1997	2106	2153	2235	2320	2298	2218	2123	2081
	10th	1435	1401	1337	1432	1438	1621	1560	1707	1681	1539	1453	1451
9 months	90th	3834	3988	4197	4263	4191	4048	4125	4076	4207	4093	3980	3909
	Mean	2959	3063	3186	3275	3273	3197	3197	3282	3317	3245	3060	2989
	10th	2073	2242	2235	2321	2476	2412	2449	2498	2403	2429	2239	2240
Annual	90th	5317											
	Mean	4245											
	10th	3117											

Table 8. Rainfall means and deciles at monthly, 3-monthly, 6-monthly, 9-monthly and annual intervals for Christchurch from all available data.

Christchurch		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1 month	90th	105	88	113	108	146	124	145	112	89	92	84	107
	Mean	51	43	51	55	69	65	69	56	44	47	47	55
	10th	16	12	12	16	19	21	23	18	11	12	14	14
3 months	90th	246	249	262	292	299	306	264	238	211	237	242	233
	Mean	145	150	174	186	202	189	169	148	138	148	152	149
	10th	75	69	87	103	121	103	86	75	72	79	77	78
6 months	90th	462	492	514	492	475	450	424	422	411	446	432	455
	Mean	330	346	359	354	349	327	315	299	287	294	302	323
	10th	211	217	234	226	230	206	212	191	182	184	182	193
9 months	90th	679	665	671	662	653	638	631	615	627	647	665	669
	Mean	497	493	497	502	501	475	462	449	462	479	499	509
	10th	343	341	357	353	358	330	322	304	310	338	335	344
Annual	90th	839											
	Mean	644											
	10th	461											

Table 9. Rainfall means and deciles at monthly, 3-monthly, 6-monthly, 9-monthly and annual intervals for Lake Tekapo from all available data.

Lake Tekapo		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1 month	90th	95	81	85	104	118	108	95	99	108	103	80	104
	Mean	48	39	45	51	57	54	51	53	52	52	45	50
	10th	11	5	9	9	17	10	12	15	15	15	10	12
3 months	90th	212	226	242	258	248	239	233	233	234	234	225	212
	Mean	131	135	153	160	162	159	157	157	149	148	143	136
	10th	62	57	69	89	102	79	71	80	75	79	86	74
6 months	90th	424	426	433	467	449	428	441	406	380	396	408	415
	Mean	291	294	309	315	321	309	305	301	287	279	278	288
	10th	180	166	191	202	211	200	199	218	187	171	164	165
9 months	90th	610	604	620	630	582	592	558	553	588	586	597	609
	Mean	447	453	460	463	463	444	432	432	438	440	438	445
	10th	294	311	313	336	354	331	308	317	309	291	282	279
Annual	90th	767											
	Mean	595											
	10th	425											

Rainfall frequency and intensity

Table 10 lists the average number of days per month with at least 0.1 mm (a 'rain day') and 1 mm (a 'wet day') of rain for selected locations. The number of rain and wet days recorded at a given station tends to be higher near the main divide and foothills, and lower near the east coast and in inland basins. The inland basins experience considerably fewer rain and wet days than nearby western-most locations, which is due to the rain-shadow (sheltering) created by the main divide. The seasonal variation of rain days and wet days in Kaikoura is relatively small. Therefore, the winter maximum of rainfall observed may be largely attributed to there being more heavy falls of rain, as opposed

to more total days of rain when compared to other seasons. The average number of rain days each year varies from 87 days at Waipara to 171 days at Mt Cook Village. Tara Hills and Lake Tekapo exhibit the lowest number of wet days in the region, with 72 and 74 wet days recorded on average respectively, compared with 153 wet days at Mt Cook Village.

Table 10. Average monthly rain days (a; days where at least 0.1 mm rainfall is measured) and wet days (b; days where at least 1 mm rainfall is measured) at selected Canterbury locations.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Akaroa	a	7	6	8	8	10	11	12	10	9	9	8	8	107
	b	6	5	7	7	9	10	11	9	8	7	7	7	93
Arthur's Pass	a	13	11	12	13	13	13	12	14	16	17	15	15	166
	b	12	10	11	12	12	12	11	13	15	16	14	14	152
Ashburton	a	10	9	10	11	11	10	11	11	10	11	11	11	126
	b	7	7	7	7	8	7	8	8	7	8	8	8	89
Castle Hill	a	8	6	7	7	8	7	6	7	7	8	9	9	88
	b	7	6	6	7	7	6	6	7	7	8	8	8	84
Christchurch	a	9	8	9	10	12	12	13	11	9	10	9	10	122
	b	7	5	6	7	8	9	9	7	7	7	7	7	86
Culverden	a	8	7	7	8	9	9	10	8	8	9	8	8	99
	b	7	6	6	6	7	7	8	7	7	8	7	6	82
Darfield	a	10	9	9	10	10	10	11	10	10	11	10	11	120
	b	7	7	7	7	8	8	8	8	7	8	8	8	92
Kaikoura	a	8	7	9	9	9	9	9	9	8	8	8	9	103
	b	7	6	7	7	8	8	8	8	7	7	7	7	86
Lake Tekapo	a	7	6	7	8	9	8	8	9	9	9	8	8	97
	b	6	5	5	6	7	6	6	7	7	7	6	6	74
Methven	a	11	10	10	10	10	9	10	10	10	11	11	11	123
	b	8	8	8	8	8	7	8	8	8	9	9	9	97
Mt Cook Village	a	14	12	14	14	14	13	13	14	15	16	16	15	171
	b	12	10	12	13	13	12	12	13	13	15	14	14	153
Rangiora	a	10	9	8	11	12	12	12	12	9	12	9	10	124
	b	6	6	5	7	7	7	7	7	5	8	6	7	77
Tara Hills (Omarama)	a	8	7	8	8	10	12	11	11	10	11	8	10	113
	b	6	5	5	5	6	7	5	6	6	7	6	7	72
Timaru	a	11	10	10	10	9	8	9	8	8	10	10	11	114
	b	8	7	7	7	6	6	6	6	6	7	7	8	81
Waimate	a	12	10	11	10	9	9	9	9	9	11	11	12	122
	b	8	7	8	7	7	6	6	6	7	8	8	9	87
Waipara	a	6	6	6	7	8	8	8	8	7	8	7	8	87
	b	5	5	6	6	7	6	7	7	6	7	6	7	75

The heaviest short period rainfalls in Canterbury are recorded nearest the main divide, which often occur when persistent west/northwesterly airflows are established as a trough approaches the South Island. For remaining areas of Canterbury, heavy short period rainfalls occur with the passage of a depression over or close to the region, or in association with slow moving fronts. Eastern areas of Canterbury typically experience heaviest 12-hour to 72-hour period rainfall when a depression is centred to the east of the South Island, due to the prevalence of moisture-laden easterly or south-easterly winds under such circumstances. In Table 11, maximum short period rainfalls for periods of 10 minutes to 72 hours with

calculated return periods are given for Christchurch and Mt Cook Village. Also listed in this table are the maximum rainfalls expected in 2, 5, 10, 20, and 50 years. Depth-duration frequency tables for Canterbury 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 hirds.niwa.co.nz.

Table 11. Maximum recorded short period rainfalls and calculated return periods (or average recurrence intervals, ARI) from HIRDS.

Location		10min	20min	30min	1hr	2hrs	6hrs	12hrs	24hrs	48hrs	72hrs
Christchurch	a	16.1	20.3	21.5	27.4	50.6	80.6	107.9	118.4	121.3	137.6
	b	Jan 1968	Nov 1979	Nov 1979	Mar 1975	Mar 1975	Mar 1975	Jan 1980	Jan 1980	Jan 1980	Apr 1968
	c	100+	71	37	23	75	83	89	40	18	18
	d	4.7	6.9	8.6	12.7	17.6	29.4	40.6	56.1	69.0	77.9
	e	6.4	9.5	11.9	17.5	23.8	39.0	53.1	72.4	89.1	100.6
	f	7.9	11.7	14.7	21.6	29.2	47.0	63.5	85.8	105.6	119.2
	g	9.7	14.3	17.9	26.4	35.4	56.2	75.3	101.0	124.2	140.2
	h	12.6	18.6	23.3	34.3	45.4	71.0	94.0	124.6	153.3	173.0
Mt Cook Village	a	11.6	22.7	31.8	50.0	70.4	164.5	287.2	442.8	665.2	768.3
	b	Dec 2000	Dec 2000	Dec 2000	Dec 2000	Mar 2004	Mar 2004	Apr 2009	Apr 2009	Apr 2009	Apr 2009
	c	23	33	33	19	12	19	32	29	98	100+
	d	6.2	11.0	15.4	27.4	45.3	100.2	165.4	273.0	334.5	376.6
	e	8.0	14.3	20.1	35.7	58.0	124.8	202.5	328.5	402.4	453.1
	f	9.6	17.1	23.9	42.6	68.3	144.3	231.5	371.3	454.8	512.1
	g	11.3	20.2	28.3	50.4	79.9	166.0	263.3	417.6	511.5	575.9
	h	14.1	25.1	35.1	62.6	97.9	198.8	310.9	486.1	595.5	670.5

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

Recent extreme events in Canterbury

Canterbury has experienced numerous extreme weather events, with significant damage and disruption caused by heavy rain and flooding. The events listed below are some of the most severe rainfall and flooding events to have affected the Canterbury region between 1986 and 2015.

March - April 2014: March and April 2014 were remarkably wet months for eastern parts of Canterbury. Christchurch (Riccarton) endured its wettest March on record at the time (records began in 1863). Additionally, of the 200 mm (437% of the March normal) that fell during the month at Christchurch, 123 mm accumulated on one day (4 March), which was the greatest one-day March rainfall on record for the city at the time. The highest one-day rainfall total in New Zealand for the month of March 2014 was 153 mm, recorded at Lyttelton on the 4th. These records were largely as a result of heavy rain that fell on 4 and 5 March, which caused considerable flooding throughout Christchurch and surrounding areas. At least 100 homes in Woolston, Richmond, St Albans and Mairehau were inundated with water, and residents of Akaroa and Sumner were temporarily isolated by flooding. Further significant rainfall was recorded

during April 2014. Winchmore experienced its wettest April on record at the time, with 301 mm recorded there (599% of the April normal). In Christchurch (Riccarton), 224 mm of rain was recorded (499% of the April normal): the second-wettest April observed there on record at the time. Farther north, Kaikoura recorded 264 mm of rain in April (475% of the April normal). Christchurch (Riccarton) received a total of 424 mm of rain for the March-April 2014 period. This is more than four-times greater than the normal March-April rainfall, with the city receiving 71% of its average annual rainfall over the two-month period.

11–14 December 1995: Heavy rain during this period was caused by a front that stalled over the southern South Island. On the evening of 11 December, an active cold front crossed Fiordland and Southland, preceded by a long fetch of northerlies originating from the subtropics. During 12 December, this front was blocked by a large high east of New Zealand and became stationary, while a weak southerly spread into eastern parts of the South Island. Overrunning of moist warm air produced high rainfalls in eastern areas on this day. The combination of snow-melt and heavy rain in the headwaters contributed to a major flood event, and

the hydro-lakes were at abnormally high levels. A Civil Defence Emergency was declared for Hakataramea, Waimate and Omarama districts. Seventeen people were evacuated from seven houses at Hakataramea, and 35 people were evacuated from Omarama. Rivers throughout Canterbury were running high. The Waitaki River at the Waitaki Dam had a peak flow of 3,300 cumecs: the highest flow since recordings began 55 years earlier. Farther north, the main trunk railway line was washed out near Rangitata. Mount Cook Village recorded 515 mm of rain in 72-hours from 9 a.m. on 11 December to 9 a.m. on 14 December.

12–13 March 1986: A very intense rainstorm brought flooding to large parts of Canterbury, resulting in very high damage costs and stock losses. Two key features combined to create this extreme event. Firstly, warm and moist air originating from a tropical cyclone near the Kermadec Islands spread down onto the South Island. Secondly, a high-latitude anticyclone brought cool south-easterly air up the east coast of the South Island. Convergence between the cool and warm airmasses resulted in intense convection. The highest rainfalls of the event occurred in the Timaru district and the western foothills of Ashburton, especially near Peel Forest. A Civil Defence Declaration was in place for the entire Canterbury region. The flood damage to property, roads, railway lines, bridges, crops and livestock throughout South Canterbury was extensive, and estimated to cost \$60,000,000 (1986 dollars). Other damage costs included another \$6,170,000 (1986 dollars) to river control works such as embankments and plantings. Geraldine recorded 102 mm of rain

in the 24-hours from 9 a.m. on 12 March to 9 a.m. the following day, and reported its worst flood since 1929. Rangiora recorded 86 mm of rain in the three hours from 1 a.m. to 4 a.m. on 13 March, and Timaru recorded 100 mm of rain in the 48-hours to 9 a.m. on 13 March.

Periods of low rainfall

Periods of fifteen days or longer with less than 1mm of rain on any day are referred to as 'dry spells'. Dry spells are quite common in most areas of Canterbury, however they occur relatively infrequently in the western-most parts of the region. Dry spells throughout Canterbury typically occur when a persistent (blocking) anticyclone becomes established over the South Island. Additionally, the western ranges provide a great deal of sheltering for eastern areas, such that dry spell conditions can occur in westerly and north-westerly airstreams. Table 12 outlines the dry spell frequency and duration for selected Canterbury locations. On average, a dry spell occurs once every four months in Christchurch, and once every fourteen months in Arthur's Pass. To date, the longest dry spell is 49 days, recorded in Lake Tekapo on three separate occasions. Table 13 shows the seasonal distribution of dry spells at selected Canterbury locations. Dry spell occurrence is fairly evenly distributed throughout the year in Lake Tekapo. In contrast, dry spell occurrence is notably infrequent during spring in Arthur's Pass, reflecting the high frequency of westerly airflows in that season.

Table 12. Average dry spell (at least 15 consecutive days with less than 1 mm rainfall per day) frequency and duration for selected Canterbury locations, from all available data.

Location	Frequency	Mean duration (days)	Max duration (days)	Max duration date
Arthur's Pass	One every 14 months	19	37	18/5/1922 to 23/6/1922
Christchurch	One every 4 months	20	44	2/8/1911 to 14/9/1911
Lake Tekapo	One every 3 months	21	49	18/2/1930 to 7/4/1930 30/9/1937 to 17/11/1937 10/2/1976 to 29/3/1976

Table 13. Seasonal distribution (%) of dry spells at selected Canterbury locations, from all available data.

Location	Summer	Autumn	Winter	Spring
Arthur's Pass	28%	32%	33%	7%
Christchurch	27%	27%	19%	27%
Lake Tekapo	27%	27%	24%	22%

Temperature

Sea surface temperature

Monthly mean sea surface temperatures (SST) off the east coast of Canterbury are compared with mean air temperature for Christchurch and Lake Tekapo in Figure 9. There is a lag in the increase of sea surface temperatures when compared to air temperatures from July to September. This may be at least in part attributed to the greater heat capacity of the sea compared to land, which results in the sea surface temperatures taking longer to increase and decrease in response to changing seasons compared to land-based areas. Christchurch records considerably higher mean air temperatures in winter compared to the inland location of Lake Tekapo. This may be partly attributed to the moderating influence of the sea on overnight minimum temperatures near the coast. Figure 10 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.

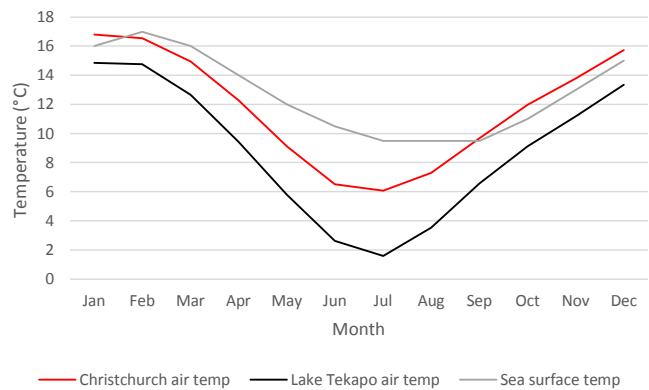


Figure 9. Mean monthly air temperature (Christchurch and Lake Tekapo) and estimated sea surface temperatures (off the east coast of Canterbury).

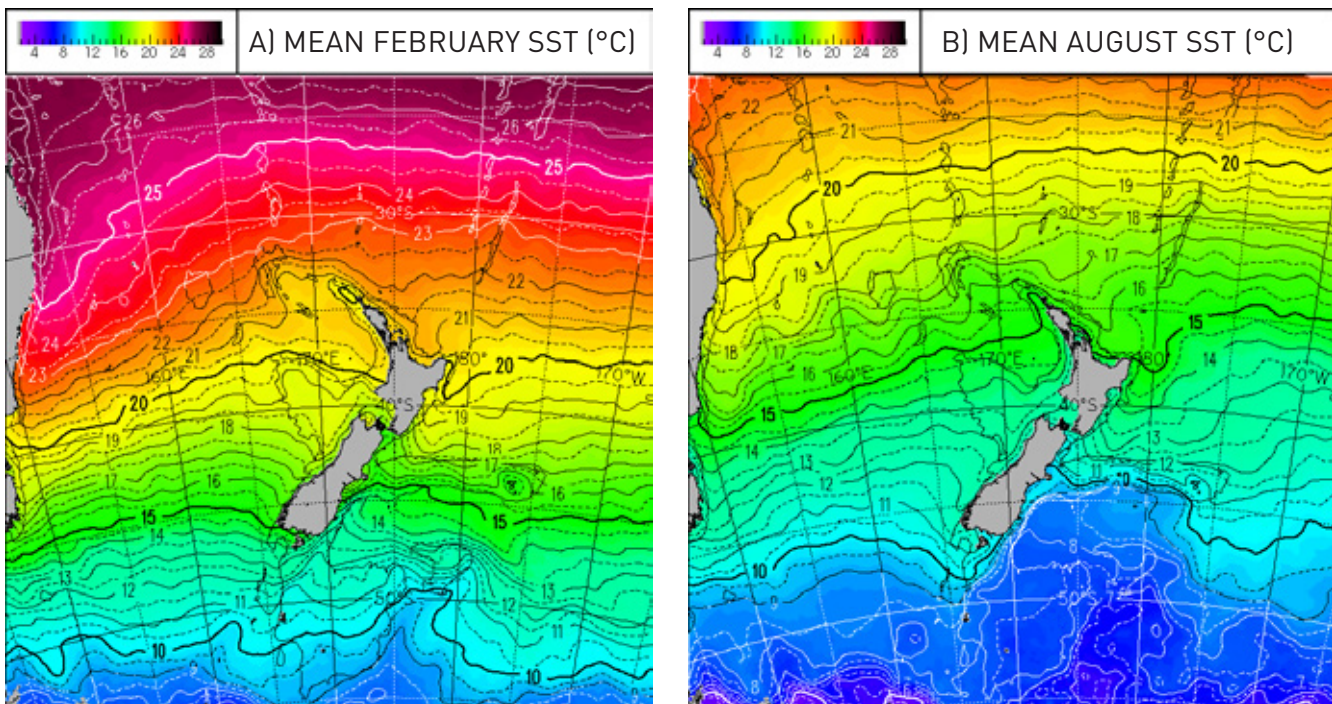


Figure 10. Monthly mean sea surface temperatures (°C) for: a) February; b) August. Source: NIWA SST Archive, Uddstrom and Oien (1999).

Air temperature

Canterbury typically observes afternoon temperatures reaching between 20°C and 23°C in summer, and overnight temperatures falling to between -2°C and 4°C in winter (Figure 11). Similar daily maximum

temperatures are recorded throughout Canterbury, with the notable exception of high elevation hills and mountains where temperatures become increasingly lower as elevation increases. In winter, daily minimum temperatures become lower as distance from the

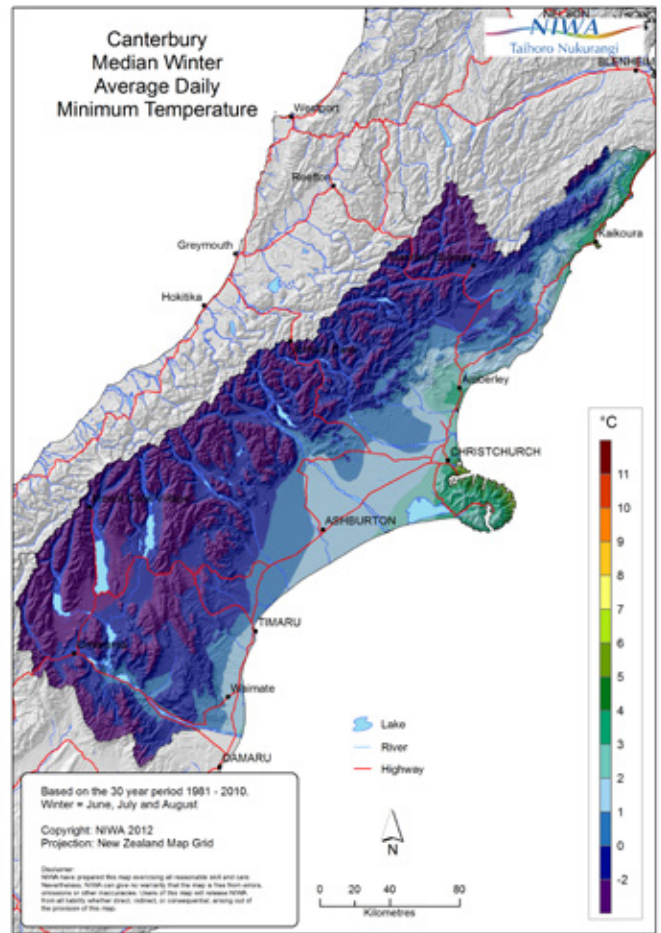
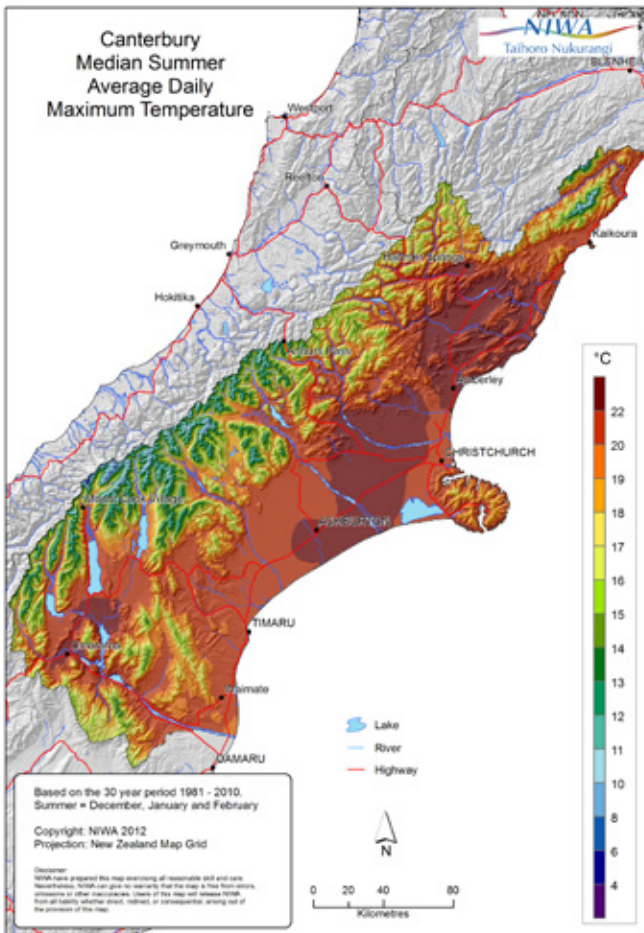


Figure 11. Left: Canterbury median summer [December, January and February] average daily maximum temperature; Right: Canterbury median winter [June, July and August] average daily minimum temperature, 1981–2010.

east coast and elevation increases. Figure 12 shows the median annual average temperature in the Canterbury region, and clearly demonstrates that lower temperatures are recorded at higher elevation locations. Locations near the coast and on the plains have a median annual temperature of between 11°C and 13°C. Median annual temperatures are between 10°C and 11°C nearer the foothills, and between 8°C and 10°C in the inland basins. Median annual temperatures of below 2°C occur along the main divide especially around Mt Cook, which contributes to the perennial snow and glaciers at high elevations in those areas. Figure 13 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 locations in Canterbury.

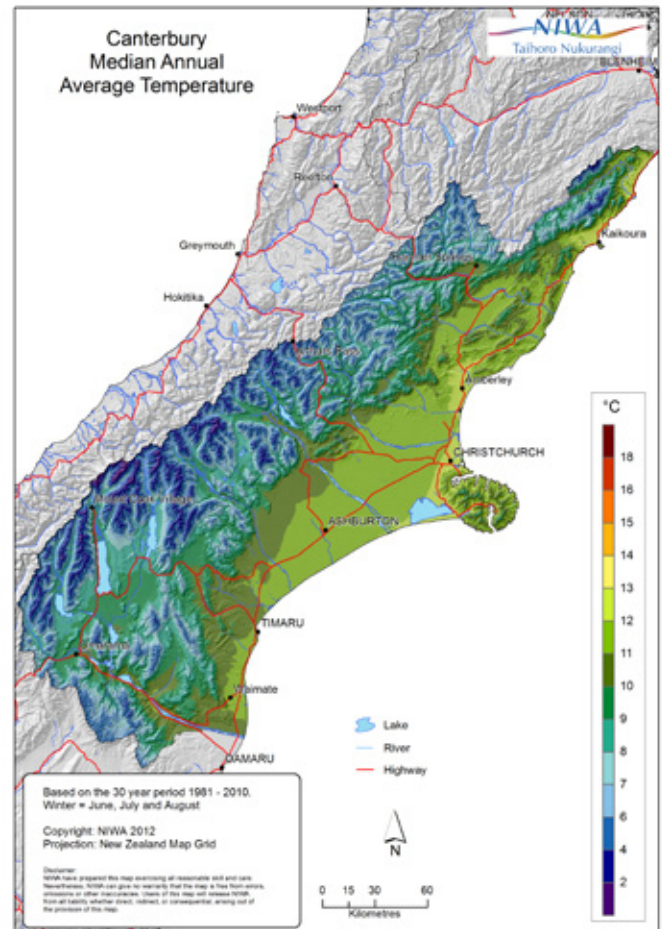


Figure 12. Canterbury median annual average temperature, 1981–2010.

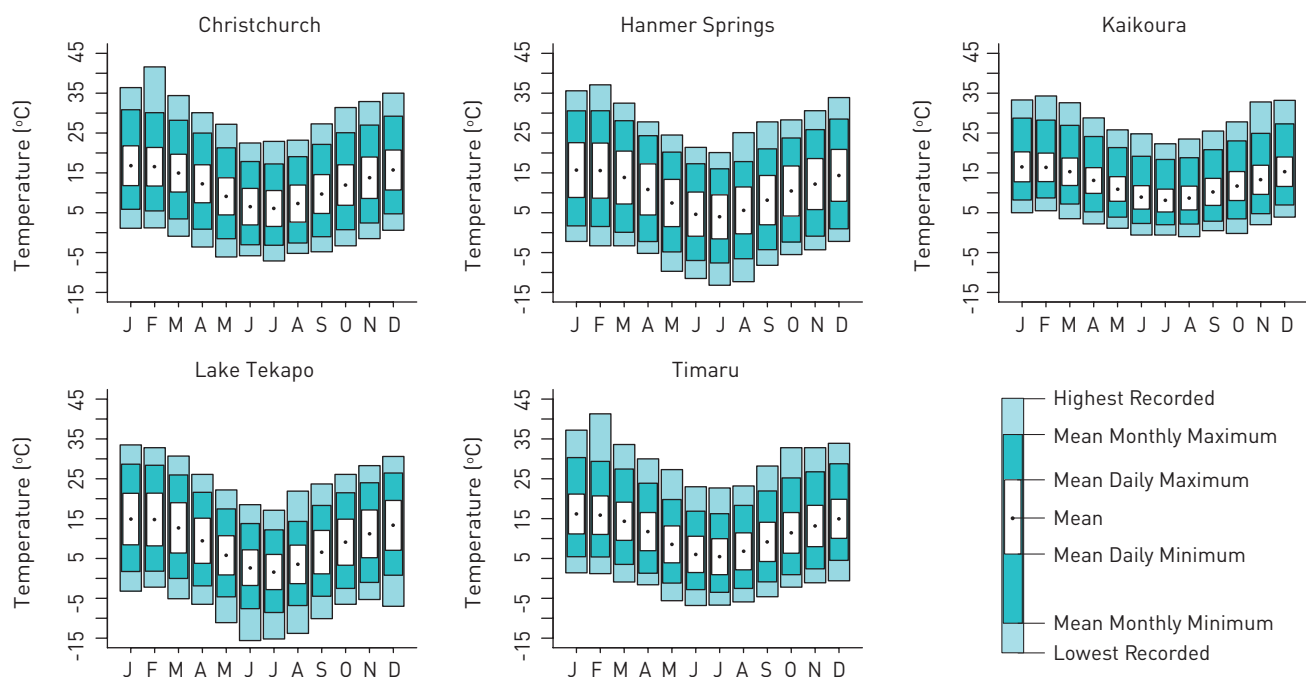


Figure 13. Monthly variation in air temperatures for selected Canterbury locations from all available data.

Table 14 shows that the average daily temperature range, i.e. the difference between the daily maximum and minimum temperature, is typically smaller at the coast (e.g. Kaikoura) than in inland areas (e.g. Hanmer Springs). This is the case for most of the year, however the difference is most prominent from January to April. The average daily temperature range in Lake

Tekapo isn't as pronounced as may be expected given its inland location. This is because the town is located at a relatively high elevation (the local climate station is 762 metres above sea level), which constrains the daily maximum air temperatures, particularly during the summer months.

Table 14. Average daily temperature range ($T_{max} - T_{min}$, °C) for selected Canterbury locations.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Christchurch	10.0	9.7	9.5	9.5	9.3	9.2	9.0	9.3	9.8	10.2	10.4	10.0	9.6
Hanmer Springs	13.7	13.8	13.3	12.8	11.8	11.1	11.0	11.8	12.4	12.6	12.8	13.0	12.5
Kaikoura	7.5	7.2	6.9	6.5	6.2	5.9	5.7	6.0	6.8	7.3	7.3	7.4	6.7
Lake Tekapo	12.9	13.2	12.6	11.3	9.8	8.9	8.8	9.7	10.9	11.6	12.0	12.5	11.2
Timaru	10.0	9.7	9.6	9.6	9.3	9.1	9.0	9.3	9.8	10.2	10.4	9.8	9.6

Table 15. Median hourly mean air temperatures for January and July at Christchurch and Lake Tekapo.

		00	01	02	03	04	05	06	07	08	09	10	11
Christchurch	January	14.7	14.4	14.0	14.0	13.8	13.7	13.7	14.4	15.7	16.8	17.8	18.8
	July	5.3	4.8	4.6	4.3	4.0	3.9	3.8	3.7	3.6	3.8	5.4	7.3
		12	13	14	15	16	17	18	19	20	21	22	23
	January	19.3	19.8	19.9	19.8	19.2	18.7	18.1	17.3	16.2	15.7	15.3	15.1
	July	8.7	9.5	9.9	10.0	9.7	8.9	7.8	7.0	6.5	6.2	6.0	5.6
	Lake Tekapo	January	11.4	11.1	10.8	10.3	9.8	9.6	9.5	11.2	13.2	14.8	16.1
July		-0.2	-0.3	-0.4	-0.6	-0.7	-0.8	-0.8	-0.9	-0.8	-0.6	0.9	2.6
		12	13	14	15	16	17	18	19	20	21	22	23
January		18.4	19.3	19.9	20.1	20.2	19.9	19.2	18.2	16.8	14.4	13.2	12.3
July		3.8	4.4	5.1	5.4	5.1	4.2	2.0	0.9	0.6	0.6	0.2	0.0

Table 15 and Figure 14 further highlight the diurnal temperature range, showing the median hourly mean air temperature for January and July at Christchurch and Lake Tekapo. Air temperatures at Lake Tekapo remain lower than Christchurch at all hours of the day in July, but become higher from 3 p.m. to 8 p.m. in January. Note that hourly mean air temperature at a given time is calculated as the mean of many air temperature observations recorded over the previous hour. As such, both the daily maximum and minimum air temperatures calculated from hourly values are dampened, resulting in a reduced diurnal temperature range (Table 15) compared to the absolute daily temperature range (Table 14) recorded at Christchurch and Lake Tekapo.

Maximum air temperatures in excess of 25°C occur relatively frequently throughout the plains, particularly in Darfield, where an annual average of 45 such days occur (Table 16). Furthermore, locations on the plains reach maximum air temperatures in excess of 30°C relatively frequently when compared to remaining parts of New Zealand. Inland parts of

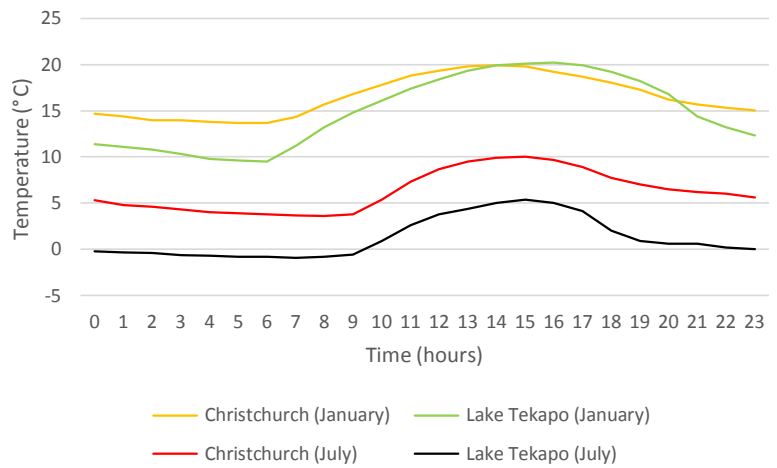


Figure 14. Median hourly mean air temperatures at Christchurch and Lake Tekapo in January and July.

Canterbury record considerably more days with a minimum temperature below 0°C compared to locations closer to the coast. Indeed, the inland basins of Canterbury frequently observe New Zealand’s lowest daily minimum temperature during winter. The highest air temperature recorded in Canterbury to date is 42.4°C at Rangiora on 7 February 1973. This temperature is additionally the highest recorded in New Zealand, and occurred on the last day of an extremely hot spell in Rangiora between 31 January and 7 February 1973. During these eight days, the average daily maximum temperature was 32.1°C, with the temperature reaching at least 32.5°C on five out of the eight days. Tara Hills (Omarāma) recorded the lowest air temperature in Canterbury; -21.0°C on 24 June 2015.

Table 16. Highest and lowest recorded air temperatures, average number of days per year where maximum air temperature exceeds 30°C and 25°C, and average number of days per year where the minimum air temperature falls below 0°C, for selected Canterbury locations from all available data.

Location	Highest recorded (°C)	Annual days max temp > 30°C	Annual days max temp > 25°C	Lowest recorded (°C)	Annual days min temp < 0°C
Akaroa	35.5	5	35	-8.0	11
Arthur’s Pass	32.1	0.03	3	-12.5	90
Ashburton	41.3	7	39	-11.6	51
Christchurch	41.6	3	25	-7.2	34
Culverden	38.0	6	41	-11.0	70
Darfield	40.7	8	45	-11.8	34
Kaikoura	34.3	1	14	-1.0	0.1
Lake Tekapo	33.5	0.8	17	-16.7	100
Mount Cook Village	32.8	0.3	11	-13.9	98
Rangiora	42.4	5	31	-7.6	47
Tara Hills (Omarāma)	34.9	3	25	-21.0	88
Timaru	41.3	2	17	-9.1	35
Waimate	39.0	2	17	-10.0	36
Waipara	38.0	7	43	-7.5	25

Earth temperatures

Earth (soil) temperatures are measured once daily at 9 a.m. at several Canterbury locations. Earth temperatures are measured at varying depths and are important 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 17 lists mean monthly earth temperatures for a number of standard depths. At the coastal Christchurch location, higher winter earth temperatures are observed when compared to the inland location of Tara Hills.

Figure 15 shows how earth temperatures change throughout the year at Christchurch, compared with mean air temperature. The 10 cm earth temperatures are lower than the mean air temperature except during summer. The annual earth temperature cycle at 100 cm depth is more dampened and lagged than at shallower depths. As a result, earth temperatures at 100 cm remain above mean air temperature in June and July, but fall slightly below mean air temperatures during spring, before returning to higher temperatures than the mean air temperature in summer. Diurnal

variation of earth temperatures (not shown) decreases with increasing depth, such that earth temperatures may show little-to-no diurnal variation at 100 cm depth.

Frosts

Frost is a local phenomenon and both its frequency of occurrence and intensity can vary widely over small areas. Frosts occur most frequently in winter during periods of anticyclonic conditions, primarily for two reasons. Firstly, clear skies associated with anticyclones enhance the rate of radiative cooling during the night. Secondly, anticyclones are associated with light winds, which reduces the amount of turbulent mixing of air. Cold air is relatively dense, so when there is a lack of turbulent mixing it tends to sink towards the earth surface. Therefore, areas most likely to experience frost are flat areas, where relatively cold air is not able to drain away on calm nights, and in valleys and basins, where relatively cold air pools after descending from higher elevation areas nearby. Under such conditions, temperature inversions (where the air temperature increases with elevation) are common.

Table 17. Monthly and annual mean 9 a.m. earth temperatures (°C) at varying depths from the ground surface for selected Canterbury locations.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Christchurch	10 cm	17.4	16.7	14.3	10.8	7.3	4.5	3.8	4.8	7.3	10.5	13.7	16.2	10.6
	20 cm	18.5	18.1	15.6	12.2	8.4	5.4	4.6	5.7	8.1	11.2	14.5	16.9	11.6
	30 cm	19.2	18.9	16.6	13.3	9.5	6.3	5.4	6.5	8.9	12.0	15.1	17.6	12.5
	100 cm	18.1	18.4	17.2	14.8	11.6	8.6	7.0	7.4	9.0	11.4	14.2	16.4	12.9
Rangiora	10 cm	17.3	16.5	14.0	11.2	7.8	5.0	4.3	5.7	8.3	10.7	13.9	16.3	10.8
	20 cm	17.9	17.6	15.7	12.3	9.1	6.2	5.4	6.6	8.8	11.2	14.4	16.7	11.9
	50 cm	17.9	17.8	16.3	13.9	11.1	8.3	6.9	7.7	9.6	11.7	14.5	16.5	12.6
	100 cm	17.2	17.7	16.8	15.1	12.9	10.5	8.9	9.0	10.2	11.8	14.0	15.7	13.3
Tara Hills (Omarama)	10 cm	16.7	15.9	13.0	8.5	4.2	1.4	0.5	2.1	5.1	8.8	12.6	15.5	8.7
	20 cm	17.8	17.6	14.6	10.1	5.6	2.4	1.3	2.9	5.9	9.4	13.2	16.2	9.7
	30 cm	18.5	18.2	15.5	11.0	6.3	2.9	1.8	3.3	6.3	10.1	13.8	16.6	10.4
	50 cm	18.1	18.5	15.3	11.6	7.7	5.0	3.1	4.2	7.0	9.8	13.2	16.2	11.1
	100 cm	17.0	17.8	16.0	13.0	9.3	5.8	3.7	4.4	6.8	9.4	12.6	15.3	11.1

There are two types of frost recorded. Air frosts occur when air temperature measured by a thermometer in a screen 1.3 m above the ground falls below 0°C. Ground frosts are recorded when the air temperature 2.5 cm above a closely cut grass surface falls to -1.0°C or lower. Both types of frost are common in Canterbury in the cooler months. Table 18 lists for selected locations the mean daily grass minimum and extreme grass minimum temperatures, and the average number of days each month with ground and air frosts. Ground frosts occur more frequently than air frosts, and air frosts occur most frequently at the inland location of Lake Tekapo.

Hoar frost is another form of frost which occurs infrequently, and its occurrence in Canterbury is typically limited to the inland basins. Hoar frost occurs when water vapour in the air contacts features at the Earth's surface (e.g. tree leaves, branches, fences) that are below 0°C. The water vapour condenses and freezes upon contact, enabling ice crystals (frost) to form on the individual features, making for a scenic phenomenon.

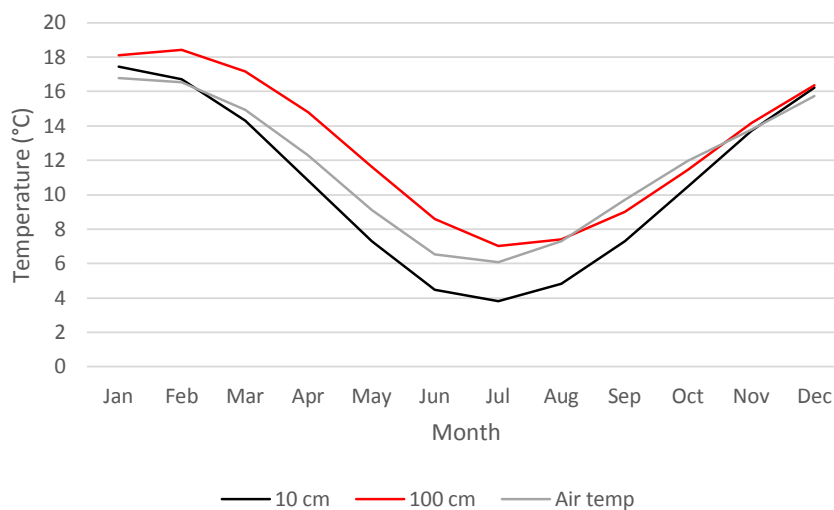


Figure 15. Monthly mean 9 a.m. earth temperature at different depths from the ground surface, and monthly mean air temperature, from all available data at Christchurch.

Table 18. Frost occurrence and grass minimum temperatures at selected Canterbury locations from all available data.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Christchurch	a	9.1	9.0	7.1	4.1	1.2	-1.2	-1.5	-0.8	1.1	3.2	5.2	7.8
	b	-4.9	-3.0	-6.2	-11.3	-11.5	-14.9	-12.1	-12.9	-11.7	-9.0	-6.9	-6.3
	c	0.1	0.2	1	4	11	18	19	17	10	5	2	0.4
	d	0	0	0.01	0.5	3	9	11	7	2	0.3	0.1	0
Darfield	a	8.3	8.3	6.4	3.3	0.5	-2.0	-2.6	-1.6	0.3	2.6	4.5	7.1
	b	-0.8	-1.6	-4.2	-5.8	-8.9	-9.7	-14.1	-10.7	-8.6	-9.1	-6.7	-3.0
	c	0	0.1	0.8	5	13	20	22	19	13	7	3	0.3
	d	0	0.01	0.03	0.7	4	10	13	9	4	1	0.3	0
Lake Tekapo	a	5.0	4.7	2.7	-0.1	-2.7	-5.1	-6.0	-4.5	-2.0	0.1	2.0	4.0
	b	-10.7	-9.5	-11.7	-12.5	-14.4	-21.1	-20.6	-21.6	-14.9	-15.3	-11.1	-8.8
	c	3	3	7	13	21	25	27	25	18	12	8	4
	d	0.2	0.2	0.9	4	12	21	24	20	10	5	2	0.5

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

Sunshine and Solar Radiation

Sunshine

Sunshine hours are highest in the inland basins of Canterbury, which typically receive between 2,100 and 2,300 hours of sunshine annually (Figure 16). Lake Tekapo is frequently one of the top-5 sunniest locations in New Zealand on an annual basis. The remainder of the Canterbury region receives moderate annual sunshine hours compared to the rest of New Zealand. The notable exception is high elevation mountainous areas, where increased cloudiness reduces the annual sunshine totals experienced. Figure 17 shows the monthly mean, maximum, and minimum recorded bright sunshine hours for selected locations in Canterbury. Note that the lower sunshine hours recorded in the winter months tends to reflect the northerly declination of the sun, as opposed to signalling an increase in cloudiness during those times.

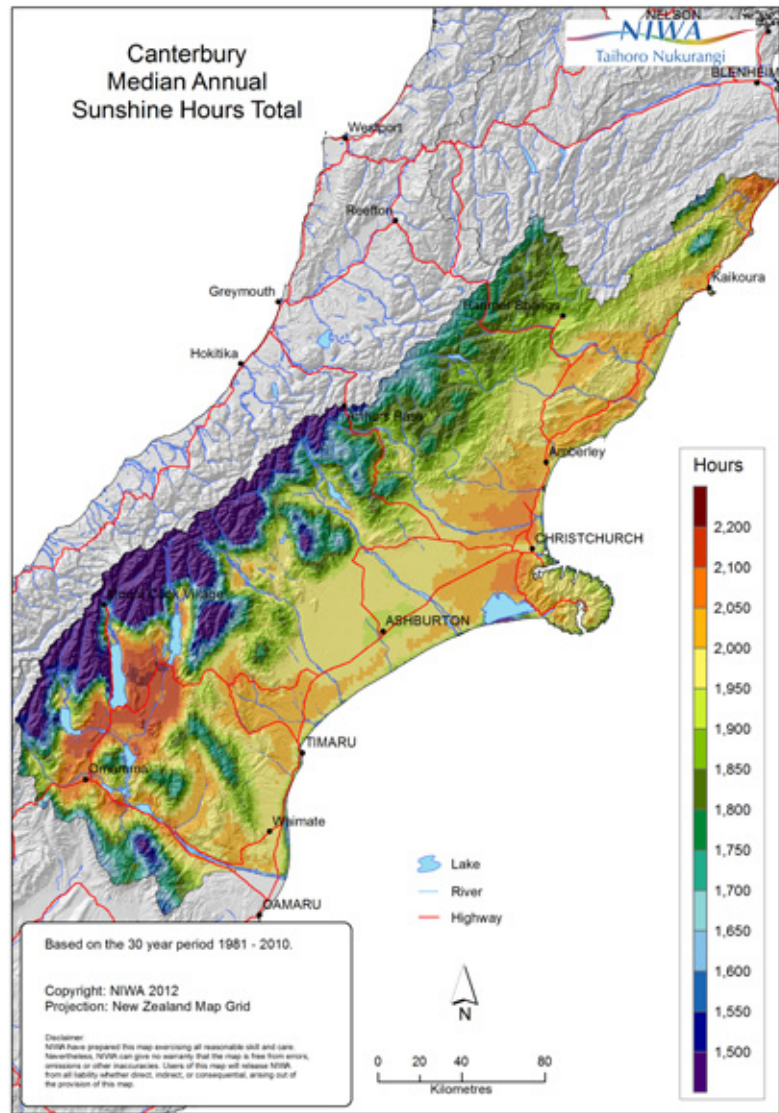


Figure 16. Median annual sunshine hours for Canterbury, 1981–2010.

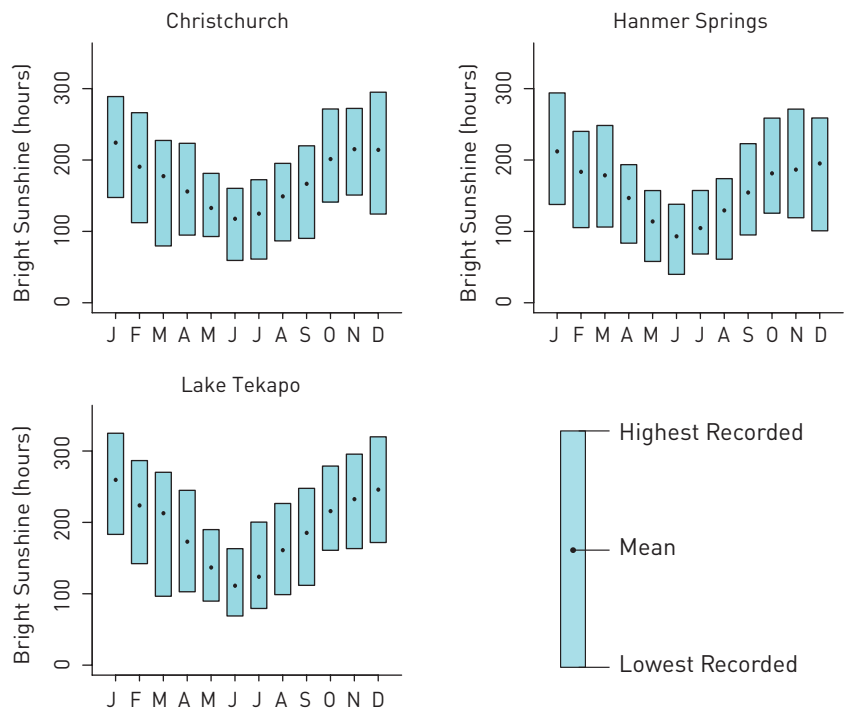


Figure 17. Mean, highest and lowest recorded monthly bright sunshine hours for selected locations in Canterbury from all available data.

Solar radiation

Solar radiation observations of greater than 10 years are available for only a few sites in Canterbury. Table 19 presents the mean daily global (i.e. direct and diffuse) solar radiation for Christchurch, Hanmer Springs and Lake Tekapo. Insolation is highest in December in Christchurch and Hanmer Springs, but peaks in January at Lake Tekapo. Insolation is at a minimum in June at all locations.

Table 19. Mean daily global solar radiation (MJ/m²/day) for selected Canterbury locations from all available data.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Christchurch	21.9	18.8	14.1	9.7	6.2	4.7	5.3	8.0	12.3	17.3	21.2	22.3	13.5
Hanmer Springs	21.7	19.1	15.0	9.9	6.6	5.0	5.9	8.4	12.8	17.1	21.0	21.9	13.7
Lake Tekapo	24.9	21.5	16.4	11.1	6.8	5.7	6.3	9.4	13.9	18.7	24.0	24.5	15.3

UV (ultra-violet) radiation

The mean daily ultra violet radiation (UV) index recorded at Christchurch is compared to that recorded at Leigh (a site north of Auckland) in Figure 18. Christchurch records lower UV levels than Leigh throughout the year due to its relatively southern location. Both sites record significantly higher UV levels in summer than in winter, with maximum UV levels recorded in January and minimum UV levels recorded in June. Figure 19 shows an example of a UV forecast for Christchurch, indicating the UV levels and times of the day when sun protection is required.

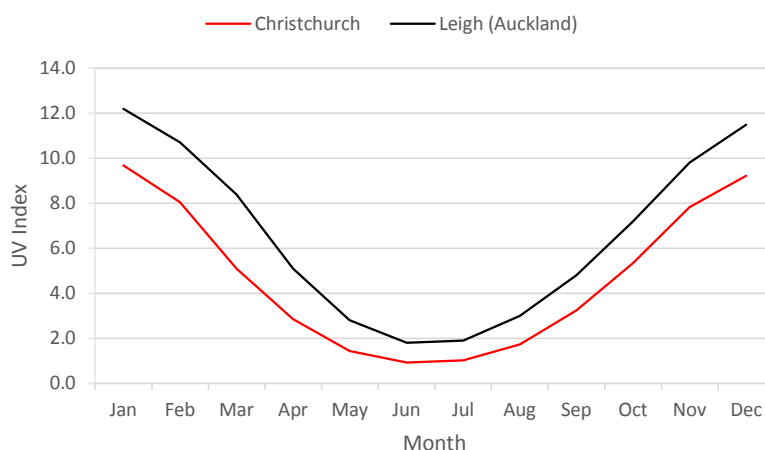


Figure 18. Mean daily maximum UV index for each month at Christchurch and Leigh.

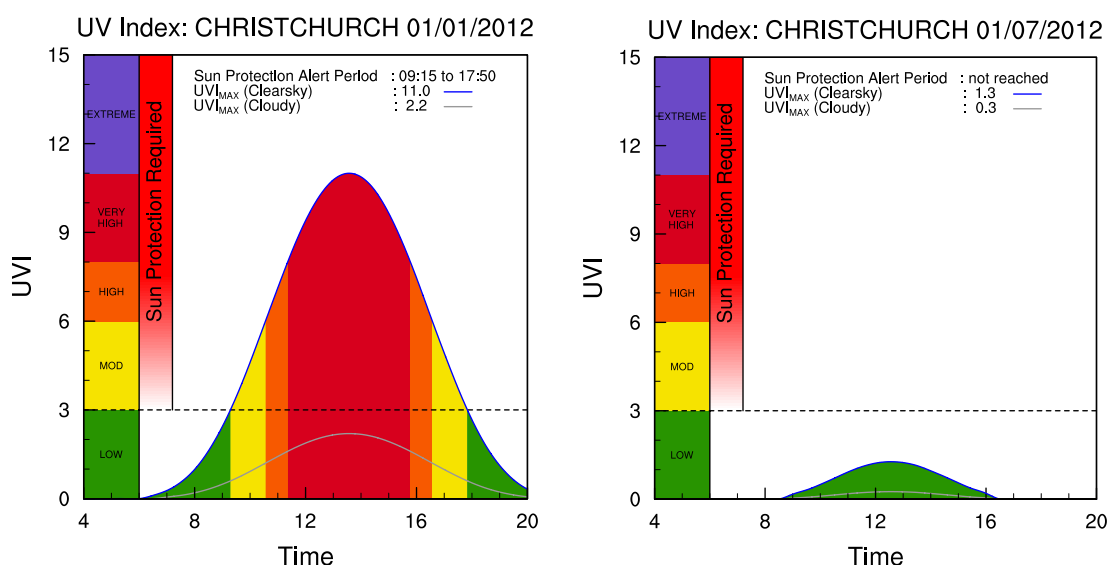


Figure 19. UV Index forecast for Christchurch, January and July. Source: <https://www.niwa.co.nz/our-services/online-services/uv-and-ozone>.

Other elements

Snow

Snowfalls occur quite frequently in Canterbury relative to other parts of New Zealand. Table 20 shows the average number of days each year that snowfall occurs at selected Canterbury locations. Snow doesn't tend to settle for longer than a day or two at a time, except after particularly heavy snowfall events or in higher elevation inland locations. The exception is Canterbury's extensive mountainous terrain, where seasonal snowfields typically begin to accumulate in late autumn, and persist through to early summer. Heavy and frequent snowfalls occur in the western-most mountains of Canterbury which contributes to the perennial snow and glaciers at high elevations in those areas. A single winter storm cycle can deposit 2 - 3 m of snow in the Fiordland mountains farther south (Conway et al., 2000), and it is likely that similar totals would be recorded along and near the main divide in Canterbury. The alpine passes over Porters Pass, Arthur's Pass and Lewis Pass are often subject to snowfall in winter, requiring the use of chains by motorists and forcing closure of those roads from time to time. Snow has an important role to play for the economy of the Canterbury region. Commercial skifields and heli-ski companies operate throughout the region, attracting thousands of visitors each winter.

In June 2006 a significant snow event struck throughout Canterbury. The snowstorm was a result of a rapidly deepening depression moving south-eastward from the Tasman Sea across New Zealand, with a strong moist north-westerly flow preceding it and a very cold southerly airflow behind. Notably, the depression's central pressure fell by 20 hPa in the 24-hours between midnight 10 June and midnight 11 June. Snow fell in Canterbury overnight on 11 June and lay for about two weeks across the plains. The weight of snow and ice destroyed more than 500 power poles around the region, cutting power to 35,000 homes and businesses. On 21 June, 800 mid- and south-Canterbury homes went into their 10th day without power. Between 30 and 60 cm of snow accumulated over much of the plains, with approximately 40 cm recorded in Ashburton, 30 cm in Timaru and 15 cm in Christchurch. The insurance cost of the June snow in the South Island was \$43.91 million (in 2006 dollars), making it the third-most expensive single weather event in New Zealand at that time.

Table 20. Average number of days each year with snow, thunder, hail and fog recorded at selected Canterbury locations, from all available data. The elevation of each station above mean sea level is also shown.

Location	Snow	Thunder	Hail	Fog
Christchurch Airport (37 m)	3	3	6	49
Darfield (195 m)	4	3	2	14
Kaikoura (108 m)	2	4	6	26
Lake Tekapo (762 m)	12	2	0.3	9
Mount Cook Village (765 m)	24	9	2	12
Tara Hills, Omarama (488 m)	11	6	2	22
Timaru Airport (25 m)	1	2	2	18



Thunderstorms

Thunder occurs relatively infrequently in Canterbury compared to other regions of New Zealand, with three or fewer days of occurrence per year in Christchurch, Darfield and Timaru (Table 20.) However, thunder occurs more frequently in the west of the region, with Mount Cook Village recording thunder on nine days per year, on average. Due to the localised nature of thunderstorm occurrence, it is possible that not all thunderstorms are detected at each station.

Thunderstorms in Canterbury are associated with bouts of high intensity rainfall, lightning, hail, and wind squalls which sometimes cause considerable localised flooding and damage to vegetation and buildings.

Hail

Table 20 gives the average number of days per year on which hail is reported at selected locations. Hail occurs most often at Christchurch and Kaikoura compared with the other locations shown. As with thunder, hail can be a localised event, meaning some falls may escape detection at some stations. Severe hailstorms may be classified as those which cause damage and/or have hailstones of at least 0.5 cm in diameter. One such severe hailstorm occurred in Ashburton late in the afternoon on 17 November 2008. The hail stones were larger than 2.5 cm in diameter, with some reportedly as large as golf balls. The hail smashed glasshouses, skylights and windows, ruined gardens, damaged street lights and shop signs and created hazardous driving conditions. Hundreds of cars were damaged, and local orchardists had their crops decimated. Ashburton Airport recorded 13.6 mm of rainfall in the hour between 4 p.m. and 5 p.m.

Fog

The most common type of fog in the Canterbury basins is radiation fog, formed when the air cools to its dew-point on clear nights, allowing the water vapour in the air to condense. Near the coast, advection fog can occur, where sea fog spreads onto the land as evening cooling proceeds. The average number of days per year with fog for selected locations in Canterbury is listed in Table 20. The frequency of fog varies widely over the Canterbury region, ranging from an average of nine days with fog per year at Lake Tekapo to an average of 49 days per year at Christchurch Airport. Although fog can occur at any time of the year in Canterbury, it is recorded most frequently during late-

autumn and winter. For example, of the annual average of 49 days with fog at Christchurch Airport, 24 days (49%) are recorded between May and August. Similarly at Tara Hills, of the annual average of 22 days with fog there, 11 days (50%) are recorded between these same months.



DERIVED CLIMATOLOGICAL PARAMETERS

Apart from elements such as temperature and rainfall which can be measured directly, it has been found that parameters calculated 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 and their uses are discussed in the following paragraphs. Note that short-duration high intensity rainfalls have already been addressed in this publication.

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 hygograph may be used to obtain continuous humidity readings.

Vapour pressure is the part of the total atmospheric 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). Mean monthly 9 a.m. vapour pressures for several locations are given in Table 21, which shows that vapour pressures are lowest in the winter months.

Relative humidity relates the amount of water present in the atmosphere to the amount of water necessary to saturate the atmosphere. Unlike vapour pressure, relative humidity is dependent on the air temperature. This is because as air temperature increases, the capacity of the atmosphere to hold water also increases. Therefore, relative humidity often displays large diurnal variation. Table 22 highlights this diurnal variation, showing 9 a.m. relative humidity is higher than that recorded at 3 p.m. at corresponding times of the year. Highest relative humidity is experienced in the winter months due to lower air temperatures.

Table 21. Mean monthly and annual 9 a.m. vapour pressure (hPa) at selected Canterbury locations from all available data.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Arthur's Pass	11.1	11.2	10.2	8.8	7.8	6.8	6.2	6.6	7.3	8.0	8.9	10.3	8.6
Christchurch	13.3	13.8	12.8	11.0	8.9	7.3	7.0	7.8	9.0	10.0	10.8	12.3	10.3
Darfield	12.8	13.3	12.1	10.6	8.7	7.4	7.0	7.5	8.5	9.5	10.6	12.0	10.0
Kaikoura	13.5	13.7	12.4	10.9	9.2	7.9	7.3	7.8	8.6	9.6	10.9	12.7	10.4
Lake Tekapo	10.1	10.5	9.7	8.2	6.5	5.6	5.2	5.7	6.4	7.2	7.9	9.4	7.7
Timaru	13.5	13.7	12.2	10.7	8.6	6.7	6.4	7.4	8.8	9.7	10.8	12.6	10.1

Table 22. Mean monthly and annual 9 a.m. (a) and 3 p.m. (b) relative humidity (%) at selected Canterbury locations.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Arthur's Pass	a	85	88	89	90	91	92	92	91	87	86	82	83	88
	b	60	61	65	68	76	77	75	72	65	56	62	61	67
Christchurch	a	72	79	81	84	86	87	88	86	79	74	70	71	80
	b	58	60	57	59	69	76	69	69	58	63	59	59	63
Darfield	a	75	82	81	82	82	83	83	81	76	75	74	74	79
	b	53	60	53	54	65	71	65	67	55	59	56	57	60
Kaikoura	a	75	78	76	75	72	71	70	71	70	72	73	75	73
	b	71	73	71	69	74	76	73	75	63	73	72	69	72
Lake Tekapo	a	63	70	73	77	79	82	83	80	71	65	62	63	72
	b	40	43	41	49	61	66	65	61	46	44	38	39	49
Timaru	a	78	84	85	86	87	85	86	84	78	79	75	76	82
	b	64	65	62	65	72	68	64	70	58	66	64	65	65

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 potential rate until total 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 at field capacity. 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 deficit occurs and irrigation becomes necessary to maintain plant growth. Runoff occurs when the rainfall exceeds the field capacity (assumed to be 150 mm for most New Zealand soils).

Mean monthly and annual water balance values for a number of locations in Canterbury are given in Table 23. Soil moisture deficit peaks in summer throughout Canterbury, with highest soil moisture deficit observed in Christchurch and Tara Hills, whereas runoff peaks in the winter months. Compared to the remainder of New Zealand, mean soil moisture deficit observed throughout the year in Christchurch and Tara Hills is relatively high. Figure 20 shows region-wide variability in days of soil moisture deficit per year, which further illustrates the dryness of Christchurch, Tara Hills, and the east coast north of Kaikoura compared to other areas of Canterbury.

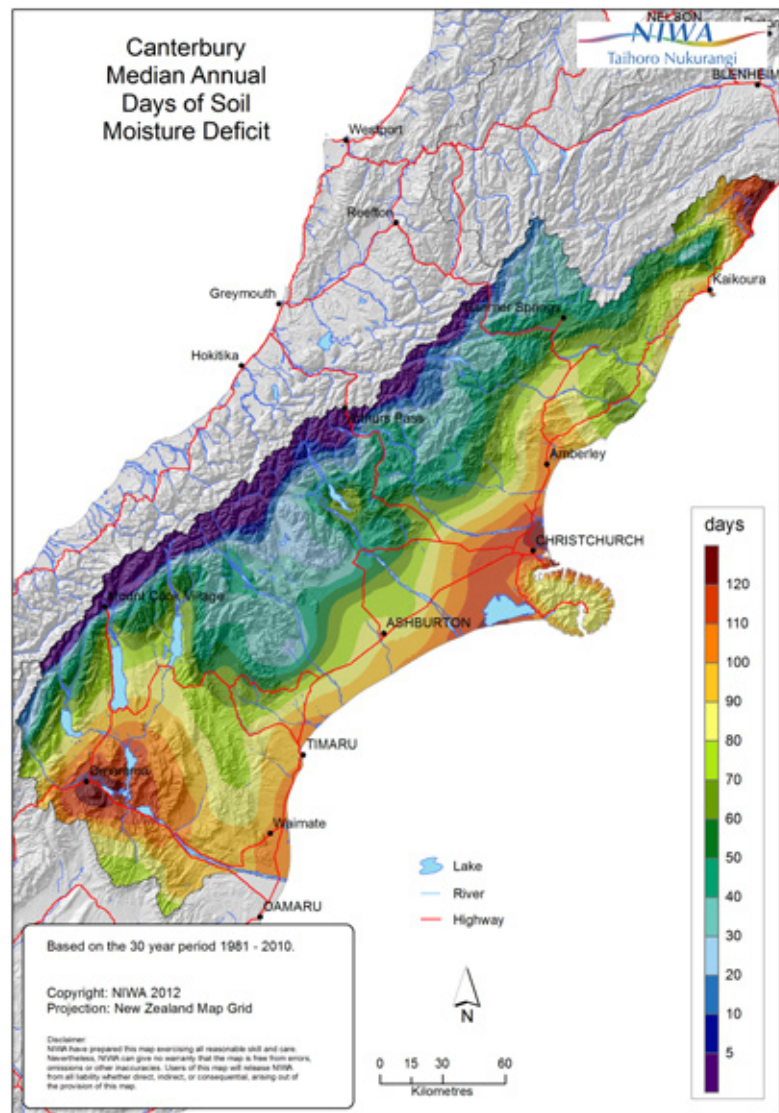


Figure 20. Median annual days of wilting point deficit for Canterbury, 1981-2010.

Potential evapotranspiration (PET) has been calculated for Christchurch, Hanmer Springs and Tara Hills using the Penman method (Penman, 1948). The monthly mean, minimum, and maximum PET values for these locations are listed in Table 24.

Table 23. Mean monthly and annual water balance summary for a soil moisture capacity of 150 mm at selected Canterbury locations.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Christchurch	DE	108	73	43	15	2	1	0	0	3	26	71	97	439
	ND	22	18	15	9	3	1	0	0	1	8	17	20	114
	RO	0	0	0	2	8	18	33	29	8	2	1	0	101
	NR	0	0	0	0	1	3	4	3	1	0	0	0	13
Hanmer Springs	DE	50	42	19	3	0	0	0	0	0	1	11	34	160
	ND	12	12	7	2	0	0	0	0	0	0	3	8	45
	RO	7	5	14	25	62	82	92	92	47	34	15	12	486
	NR	0	0	1	2	6	9	10	8	5	4	1	1	47
Methven	DE	54	37	25	7	1	0	0	0	0	7	23	41	195
	ND	12	10	9	4	1	0	0	0	0	2	6	9	53
	RO	4	4	8	11	18	34	40	45	18	14	6	6	209
	NR	0	0	0	1	2	4	5	5	2	1	0	0	21
Tara Hills (Omarama)	DE	99	79	44	18	2	0	0	0	3	26	73	92	436
	ND	20	19	15	11	2	0	0	0	2	8	17	19	115
	RO	0	0	0	0	0	7	7	12	7	1	0	0	33
	NR	0	0	0	0	0	1	1	2	1	0	0	0	5
Timaru	DE	60	45	26	10	1	1	0	1	4	16	41	57	263
	ND	16	14	11	8	2	1	1	1	3	6	12	16	91
	RO	1	2	1	3	4	11	15	15	8	3	1	1	65
	NR	0	0	0	0	1	1	2	2	1	0	0	0	8

DE: average amount of soil moisture deficit (mm)
 ND: average number of days on which a soil moisture deficit occurs
 RO: average amount of runoff (mm)
 NR: average number of days on which runoff occurs

Table 24. Penman calculated maximum, mean, and minimum monthly potential evapotranspiration (mm), and mean annual total potential evapotranspiration, for selected Canterbury locations.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Christchurch	Max	194	139	124	61	40	26	26	49	82	146	175	191	
	Mean	152	114	86	47	26	16	19	33	57	95	126	148	919
	Min	113	91	59	33	16	10	12	25	44	70	98	111	
Hanmer Springs	Max	163	130	110	53	33	23	19	38	70	105	137	150	
	Mean	124	95	73	38	19	11	13	26	50	79	101	117	745
	Min	94	71	53	27	10	3	7	16	30	58	75	86	
Tara Hills (Omarama)	Max	200	142	118	64	40	23	20	38	81	114	172	175	
	Mean	151	115	84	44	21	9	11	26	55	91	121	144	872
	Min	100	87	52	26	8	2	4	14	40	60	83	109	

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 25 lists the mean monthly growing degree-day totals above base temperatures of 5°C and 10°C for locations in Canterbury.

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 26 shows that the number of cooling degree days reaches

a peak in mid-late summer in Canterbury, when energy required to cool building interiors to 18°C is highest. Conversely, heating degree days reach a peak in winter, when the energy required to heat buildings to 18°C is highest. Figure 21 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.

Table 25. Average growing degree-day totals above base 5°C and 10°C for selected Canterbury locations.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Arthur's Pass	5°C	247	231	187	101	39	11	5	9	35	75	130	200	1268
	10°C	99	95	51	9	1	0	0	0	0	4	23	61	344
Christchurch	5°C	365	326	308	218	129	55	47	77	142	216	264	333	2480
	10°C	211	185	154	78	23	4	3	7	28	74	117	178	1062
Darfield	5°C	380	336	315	221	133	58	48	82	142	202	253	328	2499
	10°C	225	195	161	82	26	6	4	9	31	66	110	175	1091
Kaikoura	5°C	358	322	317	244	188	119	99	115	159	208	249	320	2699
	10°C	203	180	162	98	51	20	11	16	37	68	104	166	1117
Lake Tekapo	5°C	307	276	241	136	53	13	7	18	63	132	188	259	1693
	10°C	155	138	96	29	4	0	0	0	5	26	61	113	628
Timaru	5°C	345	306	290	202	111	44	33	63	125	200	245	309	2274
	10°C	190	165	136	62	13	2	1	3	19	58	98	154	903

Table 26. Average cooling (CDD) and heating (HDD) degree-day totals with base 18°C for selected Canterbury locations.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Arthur's Pass	CDD	1	1	0	0	0	0	0	0	0	0	0	0	1
	HDD	157	137	216	293	390	456	498	455	376	335	262	203	3779
Christchurch	CDD	23	18	8	1	0	0	0	0	0	1	4	14	68
	HDD	60	59	103	173	275	345	370	332	249	188	130	84	2370
Darfield	CDD	32	26	11	1	0	0	0	0	0	1	4	15	91
	HDD	55	57	99	171	272	348	373	329	250	202	140	90	2386
Kaikoura	CDD	19	16	9	1	0	0	0	0	0	0	2	12	60
	HDD	64	61	96	147	215	272	305	289	231	195	143	94	2113
Lake Tekapo	CDD	10	7	1	0	0	0	0	0	0	0	1	2	21
	HDD	106	99	164	256	379	459	509	447	342	275	204	146	3385
Timaru	CDD	14	10	4	0	0	0	0	0	0	1	2	7	38
	HDD	72	71	117	188	293	359	389	347	266	204	147	101	2555

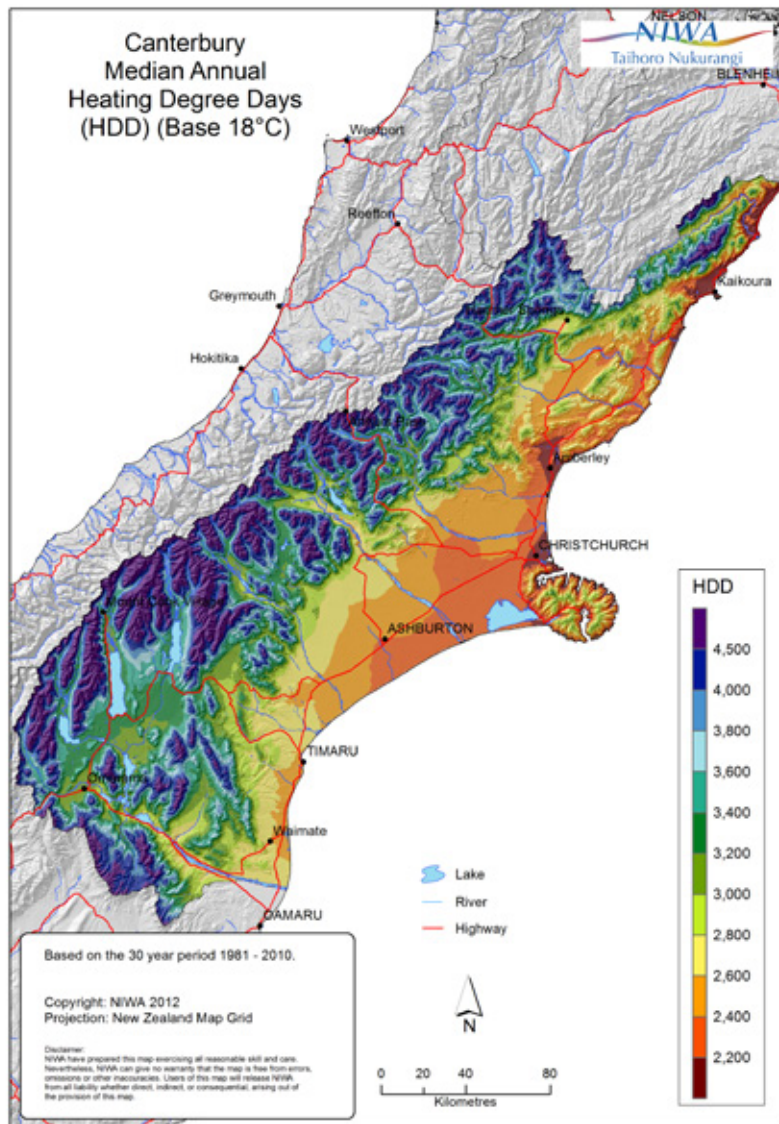


Figure 21. Median annual heating degree days for Canterbury, 1981–2010.

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