NIWA
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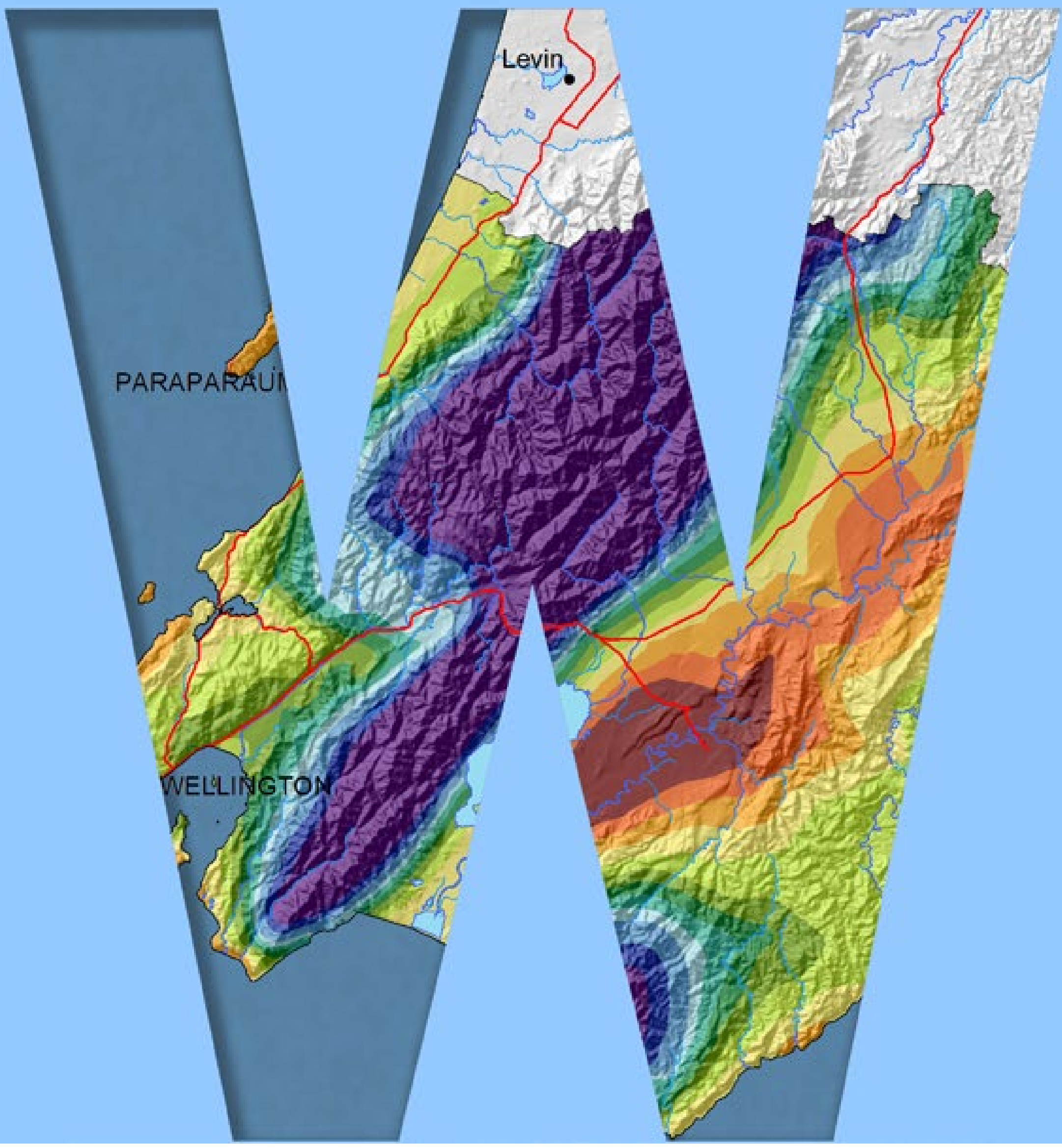
THE CLIMATE AND WEATHER OF WELLINGTON

2nd edition

P.R. Chappell



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Note to Second Edition

This publication replaces the first edition of the New Zealand Meteorological Service Miscellaneous Publication 115 (16) 'The climate and weather of the Wellington Region', written in 1984 by S.W. Goulter, and the first edition of the New Zealand Meteorological Service Miscellaneous Publication 115 (11) 'The weather and climate of the Wairarapa Region', written in 1982 by C.S. Thompson. This edition incorporates more recent data and updated methods of climatological variable calculation.

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CONTENTS

SUMMARY

The climate and weather of the Wellington region is characterised by strong variations in space and time, strongly influenced by the presence of Cook Strait and the rugged local topography. In general, the climate of the region is a reflection of the general disturbed westerly flow with interspersed anticyclones, modified in specific places by the local topography. To the east of the Tararua and Rimutaka Ranges, the Wairarapa area experiences more temperature and rainfall extremes than the western part of the region. Wind conditions are the strongest around the southwestern tip of the region. The region as a whole is generally sunny and windy compared with other parts of New Zealand.

INTRODUCTION

New Zealand is a narrow, mountainous country situated in the vast oceans of the Southern Hemisphere. The nearest land mass is the continent of Australia, some 1600 km to the northwest. The day-to-day weather of New Zealand is affected by a succession of anticyclones and depressions moving eastward. The weather characteristics of these systems determine the broad climatic features of the New Zealand region. The predominant wind flow over the country is westerly, and this together with the mountain ranges exerts a major influence on New Zealand's climate. Winds are often deflected by the ranges, and speed is increased through gaps, such as the Manawatu Gorge, Cook, and Foveaux Straits. As the main ranges lie in a northeast to southwest direction, regions in their lee are significantly drier and sunnier than those exposed to the predominant westerlies. Occasionally the country is affected by airmasses which originate in the Antarctic region or in the tropics. These airmasses are modified as they move over the seas bringing to New Zealand periods of intense showery weather associated with the cold air, or heavy rainfalls from a warm humid airmass.

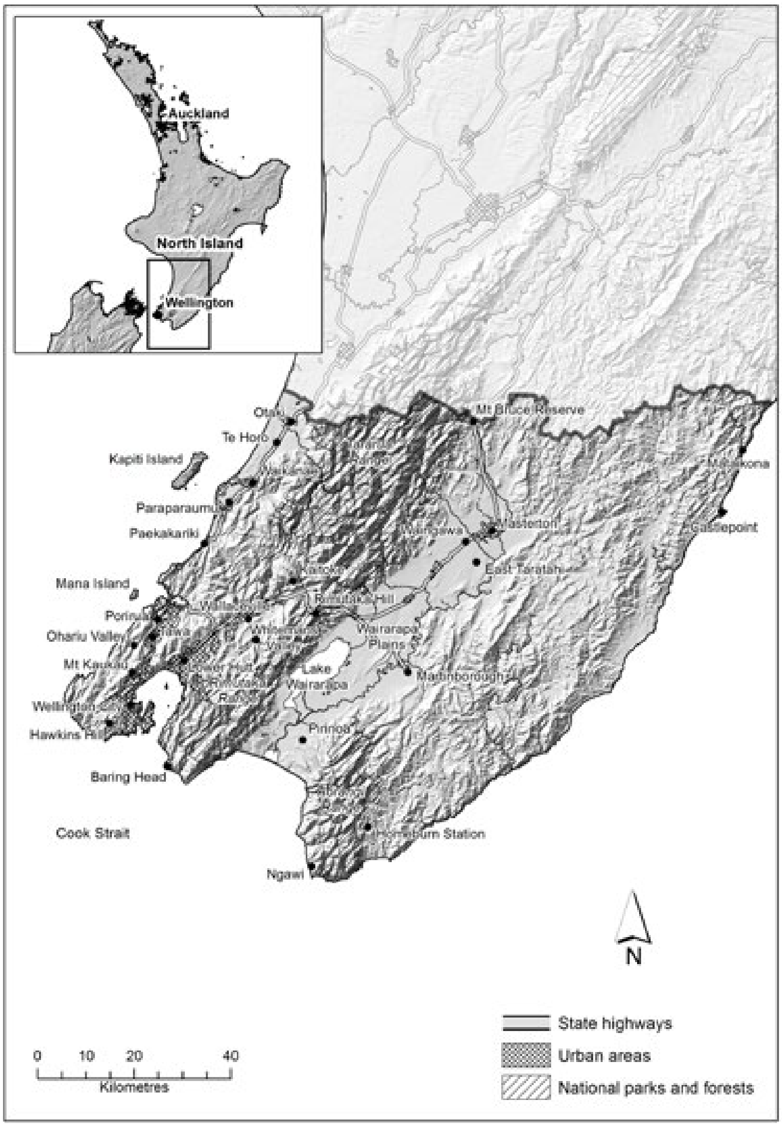

Figure 1. Map of Wellington region, with locations of places mentioned in the text, tables, and figures.

In this publication, the Wellington region is that administered by the Greater Wellington Regional Council (Figure 1). This region covers the southern part of the North Island, with its northern extent roughly a line from Otaki in the west to Mataikona in the east. The region borders the Manawatu-Wanganui region to the north. The Rimutaka and Tararua Ranges follow a northeast-southwest orientation through the centre of the region. The highest point in the Rimutaka Ranges is Mt Matthews (941 m) and in the Tararua Ranges, Mitre rises to 1571 m. In the southeast of the region lies the steep but low Aorangi Range, with Mt Ross rising to 983 m. Apart from the Wairarapa Plains to the east of the Tararua Ranges, which contain Lake Wairarapa, the remainder of the region is mostly rolling country. Wellington Harbour opens into Cook Strait, the body of water separating the North and South Islands.

Numerous coastal towns follow State Highway 1 along the west coast, and New Zealand's capital city Wellington is located in the southwest of the region. The Hutt Valley to the north of Wellington Harbour is densely populated. Masterton is the largest town in the eastern part of the region. The land uses of the non-urban areas in the region comprise mostly semi-intensive sheep and beef farming, as well as cash cropping, although some dairying, market gardening, orcharding, viticulture, and forestry are carried out.

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.

TYPICAL WEATHER SITUATIONS IN WELLINGTON REGION

The weather of the Wellington region is dominated by migratory anticyclones and intervening troughs of low pressure. The majority of anticyclones passing over New Zealand have their centres to the north of the region and the wind flow in the lower atmosphere over Wellington is generally from the westerly quarter. The lifting of westerly airstreams over the high ground in the north and northeast of the region, as well as the Rimutaka and Tararua Ranges, often results in increased shower activity and also in heavier falls during a period of general rain. When the prevailing airflow is east or southeast there is a sheltering effect in the areas to the west of the Rimutaka and Tararua Ranges. Anticyclones usually give settled dry weather in the Wellington region, with moderate frosts in the winter, and sea breezes on the west coast.

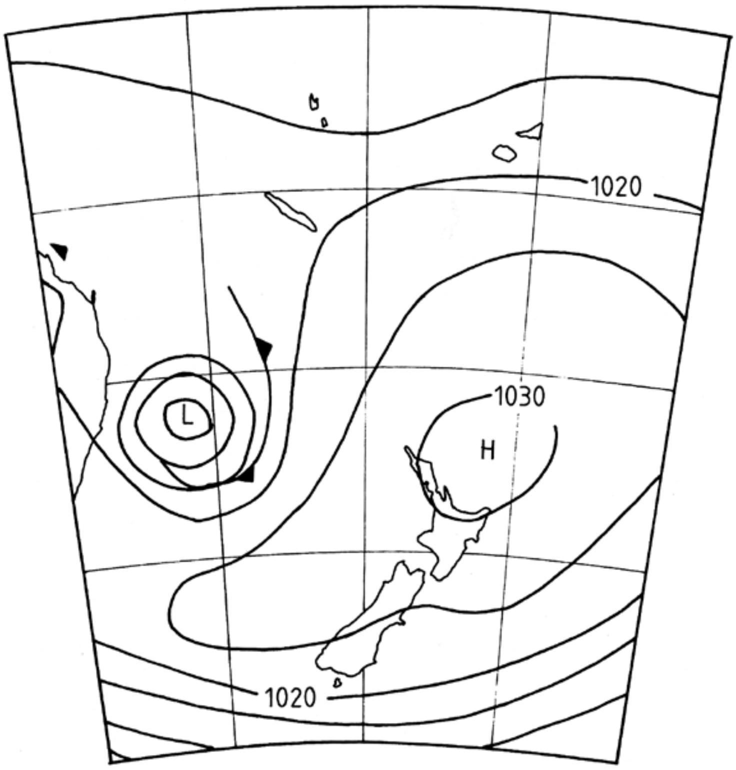

Figure 2. The synoptic situation at 0000 hours NZST on 24 September 1982.

Anticyclone centred over, or north of, the North Island

When an anticyclone is centred over, or to the north of the North Island, a north or northeasterly flow generally occurs in the Wellington region. Scattered cloud may occur over the Wellington region, but it may be cloudy with stratocumulus on the Kapiti Coast. The strength of the northerly winds will fluctuate as low pressure centres pass to the south of New Zealand. The synoptic situation of 24 September 1982 is shown in Figure 2. Scattered patches of stratiform cloud were observed over the region, with a small area of continuous stratiform cloud at the northern entrance to Cook Strait. During the day surface heating led to the development of cumuliform cloud.

In these situations the wind flow over the Wairarapa is generally parallel to the Rimutaka and Tararua Ranges.

The weather is usually dry, but rain may form from the stratiform cloud ahead of southward-moving warm fronts. It is common for depressions moving southeast along the eastern side of the North Island to give periods of moderate or heavy rainfall to the Wairarapa, while for those depressions which move southwards in the Tasman Sea little rain falls on the eastern side of the Tararua and Rimutaka Ranges, unless the associated front is particularly active.

Anticyclone centred east of the Canterbury coast

This situation is often associated with light southeast winds, together with a tongue of stratiform cloud extending into and through Cook Strait. In the southern areas, a broken cover of stratocumulus and patches of lower stratus extending over Wellington and into the Hutt Valley may be expected. The west coast may have a southwesterly breeze, with the sky partly covered by stratocumulus at a higher level than in the south. The synoptic situation of 2 July, 1982 serves as an example (Figure 3). A broad mass of stratiform cloud on the western flank of the anticyclone lying east of New Zealand extended onto the northeast coast of the South Island and north into Wairarapa. The day was partly cloudy in a light southeast flow, with moderate temperature variations in more exposed positions. However in sheltered locations, ground frosts were quite widespread, and some light air frosts occurred about the west coast. While skies were largely clear over southern Wellington, the Hutt Valley, and about some of the western coasts overnight on 2 July, the southeasterly flow brought largely stratiform low level cloud into Wellington during the day. During the morning Paraparaumu had occasional light southwesterlies with intermittent calms. The sky was largely clear and visibilities were high. During the afternoon there were periods of light

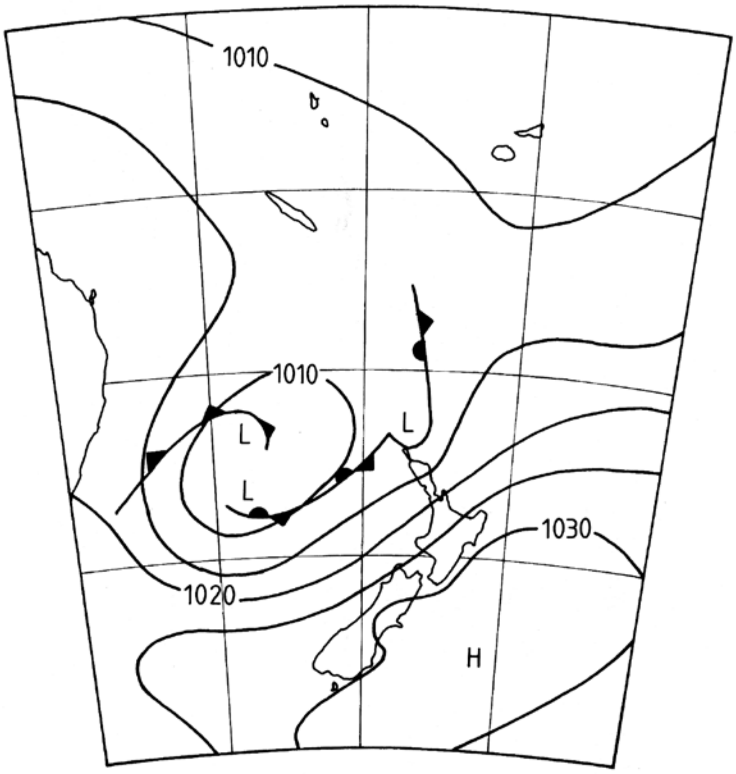

Figure 3. The synoptic situation at 0000 hours NZST on 2 July 1982.

Photo: ©mychillybin.co.nz/Thomas Neubauer winds from west to southwest, as a weak sea breeze developed. There was little low cloud, but high cloud associated with the frontal system in the mid Tasman Sea progressively covered the sky during the afternoon.

Stable westerlies over New Zealand

A strong westerly flow over New Zealand will be turned northwest over the Wellington region, because of topographic forcing. An extensive layer of stratocumulus may form over the Wellington region if the flow is anticyclonic. The flow off the Tasman Sea may be moist, and when constricted by Cook Strait it may be forced to rise over the coastal hills. In some of these flows, lenticular altocumulus and stratocumulus cloud sheets form in the crests of the wave motions induced by the forcing of the stable air flow over the Rimutaka and Tararua Ranges. Figure 4 shows that an anticyclone covered the Tasman Sea and a belt of westerly winds flowed across central and southern New Zealand on 10 August 1982. No rain fell at Paraparaumu or Kelburn (a central suburb in Wellington city) in the 24 hours from midnight on the 10th. Some turbulent mixing of the wind flow together with the cloud cover kept temperature variations moderate. Some reports of haze from about the region were made. In stable westerly conditions, areas to the east of the Tararua and Rimutaka Ranges may experience foehn conditions of warm dry weather with gusty westerlies and low humidities.

Unstable westerlies

When the flow is unstable, convective motions develop and showers occur. Cumulus growth may be extreme. Cumulonimbus appear with possible thunderstorms and hail. These cells move inland with the westerly flow, affecting the upper valleys and ranges. If the cyclonic flow is northwesterly then these conditions can spread to the south of the region.

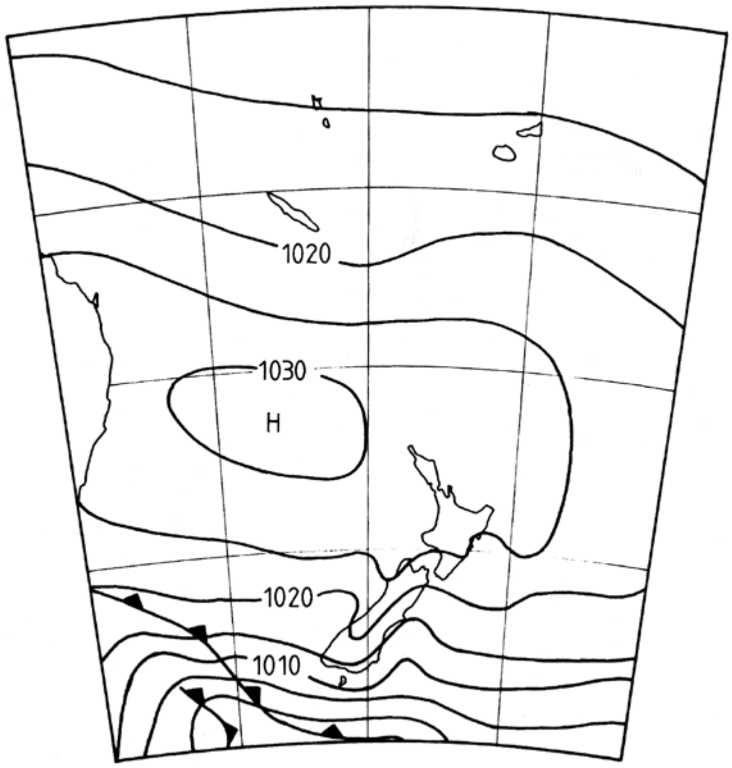

Figure 4. The synoptic situation at 0000 hours NZST on 10 August 1982.

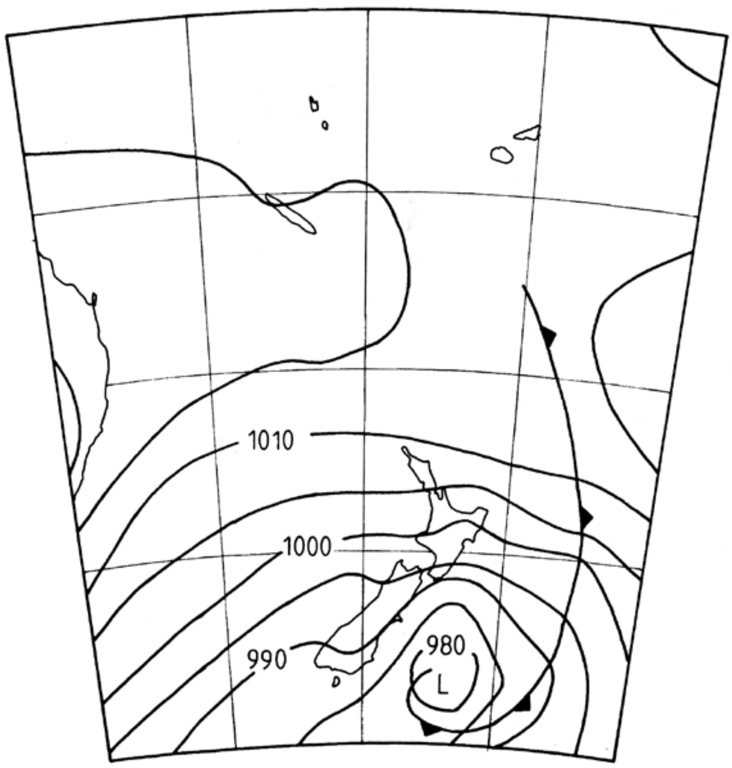

Figure 5. The synoptic situation at 0000 hours on 23 May 1982.

Figure 5 shows a trough of low pressure covering New Zealand at midnight on 23 May 1982. There was an extensive area west of the South Island with large cumulus and cumulonimbus cells present. A northwesterly flow covered the Wellington region during the day, which was cloudy and windy. Some locally heavy falls of rain occurred, mainly during the morning, especially in the northwest. The low cloud cover was cumuliform, with cumulonimbus especially in the west. Convection was vigorous, and reports of hail came from Kelburn and Wallaceville, and of lightning or thunder from Titahi Bay (north of Porirua) and Wallaceville. At lower middle levels large areas of altocumulus and altostratus were present.

Depression centred west of the South Island, trough of low pressure west of New Zealand

Strong northerlies with the development of an extensive layer of low stratus and stratocumulus, with later development of drizzle and perhaps rain, are associated with these general situations. Because of the greater exposure of the western coastal areas to the air flow and the orographic enhancement of the rainfall there, the cloud base may be a little higher in the south, over Wellington City for example. A band of high rainfall may extend from Porirua across Lower Hutt. Similar conditions prevail in the approach of a cold front or trough of low pressure from the west. At midnight on 8 October 1983, a deep low pressure trough lay west of New Zealand and a frontal system associated with this trough lay north-south off the coast of Westland (Figure 6). At Paraparaumu, on the west coast, the moist northeasterly flow gave rain to 1pm, from a basically stratiform cloud mass. By evening visibilities were reduced to 18km, and haze was being reported, with some scattered cumulus. The flow remained northeasterly at Paraparaumu after the frontal passage, because of orographic

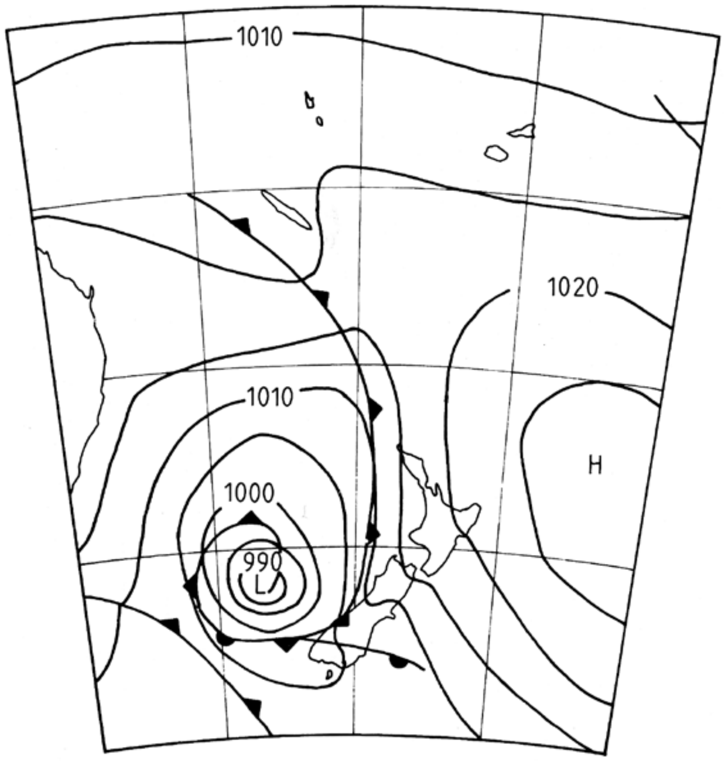

Figure 6. The synoptic situation at 0000 hours NZST on 8 October 1983.

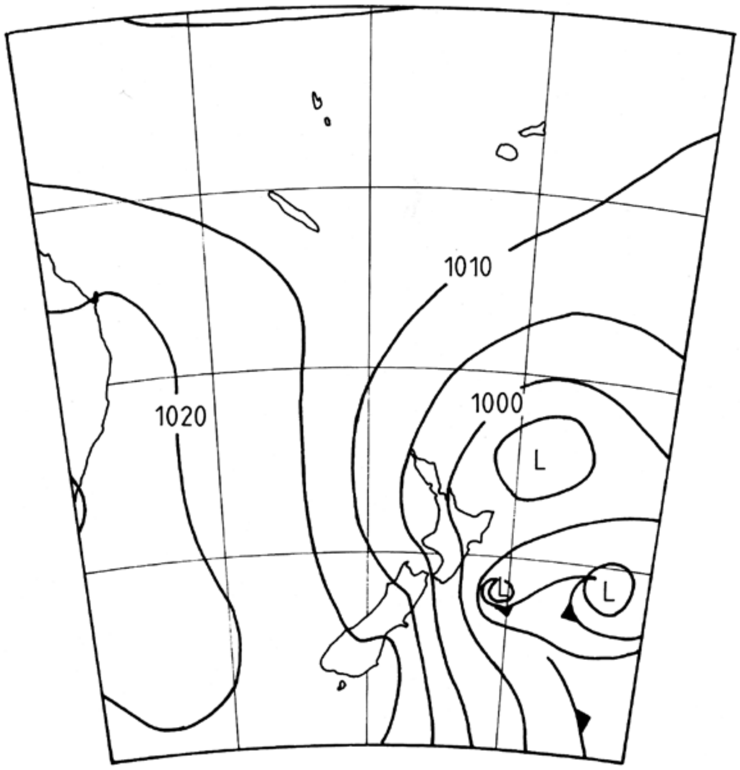

Figure 7. The synoptic situation at 0000 hours NZST on 2 May 1982.

forcing. The wind change was more distinct at Kelburn. During the morning, in a strong northerly flow, rain and showers fell from a cloud mass which had both stratiform and cumuliform types present. After midday a wind shift to northwesterlies occurred with the frontal passage. Some showers fell, visibility improved, and the westerly flow strengthened.

Depression centred east of New Zealand

In this situation, a strong gusty southerly is often encountered. At midnight on 2 May 1982, a large anticyclone over southeast Australia covered much of the Tasman Sea (Figure 7). To the east of New Zealand lay an extensive trough of low pressure, moving east. Within this trough were several low centres, with central pressures to below 990 mb. Between the trough and the ridge a strong southerly flow covered much of New Zealand.

As the trough moved east, a broad ridge extended over New Zealand from the anticyclone in the Tasman. The flow over the North Island turned to the southeast. A cool, windy, and cloudy day occurred in the Wellington region, with a small amount of rain. Several interesting meteorological features were apparent:

1. Cumuliform cloud masses over much of the region and concentrated in the hills to the north of Wellington and also in the Wairarapa ranges
2. Cumuliform cloud streaming through Cook Strait
3. A vortex sheet associated with the southeast flow in the wake of Mt Taranaki

Generally, such an airstream will be unstable. As the cold air moves rapidly north over warmer waters, convection may occur and towering cumulus or cumulonimbus clouds may develop. This instability may be triggered by forced uplift even in weak flows. Strong southerly flows also occur when a deep trough of low pressure crosses the North Island, or following a cold front as it moves across the country, generally from the southwest or west. If the depression is just east of Canterbury the surface flow will be light northerly through Cook Strait, and conditions may be overcast, with low stratus on the western coasts. A southwest flow over New Zealand often occurs with the movement east or southeast of the low pressure centres. When the flow is aligned with, or slightly west of, the axis of the Southern Alps, Wellington will be sheltered by the South Island high country. Fine weather in the region then occurs, and in fact there may be northerlies through Cook Strait. Then the atmosphere has a very clear, bright appearance. This is because the occurrence of recent rain will have washed much of the particulate matter out of the air. A weakening depression east of the North Island is another situation with a characteristic pattern of weather. Here a light southeast flow is deflected into a very light southerly or southwesterly. The flow is moist and often an extensive sheet of low stratus and sea fog is advected onto Wellington Harbour and the Hutt Valley. Similar situations arise when a ridge of high pressure lies across the seas to the southeast of New Zealand with a weak southerly or southeasterly flow onto the North Island. If the flow strengthens the stronger southerly will disperse the fog by turbulent mixing and the cloud base will rise.

Southerly changes

The approach of a cold front is indicated by strengthening northerlies and a lowering cloud cover of stratocumulus and stratus, especially along the western coasts. A rapid wind shift to the south occurs with the arrival of the cold front, often occurring within one minute or less. The onset of these southerly winds may be seen in a line of towering cumulus cloud and squally showers approaching from the south. The showers may be tracked as they move northeastward at speeds of up to 60km/hr. Generally accompanying the wind change is a sharp temperature drop, a pressure rise and the onset of a period of showers or more general rain, which may be quite persistent and heavy if the air is moist with a low cloud base. Because of the powerful modification to flow by the Southern Alps and the local topography, the wind change may precede the onset of rain by about an hour. A generally similar sequence of events is the 'southerly buster' known to occur along the Canterbury coast, and the coast of southeast Australia. The standard textbook sequence of events is appreciably modified by frictional and obstructive events at the surface.

CLIMATIC ELEMENTS

Wind

Wellington's proximity to Cook Strait leads to high frequency of strong winds. Because the lower level flow is strongly forced by the rugged topography, the winds are very gusty. The anemograph on the 122m high TV tower on Mt Kaukau (425 m) records a very high (44 km/hr) average wind speed. This instrument measures the wind flowing above the level of the highest hills in Wellington city and neighbouring regions. Below hill-top level the winds are strongly disturbed by the terrain and although average wind speeds are much less, gust speeds may be comparable with the higher level winds. A marked reflection of the wind regime over the southwest part of the region is shown by the permanent eastward lean of much of the larger vegetation on exposed hillslopes and ridge-tops. However, strong spatial variation from coastal to inland locations is evident, with the Wairarapa plains observing a much lower average wind speed compared with the southwest coast (Figure 8).

At the surface, wind direction and speed is strongly modified by topography. The Rimutaka and Tararua Ranges, as well as the steep hill country around Wellington city, have a strong influence on wind in the Wellington region. In the hill country, winds tend to flow along the line of valleys. In addition, Cook Strait and the Manawatu Gorge funnel the low level airstreams so that they tend to blow as northwesterlies east of the Manawatu Gorge, and as southwesterlies east of the ranges.

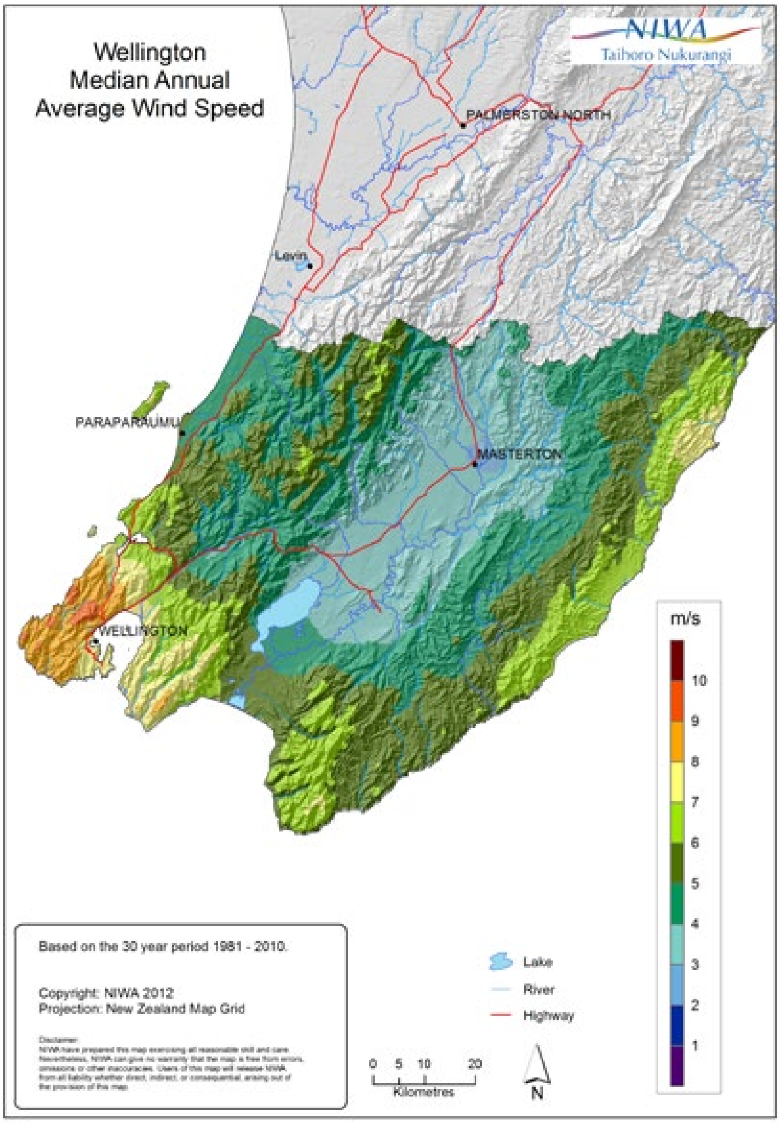

Figure 8. Wellington region median annual average wind speed 1981–2010.

Table 1. Mean monthly/annual wind speeds (km/hr) for Wellington sites (Martinborough EWS and Wallaceville EWS averages are from 2000–2013, and 1999–2013, respectively; all other sites are averages of all available data from 1981–2010).

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Baring Head	35.9	33.7	35.4	33.9	35.2	37.9	34.8	35.2	37.1	39.5	38.7	36.2	36.1
Castlepoint Aws	30.1	28.4	29.7	26.8	29.2	31.3	28.1	30.7	33.1	35.8	35.1	33.2	31.0
Ngawi Aws	16.8	15.9	18.0	16.6	17.7	19.8	17.6	19.2	21.1	21.8	20.5	20.5	18.8
Paraparaumu Aero AWS	16.8	15.0	15.5	14.4	15.3	15.4	14.5	15.5	17.0	18.7	18.4	17.5	16.2
Wellington Aero	27.2	24.4	24.8	24.1	24.9	25.6	24.1	24.3	25.8	28.7	28.2	27.7	25.8
Martinborough EWS	15.4	14.1	13.6	11.2	11.4	12.0	11.4	12.3	15.7	16.2	16.6	15.9	13.8
Wallaceville EWS	10.1	9.2	8.9	7.4	7.6	7.8	7.6	8.0	10.1	10.9	11.1	10.6	9.1

The sheltering effect of the Rimutaka and Tararua Ranges gives a high frequency of calm or very light winds to the inland northern plains area; this effect is usually more pronounced at night-time.

Figure 9 shows mean annual wind frequencies of surface wind based on hourly observations from selected stations. Due to its exposed location, Wellington airport has a higher percentage of strong winds than the other selected stations. Wallaceville has the lowest mean wind speeds, due to its sheltered location in the Hutt Valley.

Table 2. Seasonal percentages of strong or light winds (%) for Wellington sites (Martinborough EWS data from 2000–2013, other sites all data available between 1981–2010).

Location		Summer	Autumn	Winter	Spring
Martinborough EWS	Strong	27	18	18	37
	Light	24	26	27	23
Ngawi AWS	Strong	23	22	25	31
	Light	25	26	26	23
Paraparaumu Aero AWS	Strong	21	19	23	37
	Light	25	26	25	24
Wellington Aero	Strong	26	23	23	28
	Light	24	27	26	23

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

Location	00	03	06	09	12	15	18	19	21
Martinborough EWS	11.2	10.9	10.7	12.6	17.4	19.3	15.9	14.2	12.0
Ngawi AWS	17.8	18.0	17.9	18.7	20.8	21.1	19.1	18.4	17.8
Paraparaumu Aero AWS	13.3	13.3	13.2	15.6	18.8	18.5	15.4	14.6	13.5
Wellington Aero	24.0	23.9	24.0	26.3	29.4	30.2	27.3	26.2	24.7

Table 4. Average number of days per year with gusts exceeding 63 km/hr and 96 km/hr for selected stations (Martinborough EWS data from 2001–2013, other sites all available data between 1981–2010).

Location	Days with gusts >63 km/hr	Days with gusts >96 km/hr
Baring Head	255	72
Castlepoint Aws	227	102
Martinborough Ews	77	7
Paraparaumu Aero	77	8
Wellington Aero	166	24

Table 5. Highest recorded gusts at selected Wellington stations, from all available data.

Location	Gust (km/hr)	Direction (°)	Date
Wellington Aero	187	210	10/04/1968
Wellington, Kelburn	198	210	10/04/1968
Baring Head	217	190	12/03/2010
Lower Hutt, Gracefield	135	200	5/08/1961
Mana Island AWS	148	187	20/06/2013
Wallaceville EWS	115	301	21/02/2004
Paraparaumu Aero AWS	152	315	31/03/2011
Martinborough EWS	117	298	24/12/2010
East Taratahi AWS	124	310	19/10/1998
Masterton Aero	148	300	25/11/1957
Castlepoint AWS	186	300	19/10/1998
Hawkins Hill	248	-	6/11/1959 4/7/1962

Mean wind speed data (average wind speeds are taken over the 10 minute period preceding each hour) are available for several sites in the Wellington region and these illustrate the several different wind regimes of the region (Table 1). Inland areas such as around Martinborough, which are protected from the prevailing westerly winds, generally have lower mean wind speeds than locations that are more exposed, such as Baring Head and Castlepoint.

Spring is generally the windiest season throughout the region, whereas autumn records the lowest percentage of strong winds. Table 2 gives the seasonal proportion of strong or light winds as a percentage of the annual total. For example, of all strong winds recorded at Martinborough, 27% occurred in summer, 18% in autumn, 18% in winter and 37% in spring. In compiling this table a strong wind was defined as having a mean wind speed of at least 31 km/hr.

Diurnal variation in wind speed is well-marked, with greatest wind speeds occurring in the middle 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. During clear, cold nights, especially in winter under anticyclonic conditions, the hill country may give rise to a light but weak katabatic breeze. Calm conditions are most frequent during the early hours of the morning just before sunrise, especially on cold winter mornings. Table 3 gives average wind speeds at three-hourly intervals for selected stations.

Strong gusts over 96 km/hr are relatively frequent at the more exposed sites in the Wellington region, such as Baring Head, Castlepoint, and Wellington Airport (Table 4). It is likely that in the high country, strong gusts are even more common, but long records (> 10 years) are lacking for those locations and therefore are not included here. Gusts of at least 63 km/hr are recorded at Castlepoint on an average of 227 days each year, and gusts over 96 km/hr occur on average 102 days each year. In comparison, Martinborough is more sheltered, with 77 days per year with gusts over 63 km/hr, and seven days per year with gusts over 96 km/hr.

Although gale force winds can occur in any month, they are most frequent in winter. The highest gust recorded in the region was 248 km/hr at Hawkins Hill, on both 6 November 1959 and 4 July 1962 – this wind speed is the highest recorded in the North Island (and only 2 km/hr off the highest recorded wind speed in New Zealand). See http://www.niwa.co.nz/education-and-training/schools/resources/climate/extreme for New Zealand climate extremes.

Maximum gusts recorded at different stations in the region are listed in Table 5. The extreme wind gusts recorded at Kelburn and Wellington airport are 198 and 187 km/hr, respectively, both from a direction of 210°. These occurred during the *Wahine* storm on 10 April 1968.

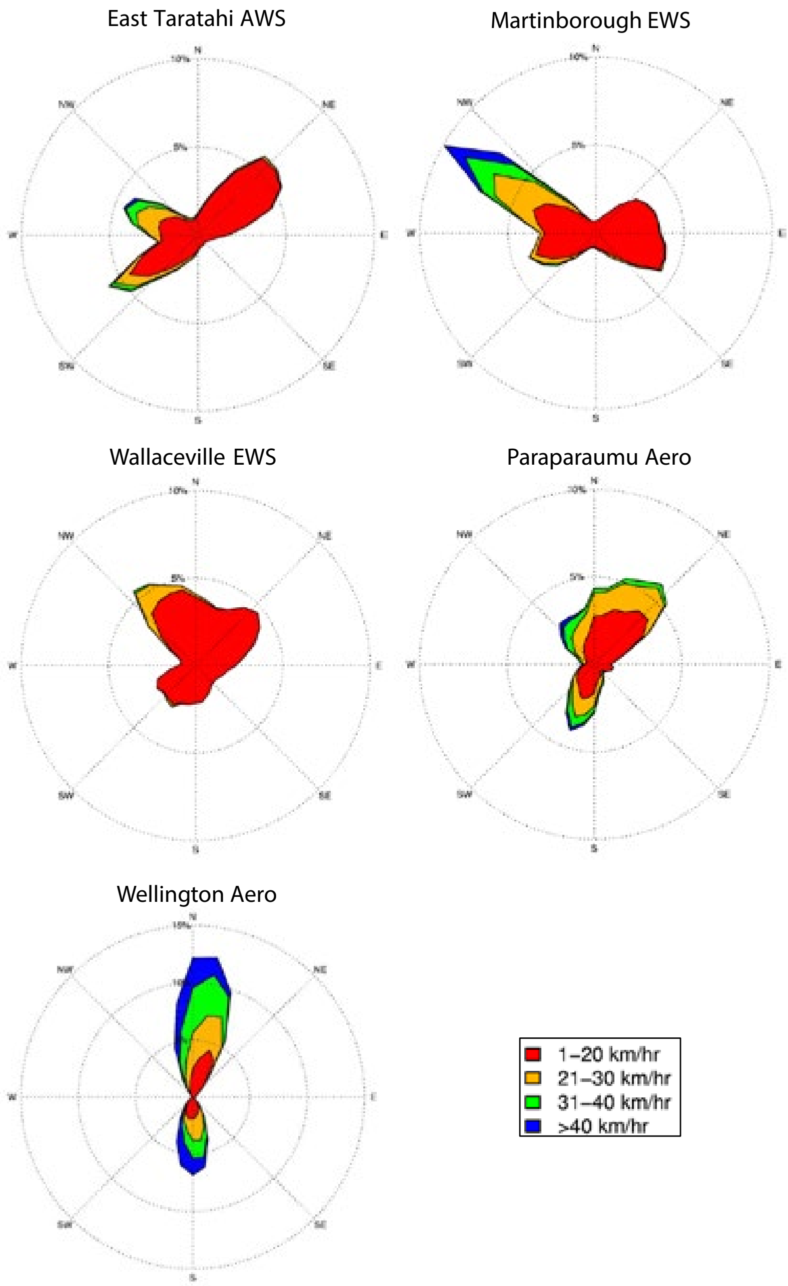

Figure 9. Mean annual wind frequencies (%) of surface wind directions from hourly observations at selected Wellington stations. The plots show the directions from which the wind blows, e.g. the dominant wind direction at Martinborough is from the west-northwest.

Rainfall

Rainfall distribution

Average annual rainfall is highly variable across the Wellington region, as shown in Figure 10 and Table 6. This is due to the topography of the region, which influences airflows and thus the patterns of precipitation. The Rimutaka and Tararua Ranges, along with the southeastern part of the Aorangi Ranges, receive over 2000 mm of rainfall per year. In stark contrast, some areas on the Wairarapa Plains, to the east of the main ranges, receive less than 800 mm per year. The Tararua and Rimutaka Ranges provide sheltering from westerly winds, and the Aorangi Ranges provide sheltering from east and southeast winds in this area. Much of the remainder of the region experiences 1000–1200 mm of rainfall annually.

Table 6 lists monthly rainfall normals and percentage of annual total for selected stations. The season with the highest proportion of annual rainfall is winter (June–August), ranging from 28% at Te Horo, Longcroft to 34% at Wainuiomata Reservoir (on the eastern side of Wellington Harbour). A weak secondary maximum appears in mid-spring (October) at the locations with a more westerly exposure, reflecting the increased

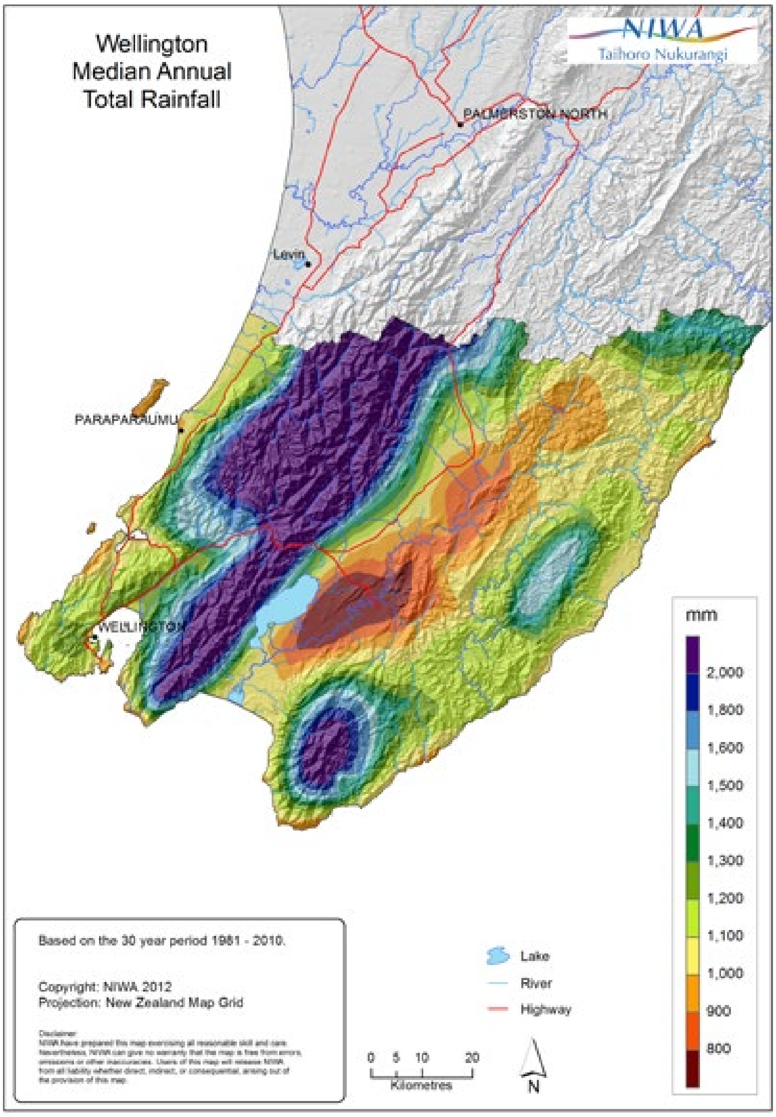

Figure 10. Wellington region median annual total rainfall 1981–2010.

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
Castlepoint Station	a	59	74	73	69	94	109	113	89	71	77	68	59	956
	b	6	8	8	7	10	11	12	9	7	8	7	6	
Kapiti Island	a	62	76	74	76	86	119	98	91	84	113	88	98	1064
	b	6	7	7	7	8	11	9	9	8	11	8	9	
Lower Hutt, Gracefield	a	54	72	105	58	156	128	168	92	94	82	99	100	1206
	b	4	6	9	5	13	11	14	8	8	7	8	8	
Martinborough, Riverside	a	44	55	60	50	70	84	87	76	59	67	62	55	767
	b	6	7	8	7	9	11	11	10	8	9	8	7	
Masterton, Bagshot Stn	a	63	71	74	70	92	112	126	98	82	90	74	58	1010
	b	6	7	7	7	9	11	13	10	8	9	7	6	
Ohariu Vly, Papanui	a	65	53	86	72	94	123	109	93	88	86	83	68	1019
	b	6	5	8	7	9	12	11	9	9	8	8	7	
Paraparaumu Aero	a	66	66	69	65	83	109	95	91	86	108	79	92	1009
	b	7	6	7	6	8	11	9	9	9	11	8	9	

Table 6 continued.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Pirinoa	a	64	68	76	77	108	128	123	114	82	106	79	79	1103
	b	6	6	7	7	10	12	11	10	7	10	7	7	
Te Horo, Longcroft	a	83	82	82	77	100	124	113	108	109	129	110	126	1243
	b	7	7	7	6	8	10	9	9	9	10	9	10	
Wainuiomata Reservoir	a	81	89	148	130	180	224	224	173	146	159	139	107	1800
	b	4	5	8	7	10	12	12	10	8	9	8	6	
Wallaceville EWS	a	78	76	83	81	110	134	133	122	107	136	101	107	1268
	b	6	6	7	6	9	11	11	10	8	11	8	8	
Wellington Aero	a	58	61	67	68	86	101	113	93	75	95	75	65	957
	b	6	6	7	7	9	11	12	10	8	10	8	7	

westerly wind flow which occurs over New Zealand then. The wintertime maximum is associated with the increased frequency of depressions which cross the North Island during this period. Summer (December–February) records the lowest proportion of annual rainfall throughout the region, ranging from 15% at Wainuiomata Reservoir to 24% at Te Horo, Longcroft.

The distribution of monthly rainfall is shown in Figure 11. The 10th percentile, 90th percentile, and mean rainfall values for each month are shown along with maximum and minimum recorded values for several stations in the Wellington region.

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 Homeburn Station (in the Aorangi Range), it can be seen that in the three month period beginning in April, less than 296 mm can be expected in one year in ten, between 296 and 718 mm eight years in ten, and more than 718 mm one year in ten.

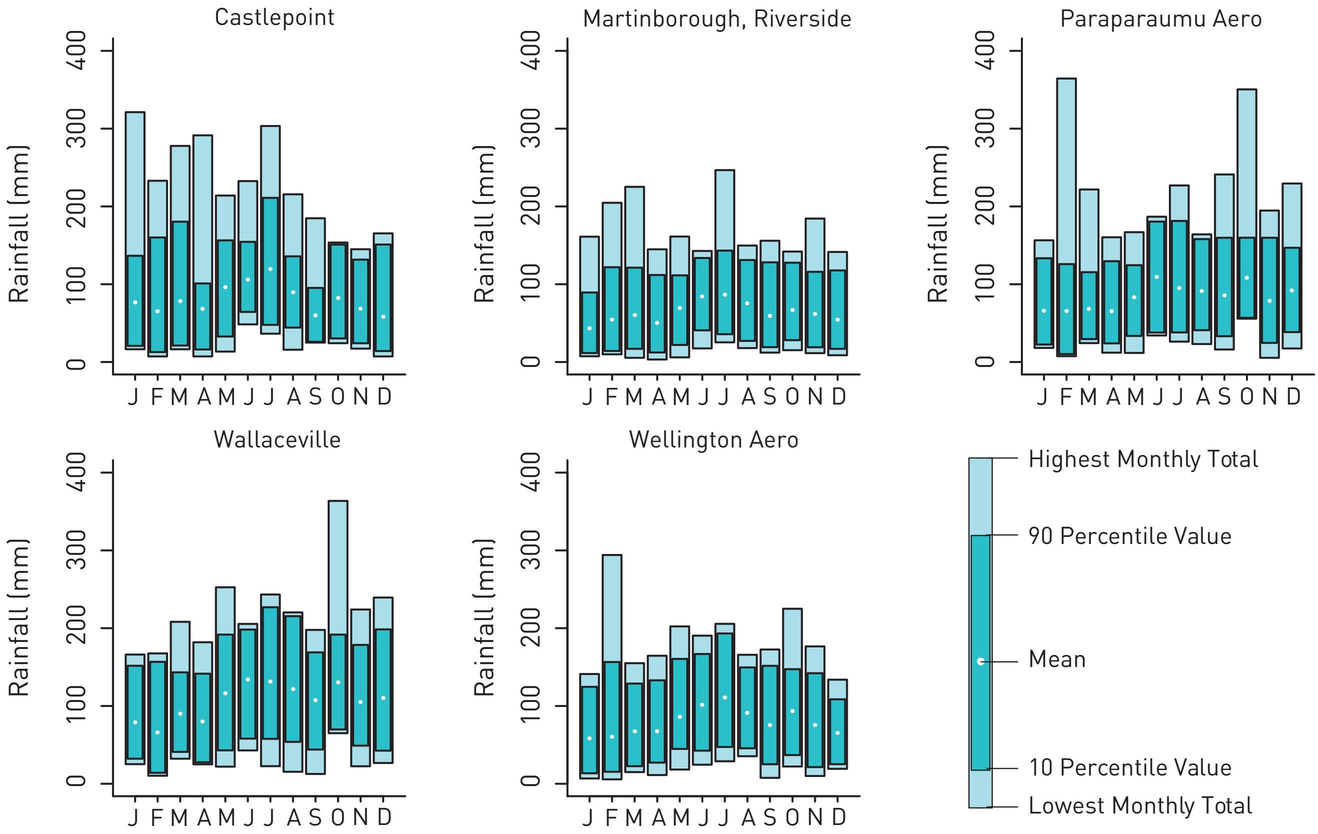

Figure 11. Monthly variation in rainfall for selected Wellington stations.

Table 7. Rainfall deciles for consecutive months for selected Wellington stations.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Homeburn Station												
1 month												
10th	18	22	43	47	68	91	61	63	39	43	38	31
90th	189	188	321	190	331	295	428	321	262	242	200	224
3 months												
10th	149	151	245	296	349	343	262	253	273	214	146	127
90th	618	632	634	718	938	1001	896	732	545	595	528	499
6 months												
10th	509	592	620	647	627	690	590	499	445	382	316	397
90th	1137	1335	1546	1526	1510	1308	1278	1139	955	1088	979	968
12 months												
10th	1196	1260	1208	1186	1157	1195	1174	1170	1206	1224	1163	1220
90th	2363	2351	2145	2411	2349	2216	2214	2283	2322	2245	2287	2226
Martinborough, Riverside												
1 month												
10th	12	14	17	12	22	41	36	27	19	28	19	17
90th	89	122	121	112	111	134	143	131	128	128	116	118
3 months												
10th	63	59	90	110	155	143	132	123	129	97	94	90
90th	273	274	247	293	356	338	312	285	296	265	276	271
6 months												
10th	205	235	296	314	319	286	293	247	231	194	186	204
90th	456	511	564	576	607	553	566	513	507	522	468	449
12 months												
10th	612	609	598	557	552	550	581	621	594	626	595	615
90th	1012	1022	974	977	1009	996	991	941	927	976	968	949
Paraparaumu Aero												
1 month												
10th	22	10	29	24	34	38	38	41	33	57	25	38
90th	133	126	115	130	124	181	181	158	160	160	160	147
3 months												
10th	109	107	158	145	196	192	177	188	185	181	151	132
90th	318	301	301	339	370	429	380	384	373	368	344	310
6 months												
10th	346	386	407	411	460	400	394	366	351	333	314	283
90th	599	631	673	661	678	704	721	679	668	679	585	592
12 months												
10th	825	770	771	800	778	803	837	851	845	811	810	797
90th	1218	1257	1251	1233	1225	1239	1236	1209	1223	1238	1253	1274
Wellington Aero												
1 month												
10th	14	15	23	27	45	43	47	46	25	37	21	25
90th	125	157	129	133	161	167	193	150	152	147	142	109
3 months												
10th	80	82	129	162	216	193	155	175	156	140	93	103
90th	254	291	311	343	409	437	383	389	342	334	314	339
6 months												
10th	322	384	417	410	419	370	385	312	264	275	238	255
90th	588	619	658	668	767	696	661	588	609	643	555	558
12 months												
10th	762	750	760	761	714	693	742	766	768	757	740	757
90th	1118	1126	1147	1174	1175	1181	1134	1127	1117	1137	1111	1087

Rainfall frequency and intensity

Rain day frequency (where at least 0.1 mm of rain falls) varies over the Wellington region, and is highest in the Hutt Valley at Wallaceville (highest out of the stations in Table 8). Rain day frequency is assumed to be higher in the Rimutaka and Tararua Ranges, but there is no available data for those areas. The least rain days occur in the Wairarapa around Martinborough. Rain days are less frequent from January to March (coinciding with the driest time of the year), and occur most often between June and September. In most places there are only a few more rain days in winter than in spring. The annual number of wet days (where at least 1 mm of rain falls) exhibits the same geographic variability as rain days. Table 8 lists the average number of days per month with at least 0.1 mm and 1 mm of rain for selected stations.

Table 8. Average monthly rain days and wet days for Wellington stations; 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
Castlepoint Aws	a	10	9	11	12	14	16	17	16	13	13	12	11	153
	b	8	7	8	8	11	12	13	12	9	10	9	8	114
Martinborough, Riverside	a	7	6	9	9	11	14	13	13	11	11	9	8	121
	b	6	5	7	7	9	11	11	11	9	9	7	7	98
Paraparaumu Aero	a	10	9	11	11	14	16	16	16	16	15	13	14	159
	b	7	6	8	8	9	12	11	10	11	11	9	10	112
Wallaceville	a	12	10	13	14	16	19	19	19	18	18	15	16	188
	b	8	7	10	9	11	14	14	14	13	13	12	11	134
Wellington Aero	a	9	9	11	12	13	17	16	16	14	15	12	12	155
	b	6	7	7	8	9	12	12	12	10	11	9	8	110

Most heavy rainfalls in Wellington region (west of the ranges) occur with the approach of an active frontal system and are preceded by a warm moist north to northwest flow. To the east of the ranges the heaviest rain is often accompanied by a strong south to easterly airflow. This is usually associated with a depression located just to the northeast of the region. Heavy rain and consequent flooding may occur when a warm moist northerly airstream, associated with a depression situated in mid-Tasman or just west of the North Island, affects the region. On other occasions, if an active cold front orientated in a northwest/southeast direction becomes slow moving over the southwest of the North Island, prolonged heavy rain may occur. High rainfall also occurs in the Wairarapa when a moist south or southeast airstream is associated with a depression situated over, or just east of the region.

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 Wellington region 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 9. 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
Paraparaumu Aero	a	11	20	26	33	41	72	94	133	137	138
	b	8	29	44	25	18	33	32	56	28	20
	c	7	11	13	18	25	41	56	76	85	90
	d	9	13	16	23	31	50	68	91	102	109
	e	11	16	19	27	36	57	77	103	115	123
	f	13	18	22	32	42	66	87	115	129	138
	g	16	22	27	39	51	78	102	134	150	160
Wallaceville	a	11	17	19	29	45	106	151	194	206	224
	b	20	23	18	30	43	100+	100+	100+	65	60
	c	7	9	11	16	23	41	59	85	103	116
	d	9	12	14	20	29	51	73	105	127	142
	e	10	14	17	23	33	58	84	120	145	162
	f	12	16	19	27	38	67	95	136	165	184
	g	14	19	23	32	46	80	113	161	195	218
Wellington Aero	a	12	20	24	25	35	54	98	141	159	172
	b	25	59	49	8	10	9	38	54	34	27
	c	7	10	12	18	24	39	53	71	88	99
	d	8	12	15	22	30	48	65	88	109	123
	e	10	14	18	26	35	56	76	102	125	142
	f	11	16	21	30	41	65	87	117	144	163
	g	13	20	25	37	49	78	104	139	172	194

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 Wellington region

The Wellington region 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 region between 1980 and 2013. In addition, the severe storm in 1968 that caused the ferry *Wahine* to sink is included as it is the worst storm on record for New Zealand.

9–15 April 1968: Ex-tropical cyclone Giselle and another strong depression created the worst storm in New Zealand's history. The storm hit Wellington and caused severe damage. Wellington experienced hurricane-force winds for several hours on the 10th - the winds were the strongest yet to be recorded in any built-up area in New Zealand. The interisland ferry *Wahine* sank in Wellington Harbour during the storm, with the loss of 51 lives. Three other people died in Wellington as a result of the high winds. Road and rail travel was disrupted due to downed trees, flooding, and fallen power and trolley bus lines. Buildings were damaged by the wind, with windows smashed, roofs lifted, and trees blown onto houses. The storm was the worst on record for many places in New Zealand, and insurance payouts totalled $194 million 2008 dollars. The North Island had no power from the South Island Cook Strait cable due to faults caused by the wind.

3–5 October 2003: A deepening low moved over New Zealand from the Tasman Sea, accompanied by an active trough that was preceded by a very strong moist northerly flow. A Civil Defence Emergency was declared for five days on the Kapiti Coast after heavy rain caused severe flooding in Paekakariki, an event which had a 125-year return period. Homes and almost every business in the town were flooded. The water was waist deep in some houses. There was a huge land and mudslide across SH 1 at Paekakariki, where 10,000 m^3 of gravel poured down the hillside. A rockfall destroyed a motel on SH 1. The initial damage estimate for Paekakariki was $2.9 million 2008 dollars. Wellington was cut off by road and rail, and motorists were trapped on SH 1. Eight houses were left uninhabitable due to flooding. Snow settled on the Wellington hill suburbs of Brooklyn, Karori, and Broadmeadows, and two men were killed in a plane crash off the Kapiti Coast during the storm.

14–19 February 2004: A deep low moved over the North Island, bringing high winds, heavy rain, flooding, and slips to many regions including Wellington. Several Wairarapa rivers flooded, killing hundreds of sheep and lambs. The Ruamahanga River experienced a 50-year flood. Severe flooding affected the Hutt Valley, with hundreds of people evacuated and 20 properties deemed uninhabitable. Power was cut due to falling trees, and 2000 Wellington and 600 Wairarapa homes were without power. Train services in the region were disrupted due to damaged railway lines, and numerous roads were closed due to flooding and slips. Wellington airport was also closed for a time. Wellington city was isolated by road and rail from the rest of the North Island with the closures of SH 1 and SH 2. 14 slips closed SH 2 at Rimutaka Hill. Interisland ferry services were cancelled due to heavy swells and gale force winds. The short-term impact (cost of damage and economic impact) from the floods and wind damage in the lower North Island (including the Manawatu Region where severe flooding occurred) was estimated at $350 million 2008 dollars.

14–18 August 2004: A depression developed and intensified east of the North Island, bringing a southerly storm to the country. Wellington experienced gales and driving rain, and roads in the region were closed due to huge seas, flooding, slips, windblown debris and fallen trees and power lines. Bus, rail, and interisland ferry services were cancelled. Schools were also closed, and hundreds of households and businesses were without power. Extensive property damage resulted from flooding and high winds, with roofs being lifted, windows smashed, and trees and fences being blown over. There was surface flooding in the Wairarapa, and several roads were closed. Some homes were evacuated in Lower Hutt, Wainuiomata, and Eastbourne (on the eastern side of Wellington Harbour) due to slips and floods. SH 2 at the Rimutaka Hill was closed on the 17th and 18th due to heavy snow. Postal deliveries were cancelled in Wellington city due to the weather, and many Air New Zealand flights were cancelled, affecting 9000 domestic and international passengers.

20–21 June 2013: A significant storm event caused severe gales, surface flooding, and heavy seas in Wellington. The wind caused widespread damage to infrastructure and vegetation in the region. The storm brought the highest sustained 10-minute winds that Wellington airport had seen since 1985. 30,000 homes were without power, and the Fire Service attended over 900 callouts on the night of 20 June. Trees were felled, roofs blown off, and windows smashed due to the wind. The airport was closed to all flights during the worst of the storm, and train, harbour ferry, and interisland ferry services were also cancelled. The Interislander ferry Kaitaki broke its moorings and had to anchor in Wellington Harbour for the night with 50 crew on board. A large number of schools were closed in the region. A gust of 202 km/hr was recorded at Wellington's Mt Kaukau, and swells were up to 15 m in Cook Strait. Surface flooding was recorded in many areas, and train tracks were undermined by high swells. Some rail lines were closed for almost a week for repairs.

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'. There is an average of two such periods each year in the Wellington region, with most dry spells occurring in the summer months when anticyclonic conditions are prevalent. The average duration of a dry spell in the region is about 19 days. The longest recent dry spell between three key Wellington region sites (Wellington Aero, Martinborough Riverside, and Paraparaumu Aero) was 39 days recorded in Martinborough from 7 February to 17 March 2013 (all days with no rain). The longest recent dry spell at Paraparaumu was 35 days between 15 March and 18 April 1985 (22 consecutive days with no rain), and at Wellington the longest recent dry spell was 33 days between 13 February and 17 March 2013, with 32 consecutive days with no rain.

Temperature

Sea surface temperature

Monthly mean sea surface temperatures off the south coast of Wellington city are compared with mean air temperature for Wellington Airport in Figure 12. Between March and September, mean air temperatures are lower than mean sea surface temperatures. However in the warmer months, mean air temperatures are higher than mean sea surface temperatures. Figure 13 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.

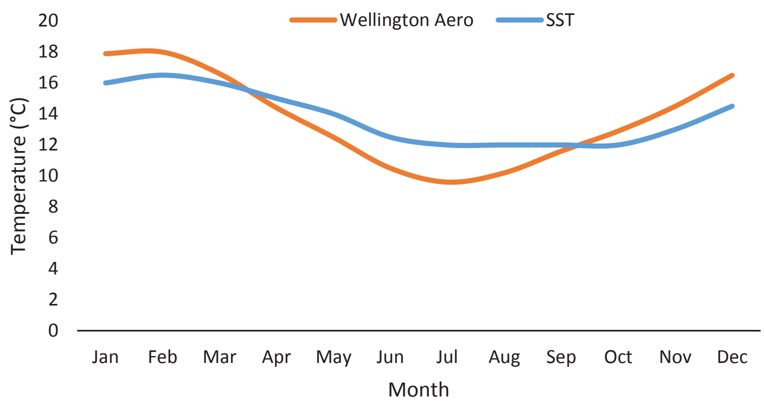

Figure 12. Mean monthly land (Wellington Aero) and sea surface temperatures (SST) (off the coast of Wellington city).

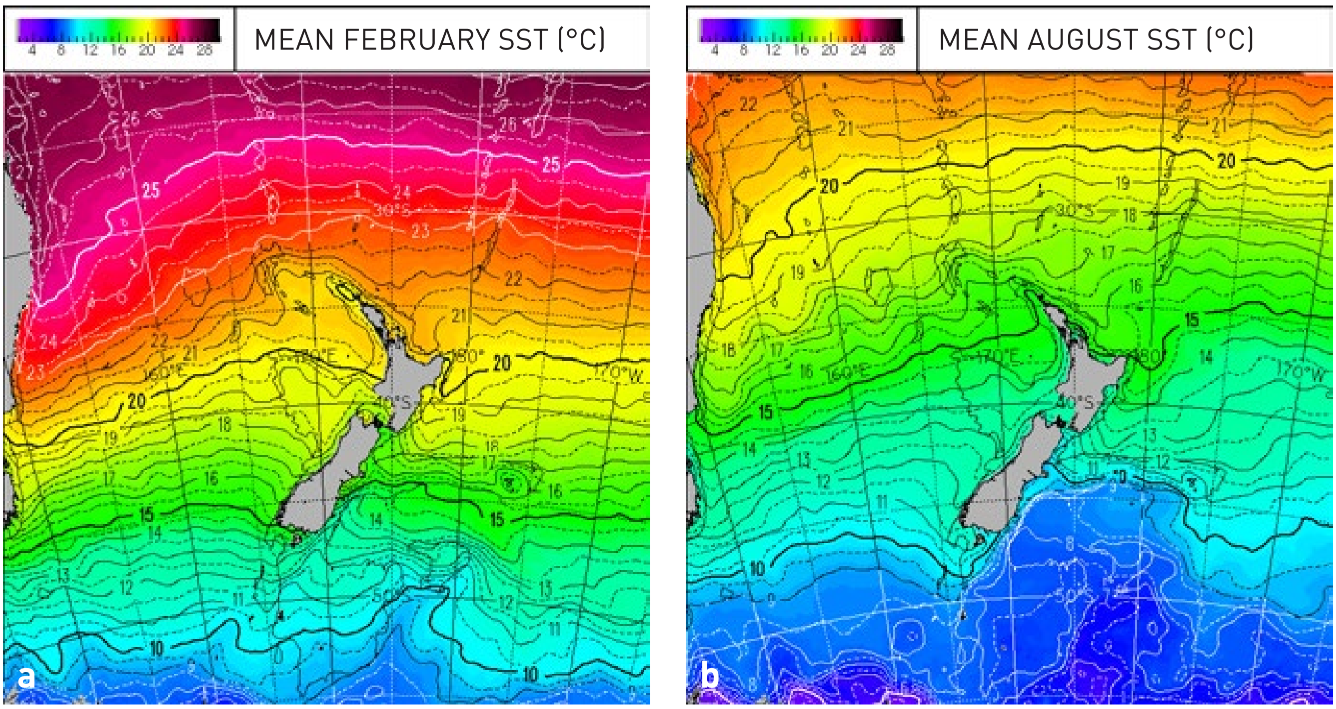

Figure 13. Monthly mean sea surface temperatures (°C) for: a) February; b) August. Source: NIWA SST Archive, Uddstrom and Oien (1999).

Air temperature

Most of the western part of the Wellington region experiences warm summer afternoon temperatures of 18–20°C, with temperatures appreciably cooler towards higher elevation areas of the Rimutaka and Tararua Ranges (Figure 14a). To the east of the dividing ranges, summer afternoon temperatures are appreciably warmer, ranging between 21 and 24°C. The moderating effect of the sea and prevailing wind on air temperature keeps maximum temperatures lower in the western part of the region. During winter nights, the western and eastern coastal strip is warmer than further inland and at higher elevations, in part due to the modifying effect of the sea on air temperature and partly because air temperature decreases with height above sea level by about 0.6°C for each 100 m increase in elevation (6–8°C average minimum daily winter temperature at the coast, 3–5°C further inland, and less than 3°C in the Tararua Ranges, Figure 14b).

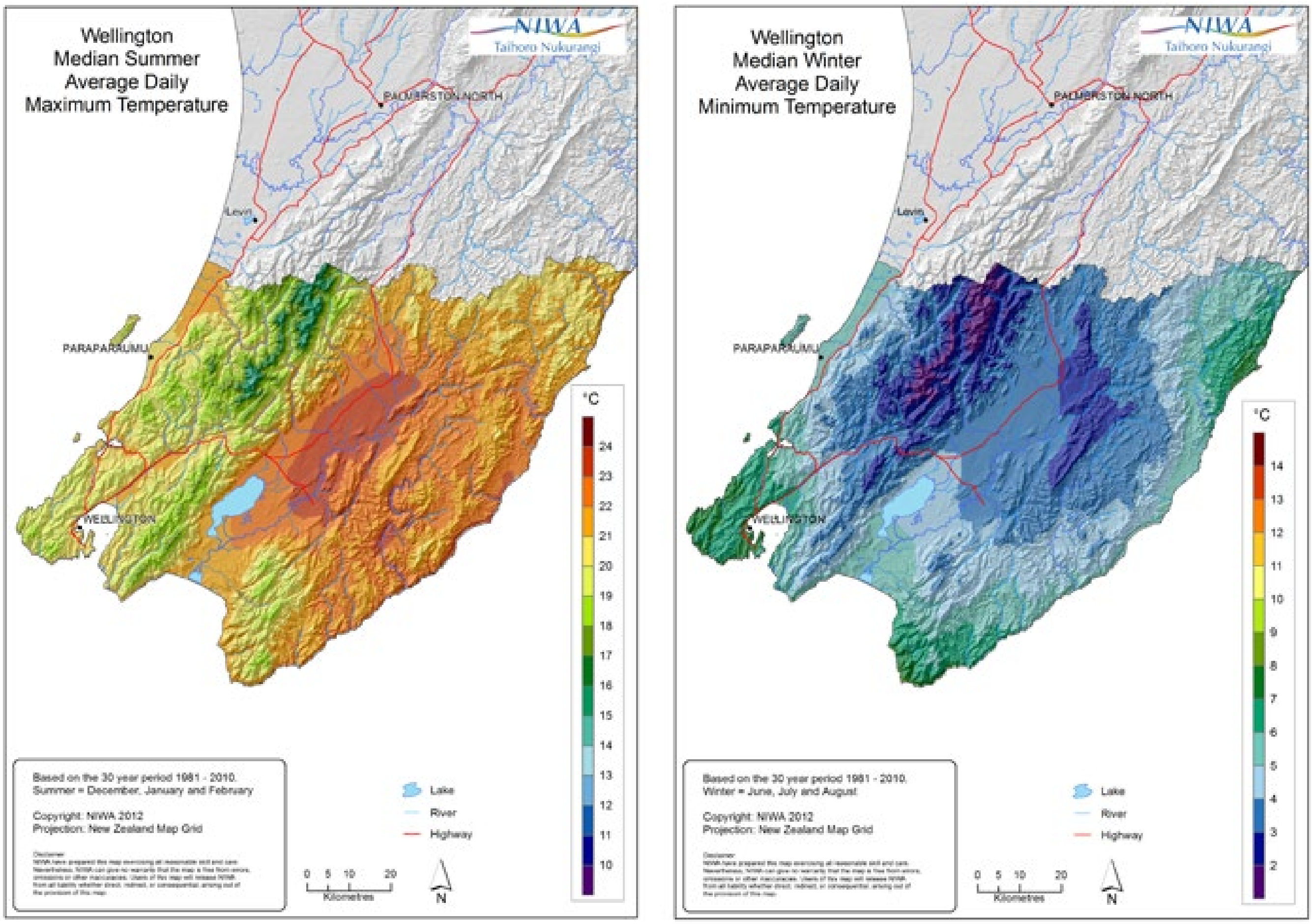

Figure 14. a) Left: Wellington median summer average daily maximum temperature; b) Right: Wellington median winter average daily minimum temperature 1981–2010.

Figure 15 shows that median annual average temperature in the Wellington region varies strongly with elevation. Low-lying areas around the coast have a median annual temperature of around 13.5°C, whereas the inland hill country experiences median annual temperatures of about 11–13°C. Median annual air temperatures are significantly cooler higher in the Tararua and Rimutaka Ranges (less than 10°C). 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 16 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 the Wellington region.

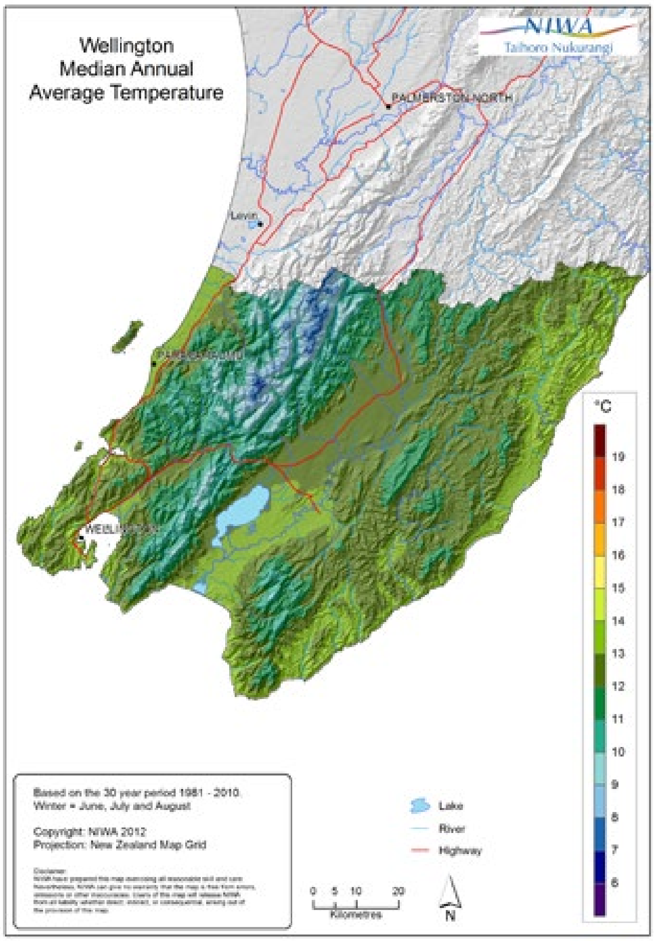

Figure 15. Wellington median annual average temperature 1981–2010.

Daily temperature ranges in Wellington vary across the region (Table 10). The daily range of temperature, i.e. the difference between the maximum and the minimum, is smaller at the coast (e.g. Castlepoint, Paraparaumu, and Wellington) than inland areas (e.g. Martinborough). In the mountain ranges the daily variation is also influenced by cloudiness and elevation; the higher the elevation and cloudier the conditions, the smaller the temperature range.

The daily temperature range for Wellington is moderate. Martinborough, which is inland and away from the modifying effect of the sea, has a larger diurnal temperature range than Wellington. Table 11 and Figure 17 show mean hourly temperatures for Wellington and Martinborough for January and July.

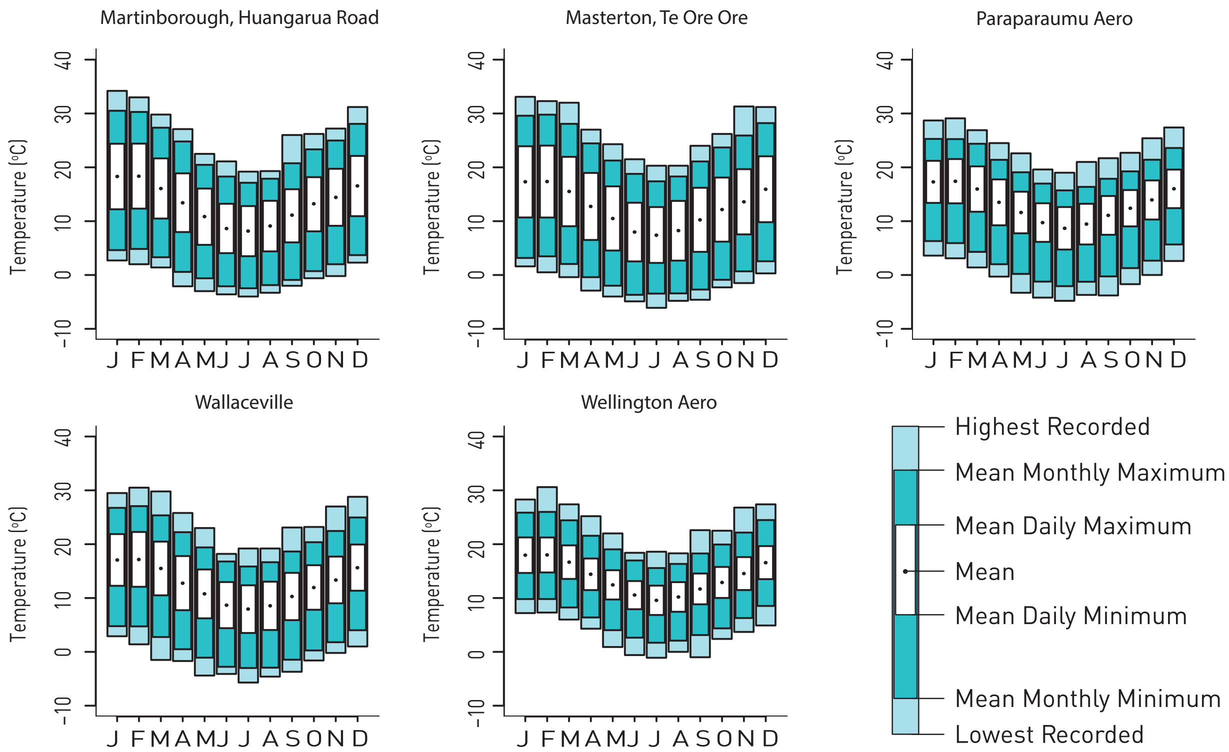

Figure 16. Monthly variation in air temperatures for selected Wellington region stations.

Table 10. Average daily temperature range (Tmax – Tmin, °C) for Wellington sites.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Castlepoint Aws	7.0	6.7	6.2	5.9	5.3	5.0	4.8	5.1	5.7	6.1	6.5	6.6	5.9
Martinborough, Huangarua Rd	12.2	12.1	11.3	11.1	10.5	9.2	9.3	9.4	10.1	10.3	10.7	11.0	10.6
Paraparaumu Aero	7.8	8.2	8.4	8.5	7.7	7.2	7.9	7.5	7.2	6.8	7.3	7.2	7.6
Wellington Aero	6.5	6.5	6.3	5.9	5.5	5.2	5.4	5.5	5.7	5.8	6.1	6.1	5.9

Table 11. Mean hourly temperatures at Wellington Aero and Martinborough EWS for January and July (Martinborough data 2000–2013).

hrs	00	01	02	03	04	05	06	07	08	09	10	11
Wellington, January	16.1	15.9	15.8	15.6	15.5	15.4	15.7	16.4	17.1	18.0	18.6	19.1
Wellington, July	9.0	8.9	8.9	8.8	8.7	8.7	8.6	8.7	8.7	9.3	10.1	10.8
Martinborough, January	14.5	14.2	13.9	13.7	13.4	13.3	14.0	15.9	17.6	19.1	20.2	21.1
Martinborough, July	6.4	6.2	6.0	5.9	5.8	5.7	5.6	5.4	5.4	6.7	8.5	10.1
hrs	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Wellington, January	19.5	19.8	19.8	19.8	19.5	19.1	18.5	17.9	17.2	16.9	16.6	16.4
Wellington, July	11.2	11.5	11.5	11.3	11.1	10.6	10.1	9.9	9.6	9.4	9.3	9.1
Martinborough, January	21.7	22.1	22.3	22.1	21.6	20.9	20.1	18.9	17.3	16.2	15.6	15.1
Martinborough, July	11.0	11.5	11.7	11.6	11.1	9.9	8.5	7.9	7.5	7.1	6.8	6.5

The Wairarapa, like other regions east of the main ranges, can experience sharp and sudden changes in temperature (Figure 18), and has a larger daily range (or diurnal variation) of temperature than is found in western coastal parts of the region.

Wellington has the least extreme temperatures out of the sites in Table 12, with 6 days per year on average where the maximum air temperature exceeds 25°C and no days, on average, when temperatures fall below 0°C. In contrast, East Taratahi (near Masterton) records 40 days where temperatures rise above 25°C, and 33 days when temperatures fall below freezing on average. In general, coastal sites have fewer extremes than inland sites.

Extreme maximum temperatures in the Wellington region are not as high as have been recorded under foehn conditions in other east coast regions. The highest maximum temperature measured in the region to date is 35.2°C, recorded at Waingawa in January 1924. The extreme minimum temperature of -7.2°C was recorded at Wallaceville in June 1944. These extreme temperatures compare to national extremes of 42.4°C and -25.6°C.

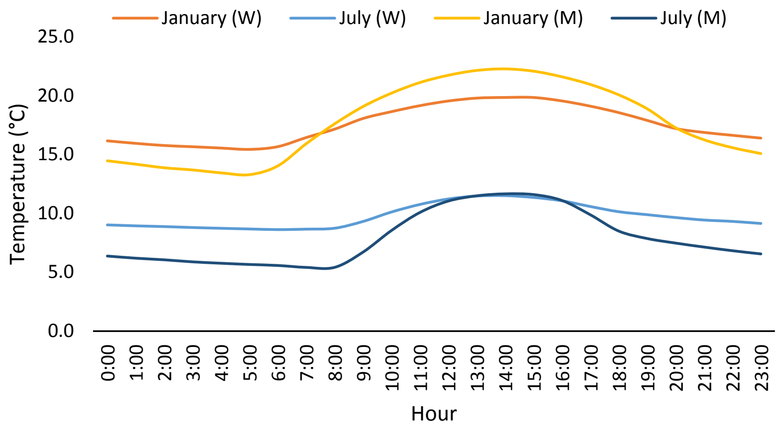

Figure 17. Mean hourly temperatures at Wellington Aero (W) and Martinborough EWS (M) for January and July.

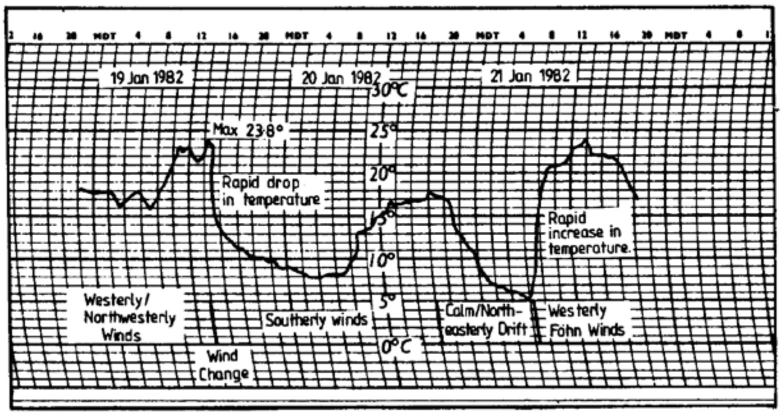

Figure 18. Thermogram trace 19–21 January 1982 at Waingawa, showing large and sudden temperature changes.

Table 12. Number of days where maximum temperature exceeds 25°C and minimum temperature falls below 0°C for Wellington sites.

	Days >25°C	Days <0°C
Castlepoint AWS	13	0
East Taratahi AWS	40	33
Paraparaumu Aero	4	12
Wallaceville	11	24
Wellington Aero	6	0

Earth temperatures

Earth (soil) temperatures are measured once daily at 9 am at several Wellington 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, and 100 cm depths. Table 13 lists mean monthly earth temperatures for a number of standard depths.

In the Wellington region, earth temperatures, like air temperatures, vary spatially. Inland sites, such as Masterton, exhibit cooler 9 am earth temperatures than coastal sites, such as Paraparaumu and Wellington. Figure 19 shows how earth temperatures change throughout the year at Wellington, compared with air temperature. The temperature cycle for 100 cm depth is more damped and lagged than at shallower depths.

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 Wellington region in the cooler months, especially at inland and higher elevation sites. The highly variable hilly landscape in the Wellington region causes a high spatial variation in frostiness on the local scale. Air frosts are rare in the Wellington city area in exposed positions such as Kelburn, but are more common in sheltered locations, such as Wallaceville.

Table 14 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 16.

Table 13. Mean 9 am earth temperatures at different Wellington locations, with station elevations.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Masterton, Te Ore Ore (110m)	5cm	17.3	16.8	14.4	11.2	8.2	5.7	5.3	5.8	8.3	10.7	13.4	16.2	11.1
	10cm	18.0	17.8	15.3	11.9	9.0	6.5	5.9	6.5	8.7	11.3	13.9	16.6	11.8
	20cm	19.7	19.6	17.1	13.5	10.4	7.6	6.9	7.6	9.8	12.6	15.4	17.9	13.2
	30cm	20.3	20.1	17.7	14.1	11.0	8.2	7.4	8.1	10.3	13.2	15.9	18.5	13.7
	100cm	18.7	19.2	18.0	15.7	13.2	10.6	9.1	9.3	10.6	12.6	15.0	17.0	14.1
Paraparaumu Aero (5m)	5cm	20.0	18.9	16.6	13.6	10.4	7.8	6.6	8.3	11.6	13.6	16.4	18.7	13.5
	10cm	19.3	18.8	16.4	13.1	10.4	8.1	6.8	7.9	10.6	12.8	15.4	17.8	13.1
	20cm	20.2	20.1	17.6	14.2	11.4	9.1	7.8	8.7	11.0	13.3	16.0	18.4	14.0
	30cm	20.6	20.6	18.3	15.0	12.1	9.7	8.5	9.4	11.5	13.8	16.5	18.8	14.6
	100cm	18.5	19.2	18.3	16.4	14.3	12.3	10.9	10.9	11.8	13.2	15.0	16.8	14.8
Wallaceville (56m)	10cm	17.6	17.5	15.7	12.7	10.2	8.1	7.0	7.6	9.7	11.9	13.9	16.2	12.4
	20cm	18.4	18.5	16.5	13.6	11.1	9.0	7.8	8.4	10.2	12.3	14.5	16.7	13.1
	30cm	18.7	18.9	17.1	14.3	11.9	9.6	8.5	9.0	10.7	12.8	14.8	17.0	13.6
	100cm	17.7	18.3	17.6	15.8	13.7	11.7	10.3	10.2	11.1	12.6	14.4	16.0	14.1
Wellington, Kelburn (125m)	10cm	17.5	17.3	15.4	12.5	10.1	8.1	6.9	7.5	9.3	11.5	13.7	16.0	12.1
	20cm	18.7	18.6	16.7	13.8	11.3	9.1	7.9	8.5	10.3	12.4	14.7	17.0	13.2
	50cm	19.3	19.3	17.6	14.8	12.2	9.9	8.7	9.3	11.0	13.1	15.5	17.6	14.0
	100cm	18.1	18.7	18.1	16.3	14.3	12.1	10.6	10.4	11.3	12.8	14.8	16.5	14.5

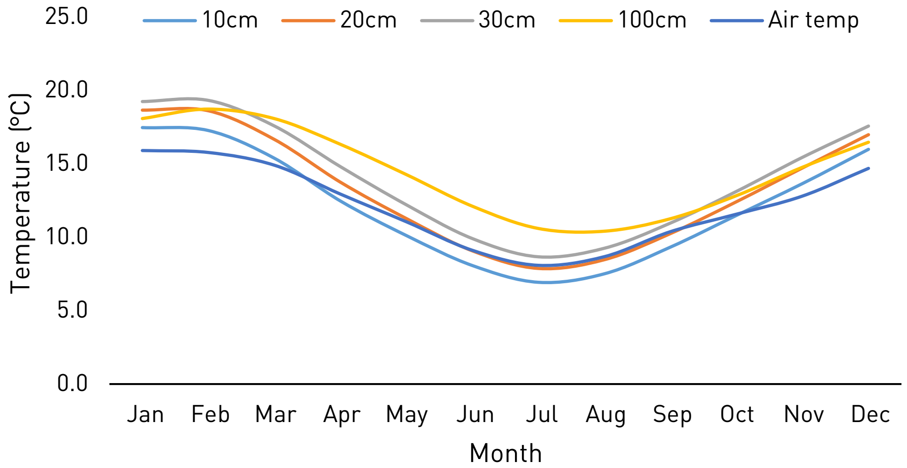

Figure 19. Average monthly 9 am earth temperatures for different depths and mean 9 am air temperature at Wellington, Kelburn.

Table 14. Occurrences of frosts and grass minimum temperatures in Wellington region.

Location		**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Ann**
Martinborough, Huangarua Rd	a	10.0	10.1	8.1	5.0	2.4	0.9	0.3	0.9	2.6	5.4	6.7	8.4	5.1
	b	-0.1	-0.2	-1.9	-4.2	-6.6	-7.8	-8.5	-7.2	-6.4	-4.0	-3.3	-0.2	
	c	0	0	0.3	2.8	9.3	12.5	13.9	12.9	7.9	2.8	0.9	0	63.5
	d	0	0	0	0.4	1.9	4.7	5.5	4.7	1.4	0.2	0.1	0	18.8
Masterton, Te Ore Ore	a	8.4	8.1	6.5	3.9	1.9	-0.4	-0.6	-0.4	1.3	3.6	5.3	7.5	3.8
	b	-0.7	-1.5	-4.0	-6.8	-8.2	-10.0	-8.9	-8.5	-7.5	-6.3	-4.4	-3.3	
	c	0	0.3	0.5	4.7	9.8	14.9	15.9	15.4	10.9	5.3	2.8	0.5	81.0
	d	0	0	0.1	1.1	4.8	9.6	9.8	8.7	4.1	2.0	0.6	0	40.8
Paraparaumu Aero	a	10.8	10.6	8.8	6.0	4.7	3.3	1.8	2.7	4.7	6.4	7.6	10.1	6.5
	b	-2.6	-3.3	-5.2	-6.2	-8.3	-9.2	-8.7	-7.2	-8.2	-6.6	-6.2	-2.6	
	c	0.2	0.2	0.9	3.3	5.8	7.9	10.8	8.5	5.0	2.6	1.6	0.3	47.1
	d	0	0	0	0	0.7	2.3	4.9	2.6	0.8	0.2	0	0	11.6
Wallaceville	a	9.6	9.2	7.8	5.0	3.6	1.9	1.1	1.6	3.1	5.3	6.6	8.9	5.3
	b	-0.6	-3.1	-5.7	-5.5	-7.3	-8.0	-8.7	-9.1	-7.0	-7.4	-5.2	-2.5	
	c	0	0.3	0.8	3.5	6.7	9.2	10.8	10.3	7.2	3.3	1.6	0.5	54.0
	d	0	0	0	0.5	2.2	5.1	7.1	6.0	2.5	0.5	0.1	0	24.1
Wellington, Kelburn	a	11.4	11.5	10.2	7.7	6.3	4.6	3.6	3.8	5.3	7.0	8.1	10.3	7.5
	b	2.5	2.5	0.4	-2.4	-3.1	-3.0	-4.4	-4.6	-3.5	-2.0	0.4	0.2	
	c	0	0	0	0.1	0.6	1.6	3.4	3.2	1.2	0.4	0	0	10.5
	d	0	0	0	0	0	0	0	0	0	0	0	0	0

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 southwestern tip of the Wellington region is the sunniest part of the region, recording over 2100 hours of bright sunshine per year (Figure 20). In general, coastal areas are sunnier than further inland throughout the region. Cloudiness increases towards the Tararua and Rimutaka Ranges – bright sunshine hours total less than 1750 hours per year for much of the Tararua Ranges. Because of the complex topography of the Wellington region there will be quite large deviations from these values in sheltered valleys and gullies, with the cumulative effects of topography on the wind, cloud, and sunshine distributions. Figure 21 shows the monthly mean, maximum, and minimum recorded bright sunshine hours for selected sites in Wellington.

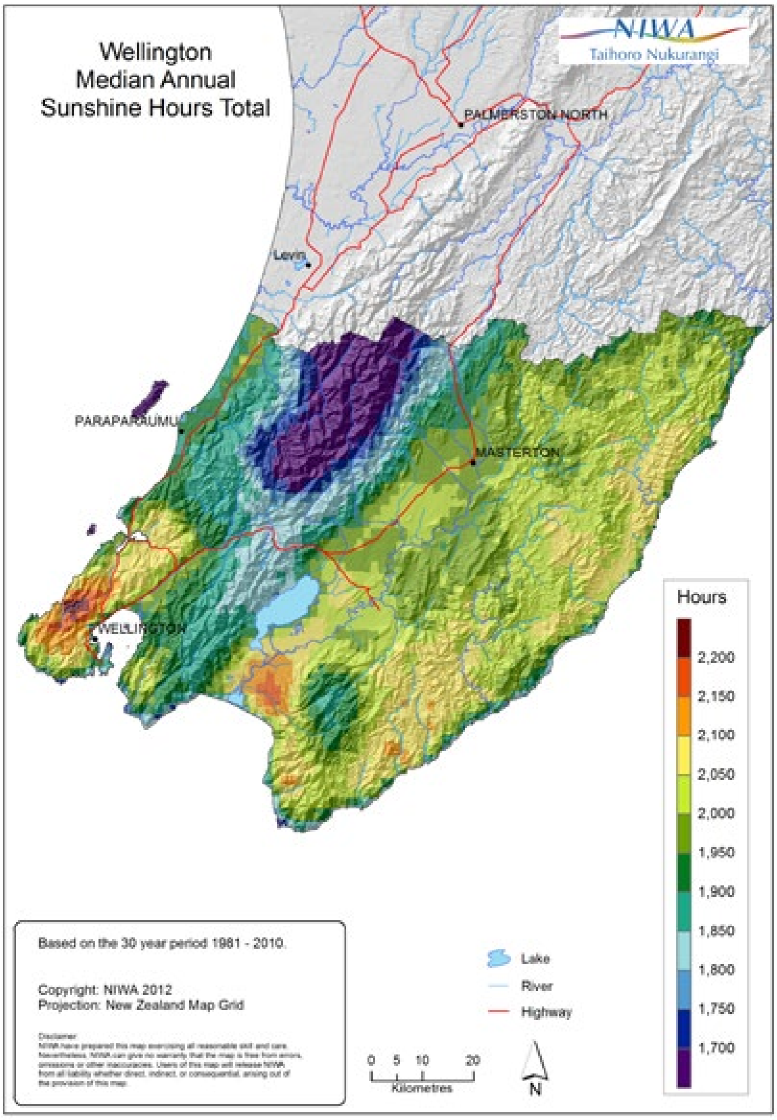

Figure 20. Median annual sunshine hours for Wellington 1981–2010.

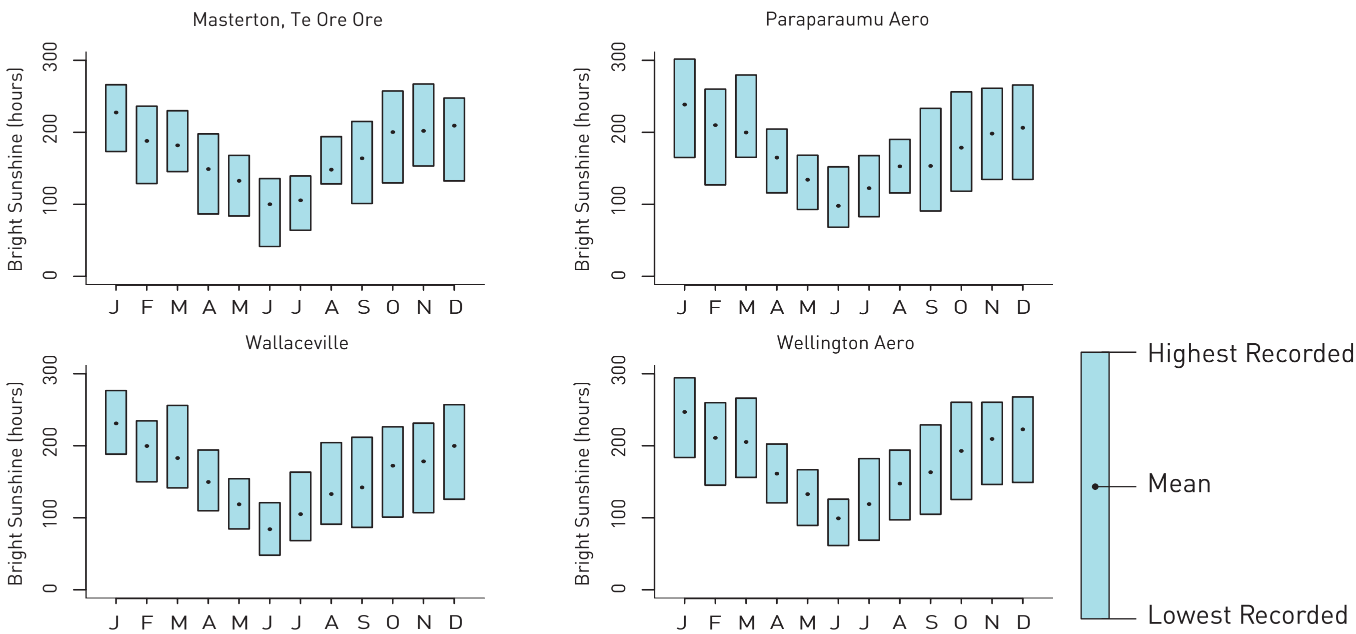

Figure 21. Mean, highest, and lowest recorded monthly bright sunshine hours for selected sites in Wellington region.

Solar radiation

Solar radiation records are available for a number of sites in the Wellington region, but only a small number of sites have a long record (>10 years). Solar radiation (mean daily global solar radiation) is presented for East Taratahi, Paraparaumu, and Wellington in Table 15. Insolation is at a maximum in December and January and a minimum in June.

Table 15. Mean daily global solar radiation (MJ/m2/day) for Wellington sites, from all available data.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
East Taratahi AWS	22.4	18.8	15.1	10.0	7.0	5.4	5.8	8.7	12.8	16.9	21.0	22.1	13.8
Paraparaumu Aero AWS	22.4	19.8	15.6	10.5	7.1	5.3	6.1	8.9	12.2	16.1	20.2	21.3	13.8
Wellington, Kelburn	23.4	19.9	15.0	10.3	6.5	5.1	5.6	8.1	12.5	17.1	20.9	22.5	13.9

UV (Ultra-violet radiation)

UV measurements are available for Wellington (Kelburn) and Paraparaumu. Figure 22 shows that the mean daily maximum UV Index is higher in Paraparaumu than Kelburn year round, due to Paraparaumu's sunnier west coast location. However, both sites show a strong summer maximum and winter minimum of UV Index measurements. Figure 23 shows an example of a UV forecast for Wellington, and indicates the levels of UV and times of the day where sun protection is required. In the summer (Figure 23a) UV radiation is high, prompting warnings for sun protection between 9 am and 5.30 pm. In the winter (Figure 23b), the amount of UV radiation does not reach the level at which sun protection is advised.

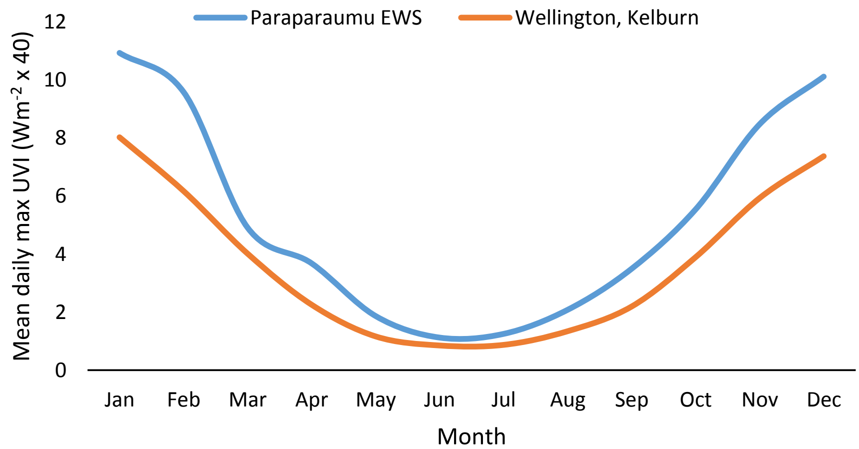

Figure 22. Mean daily maximum UV Index at Paraparaumu EWS and Wellington Kelburn.

Photo: ©mychillybin.co.nz/Pippa de Court

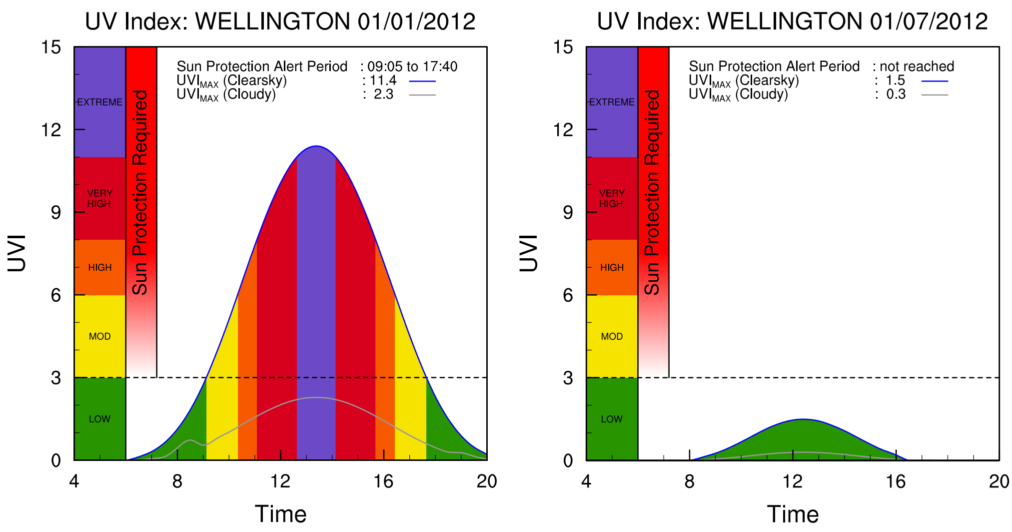

Figure 23. UV Index forecast for Wellington, January and July. Source: https://www.niwa.co.nz/our-services/online-services/uv-and-ozone.

Fog

Most incidents of fog in the Wellington region form at night under anticyclonic conditions with clear skies and very little air movement. Radiational cooling of the land also contact cools the air above and fog will normally form if the air is cooled to its dew-point, allowing the water vapour in the air to condense. Occasional sea fog or very low stratus cloud form along the coast, and can occur at any time of the day or night.

The frequency of fog varies widely over the Wellington region, ranging from an average of 43 days with fog per year at Wallaceville to an average of only three times per year at Paraparaumu. More fogs occur in Wallaceville due to the sheltered nature of the Upper Hutt valley. Although fog can occur at any time of the year it is recorded most frequently between March and July. The average number of days per year with fog for selected stations in the Wellington region is listed in Table 16.

Table 16. Average number of days each year with thunder, fog, and hail, from all available data.

Location	Thunder	Fog	Hail
Paraparaumu Aero	6	3	4
Waingawa	2	5	1
Wallaceville	4	43	3
Wellington, Kelburn	5	9	9

Severe convective storms

Thunderstorms

Thunderstorms are fairly evenly distributed throughout the year, but there is a tendency for them to be more frequent during the winter when cold and unstable air masses cross the region. Thunderstorms are usually associated with cold south or southwest airstreams, but during the warmer months thunderstorms may result from strong afternoon surface heating leading to intense convection and cumuliform cloud development. Average annual frequencies for selected stations are given in Table 16, and range from two per year at Waingawa to six per year at Paraparaumu. 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

Table 16 gives the average number of days per year on which hail is reported at selected stations. These range from one day per year at Waingawa to nine days per year at Kelburn. Hail is more frequent at the southern coast of the region, in part because of the uplifting effect of the land on unstable southerly flows as they leave the sea. 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, and like thunderstorms (with which hail is normally associated), hail is more frequent when cold and unstable air masses cross the region.

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 10–20 m 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 infrequent in the Wellington region, with only six damage-causing tornadoes being reported in NIWA's Historical Weather Events Archive (1900–2012) and climate summaries (2000–2013).

One tornado that caused damage in the region was at Peka Peka Beach, north of Waikanae, on 9 July 2011. Trees were brought down, crushing cars and a caravan, injuring the occupants. Sheds were demolished, roofs blown off, and cars blown over. One vehicle on SH 1 was tossed 30 m into a paddock, with the driver suffering only minor injuries. A woman walking near the coast also suffered minor injuries when she was blown over. Power lines were damaged, cutting power to some areas.

Snow

Snow is relatively frequent during winter in the Rimutaka and Tararua Ranges. SH 2 at Rimutaka Hill is sometimes closed due to heavy snow and icy conditions. However, no high elevation sites in the Wellington region have long enough records (>10 years) to enable calculation of average snow days. Kaitoke, near the head of the Hutt Valley, has an elevation of 223 m, and observes on average 2.5 days of snowfall per year, and 0.9 days per year where snow lies on the ground (i.e. the snow does not melt before or soon after it hits the ground). Mt Bruce Reserve, on the eastern slopes of the Tararua Ranges at 305 m elevation, averages 2.6 days per year with snowfall and 1.3 days per year with lying snow.

Lower elevations rarely observe snowfall – Kelburn in Wellington city records the most snowfall days out of the lower elevation sites with records of at least 10 years, with an average of 0.9 days of snowfall per year, and one day every five years where snow lies on the ground. Most other low elevation sites record snowfall about once every two to ten years. Days with snow are averaged from all available data.

When a snowfall does occur in the lowland areas, it is usually associated with a deep depression just to the east of the region together with a very cold south to southwest airstream over much of New Zealand. On 15 and 16 August 2011, a bitterly cold southerly airstream caused widespread snow in both Islands, causing significant disruption. In the Wellington region, snow was observed down to sea level, the heaviest and most widespread snowfall in at least 50 years. Roads were closed, public transport and postal services were cancelled, schools were closed, and power was out to 13,000 people across Lower Hutt, Whitemans Valley, and Tawa.

Sea swell and waves

The ocean off the west coast of New Zealand is exposed to the prevailing west to southwest swells of its latitude zone. Consequently, swells off the west coast are much higher than those off the east coast.

Cook Strait is the only gap between the mountainous North and South Islands, and because it is located in the westerly wind belt known as the Roaring Forties, the strait acts as a giant wind tunnel. The swells on Cook Strait can increase rapidly with a southerly storm, sometimes reaching heights of 15 m or more. Because of the wind funnelling and strong tidal flows, Cook Strait is regarded as one of the most dangerous and unpredictable stretches of water in the world.

At Baring Head, on Wellington's south coast, prevailing swells come from the south 45% of the time, and from the southwest 35% of the time (Gorman et al., 2003). Of all swells observed, the frequency of those from one to two metres is 40%, while for those greater than two metres is about 12%. About 1% of swells are over four metres.

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 17.

Table 17. 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+

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 and their uses are discussed in the following section. Short-term high intensity rainfalls have been covered previously in this report.

Vapour pressure and relative humidity

Vapour pressure and relative humidity are 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 18.

Relative humidity relates the amount of water present in the air to the amount required to saturate it. This varies with temperature, and so a large diurnal variation is usually noticeable. Relative humidity is quite high in all seasons, but there is a peak in winter, as shown in Table 19. Inland areas (e.g. East Taratahi) tend to have lower relative humidity than coastal sites (e.g. Paraparaumu and Wellington). The atmosphere in the Wellington region is relatively moist, reflecting the region's maritime location.

Table 18. Mean monthly/annual 9 am vapour pressure (hPa) for selected Wellington sites.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
East Taratahi AWS	13.7	14.0	13.3	11.7	10.1	8.6	8.2	8.7	9.8	10.5	11.4	13.1	11.1
Paraparaumu Aero	15.5	15.7	14.5	13.0	11.7	10.4	9.6	10.0	10.8	11.7	12.6	14.5	12.5
Wallaceville	15.5	15.6	14.4	12.7	11.3	9.8	9.1	9.4	10.5	11.7	12.5	14.4	12.2
Wellington Aero	14.9	15.2	14.2	12.8	11.5	10.3	9.6	9.8	10.5	11.3	12.1	13.9	12.2

Table 19. Mean monthly/annual 9 am relative humidity (%) for selected Wellington sites.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
East Taratahi AWS	68.4	74.3	75.8	78.3	82.7	83.6	83.2	80.5	73.9	72.1	70.1	69.4	76.0
Paraparaumu Aero	75.9	77.1	75.3	76.7	80.2	82.4	82.1	79.3	76.3	76.8	75.6	77.1	77.9
Wallaceville	79.7	83.7	83.3	86.5	89.6	89.9	88.5	87.2	81.9	81.4	79.2	80.0	84.2
Wellington Aero	75.6	77.8	77.2	77.8	79.9	81.1	81.1	79.6	76.0	76.0	74.2	75.5	77.6

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 total moisture depletion of the soil occurs.

Table 20. 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
East Taratahi Aws (91m)	NR	0	0	0	0	2	8	11	9	3	2	0	0	35
	RO	0	2	2	1	14	48	78	51	15	20	3	1	237
	ND	20	16	10	6	2	0	0	0	0	0	5	13	73
	DE	92	65	30	9	2	0	0	0	0	0	18	58	275
Paraparaumu Aero (5m)	NR	0	0	0	0	1	8	9	7	4	3	1	0	33
	RO	1	6	2	2	11	68	70	58	33	32	10	4	297
	ND	17	16	12	6	1	0	0	0	0	0	6	10	69
	DE	79	64	37	10	1	0	0	0	0	0	25	46	263
Wallaceville (56m)	NR	0	0	1	2	7	15	13	11	7	5	2	1	65
	RO	1	3	6	14	73	119	116	95	62	59	27	21	598
	ND	10	12	6	2	0	0	0	0	0	0	1	4	35
	DE	43	42	16	2	0	0	0	0	0	0	3	16	123
Wellington Aero (4m)	NR	0	0	0	0	3	8	10	8	4	2	1	0	37
	RO	0	6	1	2	24	61	89	59	28	25	11	1	305
	ND	18	16	10	7	1	0	0	0	0	0	7	13	73
	DE	83	62	31	12	1	0	0	0	0	1	28	58	275

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

Table 21. 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
East Taratahi AWS	Max	164	135	112	55	34	25	28	39	68	104	147	156	
	Mean	144	109	86	42	25	17	18	33	56	90	114	135	870
	Min	118	92	72	33	18	12	12	28	43	78	97	106	
Paraparaumu Aero	Max	162	124	101	62	39	25	27	43	73	101	134	150	
	Mean	146	111	91	51	30	20	22	36	61	90	113	132	902
	Min	123	96	80	40	21	16	12	29	49	75	101	113	
Wallaceville	Max	151	113	92	48	26	14	21	33	57	88	114	136	
	Mean	128	100	76	40	20	10	15	27	48	76	97	119	755
	Min	107	81	65	30	10	5	10	21	37	60	78	92	
Wellington, Kelburn	Max	168	131	98	60	35	21	25	40	71	102	123	146	
	Mean	142	108	86	50	29	17	21	33	56	87	107	130	865
	Min	123	90	72	40	22	13	16	28	43	70	93	101	

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 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).

Mean monthly and annual soil water balance values are given in Table 20, for a number of sites in the Wellington region. It can be seen from this table that coastal sites such as Paraparaumu and Wellington airport, as well as inland at East Taratahi, have more days of soil moisture deficit (around 70 days between November and April for these three sites) compared with Wallaceville (35 days of soil moisture deficit during the same period). Wallaceville observes approximately double the amount of runoff compared to Wellington and Paraparaumu, and more than double that of East Taratahi. There is usually adequate moisture available to maintain plant growth between June and October. Higher elevation sites exhibit more runoff than lower elevation sites. Figure 24 shows region-wide variability in days of soil moisture deficit per year.

Evapotranspiration relates to the amount of water used by plants in transpiration. Penman (1948) developed an energy-based method of estimating this quantity, i.e. potential evapotranspiration (PET). PET has been calculated for East Taratahi, Paraparaumu, Wallaceville, and Wellington using the Penman method. The monthly mean, minimum, and maximum PET values are listed in Table 21.

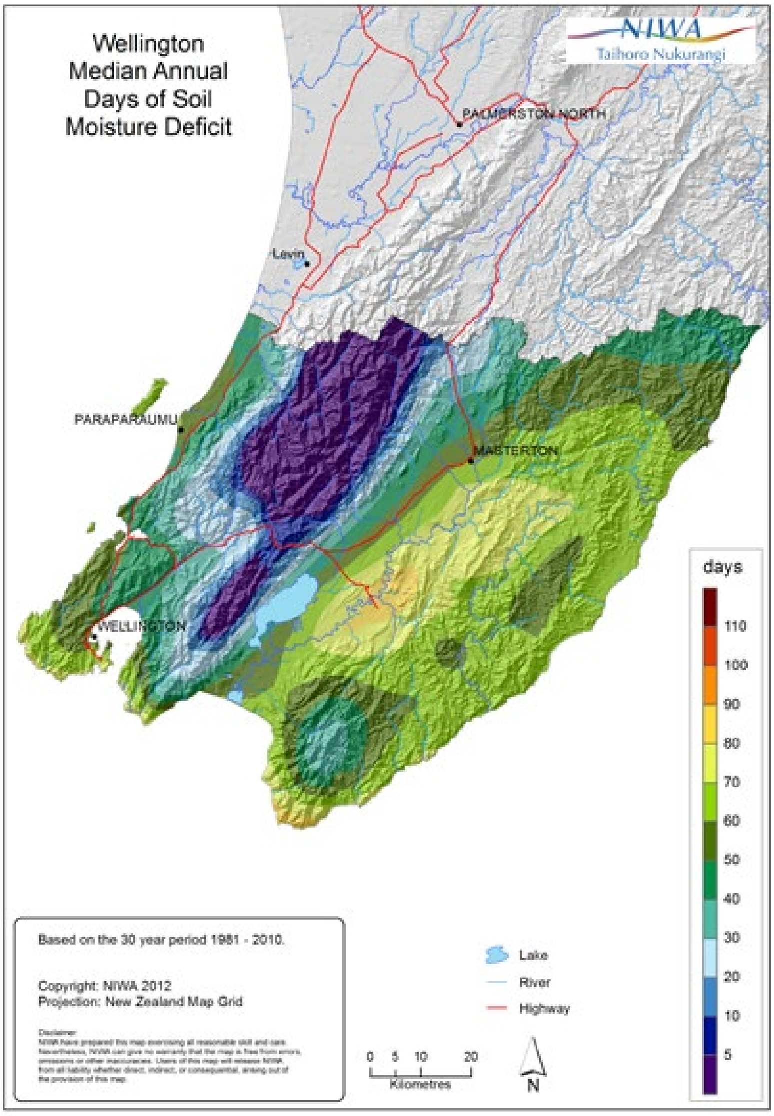

Figure 24. Wellington median annual days of soil moisture deficit 1981–2010.

Wellington, Paraparaumu, and East Taratahi, with greatest exposure to sunshine (and hence radiation), have the greatest yearly PET, while the greater cloudiness inland in the Hutt Valley coupled with lower wind runs from greater sheltering leads to lower PET in Wallaceville.

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 22 lists the monthly totals of growing degree-day totals above base temperatures of 5°C and 10°C for sites in the Wellington region.

Cooling and heating degree days are quantities 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 23 shows that the number of cooling degree days reach a peak in summer in the Wellington region, where there is a higher demand for energy to cool building interiors to 18°C. Conversely, heating

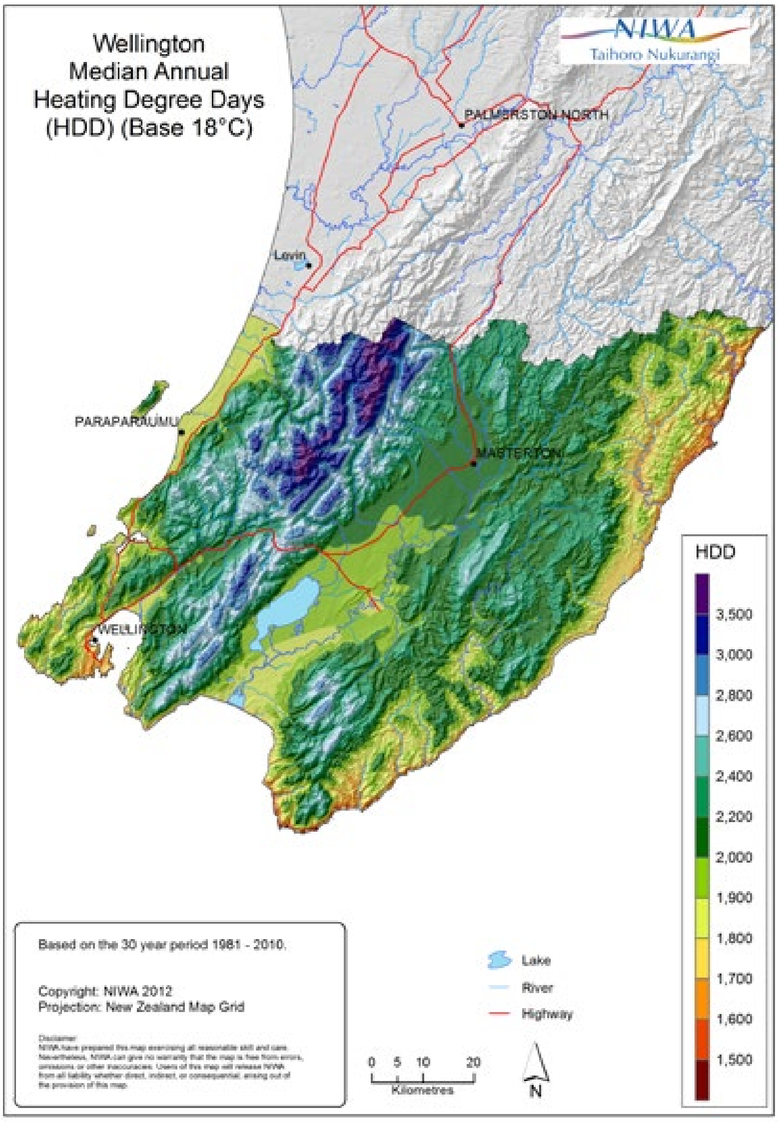

Figure 25. Median annual heating degree days for Wellington 1981–2010.

Table 22. Average growing degree-day totals above base 5°C and 10°C for selected Wellington sites.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
East Taratahi AWS	5°C	389	358	334	237	166	98	85	111	158	218	260	336	2750
	10°C	234	217	180	94	40	15	9	14	36	75	113	181	1209
Paraparaumu Aero	5°C	381	351	340	255	205	142	116	138	182	230	268	341	2949
	10°C	226	210	185	108	65	30	16	23	49	81	119	186	1299
Wallaceville	5°C	374	343	325	233	179	111	94	111	159	216	250	330	2725
	10°C	219	202	170	88	49	18	11	15	36	71	102	175	1157
Wellington Aero	5°C	402	367	362	283	231	166	142	161	200	245	286	360	3204
	10°C	247	226	207	133	81	36	20	29	58	93	136	205	1470

degree days reach a peak in winter, where the demand for energy to heat buildings to 18°C is highest. Figure 25 shows region-wide variability in the number of heating degree days per year. The number of heating degree days is lower in low elevation coastal areas (e.g. Wellington and Paraparaumu), compared with areas further inland and at higher elevations (e.g. Wallaceville and East Taratahi). The coastal sites also experience more cooling degree days than the inland sites.

Table 23. Average cooling (CDD) and heating (HDD) degree-day totals with base 18°C for selected Wellington sites.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
East Taratahi AWS	CDD	32	32	14	2	0	0	0	0	0	0	2	14	96
	HDD	45	41	83	155	238	295	325	294	232	185	132	81	2106
Paraparaumu Aero	CDD	17	19	9	1	0	0	0	0	0	0	1	6	52
	HDD	39	35	72	136	198	248	289	265	208	173	123	68	1854
Wallaceville	CDD	19	19	7	1	0	0	0	0	0	0	0	6	52
	HDD	48	42	85	158	224	280	312	293	232	187	141	79	2081
Wellington Aero	CDD	28	26	14	1	0	0	0	0	0	0	1	11	80
	HDD	29	26	55	109	172	224	261	242	190	158	105	54	1625

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REFERENCES

NIWA databases used:

The National Climate Database cliflo.niwa.co.nz

HIRDS (High Intensity Rainfall Design System) hirds.niwa.co.nz

New Zealand Historic Weather Events Catalogue hwe.niwa.co.nz

NIWA Sea Surface Temperature Database

References:

GORMAN, R. M., BRYAN, K. R. & LAING, A. K. 2003. Wave hindcast for the New Zealand region: Nearshore validation and coastal wave climate. New Zealand Journal of Marine and Freshwater Research, 37, 567–588.

PENMAN, H. L. 1948. Natural evaporation from open water, bare soil, and grass. Proceedings of the Royal Society of London A, 193, 120–145.

UDDSTROM, M. J. & OIEN, N. A. 1999. On the use of high resolution satellite data to describe the spatial and temporal variability of sea surface temperatures in the New Zealand Region. Journal of Geophysical Research (Oceans), 104, 20729–20751.

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