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THE CLIMATE AND WEATHER OF AUCKLAND

2nd edition

P.R. Chappell

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Note to Second Edition

This publication replaces the first edition of New Zealand Meteorological Service Miscellaneous Publication 115 (20), written in 1988 by J.W.D. Hessell. This edition incorporates more recent data and updated methods of climatological variable calculation.

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CONTENTS

SUMMARY

Auckland experiences a subtropical climate. The region lies some 13° of latitude south of the Tropic of Capricorn, so tropical plants which are protected for the winter months will flower and fruit in the summer, and cold climate vegetables planted in autumn will mature in early spring – providing the ground is well-drained. Almost any plant can be grown in Auckland providing the location is optimised with regard to radiation, shelter, drainage, and irrigation. Summers tend to be warm and humid, while winters are relatively mild, and many parts of the region only receive a few frosts each year. Rainfall is typically plentiful all year round, with sporadic very heavy falls. Dry spells may occur during the summer months, but they are usually not long-lived. Most parts of Auckland receive around 2000 hours of bright sunshine per year. Sometimes Auckland experiences extreme events that cause flooding and wind damage, but generally these events are not as severe as in other regions.

INTRODUCTION

The mean high pressure belt in the New Zealand sector of the Southern Hemisphere is centred near 30° S so that westerly winds predominate over the country. On a day to day basis, however, there is great variability in the pressure distribution, and sometimes intense anticyclones occur to the south of the country with depressions to the north, causing an easterly flow with the reversal of the usual weather pattern. These blocking situations may be rather persistent and interrupt the more common westerlies associated with the eastward progression of weather systems.

The Auckland region, lying in the northern part of the country, and north of the main mountain chains and the volcanic plateau, is less vulnerable to outbreaks of Antarctic air than most of the country. However, it is one of the first areas to encounter storms of tropical origin. Auckland's rain occurs mainly with northerly winds. The region is relatively warm and the higher absolute humidities give the climate a different character to that of the southern and eastern regions.

The Auckland region (i.e. the area administered by the Auckland Council) has an indented coastline including three major harbours (Kaipara, Waitemata, and Manukau). The Auckland isthmus is less than 2 km wide at its narrowest point. There are two dissected plateaux rising to 480 m and 690 m (Waitakere and Hunua Ranges[1], respectively) and numerous islands – the largest being Great Barrier Island (285 km^2). Great Barrier, along with islands in the inner Hauraki Gulf (e.g. Waiheke Island), as well as the Coromandel Peninsula (which is not in the Auckland region), shelter the waters of the eastern seaboard. The Hauraki Gulf is consequently a popular area for maritime activities. The west coast of the region is exposed to ocean swells emanating from the Tasman Sea and the Southern Ocean, which may be further disturbed by the prevailing southwest winds. These black sand coasts present a startling contrast to those of the east. Figure 1 provides geographic context for the Auckland region, and shows all locations mentioned in the text and following tables.

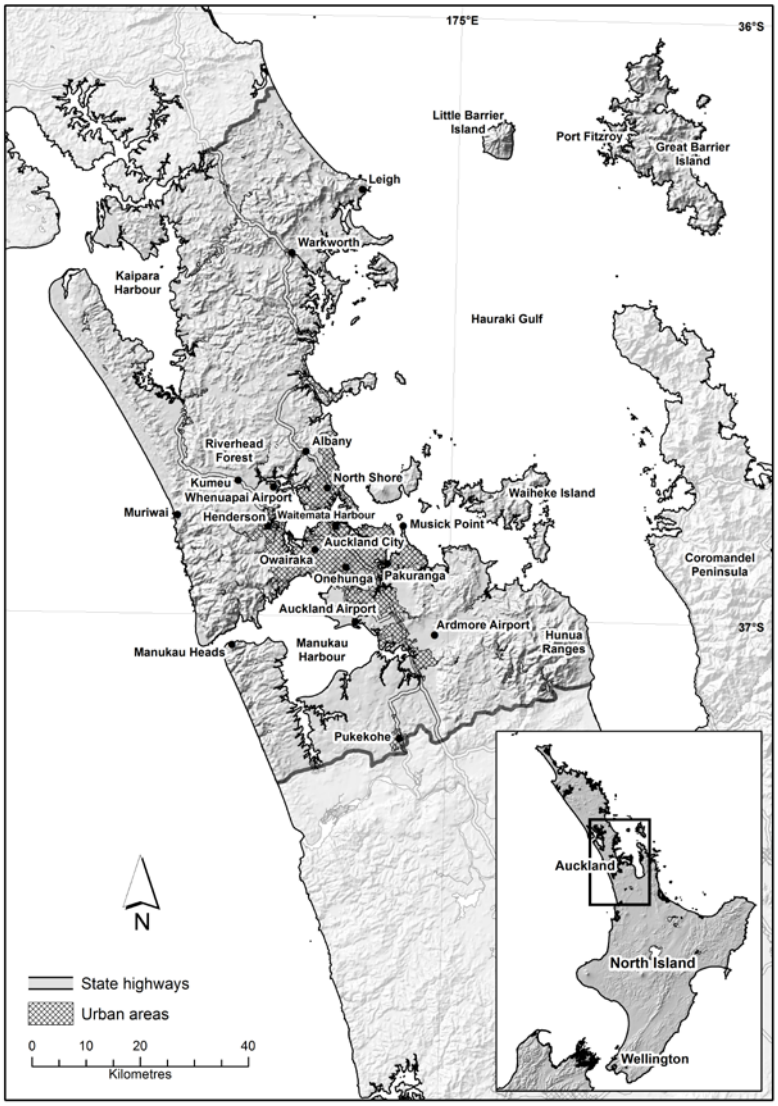


Figure 1. The Auckland region, showing places mentioned in the tables, figures, and text.

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

[1]As of 2010, the Hunua Ranges are outside the jurisdiction of Auckland Council (now part of Waikato Region), but have been included in this publication.

TYPICAL WEATHER SITUATIONS IN AUCKLAND

Strong easterlies with rain

Auckland's heaviest rainfalls occur when there is a depression to the north or northwest with a strong north to northeast wind flow over the city, and a front embedded in the flow. Such a situation occurred on July 15, 1987 (Figure 2). The usual pattern of anticyclones to the north of the country and depressions to the far south is reversed on this occasion. An intense anticyclone is centred southeast of the South Island, and a deep, complex depression lies to the north of the country, with a strong north-easterly flow lying between the two pressure systems. These are prevented from moving rapidly by another anticyclone to the east, acting as a block. The frontal zone demarks the boundary between air arriving from the Cook Islands region and that arriving from the south Tasman Sea. Surface winds over Auckland reached 50-60 km/hr with winds of 80 km/hr at 1000 m altitude. Very heavy rain was recorded on the Coromandel Peninsula (up to 200 mm) and rainfall over Auckland during the episode totalled 43 mm. Flooding occurred in South Auckland about the Hunua Ranges and there was also some wind damage.

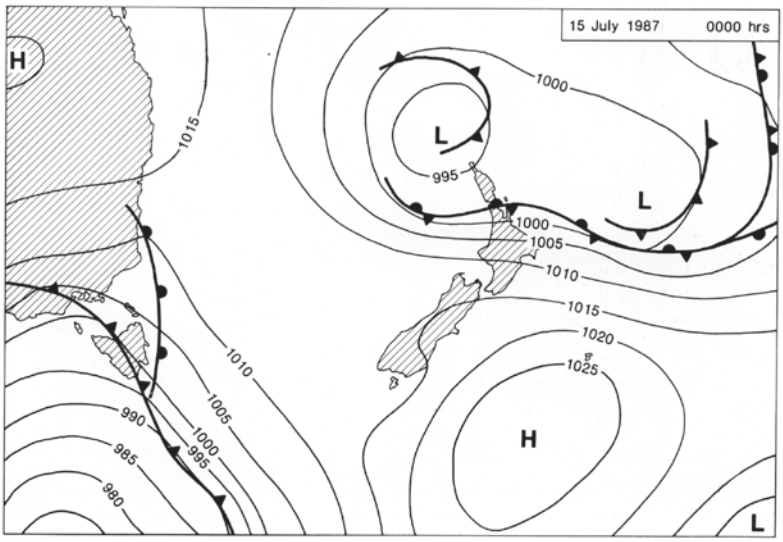


Figure 2. Strong easterlies with rain in Auckland.

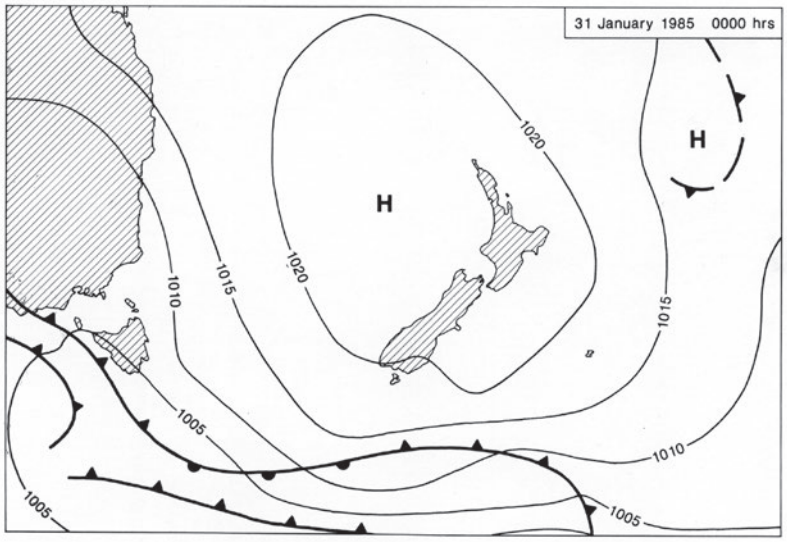


Figure 3. Fine weather in Auckland.

Fine weather

Auckland's sunniest days occur during anticyclonic conditions in a light southeasterly flow, as on 31 January 1985 (Figure 3). Due to minor causes (e.g. sea breeze convergence zones or an anticyclonic subsidence inversion) local variations in wind direction and cloud cover may occur, but fine weather predominates. On the day of this example, over twelve hours of sunshine were recorded in Auckland city.

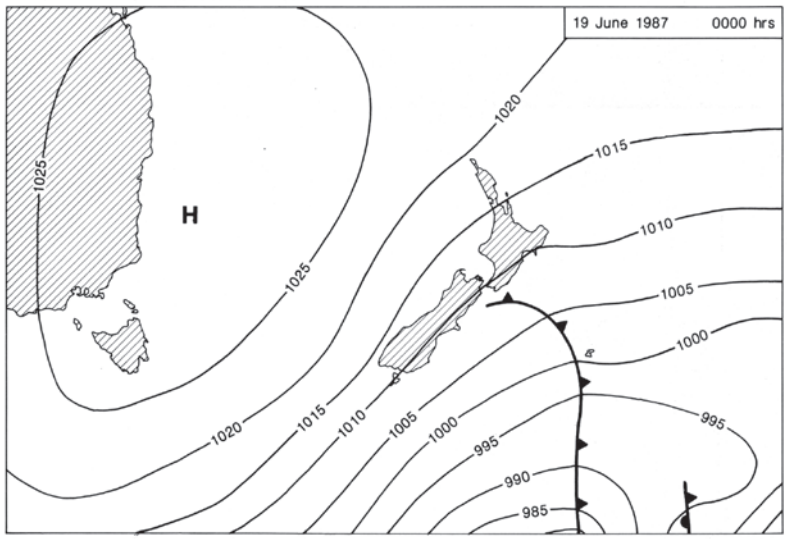


Figure 4. Southwesterly wind flows in Auckland.

Southwesterly wind flows in winter

Due to the tendency for anticyclones to form over Australia in winter, and for a major trough of low pressure to lie to the east of New Zealand, southwest airstreams are relatively common in the cooler half of the year. They are particularly persistent during periods when the Southern Oscillation Index is low (El Niño conditions). Southwesterlies produce cloudy, showery weather in Auckland, especially in winter when comparatively warm seas tend to destabilise the flow. Showers are more frequent in the hilly areas of the Waitakere and Hunua Ranges. The southwest flow is seldom undisturbed, and decaying cold fronts embedded in the flow frequently cause increases in the shower activity as they pass. Sometimes this is followed by a brief fine spell, but the cloudy, showery conditions quickly become re-established. Southwesterlies in summer are frequently fine, as the lower layers are not destabilised by comparatively warmer seas as they are in winter. Figure 4 is the synoptic analysis for a typical southwest day.

Squally westerlies

Auckland is vulnerable to strong gusty westerlies which may be accompanied by thunderstorms, and rarely tornadoes. These conditions are most likely to occur in winter and spring. Such a situation is represented by Figure 5. Typical of these situations are strongly cyclonically-curved isobars with a strong wind flow rapidly decreasing towards the depression centre. Also typical are features in the upper atmosphere such as jet streams just to the north, and a column of very cold air to high levels. On this day thunderstorms were present over the Auckland, Taranaki, Waikato, and Bay of Plenty regions, and Auckland city experienced several tornadoes which damaged buildings and brought down power lines.

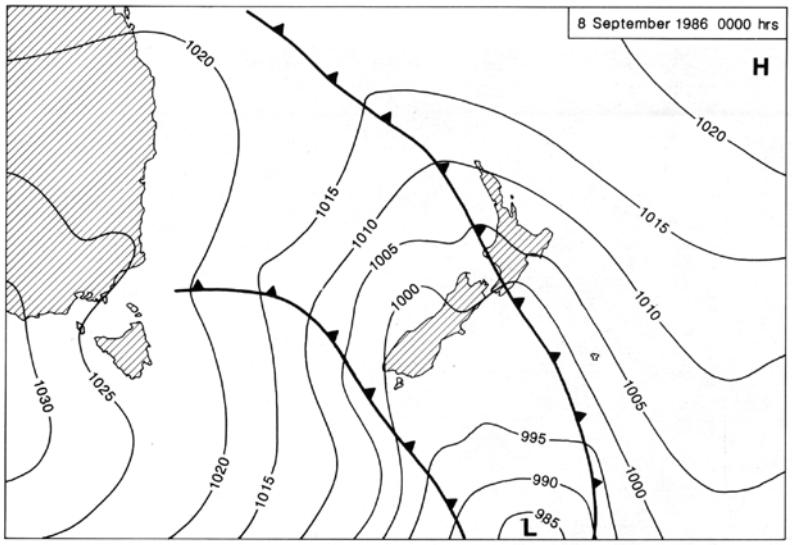


Figure 5. Squally westerlies in Auckland.

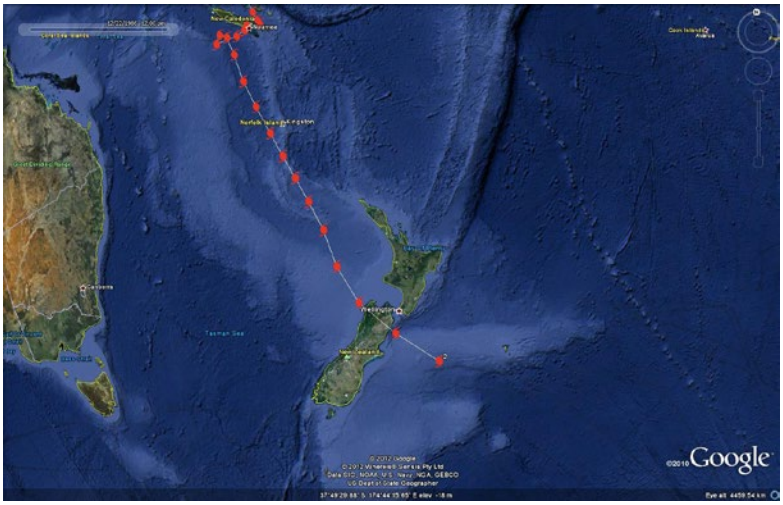


Figure 6a. Tropical cyclones which made landfall in New Zealand during December, 1970-2010. Source: Southwest Pacific Enhanced Archive of Tropical Cyclones (SPEArTC; Diamond et al., 2012).

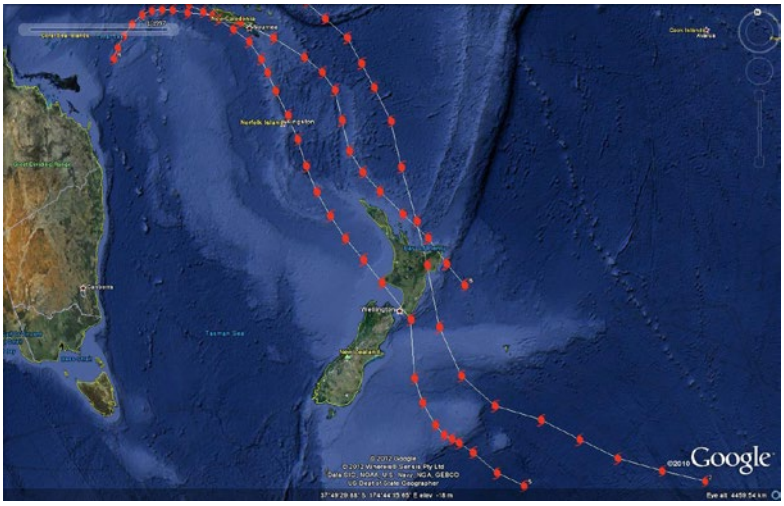


Figure 6b. Tropical cyclones which made landfall in New Zealand during January, 1970-2010. Source: SPEArTC (Diamond et al., 2012).

Tropical cyclones that reach Auckland and still retain very low pressures and hurricane force winds are very rare. However, other storms of tropical origin (which may never have been fully developed tropical cyclones) affect Auckland about once or twice each year, mainly between the months of December and April. They usually bring heavy rain and strong easterly winds.

Figure 6 shows, by months, the tracks of tropical cyclones which made landfall in New Zealand during the period between 1970 and 2010.

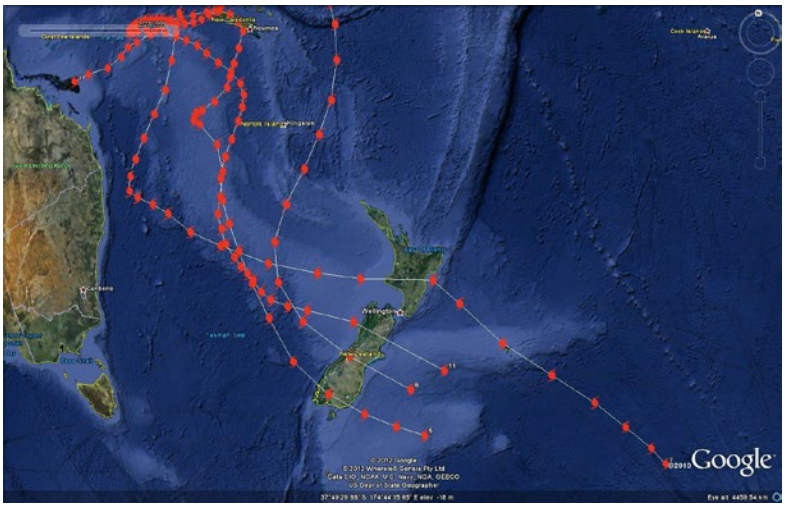


Figure 6c. Tropical cyclones which made landfall in New Zealand during February, 1970-2010. Source: SPEArTC (Diamond et al., 2012).

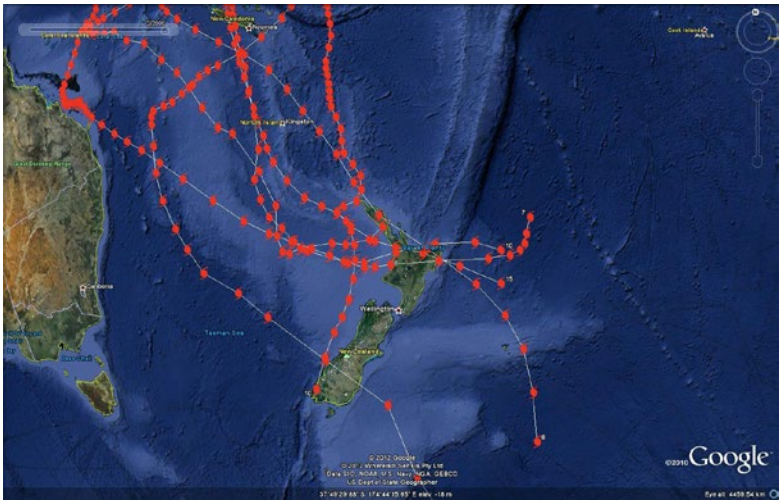


Figure 6d. Tropical cyclones which made landfall in New Zealand during March, 1970-2010. Source: SPEArTC (Diamond et al., 2012).

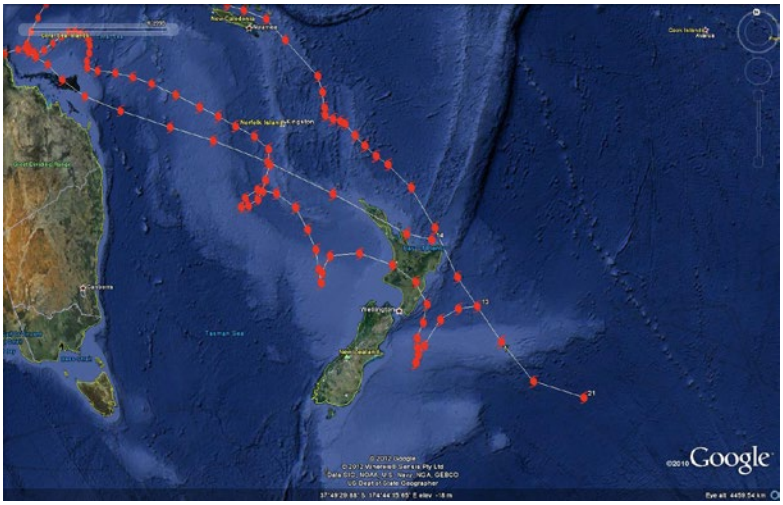


Figure 6e. Tropical cyclones which made landfall in New Zealand during April, 1970-2010. Source: SPEArTC (Diamond et al., 2012).

CLIMATIC ELEMENTS

Wind

The airflow over Auckland is predominantly from the southwest. This is particularly so in winter and spring, but in summer the proportion of winds from the northeast increases. This arises from the changing location of the high pressure belt, which is further south in summer and early autumn than it is in winter and spring. In addition, sea breezes add to the proportion of easterlies in eastern areas in summer and early autumn. Figure 6 shows mean annual wind frequencies of surface wind based on hourly observations from selected stations.

Mean wind speed data (average wind speeds are taken over the 10 minute period preceding each hour) are available for several sites in Auckland, and these illustrate the several different wind regimes of the region. Coastal areas (e.g. Auckland Airport) tend to be windier throughout the year compared with sheltered inland areas (e.g. Pukekohe). Table 1 gives mean monthly and annual wind speeds for selected stations in Auckland.

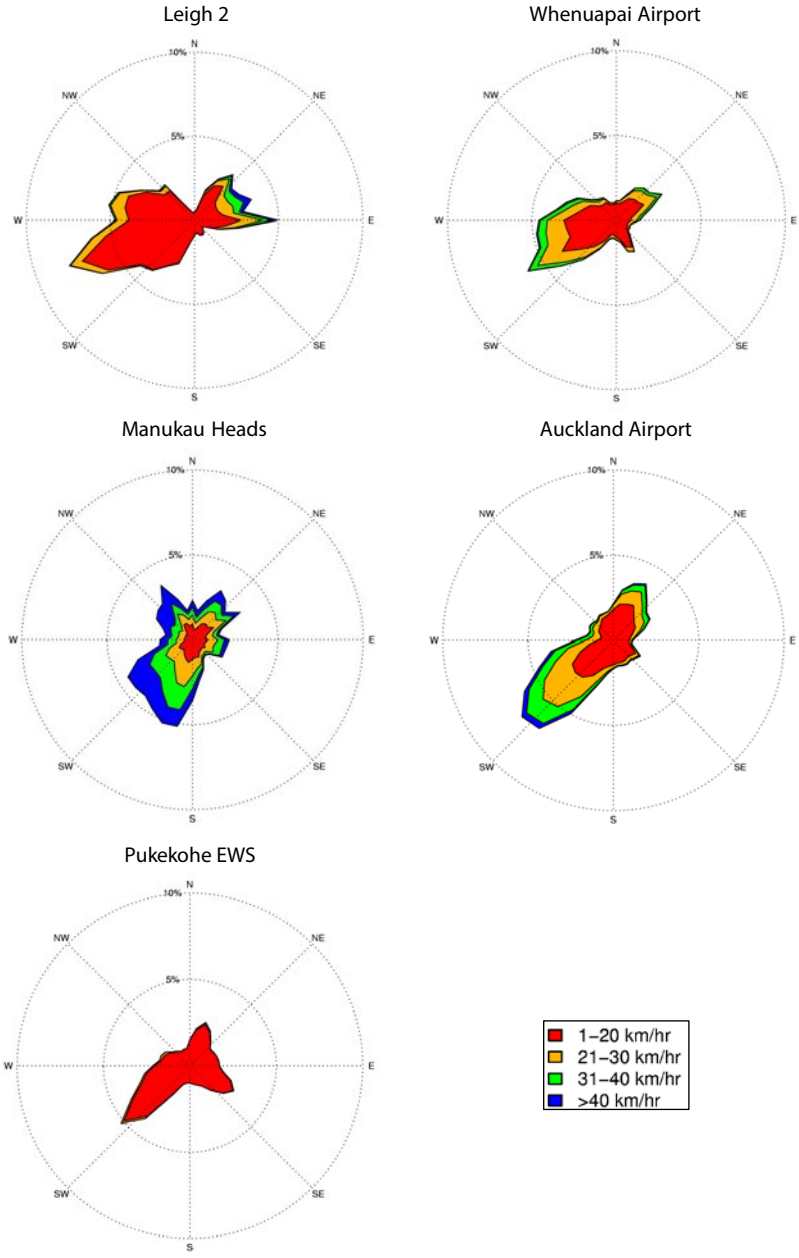


Figure 7. Mean annual wind frequencies (%) of surface wind directions from hourly observations at selected Auckland stations. The plots show the directions from which the wind blows, e.g. the dominant wind direction at Auckland Airport is from the southwest.

Table 1. Mean monthly/annual wind speeds (km/hr) for Auckland sites.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Warkworth EWS	14	13	13	12	14	14	15	14	16	17	16	16	14
Whenuapai Airport	14	13	13	12	12	12	12	14	15	16	16	14	14
North Shore ARC	10	10	9	8	9	9	9	9	10	12	12	11	10
Onehunga ARC	12	12	11	9	10	10	10	11	12	14	14	13	12
Auckland Airport	18	17	16	15	16	16	16	17	19	21	21	19	18
Pukekohe EWS	9	8	8	8	8	8	8	9	9	10	10	9	9

Spring is generally the windiest season throughout the region. Summer and autumn are the seasons when the greatest numbers of light wind days are recorded. Table 2 gives the seasonal proportion of strong and light winds as a percentage of the annual total. For example, of all strong winds recorded at Auckland Airport, 21% occurred in summer, 19% in autumn, 23% in winter and 36% in spring. In compiling this table a strong wind was defined as having a mean wind speed of at least 31 km/hr.

Table 2. Seasonal percentages of strong winds or calms (%) in Auckland.

Location		Summer	Autumn	Winter	Spring
Warkworth	Strong	22	15	24	40
	Light	25	26	25	23
Whenuapai Airport	Strong	16	15	23	45
	Light	25	25	25	24
North Shore ARC	Strong	10	11	30	49
	Light	25	25	25	25
Onehunga ARC	Strong	21	5	37	37
	Light	25	25	25	25
Auckland Airport	Strong	21	19	23	36
	Light	25	26	25	24
Pukekohe EWS	Strong	40	0	40	20
	Light	25	25	25	25

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

Location	00	03	06	09	12	15	18	21
Warkworth	11	11	11	13	19	20	17	13
Whenuapai Airport	9	9	9	13	20	21	17	11
North Shore ARC	7	7	7	9	13	15	12	9
Onehunga ARC	9	9	8	10	15	16	15	11
Auckland Airport	15	14	14	16	20	23	22	17
Pukekohe EWS	6	6	6	8	12	13	11	7

Table 4. Average number of days per year with gusts exceeding 63 km/hr and 96 km/hr, and gale force winds.

Location	Gusts >63 km/hr	Gusts >96 km/hr	Days of gale
Warkworth	90	7	3
Whenuapai Airport	48	1	1
Auckland Airport	55	3	3

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

Location	Gust (km/hr)	Direction (°)	Date
Leigh 2	150	200	14/06/1975
Warkworth	131	050	22/05/1975
Whenuapai Airport	115	310	19/07/1978
North Shore ARC	95	240	08/10/2005
Musick Point wind	148	-	02/08/1982
Onehunga ARC	96	284	28/05/2002
Auckland Airport	147	102	06/09/1981
Manukau Heads	204	270	21/02/1992
Pukekohe EWS	102	110	26/07/2008

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

Winds can be strong and gusty at times, especially in exposed coastal areas. Warkworth has the highest frequency of gusts per year that are greater than 63 km/hr and 96 km/hr. Warkworth and Auckland Airport show the same average number of days per year where gale force winds (10-minute average wind speeds in excess of 63 km/hr) are recorded, shown in Table 4. In comparison, Whenuapai Airport is more sheltered.

Although gale force winds can occur in any month, they are most frequent in winter. The highest gust recorded in the region was 204 km/hr at Manukau Heads (an exposed site on the west coast) on 21 February 1992. Maximum gusts recorded at different stations in the region are listed in Table 5.

Sea breezes

Sea breezes are local onshore daytime winds generated on fine days by the sun warming the land surface more than the sea surface. In Auckland they occur most frequently between November and March when the sunshine is greatest and the wind flows are weakest. Sea breezes occur on approximately 20% of days during the summer months (McGill, 1987). Between 8 am and 10 am, breezes are initiated from the harbours in the region (Waitemata, Manukau, Kaipara) and along Auckland's east coast, and in the late morning these 'elementary' breezes are augmented by 'mature' breezes from the main water bodies surrounding the region (Tasman Sea and outer Hauraki Gulf) (Figure 7). The breezes have speeds of less than 20 km/hr, and tend to weaken around 4 pm, and cease between 5pm and 10pm (McGill, 1987). The two breezes contribute towards the development of the sea breeze convergence zone, which is a

band of cloud that occasionally contains scattered showers, that sits parallel to the coast over the Auckland isthmus. The direction of the large-scale, or synoptic, wind controls the position of the Sea Breeze Convergence Zone. If the synoptic wind about Auckland is from between northwest and southwest, the zone will move towards and sometimes into the Hauraki Gulf. This allows the west coast sea breeze, blowing from the southwest, to cover the isthmus. Should the synoptic wind be between north-northwest and east, the east coast sea breeze, blowing from the northeast, will move over the isthmus as the zone moves towards, or into, the Tasman Sea.

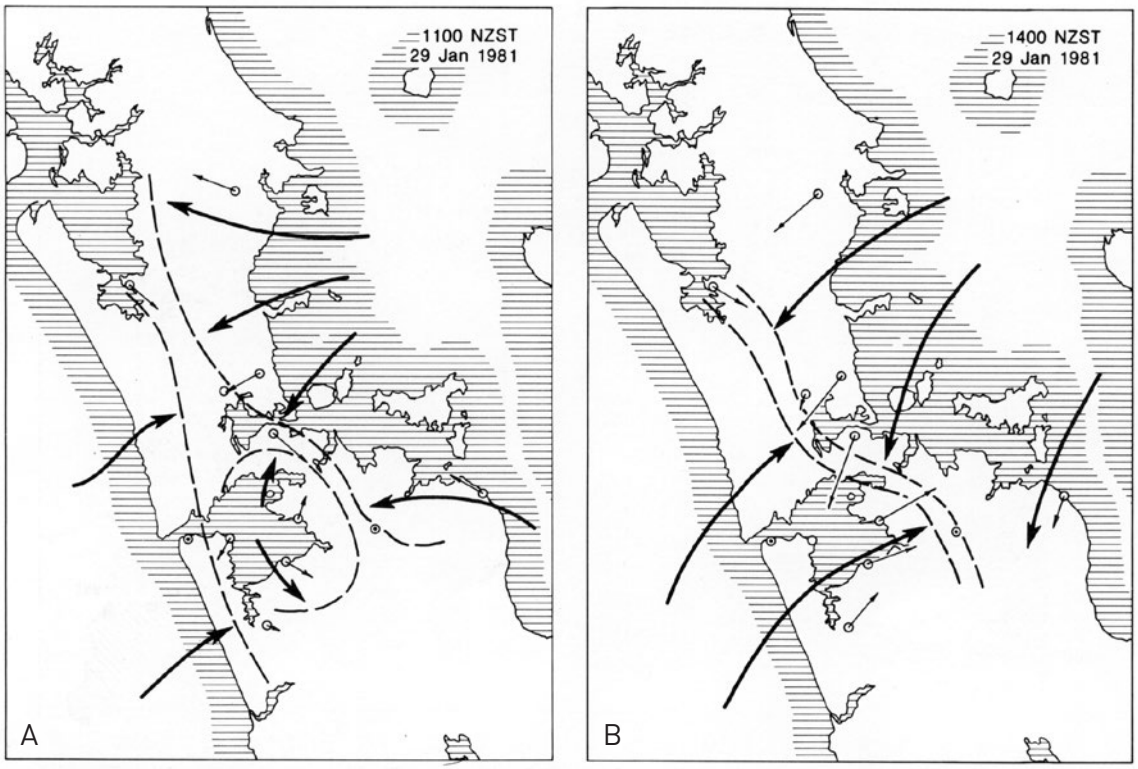


Figure 8. Typical sea breeze convergence zone; a) bay breezes from harbours at 11 am, b) mature breezes from oceans with sea breeze convergence zone at 2 pm.

Rainfall

The distribution of the Auckland region's median annual rainfall is shown in Figure 8. Rainfall totals in the Hunua Ranges are about 50% higher than in lower-lying parts of Auckland. The Waitakere Ranges, Great Barrier Island, and the area around Warkworth also have higher rainfall totals than the urban Auckland and the east coast. Eastern areas such as Leigh and parts of Waiheke Island record on average about 900 mm of rain per year.

Seasonal influences on rainfall distribution are also quite well defined. Table 6 lists monthly rainfall normals and percentage of annual total for selected stations. This table shows a clearly defined winter rainfall maximum. Monthly percentages of the annual rainfall total are fairly consistent across the Auckland region, with around 32% of annual rainfall expected in the winter months from June to August, and around 20% of rain in the summer months from December to February.

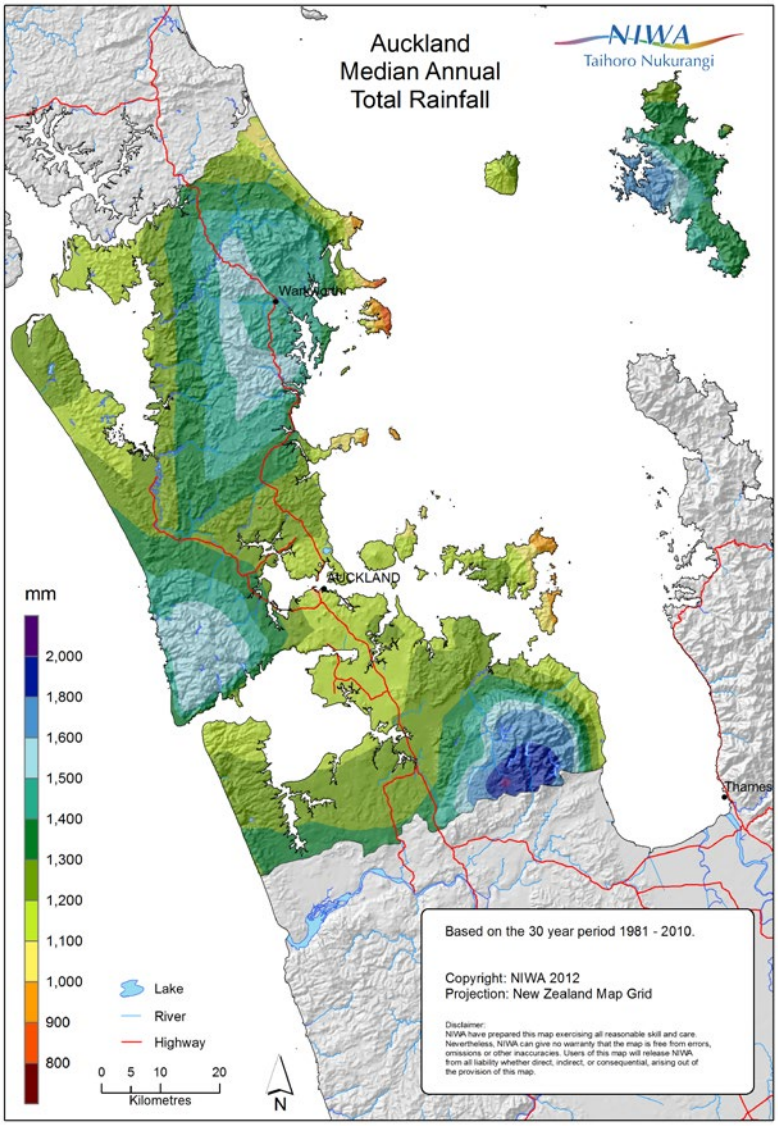


Figure 9. Median annual total rainfall for Auckland region.

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

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Leigh 2	a	73	70	98	82	105	117	130	120	95	83	69	76	1117
	b	7	6	9	7	9	10	12	11	8	7	6	7	
Warkworth Ews	a	86	88	109	107	134	155	180	152	131	108	92	113	1454
	b	6	6	7	7	9	11	12	10	9	7	6	8	
Whenuapai Airport	a	85	73	102	91	87	107	142	140	109	96	95	105	1231
	b	7	6	8	7	7	9	12	11	9	8	8	9	
Auckland, Albert Park	a	84	61	96	92	91	106	114	127	100	86	91	89	1137
	b	7	5	8	8	8	9	10	11	9	8	8	8	
Auckland, Owairaka	a	74	66	91	102	109	124	147	116	103	101	90	93	1213
	b	6	5	7	8	9	10	12	10	8	8	7	8	
Auckland, Pakuranga	a	82	64	94	103	98	113	138	129	108	95	100	90	1212
	b	7	5	8	9	8	9	11	11	9	8	8	7	
Auckland Airport	a	66	71	75	85	110	108	133	111	91	94	72	87	1101
	b	6	6	7	8	10	10	12	10	8	9	7	8	

Table 6 continued.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Manukau Heads 2	a	68	77	90	88	92	116	131	104	102	76	92	89	1124
	b	6	7	8	8	8	10	12	9	9	7	8	8	
Pukekohe Ews	a	73	64	76	86	122	141	151	144	111	120	98	98	1283
	b	6	5	6	7	10	11	12	11	9	9	8	8	
Waiheke Island, Awaroa Valley	a	76	75	88	102	114	132	154	137	107	97	81	104	1266
	b	6	6	7	8	9	10	12	11	8	8	6	8	
Port Fitzroy, Great Barrier	a	112	128	142	134	145	180	223	186	140	115	120	115	1740
	b	6	7	8	8	8	10	13	11	8	7	7	7	

The distribution of monthly rainfall is shown in Figure 9. The 10th percentile, 90th percentile, and mean rainfall values for each month are shown along with maximum and minimum recorded values for several stations.

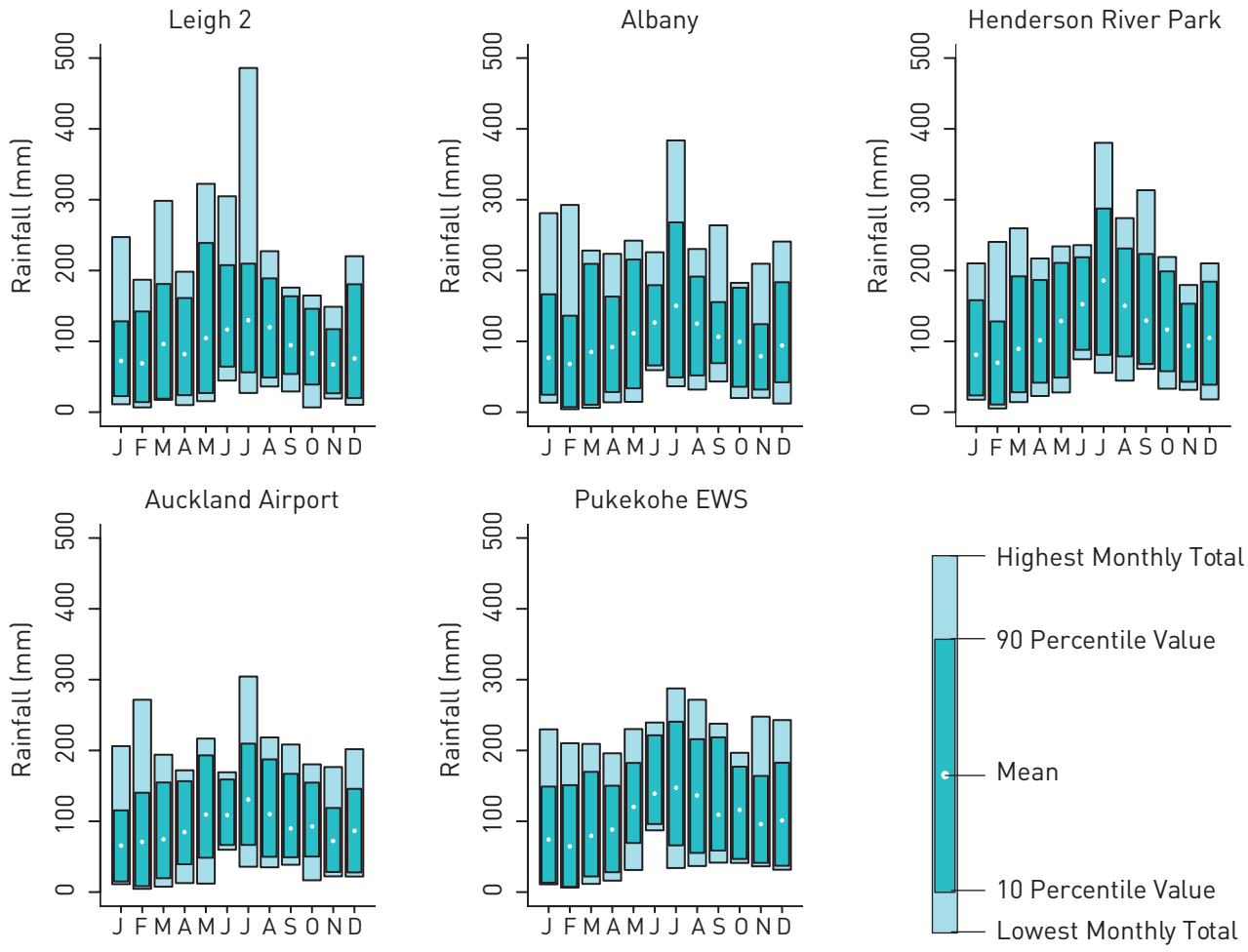


Figure 10. Monthly variation in rainfall for selected Auckland stations.

Rainfall variability over longer periods is indicated by rainfall deciles, as given in Table 7. The 10th percentile values show the accumulated rainfalls that will normally be exceeded in nine out of ten years, while the 90th percentile values indicate the accumulated falls that will normally be exceeded in only one year in ten. The table includes periods from one month to twelve months; each period over one month begins with the month stated. For example, using the table for Leigh, for three months it can be seen that in the three month period beginning in April, 181 mm or more of rainfall can be expected in nine years in ten, while a total of 443 mm or more should occur in only one year in ten.

Table 7. Rainfall deciles for consecutive months

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Leigh 2												
1 month												
10th	23	14	19	24	27	64	56	49	54	39	27	20
90th	128	142	181	161	239	208	210	189	164	146	117	181
3 months												
10th	141	126	170	181	200	249	228	203	179	134	101	102
90th	390	429	514	443	484	496	446	439	345	329	363	373
6 months												
10th	382	407	478	482	486	470	420	404	305	293	320	335
90th	726	870	922	838	795	765	737	698	636	662	598	666
12 months												
10th	906	901	861	898	839	827	817	852	797	818	832	884
90th	1441	1519	1474	1417	1376	1339	1350	1418	1395	1421	1372	1354
Auckland Airport												
1 month												
10th	15	8	20	39	49	67	67	50	49	50	28	28
90th	115	140	155	157	193	159	210	187	167	155	119	146
3 months												
10th	92	145	203	200	250	245	209	213	175	176	124	131
90th	383	336	381	399	471	483	472	373	347	329	396	428
6 months												
10th	397	462	491	488	493	470	482	388	314	290	313	355
90th	720	758	813	791	782	772	713	686	651	656	632	689
12 months												
10th	902	890	850	797	812	877	895	880	862	847	882	867
90th	1304	1324	1315	1280	1281	1289	1286	1289	1315	1300	1298	1275
Pukekohe EWS												
1 month												
10th	13	8	22	28	69	96	66	55	59	47	41	37
90th	149	151	170	150	182	221	241	216	219	177	164	183
3 months												
10th	111	160	197	225	282	262	225	239	208	208	181	148
90th	313	359	401	453	551	597	531	468	466	470	387	360
6 months												
10th	423	450	456	472	491	477	486	426	421	359	349	400
90th	783	917	995	939	943	927	854	751	771	620	665	642
12 months												
10th	896	972	952	903	907	960	937	964	947	940	1001	990
90th	1650	1648	1597	1563	1536	1466	1605	1629	1657	1557	1505	1545

Rainfall frequency and intensity

The average number of days each year on which 0.1 mm or more of rain is recorded varies from around 180 days in coastal areas of the region (e.g. Leigh) to over 210 days in inland areas (e.g. Warkworth). Table 8 lists the average number of days per month with 0.1 mm and 1 mm of rain for selected stations. The 0.1 mm rain days and 1 mm wet days show the same geographic variability.

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

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Leigh 2	a	11	11	12	13	17	17	19	20	18	15	13	12	179
	b	8	7	8	8	11	13	13	14	12	11	9	8	121
Warkworth	a	13	13	15	16	19	21	22	23	21	19	17	14	214
	b	9	8	9	11	12	15	16	16	16	13	12	9	146
Auckland Albany	a	11	10	11	13	17	19	20	19	17	16	14	13	180
	b	8	7	8	10	12	15	15	15	13	12	10	9	133
Whenuapai Airport	a	12	10	14	14	17	20	20	21	19	17	14	13	191
	b	8	7	9	9	11	15	16	15	14	12	9	9	135
Auckland Henderson River Park	a	12	12	13	16	20	22	22	23	20	19	16	15	209
	b	9	7	8	11	14	16	17	17	14	13	11	10	146
Auckland Owairaka	a	12	10	12	15	18	21	22	21	19	16	15	13	194
	b	8	7	8	11	12	15	16	15	13	12	10	9	136
Auckland Airport	a	11	10	12	14	18	19	20	20	17	16	14	13	183
	b	7	7	8	9	13	14	15	14	12	12	9	9	129
Pukekohe EWS	a	11	11	12	13	18	19	20	21	18	18	15	14	191
	b	8	8	8	10	13	15	16	16	13	13	11	10	141
Waiheke Awaroa Valley	a	9	8	10	12	15	17	16	17	15	14	12	11	156
	b	7	7	8	10	12	14	14	15	12	11	10	10	130
Great Barrier RNZN	a	12	13	14	16	19	20	21	20	17	15	15	12	195
	b	8	7	9	11	12	14	15	14	11	10	9	8	128

Heavy rainfalls can occur with the passage of depressions of tropical origin over or close to Auckland, and with northeasterly flows between ridges of high pressure to the east and troughs over the Tasman Sea. Intense rainfalls also occur with thunderstorms. In Table 9, maximum short period rainfalls for periods of 10 minutes to 72 hours with calculated return periods are given for several stations, from all available data. Also listed in this table are the maximum rainfalls expected in 2, 5, 10, 20, and 50 years. Depth-duration frequency tables for Auckland locations are available from NIWA's High Intensity Rainfall Design System (HIRDS). HIRDS uses the index-frequency method to calculate rainfall return periods. For more information on methods and to use the tool, see www.hirds.niwa.co.nz.

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

Location		10min	20min	30min	1hr	2hrs	6hrs	12hrs	24hrs	48hrs	72hrs
Warkworth	a	15	23	26	39	59	109	178	201	263	264
	b	7	9	7	9	16	26	56	22	48	25
	c	11	16	20	27	37	60	82	111	130	142
	d	14	20	24	34	47	76	104	142	166	182
	e	17	23	28	40	54	89	122	167	195	215
	f	19	27	33	46	63	104	142	195	229	251
	g	23	32	39	55	76	126	173	239	280	307
Whenuapai Airport	a	17	28	36	58	104	176	176	260	297	298
	b	20	35	39	60	100+	100+	55	100+	91	61
	c	11	16	20	29	38	57	74	95	112	124
	d	13	19	24	36	47	72	95	125	147	161
	e	15	22	28	41	55	85	112	149	175	193
	f	17	25	32	47	63	99	132	176	207	228
	g	20	30	38	56	76	121	163	219	258	284
Auckland Airport	a	14	27	38	53	61	127	153	168.4	181	181
	b	9	47	95	90	43	100+	100+	48	40	29
	c	10	14	17	25	31	46	59	75	84	90
	d	12	18	21	30	39	58	75	97	110	118
	e	14	20	25	35	45	69	89	116	131	140
	f	16	23	28	40	52	80	105	137	154	166
	g	19	27	34	48	63	98	129	170	192	206
Pukekohe MAF	a	18	20	27	32	57	142	161	167	172	172
	b	30	10	17	7	35	100+	100+	43	25	17
	c	10	14	17	23	30	46	60	79	91	100
	d	13	17	21	29	38	59	77	101	118	129
	e	14	20	24	34	44	69	91	120	140	153
	f	17	23	28	39	51	80	106	141	164	179
	g	20	28	33	46	62	98	130	174	202	221

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 Auckland

Auckland has experienced numerous extreme weather events, with significant damage and disruption caused by flooding and high winds (e.g. Figure 10). The events listed below are some of the most severe events to have affected Auckland between 1980 and 2012.

17 July 1988: Torrential rain caused flooding in west Auckland, and a Civil Defence Emergency was declared (the first CDE in west Auckland for 15 years). Thirty-two people were evacuated from their homes. State Highway 16 was closed by flooding, and the railway from Auckland to Whangarei was closed due to slips. A teenage boy was presumed drowned after being swept away in Waiwera Estuary (north Auckland).

21-22 January 1999: Heavy rain caused severe flooding in Pukekohe. The town received three times its normal January rainfall in just two hours on the 21st, an event with a return period of well over 150 years. Many homes were flooded and crops were destroyed. The floodwaters were 1 m deep in places. An elderly man drowned in a field after escaping from his car which was pinned to a fence by floodwaters. For six weeks after the flood, residents had to boil their water because of giardia contamination fears.

11-16 June 2006: High winds and rain battered Auckland, causing 700,000 people to be without power for a number of hours. Phone lines and cellphone networks were also affected, and the outage of more than 300 sets of traffic lights in central Auckland caused gridlock. The power cut also stopped and delayed trains, and hospitals cancelled all surgery.

9-11 July 2007: Torrential rain and hurricane-force winds hit Auckland during the height of this storm. 90,000 homes in the region were without power on the night of the 10th. Trains and ferries were cancelled or delayed, resulting in some commuters being unable to return home on the 10th. Two people were blown off their motorbikes on the Harbour Bridge, and the median lane barrier was moved out of alignment by the wind.

26-27 July and 29 July – 1 August 2008: Two large storms occurred within days of each other. On 26 July, about 60,000 customers were without power due to high winds bringing down power lines. More than 35 boats in the region broke free from their moorings. The second storm caused numerous slips, closing roads and damaging properties. The Muriwai Surf Lifesaving Club's patrol tower had to be moved further back from the shoreline after the storms scoured the sand dunes and left part of the tower hanging over a drop of 10 m to the beach.

Figure 11. Southbound lanes on Auckland's northern motorway are submerged during a storm that coincided with high tide in January 2011. Source: NZTA

Periods of low rainfall

Periods of fifteen days or longer with less than 1 mm of rain on any day are referred to as "dry spells". Dry spells are common in Auckland during the summer and early autumn. There is usually one, and frequently two, such periods each year between December and March. The average duration of a dry spell is about 20 days. The longest recent dry spell between three sites in Auckland (Leigh, Auckland Airport, and Pukekohe) was 34 days recorded in Pukekohe, from 22 January 1999 to 24 February 1999. During this dry spell, nine consecutive days were without any rain. Other long dry spells include 32 days at Leigh from 3 January 1988 to 3 February 1988, of which 15 consecutive days were without any rain, and the same dates at Auckland Airport, but at that site 16 consecutive days were without any rain.

Temperature

Air and sea temperatures

Auckland enjoys a mild climate with few extremes of temperature. Although this is partly due to the relatively low latitudes and elevations in the region, the extensive surrounding ocean also has a modifying effect on temperature in the region. Monthly mean sea surface temperature for the east and west coasts of the Auckland region is compared with mean monthly air temperature for Auckland Airport in Figure 11. There is a six to eight week lag between the minima of land and sea temperatures. Figure 12 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 temperatures.

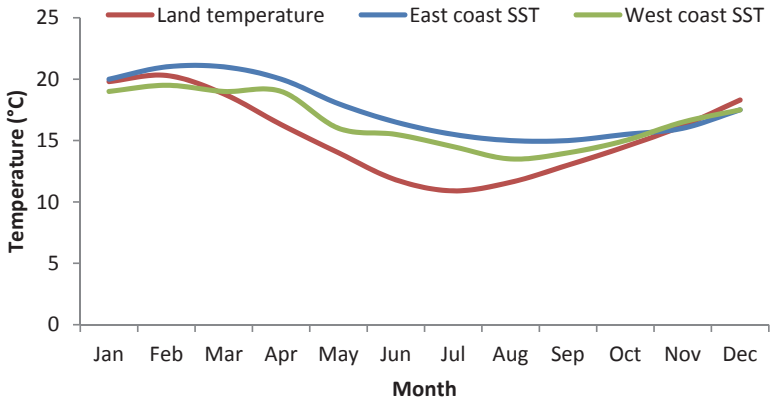


Figure 12. Mean monthly land temperatures (Auckland Airport) and sea surface temperatures (east coast and west coast).

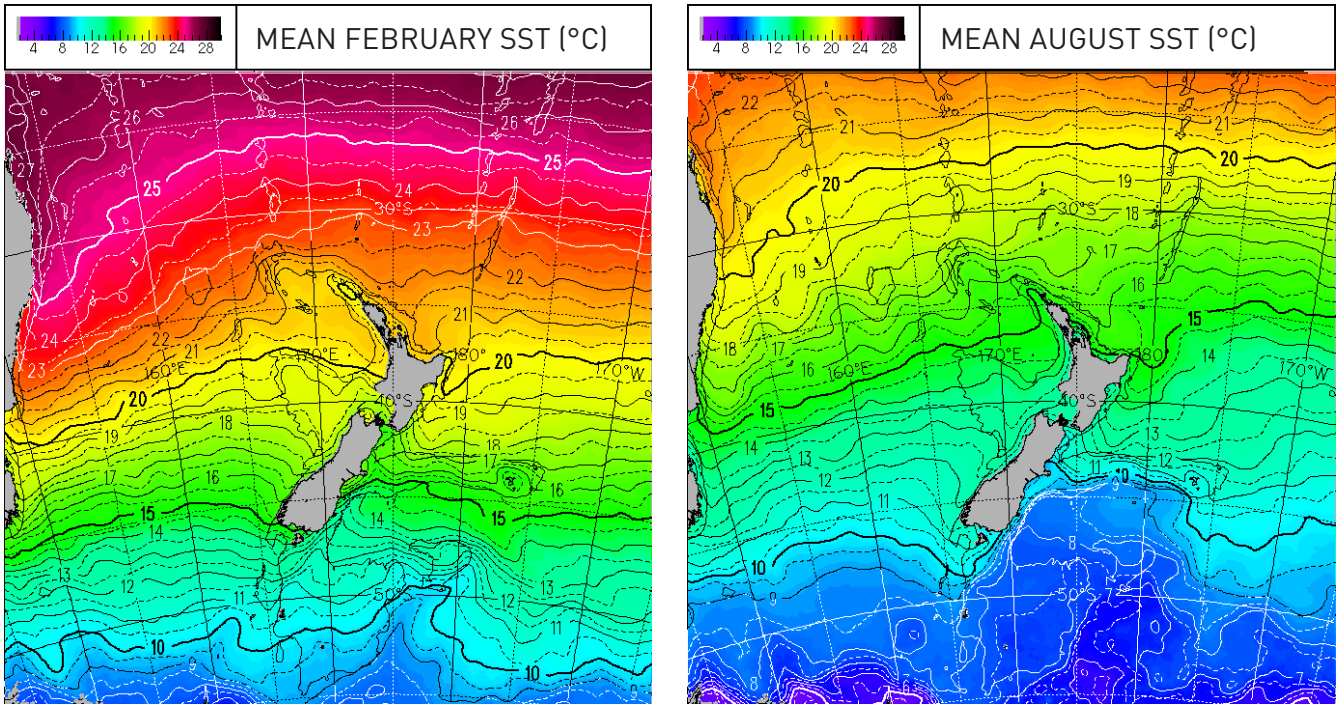


Figure 13. Monthly mean sea surface temperatures (°C) for: a) February; b) August, based on the years 1993-2002. Source: NIWA SST Archive, Uddstrom and Oien (1999).

Air temperature

Most of the Auckland region experiences mean annual temperatures between 14 °C and 16 °C, with eastern areas generally warmer than western areas. Lower mean annual temperatures are experienced over higher elevations (e.g. Hunua Ranges; 12°C) due to the decrease of temperature with altitude. There is a deal of variability about this figure with high ground being relatively colder under windy conditions, while on cold nights hill tops may be warmer than low ground because of cold air drainage. The areal variation of annual median average temperature is shown in Figure 13.

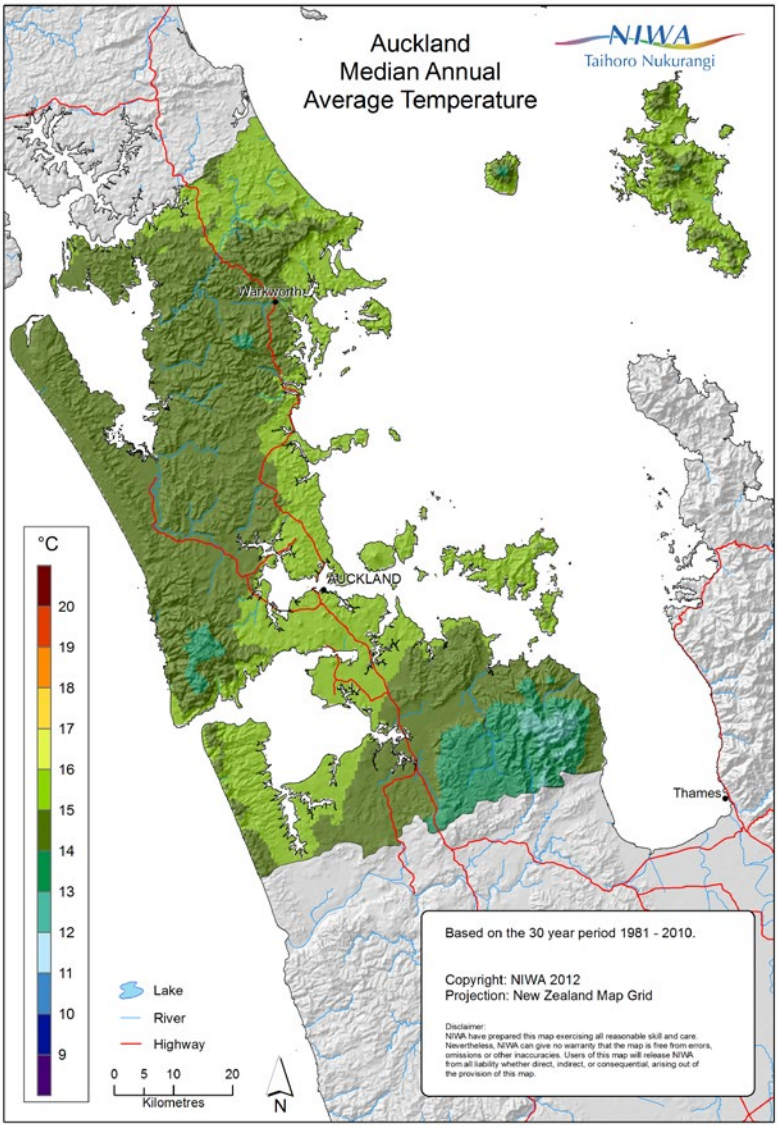
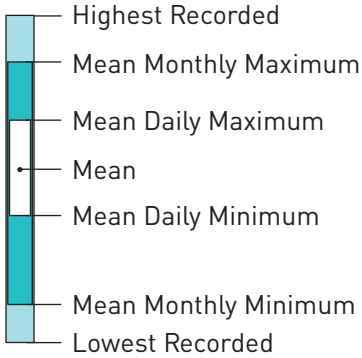


Figure 14. Median annual average temperature for Auckland region.



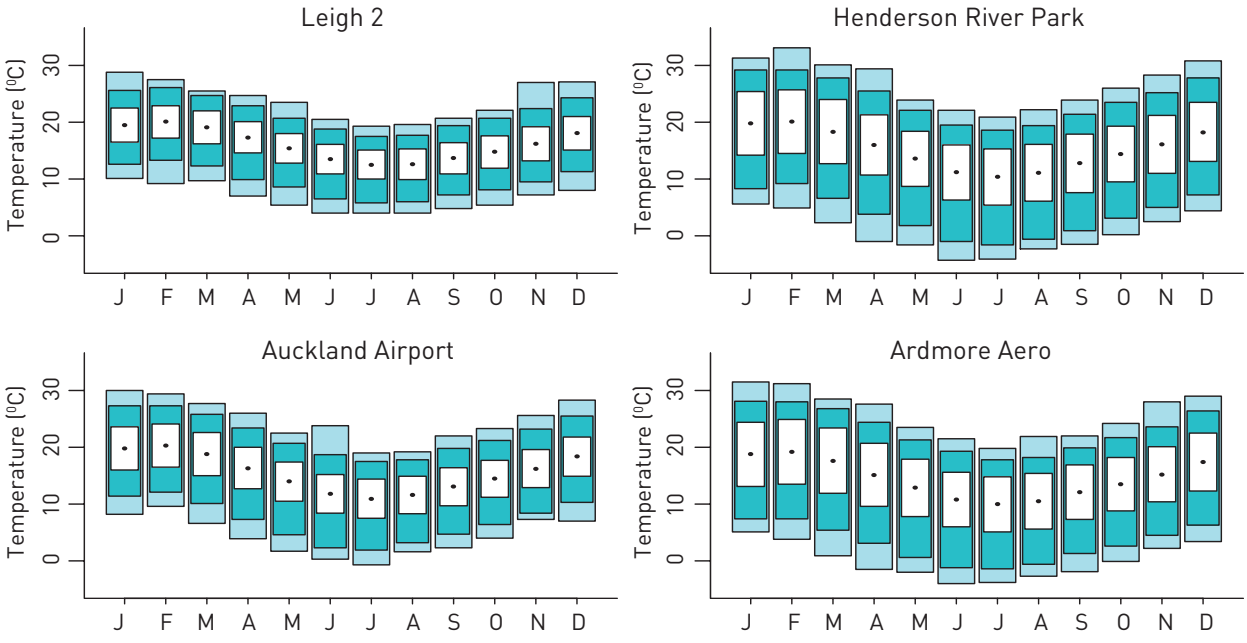


Figure 15. Monthly variation in air temperatures for selected Auckland stations.

Figure 14 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 Auckland. Coastal sites (Leigh and Auckland Airport) show a smaller temperature range when compared to sites further inland (Henderson and Ardmore Airport). All sites show a winter minimum and summer maximum temperature pattern.

Compatible with the proximity to the sea and vulnerability to sea breezes, no great extreme maxima have been recorded. The highest temperature recorded in Auckland is 34.0°C at Lincoln Road, west Auckland, on 12 February 2009, and the lowest recorded is -5.7°C at Riverhead Forest in June 1936. These compare with national extremes of 42.4°C and -25.6°C.

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

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Leigh 2	6	5.8	5.8	5.5	5.2	5.1	5.1	5.3	5.5	5.7	6	6
Whenuapai Aws	9.3	9.6	9.6	9.1	8.7	8.5	8.8	8.2	8.2	8.1	8.3	8.8
Auckland, Owairaka	8.1	7.8	8.1	8.1	7.4	7.5	7.7	7.5	7.6	7.4	7.6	7.6
Auckland, Henderson, River Pk	11.2	11.2	11.2	10.7	9.7	9.6	9.9	10	10.2	9.9	10.1	10.4
Auckland Aero	7.6	7.6	7.7	7.3	6.8	6.8	6.8	6.7	6.7	6.5	6.7	6.9
Pukekohe Ews	9.3	9.2	9.1	8.7	7.7	7.5	7.6	7.6	7.9	7.8	8.3	8.5

Many stations have not recorded any temperatures below freezing point. In particular, sites on high ground and near the coast (e.g. Leigh, Auckland Airport) almost never record temperatures as low as freezing point.

Table 11. Mean hourly temperatures at Auckland Airport in January and July.

hrs	00	01	02	03	04	05	06	07	08	09	10	11
January	17.9	17.7	17.4	17.2	17.1	16.9	17.0	18.1	19.2	20.2	21.0	21.6
July	9.8	9.7	9.6	9.4	9.3	9.2	9.1	9.1	9.3	10.1	11.3	12.2
hrs	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
January	22.1	22.4	22.5	22.5	22.2	21.5	21.0	20.2	19.2	18.8	18.6	18.2
July	12.8	13.3	13.5	13.4	13.2	12.5	11.6	11.3	10.9	10.5	10.3	10.0

The annual mean daily temperature range for Auckland is small, averaging 7.9°C. Table 10 shows the average daily temperature range for each month for a number of sites in Auckland. Owairaka has the smallest temperature range for any station and Pukekohe has the largest.

Diurnal temperature ranges are also relatively minor. Table 11 and Figure 15 show mean hourly temperatures for Auckland Airport for January and July.

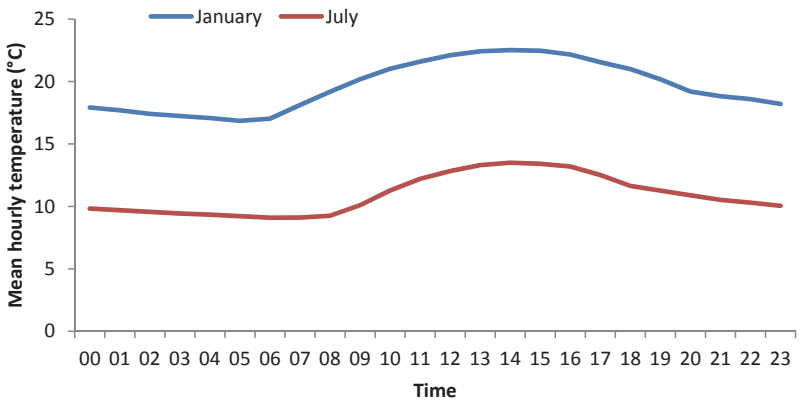


Figure 16. Mean hourly temperatures at Auckland Airport, January and July.

Earth Temperatures

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 earth temperatures are routinely monitored at 10, 20, 30, 50, and 100 cm depths.

Although earth temperatures are particularly sensitive to specific site conditions (aspect, elevation, soil colour and type, etc.) no great spatial variations in earth temperatures are apparent in Auckland. Fluctuations in earth temperatures are less than air temperatures due to the slower heating and cooling rates of the soil. Highest temperatures are found in January or February and lowest in July or August. Table 12 lists mean monthly earth temperatures for a number of standard depths. Figure 16 shows how earth temperatures change throughout the year for different depths at Auckland Airport. The temperature cycle for 100 cm depth is more damped than shallower depths.

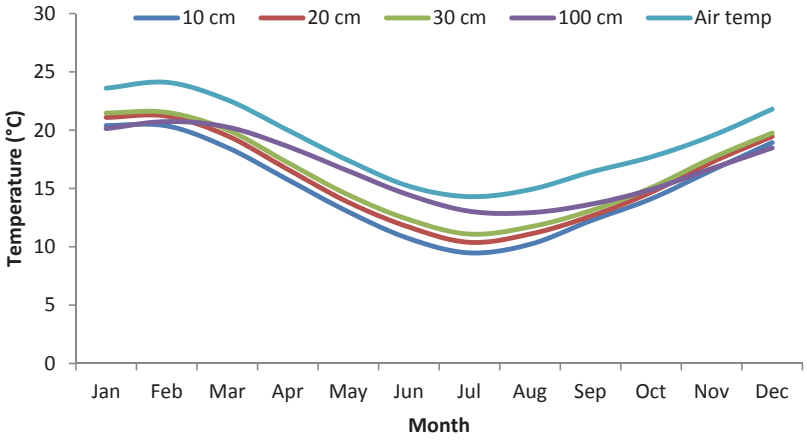


Figure 17. Average monthly 9 am earth temperatures for different depths and monthly mean air temperature at Auckland Airport.

Table 12. Mean 9am earth temperatures at different Auckland locations (°C), with site elevations in brackets

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Whenuapai Airport (26m)	10cm	19.2	19.3	17.5	14.5	11.5	9.7	8.4	9.4	11.0	13.1	15.8	17.9	13.9
	20cm	20.7	20.9	19.1	16.2	13.2	11.2	9.8	10.7	12.1	14.1	17.0	19.2	15.3
	30cm	20.4	20.7	19.3	16.7	13.9	11.8	10.4	11.1	12.4	14.3	16.9	18.9	15.6
Auckland, Owairaka (41m)	10cm	20.1	20.2	18.6	16.0	13.5	11.1	9.7	10.4	12.3	14.4	16.5	18.7	15.1
	20cm	20.8	21.0	19.3	16.7	14.2	11.9	10.5	11.1	12.8	14.9	17.2	19.4	15.8
	30cm	21.4	21.7	20.2	17.7	15.3	13.0	11.6	12.1	13.6	15.7	17.9	19.9	16.7
Auckland Airport (7m)	10cm	20.4	20.4	18.5	15.8	13.0	10.7	9.5	10.2	12.2	14.1	16.6	18.9	15.0
	20cm	21.1	21.2	19.5	16.6	13.8	11.7	10.4	11.1	12.6	14.7	17.2	19.5	15.8
	30cm	21.5	21.5	20.0	17.2	14.5	12.3	11.1	11.7	13.1	15.1	17.6	19.8	16.3
	100cm	20.1	20.7	20.3	18.6	16.5	14.4	13.1	12.9	13.6	14.9	16.7	18.5	16.7
Pukekohe EWS (88m)	10cm	20.3	20.2	18.2	15.5	12.7	10.1	9.1	10.0	12.2	14.0	16.3	18.9	14.8
	20cm	21.1	21.4	19.5	16.7	13.9	11.4	10.2	10.8	12.7	14.9	17.0	19.5	15.8
	50cm	20.9	21.6	20.4	18.2	15.8	13.3	11.7	12.0	13.2	15.1	17.0	19.3	16.6
	100cm	18.9	19.9	19.8	18.6	16.9	15.0	13.4	12.9	13.3	14.4	15.9	17.5	16.4

Frosts

Compared with many parts of the country, Auckland is mild and frosts are generally light and infrequent. Frosts only occur under very stable conditions and are accompanied by shallow inversions where temperature increases with height. 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, when air temperature measured in a screen by a thermometer 1.3 m above the ground falls below 0°C, are rare in most parts of Auckland. Ground frosts are recorded when the air temperature 2.5 cm above a clipped grass surface falls to -1.0°C or lower. Ground frosts can be quite frequent in Auckland, especially in sheltered inland areas. Areas vulnerable to radiation fog are those most likely to suffer frost; whether fog or frost occurs is usually the result of the moisture content of the air. Table 13 lists for selected sites the mean daily grass minimum and extreme grass minimum temperatures and the average number of days each month with ground and air frosts. Data on air temperatures (mean daily, monthly minima and extreme minima) can be obtained from Figure 14.

Table 13. Occurrences of frosts and grass minimum temperatures in Auckland.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Leigh 2	a	13.5	14.2	12.9	11.1	8.9	7.2	6.5	6.5	7.3	8.6	10.2	11.9	9.9
	b	4.3	5.4	2.4	0.4	-0.5	-1.8	-2.0	-0.6	0.0	1.0	2.6	4.3	-2.0
	c	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.4
	d	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Henderson River Park	a	11.7	12.0	9.9	7.8	5.9	3.5	2.3	3.0	4.7	6.9	8.6	10.7	7.3
	b	2.2	1.3	-1.3	-4.2	-4.7	-8.9	-8.3	-6.7	-4.7	-3.4	-0.6	0.8	-8.9
	c	0.0	0.0	0.0	0.5	2.2	6.3	7.9	6.4	3.4	0.8	0.0	0.0	27.4
	d	0.0	0.0	0.0	0.0	0.1	2.7	3.8	1.5	0.6	0.0	0.0	0.0	8.8
Auckland Airport	a	13.8	14.2	12.4	9.6	7.6	5.7	4.9	5.6	7.1	9.0	10.7	12.8	9.5
	b	3.1	4.2	2.2	-0.8	-2.7	-4.4	-6.0	-4.2	-3.0	-1.8	1.5	2.5	-6.0
	c	0.0	0.0	0.0	0.0	0.7	2.5	3.7	1.2	0.6	0.1	0.0	0.0	8.7
	d	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1
Pukekohe EWS	a	11.9	12.1	10.4	8.3	6.9	4.7	3.7	4.2	5.6	7.6	8.6	10.8	7.9
	b	2.4	0.6	0.1	-2.9	-2.2	-5.4	-5.0	-5.1	-3.3	-2.9	-1.4	0.0	-5.4
	c	0.0	0.0	0.0	0.1	0.5	4.2	4.9	2.5	1.2	0.5	0.0	0.0	13.9
	d	0.0	0.0	0.0	0.0	0.1	0.4	0.1	0.1	0.0	0.0	0.0	0.0	0.7

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

Most parts of Auckland receive about 2000 hours of bright sunshine per year (Figure 17). In general, central and eastern areas receive more bright sunshine than western and southern areas of the region, and islands in the Hauraki Gulf (e.g. Waiheke, Little Barrier, and Great Barrier Islands) receive even higher sunshine hours – over 2100 hours in some places. Southern areas around Pukekohe receive the least bright sunshine in the region. Figure 18 shows the monthly breakdown of bright sunshine experienced in Auckland, showing that it is cloudier during the winter months than in the summer.

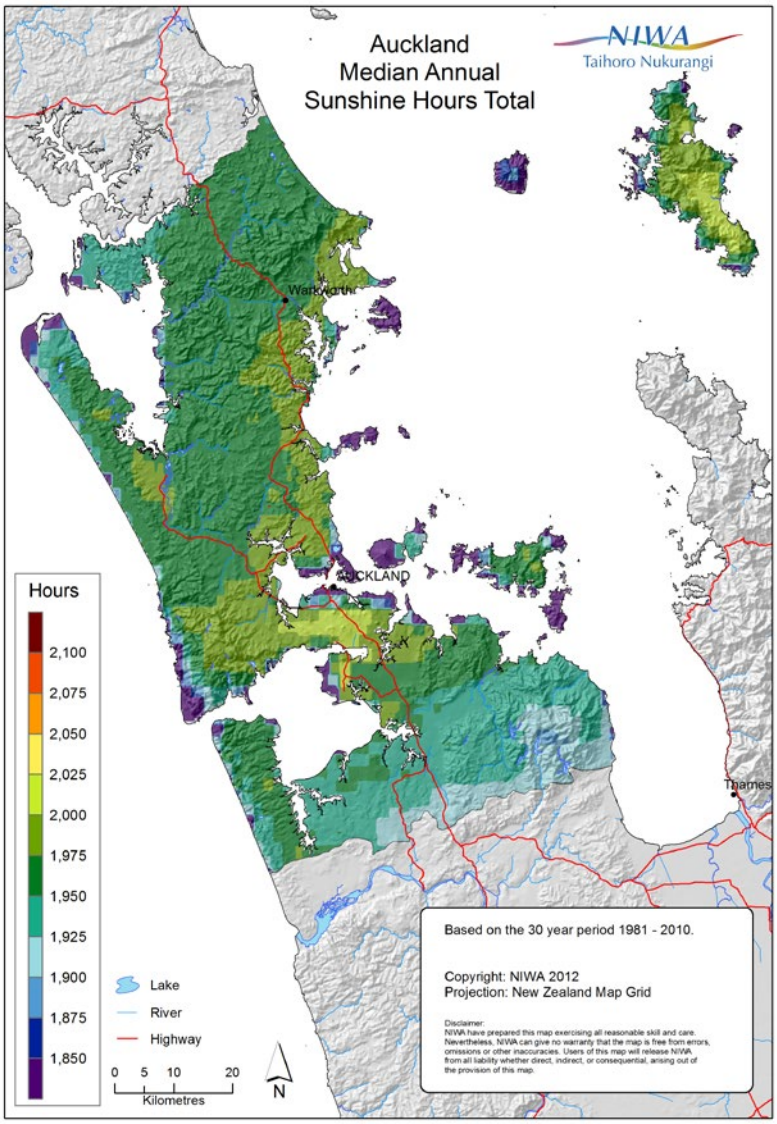


Figure 18. Median annual sunshine hours for Auckland, 1981-2010.

Figure 18. Mean monthly sunshine for Auckland sites, and minimum and maximum sunshine hours recorded. These graphs were calculated from all available data.

Solar radiation

Solar radiation records are available for a number of sites in Auckland. Mean daily global solar radiation is presented in Table 14 for Leigh, Henderson, Auckland Airport, and Pukekohe. Insolation is at a maximum in December and January and a minimum in June.

Table 14. Mean daily global solar radiation (MJ/m2/day).

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Leigh 2	23	20	17	12	9	7	8	10	14	18	21	23	15
Henderson, AKL	21	18	15	11	8	6	7	9	13	16	19	20	13
Auckland Airport	23	20	16	12	8	7	7	10	14	17	21	22	15
Pukekohe EWS	21	19	16	11	8	7	7	10	13	16	19	21	14

UV (Ultra-violet radiation)

Ultra-violet radiation (UV) is recorded at two sites in Auckland, and the site with the most data is Leigh. Table 15 and Figure 19 show the mean daily UV Index at Leigh compared with Lauder, a site in the lower South Island. Leigh records higher UV levels than Lauder throughout the year due to Leigh's northern location, although at both sites, summer months record significantly higher UV levels than winter months. Figure 20 shows an example of a UV forecast for Auckland city, and indicates the levels of UV where sun protection is required.

Table 15. Mean daily maximum UV Index at Leigh and Lauder.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Leigh	12.2	10.7	8.4	5.1	2.8	1.8	1.9	3.0	4.8	7.2	9.8	11.5	6.6
Lauder	10.4	8.9	6.0	2.9	1.3	0.8	0.9	1.7	3.3	5.2	7.9	10.0	4.9

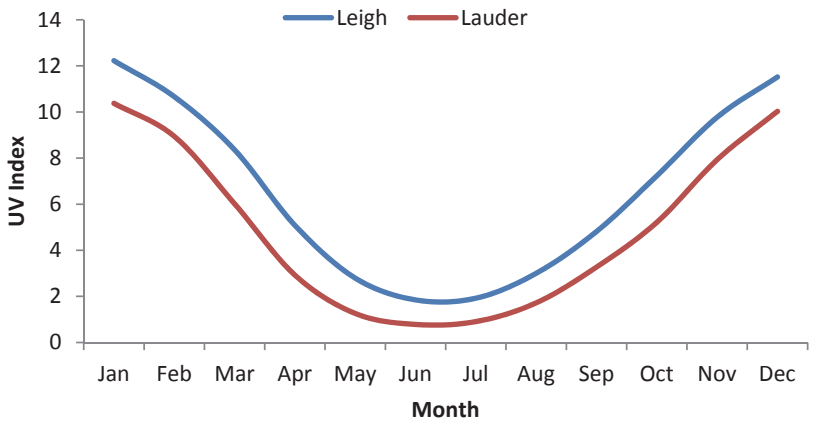


Figure 20. Mean daily maximum UV Index at Leigh and Lauder.

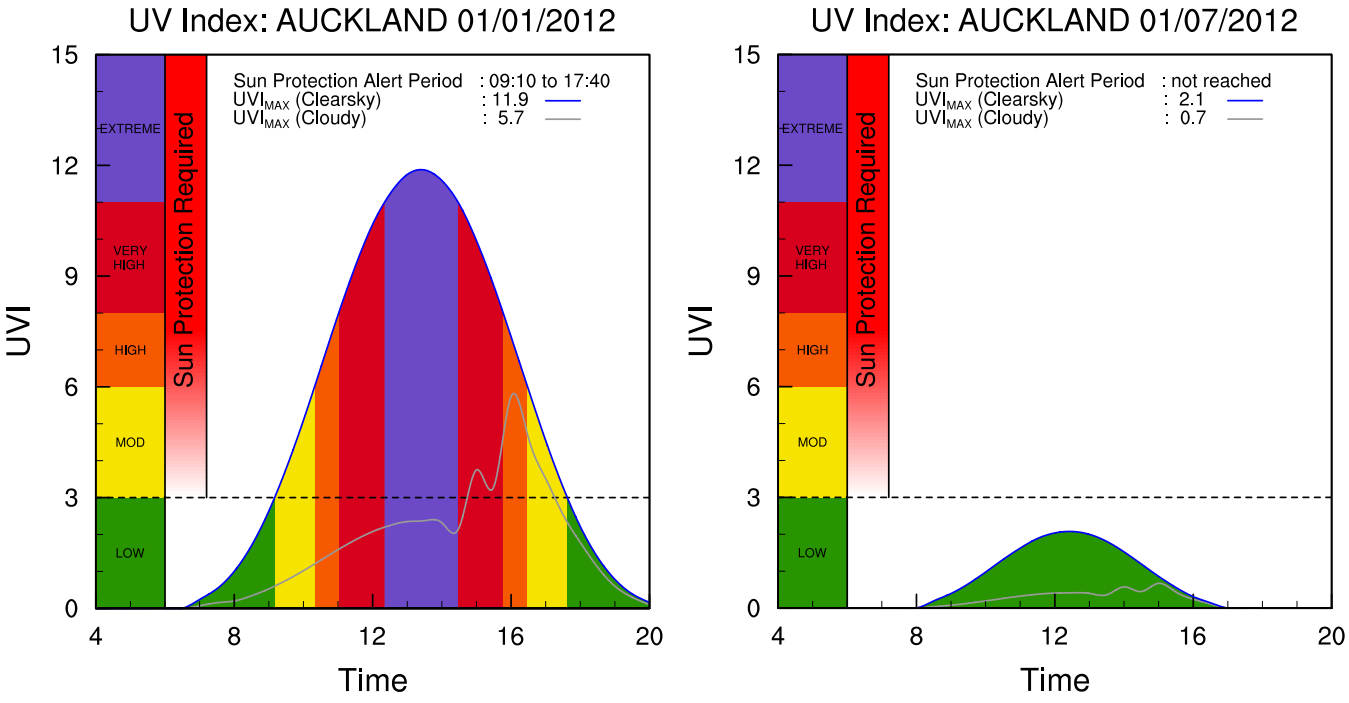


Figure 21. UV Index forecast for Auckland city, January and July.
Source: https://www.niwa.co.nz/our-services/online-services/uv-ozone

Fog

The frequency of fog varies widely over the Auckland region. As the definition of fog is cloud at ground level with a horizontal visibility of 1000 m or less, the stratus cloud which forms on hill tops in rain must be regarded, and is sometimes called 'high fog'. Areas predominantly affected by this type of fog are the Waitakere and Hunua Ranges.

Advection fogs, caused by warm moist air masses moving over cooler surfaces, are most common in late summer or autumn. They are associated with the tropical wet season, and mainly occur in the warm northeast winds ahead of decaying storms of tropical origin. Advection fogs can affect large areas and are deep enough to blanket most high ground. They can dominate the weather for one to three days and occur several times each year in the Auckland region, though mainly in autumn.

The third type of fog is that caused by radiation cooling in low lying areas where there is little wind. These radiation fogs have preferred locations where the air tends to pond, and usually occur in winter. The average number of days per year with fog for selected stations in the Auckland region is listed in Table 16. Favoured areas for fog formation in the Auckland region are Whenuapai (44 fogs per year on average) and Warkworth (23 fogs per year).

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

Location	Thunder	Fog	Hail
Leigh 2	7	5	1
Warkworth	5	23	8
Whenuapai Airport	11	44	5
Auckland, Albert Park	12	10	4
Auckland, Owairaka	6	15	3
Auckland, Henderson, River Pk	3	6	8
Auckland Airport	12	17	4
Auckland, Ardmore	1	4	1
Hunua Edl	4	16	15
Port Fitzroy, Great Barrier	3	1	1

Severe convective storms

Thunderstorms

In Auckland thunderstorms occur throughout the year, and have a maximum frequency in the winter months when cold, unstable air masses cross the region. Average annual frequencies for selected stations are given in Table 16, and range from 12 in Auckland city (Albert Park) and Auckland Airport to only one per year at Ardmore Airport. At some of the stations, it is likely that not all the 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 15 at Hunua to one at Leigh, Ardmore, and Great Barrier Island. As with thunderstorms, an unknown number of hail falls will escape detection at some of the stations. Hail is most likely over the six months from June to November.

Severe hailstorms are those containing stones with diameters of at least 0.5 cm or those which cause damage to crops. One such severe hail event occurred in November 1984, when parts of west Auckland near Kumeu experienced a hail storm of up to 30 minutes in duration. The storm, with hailstones up to 2.5 cm in diameter, caused significant damage to crops, glasshouses, sheds, trees, and houses. The estimated damage cost was over $10 million 2008 dollars.

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. During the period 1981-2012, 26 damage-causing tornadoes were reported in Auckland. One particularly severe tornado event was on 6 December 2012, when a tornado swept through the Hobsonville area near Whenuapai. Three people were killed when concrete slabs on a construction site crushed their truck, and there were dozens of other injuries. On one street in Hobsonville, no houses escaped damage, with roofs and windows broken and trees felled. Hundreds of people were displaced by the tornado, 150 homes were damaged, and an emergency Civil Defence centre was set up at Whenuapai Airport. Damage costs were estimated at $11 million.

Sea swell and waves

In enclosed waters such as the Waitemata, Manukau, and Kaipara Harbours, it is unlikely that the wind generated waves ever exceed two metres. This is because the winds to generate such waves would need to be either a steady wind of 70 km/hr or more (a very rare event in Auckland), or would require a much longer fetch than the enclosed harbours provide.

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.

Much of the swell that affects the west coast of New Zealand originates in the ocean to the south of Australia. On the west coast of Auckland, the most frequent swell direction is from the southwest, occurring nearly 40% of the time (Gorman et al., 2003). The frequency of swells of less than one metre is about 20%, while swell over two metres occur approximately 35% of the time. Heavy southwest swells are particularly noticeable in winter and spring.

On the east coast of Auckland, swells from an easterly or northeasterly direction tend to predominate. These can originate from tropical cyclones well to the north of New Zealand or from anticyclones far to the east. Of all swells observed on the east coast the frequency of those less than one metre is about 40%, while for those greater than two metres is 8% (Gorman et al., 2003). The islands in the Hauraki Gulf form a buffer to large swells for the majority of the region.

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 parameters and their uses are discussed in the following paragraphs. Short-term high intensity rainfalls have been covered previously.

Vapour pressure and relative humidity

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

Vapour pressure is the part of total air pressure that results from the presence of water vapour in the atmosphere. It varies greatly with air masses from different sources, being greatest in warm air masses that have tropical origins and lowest in cold, polar-derived air masses. Vapour pressure can be important in determining the physiological response of organisms to the environment (very dry air, especially if there is a pre-existing soil moisture deficit, can cause or increase wilting in plants). Average 9 am vapour pressures for several stations are given in Table 18.

Relative humidity is high in all seasons throughout the region due to the influence of the surrounding sea and the lack of any large mountain masses. Table 19 gives the average relative humidity at 9 am for selected stations in Auckland. Most of the region shows similar relative humidity throughout the year, with Leigh generally experiencing the lowest average relative humidity for the region and Ardmore experiencing the highest average relative humidity.

As Auckland's mean temperature is higher than in places further south and relative humidity is similar, Auckland has a somewhat higher vapour pressure than other main centres. The effect of this on people is what leads to Auckland's climate being considered humid in comparison to other centres. Figure 21 shows how vapour pressure varies in the main centres across New Zealand.

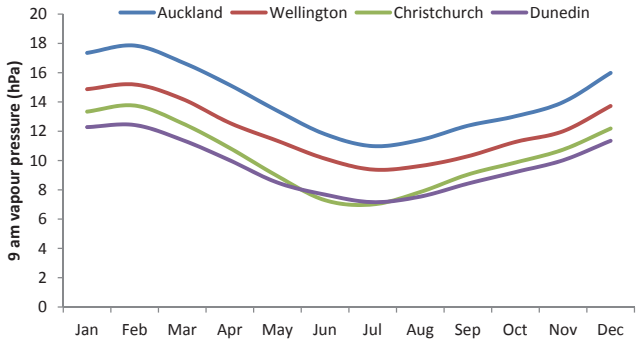


Figure 22. Monthly average 9 am vapour pressures; Auckland, Wellington, Christchurch, Dunedin.

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

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Leigh 2	17.9	18.4	17.4	15.7	14.0	12.5	11.7	11.8	12.5	13.2	14.3	16.4	14.6
Henderson River Park	18.2	18.6	17.1	15.8	13.7	11.5	10.8	11.6	12.9	13.6	14.6	16.7	14.6
Auckland Airport	17.4	17.9	16.7	15.2	13.4	11.8	11.0	11.4	12.4	13.0	14.0	16.0	14.2
Auckland Ardmore	18.3	18.6	16.9	15.2	13.4	11.6	10.9	11.4	12.9	13.9	14.7	17.0	14.6
Pukekohe EWS	17.5	18.3	16.5	14.8	13.3	11.6	10.7	11.4	12.5	13.1	14.0	16.1	14.1

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

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Leigh 2	79	80	79	78	80	81	81	81	79	78	78	78	79
Henderson River Park	80	85	86	89	91	92	92	91	85	82	78	78	86
Auckland Airport	77	80	81	83	86	88	88	85	81	79	77	77	82
Auckland Ardmore	86	88	87	89	91	92	92	91	88	88	84	85	88
Pukekohe EWS	81	85	84	84	88	90	90	88	85	83	80	80	85

Evapotranspiration and soil water balance

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

Table 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
Leigh 2	DE	78	68	40	18	2	0	0	0	0	4	45	73	329
	ND	16	15	11	8	1	0	0	0	0	1	10	16	79
	RO	3	0	10	8	28	53	89	72	35	10	0	2	309
	NR	0	0	0	1	2	6	9	9	4	1	0	0	32
Auckland Albany	DE	78	74	41	15	2	0	0	0	0	1	27	55	293
	ND	16	16	12	7	1	0	0	0	0	0	6	12	70
	RO	9	4	7	7	33	84	120	81	44	22	3	1	415
	NR	0	0	0	1	3	10	12	10	5	2	0	0	46
Henderson River Park	DE	70	62	34	10	1	0	0	0	0	0	13	46	235
	ND	15	14	10	5	1	0	0	0	0	0	3	10	57
	RO	6	3	6	10	50	122	152	107	66	36	7	4	570
	NR	0	0	0	1	6	14	15	13	8	4	1	0	62
Auckland Airport	DE	98	73	43	16	2	0	0	0	0	3	47	74	357
	ND	19	16	12	7	2	0	0	0	0	1	10	15	81
	RO	3	3	1	2	29	66	98	66	30	15	0	3	315
	NR	0	0	0	0	3	9	12	9	4	2	0	0	40
Pukekohe EWS	DE	56	53	26	8	0	0	0	0	0	0	5	26	174
	ND	13	14	8	4	0	0	0	0	0	0	1	6	48
	RO	6	2	1	9	44	117	124	99	51	45	13	13	522
	NR	0	0	0	1	6	14	15	13	6	6	1	1	63

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

deficit occurs and irrigation becomes necessary to maintain plant growth. Runoff occurs when the rainfall exceeds the soil moisture capacity (assumed to be 150 mm for most New Zealand soils). The Auckland region is comparatively well served by frequent rainfalls in winter, but due to high evapotranspiration and a minimum of rainfall, soil moisture levels in summer are frequently such that irrigation or watering is necessary.

Mean monthly and annual water balance values are given in Table 20, for a number of sites in Auckland. It can be seen from this table that Auckland has about 11 days between November and April when there is insufficient soil moisture to maintain plant growth without irrigation, but this number varies between sites and between months. There is adequate moisture available to maintain plant growth between May and October. Figure 22 shows region-wide variability in days of soil moisture deficit per year.

Potential evapotranspiration (PET) has been calculated for Leigh, Auckland Airport, and Pukekohe, using the Penman method (Penman, 1948). The monthly mean, minimum, and maximum PET values are listed in Table 21.

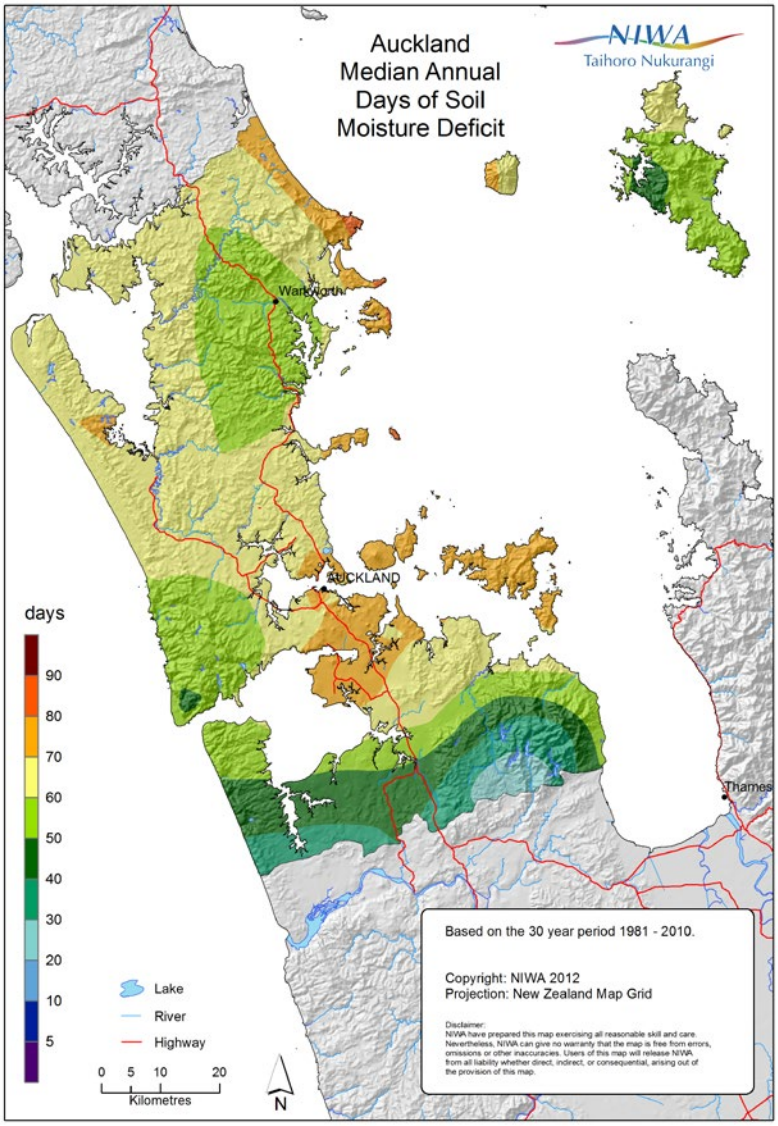


Figure 23. Auckland median annual days of soil moisture deficit, 1981-2010

Table 21. Penman calculated maximum, mean, and minimum monthly average potential evapotranspiration (mm)

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Leigh 2	Max	169	143	123	89	60	42	50	61	84	120	144	159	
	Mean	150	123	110	72	49	35	39	53	74	104	124	141	1074
	Min	117	103	89	56	38	29	30	47	59	82	104	118	
Auckland Airport	Max	187	146	124	79	51	36	45	60	81	126	150	176	
	Mean	161	129	109	65	40	27	31	48	72	107	133	153	1075
	Min	137	113	91	52	33	18	23	35	61	87	116	139	
Pukekohe EWS	Max	155	112	98	61	37	25	26	43	61	93	119	135	
	Mean	129	103	88	52	31	19	22	35	54	82	102	120	837
	Min	111	92	78	43	27	14	17	29	45	65	92	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 22 lists the monthly totals of growing degree-day totals above base temperatures of 5 °C and 10 °C for sites in Auckland.

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

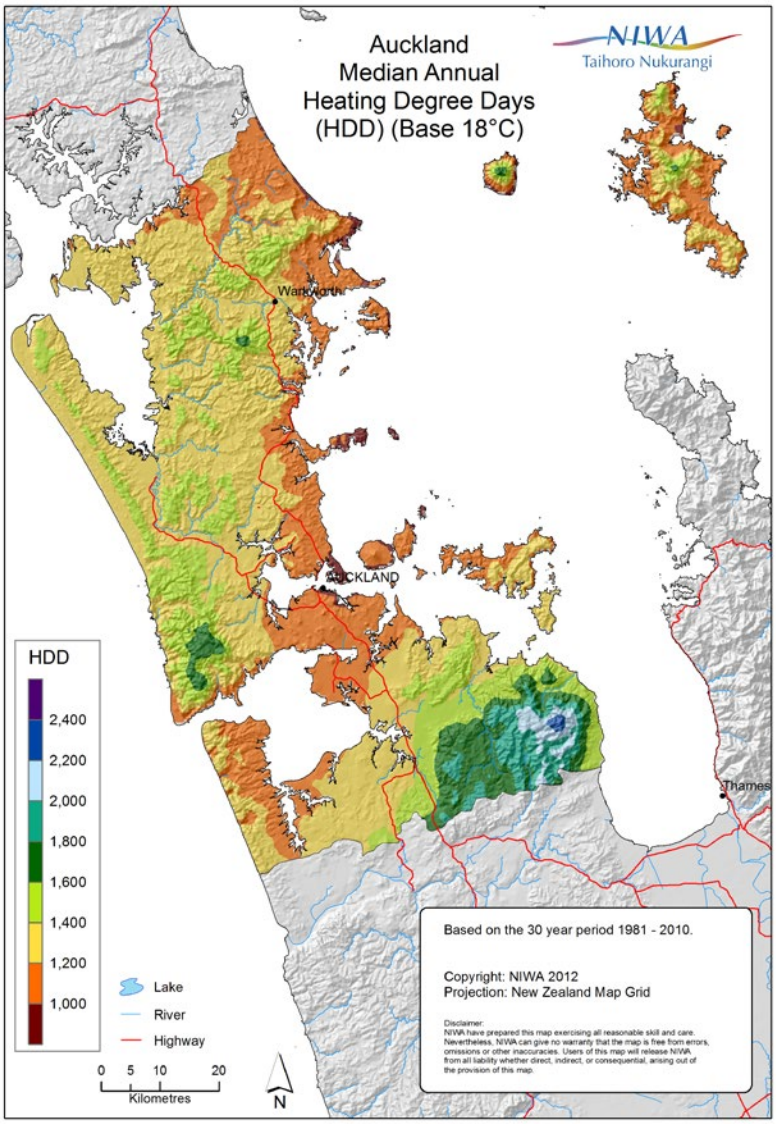


Figure 24. Median annual heating degree days for Auckland, 1981-2010.

Table 22. Monthly/annual average growing degree-day totals above base 5°C and 10°C.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Leigh 2	5°C	449	425	439	370	323	255	234	235	260	303	336	405	4032
	10°C	294	284	284	220	168	105	80	81	110	148	186	250	2209
Whenuapai Airport	10°C	429	400	395	305	242	179	158	184	217	266	320	385	3481
	5°C	274	259	240	156	91	48	32	44	71	112	170	230	1728
Henderson River Park	5°C	458	426	414	329	267	185	166	189	233	293	333	411	3704
	10°C	303	285	259	180	113	52	36	48	87	138	183	256	1939
Auckland Airport	10°C	459	432	428	340	277	204	184	205	243	293	337	415	3817
	10°C	304	290	273	190	123	64	45	56	94	138	187	260	2025
Pukekohe EWS	5°C	426	403	397	317	262	188	166	181	220	268	300	376	3504
	10°C	271	262	242	168	109	52	32	39	74	113	150	221	1734

reach a peak in winter, where the demand for energy to heat buildings to 18°C is highest. Figure 23 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 23. Average cooling (CDD) and heating (HDD) degree-day totals with base 18 °C

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Leigh 2	CDD	50	60	42	12	1	0	0	0	0	0	3	21	190
	HDD	4	2	7	32	82	136	169	168	130	100	57	20	907
Whenuapai Airport	HDD	39	42	23	3	0	0	0	0	0	0	3	18	129
	CDD	14	8	31	87	161	211	246	219	173	137	73	36	1396
Henderson River Park	CDD	63	63	32	8	1	0	0	0	0	1	6	31	205
	HDD	8	4	21	69	137	205	237	214	157	111	63	23	1250
Auckland Airport	HDD	61	67	38	7	1	0	0	0	0	0	4	30	209
	HDD	5	3	13	57	126	186	219	198	147	110	57	18	1140
Pukekohe EWS	CDD	40	44	23	5	1	0	0	0	0	0	2	15	129
	HDD	17	8	29	77	142	203	237	222	170	135	91	42	1373

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