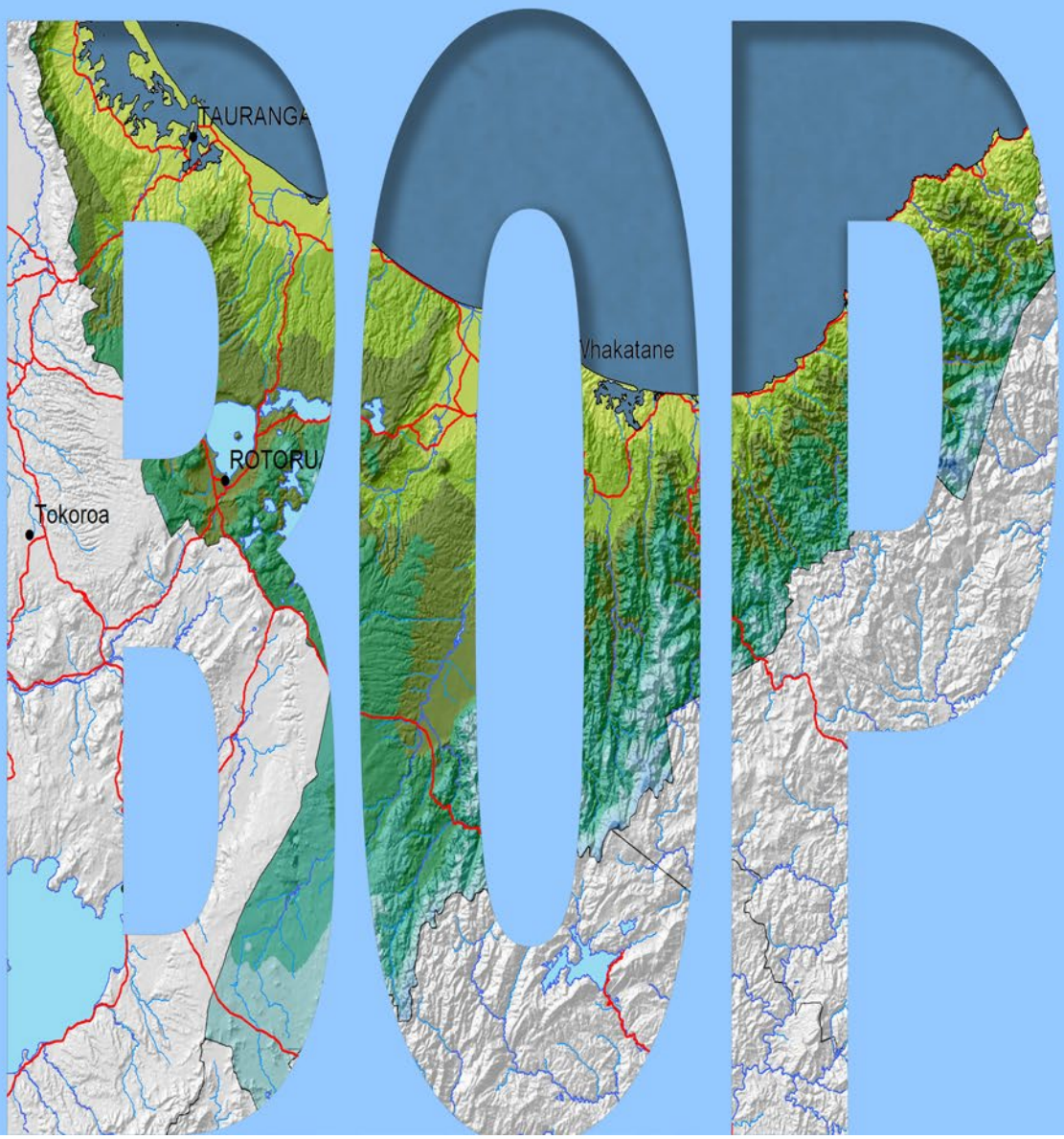
NIWA
Taihoro Nukurangi

THE CLIMATE AND WEATHER OF BAY OF PLENTY

3rd edition

P.R. Chappell



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Note to Third Edition

This publication replaces the second edition of the New Zealand Meteorological Service Miscellaneous Publication 115 (1), written in 1984 by A.M. Quayle. It was considered necessary to update the second edition, incorporating more recent data and updated methods of climatological variable calculation.

THE CLIMATE AND WEATHER OF BAY OF PLENTY

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CONTENTS

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SUMMARY

The topography of the North Island has a profound effect on the weather of the Bay of Plenty region. The sheltering provided by high country on three sides produces a climate that is one of the sunniest and least windy in New Zealand. The annual rainfall is quite plentiful compared with some eastern parts of the country, although there is considerable rainfall variability. Most of the rainfall in the region, and especially heavy rain, occurs when northerly airstreams of tropical origin are forced to ascend over the land. Temperatures too are subject to considerable variability. The seas in the Bay of Plenty, because of the presence of a warm ocean current and sheltering provided by the North Island, are among the calmest and warmest in New Zealand.

INTRODUCTION

Bay of Plenty is defined as the region administered by Bay of Plenty Regional Council, encompassing the jurisdictions of Western Bay of Plenty, Tauranga, Rotorua, Whakatane, and Opotiki Districts, as well as part of Taupo District. The region is bounded by the Kaimai and Mamaku Ranges in the west, the Huiarau and Raukumara Ranges in the east, and by the Pacific Ocean to the north (Figure 1). The southern extent of the region is near Rangitaiki in Taupo District, and the region includes part of Te Urewera National Park.

Geographically, Bay of Plenty is a diverse region. Volcanic landscapes dominate the area from Rotorua south towards Taupo, and heavily forested ranges cover a vast area in Te Urewera National Park and Raukumara Ranges. These areas are a marked contrast to the coastal lowlands, extending from Waihi Beach in the northwest to Opotiki in the east.

Large parts of the volcanic plateau are now covered by exotic pine plantations. The coastal strip supports a large dairying industry but much of this area is best known for its kiwifruit and citrus orchards. The volcanic resources of the region have also been exploited – tourists provide a significant part of New Zealand's income while the Kawerau Geothermal System is utilised in the production of electric power. The port of Tauranga provides a means of export for much of the region's produce and the seas off Bay of Plenty support important commercial and recreational fisheries.

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.

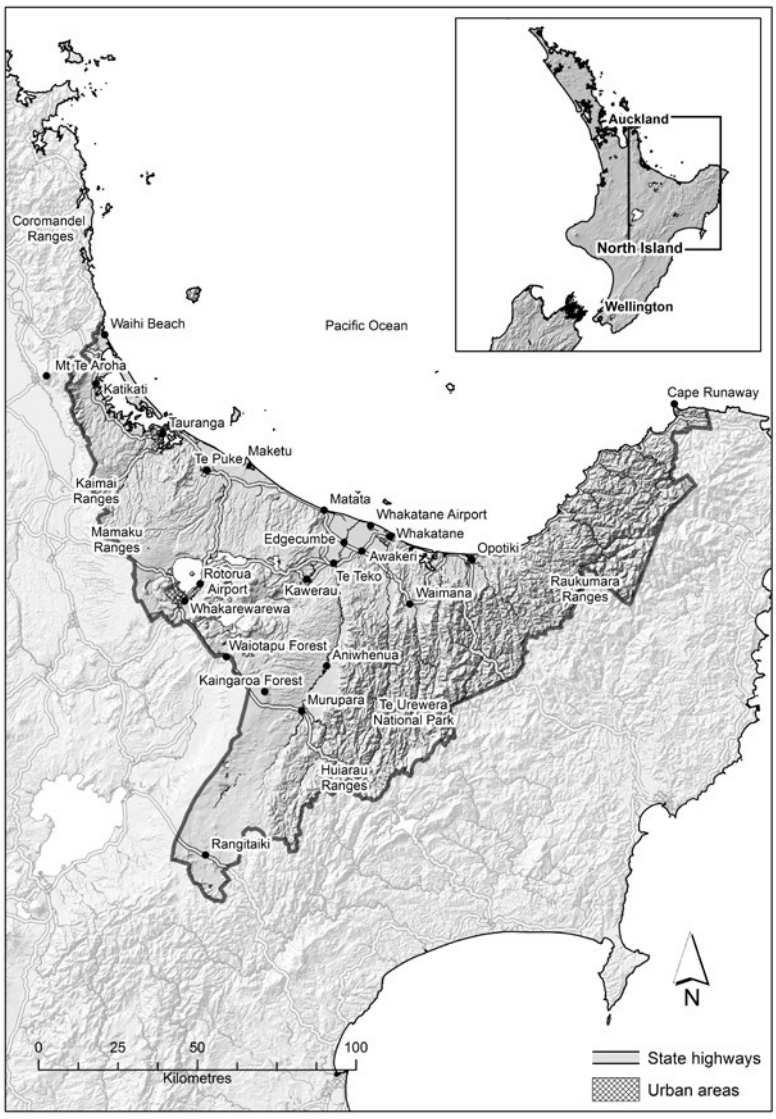

Figure 1. Map of Bay of Plenty, with locations of places mentioned in the text, tables, and figures.

THE WEATHER IN BAY OF PLENTY

Typical weather situations

Because Bay of Plenty is sheltered by high country to the west, south, and east, day to day variations of the weather are largely determined by the direction of the wind. While high country areas may receive rain with airstreams from any direction, most of the area receives a large part of its annual rainfall during periods of onshore north to northeast winds. The following sections describe the effects of various meteorological situations on the weather of the Bay of Plenty region.

North to northeast airstreams

Airstreams from the north and northeast frequently have long trajectories over the warm ocean to the north of New Zealand and, as a result, the air flowing onto Bay of Plenty under these conditions is very humid. As the whole region is exposed to the north, these airstreams often produce widespread and heavy rain when the moist air is forced to ascend over the rising ground of the North Island. Such flows are normally associated with one of two types of situation. Firstly, when a cold front, oriented north-south, is approaching from the west, the northerly winds ahead of the front spread over the region, bringing widespread rain until the passage of the front when there is usually a clearance. The second type occurs when depressions cross the northern half of the North Island. These lows often move only slowly east, and the north to northeast flows on the eastern side of the centre may bring prolonged rain to the region.

An example of this type of situation occurred on 28-29 July 1982. A large depression had developed near Lord Howe Island and on the 28th moved into the area northwest of Cape Reinga. A moist northeasterly airstream, extending from just south of Fiji, spread onto the North

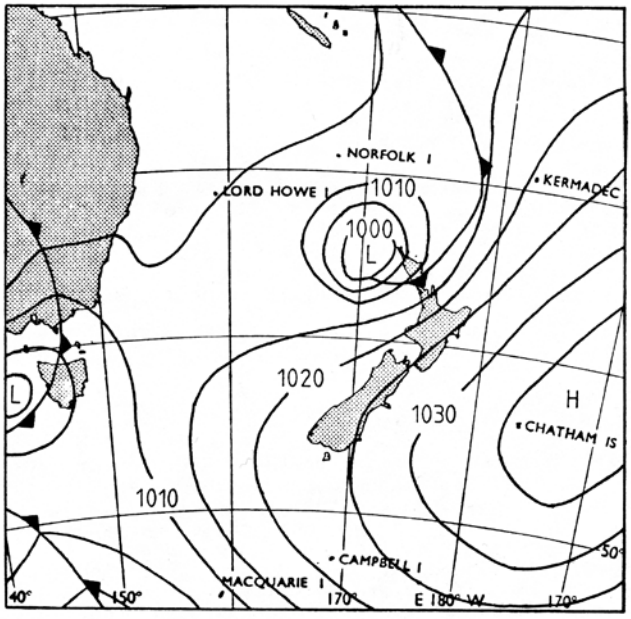

Figure 2. Sea level pressure analysis for 0000 NZST on 29 July 1982

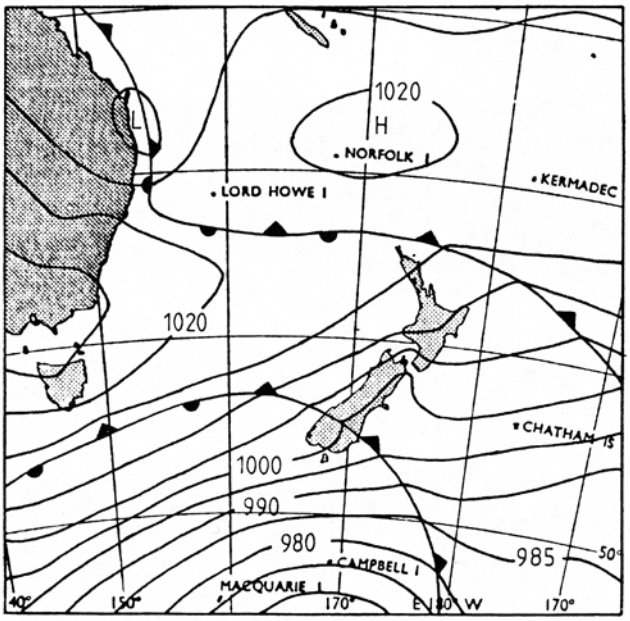

Figure 3. Sea level pressure analysis for 0000 NZST on 11 October 1982

Island ahead of the cold front associated with the low (Figure 2). The northeasterlies brought some light rain to the Bay of Plenty on the 27th but widespread heavy rain developed during the 28th. Heavy rain continued to fall throughout the 29th, with 40-50 mm of rain falling over much of the region. The front and northeasterly airstream moved off to the east on the 30th and the rain cleared.

Disturbed west to southwest flows

This is a common situation in the New Zealand region, occurring most frequently during the spring months. Cold fronts move quickly east-north-east across the country, giving showers, chiefly to western areas. The Bay of Plenty region however, is sheltered by high ground to the south and west and, as a result, only a few showers are experienced in most places.

For example, a strong southwesterly airstream spread onto the North Island behind a cold front during 10 October 1982. The initial front, and subsequent disturbances (Figure 3) in the southwesterlies gave brief light showers to the Bay of Plenty region but rainfall amounts were very small (less than 1 mm).

South to southeast airstreams

The area to the east and south of Bay of Plenty comprises the central high country of the North Island. South to southeast airstreams will normally have released much moisture as rain on the ranges and usually produce fine, dry weather over the region. Such flows are normally associated with low pressures to the east or northeast of the North Island. During 20-21 February 1984 a southerly airstream (Figure 4) over the North Island was giving showers to areas about and east of the ranges from East Cape to Hawkes Bay, while Bay of Plenty experienced fine, sunny weather.

Flows from the south and southeast are subject to foehn warming as they traverse the high country and, as a result, temperatures in Bay of Plenty are often notably warmer than on the windward side of the ranges. Temperatures on 20 February 1984 were some 3-4°C warmer in Bay of Plenty than on the eastern side of the ranges, as a result of this effect.

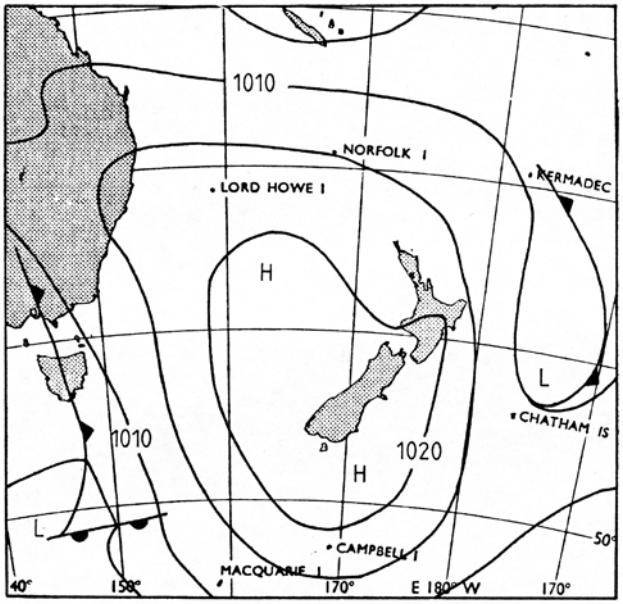

Figure 4. Sea level pressure analysis for 0000 NZST on 21 February 1984

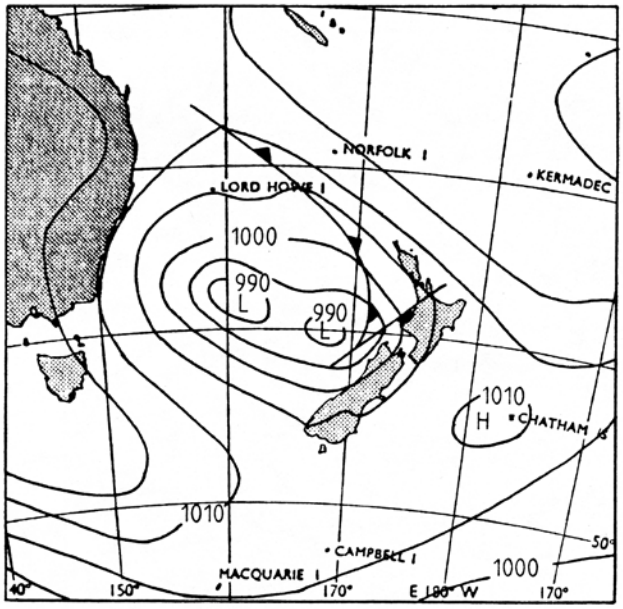

Figure 5. Sea level pressure analysis for 0000 NZST on 10 September 1983

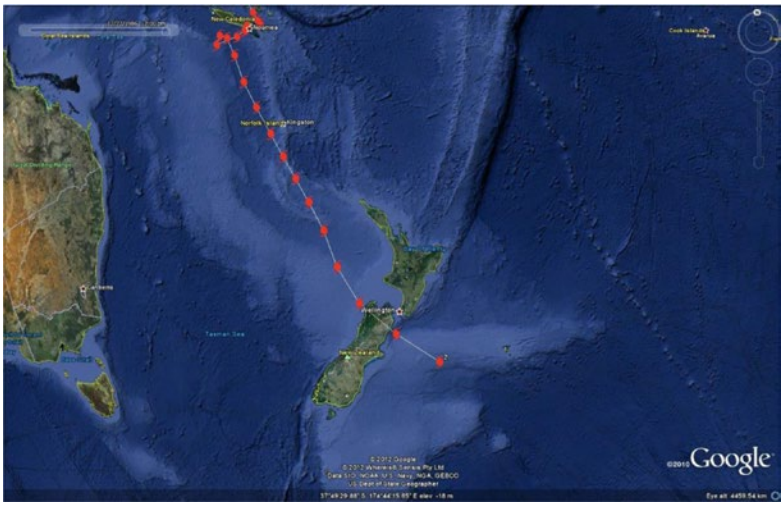

Figure 6a. Tropical cyclones which made landfall in New Zealand during December, 1970-2010. Source: Southwest Pacific Enhanced Archive of Tropical Cyclones (SPEArTC; Diamond et al., 2012).

West to northwest flows

The Coromandel, Kaimai, and Mamaku Ranges provide sheltering to much of the Bay of Plenty region in west to northwest situations, although the area from Cape Runaway to Whakatane and Murupara is open to flows from the northwest. Because of the sheltering, much of the rain that falls in the western Bay of Plenty with this type of situation occurs with the passage of fronts, rather than as a result of orographic effects on the northwesterly flow. Eastern areas, however, tend to experience rain both with fronts and with the northwesterlies ahead of fronts.

During the period 8-15 September 1983 a series of fronts moved east-south-east across the North Island in a predominantly northwesterly airstream. For much of the time the weather over the region was cloudy, with periods of rain occurring as fronts moving across the area. Daily rainfalls of up to 40 mm were recorded on the days when fronts crossed the region but on the other days rainfalls were generally less than 5 mm. The situation at midnight on 10 September 1983 is depicted in Figure 5. The front west of Auckland moved quickly east-south-east across the North Island during the day.

Cyclones of tropical origin

The tropical cyclone season in the southern hemisphere lasts from November to April. Originating in low latitudes within the cloud masses of the South Pacific Convergence Zone, tropical cyclones reaching northern New Zealand and still retaining true cyclonic characteristics, such as a warm core, are extremely rare. They are nevertheless accompanied by heavy rain and strong winds. Tracks of tropical cyclones which have made landfall in New Zealand between 1970 and 2010 are shown in Figure 6a-e.

Tropical Cyclone Bernie developed near the Solomon Islands on 1 April 1982 and

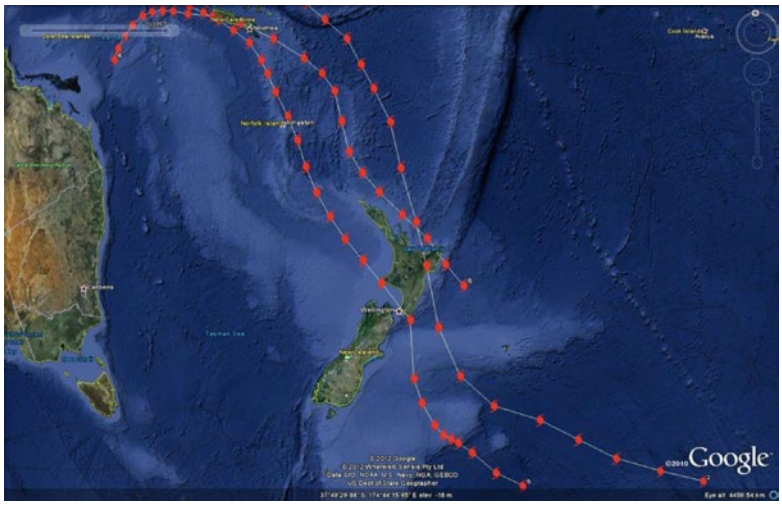

Figure 6b. Tropical cyclones which made landfall in New Zealand during January, 1970-2010. Source: SPEArTC (Diamond et al., 2012).

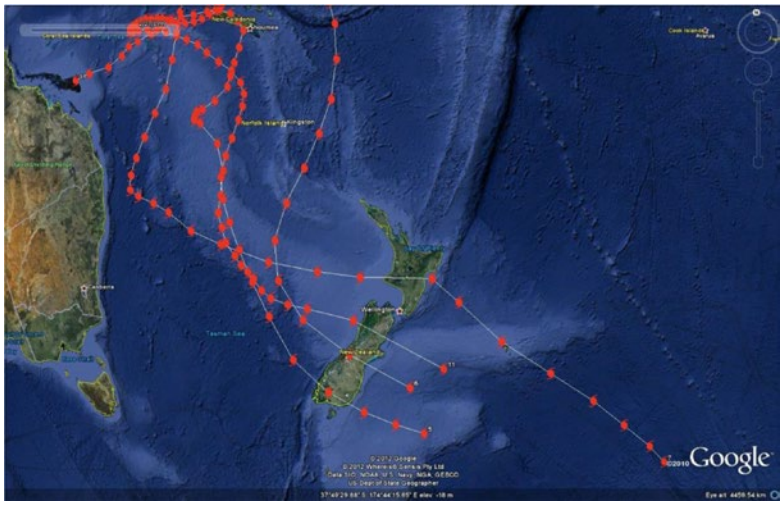

Figure 6c. Tropical cyclones which made landfall in New Zealand during February, 1970-2010. Source: SPEArTC (Diamond et al., 2012).

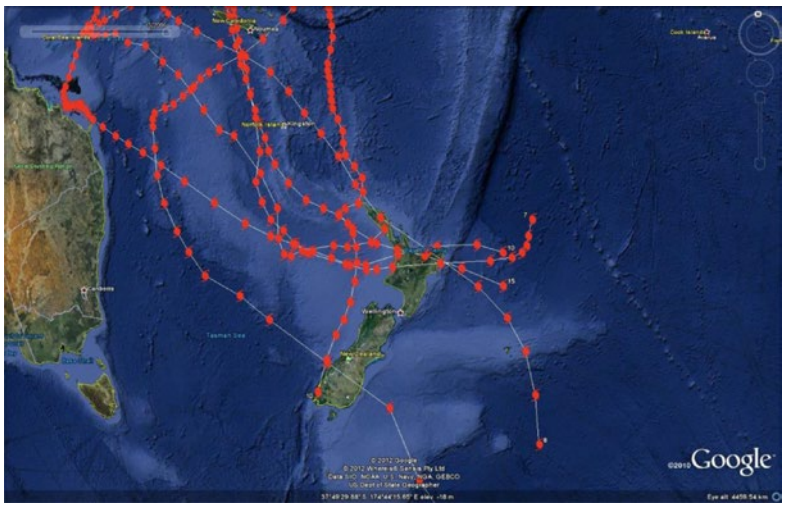

Figure 6d. Tropical cyclones which made landfall in New Zealand during March, 1970-2010. Source: SPEArTC (Diamond et al., 2012).

during the following six days moved south into the area just west of New Caledonia, before turning southeast towards northern New Zealand. During the 9th Bernie moved fairly quickly southeast from near Norfolk Island to near East Cape. The very moist easterlies on the southern side of the cyclone gave continuous rain to the region throughout that day (up to about 25 mm). On the 10th there was a rapid clearance when the flow turned southerly over the North Island as Bernie moved away. Very strong winds were experienced in the Bay of Plenty region during the 9th, causing severe damage to crops such as kiwifruit and apples and to trees in the Kaingaroa Forest.

More recently, on 12-14 April 2001, ex-tropical cyclone Sose caused heavy rainfall in the Bay of Plenty region. Numerous roads were flooded (including SH 2 between Te Puke and Mt Maunganui) and high winds felled trees. Some rivers were pushed to flood level by the heavy rain. A 22-year-old man drowned in the Wairoa River. A landslide at Te Puke cut off the water supply from Te Puke to Maketu on the 13th, and water from some streams were unsuitable for drinking because of the heavy rain.

Dry spells

As a result of the extensive sheltering provided by the high country surrounding three sides of the Bay of Plenty region, the frequency of rain is rather less than in many other parts of the country and dry spells are relatively common. Quite frequently, long periods occur when west to southwest flows persist over New Zealand without being interrupted by the north to northeast flows which give Bay of Plenty most of its rain. The summer of 1982-1983 was an excellent example and Bay of Plenty, along with many other eastern areas of New Zealand, received very little rain.

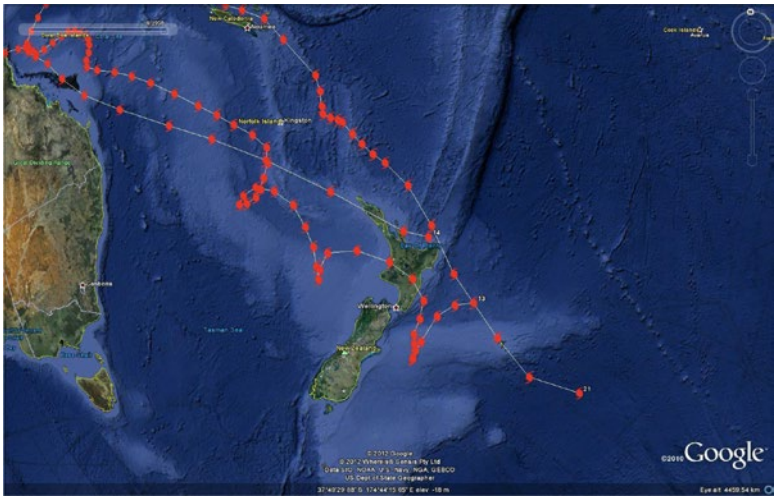

Figure 6e. Tropical cyclones which made landfall in New Zealand during April, 1970-2010. Source: SPEArTC (Diamond et al., 2012).

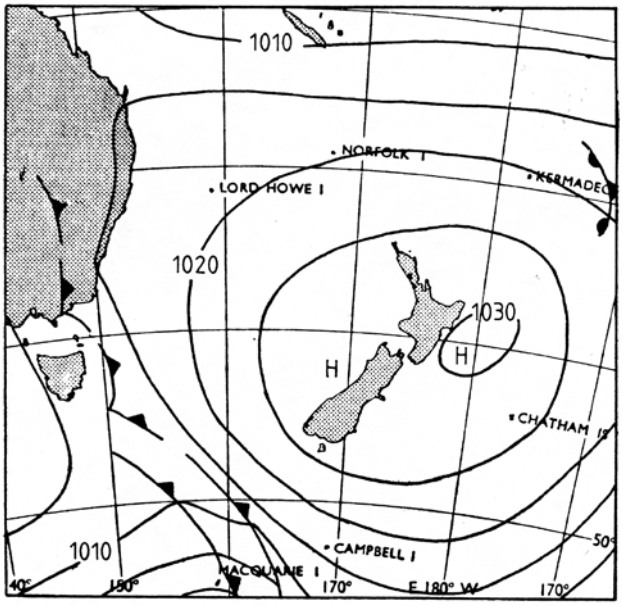

Figure 7. Sea level pressure analysis for 0000 NZDT on 23 February 1983.

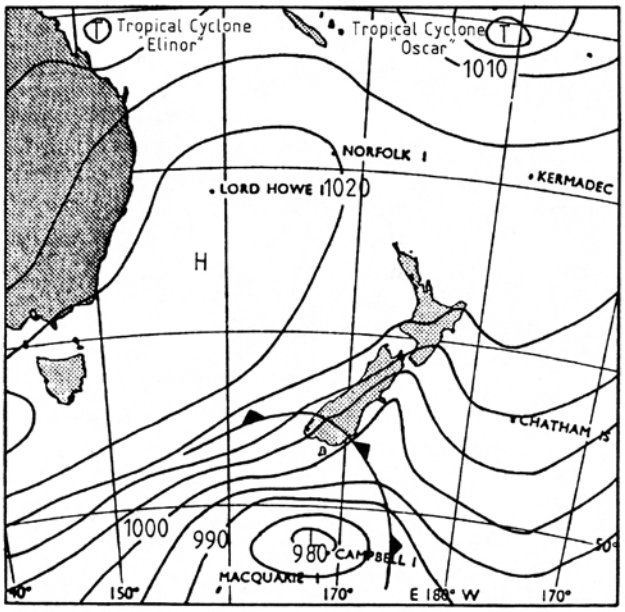

Figure 8. Sea level analysis for 0000 NZDT on 3 March 1983.

During the 25-day period from 15 February to 11 March 1983, rain was recorded on only two days at Rotorua and three days at Tauranga, with the falls in each case amounting to only about 0.5 mm. Figures 7 and 8 show typical weather situations affecting the region during this period.

Pressures over New Zealand during the latter half of February were high and during the first eleven days of March a west to southwest airstream covered the country. The few fronts which crossed New Zealand were weak and at no stage did northeasterly winds affect Bay of Plenty.

Convection showers

During the summer, on days when the air is unstable (i.e. there is a rapid decrease of temperature with height) surface heating will often cause the air to rise. This, in turn, leads to the formation of cumulus or cumulonimbus clouds and eventually, showers. Showers of this type are quite frequent in Bay of Plenty and normally occur on days which have begun fine. The showers are normally confined to inland areas, although on some occasions cumulonimbus clouds spread out and become very extensive, giving widespread showers and, occasionally, thunderstorms.

On 2 January 1984 a ridge of high pressure covered the North Island and clear skies permitted rapid heating over the land. As a result of this heating the air began to ascend and this led to the formation of a 'heat low' over the Bay of Plenty region in the afternoon (Figure 9). The ascending air also led to a general increase in cloudiness during the day. By late afternoon 'towering cumulus' clouds were developing in the Rotorua area and at about 7.30 pm heavy showers developed. Showers were reported over a wide area around Rotorua but many other parts of the region recorded no rain at all. Between 7.30 pm and midnight a total of 33 mm of rain was recorded at Rotorua Airport. The showers then rapidly cleared and the cloud dispersed.

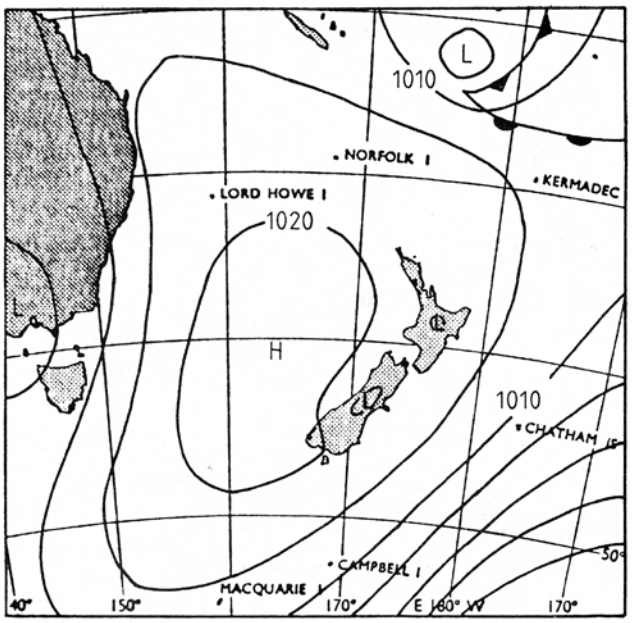

Figure 9. Sea level pressure analysis for 3 pm on 2 January 1984.

CLIMATIC ELEMENTS

Wind

Although the prevailing windflow over northern New Zealand is west to southwest, winds over the Bay of Plenty region are modified by the local topography. Because of the sheltering provided by the high country to the west, south, and east, the Bay of Plenty lowlands experience considerably less wind than many other parts of the country.

Wind roses (mean annual frequency of surface wind speed and direction based on hourly observations) for sites in Bay of Plenty are shown in Figure 10. Winds from the west and southwest prevail at Mt Te Aroha[1] (elevation 951 m) and at Tauranga, while at Whakatane, northwesterly and southwesterly winds are the most frequent. At Rotorua the prevailing wind is northeasterly, but winds from between south and west are also common.

Mean wind speed data (average wind speeds are taken over the 10 minute period preceding each hour), are available for several sites in Bay of Plenty, and these illustrate the several very different wind regimes of the region. There is little difference in mean wind speeds between coastal areas (e.g. Tauranga and Whakatane) and areas further inland (e.g. Rotorua). However, Te Puke is very sheltered. Table 1 gives mean monthly wind speeds for selected stations in Bay of Plenty.

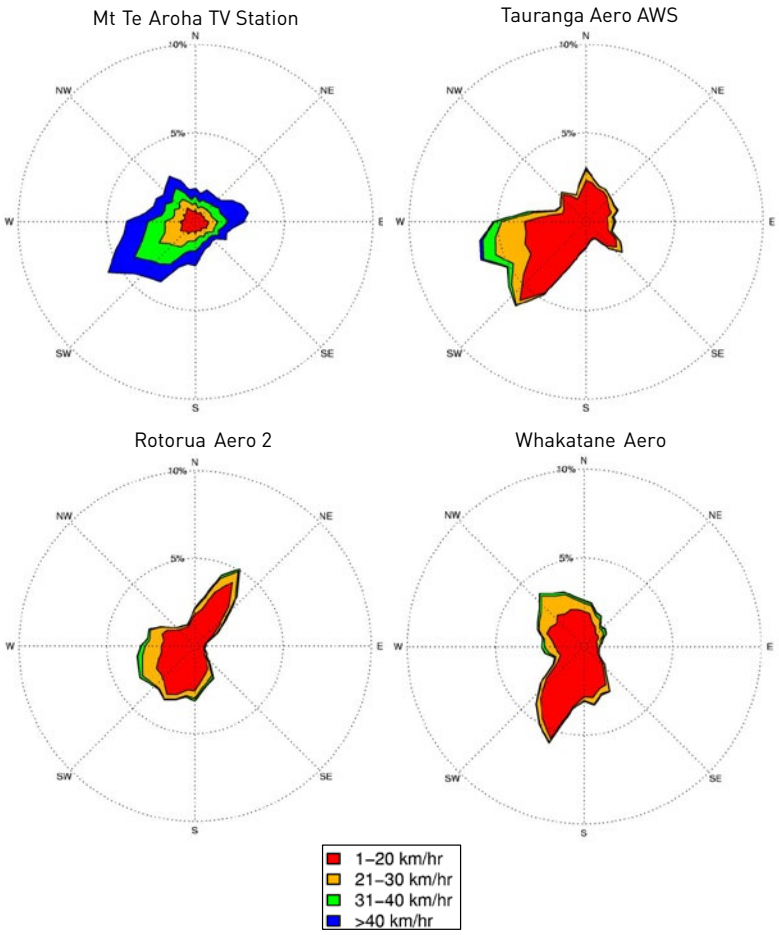

Figure 10. Mean annual wind frequencies (%) of surface wind directions from hourly observations at selected Bay of Plenty (and surrounding) stations. The plots show the directions from which the wind blows, e.g. the dominant wind direction at Rotorua is from the northeast.

Table 1. Mean monthly and annual wind speed (km/hr).

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Tauranga Aero AWS	14	14	13	12	13	13	13	14	14	16	16	15	14
Te Puke EWS	5	5	4	4	5	5	5	5	6	6	6	6	5
Rotorua Aero AWS	13	12	12	11	11	12	12	12	13	15	15	14	13
Whakatane Aero AWS	14	13	13	12	12	12	12	13	14	15	16	15	13

[1]Mt Te Aroha is outside the Bay of Plenty region (in the Waikato region), but is included here as lengthy wind records from western Bay of Plenty are scarce.

Spring is generally the windiest season throughout the region. Summer and autumn are the seasons when the greatest number 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 Tauranga Airport, 21% occurred in summer, 16% in autumn, 27% 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 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.

When pressure gradients are weak on fine summer days, northerly sea breezes of 20 to 30 km/hr develop in many coastal areas and on some occasions the sea breezes penetrate inland for considerable distances. At night, especially on clear nights, coastal areas experience light winds from the southerly quarter as a result of the drainage of cool air from inland. This effect is also noticeable in some inland places, but directions are more variable due to the rather complex topography. Generally, however, inland areas experience very light winds during most clear nights.

Winds can be strong and gusty at times, especially in coastal areas. Tauranga has the highest number of gusts per year that are greater than 63 km/hr, but Whakatane has the highest number of gusts per year that exceed 96 km/hr (Table 4). However, all sites have relatively similar gust frequency characteristics.

Table 2. Seasonal proportions of strong or light winds (%).

Location		Summer	Autumn	Winter	Spring
Tauranga Aero AWS	Strong	21	16	27	37
	Light	25	25	25	25
Rotorua Aero AWS	Strong	17	19	31	32
	Light	25	25	25	25
Kawerau	Strong	24	19	24	33
	Light	25	25	25	25
Whakatane Aero AWS	Strong	21	19	30	30
	Light	25	25	25	25

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

Location	00	03	06	09	12	15	18	21
Tauranga Aero AWS	12	11	11	13	17	19	17	13
Rotorua Aero AWS	10	9	9	11	15	17	16	12
Whakatane Aero AWS	11	10	10	12	17	19	16	12

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

Location	Gusts >63 km/hr	Gusts >96 km/hr
Tauranga Aero AWS	27	0.2
Rotorua Aero AWS	24	0.1
Whakatane Aero AWS	23	0.3

Table 5. Highest recorded gusts at selected Bay of Plenty stations, from all available data.

Location	Gust (km/hr)	Direction (°)	Date
Tauranga Aero	119	SW	15/4/1969
Rotorua Aero	113	SSE	9/4/1968
Whakatane Aero	146	E	9/4/1982

Although gale force winds can occur in any month, they are most frequent in winter. The highest gust recorded from selected stations in the region was 146 km/hr at Whakatane Airport on 9 April 1982. Maximum gusts recorded at different stations in the region are listed in Table 5.

Rainfall

Spatial variability of rainfall

The pattern of rainfall distribution over Bay of Plenty largely reflects the region's exposure to the main rain-bearing northeasterly winds, and also variations in elevation. The terrain slopes steadily upwards for some 25 to 30 km inland. In the south the terrain then descends again, towards Murupara and Rotorua. Annual rainfall distribution closely follows these variations in topography, rising from 1300 mm or less near the coast to around 2000 mm in the Kaimai and Mamaku Ranges, and over 2200 mm in the Raukumara Ranges. Rainfalls steadily decrease as the terrain descends again, with the area around Murupara receiving less than 1300 mm per year. Figure 11 shows the distribution of median annual rainfall over the Bay of Plenty region.

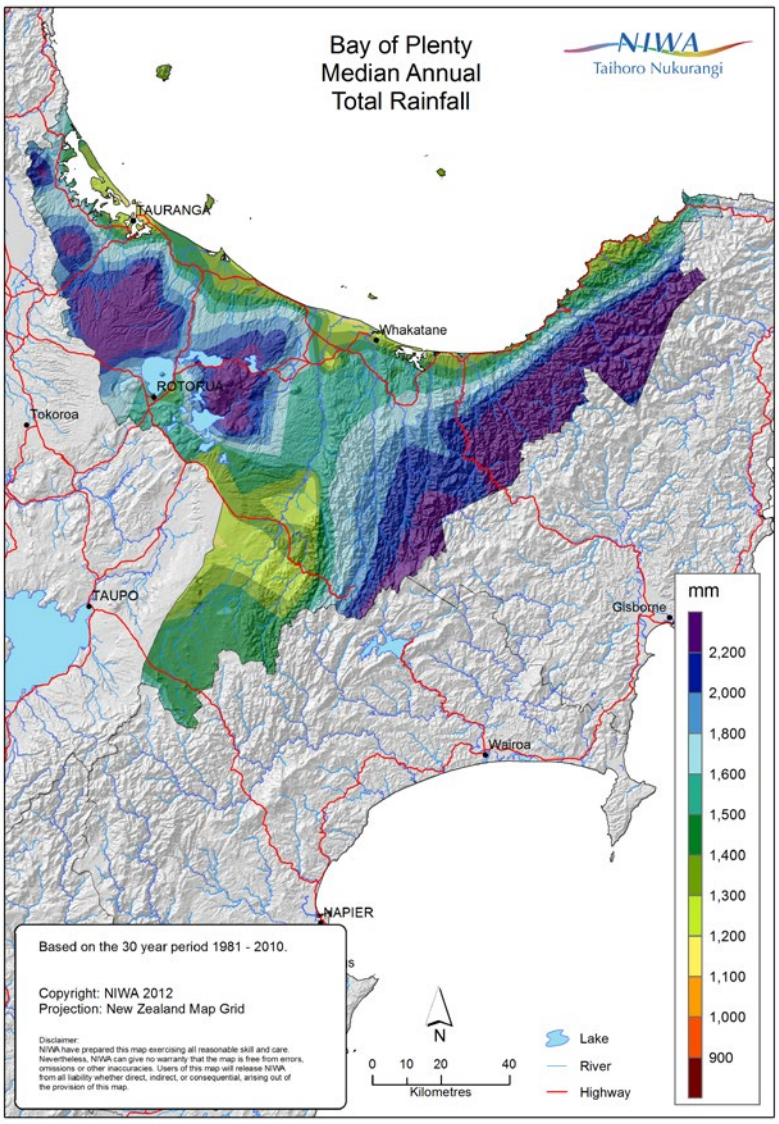

Figure 11. Median annual total rainfall for Bay of Plenty, 1981-2010.

Table 6. Monthly/annual rainfall normal (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
Waihi Beach	a	110	102	156	158	99	159	166	149	137	118	125	101	1579
	b	7	6	10	10	6	10	11	9	9	7	8	6	
Katikati 2	a	95	110	111	134	96	122	135	111	102	99	106	99	1319
	b	7	8	8	10	7	9	10	8	8	7	8	7	
Tauranga Aero AWS	a	78	86	97	121	110	115	129	110	85	89	74	95	1189
	b	7	7	8	10	9	10	11	9	7	7	6	8	
Te Puke EWS	a	106	115	144	144	132	169	163	160	126	142	102	139	1642
	b	6	7	9	9	8	10	10	10	8	9	6	8	
Rotorua Aero AWS	a	92	95	99	112	123	133	135	136	108	110	94	118	1353
	b	7	7	7	8	9	10	10	10	8	8	7	9	
Kawerau	a	118	132	135	134	116	155	140	149	128	162	141	133	1643
	b	7	8	8	8	7	9	9	9	8	10	9	8	
Edgecumbe	a	87	97	99	132	123	147	149	136	104	107	85	109	1376
	b	6	7	7	10	9	11	11	10	8	8	6	8	

Table 6 continued.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Whakatane Aero AWS	a	75	83	86	103	105	129	132	113	92	99	76	96	1189
	b	6	7	7	9	9	11	11	9	8	8	6	8	
Opotiki	a	81	81	107	113	118	150	131	126	104	98	86	117	1311
	b	6	6	8	9	9	11	10	10	8	7	7	9	
Aniwhenua	a	105	110	118	134	139	162	141	152	132	138	112	141	1582
	b	7	7	7	8	9	10	9	10	8	9	7	9	

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 Bay of Plenty region, with around 30% of annual rainfall expected in the winter months from June to August, and around 22% of rain in the summer months from December to February.

Because the region is sheltered and depends on northerly airstreams for much of its rainfall there is considerable variability from season to season. There is considerably greater rainfall variability in the western Bay of Plenty than in the east and southeast where rain occurs with a wider range of situations. The greatest rainfall variability occurs in the summer and autumn months when there may be long dry spells or periods of heavy rain.

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

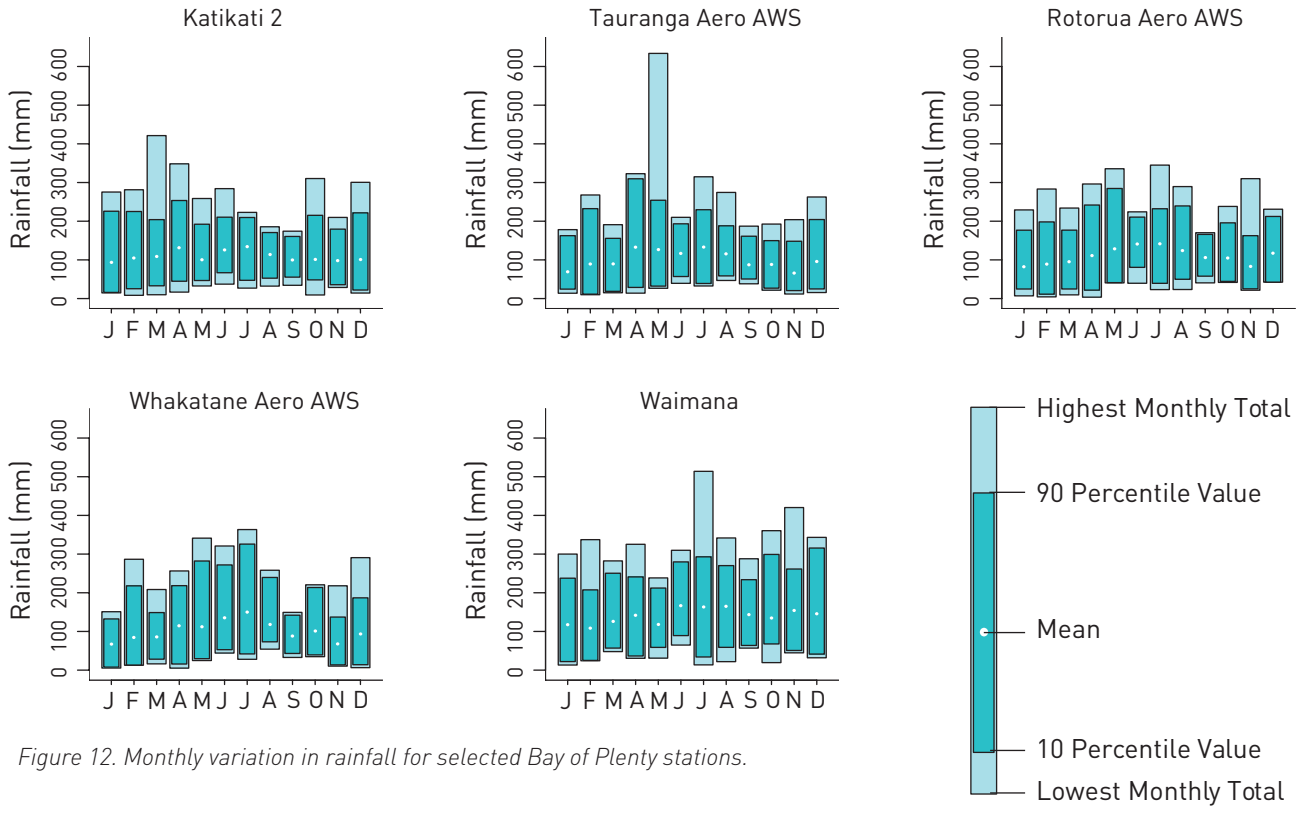

Figure 12. Monthly variation in rainfall for selected Bay of Plenty stations.

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 Tauranga, for three months it can be seen that in the three month period beginning in April, 234 mm or less of rainfall can be expected in one year in ten, between 235 mm and 572 mm can be expected in eight out of ten years, and more than 572 mm of rainfall can be expected in one year in ten.

Table 7. Rainfall deciles for consecutive months for sites in the Bay of Plenty region.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tauranga Aero AWS												
1 month												
10th	24	11	19	29	32	57	39	59	51	27	21	25
90th	163	233	156	310	254	193	230	188	161	150	148	204
3 months												
10th	151	168	196	235	209	234	219	157	146	147	113	141
90th	364	520	595	572	527	517	465	390	334	411	356	352
6 months												
10th	408	443	460	480	418	407	345	347	343	374	321	406
90th	919	984	1030	958	973	755	768	678	603	613	730	908
12 months												
10th	745	773	842	914	927	957	891	967	986	1020	960	904
90th	1627	1636	1620	1593	1541	1491	1453	1451	1456	1512	1478	1536
Rotorua Aero AWS												
1 month												
10th	23	11	24	42	41	79	38	51	58	43	25	46
90th	172	201	169	255	285	212	235	246	166	187	163	213
3 months												
10th	153	181	218	199	257	211	196	188	192	185	142	137
90th	429	557	545	555	584	578	514	458	438	448	458	543
6 months												
10th	518	511	533	531	552	504	429	424	355	334	360	411
90th	925	1010	1029	1030	964	903	898	766	822	860	960	1008
12 months												
10th	964	1002	1020	993	1061	998	1001	1092	1093	1138	1051	1077
90th	1623	1640	1582	1593	1787	1736	1682	1690	1673	1631	1631	1662
Whakatane Aero AWS												
1 month												
10th	8	13	28	16	30	53	42	73	43	39	14	14
90th	132	218	149	218	282	272	326	240	142	214	137	187
3 months												
10th	139	138	198	255	232	275	193	167	138	118	87	106
90th	346	478	471	464	665	591	499	420	428	393	363	376
6 months												
10th	458	469	502	511	437	456	376	306	290	239	341	378
90th	782	889	902	951	922	858	836	690	676	657	703	694
12 months												
10th	834	861	853	847	899	857	903	986	997	968	975	937
90th	1542	1537	1420	1473	1409	1446	1486	1480	1550	1550	1463	1482

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 135 days in eastern parts of the region (e.g. Kawerau, Whakatane, Opotiki) to almost 200 days in western areas (e.g. Waihi Beach). Whakatane exhibits the lowest number of wet days, at 103 days per year. The 0.1 mm rain days and 1 mm wet days show the same geographic variability. Table 8 lists the average number of days per month with 0.1 mm and 1 mm of rain for selected stations.

Table 8. Average monthly rain days and wet days for Bay of Plenty; 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
Waihi Beach	a	13	13	14	15	16	18	19	20	18	19	15	14	195
	b	9	8	11	11	11	14	14	14	13	13	11	9	138
Tauranga Aero AWS	a	10	10	10	11	13	15	15	16	14	13	12	12	151
	b	6	7	8	9	9	11	12	12	10	10	9	8	112
Rotorua Aero AWS	a	11	10	11	11	15	17	17	16	16	15	13	14	165
	b	8	8	8	8	10	11	11	12	11	11	9	11	119
Kawerau	a	9	9	9	9	9	12	11	12	11	12	11	10	124
	b	8	8	8	8	8	10	10	11	10	11	10	9	112
Whakatane Aero AWS	a	9	8	10	10	13	14	14	14	13	12	12	11	140
	b	7	7	7	8	9	10	10	10	9	9	8	8	103
Opotiki	a	10	9	11	10	11	12	12	13	13	12	11	12	136
	b	7	7	8	8	9	10	10	10	9	10	8	9	104
Aniwhenua	a	10	10	11	11	13	15	15	15	14	15	12	13	154
	b	8	8	9	9	10	12	11	12	11	12	10	11	122

Heavy rainfalls can occur in Bay of Plenty with the passage of depressions from the northwest 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 stations in Rotorua and Whakatane. Also listed in this table are the maximum rainfalls expected in 2, 5, 10, 20, and 50 years at those locations. Depth-duration frequency tables for Bay of Plenty 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 from HIRDS.

Location		10min	20min	30min	1hr	2hrs	6hrs	12hrs	24hrs	48hrs	72hrs
Rotorua Aero 2	a	20	32	34	51	86	130	178	210	227	228
	b	21	35	19	24	62	53	60	37	23	16
	c	11	16	19	28	37	58	76	102	121	135
	d	14	20	25	36	47	74	99	131	157	174
	e	17	24	30	42	56	88	117	156	187	207
	f	20	28	35	50	66	104	138	184	220	244
	g	25	35	43	62	82	129	171	227	272	302
Whakatane Aero	a	16	22	29	44	56	82	110	148	184	195
	b	10	9	14	17	15	10	11	11	16	13
	c	10	15	18	25	33	53	70	93	109	120
	d	13	19	23	33	43	68	91	120	141	155
	e	16	23	28	39	52	81	107	143	168	184
	f	19	27	33	46	61	95	127	168	197	217
	g	23	33	40	57	76	118	156	207	243	267

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 Bay of Plenty

Bay of Plenty 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 Bay of Plenty region between 1980 and 2012.

8-10 April 1982: Ex-tropical Cyclone Bernie brought high winds to Bay of Plenty, causing significant damage to plantation forests (3500 ha), orchards, and crops throughout the region. Loss or damage to kiwifruit crops in the region was estimated at $3.7 million 2008 dollars. In addition, buildings and power lines were damaged, cutting power to many areas.

15-18 July 2004: Heavy rain caused by a stationary front resulted in extensive flooding and slips in the eastern Bay of Plenty. 17,000 ha of farmland were under water, and large areas were still flooded two weeks after the storm. Landslips were aggravated by a swarm of earthquakes that occurred at the same time as the flooding. 3200 homes were evacuated, and 211 homes were declared uninhabitable after the event. One person was killed in a landslide and another was killed when a tree fell on a car. Damage from the event was estimated at $52 million 2008 dollars, including 500 insurance claims for flooding.

18-19 May 2005: Convergence zones within airstreams produced phenomenal, unprecedented high rainfall which affected Bay of Plenty especially in the Tauranga and Matata areas. Landslides and flooding caused much damage to property, and Matata was hit by devastating debris flows (Figure 13). The rainfall near Matata had a ~500-year recurrence interval, and following the debris flows a state of emergency was declared. Houses and vehicles were buried under up to five metres of silt, and two houses and eight caravans were swept out to sea. An estimated 700,000 m^3 of debris, ranging from silt to boulders (up to 7 m in diameter) and trees, was deposited in and around Matata and the Matata Lagoon. Throughout the region, 156 homes were uninhabitable following the event. In Tauranga, a state of emergency was also declared due to flooding, and 400 people were evacuated. The total cost of damage was estimated at $46-57 million 2010 dollars.

8-14 May 2009: Thunderstorms, waterspouts, and a severe hailstorm hit parts of Bay of Plenty, causing disruption and damage. Around 15,000 lightning strikes were recorded in 24 hours, most of them in the Bay of Plenty area, which caused short-term power cuts. An intense hail storm was experienced in western Bay of Plenty, with hail stones of marble size, and some were half the size of golf balls. The hail caused up to $10 million in damage to kiwifruit crops (more than 2.4 million kiwifruit were damaged). Ice made driving hazardous and caused short-term flooding due to blocked drains. Five waterspouts were observed off the coast near Maketu.

Figure 13. Debris and damaged houses following the 2005 Matata debris flow.

Snow

Snow is rare in most parts of Bay of Plenty region and is unknown near the coast. Several snowfalls occur each winter on the high country of the Raukumara and Huiarau Ranges and an average of one fall per year has been recorded at Kaingaroa Forest. The Rotorua area records, on average, one snowfall every three years.

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 Bay of Plenty during the summer and early autumn. There is usually one, and frequently two, such periods each year between December and March. This frequency is similar to that recorded in other eastern parts of New Zealand. The average duration of a dry spell is about 19 days. The longest recent dry spell between three key sites in Bay of Plenty (Tauranga Airport, Rotorua Airport, and Whakatane Airport) was 33 days recorded in Whakatane, from 13 February to 17 March 1999. During this dry spell, rain did not occur on any day. Other long dry spells include 32 days at Rotorua from 24 February to 31 March 1990, of which 13 consecutive days were without any rain, and 31 days at Tauranga from 22 December 2007 to 21 January 2008, of which 12 consecutive days were without any rain.

Temperature

Sea surface temperature

The east coast of the North Island from North Cape to East Cape, swept by the East Auckland current, has the warmest seas around New Zealand. Average sea surface temperatures range from around 14°C in August up to 20-21°C during February (Figure 14, 15). Monthly mean sea surface temperatures off the coast of the Bay of Plenty region are compared to mean air temperature for Tauranga in Figure 14. There is a six to eight week lag between the minima of land and sea temperatures. Figure 15 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.

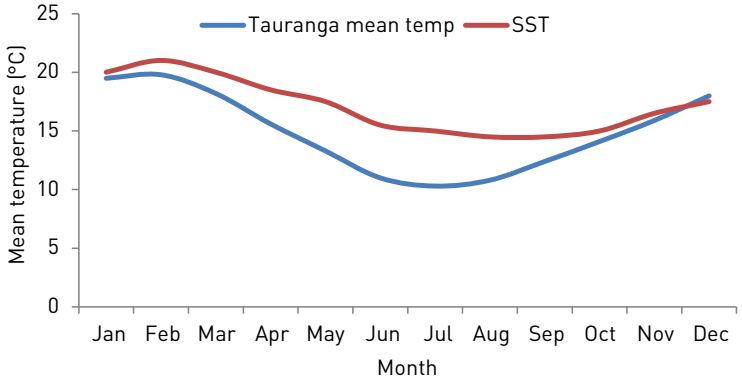

Figure 14. Mean monthly land (Tauranga Aero AWS) and sea surface temperatures.

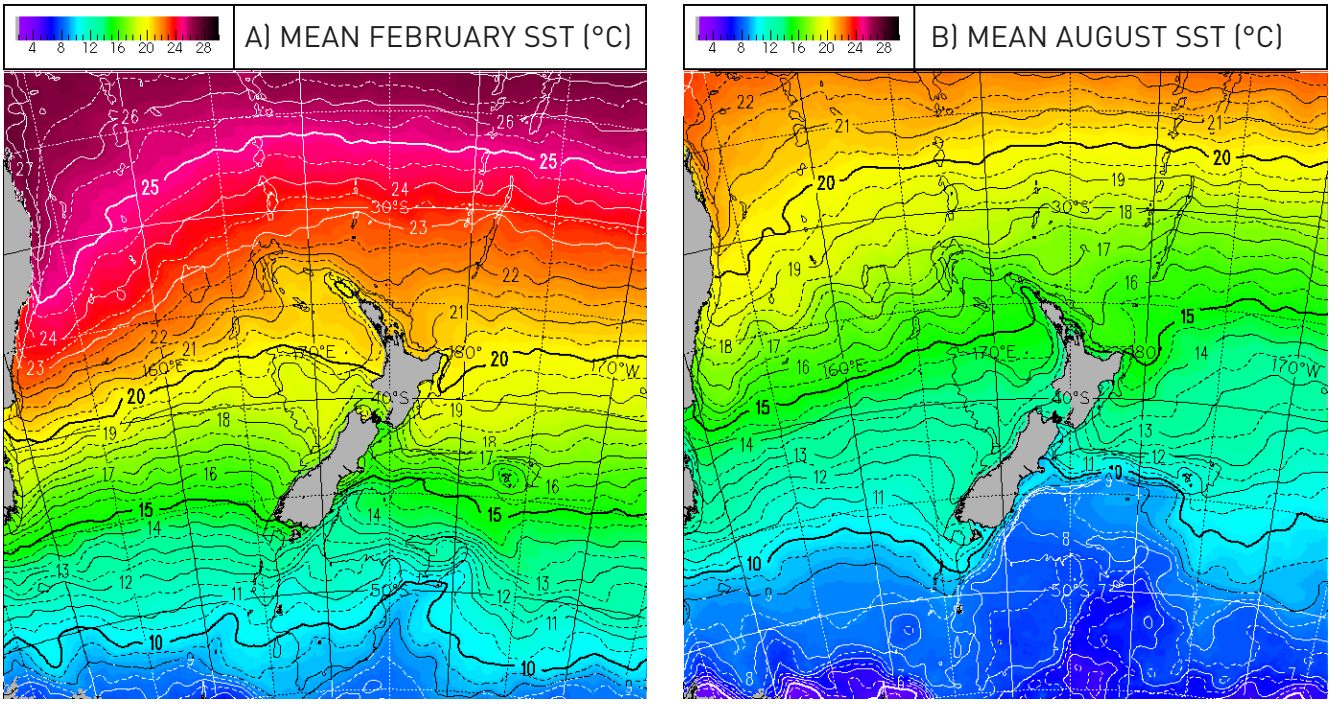

Figure 15. Monthly mean sea surface temperatures (°C) for: a) February; b) August. Source: NIWA SST Archive, Uddstrom and Oien (1999).

Air temperature

Because New Zealand has a relatively small land area and is surrounded by a vast area of ocean, seasonal and diurnal temperature variations are relatively small. However, Bay of Plenty does have larger variations than many other parts of the country. Because of the prevailing west to southwest flow over the North Island the Bay of Plenty region experiences warm foehn winds quite frequently. Average daily maximum temperatures over 20°C are recorded over most of the region during the months December to March (Figure 16a) and most places have recorded temperatures over 30°C on at least one occasion.

Inland areas in particular are subject to cold night-time temperatures during winter, especially when clear skies permit rapid radiational cooling. Air temperatures below 0°C are recorded in most parts of the region each winter, with mean daily minimum winter temperatures between 1°C and 7°C experienced for most of the region (Figure 16b). Figure 17 shows that median annual average temperature in the Bay of Plenty region varies with elevation. Low-lying coastal areas around Tauranga and Whakatane have a mean annual temperature of around 14°C, whereas the higher-elevation Raukumara Ranges experience a mean annual temperature of around 9°C. Figure 18 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 Bay of Plenty.

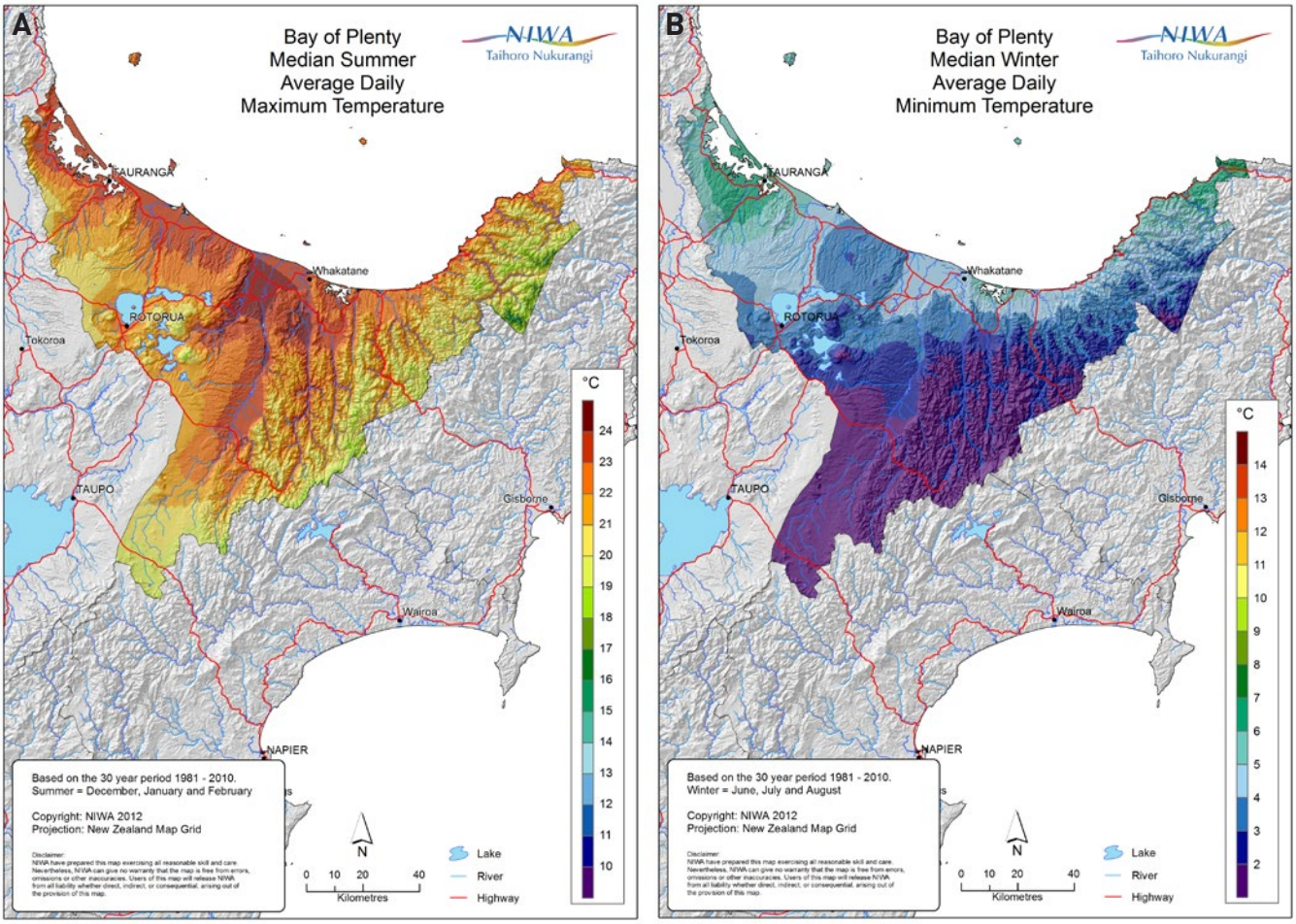

Figure 16. a) Bay of Plenty median summer average daily maximum temperature; b) Bay of Plenty median winter average daily minimum temperature.

The annual mean daily temperature range for Bay of Plenty is 9.5°C. Table 10 shows the average daily temperature range for each month for a number of sites in Bay of Plenty. Tauranga has the smallest temperature range and Whakatane has the largest.

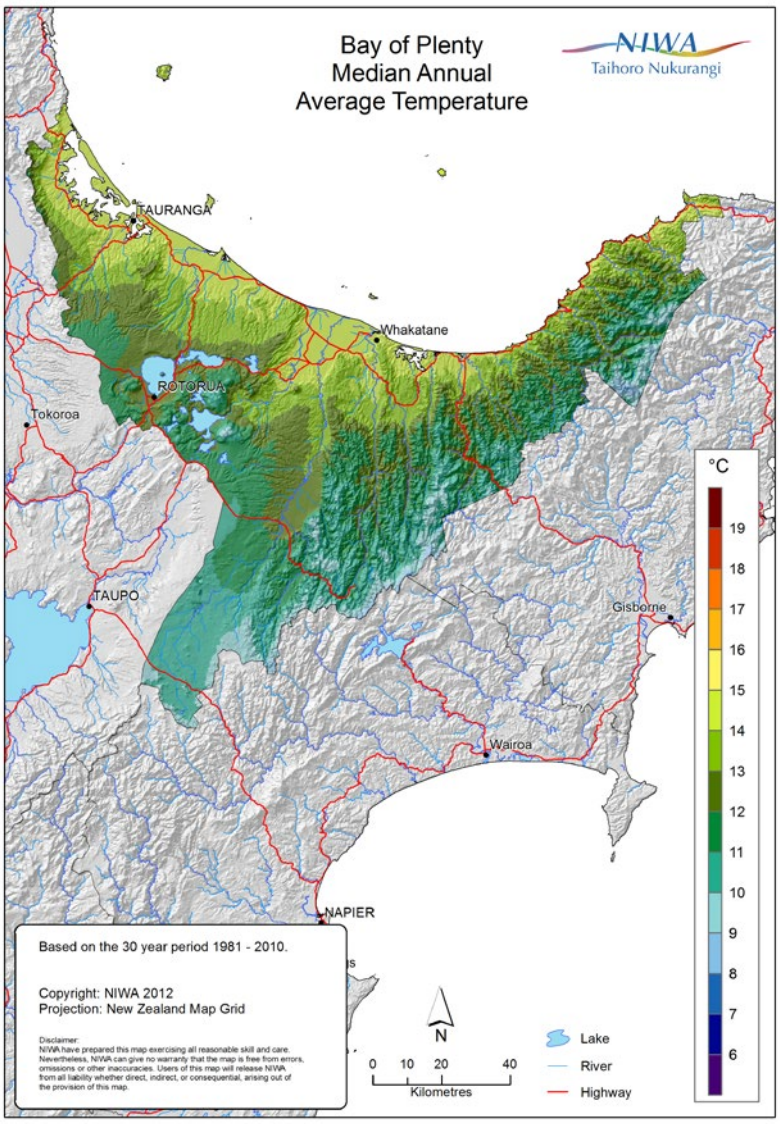

Figure 17. Bay of Plenty median annual average temperature, 1981-2010.

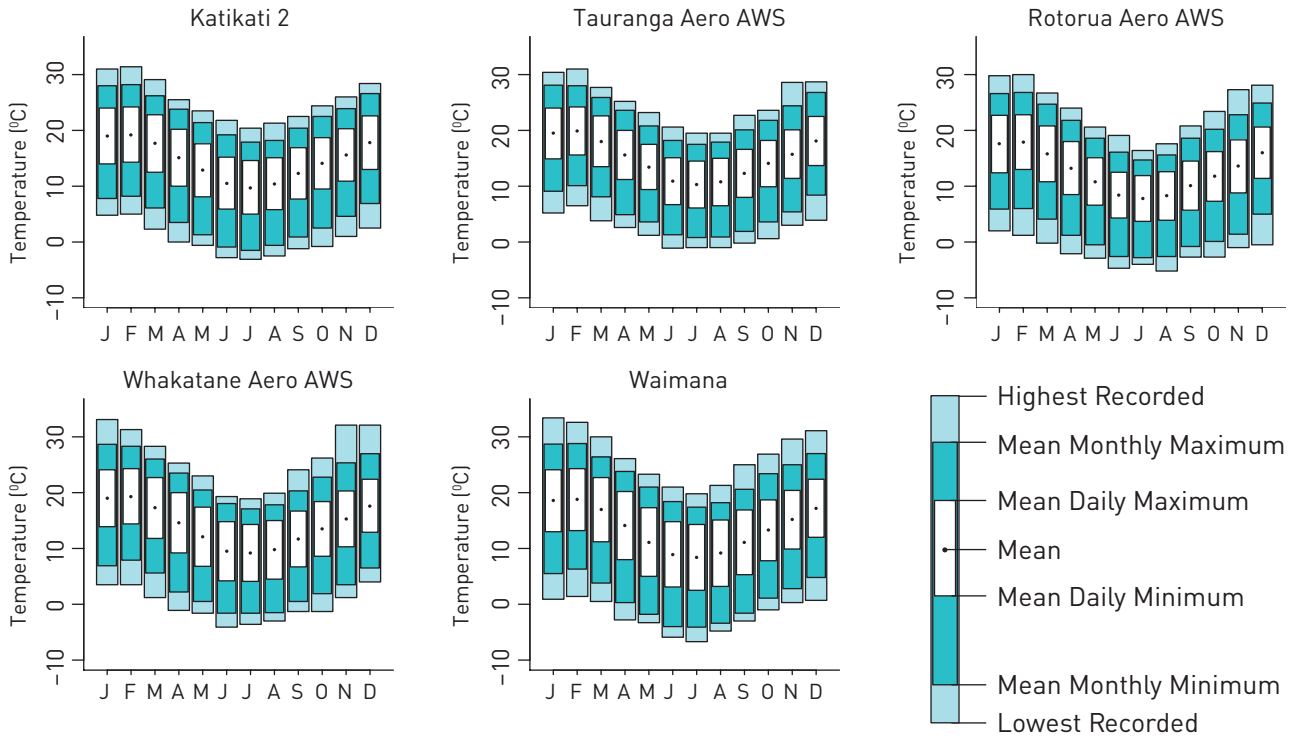

Figure 18 Monthly variation in air temperatures for selected Bay of Plenty stations.

The diurnal temperature range for Tauranga is moderate. Table 11 and Figure 19 show mean hourly temperatures for Tauranga Airport for January and July. From this, it can be seen that the average daily range for January is 7.1°C and for July it is 5.8°C.

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

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Katikati 2	10.1	9.9	10.4	10.3	9.5	9.3	9.5	9.2	9.2	9.3	9.5	9.6	9.6
Tauranga Aero AWS	8.8	8.5	8.7	8.7	8	8.2	8.4	8.3	8.3	8	8.4	8.3	8.4
Rotorua Aero AWS	10.2	9.8	9.8	9.5	8.8	8.3	8.5	8.7	8.8	8.8	9.4	9.3	9.2
Kaingaroa Forest	11.1	10.7	11.1	10.8	9.7	8.9	9.2	9.5	10.2	10.1	11.1	10.6	10.2
Whakatane Aero AWS	10.2	10.1	10.7	11.1	10.8	10.7	10.6	10.6	10.1	9.8	9.9	9.6	10.3
Opotiki	8.8	8.9	9.6	9.9	10.1	10	9.8	10	9.3	9.1	8.7	8.3	9.4

The highest daily temperature recorded to date in Bay of Plenty is 38.1°C, at Te Teko on 7 February 1973. The coldest air temperature recorded in Bay of Plenty to date is -9.4°C, at Kaingaroa Forest on 9th July 1960. These extreme temperatures compare to national extremes of 42.4°C and -25.6°C.

Table 11. Mean hourly temperatures at Tauranga Aero AWS for January and July.

hrs	00	01	02	03	04	05	06	07	08	09	10	11
January	17.3	17.0	16.5	16.3	16.1	15.7	16.3	17.8	19.1	20.4	21.2	21.8
July	8.8	8.7	8.6	8.4	8.3	8.1	8.0	8.0	8.2	9.6	11.2	12.5
hrs	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
January	22.4	22.7	22.8	22.8	22.5	21.9	21.3	20.3	19.2	18.7	18.3	17.7
July	13.2	13.6	13.8	13.6	13.2	12.2	10.9	10.5	10.1	9.6	9.4	9.1

Earth temperatures

Earth (soil) temperatures are measured once daily at 9 am at several Bay of Plenty 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 earth temperatures are routinely monitored at 10, 20, 30, 50, and 100 cm depths. Table 12 lists mean monthly earth temperatures for a number of standard depths.

In the Bay of Plenty region, earth temperatures, like air temperatures, vary spatially. Whakarewarewa is at an elevation of 307 m, and therefore exhibits cooler 9 am earth temperatures than the sites at lower elevations. Figure 20 shows how earth temperatures change throughout the year at Te Puke, compared with air temperature. The temperature cycle for 100 cm depth is more damped and lagged than at shallower depths.

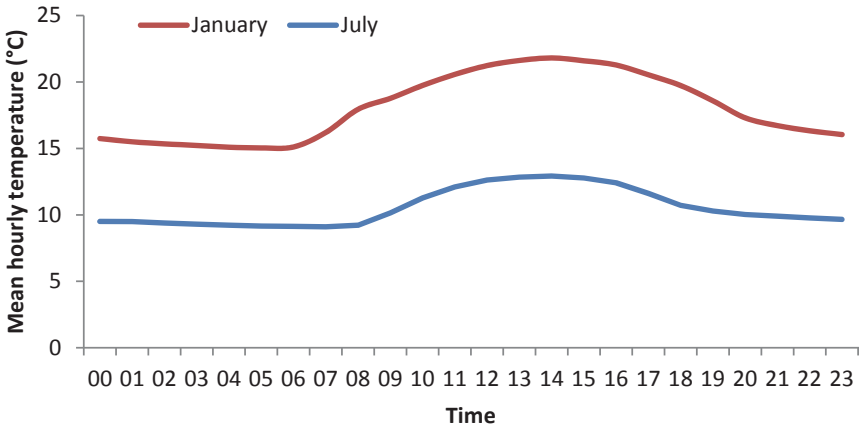

Figure 19. Mean hourly temperatures at Tauranga Aero AWS for January and July

Table 12. Mean 9 am earth temperatures at different Bay of Plenty stations, with station elevations.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Te Puke EWS (91m)	10cm	20	20	18	15	12	9	8	9	12	14	16	19	14
	20cm	21	22	20	17	14	10	9	10	13	15	17	20	16
	30cm	21	22	20	17	14	11	10	11	13	15	18	20	16
	100cm	18	19	19	18	16	14	13	12	13	14	16	17	16
Whakarewarewa (307m)	10cm	19	19	17	14	10	8	6	7	9	12	15	17	13
	20cm	20	20	19	16	12	9	8	9	11	13	16	18	14
	30cm	21	21	19	17	13	10	9	9	11	14	16	19	15
Waimana (37m)	10cm	20	20	18	14	11	8	7	8	11	13	16	18	14
	20cm	21	21	19	16	12	10	9	10	12	14	17	19	15
	30cm	21	21	20	17	13	11	9	10	12	15	17	20	15

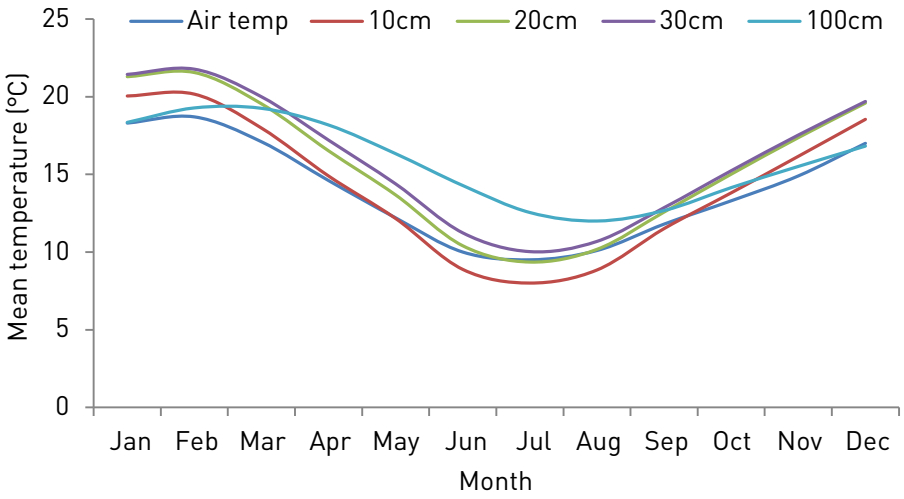

Figure 20. Average monthly 9 am earth temperatures for different depths and mean 9 am air temperature at Te Puke EWS.

Frosts

Frost is a local phenomenon and its frequency of occurrence can vary widely over 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 inland valleys, where cold air is likely to drift from higher areas. In general, frosts are infrequent close to the moderating effects of the sea.

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 Bay of Plenty region in the cooler months. Table 13 lists for selected sites the mean daily grass minimum and extreme grass minimum temperatures and the average number of days each month with ground and air frosts. Data on air temperatures (mean daily, monthly minima, and extreme minima) can be obtained from Figure 18.

Table 13. Occurrences of frosts and grass minimum temperatures in Bay of Plenty.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Tauranga Aero	a	10.5	11.0	9.4	6.3	3.9	1.9	0.8	2.0	3.4	5.0	7.1	9.3	5.9
	b	0.3	-2.0	-1.8	-2.6	-5.7	-7.0	-9.4	-8.1	-5.0	-5.7	-3.2	-1.7	
	c	0.1	0.1	0.3	1.4	6.4	10.9	13.4	10.5	6.4	3.6	1.3	0.3	54.6
	d	0.0	0.0	0.0	0.0	0.1	1.2	1.9	0.5	0.2	0.0	0.0	0.0	3.9
Rotorua Aero 2	a	10.1	10.4	9.1	5.7	2.9	1.2	0.1	1.6	3.0	4.8	6.8	8.9	5.4
	b	-0.2	-1.0	-3.1	-4.4	-6.8	-8.0	-9.0	-7.9	-6.4	-4.1	-4.5	-2.1	
	c	0.0	0.0	0.3	1.8	7.9	11.9	14.0	10.5	6.4	3.1	1.1	0.1	57.3
	d	0.0	0.0	0.0	0.1	1.7	6.0	7.3	3.7	0.9	0.2	0.1	0.0	19.9
Waiotapu Forest	a	8.0	8.4	6.7	3.6	1.0	-0.8	-1.8	-0.8	0.9	3.0	4.9	7.1	3.4
	b	-2.4	-2.0	-6.0	-8.7	-9.8	-12.5	-10.5	-11.6	-9.1	-8.9	-7.6	-3.2	
	c	0.6	0.4	2.1	5.7	12.6	15.3	18.4	16.3	12.2	7.5	3.1	0.9	95.0
	d	0.0	0.0	0.7	2.0	7.6	12.5	15.1	11.2	5.8	2.4	0.7	0.1	58.1
Whakatane Aero	a	11.6	11.7	10.5	6.2	2.9	1.7	0.5	1.7	3.3	5.5	7.7	10.2	6.1
	b	0.3	0.3	-1.3	-2.3	-5.5	-7.2	-7.3	-6.1	-4.9	-4.4	-3.6	-0.1	
	c	0.0	0.0	0.2	0.7	5.9	11.1	13.1	9.9	6.6	2.5	0.8	0.0	50.8
	d	0.0	0.0	0.0	0.0	1.1	5.1	7.6	4.3	0.8	0.1	0.0	0.0	19.0

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 extensive sheltering from the prevailing winds provided by the high country to the west, south, and east of Bay of Plenty, makes the region one of the sunniest parts of New Zealand. For example, Whakatane records 2237 hours per year on average. In the Bay of Plenty region, a general north–south gradient of bright sunshine hours is observed related to the distance from the coast and increases in elevation (Figure 21). The area surrounding Rotorua receives around 2000 hours of bright sunshine per year on average. Figure 22 shows the monthly mean, maximum, and minimum recorded bright sunshine hours for selected sites in Bay of Plenty.

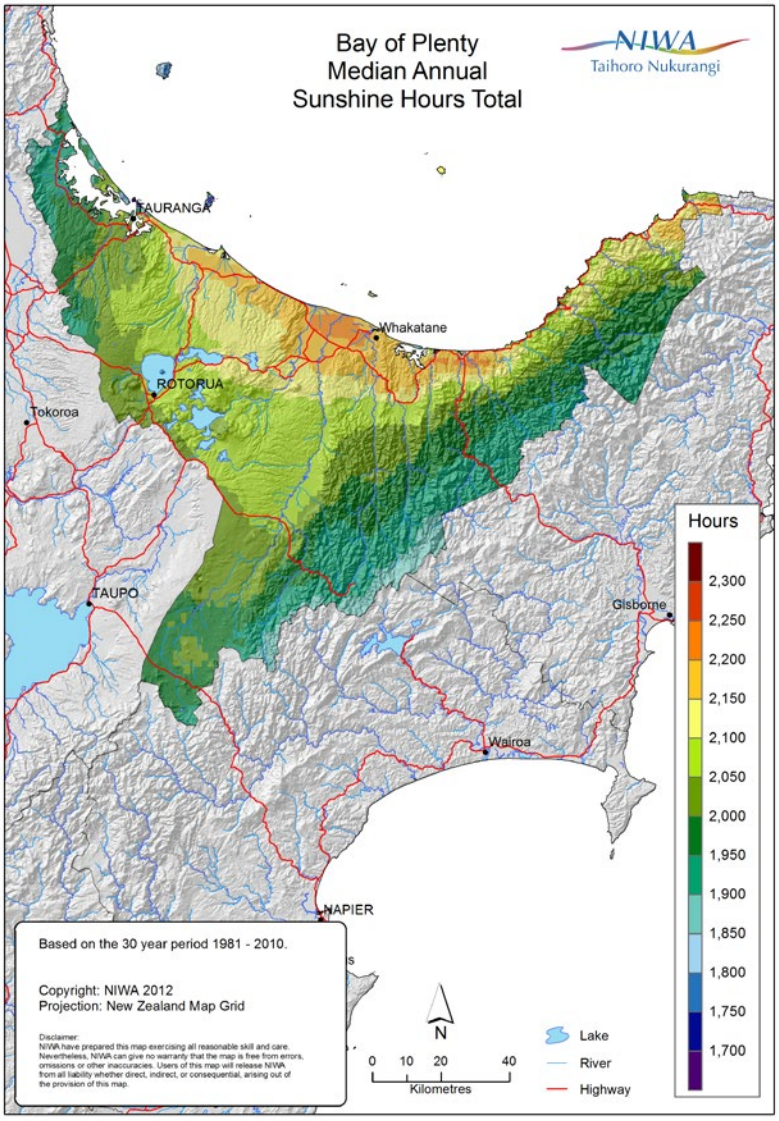

Figure 21. Median annual sunshine hours for Bay of Plenty, 1981-2010.

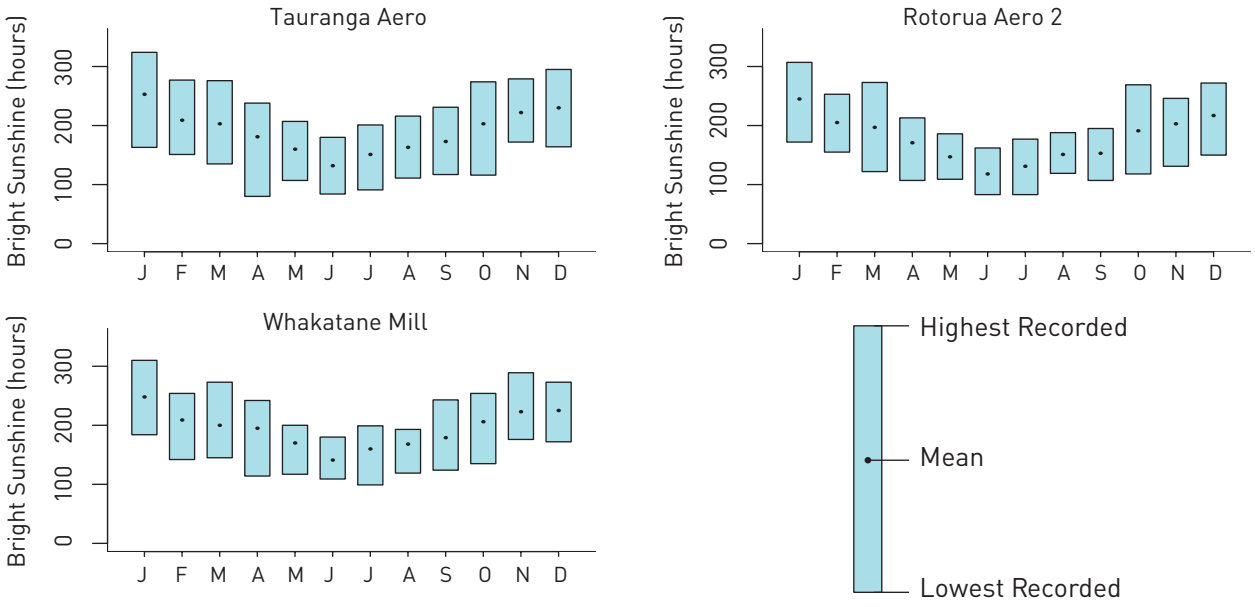

Figure 22. Mean, highest, and lowest recorded monthly bright sunshine hours for selected sites in Bay of Plenty.

Solar radiation

Solar radiation records are available for a number of sites in Bay of Plenty, but only a few sites have a long record (>10 years). Solar radiation is presented here for Tauranga, Rotorua, and Whakatane, using all available data. Insolation is at a maximum in December and January and a minimum in June. Table 14 shows mean daily solar radiation (global) for each month for these three sites.

UV (Ultra-violet radiation)

Ultra-violet radiation (UV) measurements are not available for the Bay of Plenty region. Figure 23 shows an example of a UV forecast for Tauranga which is representative of most locations in Bay of Plenty. In the summer (Figure 23a) UV radiation is high, prompting warnings for sun protection between 9 am and 5.30 pm. The amounts of UV radiation in winter are much lower (Figure 23b).

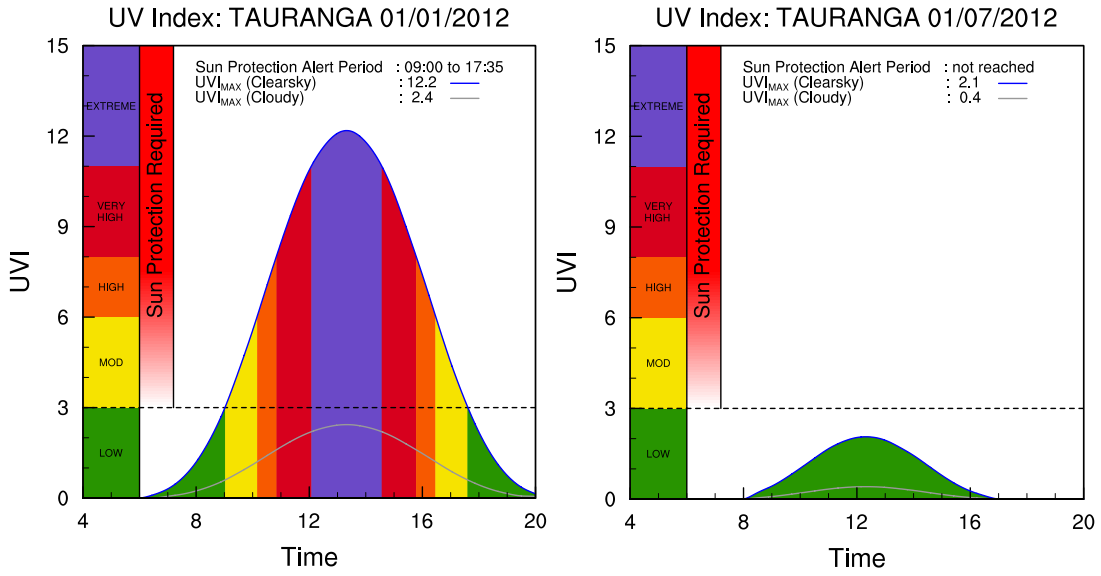

Figure 23. UV Index forecast for Tauranga, January (a) and July (b).
Source: https://www.niwa.co.nz/our-services/online-services/uv-ozone

Table 14. Mean daily global solar radiation (MJ/m2/day) for Bay of Plenty sites, using all available data.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Tauranga Aero AWS	23	20	17	12	8	7	7	10	14	18	21	22	15
Rotorua Aero AWS	23	19	16	11	8	6	7	9	13	17	20	21	14
Whakatane Aero AWS	24	21	17	12	9	7	7	11	14	19	22	23	15

Fog

The most common type of fog in Bay of Plenty is radiation fog, formed when the air cools to its dew-point on clear nights, allowing the water vapour in the air to condense. Coastal areas occasionally experience sea fogs, and extensive low cloud, with very moist onshore flows. Another type of fog sometimes seen in the region is 'steaming fog'. This forms predominantly on cold nights when the water vapour evaporating off lakes and rivers condenses as it rises into the cool air, giving the impression of steam rising off the water surface. Fogs also sometimes form when the humidity of the air near the ground has been raised by falling rain.

The frequency of fog in the Bay of Plenty region varies considerably (Table 15). Many inland areas experience frequent fogs; for example Waimana has an average of 96 days each year with fog. On the other hand, fogs are rare at Kawerau, occurring on an average of 3 days per year. Fogs at some inland places are sometimes slow to clear and may persist until the early afternoon. High country areas experience frequent fogs, often because the ranges are enveloped in cloud. Although fog can occur at any time of the year it is recorded most frequently between March and August.

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

Location	Thunder	Fog	Hail
Tauranga Aero	5	15	1
Rotorua Aero 2	12	22	2
Kaingaroa Forest	8	40	4
Kawerau	5	3	1
Whakatane Aero	7	15	1
Waimana	11	96	1

Severe convective storms

Thunderstorms and hail

While thunderstorms and hail may occur in the Bay of Plenty region in any month, thunderstorms are most frequent in the summer and hail is more likely in winter. Thunder and hail both occur more frequently in and near the high country than in other parts of the region. Average annual frequencies of thunder and hail for selected stations are given in Table 15. Thunder is recorded most frequently in Rotorua (12 days per year) and Waimana (11 days per year), and least frequently in Kawerau (5 days per year). Hail is observed in Rotorua most often (4 days per year), whereas other sites record only one or two days per year with hail. At some of the stations, it is likely that not all thunderstorms and hail events 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.

One particularly severe thunderstorm occurred on 14 January 2009 in the western Bay of Plenty region. The storm was caused by high humidity and unstable air pressure over the upper North Island, and the electrical storm was the result of sea breezes converging over the Coromandel Peninsula (north of the Bay of Plenty region). At the peak of the storm, the lightning strike rate was 1200 strikes per hour – a scale not usually seen outside Tornado Alley in the USA. In the Kaimai Ranges in the northwest of the region, hail lay up to 4 cm deep on SH 29, disrupting traffic. Hail stones the size of golf balls were recorded. In Katikati, hail blocked drains and caused flooding.

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, 17 damage-causing tornadoes were reported in the Bay of Plenty region. One particularly severe tornado event was on 3 November 2001, when a tornado swept through the Awakeri area near Whakatane. The tornado left a trail of damage from Awakeri towards the sea, carving a clear path through the countryside. Holes were punched in shelterbelts, and many trees were uprooted or had limbs torn from them. A 12 m high macrocarpa tree was snapped in half, and sheets of corrugated iron were left dangling from overhead power lines. The tornado caused some buildings to be damaged or partly demolished, with roofs lifted and windows broken. One garage was destroyed.

Sea swell and waves

The area of the Pacific Ocean which is bounded by the Bay of Plenty region is sheltered from the prevailing west to southwest swells of its latitude zone by the land mass of New Zealand. Consequently high waves are less frequent than in corresponding western areas. Similarly it is protected from the cool ocean currents induced by the prevailing westerly winds, but is influenced by the warm East Auckland Current which has a subtropical origin.

Sea and swell wave characteristics in Bay of Plenty are determined by the area's exposure to the prevailing winds and by the sheltering provided by the North Island. Thus sea waves from the west are the most frequent (due to the prevailing westerly wind flow), while swells from the east and north predominate due to the long fetches available in those directions and the sheltering given by the North Island. The prevailing easterly flow over the Pacific Ocean to the north of New Zealand produces a persistent easterly swell in the latitude of northern New Zealand, especially during the summer and autumn when the belt of southeasterly trade winds tends to lie further south than in other seasons. Of all swells observed on the eastern coast the frequency of those less than one metre is 50%, while for those greater than two metres is 5% (Gorman et al., 2003).

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

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

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

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 paragraphs. Short-term high intensity rainfalls have been covered previously.

Vapour pressure and relative humidity

The water vapour content of air can be expressed in several ways – the most commonly used being vapour pressure and relative humidity. Vapour pressure is the part of the total air pressure which results from the presence of water vapour. Relative humidity expresses the actual vapour pressure as a percentage of the saturation vapour pressure at the ambient temperature. Relative humidity is therefore normally highest in the morning at the time of the minimum temperature and lowest during the afternoon when temperatures are at their warmest.

The moisture content of air varies according to the source of the air and its trajectory. Air from the tropics normally has a high moisture content (hence the heavy rain associated with north to northeast airstreams) while air from the south is often drier. The Bay of Plenty region, with substantial sheltering from all directions except the north, experiences considerable variations in vapour pressure and of relative humidity. Air from the south must cross substantial areas of high country before reaching the region and therefore loses much of its moisture before reaching Bay of Plenty.

Vapour pressure can be important in determining the physiological response of organisms to the environment (very dry air, especially if there is a pre-existing soil moisture deficit, can cause or increase wilting in plants). Average 9 am vapour pressures for several stations are given in Table 17.

Relative humidity is high in all seasons, but there is a peak in winter, as shown in Table 18. Overall throughout the year, Waimana exhibits the highest relative humidity, whereas Tauranga exhibits the lowest.

Table 17. Mean monthly/annual 9 am vapour pressure (hPa) for selected Bay of Plenty sites.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Katikati 2	17.6	17.8	16.6	14.9	12.8	11.1	10.3	10.7	11.8	13.0	14.1	16.5	13.9
Tauranga Aero AWS	16.5	17.1	15.6	14.3	12.6	10.8	10.2	10.5	11.6	12.3	13.0	15.3	13.3
Rotorua Aero AWS	15.1	15.4	14.3	12.8	11.1	9.4	8.9	9.3	10.3	11.1	12.0	14.2	12.0
Kawerau	16.3	16.3	15.1	13.1	10.9	9.6	8.9	9.5	10.6	12.1	13.2	15.2	12.6
Whakatane Aero AWS	16.9	17.3	15.6	14.1	12.0	10.0	9.6	10.1	11.6	12.4	13.0	15.6	13.2
Waimana	17.0	17.1	15.9	13.7	11.2	9.9	9.3	10.0	11.3	12.8	14.1	16.0	13.2

Table 18. Mean monthly/annual 9 am relative humidity (%) for selected Bay of Plenty sites.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Katikati 2	79	83	82	83	85	88	86	82	78	78	77	78	82
Tauranga Aero AWS	73	77	78	80	83	85	84	81	77	76	72	74	78
Rotorua Aero AWS	78	81	81	83	86	87	86	85	81	79	77	79	82
Kawerau	77	81	80	82	85	87	86	84	78	77	75	76	81
Whakatane Aero AWS	77	81	83	86	89	90	89	87	82	80	74	76	83
Waimana	85	87	88	89	91	90	89	85	82	82	83	82	86

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. 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). The Bay of Plenty 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.

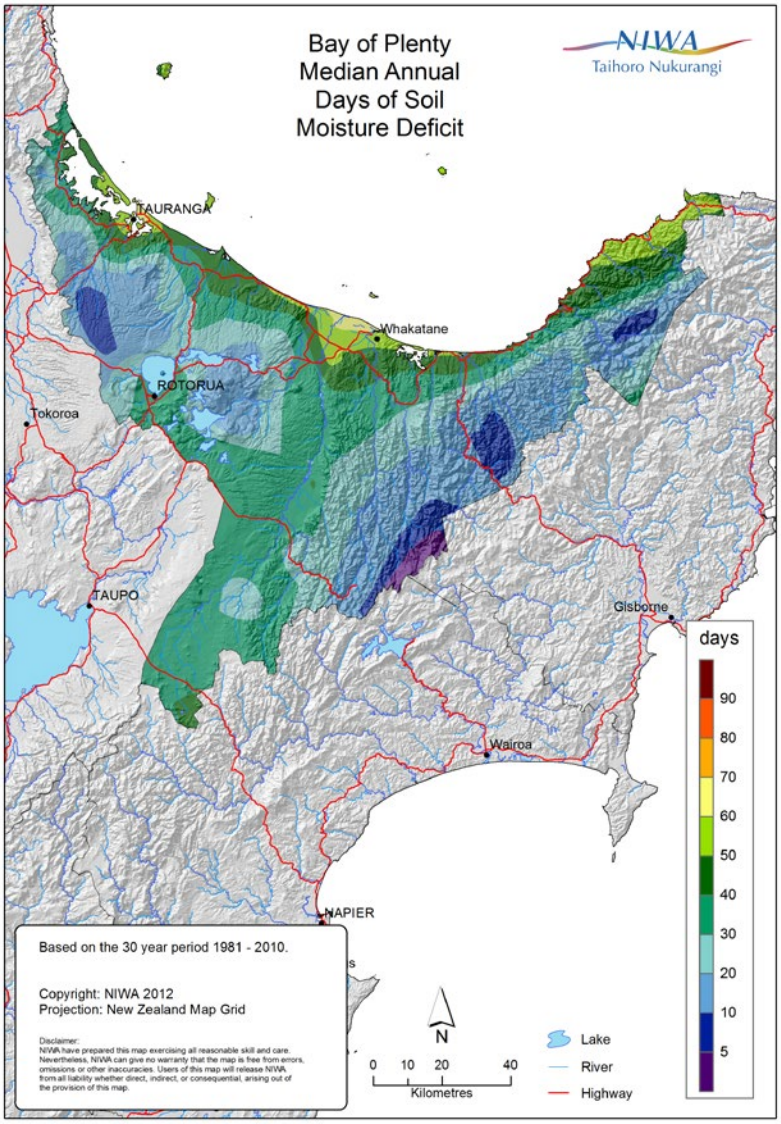

Figure 24. Bay of Plenty median annual days of soil moisture deficit, 1981-2010.

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

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Tauranga Aero AWS	DE	91	59	27	13	2	0	0	0	0	8	50	65	315
	ND	18	13	8	6	1	0	0	0	0	2	11	13	73
	RO	0	5	4	45	67	70	107	76	36	19	5	9	442
	NR	0	0	0	2	3	7	10	8	3	2	0	1	37
Rotorua Aero AWS	DE	62	41	20	8	1	0	0	0	0	0	16	33	181
	ND	13	10	7	5	1	0	0	0	0	0	4	7	47
	RO	6	16	7	32	69	113	118	99	54	29	9	21	574
	NR	0	1	1	2	5	9	9	9	5	3	1	1	46
Whakatane Aero AWS	DE	85	59	30	12	1	0	0	0	0	4	44	67	301
	ND	17	13	9	6	1	0	0	0	0	1	10	14	72
	RO	0	10	5	27	53	98	119	75	36	27	5	8	463
	NR	0	0	0	2	4	8	8	7	4	2	0	1	35

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

Mean monthly and annual water balance values are given in Table 19, for a number of sites in Bay of Plenty. It can be seen from this table that coastal parts of Bay of Plenty have about 70 days between November and April when there is insufficient soil moisture to maintain plant growth without irrigation, but only around 50 days in inland areas (Rotorua). There is usually adequate moisture available to maintain plant growth between June and October. Figure 24 shows region-wide variability in days of soil moisture deficit per year.

Potential evapotranspiration (PET) has been calculated for Tauranga, Rotorua, and Whakatane, using the Penman method (Penman, 1948). The monthly mean, minimum, and maximum PET values are listed in Table 20.

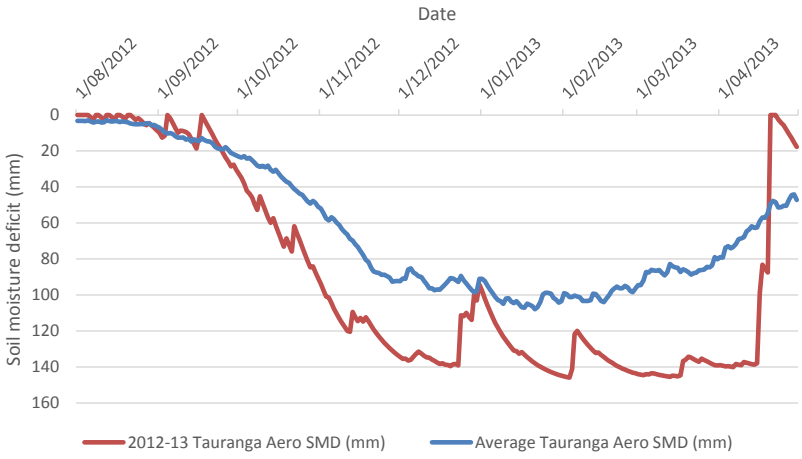

Figure 25. Soil moisture deficit at Tauranga Airport during the 2012-2013 drought, compared with normal soil moisture deficit conditions for the same time of year at Tauranga Airport (1981-2010).

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

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Tauranga Aero AWS	Max	136	109	92	46	34	19	27	36	58	80	104	123	
	Mean	161	127	106	62	40	27	31	45	68	105	131	150	1052
	Min	179	150	117	72	47	33	44	50	77	124	148	186	
Rotorua Aero AWS	Max	127	90	75	43	22	12	18	24	48	72	94	106	
	Mean	143	111	90	49	27	17	20	33	54	87	112	129	873
	Min	163	128	104	56	41	35	29	37	60	104	127	154	
Whakatane Aero AWS	Max	140	107	88	50	30	19	21	34	54	90	107	132	
	Mean	156	123	102	57	34	22	27	41	64	102	129	149	1006
	Min	171	139	122	63	39	25	34	46	69	115	153	177	

The Bay of Plenty region experienced a severe drought during the summer and early autumn of 2012-2013. Between September 2012 and March 2013, only 47% of normal rainfall for that period was recorded in Tauranga (287 mm), and 39% of normal rainfall for September to March was recorded in Whakatane (238 mm). Whakatane experienced its driest summer since records began in 1952 (83 mm, 33% of normal rainfall for summer), and Tauranga had its 9th-driest summer since 1898 (114 mm, 44% of normal summer rainfall). In January, Te Puke experienced its driest month of all time (since records began in 1973) of 3 mm (3% of normal January rainfall). Tauranga recorded only 4 mm

of rainfall in January (5% of normal January rainfall) which was the 2nd-lowest rainfall total for January since 1898. Figure 25 shows the soil moisture deficits reached at Tauranga Airport over the drought period, compared to normal soil moisture deficit conditions for the same time of year (soil moisture deficit from August to May averaged from 1981-2010). Much of the region was suffering from extreme soil moisture deficits (more than 130 mm of deficit), which meant that pasture growth had ceased (Figure 26). The dry conditions meant that farmers had to dry off cattle early and sell off stock. The stock feed situation remained very low in drought-stricken areas, and the price of feed significantly increased. Based on one measure of drought severity (the Potential Evapotranspiration Deficit) the 2012-13 drought was the worst drought to hit the Bay of Plenty region since records began in 1950. At the time of writing (August 2013), economic costs due to the 2012-13 drought across the North Island and Westland were estimated at a minimum of $2 billion.

Degree-day totals

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

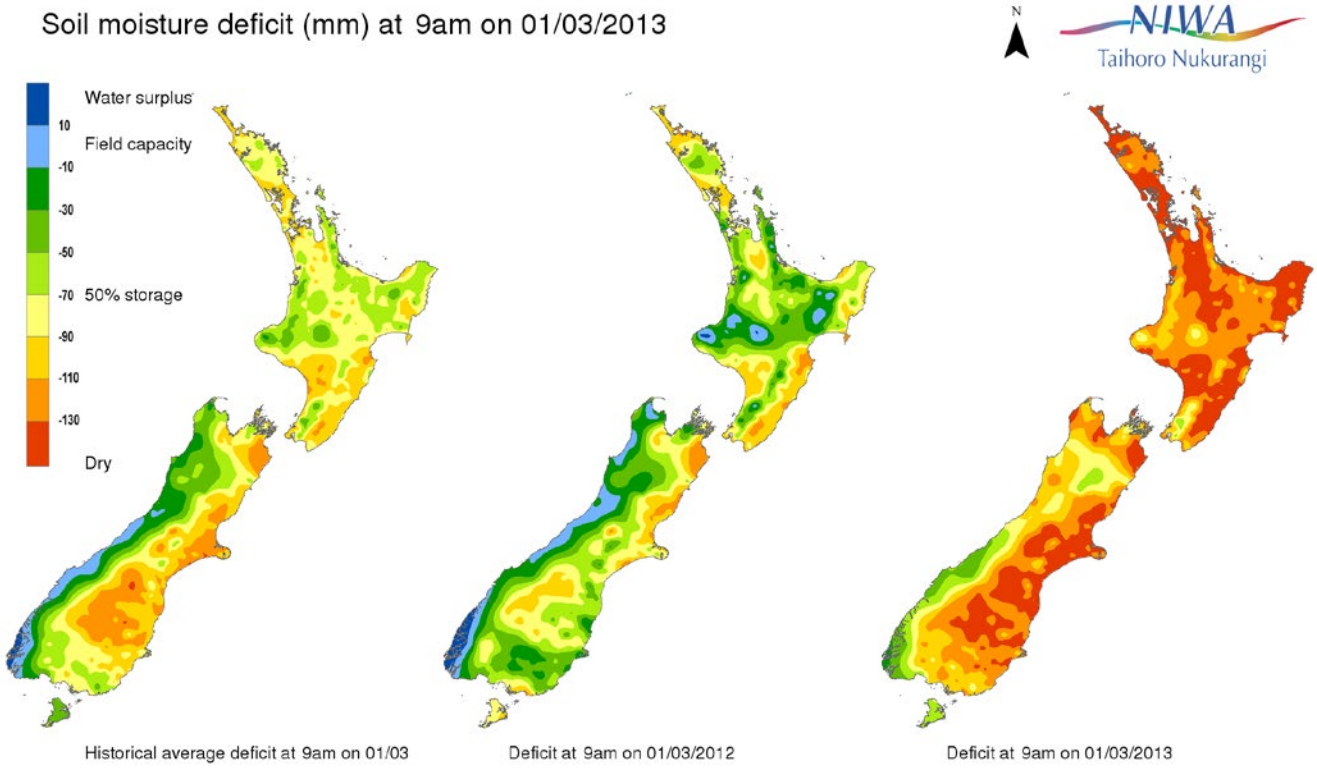

Figure 26. Soil moisture deficit as at 1 March 2013 (right hand map). Areas of extreme soil moisture deficit (more than 130 mm of soil moisture deficit) are shown in red, and areas of significant soil moisture deficit (more than 110 mm of soil moisture deficit) are shown in dark orange. Normal soil moisture deficit conditions for the time of year are given in the left hand figure, and the middle figure shows soil moisture deficit conditions as at 1 March 2012.

Cooling and heating degree days are measurements that reflect the amount of energy that is required to cool or heat buildings to a comfortable base temperature, which in this case is 18°C. Table 22 shows that the number of cooling degree days reach a peak in summer in Bay of Plenty, where there is a higher demand for energy to cool building interiors to 18°C. Conversely, heating degree days reach a peak in winter, where the demand for energy to heat buildings to 18°C is highest. Figure 27 shows region-wide variability in the number of heating degree days per year. The number of heating degree days tends to be lower in low elevation coastal areas, compared with areas further inland and at higher elevations.

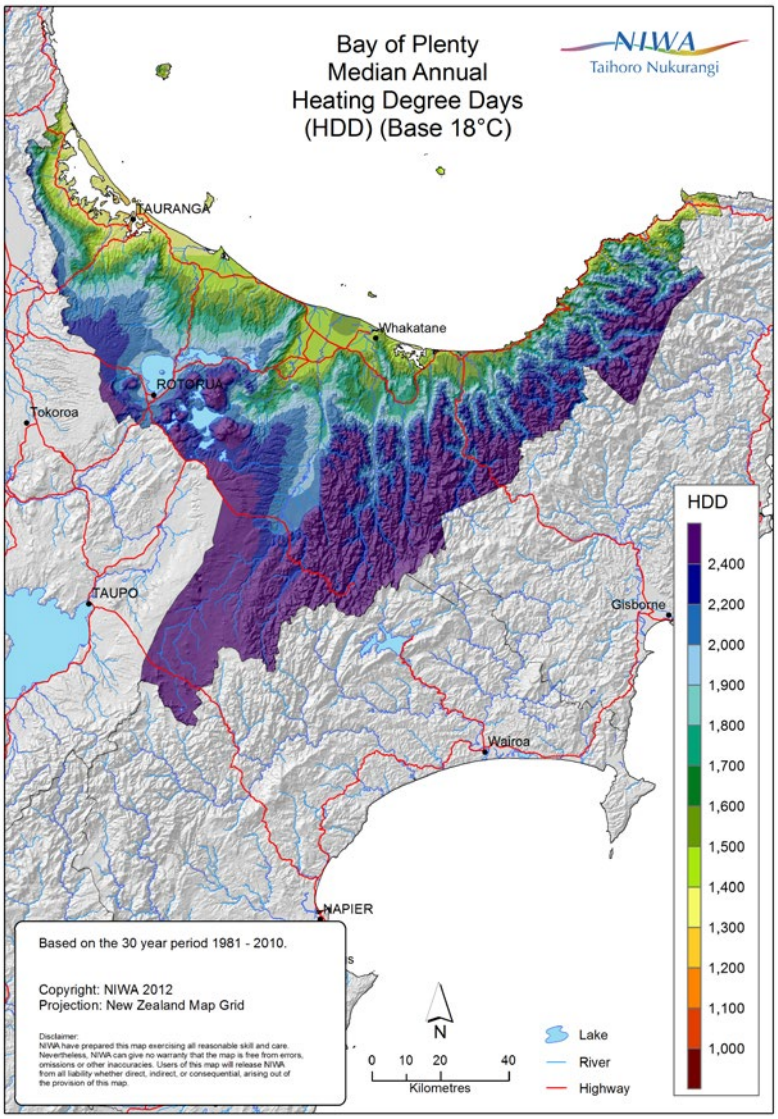

Figure 27. Median annual heating degree days for Bay of Plenty, 1981-2010.

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

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Tauranga Aero AWS	5°C	448	420	405	318	262	178	165	179	219	281	322	405	3601
	10°C	293	279	250	168	109	45	33	39	74	127	172	250	1839
Rotorua Aero AWS	5°C	389	365	336	247	181	105	91	102	153	210	258	344	2782
	10°C	234	224	181	102	48	15	8	8	30	65	109	189	1214
Whakatane Aero AWS	5°C	433	405	381	288	222	135	130	147	200	263	309	392	3305
	10°C	278	264	226	140	76	26	20	25	60	110	159	237	1620

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

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Tauranga Aero AWS	CDD	55	58	26	6	1	0	0	0	0	0	4	27	176
	HDD	10	5	25	78	142	212	238	224	171	122	72	25	1324
Rotorua Aero AWS	CDD	20	24	6	1	0	0	0	0	0	0	0	7	58
	HDD	34	26	73	143	222	288	315	302	237	193	133	66	2033
Whakatane Aero AWS	CDD	45	48	19	4	0	0	0	0	0	0	3	23	142
	HDD	15	10	41	106	181	256	274	256	190	140	84	34	1586

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