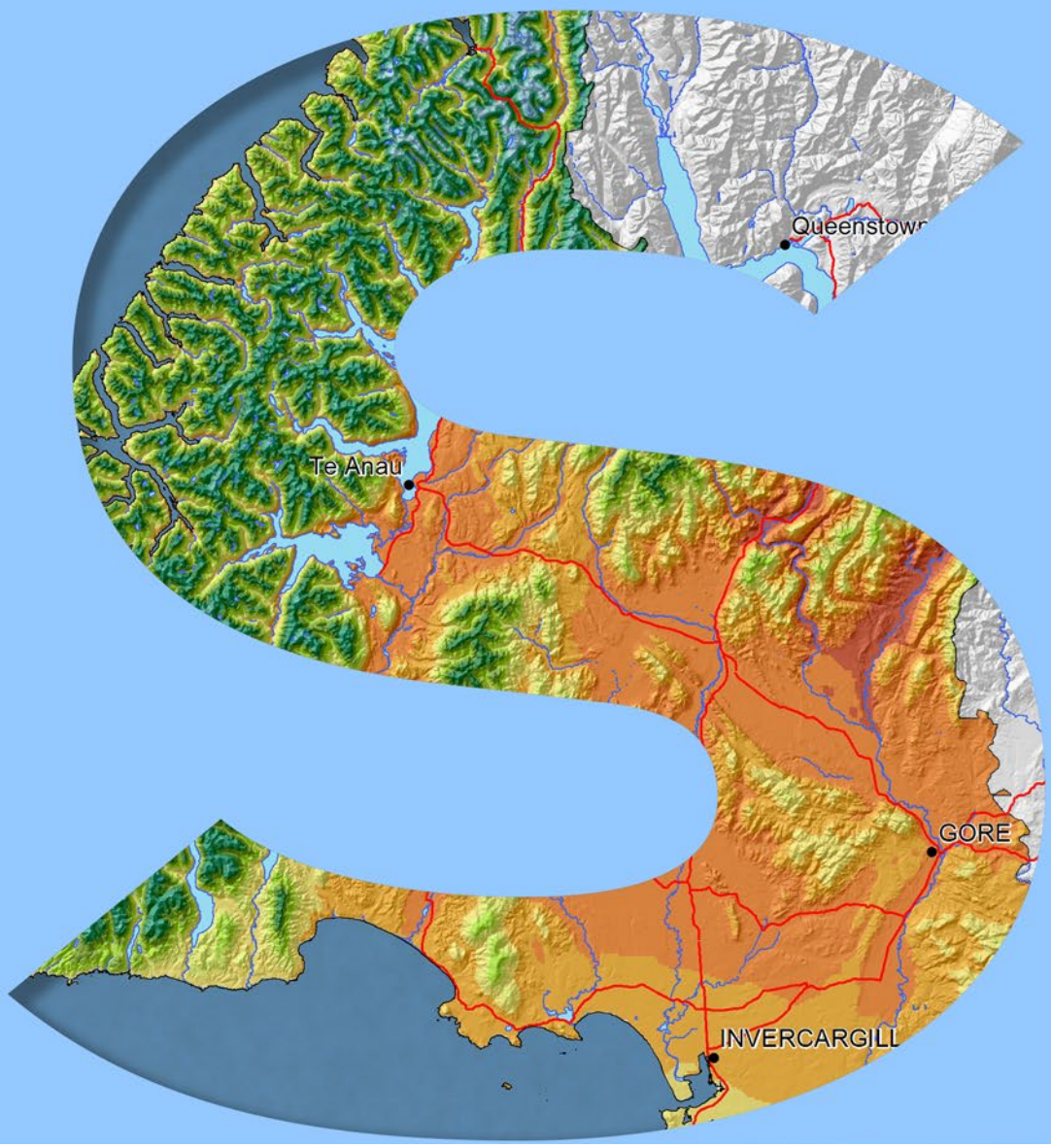
NIWA
Taihoro Nukurangi

THE CLIMATE AND WEATHER OF SOUTHLAND

2nd edition

G.R. Macara



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Note to Second Edition

This publication replaces the first edition of New Zealand Meteorological Service Miscellaneous Publication 115 (15), written in 1984 by J. Sansom. It was considered necessary to update the first edition, incorporating more recent data and updated methods of climatological variable calculation.

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CONTENTS

SUMMARY

Southland is both the most southerly and most westerly part of New Zealand and generally is the first to be influenced by weather systems moving onto the country from the west or south. It is well exposed to these systems, although western parts of Fiordland are sheltered from the south and the area east of the western ranges is partially sheltered from the north or northwest. The region is in the latitudes of prevailing westerlies, and areas around Foveaux Strait frequently experience strong winds, but the winds are lighter inland. Winter is typically the least windy time of year, as well as for many but not all areas, the driest. The western ranges, with annual falls exceeding 8000 mm in some parts, are among the rainiest places on earth. The drier eastern lowlands and hills form a complete contrast, with annual falls predominantly between 1200 mm and 800 mm. Dry spells of more than two weeks are not common. Temperatures are on average lower than over the rest of the country with frosts and snowfalls occurring relatively frequently each year. On average, Southland receives less sunshine than the remainder of New Zealand.

INTRODUCTION

New Zealand spans latitudes 34 to 47 degrees south, and so lies within the Southern Hemisphere temperate zone. In this zone, westerly winds at all levels of the atmosphere move weather systems, which may also be either decaying or developing, eastwards over New Zealand giving great variability to its weather. These prevailing westerlies sometimes abate, and air from either tropical or polar regions may reach New Zealand with heavy rainfalls or cold showery conditions respectively. Southland is both the most southerly and westerly area of New Zealand (Figure 1), with most weather experienced in the region arising from its exposure to the prevailing westerly airflows, as well as polar southerly outbreaks. As such, elevation and orientation of the land itself are key factors influencing the weather conditions in Southland. The high ranges in the west, which lie in a southwest to northeast direction, form a partial barrier to any airstreams crossing them, providing shelter on their lee side and enhanced rainfall on the windward side. Agriculture is the predominant economic activity in the region, with a climate generally comprising moderate air temperatures and consistent rainfall providing conditions particularly conducive for such activity.

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

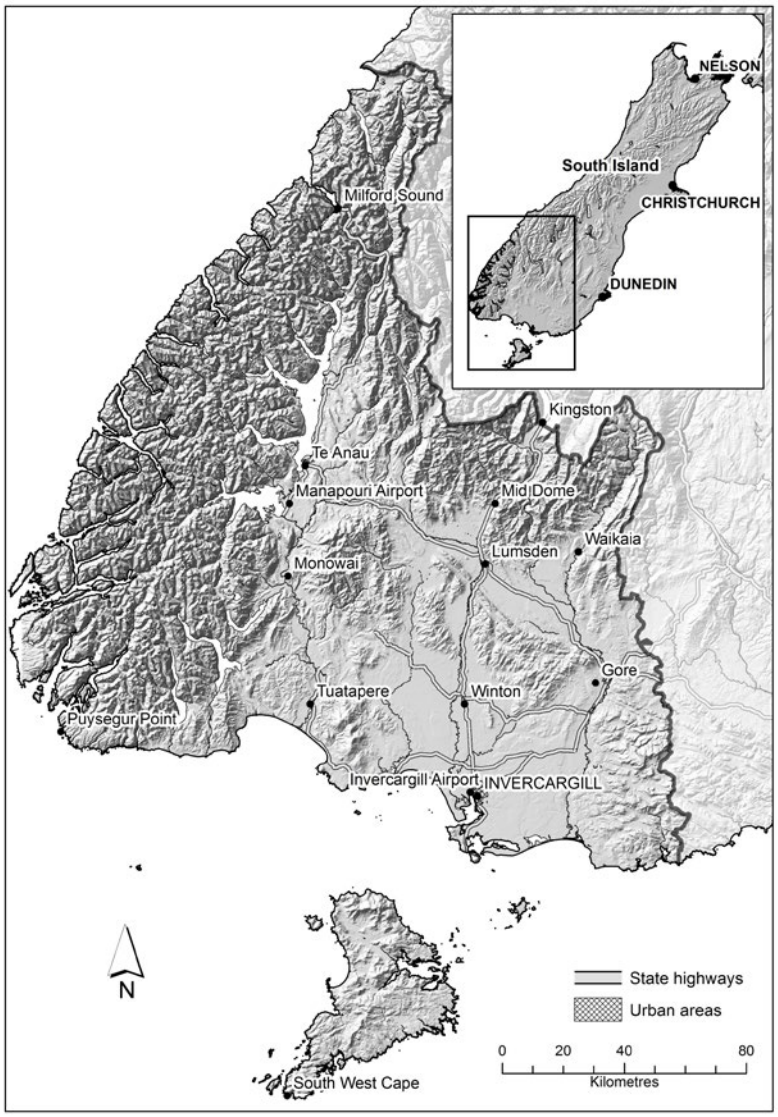


Figure 1. Map of the Southland region, showing the locations of weather stations mentioned in this publication.


8790
8230

TYPICAL WEATHER SITUATIONS IN SOUTHLAND

The air temperature, wind, rain, fog, frost etc. are the elements comprising the weather at a particular moment while the climate is their integrated effect over a longer period of time. The types and sequence of weather elements affecting Southland are determined by large-scale synoptic situations consisting of the distribution of pressure and fronts over a large part of the Southern Hemisphere. Although many different situations are possible, they tend to fall into only a few characteristic categories:

1. Disturbed westerlies, when a persistent westerly flow is interrupted for short periods by fast moving and usually weak fronts;
2. The passage of a major trough with perhaps several frontal zones. Its approach turns the flow over Southland northerly, whereas behind the trough southerly airstreams prevail; and
3. The low index situation. Here, the usual pressure distribution is reversed, with depressions north of 40 degrees south latitude and anticyclones to the south of New Zealand. In these situations, easterly airstreams flow over Southland.

Disturbed westerlies

The synoptic-scale flow over Southland is westerly when pressures are high to the north and depressions lie to the south of New Zealand. The depressions are usually moved rapidly eastwards by strong westerly winds in the upper atmospheric flow, and similar upper flows in sub-tropical latitudes (the subtropical jet streams) often intensify mid-latitude anticyclones. These circumstances combine to give periods of strong westerlies over Southland. The annual

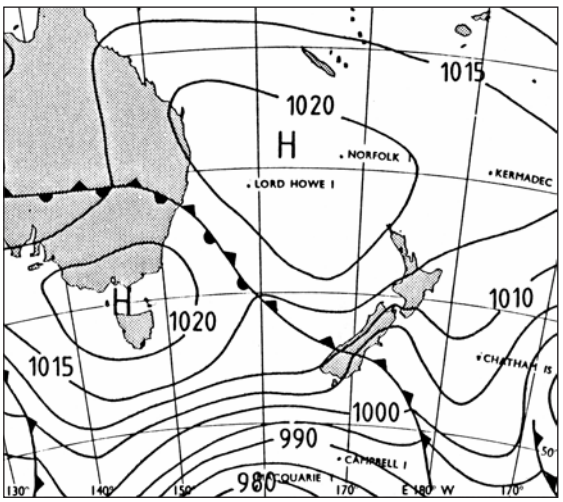


Figure 2. Mean sea level pressure analysis for 0000 hours NZDT on 15 November 1980.

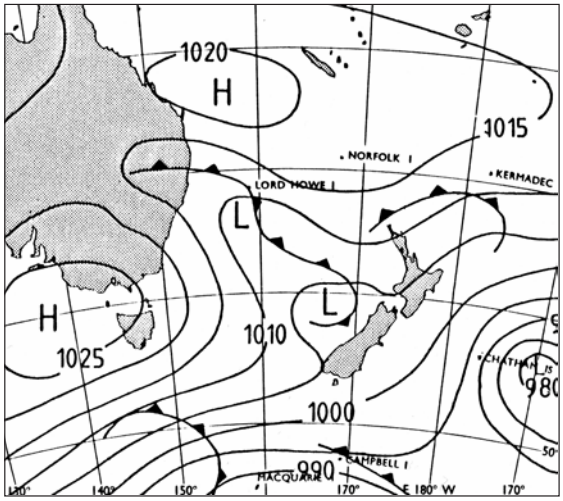


Figure 3. Mean sea level pressure analysis for 0000 hours NZST on 5 October 1982.

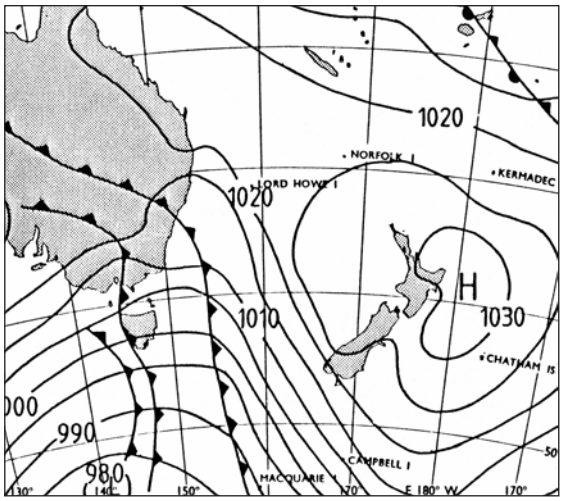


Figure 4. Mean sea level pressure analysis for 0000 hours NZST on 18 September 1982.

cycle of changes in the upper atmospheric flow is such that there is a minimum in the frequency of westerly winds over the South Island in winter (Reid, 1980) and a maximum in spring.

For strong westerlies, air pressures of 1020 hPa or more are required in the 30 to 40 degrees south latitude belt, extending longitudinally from about 130 degrees east to 170 degrees west, while air pressures in the Macquaire/Campbell Island region should be about 980 hPa (Figure 2). Such strong westerlies will persist over Southland while weak fronts pass with only minor wind speed and direction changes. However, with more active fronts pressures to the north will not be so high and, therefore, the strength of the westerly flow will decrease. Additionally, if the high pressure belt is much less extensive, then only moderate wind speeds will prevail (Figure 3). These westerly flows are onshore, bringing showers which are usually frequent and heavy about the western coast and ranges, but scattered about the south coast and isolated inland. As a front approaches, rain develops in the west and this spreads elsewhere with the frontal passage.

Passage of a major trough

As troughs of large amplitude approach from the west, the flow over Southland tends northwesterly (Figure 4). Northwesterly wind directions are still onshore in western areas, resulting in rain (which may be persistent and heavy) there. However, eastern areas are sheltered by the rain-shadow effect of the western ranges and remain fine. Additionally, air temperatures may become relatively high due to foehn winds, especially in the summer months. Although these major troughs are typically slow-moving, they are often accompanied by faster moving frontal zones which pass through them, bringing periods of rain throughout Southland.

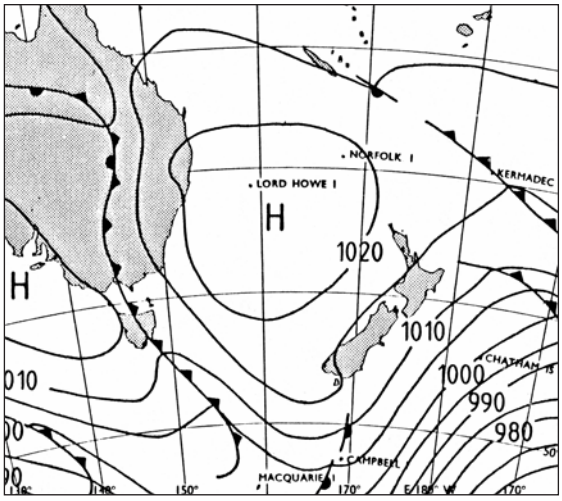


Figure 5. Mean sea level pressure analysis for 0000 hours NZDT on 14 December 1982.

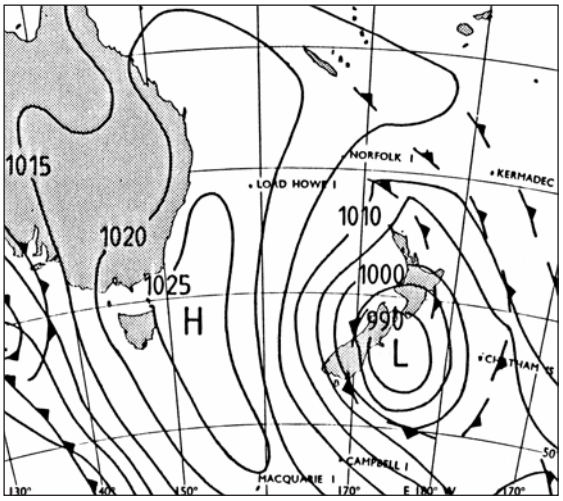


Figure 6. Mean sea level pressure analysis for 0000 hours NZST on 25 October 1982.

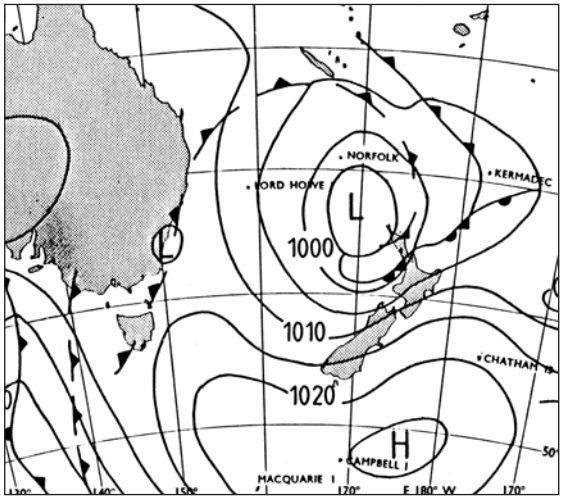


Figure 7. Mean sea level pressure analysis for 0000 hours NZST on 8 September 1976.

The amplitude of the trough and ridge to the west may be such that the flow turns to the southwest, but not any more southerly, before another trough approaches or the westerlies are re-established (Figure 5). In this case, showery conditions prevail in most areas. However, with a larger amplitude system when the ridge extends well to the south (Figure 6) a cold south to southeast flow covers Southland. In this case, western areas are sheltered and fine but the east and south are subject to periods of rain and drizzle. This latter case is more frequent in winter than any other season.

Low index situations

A low index situation can develop from the passage of a major trough if the trough becomes slow-moving over New Zealand; the southern part of it becoming very weak or disappearing as the ridge in the south intensifies, and the northern part of the trough develops into a depression over the northern Tasman Sea or the North Island. Other processes can also result in a low index situation, such as a depression near the North Island and an intense anticyclone to the south of the South Island (Figure 7). This situation is slow-moving, and once established usually persists for some days. The flow over Southland is easterly and so western areas are sheltered and fine. The east will also be fine on many occasions, and as such this type of situation can cause extended dry spells in Southland. However, the east can be subject to low cloud and drizzle, especially about coastal areas in winter, which is the season when this situation occurs most frequently. Also, if an active front is associated with the depression in the north, and this moves sufficiently far south, then periods of rain are likely.

CLIMATIC ELEMENTS

Wind

Wind direction over New Zealand in the zone directly above the earth's surface may be interpreted from a mean sea level pressure (MSLP) map, following the general principle that air flows in a clockwise direction around a depression, and in an anticlockwise direction around an anticyclone. As such, MSLP maps can be used to indicate the general wind direction at the earth's surface. However, actual wind direction at a particular locality is modified by the influence of friction and topography. Furthermore, wind speeds are also subject to topographical influence. Figure 8 shows mean annual wind frequencies of surface wind based on hourly observations from selected stations. The exposed coastal site of Puysegur Point has a considerably higher percentage of strong winds compared to the other sites shown. Invercargill receives a relatively high percentage of strong westerly winds, which is partly attributed to the channelling of air through Foveaux Straight. Milford Sound is surrounded by mountainous terrain, which typically shelters the area from strong winds. Furthermore, wind direction recorded at Milford Sound is constrained by the local topography, with the predominance of northwesterly and southeasterly winds reflecting the northwest to southeast orientation of the adjacent Sound itself.

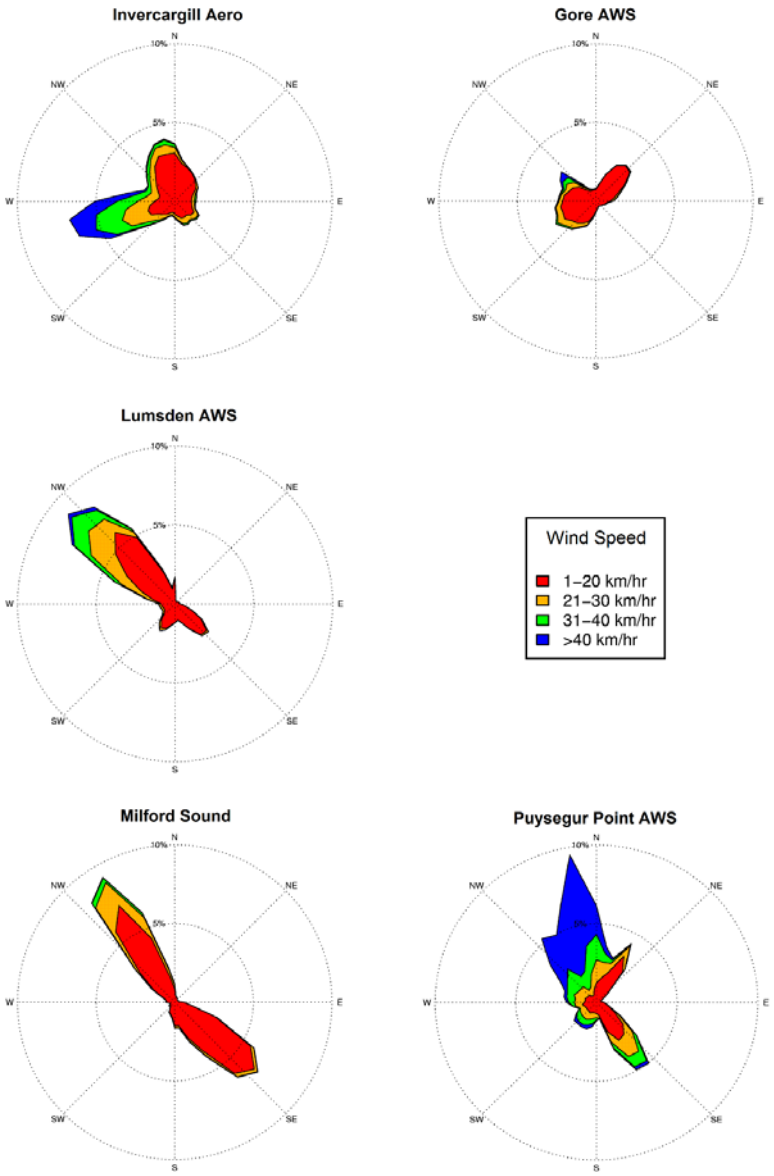


Figure 8. Mean annual wind frequencies (%) of surface wind directions from hourly observations at selected Southland stations. The plots show the directions from which the wind blows, e.g. the dominant wind direction at Lumsden is from the northwest.

Table 1. Mean monthly and annual wind speed (km/hr) for selected Southland stations.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
South West Cape AWS	37.8	35.2	38.9	36.9	40.0	37.8	35.0	36.9	41.6	40.7	40.3	36.4	38.1
Puysegur Point AWS	30.1	27.9	30.0	27.4	28.6	26.3	24.6	26.5	30.9	31.5	30.9	29.0	28.7
Invercargill Aero	19.2	17.6	17.1	16.2	15.5	14.2	12.5	13.5	17.2	19.6	20.4	18.8	16.8
Gore AWS	14.1	12.4	12.5	11.5	11.6	11.6	11.2	12.2	13.6	14.4	14.9	13.8	12.8
Lumsden AWS	11.2	9.4	9.8	7.9	8.3	8.0	6.8	7.9	10.9	11.9	12.1	10.6	9.6
Manapouri Aero AWS	11.5	10.4	10.0	8.4	7.7	7.0	6.5	7.5	10.0	11.2	12.2	11.5	9.5
Milford Sound AWS	8.8	8.2	7.7	7.5	7.9	8.3	8.6	8.1	8.4	9.1	9.0	9.0	8.4

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

Location	Summer		Autumn		Winter		Spring		Annual Frequency
	Distribution	Frequency	Distribution	Frequency	Distribution	Frequency	Distribution	Frequency	
South West Cape AWS	23.1%	50	25.6%	56	24.6%	54	26.7%	58	218
Puysegur Point AWS	25.2%	33	25.4%	34	21.0%	28	28.4%	37	132
Invercargill Aero	27.5%	13	24.2%	12	16.0%	8	32.3%	15	48
Gore AWS	22.7%	3	23.6%	4	19.0%	3	34.7%	5	15
Lumsden AWS	23.7%	3	22.5%	3	12.7%	2	41.1%	5	13
Manapouri Aero AWS	35.0%	1	17.3%	0.5	9.4%	0.3	38.3%	1	3
Milford Sound AWS	10.0%	0.2	24.8%	0.4	35.4%	0.6	29.8%	0.5	2

Mean wind speed data (average wind speeds are taken over the 10 minute period preceding each hour) are available for a number of sites in Southland, and these illustrate the several different wind regimes of the region (Table 1). Mean wind speeds are highest at the exposed coastal sites of South West Cape and Puysegur Point, and lower at the inland sites of Gore, Lumsden and Manapouri. Lowest mean wind speeds are recorded at Milford Sound, due to the aforementioned sheltering from strong winds by the surrounding mountains.

Table 2 gives the seasonal distribution and frequency of occurrence of strong winds (defined as having a daily mean wind speed of greater than 30 km/hr). For example, of all strong winds recorded at Invercargill, 32.3% occur in spring. In addition, during an Invercargill spring an average of 15 days have a daily mean wind speed of greater than 30 km/hr. As a further example, South West Cape and Gore share a similar distribution of strong winds in summer, with 23.1% and 22.7% of their respective annual strong winds being recorded in that season. However, South West Cape has an average of 50 strong wind days in summer, compared to just 3 in Gore. This highlights that although a similar seasonal distribution of strong winds may be observed between different locations in Southland, the actual number of strong winds per season at those locations may be considerably different. As shown in Tables 1 and 2, spring is the windiest season throughout the region, whilst winter is the least windy.

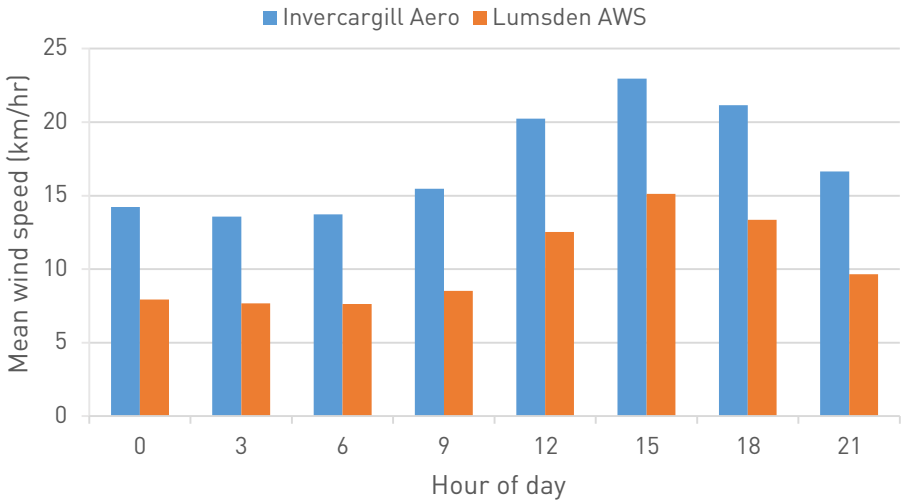


Figure 9. Mean wind speed at selected hours of the day for selected Southland stations.

Diurnal variation in wind speed is well-marked, with greatest wind speeds occurring mid-afternoon before decreasing overnight. This is because heating of the land surface is most intense during the day, and stronger winds aloft are brought down to ground level by turbulent mixing. Cooling at night generally restores a lighter wind regime. Table 3 gives average wind speeds at three-hourly intervals for selected stations, whilst Figure 9 visually highlights the typical diurnal variation of wind speed observed throughout Southland.

Winds are frequently gusty along the southern coastal areas of Southland, especially at the exposed South West Cape site, where on average gusts exceed 94 km/hr on 120 days per year. Invercargill experiences an average of 109 days per year with wind gusts exceeding 61 km/hr, considerably more than the inland location of Manapouri, where on average just 15 such days per year are recorded (Table 4). The highest gust recorded in the region was 183.5 km/hr (100knots), occurring five times at South West Cape, and once at Puysegur Point. Note that the instruments used to measure these wind speeds were unable to measure wind speeds higher than 183.5 km/hr, therefore it is likely that the true maximum gusts were indeed higher than this value. Maximum gusts recorded at different stations in the region are listed in Table 5.

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

Location	0000	0300	0600	0900	1200	1500	1800	2100
Gore AWS	10	11	11	12	16	17	16	12
Invercargill Aero	14	14	14	15	20	23	21	17
Lumsden AWS	8	8	8	9	13	15	13	10
Manapouri AWS	8	7	7	7	10	13	13	10
Milford Sound AWS	8	8	8	8	8	11	10	8
Puysegur Point AWS	27	27	27	27	29	31	30	27
South West Cape AWS	37	38	38	38	39	40	39	38

Table 4. Mean number of days per year with gusts exceeding 61 km/hr and 94 km/hr for selected stations.

Location	Days with gusts >61 km/hr	Days with gusts >94 km/hr
Gore AWS	68	6
Invercargill Aero	109	15
Manapouri Aero AWS	15	0.1
Puysegur Point AWS	210	73
South West Cape AWS	257	120

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

Location	Gust (km/hr)	Direction	Date
South West Cape AWS	183.5	NW	16/11/2003
		NNW	08/02/2009
		NNW	04/11/2009
		NNW	12/05/2011
		NW	24/10/2011
Puysegur Point AWS	183.5	WNW	16/08/1995
Invercargill Aero	142.7	WSW	16/05/1994
Gore AWS	140.8	~	21/01/1997
Manapouri Aero AWS	101.9	NW	24/09/1998

Rainfall

Rainfall distribution

The spatial distribution of Southland's median annual rainfall is shown in Figure 10, which clearly shows both its dependence on elevation and exposure to the main rain bearing airflows from the west. In Fiordland, which has both high elevation and western exposure, the rainfall is very high, and is among the highest in New Zealand and the world. Such high rainfall is primarily a result of the orographic effect. Specifically, moisture-laden air masses arrive off the Tasman Sea and are forced to rise over the western ranges. As these air masses rise, they cool rapidly, causing the stored water vapour to condense, resulting in rainfall. These air masses continue eastwards, but hold significantly less moisture once passed beyond the western ranges. As a result, near the eastern border of Fiordland, which can be taken to be Lakes Te Anau and Manapouri and the Waiau Valley, there is a marked decrease eastwards in median annual rainfall. The Waimea Plains to the northwest of Gore are among the driest areas of Southland. Here, median annual rainfall of below 800 mm is recorded, which is approximately ten times less rainfall than that which falls about high elevation locations in the western ranges.

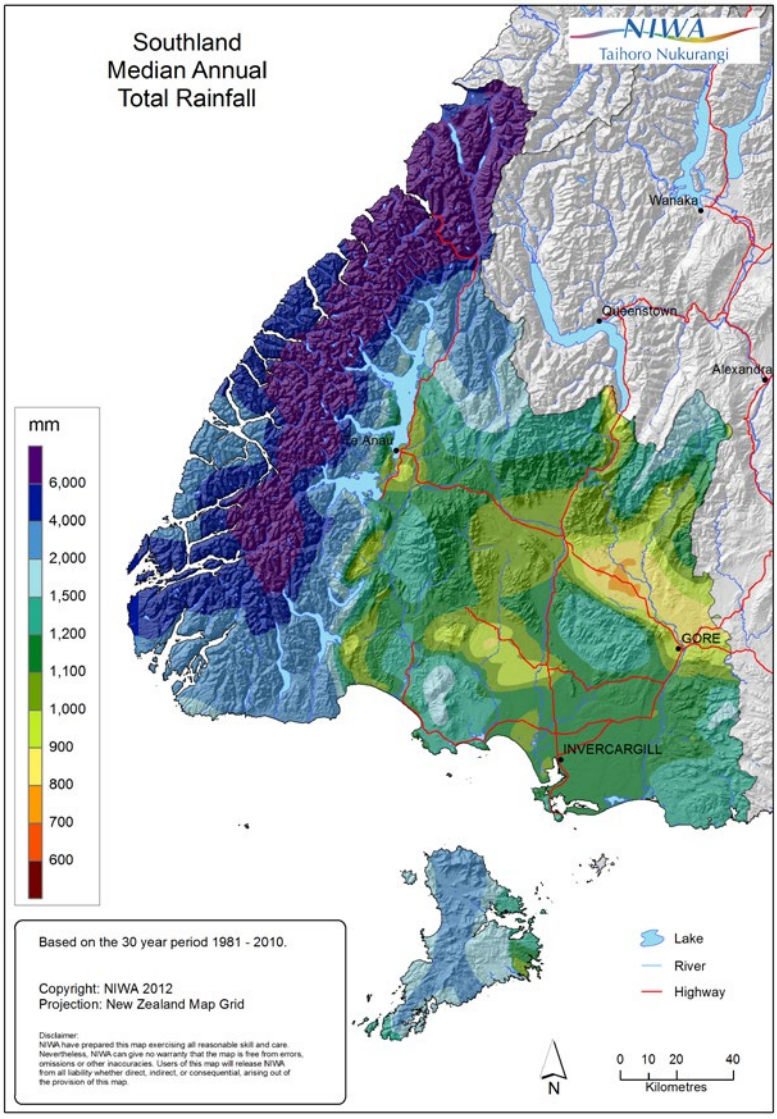


Figure 10. Southland median annual total rainfall, 1981-2010.

Table 6. Monthly and annual rainfall normals (a; mm), and monthly distribution of annual rainfall (b; %) at selected Southland stations, for the period 1981-2010.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Gore AWS	a	98	85	81	74	88	77	58	60	63	77	84	100	945
	b	10	9	9	8	9	8	6	6	7	8	9	11	
Invercargill Aero	a	115	87	97	96	114	104	85	76	84	95	90	105	1149
	b	10	8	8	8	10	9	7	7	7	8	8	9	
Kingston	a	88	61	74	75	84	85	70	79	79	87	67	96	944
	b	9	7	8	8	9	9	7	8	8	9	7	10	
Manapouri Aero AWS	a	79	85	81	91	102	105	83	99	106	106	96	105	1136
	b	7	7	7	8	9	9	7	9	9	9	8	9	
Milford Sound	a	722	455	595	533	597	487	424	464	551	640	548	700	6716
	b	11	7	9	8	9	7	6	7	8	10	8	10	
Monowai	a	119	95	105	99	117	118	92	108	108	123	98	120	1301
	b	9	7	8	8	9	9	7	8	8	9	8	9	

Table 6 continued.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Puysegur Point AWS	a	241	179	212	215	228	211	192	193	196	186	203	207	2463
	b	10	7	9	9	9	9	8	8	8	8	8	8	
South West Cape AWS	a	108	93	115	104	120	125	107	108	111	106	109	107	1313
	b	8	7	9	8	9	9	8	8	8	8	8	8	
Te Anau, Doc	a	165	92	105	80	91	112	83	85	73	134	75	108	1203
	b	14	8	9	7	8	9	7	7	6	11	6	9	
Tuatapere	a	163	123	100	103	120	92	98	91	64	105	75	104	1238
	b	13	10	8	8	10	7	8	7	5	8	6	8	
Waikaia	a	107	89	110	64	83	54	70	58	57	77	63	87	918
	b	12	10	12	7	9	6	8	6	6	8	7	9	
Winton 2	a	101	79	85	77	94	83	63	65	70	75	76	91	959
	b	11	8	9	8	10	9	7	7	7	8	8	10	

Table 6 lists monthly rainfall normals and the percentage of annual total for selected stations. Rainfall tends to be fairly evenly distributed across the year throughout Southland. However, Gore, Te Anau, Tuatapere and Waikaia are an exception, where there is a maximum of rainfall in the summer months. Specifically, these locations receive approximately 30% of their annual rainfall during summer. Gore observes a winter rainfall minimum, with 20% of annual rainfall falling between June and August. A rainfall minimum extends across winter and spring for Tuatapere and Waikaia. Both locations receive just 41% of annual rainfall between June and November.

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

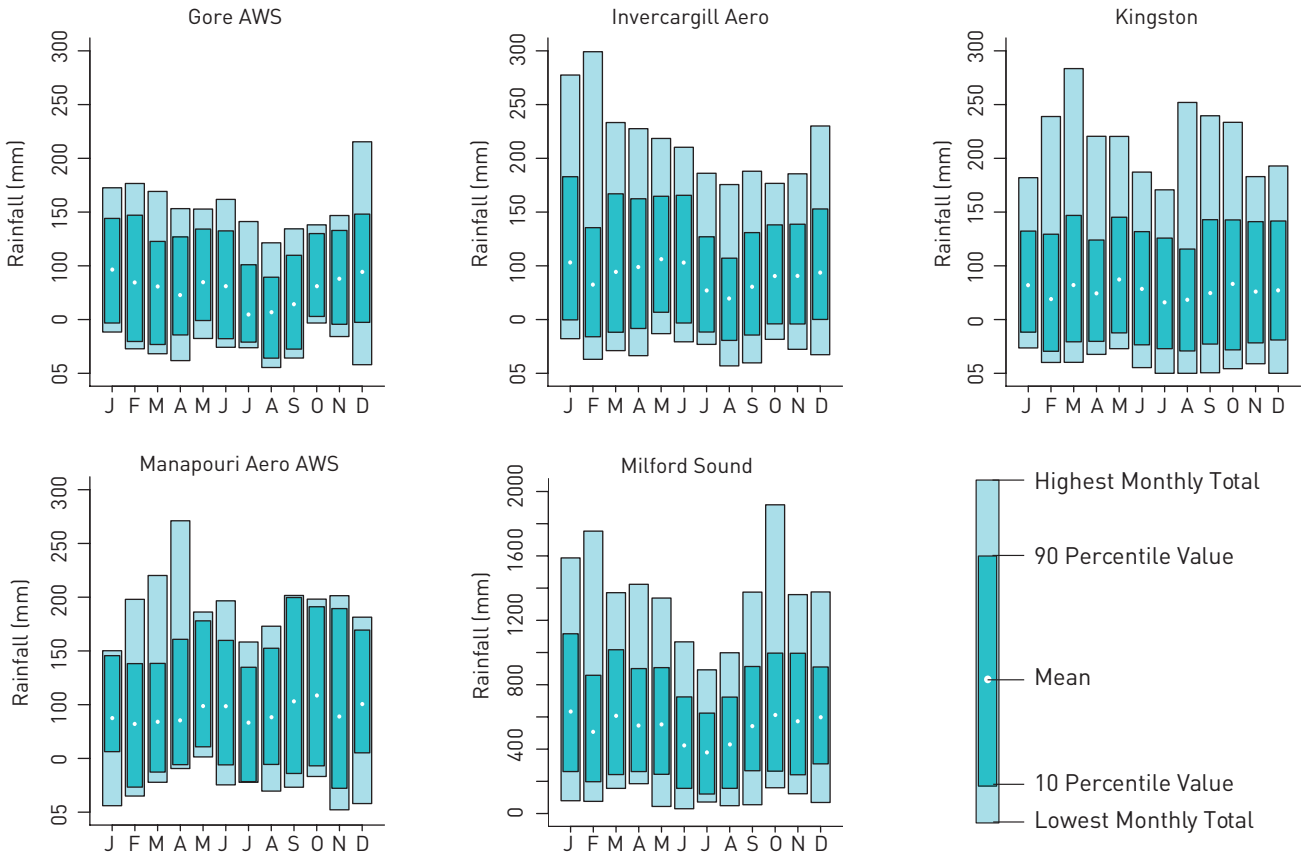


Figure 11. Monthly variation of rainfall for selected Southland stations from all available data.

Rainfall variability over longer periods is indicated by rainfall deciles, as given in Tables 7, 8 and 9. The 10th percentile values show the accumulated rainfalls that will normally be exceeded in nine out of ten years, while the 90th percentile values indicate the accumulated falls that will normally be exceeded in only one year in ten. The tables include periods from one month to twelve months (annual); each period over one month begins with the month stated. For example, using the table for Invercargill (Table 7), it can be seen that in the three month period beginning in April, 228 mm or more of rainfall can be expected in nine years in ten, while a total of 401 mm should occur in only one year in ten.

Table 7. Rainfall means and deciles at monthly, 3-monthly, 6-monthly, 9-monthly and annual intervals for Invercargill Aero from all available data.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Invercargill Aero												
1 month												
90th	183	135	167	162	165	166	127	107	131	138	139	153
Mean	103	83	94	99	106	103	77	70	81	90	91	94
10th	50	34	38	42	57	47	38	31	36	46	46	50
3 months												
90th	393	401	382	401	375	326	316	327	350	352	384	372
Mean	277	275	299	308	286	250	227	241	262	275	287	277
10th	188	175	213	228	207	171	148	149	177	192	208	190
6 months												
90th	723	698	681	649	655	643	619	650	647	678	715	707
Mean	587	565	550	535	527	512	503	528	535	548	555	571
10th	456	449	455	430	438	388	390	412	441	430	425	432
9 Month												
90th	961	964	952	962	962	920	914	950	1004	1022	1000	984
Mean	814	806	812	811	814	786	777	797	834	857	845	824
10th	684	686	678	681	677	657	602	654	685	721	717	669
Annual												
90th	1289											
Mean	1090											
10th	925											

Rainfall frequency and intensity

The average number of days each year on which 0.1 mm or more of rain is recorded (a rain day) varies from 116 days at Kingston to 269 days at South West Cape. Kingston also exhibits the lowest number of wet days (> 1.0 mm of rain) in the region, with 97 wet days recorded there on average, compared with in excess of 200 at South West Cape and Puysegur Point. Table 10 lists the average number of days per month with 0.1 mm and 1 mm of rain for selected stations. The number of rain and wet days recorded at a given station tends to increase as distance to the coast decreases. As such, inland locations experience fewer rain and wet days than coastal locations. The seasonal variation of rain days and wet days in Southland is relatively small. Therefore, the winter minimum of rainfall observed in some areas of Southland may be largely attributed to there being fewer heavy falls of rain, as opposed to fewer actual days of rain.

Heaviest short period rainfalls in Southland are recorded in Fiordland, which often occur when persistent west/northwesterly airflows are established as a trough approaches the South Island. For remaining areas of Southland, heavy short period rainfalls occur with the passage of a depression over or close to the region, or in association with slow moving fronts. High intensity rainfall, particularly at sub-hourly periods, is typically associated with thunderstorm activity. In Table 11, maximum short period rainfalls for periods of 10 minutes to 72 hours with calculated return periods are given for two stations. Also listed in this table are the maximum rainfalls expected in 2, 5, 10, 20, and 50 years. Depth-duration frequency tables for Southland 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 8. Rainfall means and deciles at monthly, 3-monthly, 6-monthly, 9-monthly and annual intervals for Kingston from all available data.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kingston												
1 month												
90th	132	129	147	124	145	132	126	116	143	143	141	142
Mean	82	69	82	74	87	78	66	68	75	83	76	77
10th	38	20	29	30	38	27	23	21	27	22	28	31
3 months												
90th	342	351	355	338	303	293	296	361	338	326	341	326
Mean	234	227	245	241	230	214	209	227	235	237	234	230
10th	130	116	135	162	153	132	125	122	135	156	129	135
6 months												
90th	636	578	582	576	592	578	593	621	625	629	624	636
Mean	475	463	461	453	463	452	449	462	466	473	462	471
10th	347	337	341	342	322	329	307	319	328	318	322	348
9 Month												
90th	907	892	871	840	864	838	867	898	895	857	866	828
Mean	691	695	701	696	701	687	688	693	709	709	698	689
10th	548	538	559	581	567	510	492	508	551	544	542	544
Annual												
90th	1146											
Mean	934											
10th	752											

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

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Milford Sound												
1 month												
90th	1116	859	1017	900	906	724	624	723	913	996	995	910
Mean	633	507	607	547	554	423	380	429	542	612	573	598
10th	261	198	242	261	244	156	121	156	266	263	241	308
3 months												
90th	2404	2343	2481	2139	1841	1670	1900	2276	2277	2359	2480	2551
Mean	1747	1661	1708	1524	1357	1232	1351	1583	1727	1781	1804	1738
10th	1069	1070	1033	1061	981	866	804	976	1114	1147	1116	1121
6 months												
90th	4145	3686	3684	3614	3764	3661	3942	4365	4530	4496	4529	4482
Mean	3280	3026	2943	2875	2940	2959	3133	3387	3467	3530	3468	3446
10th	2403	2287	2290	2152	2165	2261	2298	2308	2497	2708	2584	2503
9 Month												
90th	5666	5724	5641	5683	5827	5760	5942	6166	6383	6002	5838	5642
Mean	4631	4609	4670	4657	4744	4699	4881	5051	5175	5062	4834	4684
10th	3657	3577	3718	3624	3627	3559	3821	3796	3989	4016	3757	3680
Annual												
90th	7760											
Mean	6412											
10th	5173											

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

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Gore AWS	a	16	13	15	16	19	20	17	16	16	19	18	17	202
	b	12	10	11	11	12	14	10	10	11	13	13	13	141
Invercargill Aero	a	17	15	17	18	20	20	19	17	17	18	18	18	213
	b	13	11	13	13	15	15	14	12	13	13	13	13	157
Kingston	a	9	8	10	9	11	11	9	9	9	10	10	10	116
	b	8	7	8	8	9	9	7	8	8	9	9	9	97
Lumsden AWS	a	14	12	14	15	18	20	18	17	15	17	15	16	192
	b	10	8	9	10	11	12	9	10	11	13	11	12	126
Manapouri Aero AWS	a	12	11	12	16	19	21	20	20	17	16	14	14	192
	b	9	8	9	10	12	13	11	11	13	12	10	11	129
Milford Sound	a	17	15	16	16	17	16	16	17	18	19	18	18	203
	b	16	13	15	15	15	14	14	15	17	18	16	16	184
Monowai	a	13	12	13	14	15	16	15	15	15	15	14	14	170
	b	10	9	10	11	12	13	11	11	12	12	11	11	134
Puysegur Point AWS	a	20	18	21	22	25	24	22	24	23	24	23	20	265
	b	17	15	18	19	21	21	19	21	20	21	20	17	228
South West Cape AWS	a	20	17	21	22	25	25	25	25	23	23	23	20	269
	b	15	13	16	15	19	20	19	19	17	18	17	15	203
Te Anau, Doc	a	13	10	11	11	13	14	14	13	12	14	11	13	149
	b	11	8	9	9	11	11	11	10	10	11	10	10	120
Winton 2	a	14	11	14	15	17	16	15	14	15	16	14	14	175
	b	11	9	11	11	13	13	11	10	12	12	11	12	136

Table 11. Maximum recorded short period rainfalls and calculated return periods from HIRDS.

Location		10min	20min	30min	1hr	2hrs	6hrs	12hrs	24hrs	48hrs	72hrs
Invercargill Aero	a	13.9	21.1	22.5	26.6	36.5	53.1	96.8	134.4	142.6	143.2
	b	Feb 1989	Feb 1989	Feb 1989	Dec 1993	Nov 1962	Jan 1984	Jan 1984	Jan 1984	Jan 1984	Jan 1984
	c	67	94	60	36	45	42	100+	100+	100+	100
	d	4.7	6.5	7.8	10.8	15	25.5	35.6	49.7	61.9	70.3
	e	6.5	8.9	10.8	14.9	20.2	32.7	44.4	60.2	74.9	85.1
	f	8	11.1	13.3	18.4	24.5	38.5	51.3	68.3	84.9	96.5
	g	9.8	13.6	16.4	22.6	29.5	45.1	58.9	77	95.8	108.9
	h	12.8	17.7	21.3	29.4	37.5	55.3	70.6	90.1	112.1	127.4
Milford Sound	a	30.8	33.3	43.9	53	89.9	234.9	368.1	537.5	651.4	741.4
	b	Jan 1991	Jan 1991	Sep 1991	Sep 1991	Mar 1978	Mar 1978	Mar 1978	Jan 1994	Jan 1994	Jan 1983
	c	97	22	21	8	10	37	44	37	24	21
	d	10.5	16.8	22.1	35.2	57.2	123.6	200.9	326.5	421.5	489.4
	e	14.1	22.4	29.5	47.1	74.6	155	245.7	389.6	502.9	583.9
	f	17	27.2	35.8	57.1	89	180	280.8	437.9	565.3	656.3
	g	20.5	32.7	43	68.6	105.3	207.8	319.1	489.9	632.4	734.2
	h	26	41.5	54.6	87.1	131	250.3	376.5	566.4	731.1	848.9

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

Recent extreme events in Southland

Southland has experienced numerous extreme weather events, with significant damage and disruption caused by heavy rain and flooding. The events listed below are some of the most severe rainfall and flooding events to have affected the Southland region between 1983 and 2013.

26 – 28 January 1984: A deep depression of 980 hPa centred to the southwest of the South Island and a high pressure system of 1020 hPa centred over the north of the North Island created a northwesterly flow over Southland, which was noted as being particularly humid given Southland's latitude (Riddell, 1984). Continuous rainfall lasted between 12 and 18 hours across Southland, with peak intensities recorded between 1 a.m. and 4 a.m. on Friday 27 January (Riddell, 1984). Many areas in Southland recorded at least 100 mm of rain, with 24 hour rainfall totals exceeding 130 mm for 13 sites on the Southland plains. Parts of Southland experienced severe flooding, causing the evacuation of about 5000 people from their homes. A state of emergency was declared in Invercargill at 4.00 a.m. on Friday 27 January, which was extended to cover the entire province later that day. Flooding caused severe disruption to transport, phone and power services, and for a brief time, the province's only link to the rest of the country was by air. Invercargill airport was closed, with floodwaters there in excess of 2.5 m deep. The Waihopai River reached 112 times its mean flow at 280 cumecs, four to five times higher than any flood previously witnessed (Riddell, 1984). There was considerable loss of livestock and damage to infrastructure across the region. Approximately $55 million was paid out in insurance claims, which at that time was the costliest natural disaster in New Zealand since the 1931 Napier earthquake.

14 – 18 November 1999: Heavy rain was caused by a front that stalled over the area as a broad, active trough approached from the Tasman Sea. A blocking ridge lay over and east of the North Island. The original frontal cloud band remained almost stationary over Fiordland for two-and-a-half days. The Oreti and Mataura Rivers reached record levels. Surface flooding and slips closed more than 50 roads throughout the region. Milford Sound recorded a peak rainfall of 326 mm in 24 hours, and 651 mm of rain in three days.

24 – 27 April 2010: Heavy rainfall caused flooding on all major Southland rivers. Rainfall totals in parts of northern Southland from early on 25 April to midday on 26 April were around 200 mm. Southland's Civil Defence emergency operations centre was activated. Numerous road closures occurred due to surface flooding. The Telecom fibre-optic connection out of Te Anau was severed when part of the road near Whitestone Bridge was washed away. Dumpling Hut, on the Milford Track, received 739 mm of rain in three days ending 8 a.m. on 26 April. 120 trampers were evacuated from the Milford Track by helicopter. The trampers (40 each at three separate huts) had spent two nights safely inside huts but food was running low, prompting the evacuation.

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 not particularly common towards coastal areas of Southland, however they do occur more frequently in inland areas. Dry spells throughout Southland typically occur during a persistent low index situation (described earlier). On other occasions when the dry conditions are less widespread, a ridge may be persistent over Southland. Additionally, the western ranges provide a great deal of sheltering for eastern areas, such that dry spell conditions can persist in north or northwesterly airstreams. Table 12 outlines the dry spell frequency and duration for selected Southland sites. On average, a dry spell occurs once every seven months in Kingston, and once every two years and seven months in Invercargill. Although Milford Sound has a considerably higher mean annual rainfall, it shares a similar dry spell frequency and mean dry spell duration to Invercargill. The longest dry spell was 51 days, recorded in Kingston from 28 November 1935 to 17 January 1936. Some long dry spells are interspersed with only a few days where more than 1 mm of rain fell on each day. For example, in Invercargill from 28 July 1952, there was a 23-day dry spell, followed by more than 1 mm of rain on two of the next three days, followed by a 21 day dry spell. Over the course of this 47-day period, only 7.9 mm of rain was recorded.

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

Location	Frequency	Mean duration (days)	Max duration (days)	Max duration date
Invercargill Aero	One every 2 years 7 months	18	24	2/4/80 to 25/4/80
Kingston	One every 7 months	20	51	28/11/35 to 17/1/36
Milford Sound	One every 2 years 7 months	17	27	30/6/01 to 26/7/01

Temperature

Sea surface temperature

Monthly mean sea surface temperatures off the southwestern coast of Southland are compared with mean air temperature for Invercargill and Manapouri in Figure 12. There is about a four week lag between the minima of land and sea temperatures. This may be at least in part attributed to the greater heat capacity of the sea compared to land, which results in the sea surface temperatures taking longer to increase and decrease in response to changing seasons compared to land-based areas. Figure 12 highlights the influence of the sea on air temperatures at low-elevation coastal areas of Southland. The coastal location of Invercargill records lower mean air temperatures in summer and higher mean air temperatures in winter compared to the inland location of Manapouri. Figure 13 shows the mean sea surface temperatures for the New Zealand region for February and August, which are the warmest and coolest months with respect to sea surface temperatures.

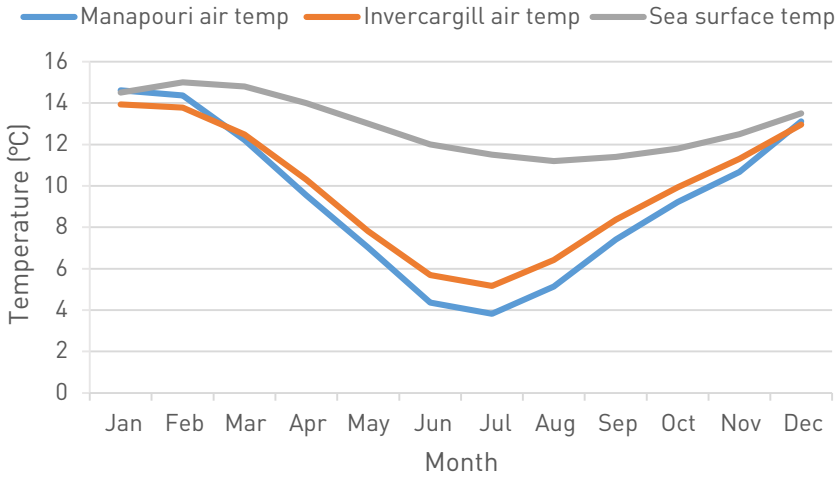


Figure 12. Mean monthly air temperatures (Manapouri Aero AWS and Invercargill Aero) and estimated sea surface temperatures (off the southwestern coast of Southland).

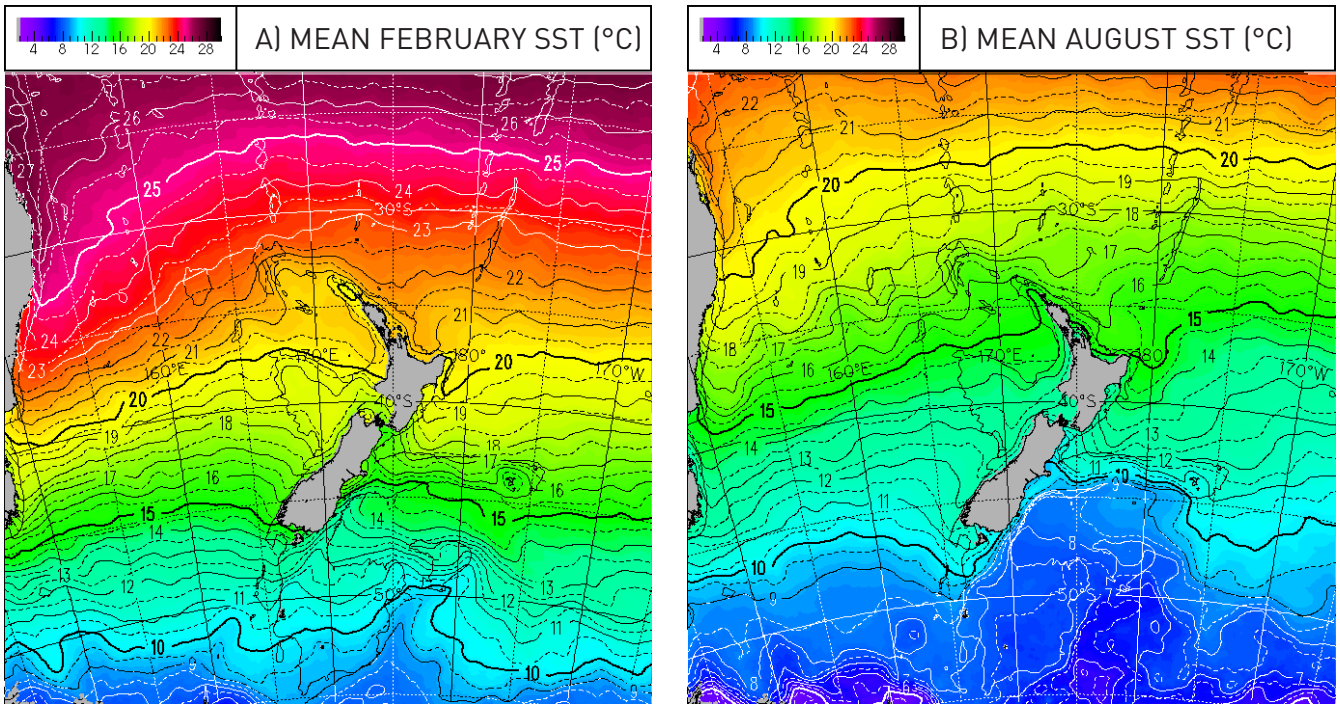
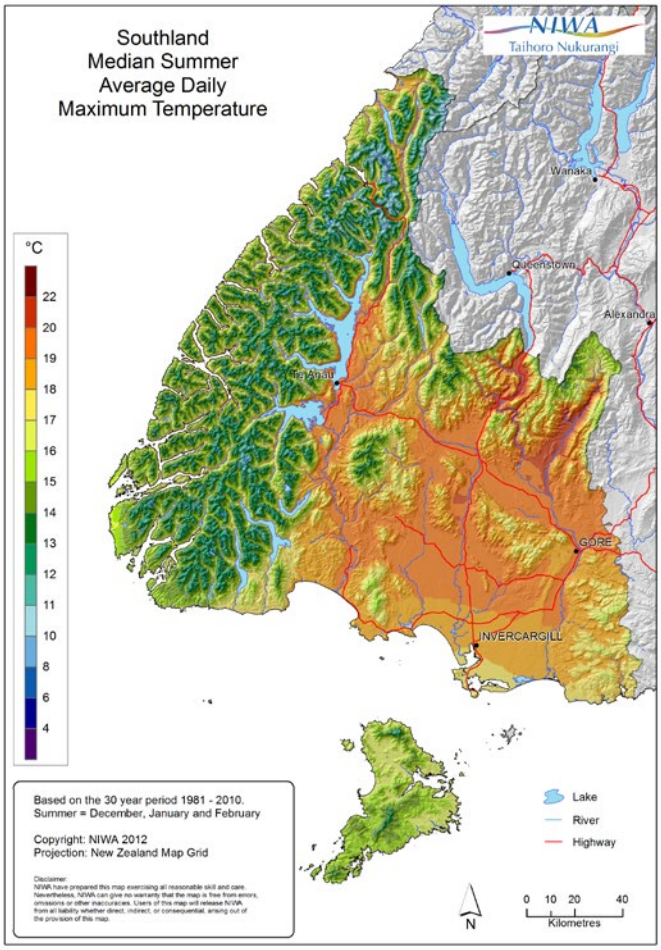


Figure 13. Monthly mean sea surface temperatures (°C) for: a) February; b) August. Source: NIWA SST Archive, Uddstrom and Oien (1999).

Air temperature

Southland typically observes afternoon temperatures reaching between 18°C and 22°C in summer, and overnight temperatures falling to between 0°C and 2°C in winter (Figure 14). Inland areas of Southland typically record higher daily maximum temperatures in summer and lower daily minimum temperatures in winter compared to areas nearer the coast. The notable exception is relatively high elevation hills and mountains, where temperatures are lower throughout the year. This is because temperatures generally decrease with elevation, reducing by about 6°C for every 1000 m increase in elevation. Figure 15 shows the median annual average temperature in the Southland region, and clearly demonstrates that lower temperatures are recorded at higher elevation locations. Relatively low elevation locations towards the coast have a mean annual temperature of between 10°C and 11°C, whereas inland areas generally observe a slightly lower mean annual temperature of between 9°C and 10°C. Mean annual temperatures of below 2°C occur in the Darran Mountains near Milford Sound, which contributes to the perennial snow and glaciers at high elevations there. Figure 16 gives the monthly temperature regime (highest recorded, mean monthly maximum, mean daily maximum, mean, mean daily minimum, mean monthly minimum, and lowest recorded) for selected sites in Southland.



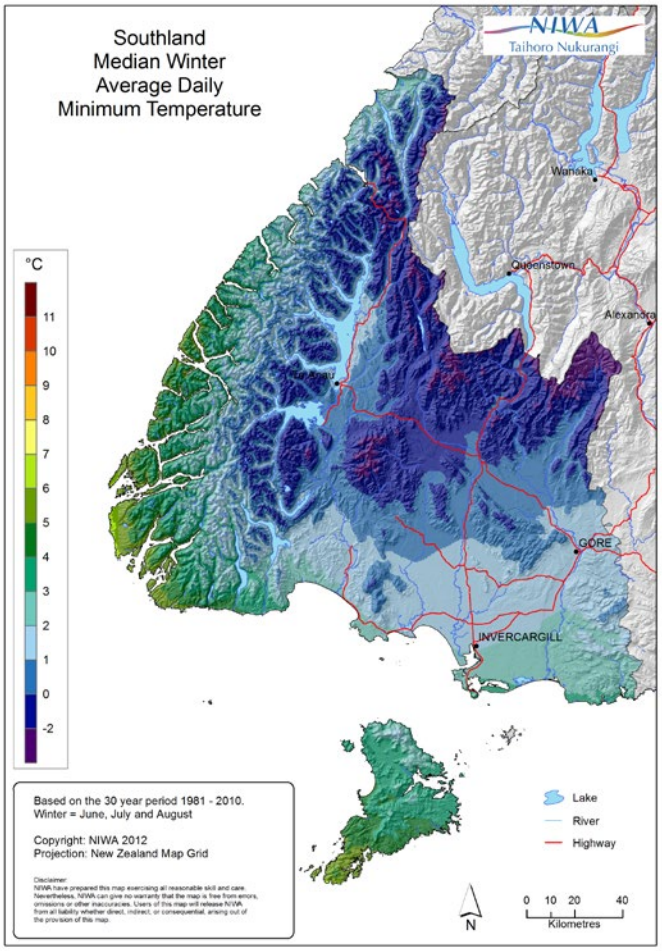


Figure 14. Left: Southland median summer (December, January and February) average daily maximum temperature; b) Right: Southland median winter (June, July and August) average daily minimum temperature.

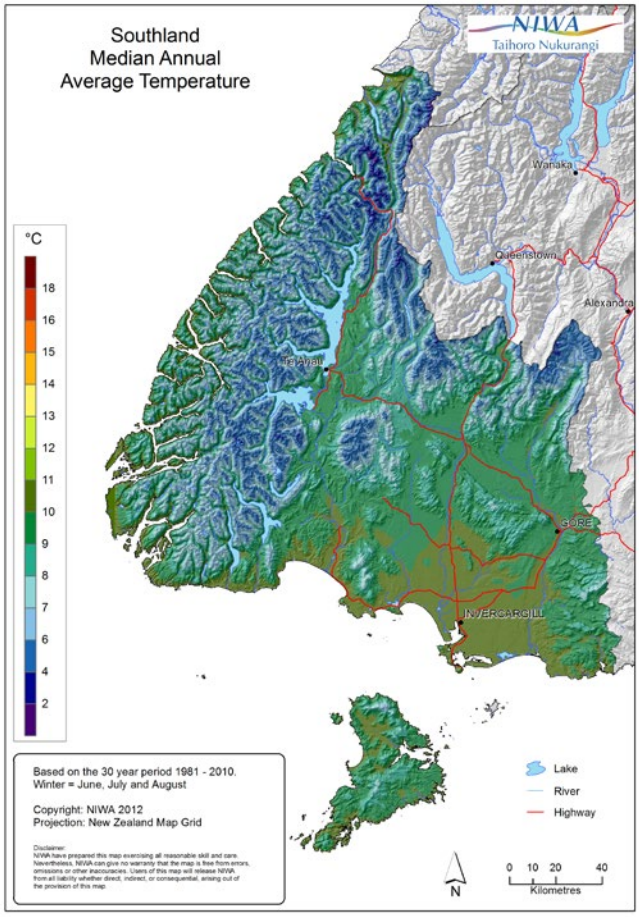


Figure 15. Southland median annual average temperature, 1981-2010.

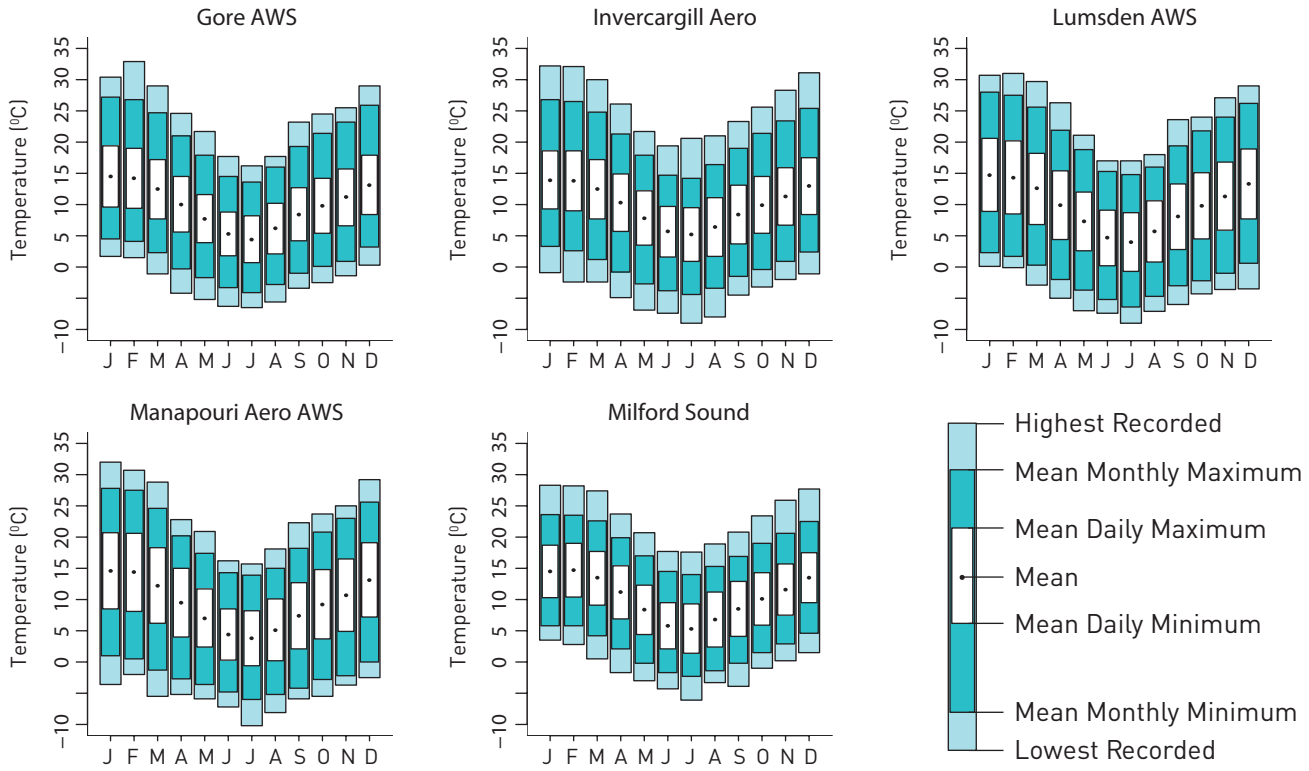


Figure 16. Monthly variation in air temperatures for selected Southland stations.

Table 13 shows that the average daily temperature range, i.e. the difference between the daily maximum and minimum temperature, is smaller at the coast (e.g. Invercargill and Milford Sound) than in inland areas (e.g. Lumsden and Manapouri). This is the case throughout the year, however the discrepancy is most prominent during spring, summer and autumn. The annual average daily temperature range in Gore is slightly lower than Invercargill, despite Gore being located further inland. This is a result of the average daily temperature ranges recorded between May and August, which in Gore are approximately 1°C lower than Invercargill during those months.

Table 14 and Figure 17 further highlight the diurnal temperature range, showing the median hourly mean air temperature for January and July at Invercargill and Manapouri. Air temperatures at Manapouri remain lower than Invercargill at all hours of the day in July. In January, air temperatures in Manapouri are lower than Invercargill in the early hours of the morning, but considerably higher during the afternoon. Note that hourly mean air temperature at a given time is calculated as the mean of many air temperature observations recorded over the previous hour. As such, both the daily maximum and minimum air temperatures calculated from hourly values are damped, resulting in a reduced diurnal temperature range (e.g. Table 14) compared to the absolute daily temperature range (Table 13) recorded at Invercargill and Manapouri.

Table 13. Average daily temperature range (Tmax – Tmin, °C) for selected Southland stations.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Gore AWS	9.6	9.8	9.4	8.8	7.7	7.0	7.4	8.0	8.7	9.0	9.2	9.3	8.7
Invercargill Aero	9.1	9.3	9.2	9.1	8.5	8.1	8.5	8.9	9.1	8.9	8.8	9.0	8.9
Lumsden AWS	11.7	11.8	11.3	10.9	9.5	8.9	9.3	9.8	10.5	10.7	10.9	11.1	10.5
Manapouri Aero AWS	12.4	12.5	11.9	10.9	9.4	8.1	8.6	9.9	10.7	11.2	11.5	11.8	10.7
Milford Sound	8.4	9.0	9.0	8.9	8.0	7.4	7.9	9.0	9.0	8.8	8.5	8.2	8.5

Table 14. Median hourly mean air temperatures for January and July at selected Southland stations.

		00	01	02	03	04	05	06	07	08	09	10	11
Invercargill Aero AWS	**January**	12.3	12.1	11.6	11.5	11.3	11.4	11.3	11.7	12.6	14.1	14.9	15.5
	July	4.2	3.8	3.8	3.5	3.5	3.4	3.4	3.4	3.7	3.9	4.6	5.6
		12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
	January	16.0	16.3	16.7	16.4	16.4	16.1	15.6	15.0	14.3	13.5	13.1	12.7
	July	7.2	8.1	8.9	9.1	8.9	8.3	7.0	6.5	6.1	5.5	5.3	5.0
		00	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**
Manapouri Aero AWS	**January**	11.9	11.4	11.0	10.9	11.1	11.0	10.5	11.3	12.3	13.7	15.2	16.1
	July	2.1	2.1	2.1	1.9	2.0	1.9	1.7	1.7	1.7	1.8	2.3	3.7
		12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
	January	17.5	18.4	19.2	19.5	19.7	18.9	18.5	16.7	15.8	14.4	13.3	12.8
	July	5.2	6.2	6.8	7.4	7.5	6.7	5.3	3.8	3.4	2.9	2.5	2.3

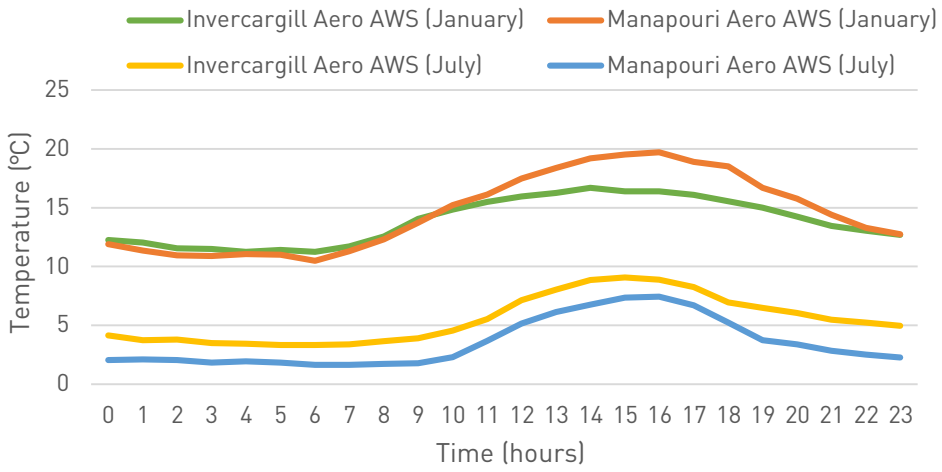


Figure 17. Median hourly mean air temperatures at Invercargill and Manapouri stations in January and July.

Maximum air temperatures in excess of 25°C occur relatively infrequently in Southland, particularly at the coastal locations of Invercargill and Milford Sound (Table 15), where an annual average of five and two such days occur respectively. Inland locations typically record a greater number of days with a maximum air temperature above 25°C and a minimum air temperature below 0°C compared to locations closer to the coast. Gore averages 34 days per year where the minimum air temperature recorded is less than 0°C – seven fewer days than Invercargill. This may contribute to the earlier observation that the average daily temperature range over winter (and annually) in Gore is less than Invercargill (Table 13), despite Gore being located further inland. The highest air temperature recorded in Southland to date is 36.5°C at Mid Dome on 21 January 1974. Mid Dome also recorded the lowest air temperature in Southland; -11.1°C on 1 August 1957.

Table 15. Highest and lowest recorded air temperatures, average number of days per year where maximum air temperature exceeds 25°C, and average number of days per year where the minimum air temperature is less than 0°C, for selected Southland stations from all available data.

Location	Highest recorded (°C)	Annual days max temp > 25°C	Lowest recorded (°C)	Annual days min temp < 0°C
Gore AWS	32.9	9	-6.5	34
Invercargill Aero	32.2	5	-9.0	41
Lumsden AWS	31.0	11	-9.0	62
Manapouri Aero AWS	32.0	11	-10.2	79
Milford Sound	28.3	2	-6.1	29

Earth temperatures

Earth (soil) temperatures are measured once daily at 9 a.m. at several Southland locations. Earth temperatures are measured at varying depths and are important, amongst other things, for determining the growth and development of plants. Different plants have different rooting depths and as such, earth temperatures are routinely monitored at 10, 20, 30, 50, and 100 cm depths. Table 16 lists mean monthly earth temperatures for a number of standard depths. At the coastal Invercargill location, lower summer earth temperatures and higher winter earth temperatures are observed when compared to the more inland locations of Gore and Winton.

Figure 18 shows how earth temperatures change throughout the year at Invercargill, compared with mean air temperature. Except during the summer, the 10 cm earth temperatures are lower than the mean air temperature. The annual earth temperature cycle at 100 cm depth is more dampened and lagged than at shallower depths. As a result, earth temperatures at 100 cm remain above mean air temperatures throughout winter, but fall slightly below mean air temperatures during spring, before returning to higher temperatures than the mean air temperature in summer. Diurnal variation of earth temperatures (not shown) decreases with increasing depth, such that earth temperatures may show very small variation at 100 cm depth, with daily variation of up to 8°C observed at 10 cm depth

Frosts

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

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 closely cut grass surface falls to -1.0°C or lower. Both types of frost are common in Southland in the cooler months. Table 17 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. Ground frosts occur more frequently than air frosts, and air frosts occur most frequently at the inland locations of Lumsden and Manapouri.

A particularly severe episode of frosts occurred in Southland during the first two weeks of July 1996. A snowfall to sea level on 1 July was followed by an anticyclone, which became stationary to the southeast of the South Island. This resulted in a two week period

of fine weather, during which significant radiative cooling (enhanced by the snow which lay on the ground) occurred. It was during this time that Invercargill recorded both its heaviest ground frost (-14.2°C) and lowest air temperature (-9.0°C) on record. The prolonged spell of heavy frosts caused thick ice to form on ponds, streams, and the outer margins of the Invercargill Estuary, whilst considerable mortality of ground-feeding birds occurred as frozen paddocks were inaccessibly hard (Wood, 1998). The event was reported to have cost insurance companies $8.1 million, mostly associated with burst water pipes.

Table 16. Monthly and annual mean 9 a.m. earth temperatures (°C) at varying depths from the ground surface for selected Southland stations.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Gore AWS													
10 cm	13.9	13.6	11.5	9.0	6.5	4.3	3.1	4.2	6.5	8.5	10.6	12.9	8.7
20 cm	14.8	14.8	12.6	10.1	7.5	5.1	3.8	4.9	7.0	9.2	11.4	13.6	9.6
50 cm	15.3	15.6	14.1	11.9	9.3	6.9	5.4	6.0	7.9	9.8	11.9	14.0	10.7
100 cm	14.1	14.8	14.0	12.4	10.5	8.5	7.0	6.7	7.8	9.3	11.1	12.8	10.8
Invercargill Aero													
10 cm	14.0	13.6	12.0	9.6	7.1	4.9	3.8	4.6	6.7	9.0	11.1	13.2	9.1
20 cm	15.0	14.8	13.3	11.0	8.3	6.0	4.8	5.6	7.6	9.8	11.9	14.0	10.2
30 cm	15.2	15.2	13.9	11.7	9.1	6.7	5.4	6.2	8.1	10.2	12.3	14.2	10.7
100 cm	14.0	14.4	14.0	12.8	11.0	9.0	7.4	7.2	8.1	9.6	11.2	12.8	10.9
Winton 2													
10 cm	14.7	14.2	12.2	9.4	6.7	4.1	3.3	4.4	6.5	8.8	11.4	13.8	9.0
20 cm	15.9	15.7	13.6	10.8	7.9	5.3	4.3	5.5	7.6	9.8	12.5	14.9	10.3
30 cm	16.4	16.2	14.4	11.7	8.7	6.1	5.0	6.1	8.2	10.4	13.0	15.3	10.9
100 cm	15.1	15.5	14.8	13.2	11.0	8.8	7.3	7.4	8.5	10.0	11.9	13.8	11.4

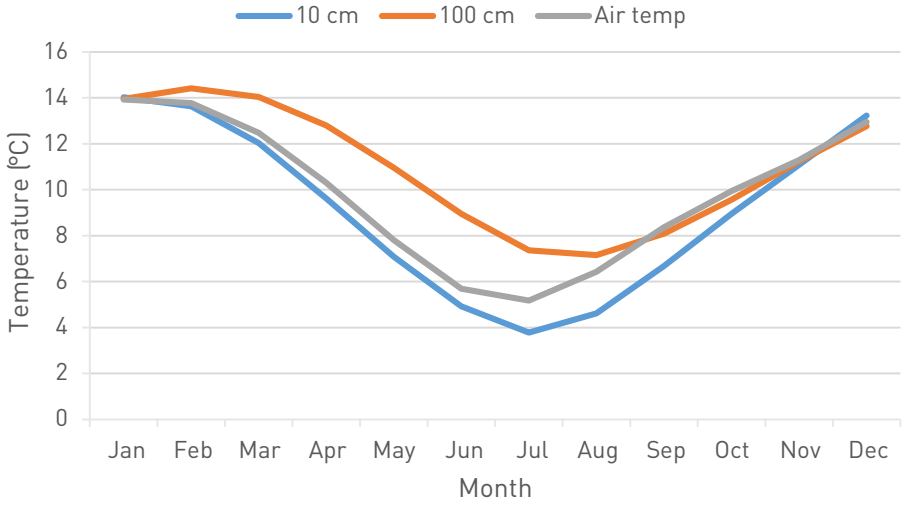


Figure 18. Monthly mean 9 a.m. earth temperature at different depths from the ground surface, and monthly mean air temperature, from all available data at Invercargill Aero.

Table 17. Frost occurrence and grass minimum temperatures at selected Southland stations.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gore AWS	a	8.4	8.1	6.2	4.0	2.1	-0.1	-1.1	0.2	2.1	3.9	5.1	7.0
	b	-1.6	-1.6	-3.4	-9.6	-5.6	-9.4	-8.1	-7.2	-6.6	-4.4	-11.7	-5.5
	c	0	0	0	2	5	11	16	11	4	2	1	0
	d	0	0	0	1	3	8	12	7	2	1	0	0
Invercargill Aero	a	6.7	6.3	5.1	3.0	0.9	-1.1	-2.1	-1.5	0.5	2.5	4.0	5.7
	b	-6.2	-6	-8.1	-9.5	-12.3	-11.7	-14.2	-11.6	-9.2	-8.5	-7.2	-7.8
	c	2	2	4	7	11	16	19	18	11	7	5	2
	d	0	0	0	2	5	9	12	9	3	1	0	0
Lumsden AWS	d	0	0	0	3	6	14	18	12	5	3	1	0
Manapouri Aero AWS	d	0	1	2	5	7	14	18	15	8	5	3	1
Milford Sound	a	8.6	8.6	7.2	5.0	2.5	0.1	-0.4	0.6	2.2	3.9	5.4	7.7
	b	-1	-1	-4.6	-2.7	-7.5	-8.8	-11	-8	-5.3	-6.9	-2.4	-1.5
	c	0	0	0	1	6	14	16	11	5	2	1	0
	d	0	0	0	0	2	8	11	6	1	0	0	0

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

Sunshine and Solar Radiation

Sunshine

Southland receives relatively low annual sunshine hours compared to the rest of New Zealand. Southwestern areas are particularly cloudy, and these areas receive less than 1300 hours of bright sunshine annually. Most of the populated areas of Southland receive between 1600 hours and 1750 hours of bright sunshine annually. Sunshine hours typically increase as distance from the coast increases (Figure 19), with the notable exception of some mountainous areas (e.g. the Takitimu and Eyre Mountains), where increased cloudiness reduces sunshine totals experienced there. Figure 20 shows the monthly mean, maximum, and minimum recorded bright sunshine hours for selected sites in Southland. Note that the lower sunshine hours recorded in the winter months tends to reflect the northerly declination of the sun, as opposed to signalling an increase in cloudiness during those times.

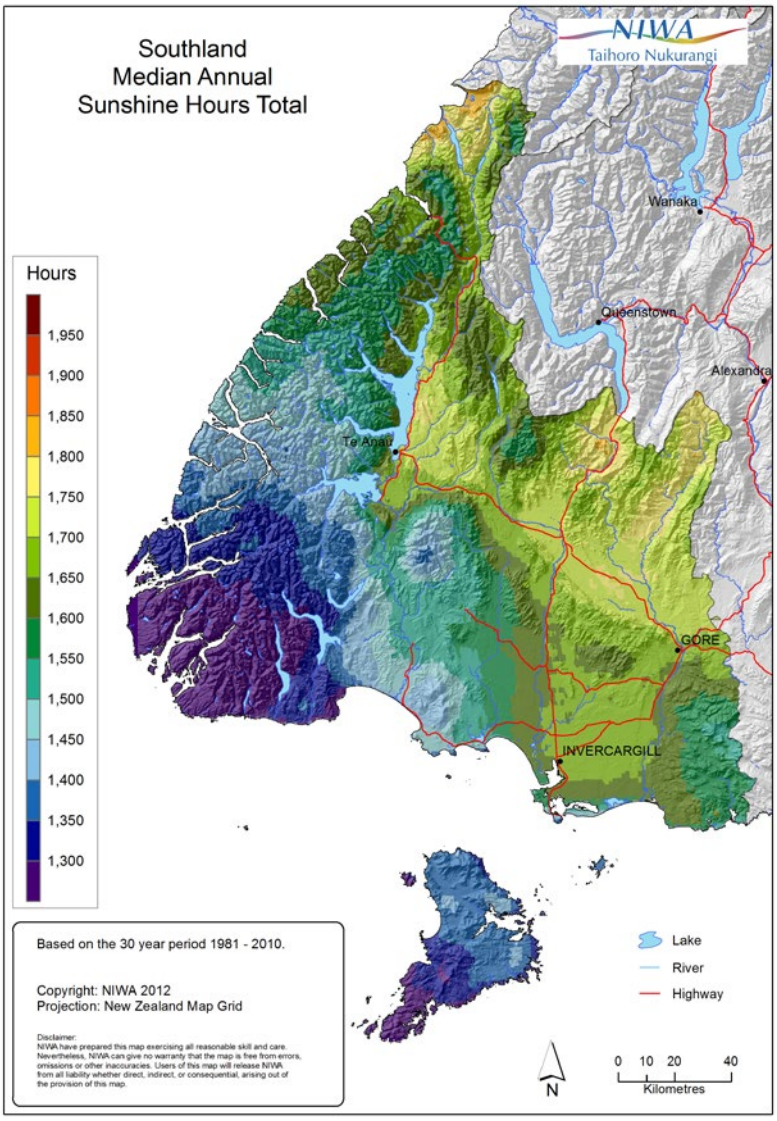


Figure 19. Median annual sunshine hours for Southland, 1981-2010.

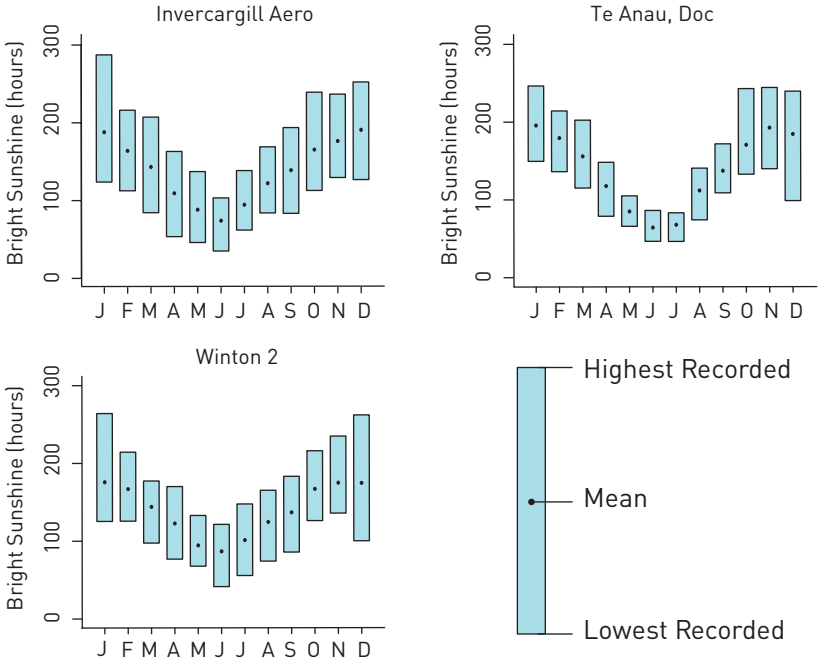


Figure 20. Mean, highest, and lowest recorded monthly bright sunshine hours for selected stations in Southland.

Solar radiation

Solar radiation records of greater than 10 years are available for a few sites in Southland. Table 18 presents the mean daily solar radiation (global) for Gore, Invercargill and Manapouri. Insolation is at a maximum in December and a minimum in June.

Table 18. Mean daily global solar radiation (MJ/m2/day) for selected Southland stations.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Gore AWS	20.4	17.5	13.3	8.7	5.2	4.0	4.9	7.4	11.5	15.8	19.6	21.2	12.5
Invercargill Aero	20.6	17.9	12.7	8.0	4.8	3.6	4.4	7.2	11.4	15.9	20.0	21.9	12.4
Manapouri Aero AWS	22.0	19.0	13.8	9.0	5.2	3.8	4.4	7.4	11.4	16.6	20.8	22.6	13.0

UV (Ultra-violet radiation)

The mean daily ultra violet radiation (UV) index recorded at Invercargill Airport is compared to that recorded at Leigh (a site in northern Auckland) in Figure 21. Invercargill records lower UV levels than Leigh due to its southern location. Both sites record significantly higher UV levels in summer than in winter, with maximum UV levels recorded in January and minimum UV levels recorded in June. Figure 22 shows an example of a UV forecast for Invercargill, indicating the UV levels and times of the day where sun protection is required.

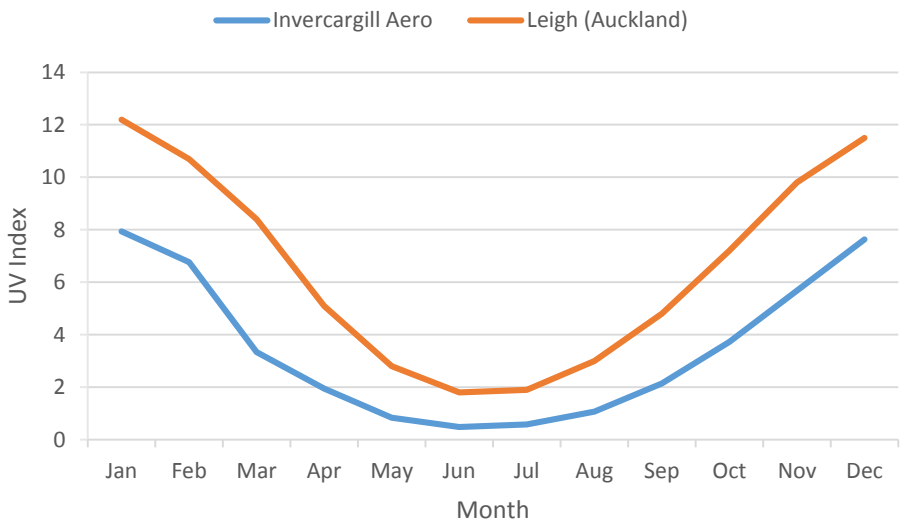


Figure 21. Mean monthly maximum UV Index at Invercargill and Leigh.

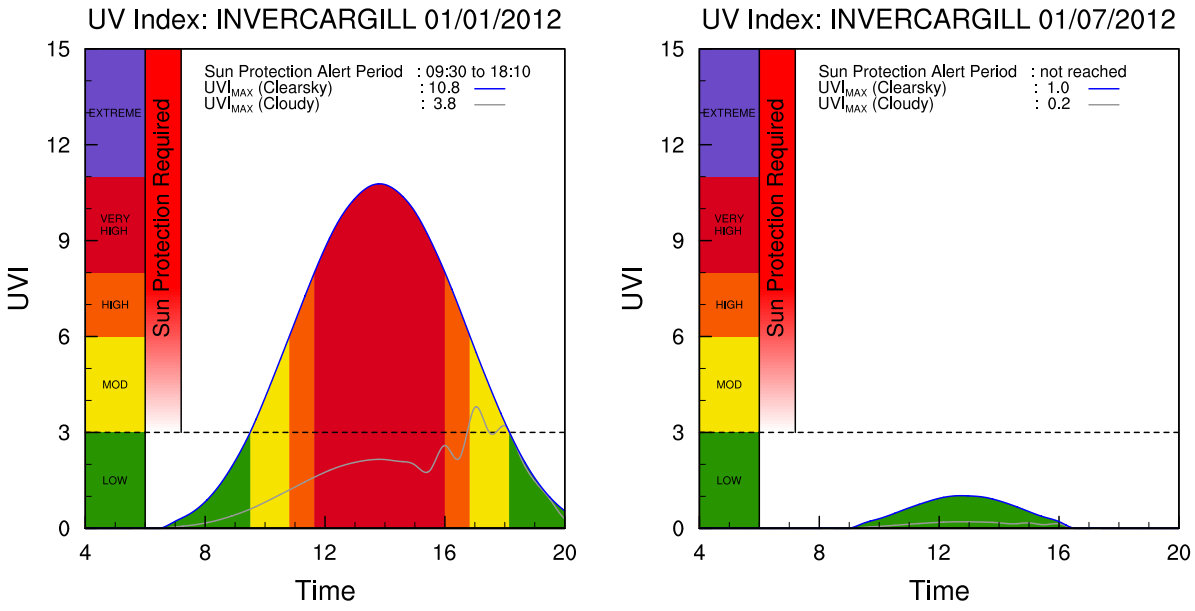


Figure 22. UV Index forecast for Invercargill, January and July.
Source: https://www.niwa.co.nz/our-services/online-services/uv-ozone

Other elements

Snow

Snowfalls occur frequently in Southland relative to other parts of New Zealand. Table 19 shows the average number of days each year that snowfall occurs at selected Southland stations. Snow doesn't tend to settle for longer than a day or two at a time, except after particularly heavy snowfall events. The exception is mountainous terrain, where extensive seasonal snowfields typically begin to accumulate in late autumn, and persist through to early summer. Considerable snowfalls occur in the mountains of Fiordland, where a single winter storm cycle can deposit 2 - 3 m of snow (Conway et al., 2000). The Milford Road passes through such mountainous areas, and heavy snowfall combined with steep terrain necessitates a sophisticated avalanche control programme along the transport route.

In September 2010, a destructive and costly snow event struck Southland. Snow began falling on the evening of 17 September in Invercargill, with approximately 14 cm of relatively dense snow accumulating by midday 18 September. The weight of snow overloaded a number of structures – most notably, Stadium Southland's roof collapsed, with collapsed or sagging roofs reported at six other businesses in Invercargill. The accepted insurance claim for Stadium Southland alone was around $20 million. In addition, extensive stock losses were experienced by farmers in the wider Southland region.

Table 19. Average number of days each year with snow, thunder, hail and fog recorded at selected Southland stations, from all available data. The elevation of each station above mean sea level is also shown.

Location	Snow	Thunder	Hail	Fog
Invercargill Aero (0 m)	5	11	30	41
Mid Dome (386 m)	13	No data	2	60
Milford Sound (3 m)	4	22	6	2
Winton 2 (44 m)	3	2	5	11

Thunderstorms

Thunder is most frequent in the west of the region, with an average of 22 days of occurrence per year at Milford Sound (Table 19). Thunder occurs about half as frequently around the south coast compared to the west coast, with Invercargill recording an average of 11 days of thunder occurrence per year. Due to the localised nature of thunderstorm occurrence, it is possible that not all thunderstorms are detected at each station. Thunderstorms in Southland are associated with bouts of high intensity rainfall, lightning, hail, and wind squalls which sometimes cause considerable localised flooding and damage to vegetation and buildings.

On 17 January 2009, a spectacular thunderstorm over Invercargill struck shortly after 6 p.m., bringing thunder, lightning and torrential rain. Invercargill received approximately 19 mm of rain in 30 minutes from 6 p.m., which caused widespread flooding across the city. Both the Invercargill and Kingswell fire services dealt with 26 storm-related calls, mainly to flooded basement garages. 160 lightning strikes were recorded, with many centred over the city. One woman reported seeing Invercargill's landmark water tower struck by forked lightning.

Hail

Table 19 gives the average number of days per year on which hail is reported at selected stations. Hail occurs considerably more often in Invercargill than any of the other stations shown. As with thunder, hail can be a localised event, meaning some falls may escape detection at some stations. Severe hailstorms may be classified as those which cause damage and/or have hailstones of at least 0.5 cm in diameter. One such severe hailstorm occurred in Invercargill on 7 January 2010. Hailstones of 0.5 cm to 0.8 cm in diameter were measured, with the New Zealand Fire Service fielding nearly 40 flooding related callouts in a single 45 minute period. Air temperatures plummeted in association with the passage of the storm, dropping from 15.6°C to 7.8°C in one hour. 7.6 mm of rainfall was recorded at Invercargill Airport during that same hour, and the mean relative humidity increased rapidly from 73% to 99% as a result of the storm's passage.

Fog

The most common type of fog in Southland is radiation fog, formed when the air cools to its dew-point on clear nights, allowing the water vapour in the air to condense. The average number of days per year with fog for selected stations in Southland is listed in Table 19. The frequency of fog varies widely over the Southland region, ranging from an average of two days with fog per year at Milford Sound to an average of 60 days per year at Mid Dome. Although fog can occur at any time of the year in Southland, it is recorded most frequently during autumn. For example, of the annual average of 41 days of fog at Invercargill, 15 days (36%) are recorded in autumn.


Leander 733A

DERIVED CLIMATOLOGICAL PARAMETERS

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

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 the total atmospheric pressure that results from the presence of water vapour in the atmosphere. It varies greatly with air masses from different sources, being greatest in warm air masses that have tropical origins and lowest in cold, polar-derived air masses. Vapour pressure can be important in determining the physiological response of organisms to the environment (very dry air, especially if there is a pre-existing soil moisture deficit, can cause or increase wilting in plants). Average 9 a.m. vapour pressures for several stations are given in Table 20, which shows that vapour pressures are lowest in the winter months.

Relative humidity relates the amount of water present in the atmosphere to the amount of water necessary to saturate the atmosphere. Unlike the vapour pressure, relative humidity is dependent on the air temperature. This is because as air temperature increases, the capacity of the atmosphere to hold water also increases. Therefore, relative humidity often displays large diurnal variation. Table 21 highlights such diurnal variation, showing 9 a.m. relative humidity is higher than that recorded at 3 p.m. at corresponding times of year. Due to lower air temperatures, highest relative humidity is experienced in the winter months.

Table 20. Mean monthly and annual 9 a.m. vapour pressure (hPa) at selected Southland stations.

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Gore AWS	11.9	11.9	10.8	9.5	8.3	7.2	6.7	7.2	8.1	8.9	9.6	11.0	9.3
Invercargill Aero AWS	12.7	12.6	11.5	10.2	9.1	7.7	7.1	7.8	8.8	9.5	10.3	11.7	9.9
Lumsden AWS	11.3	11.3	10.4	9.0	7.8	6.5	6.1	6.8	7.6	8.3	9.1	10.7	8.7
Manapouri Aero AWS	12.0	12.2	10.9	9.9	8.4	7.1	6.7	7.3	8.4	8.9	9.5	11.0	9.4
Milford Sound	13.4	13.4	12.4	10.7	9.1	7.7	7.2	7.7	8.8	9.8	10.9	12.6	10.3

Table 21. Mean monthly and annual 9 a.m. (a) and 3 p.m. (b) relative humidity (%) at selected Southland stations.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Gore AWS	a	80	84	85	85	86	87	87	85	80	80	77	78	83
	b	65	68	68	71	77	81	77	72	67	67	65	62	70
Invercargill Aero AWS	a	82	85	86	86	88	89	89	88	82	82	79	79	85
	b	70	72	72	71	77	80	78	73	71	70	70	66	73
Lumsden AWS	a	76	80	81	81	83	83	84	83	76	76	73	75	79
	b	61	64	64	64	72	77	72	69	63	62	58	57	65
Manapouri Aero AWS	a	78	84	85	89	91	92	92	92	86	83	76	76	85
	b	56	59	60	64	74	79	80	73	66	60	56	53	65
Milford Sound	a	87	90	91	92	92	92	91	91	90	88	85	85	90
	b	65	67	67	69	79	83	81	73	72	65	67	64	71

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

Table 22. Mean monthly and annual water balance summary for a soil moisture capacity of 150 mm, at selected Southland stations.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Gore AWS	DE	32	28	11	2	0	0	0	0	0	1	7	31	112
	ND	8	8	5	1	0	0	0	0	0	0	2	7	31
	RO	1	3	2	10	43	67	43	32	18	9	5	4	238
	NR	0	0	0	2	7	14	10	7	3	2	1	1	48
Invercargill Aero	DE	33	21	9	1	0	0	0	0	0	0	8	23	96
	ND	8	6	4	1	0	0	0	0	0	0	2	6	27
	RO	7	3	8	29	71	92	66	43	35	23	9	2	389
	NR	1	0	1	4	11	16	13	9	6	3	1	0	66
Kingston	DE	62	48	20	4	0	0	0	0	0	3	23	46	208
	ND	13	12	8	3	0	0	0	0	0	1	6	10	53
	RO	0	0	1	5	28	52	52	43	21	16	4	1	223
	NR	0	0	0	1	3	7	7	6	3	2	0	0	29
Lumsden AWS	DE	14	15	9	1	0	0	0	0	0	0	2	21	62
	ND	4	5	4	0	0	0	0	0	0	0	1	6	20
	RO	4	4	5	14	37	52	38	38	22	17	7	7	245
	NR	0	0	1	2	7	12	10	7	4	3	1	0	47
Manapouri Aero AWS	DE	36	32	11	2	0	0	0	0	0	0	9	28	117
	ND	8	9	5	2	0	0	0	0	0	0	2	6	32
	RO	0	1	9	25	55	92	71	69	61	40	18	5	449
	NR	0	0	1	3	7	16	11	10	8	4	2	1	63

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

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 Southland region is typically well served by frequent rainfalls throughout the year, but due to high evapotranspiration, irrigation or watering may be necessary from late spring to early autumn.

Mean monthly and annual water balance values for a number of stations in Southland are given in Table 22. Soil moisture deficit peaks in summer throughout Southland, whereas runoff peaks in the winter months. Compared to the remainder of New Zealand, mean soil moisture deficit observed throughout the year in Southland is relatively low. Figure 23 shows region-wide variability in days of soil moisture deficit per year.

Potential evapotranspiration (PET) has been calculated for Gore, Invercargill and Manapouri using the Penman method (Penman, 1948). The monthly mean, minimum, and maximum PET values for these locations are listed in Table 23.

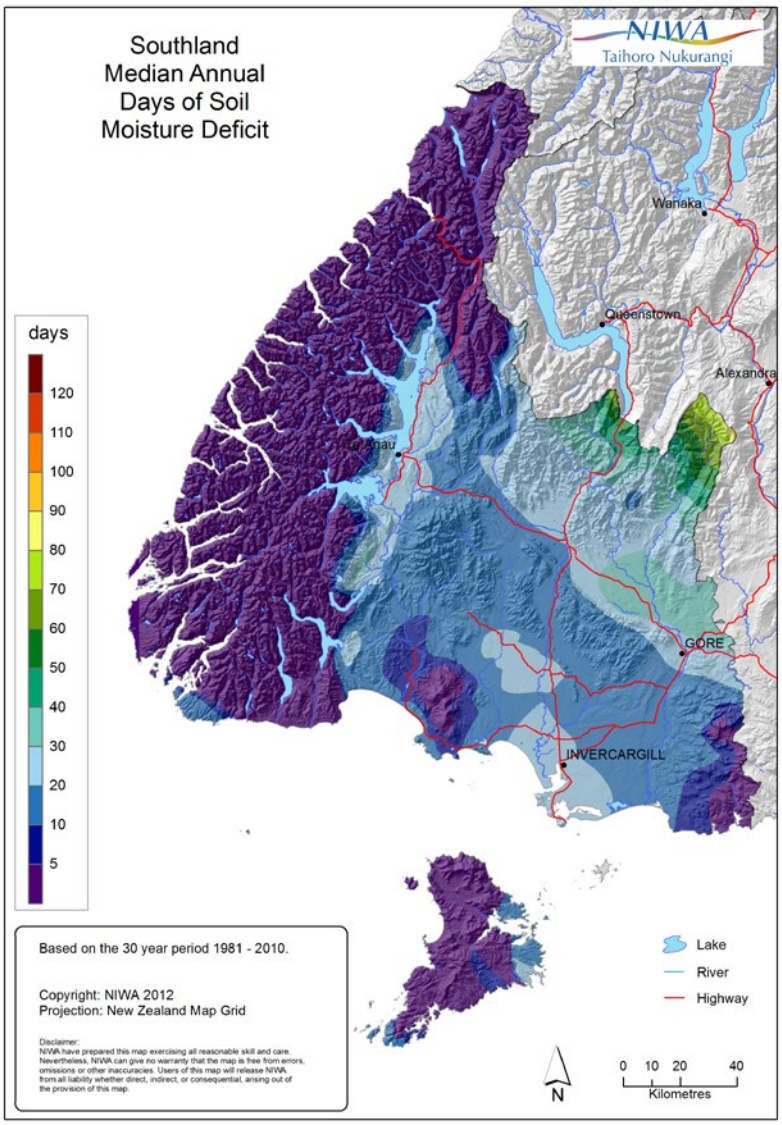


Figure 23. Median annual days of soil moisture deficit for Southland, 1981-2010.

Table 23. Penman calculated maximum, mean, and minimum monthly potential evapotranspiration (mm), as well as mean annual total potential evapotranspiration, for selected Southland stations.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Gore AWS	Max	148	116	79	52	35	19	17	37	66	97	127	150	
	Mean	125	92	73	38	20	10	13	29	54	84	106	123	768
	Min	100	75	60	30	11	4	8	21	45	74	82	93	
Invercargill Aero AWS	Max	148	113	80	45	34	19	20	36	62	96	116	145	
	Mean	125	94	72	39	20	13	15	28	53	83	106	126	772
	Min	104	80	61	32	13	6	8	22	45	68	91	101	
Manapouri Aero AWS	Max	159	120	86	42	23	19	21	30	50	92	123	159	
	Mean	130	97	69	32	13	5	7	19	42	78	104	126	723
	Min	112	82	56	25	9	1	3	14	35	70	92	103	

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

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 25 shows that the number of cooling degree days reach a peak in mid-late summer in Southland, when energy required to cool building interiors to 18°C is highest. Conversely, heating

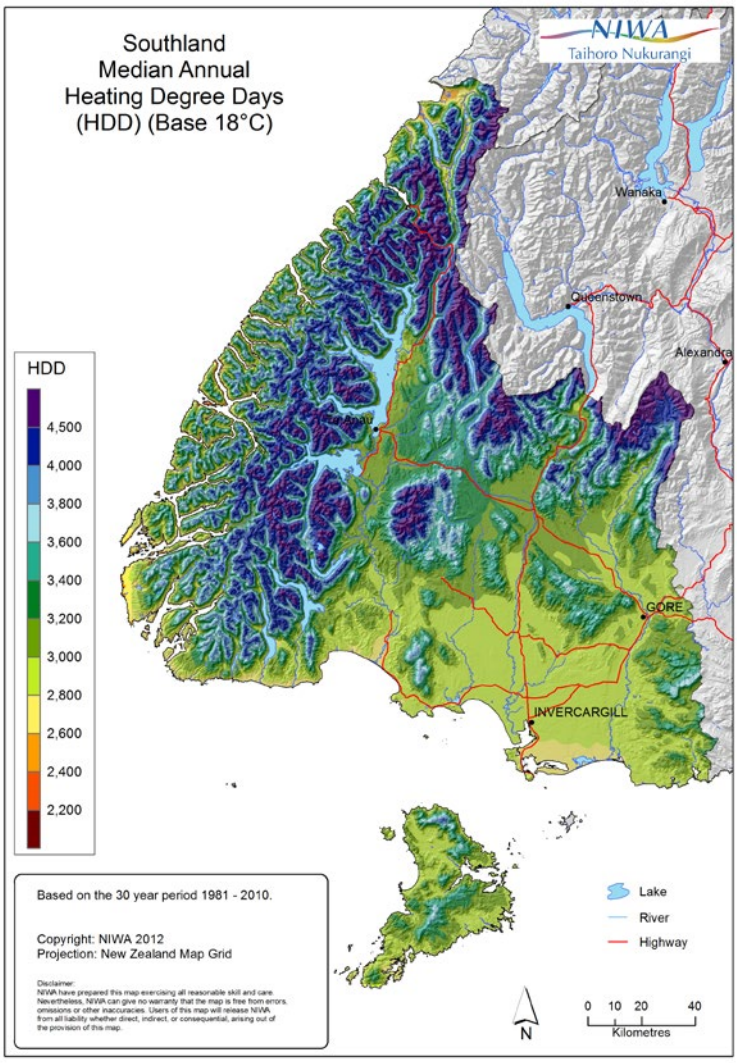


Figure 24. Median annual heating degree days for Southland, 1981-2010.

Table 24. Average growing degree-day totals above base 5°C and 10°C for selected Southland stations.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Gore AWS	5°C	294	259	231	152	91	35	23	50	106	150	183	253	1827
	10°C	140	119	83	32	9	1	0	2	13	30	53	103	586
Invercargill Aero	5°C	277	248	232	159	91	40	30	54	103	153	189	247	1822
	10°C	123	108	83	34	7	1	0	2	10	29	53	96	545
Lumsden AWS	5°C	303	264	234	149	84	33	21	44	97	149	190	255	1823
	10°C	150	124	87	34	10	2	1	2	13	32	60	105	619
Manapouri Aero AWS	5°C	298	264	224	137	75	23	17	32	79	132	171	251	1703
	10°C	144	126	80	27	7	1	0	0	8	23	45	102	564
Milford Sound	5°C	295	275	263	186	107	42	33	61	106	157	197	264	1986
	10°C	140	135	110	49	12	2	1	2	7	27	56	111	651

degree days reach a peak in winter, where the energy required to heat buildings to 18°C is highest. Figure 24 shows region-wide variability in the number of heating degree days per year. The number of heating degree days tends to be lower in low elevation coastal areas, compared with areas further inland and at higher elevations.

Table 25. Average cooling (CDD) and heating (HDD) degree-day totals with base 18°C for selected Southland stations.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Gore AWS	CDD	5	5	1	0	0	0	0	0	0	0	0	2	13
	HDD	114	113	173	238	319	381	422	367	287	254	208	152	3028
Invercargill Aero	HDD	3	3	1	0	0	0	0	0	0	0	0	1	8
	CDD	129	122	172	231	316	370	398	359	289	250	201	158	2994
Lumsden AWS	CDD	7	5	1	0	0	0	0	0	0	0	0	2	16
	HDD	106	109	171	242	330	399	435	382	298	255	200	150	3078
Manapouri Aero AWS	HDD	5	5	1	0	0	0	0	0	0	0	0	1	12
	HDD	109	108	180	255	340	409	439	399	318	272	220	153	3202
Milford Sound	CDD	2	2	0	0	0	0	0	0	0	0	0	0	4
	HDD	110	94	141	204	299	366	393	348	285	246	193	140	2817

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STONY POINT 5 km
WEST ARM POWER
CATHEDRAL PEAKS 16 km
DOUBTFUL SOUND 50
BEEHIVE 13 km
STOCKYARD COVE NATURE WALK
AND HIGH BLUFF FALLS 13 km
CHANNEL ISLANDS 8 km
INTER MOUNTAINS 13 km
NORTH ARM 31 km

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