MOUNTAIN CLIMATE

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MOUNTAIN TOP OBSERVATIONS AND THE CLIMATE OF THE FREE AIR

In many parts of the world meteorologists began to take interest in mountain meteorology in the latter half of the 19th century and at this time a number of well-known mountain top observatories were set up, among them Mt Washington and Pike's Peak in North America, Ben Nevis in Scotland, and Sonnblick and Mt Blanc in the European Alps (Stone 1934, Paton 1954, Talman 1934). Except in Europe, this interest appears to have declined by the early years of this century and many of the mountain observatories were closed down. However, there was a renewal of activity in the nineteen-thirties, when regular daily data from a network of upper air stations were needed for weather forecasting for aviation. Much effort was applied to discovering relationships between wind and weather on the mountain tops and in the free air, with a view to using mountain observations in the routine preparation of upper air weather maps.

Surface winds on isolated summits were found to be closely correlated with those in the nearby free air at the same level, but were often considerably increased in speed because of the concentration of flow across the barrier. The increase is greatest with strong winds perpendicular to a range. Thus, on Mt Washington in north-eastern United States (44° N., 1915 m.), where prevailing westerlies are concentrated across the summit by the local topography, the ratio of average wind speed at the mountain top to that in the free air is approximately 1.8 in winter and 1.4 in summer (Eustis 1942). On the other hand, in generally fine weather and light wind situations the mountain wind tends to be weaker than that in the free air (Davidson *et al.* 1964).

Air temperatures at isolated, well-ventilated peaks have been found to be similar to, but on average somewhat colder than, free air temperatures at the same level; but there are diurnal, seasonal, regional, and wind-related variations (Samson 1965). On peaks in the Alps at about 3 km. the average difference was 1–2°C. (Ekhart 1939). It is greater when stably stratified air is forced to rise over the mountain barrier. This effect is marked at Mt Washington, especially in winter. Here the temperature difference averaged approximately 3°C. in light winds (up to 6 m./s.) and more than 6°C. in strong winds (over 30 m./s.) (Schell 1935). It tends to be small with light winds and clear skies and with unstably stratified air (Eide 1945). In these circumstances, during the day solar radiation heats the surface and a relatively stagnant layer of air near the ground becomes warmer than the free air. In the free air diurnal temperature changes are slight — generally less than 1°C. in amplitude — from about 2 km. to over 10 km. above sea level (e.g., Allen and de Lisle 1965, Harris 1959). Compared with the lowlands, mountain slopes and summits characteristically have a relatively brief mid-day temperature maximum of small amplitude (Ekhart 1948).

Many measurements of solar radiation have been made on the tops of high mountains to gauge the absorption of radiation in the atmosphere and to determine the "solar constant" (the average intensity of solar radiation outside the earth's atmosphere), notably by Abbot and collaborators of the Smithsonian Institution (Fritz 1951, Johnson 1954). In the European Alps, in particular, solar radiation and its increase with height above sea level have been studied in great detail as an important and highly variable element of the local climate. For example, Thams (1961) described for alpine areas the variations of insolation caused by differences of slope and obstruction by surrounding ridges, and those resulting from föhn conditions and other characteristic weather situations. Hoinkes (1964) has discussed the variations of mountain radiation climates on a broader scale.

The relationships between wind, temperatures and humidity in the free air and on the tops of isolated high mountains have been found to be relatively simple, so that mountain observatory data from suitable sites could have been used more widely in upper air analysis (Samson 1965). In spite of this, no widespread development of mountain weather stations for this purpose took place because the need was met by the establishment of routine radiosonde and radar balloon soundings in most of the land areas of the world.

It has been said that large mountain systems form their own atmosphere, extending some distance above and around the ranges (Ekhart 1948). Here the climatic relationships between mountain and free air are influenced, not only by the characteristics of the broad scale wind and weather regimes, but also by the varying surface conditions of snow cover, vegetation, slope and aspect as they affect the radiation, heat, and moisture balances of the surface, and by topographically controlled local winds (Geiger 1965). Each mountain system thus provides a specific wide range of local climates and microclimates which comprise the physical environment of plant and animal communities. Meteorological measurements of local climates in mountain areas have often been made by biologists and others for ecological purposes, especially in the European and North American mountains. In large degree, because the area sampled and the sampling period have often been limited, and because (meteorologically) non-standard instruments and exposures have had to be used in some instances, the results of such work have not been readily integrated into standard regional climatology.

Speaking of the Californian Sierra Nevada, Miller (1955) states that "research on the layer of the atmosphere near the ground should be done with full knowledge of the upper-air circulation over the region". A knowledge of the climate of the free air above and around the mountains would be of value to the mountain ecologist, both as a standard of reference for comparing environmental data from different mountain areas and as an indication of the climate of mountains for which no surface data yet exist. These considerations may well be especially true for the New Zealand mountains which are of relatively small extent. It will therefore be of value to examine data which have accumulated in the New Zealand region for the first 3 or 4 km. of the atmosphere.

FREE AIR CLIMATE IN THE NEW ZEALAND AREA

Radiosonde and radar wind data accumulated over several years may be used to illustrate the main features of the wind, temperature, and humidity regimes over the New Zealand area (N.Z. Met. S. 1962, 1963). Gabites (1953a, b) has summarised earlier data, but emphasised those referring to higher levels. A basic network of radiation stations has provided data on incoming solar radiation (de Lisle 1966). The following discussion is, for the most part, based on these published data which cover a period of about six years. Therefore the mean values quoted cannot be taken as "normals" or long period means, and any long period variations or trends which may exist cannot yet be detected.

Solar radiation

The amount of energy supplied per day by the sun's radiation to a horizontal surface outside the atmosphere is shown in Figure 1 (a), for latitude 40 and 45 degrees south. Curve (b) gives the maximum "global" radiation (i.e., total radiation received on a horizontal surface from direct sunshine and diffuse radiation scattered from the sky) with a clear sky at sea level. This is about 80% of the extra-atmospheric radiation in summer and about 70% in winter. Maximum clear sky global radiation at higher altitudes falls between these curves. At 3 km. (10,000 ft.) above sea level in New Zealand it would be about 90% of the extra atmospheric value in summer, or about 85% in winter. For comparison, curve (c) gives the average global radiation at sea level for all days, for Invercargill (46.4° S.) and Ohakea (40.2° S.); and shows the effect of average conditions of cloud and atmospheric water vapour and dust in reducing the amount of insolation reaching the surface.

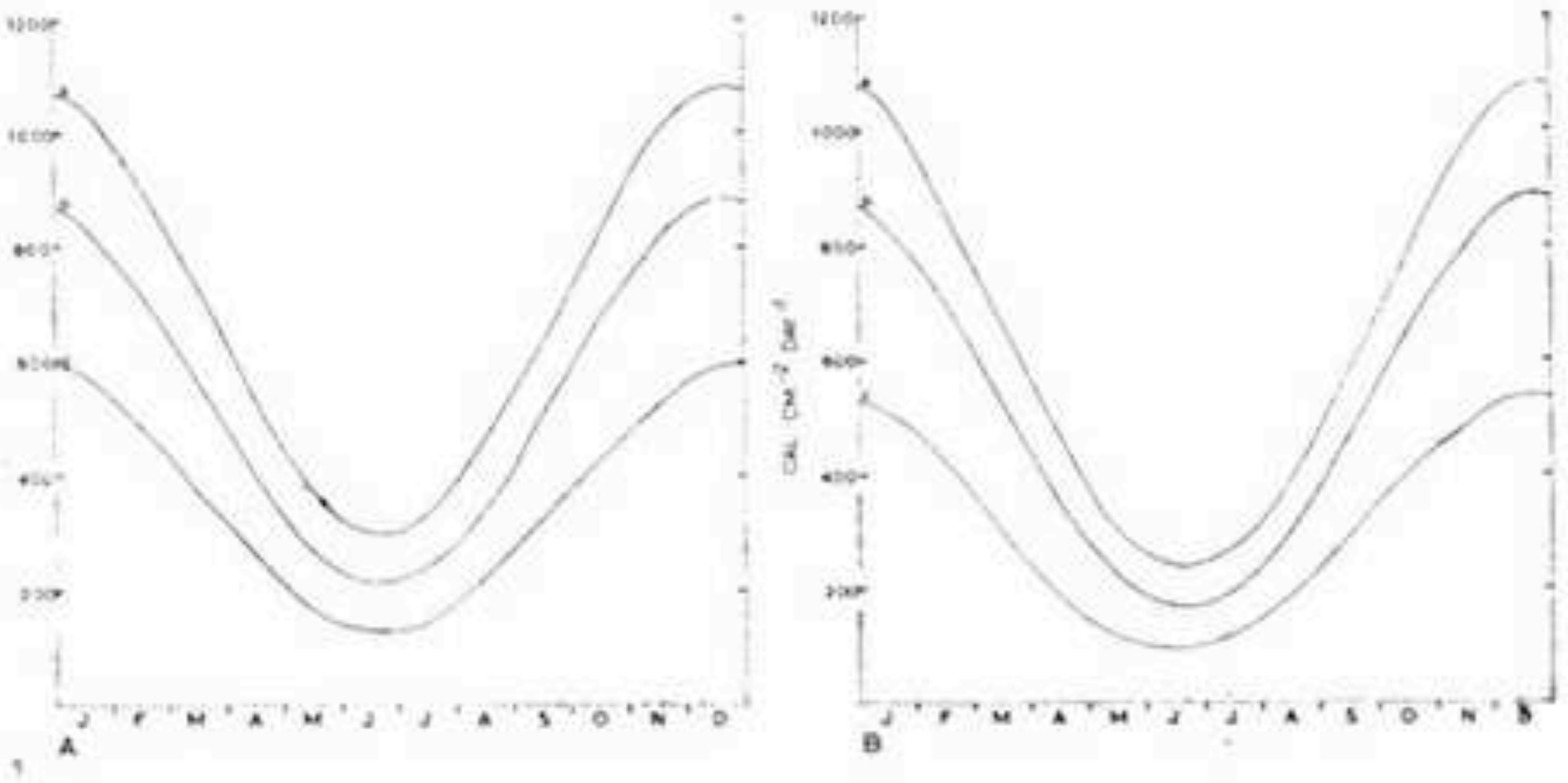


FIGURE 1. *Annual variation of solar radiation (cal. cm.*$^{-2}$ *day*$^{-1}$*) on a horizontal surface*

(a) *outside the earth's atmosphere: (A) 40° S., (B) 45° S.*
(b) *maximum global radiation at sea level calculated for clear sky: (A) 40° S., (B) 45° S.*
(c) *average global radiation (1954–65): (A) Ohakea (40.2° S.), (B) Invercargill (46.4° S.).*

Radiation values at higher altitudes have not been measured in the New Zealand area except at Mt John above Lake Tekapo in the Mackenzie country at 1,050 m. (3,377 ft.) above sea level, where solar radiation measurements began in 1966. High average values which have been measured during this period reflect the relative freedom from cloud. In other mountain areas of New Zealand totals of average radiation can be only roughly estimated from such records of sunshine or cloud cover as may exist. No observations of the variations of spectral distribution of sunlight with height or observations of the ultra-violet component of solar radiation are on record from New Zealand.

Free air temperatures

Figure 2 shows the profile of mean air temperature with latitude and height in the New Zealand area in January and July (the warmest and coldest months), based on radiosonde data for near midday (release time 1100 NZST). To adjust the profiles to give approximate mean (daily) temperatures, the surface temperatures should be reduced by the quantities given in Table 1.

In July the temperature gradients in the vertical and horizontal are relatively uniform, with a change of 5°C. in about 1 km. of altitude or 12° of latitude — except in the lowest kilometre north of 40° S., where the gradients are considerably greater. The 0°C. isotherm rises from 800 m. at latitude 52.5 ° S. (Campbell Island) to 1,500 m. at 46.5° S. (Invercargill) and to 2,100 m. at 37° S. (Auckland).

In January there is a rapid temperature decrease with height in the first kilometre (5°C. in approximately 0.6 km.) and with latitude in the south (5°C. in 4 degrees of latitude). However, rather weak gradients prevail above 1 km. at latitudes north of about 45° S. The 0°C. isotherm rises from 1,850 m. (6,000 ft.) in latitude 52.5° S. (Campbell Island to 2,950 m. (10,000 ft.) at 46.5° S. (Invercargill) and to 3,900 m. (13,000 ft.) at 37° S. (Auckland). So that comparison with published lapse rates of surface temperature (e.g., Mark 1965a, Morris 1965, and those (p. 54) for the Black Birch Range) may be made easier, lapse rates in free air from the surface to approximately 5,000 ft. (850 mb.) are given below in English units — °F./1,000 ft.

Auckland	January	4.0	July	3.6
Christchurch	January	3.4	July	2.5
Invercargill	January	3.8	July	2.5

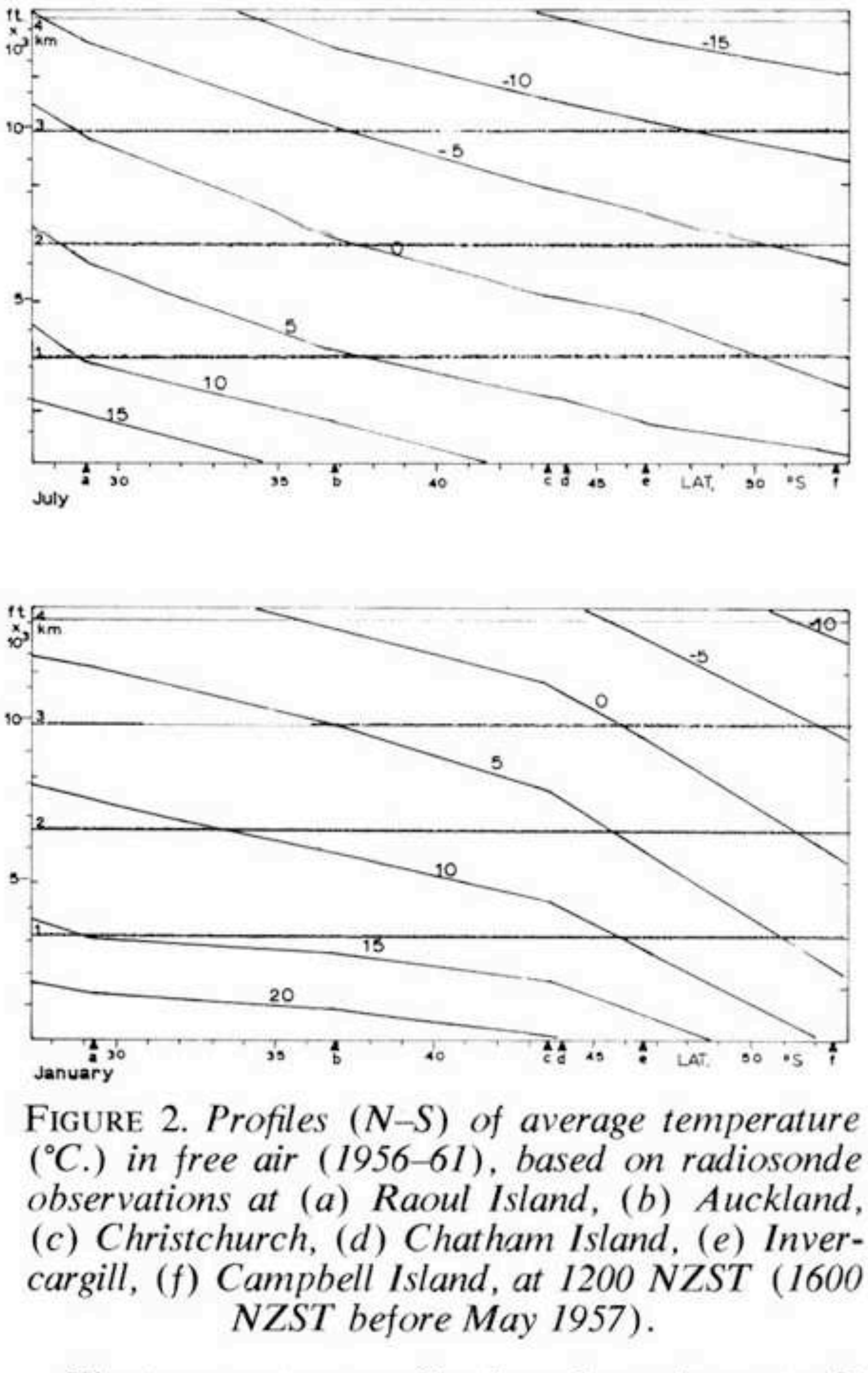


FIGURE 2. *Profiles (N–S) of average temperature (°C.) in free air (1956–61), based on radiosonde observations at (a) Raoul Island, (b) Auckland, (c) Christchurch, (d) Chatham Island, (e) Invercargill, (f) Campbell Island, at 1200 NZST (1600 NZST before May 1957).*

The temperature profiles have been drawn to fit Christchurch values and thus represent cross sections through the atmosphere in the lee of the Southern Alps. Locally-increased temperatures would be expected in this situation because of adiabatic warming of descending air, and there is some confirmation of this in the profiles and in the relative values for individual months at Christchurch and Chatham Island illustrated in Figure 3. Temperatures west of, and immediately above, the divide are likely to be on average somewhat colder than above Christchurch.

TABLE 1. *Average difference between mean surface temperature from radiosonde data and approximate mean temperature ($\frac{1}{2}$ max. + min.) from surface climatological observations. (°C.)*

	CAMPBELL ISLAND 52.5°S.	INVERCARGILL 46.4°S.	CHRIST-CHURCH 43.5°S.	AUCKLAND 36.8°S.	RAOUL ISLAND 29.5°S.	CHATHAM ISLAND 44.0°S.
JAN.	1.0	2.5	2.9	2.4	1.4	2.0
JULY	0.8	1.2	2.2	2.3	1.6	1.4

(In the free air the difference decreases rapidly with height, and almost vanishes at about 1–1.5 km. above the surface.)

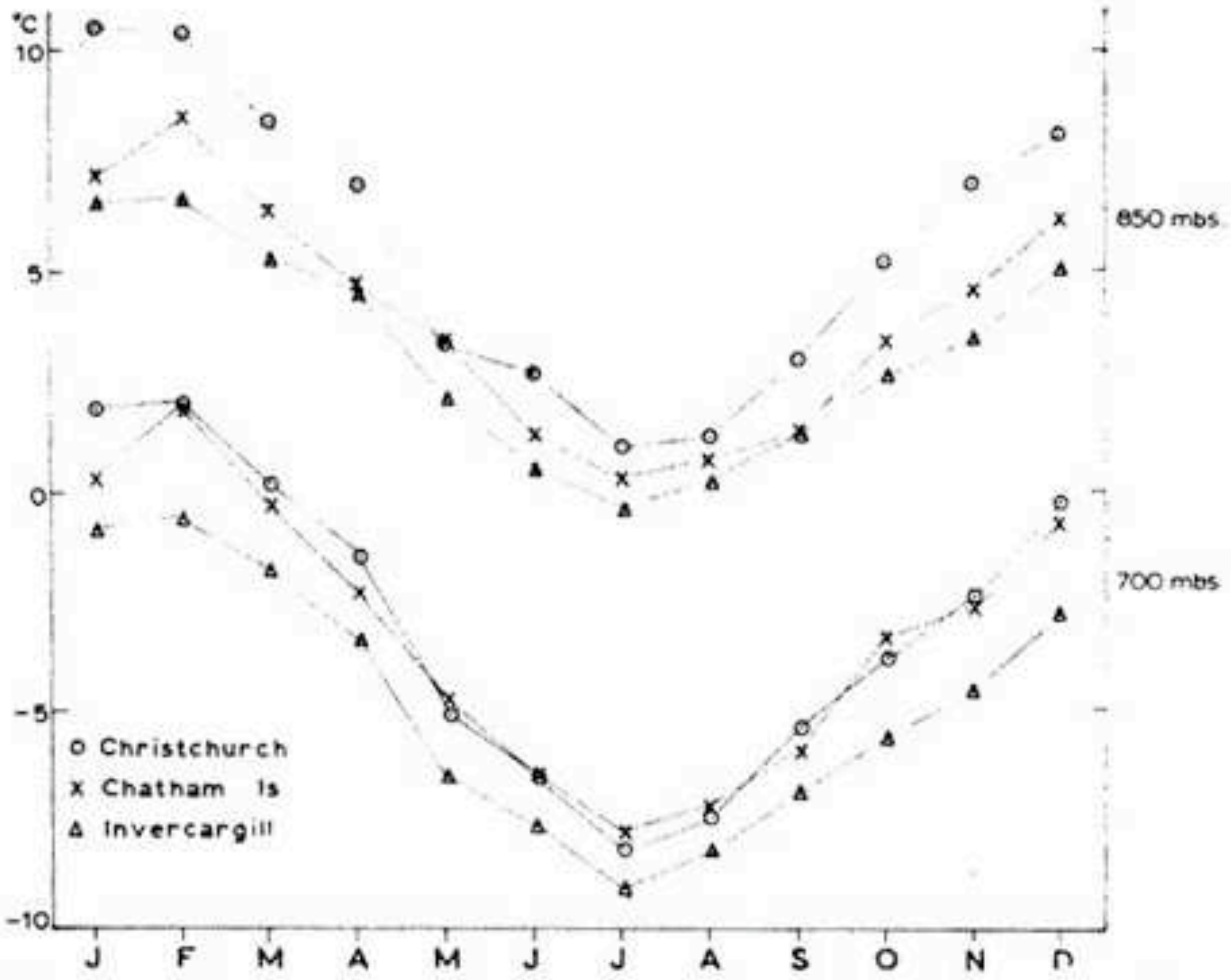


FIGURE 3. *Average temperatures (°C.) in free air at 850 mb. and 700 mb. (i.e., 1.4 to 1.5 km., and 2.9 to 3.1 km. respectively, depending on season). (Data as in Fig. 2.)*

Some irregularities in the curves of monthly mean temperatures at 850 mb. (1.4 to 1.5 km. above sea level) and at 700 mb. (2.9 to 3.1 km.) suggest that data covering a longer period would be desirable (Fig. 3).

The standard deviation of temperature (at constant pressures) at New Zealand stations ranges from 2° to 3.9°C. in July and from 2.0 to 5.4°C. in January (surface to about 4 km.). The higher values are mostly at the higher levels, and the standard deviation is greater at Christchurch than at other stations. Figure 4 illustrates the frequency distributions of temperature at Christchurch and Invercargill for winter (June, July, August) and summer (December, January, February) at 850 mb. and 700 mb.

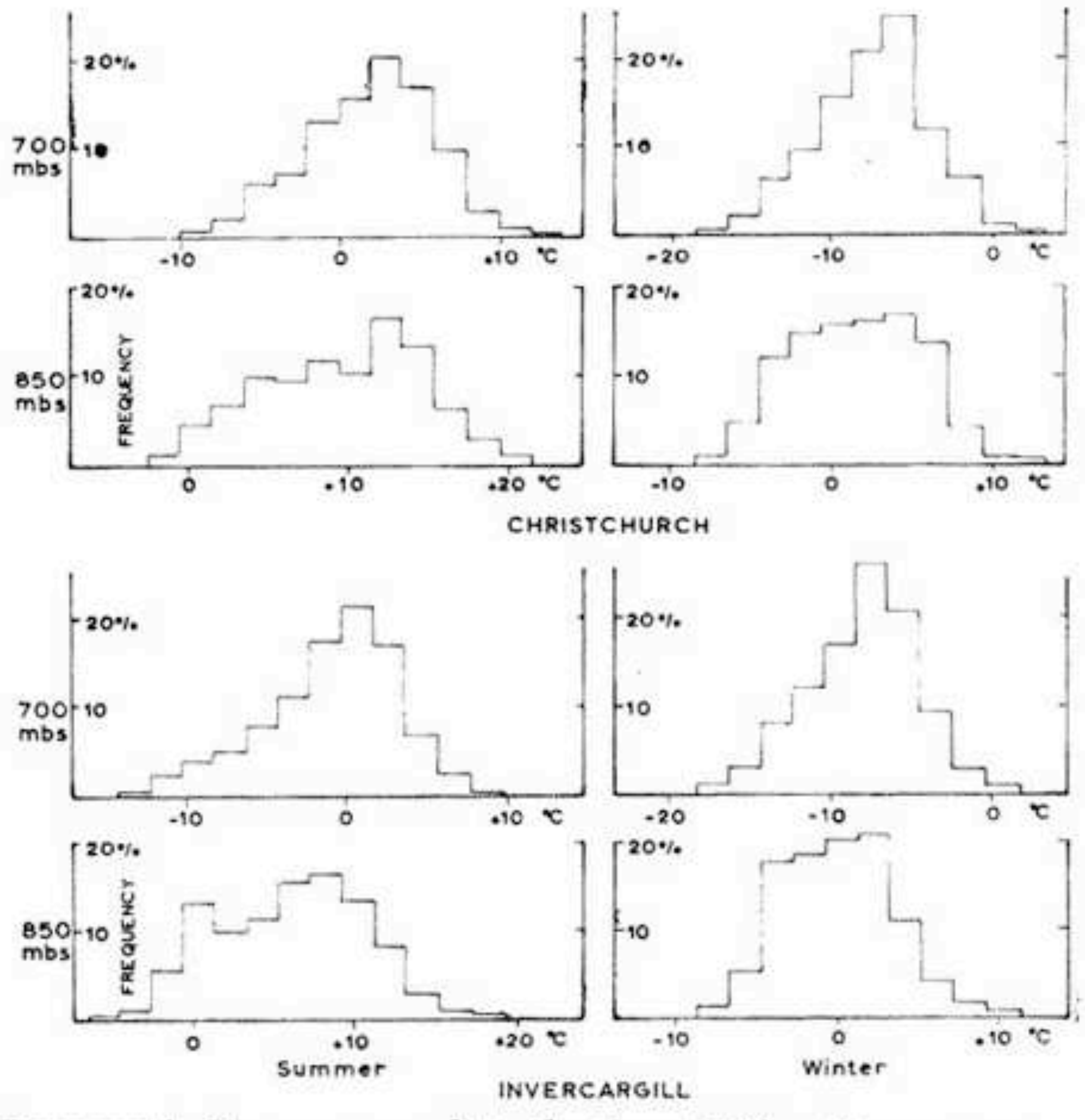


FIGURE 4. *Frequency distribution (%) of temperature in free air. (Data as in Fig. 2.)*

The distributions deviate widely from normal, although at 700 mb. (as at the surface) there is a marked mode. At 850 mb. the distribution is flat-

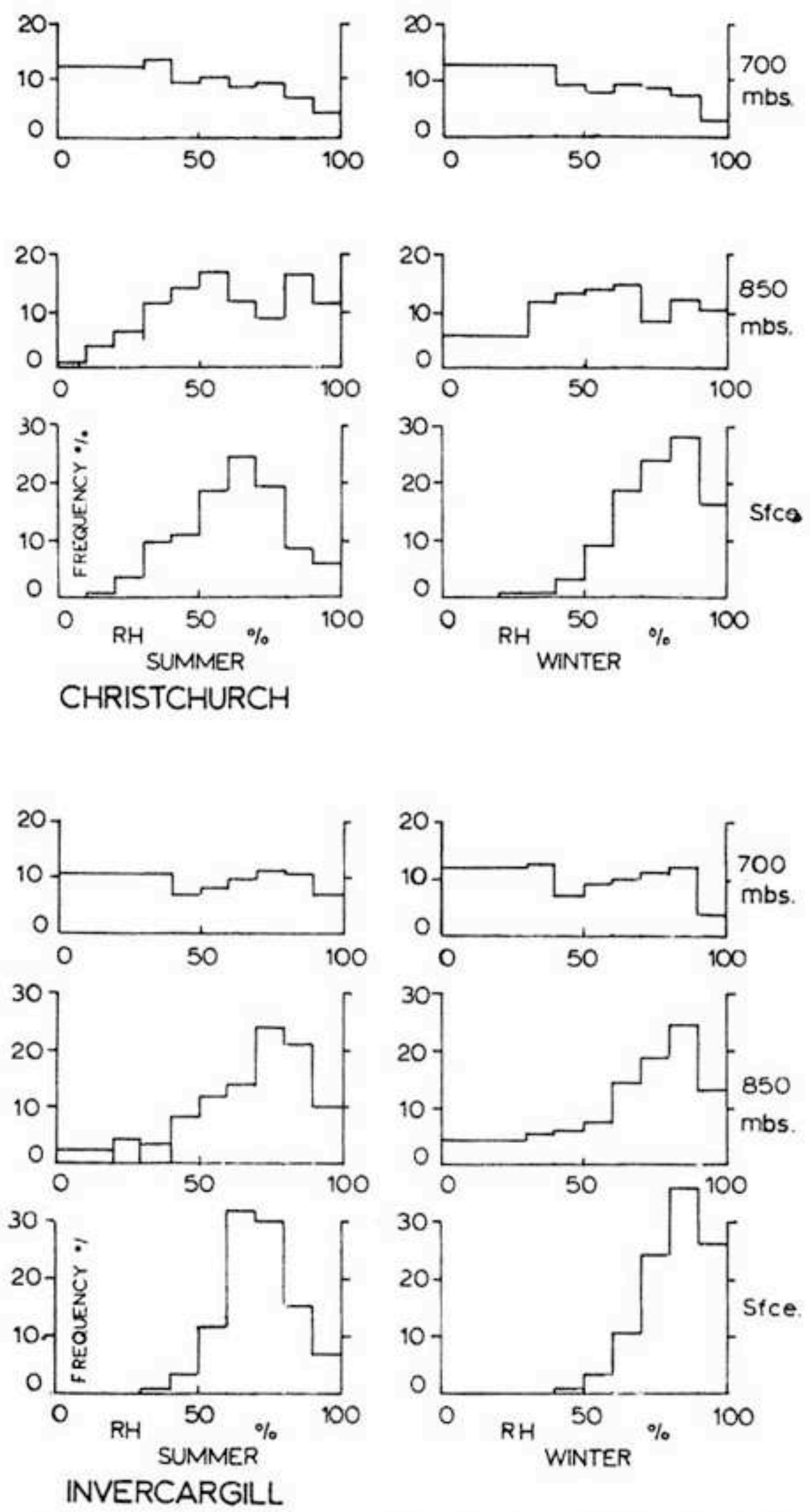


FIGURE 5. *Frequency distribution (%) of relative humidity values in free air. (Data as in Fig. 2.)*

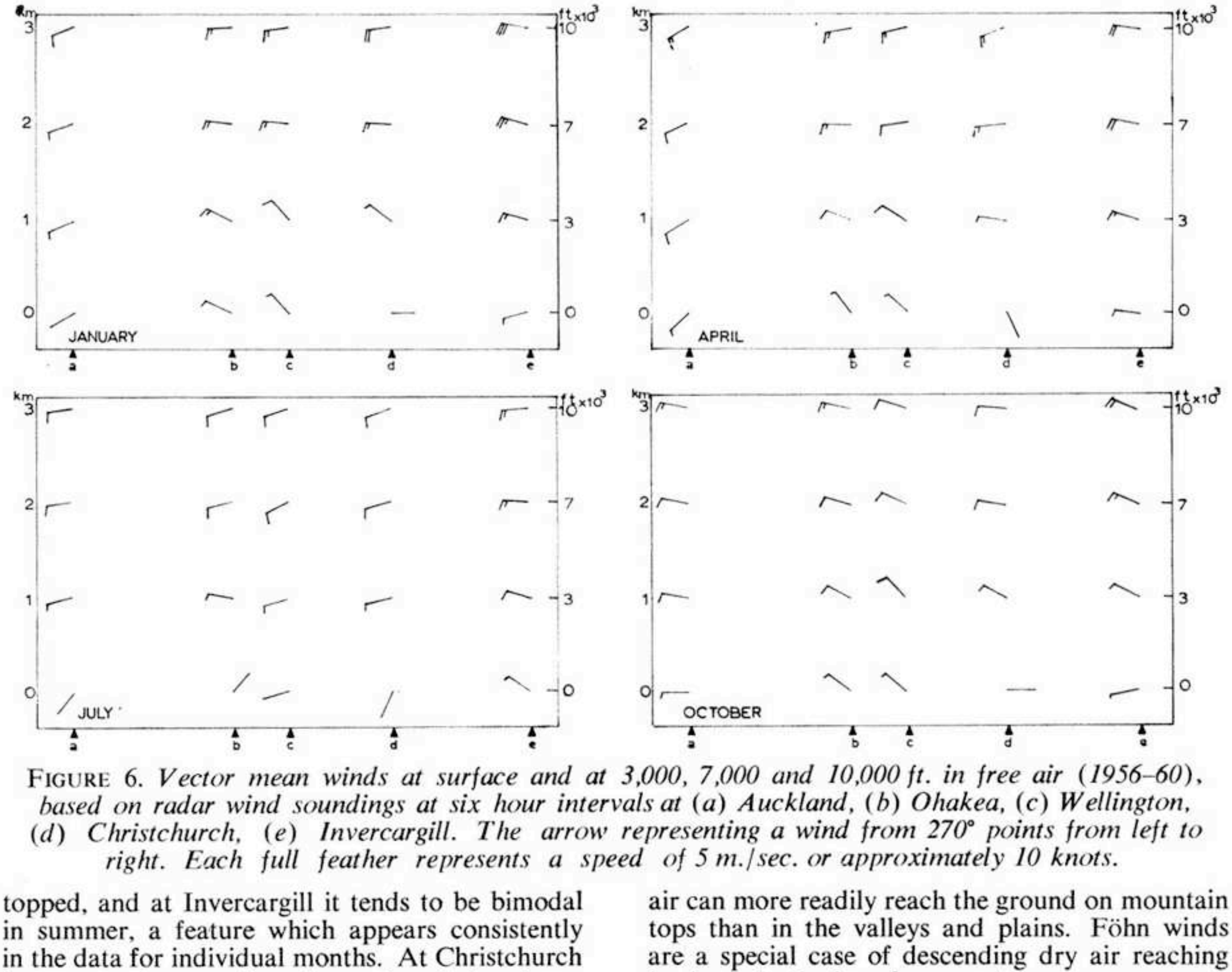


FIGURE 6. *Vector mean winds at surface and at 3,000, 7,000 and 10,000 ft. in free air (1956–60), based on radar wind soundings at six hour intervals at (a) Auckland, (b) Ohakea, (c) Wellington, (d) Christchurch, (e) Invercargill. The arrow representing a wind from 270° points from left to right. Each full feather represents a speed of 5 m./sec. or approximately 10 knots.*

topped, and at Invercargill it tends to be bimodal in summer, a feature which appears consistently in the data for individual months. At Christchurch in summer there are few observations below freezing point at 850 mb. but an appreciable number (about 10%) are found at Invercargill at this level.

Relative humidity

Frequency distributions of relative humidity for Invercargill and Christchurch are shown in Figure 5. In contrast to the surface, where relative humidity tends to be concentrated around a distinct and relatively high modal value (especially in winter), the upper levels show a gradual transition and there is nearly uniform distribution throughout the range from high to low values at 700 mb. On account of instrumental limitations at low temperatures, there is a degree of uncertainty in some of the humidity data in the range 0 to 30%. In these instances the data in this range have had to be combined into one class. Low relative humidities are caused by large-scale descending motion in the free air. It is evident that this dry air can more readily reach the ground on mountain tops than in the valleys and plains. Föhn winds are a special case of descending dry air reaching lowlands in the lee of a mountain range.

Wind

Figure 6 shows mean vector winds at the surface and at approximate heights of 0.9, 2.1 and 3 km. (3,000, 7,000 and 10,000 ft., corresponding to standard pressure surfaces of 900, 800 and 700 mb.) at radar wind finding stations. But for a few exceptions at the surface, all winds have a westerly component and, except at the highest levels and in the far south, they are relatively weak.

Figure 7 shows the profile of average wind speed without regard to direction. It reaches a maximum of 17 metres per second (34 knots) at 3 km. above Invercargill in January. A marked October maximum at all levels is found only at Auckland (Gabites 1953). The effect of Cook Strait is evident in the high wind speeds that are found up to 7,000 ft. at Wellington when compared with the relatively light winds at Christchurch. There is

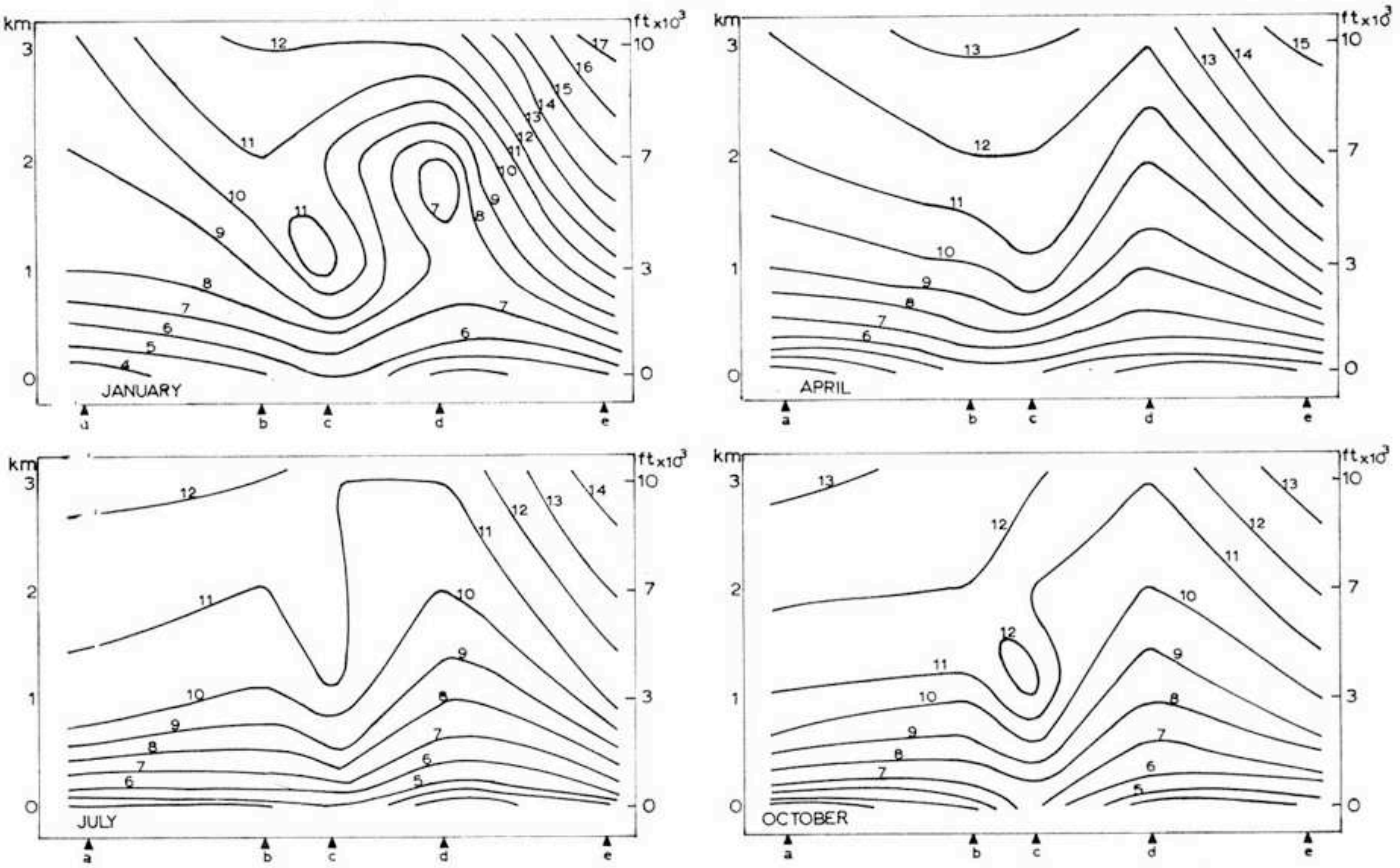


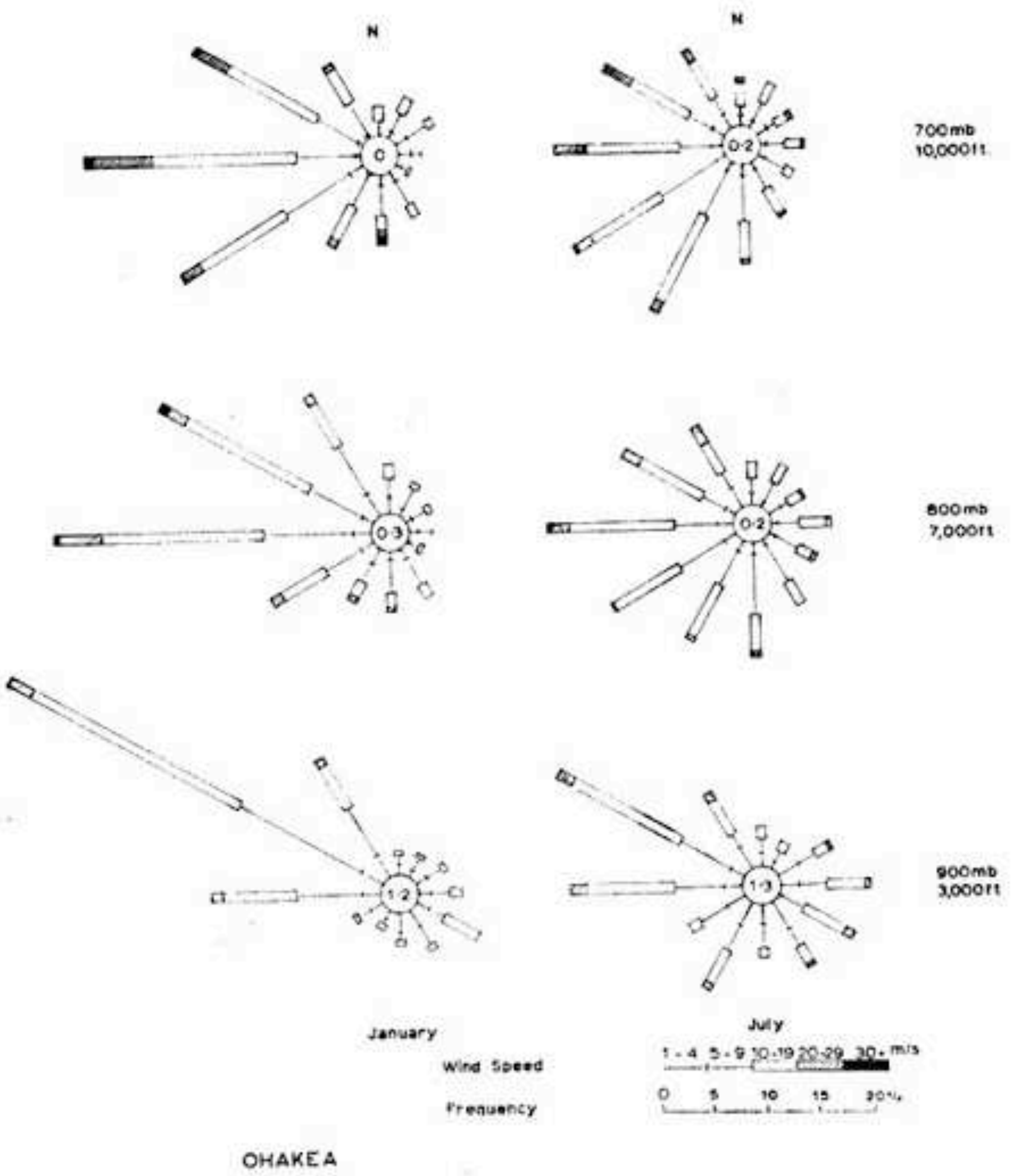
FIGURE 7. *Profiles (N–S) of average wind speed (m./sec.) in free air, without regard to direction. (Data as in Fig. 6.)*

a rapid increase in wind speed with height, much of it within the friction layer near the surface. The distribution of upper winds is shown by wind roses (Fig. 8). Noticeable features are the relatively symmetrical distributions (i.e., the variances of east-west and north-south wind components are roughly equal) and the great preponderance of westerlies at the highest level, particularly at Invercargill in January. Orographic influences are evident at low levels at Wellington in the number of southerlies and at Ohakea in the high frequency of easterlies, and at both in the high frequency of northwest or north-northwest winds instead of westerlies. They are also evident at Christchurch in the large number of northeasterlies and southwesterlies.

SURFACE CLIMATE INVESTIGATIONS IN NEW ZEALAND MOUNTAINS

New Zealand ecologists have often speculated about the influence of mountain climate on vegetation and animals; but until recently the climatic data used were necessarily based on extrapolation from lower levels and were supplemented by sporadic observations and impressions gathered on occasional visits to the mountains. Cockayne (1928) attributed major significance to snow-lines and snow cover in defining his alpine, sub-alpine and montane zones. He also pointed to the ecological significance of short dry periods in a generally humid climate. Zotov (1938) elaborated on the criteria for altitudinal zonation in the New Zealand area and pointed out the importance of high humidity, fog and cloud cover and strong winds in the ranges exposed to the west. Observations of cloud cover on the tops of the Tararua Range (Zotov *et al.* 1938), the Ruahine Range (Elder 1965) and the Kaweka Range (Elder 1959) were perhaps the first systematic series of quantitative data on mountain climate in New Zealand; but since they were made from a distance they were necessarily imprecise.

Wardle (1964) further discussed altitudinal zonation. Although his divisions of the altitudinal sequence took account of "broad climatic relations" they were based almost entirely on the characteristics of the vegetation, as the climatic factors considered significant are known in detail only for the lowlands. In his discussion of alpine



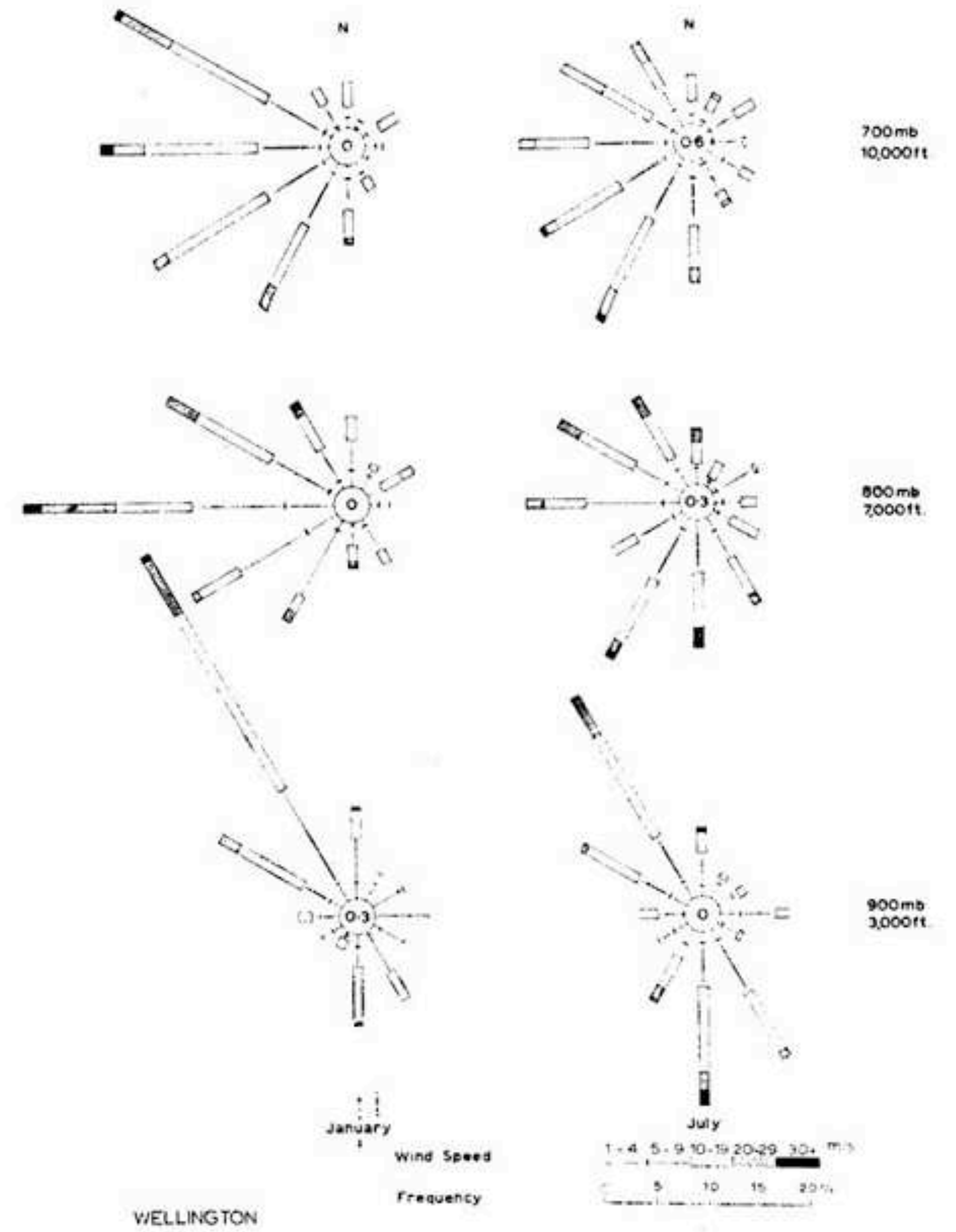
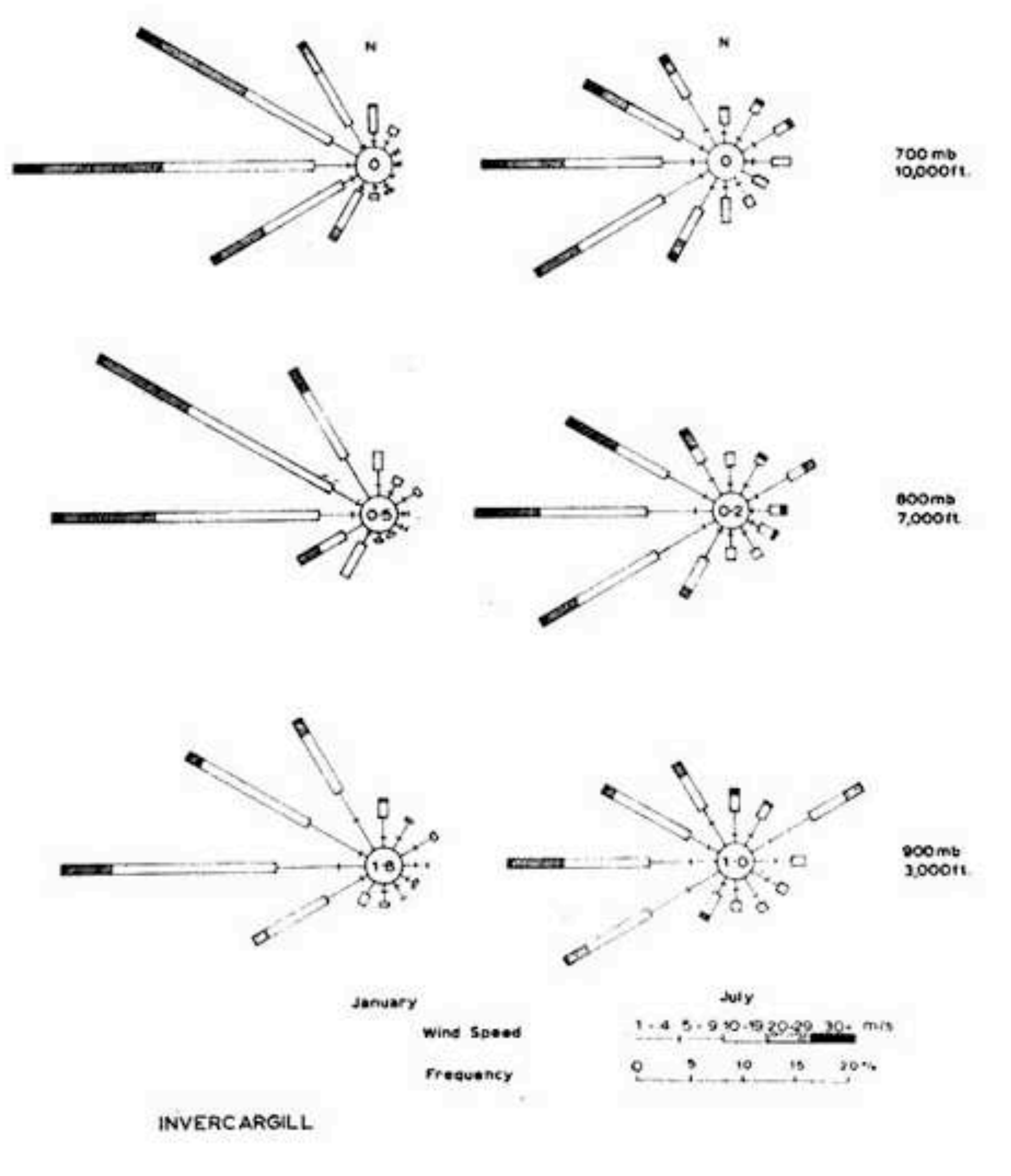
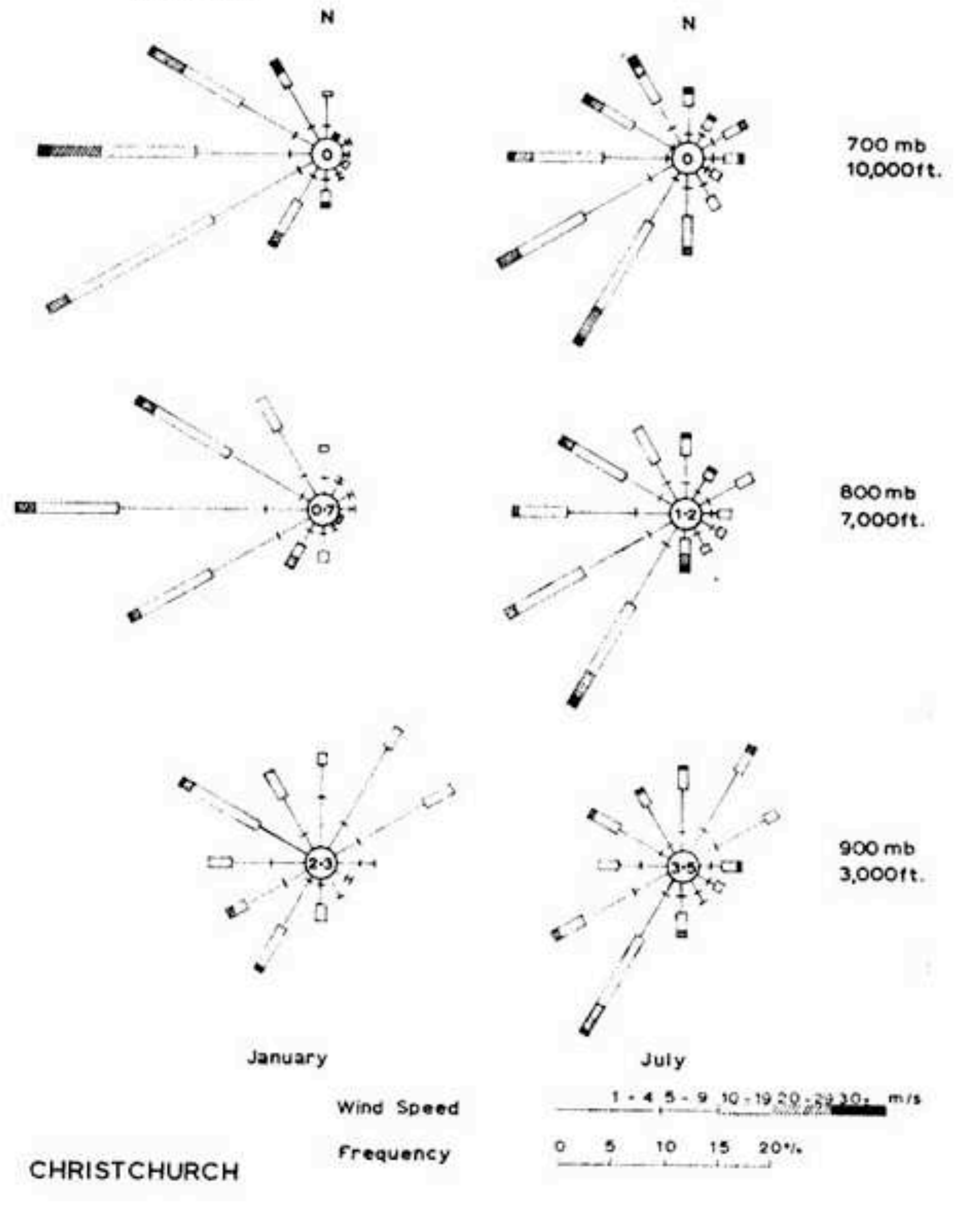


FIGURE 8. *Distribution of winds in free air: frequency (%) of winds from each 30° sector in the speed ranges indicated, and of calms (in circle). (Data as in Fig. 6.)*





timber lines, however, Wardle (1965) made use of temperature measurements from contrasting sites to explain some of the observed variations of the timber lines, e.g., their depression in valley bottoms (where low night temperatures were found) and in sites where spring snow cover kept soil temperatures down. Low temperatures in spring, factors leading to winter desiccation, and other aspects of snow cover were also considered important. Some of these factors had previously been discussed by Wardle and Mark (1956), with reference to some hill climate observations they made in the Dunedin area, and by Baylis (1958). The influence of wind and of catastrophic storms at long intervals has also been discussed (Grant 1963).

In the last 10 to 15 years a growing number of investigators have measured elements of climate in New Zealand high country, mostly as part of ecological studies. Fisher (1952) measured certain meterological elements (air-, surface- and soil temperatures; rainfall, etc.) in the Craigieburn Range in the course of an investigation of screes and scree plants in 1946–48. He found rainfall about 50% greater at 4,000 ft. than at 2,000 ft., and indicated the probable significance of periods of high surface temperature, low relative humidity, strong insolation, and strong winds in this environment. As part of an ecological study of tussock grassland at Hunters Hills, South Canterbury, in 1947–48, Barker (1953) set up two climate stations at 1,500 and 3,000 ft. on north-facing slopes. Air temperature, extreme soil temperatures, and comparative evaporation values were read once a month for twelve months and monthly rainfall totals recorded for three years. Rainfall was about 40% more at 3,000 than at 1,500 ft., and at the latter altitude was about 35% more than at a nearby station at 800 ft. The decrease in air temperature with height was noted and contrasts of temperature and moisture conditions arising from aspect were emphasised.

Gradwell (1955, 1962), in soil frost studies in Marlborough — at Molesworth and Black Birch — and in the Opuha Catchment in South Canterbury (1960), made microclimatic measurements at 3,000–4,000 ft. in snow tussock grasslands. He measured soil temperature at a depth of one inch and temperatures in and under snow cover in a variety of situations. He also investigated the effects of relatively thin layers of vegetation and of snow and scree in reducing extremes of temperature and preventing the formation of ice needles. Of wide scope is the work of the Forest Service in the Craigieburn Range (Morris 1965, Morris and O'Laughlin 1965) which has sampled the climate on eastern, i.e., leeward, South Island ranges from 3,000 to 6,000 ft. with (almost) daily readings of air temperature and precipitation. Microclimatic measurements of soil temperature and air temperatures in vegetation, and snow surveys have been made. Continuous wind recording has been started at one of the stations (at 4,700 ft.) which is now also designated as an Experimental Basin station of the International Hydrological Decade. Considerable progress has also been made in Otago:—Mark (1965a), using limited resources, measured extremes of air and soil temperature, wind run, evaporation and precipitation and collected observations of weather on the Old Man Range in 1958. This work produced useful new knowledge of a contrasting mountain environment rising to 5,300 ft. Its salient characteristics were high average wind speed, cloudiness and precipitation on the broad plateau tops and a steep lapse rate of temperature with height. Investigations have continued on other Otago mountain ranges: Rock and Pillar, Pisa, Coronet Peak, Haast Pass, etc. (Mark 1965b and pers. comm.); and Gillies (1964) has reported attempts to measure snowfall and snow cover in the same area. Molloy (1963) used similar methods on the Torlesse Range — i.e., visits at weekly intervals to read maximum and minimum thermometers — and he established approximate values for the normal rainfall and the range of temperature at two stations at 3,500 and 4,500 ft.

Climatological observations in connection with field studies are being made at Makahu Saddle in the Kaweka Range by the N.Z. Forest Service, and at Glentanner, Tasman Valley, by the D.S.I.R. In both instances reference climatological stations at approximately 3,000 ft. are operated in co-operation with the Meteorological Service, and data are to be summarised for routine publication. Some high level observations are also being made, primarily for engineering purposes, in the Mt Cook National Park area by the Ministry of Works in co-operation with the Meteorological Service. Microclimatic observations have been made at the University of Canterbury field station at Cass (Soons, pers. comm.).

New climatological stations have recently been started at Wharite Peak in the Ruahines and at Mt Te Aroha, both at approximately 3,000 ft., and on Mt John at 3,400 ft. Other climatological stations at relatively high elevations or in generally mountainous regions are the Chateau (Tongariro National Park, 3,620 ft.), Cobb Dam (2,701 ft.), Stratford Mountain House (2,775 ft.), Molesworth (2,930 ft.), Craigieburn Forest (3,000 ft.), The

Hermitage (2,500 ft.) and Waiouru (2,700 ft.). In addition there are a large number of rain-gauge stations, mostly equipped with storage rain-gauges, in the mountain areas.

Finally, two important mountain climate investigations, which will be discussed in more detail, have been made in recent years at Black Birch Range (4,580 ft.) and Cupola Basin (4,700 ft.) in the Marlborough and Nelson mountains respectively (Fig. 9). Black Birch was maintained as a temporary astronomical site testing station by Mr F. Bateson for approximately 2 years, from June 1961 to April 1963. Cupola Basin in the Nelson Lakes National Park was the site of the co-operative animal ecology study recently conducted by D.S.I.R. and Forest Service. Climatological and weather reporting stations were set up in co-operation with the Meteorological Service at both places. The report on the astronomical site comparisons published by Bateson (1964) includes detailed summaries of most of the meteorological data from Black Birch and from certain other sites. These data, and others obtained later from instruments maintained by the Marlborough Catchment Board, are summarised here in a form which, it is hoped, will be convenient for both ecologists and meteorologists. Use has also been made of a preliminary summary of some of the early Black Birch data prepared by Finkelstein (pers. comm.).

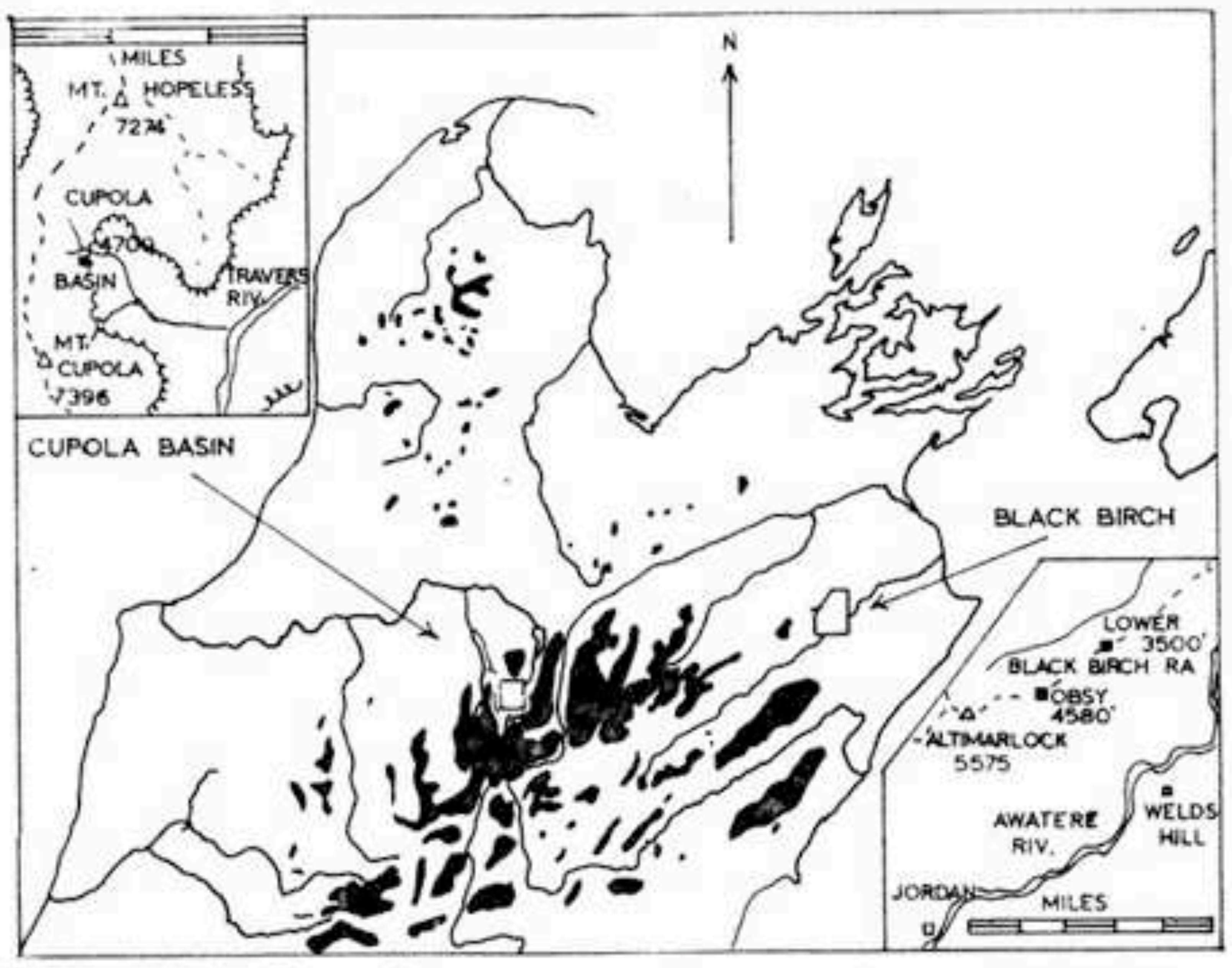


FIGURE 9. *Locality map. Areas above 5 000 ft. shaded.*

The climate of Cupola Basin will be described in detail elsewhere (Batcheler, Coulter, Christie in preparation) but some preliminary results are given here for comparison with Black Birch and as a background for later papers in this symposium.

THE CLIMATE OF BLACK BIRCH RANGE AND COMPARISON WITH CUPOLA BASIN

Detailed climatological observations made at 3-hourly intervals are available from February 1962 to April 1963, and earlier night observations have been included in the site test report (Bateson 1964). In general, observations at 3 a.m. and 6 a.m. were made only if the sky was clear and dark. Observations at noon and 3 p.m. were discontinued in 1963. In some periods hourly observations were made at night. Thus all hours are not equally represented and there is bias towards fine weather at some of them. In the results that follow data likely to contain such bias have not been used. From June 1963 till March 1964 weekly readings of temperatures and rainfall were made by the Marlborough Catchment Board and a thermograph maintained for part of this time. A storage rain-gauge was installed at the summit of the range (Altimarlock, 5,575 ft.) in December 1961 and at a lower site ("Black Birch Lower") at 3,500 ft. in September 1963. Up to April 1963 the summit gauge was read weekly. Since 1964 rainfall measurements have been made at irregular intervals at the three sites, all being now (1966) equipped with "octapent" storage rain-gauges.

Observations at 9 a.m. at Cupola Basin cover the period April 1963 to April 1966, with varying numbers in each month (some 400 in all). Thus, the records for both places are short. In addition,

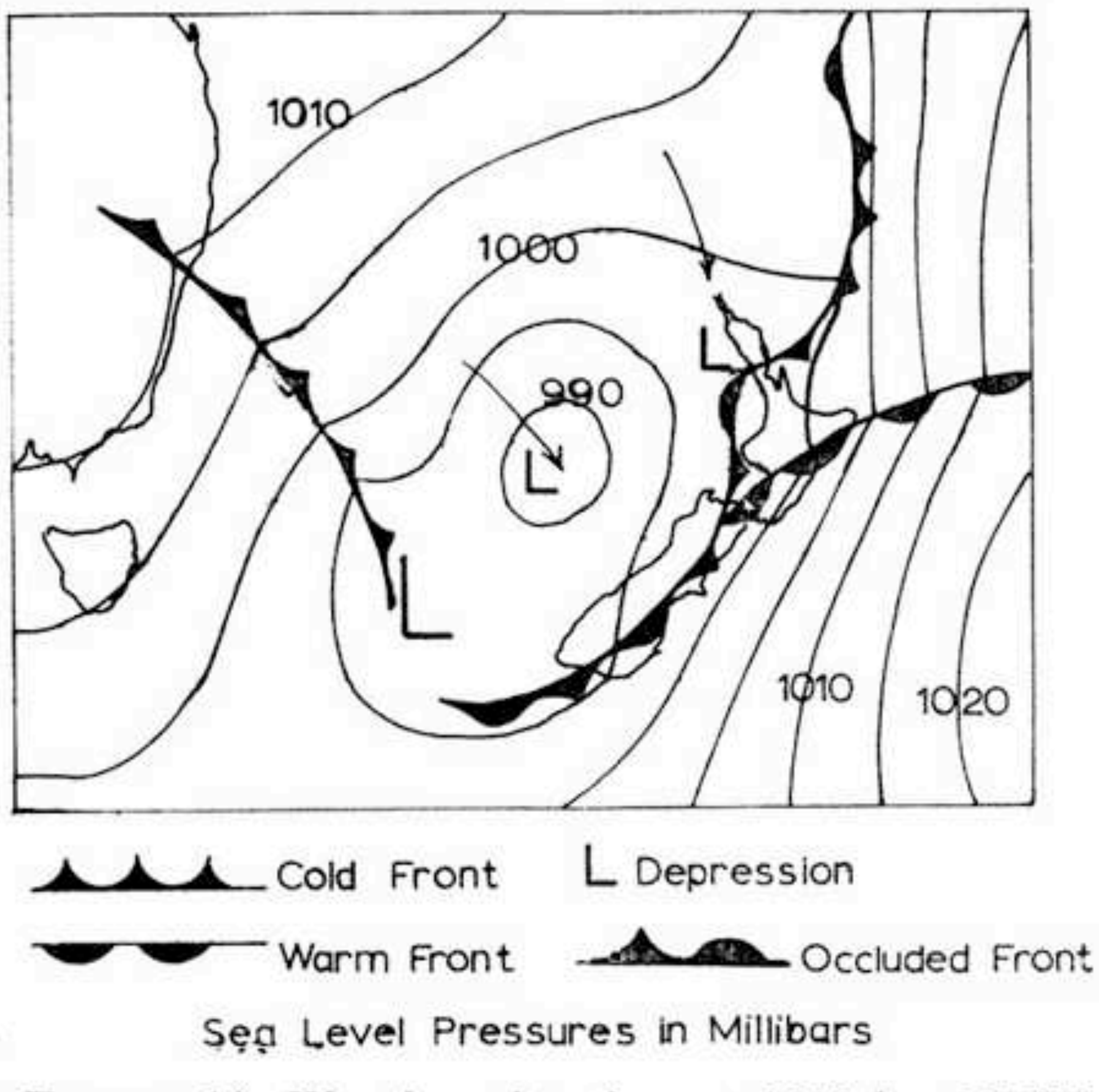


FIGURE 10. *Weather situation at 0000 hrs NZST, 1 June 1962, associated with heavy rain in the Marlborough and Nelson Mountains.*

the Cupola records are of discontinuous periods in the selection of which there may have been some bias.

The instruments used at both stations were standard N.Z. Meteorological Service equipment. At Black Birch they included an electric remote-reading cup anemometer head 15 ft. above ground), a Campbell Stokes sunshine recorder, and a raised pan evaporimeter. Exposure and methods of observation were as far as possible in accordance with the usual standards set by the Service. Table 2 summarises the climatological observations made at Black Birch Observatory.

Exposure and winds

The Black Birch Range rises from the Awatere Valley about 20 miles from the sea. It overlooks

TABLE 2. CLIMATOLOGICAL SUMMARY

BLACK BIRCH OBSERVATORY LAT. 41° 45'S LONG. 173° 48'E ELEVATION 4580 FEET 1396 METRES

BASED ON OBSERVATIONS June 1961 - April 1963, August 1963 - March 1964 UNLESS OTHERWISE STATED

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
TEMPERATURES (°F)													
MEAN: ½ (MAX + MIN)	52	51	47	43	43	36	33	33	36	43	44	49	42.4
MEAN DAILY MAXIMUM	59	58	53	49	46	42	38	38	42	49	51	56	48.6
MEAN DAILY MINIMUM	45	44	40	37	37	30	28	28	31	36	37	41	36.2
MEAN DAILY RANGE	14	14	13	12	10	12	10	10	11	13	14	15	12.4
MEAN MONTHLY MAXIMUM	70	70	65	57	58	56	46	46	54	63	65	68	71
MEAN MONTHLY MINIMUM	32	31	30	26	26	18	20	18	21	27	23	28	17
HIGHEST MAXIMUM	71	72	65	58	58	57	59	48	58	68	67	70	72
LOWEST MINIMUM	29	30	29	25	26	15	20	17	21	26	21	26	15
EARTH TEMPERATURES AT 9 A.M.													
1 FOOT Jan 1962-March 1963, July 1963-March 1964	52	54	49	44	42	37	34	34	37	42	45	49	43.3
3 FEET March 1962-March 1963, July 1963-March 1964	49	53	50	46	44	40	37	36	37	41	44	47	43.6
RELATIVE HUMIDITY (%)													
MEAN AT 9 A.M. Aug 1961-March 1963	64	68	69	71	77	65	71	76	76	69	66	71	70.2
BRIGHT SUNSHINE (HOURS) March 1962-March 1963	268	182	173	173	132	156	123	157	177	158	210	232	2141
RAINFALL (INCHES)													
ESTIMATED LONG PERIOD AVERAGE	3	4	3	4	4	4	5	5	5	5	4	4	50
NUMBER OF RAINDAYS June 1961-March 1963	10	10	14	13	22	11	12	14	14	12	14	10	156
MAXIMUM DAILY RAINFALL June 1961-March 1963	2.91	1.47	1.69	2.12	4.87	1.11	2.67	1.17	1.37	1.50	1.71	1.97	4.87
SPECIAL PHENOMENA: MEANS													
DAYS OF GALE	6	8	4	6	3	3	4	3	2	10	8	6	63
DAYS OF SNOW	0	0.5	1	2	0	7	8	5	7	0	2	1	33.5
DAYS OF HAIL	0.5	0.5	2	2	1	2	1	2	2	0	2.5	0.5	16
DAYS OF FOG	13	14	18	17	22	12	9	10	17	15	16	16	178
DAYS OF FROST IN SCREEN (Min. below 32°F)	1	1	2	3	3	16	20	26	18	6	5	2	95
DAYS WITH SCREEN MAXIMUM BELOW 32°F (ICE DAYS)	0	0	0	0	0	3	5	5	2	0	0	0	15
WIND													
AVERAGE SPEED AT 9 A.M.(KTS) June 1961-March 1964	12	12	10	12	14	9	13	11	12	15	11	10	11.8

PERCENTAGE FREQUENCY OF WINDS AT 3 HOURLY INTERVALS Feb 1962-Apr 1963

	NIGHT (21, 00, 03 HRS NZST)								DAY (09, 12, 15 HRS)								ALL HOURS (3 HOURLY)							
	N	NE	E	SE	S	SW	W	NW	N	NE	E	SE	S	SW	W	NW	N	NE	E	SE	S	SW	W	NW
SPEED 3 - 13 kts	3	+		1	11	8	9	10	9	2	1	4	12	2	4	16	6	1	1	3	11	5	7	13
14 - 27 kts	2				4	1	5	12	2		+	1	2	1	2	14	2		+	+	3	1	4	14
28 - 40 kts	1						2	9	1				+	+	1	6	1				+	+	1	7
over 40 kts	+				+		+	+	+						+	1	+				+		+	1
CALM (0 - 2 kts)								22								17								20
No. of Obs.								1138								1080								2735

(+ : less than 0.5)

PERCENTAGE FREQUENCY OF FOG (f) AND CLOUD AMOUNTS (N) AT 3 HOURLY INTERVALS Feb 1962 to April 1963

	NIGHT (21, 00, 03 HRS NZST)					DAY (09, 12, 15 HRS)					ALL HOURS (3 HOURLY)				
N(EIGHTHS)	f	6,7,8	3,4,5	0,1,2	No. of Obs.	f	6,7,8	3,4,5	0,1,2	No. of Obs.	f	6,7,8	3,4,5	0,1,2	No. of Obs.
SPRING	28	49	6	45	233	27	62	12	26	272	28	56	10	33	615
SUMMER	21	46	9	45	294	25	58	12	30	234	23	53	10	38	665
AUTUMN	29	49	7	44	316	35	61	6	32	315	31	55	7	38	804
WINTER	19	45	10	46	211	21	56	9	35	275	21	51	10	40	592
ALL SEASONS	24	47	8	45	1054	27	58	10	32	1109	26	54	9	37	2678

Cook Strait, and is separated from the sea to the southeast by lower ranges. It is thus close to some of the driest and sunniest places in New Zealand. (Near Blenheim and Lake Grassmere, annual rainfall is between 22 and 27 inches, and at Blenheim average sunshine duration exceeds 2,400 hours per year.) Extensive high country lies to the west and south. Cupola Basin in the Travers Range is centrally situated, being a little nearer to the sea (50 miles) to the north and west than to the east. The range is fairly open to winds from the sea from the north and west, but there are extensive higher ranges to the south and east (Fig. 9). Hence Cupola Basin receives fairly heavy precipitation from disturbances with low level westerly or southwesterly winds from which Black Birch generally receives much less. Conversely, rain falling in deep easterly or southeasterly airstreams may be heavy at Black Birch but is generally negligible at Cupola. In both areas the heaviest falls result from depressions from the Tasman Sea moving across the Cook Strait area. The supply of moisture is in the deep north or northwest airstream which flows to the north of, and aloft across, such a depression. Such a system, shown in Figure 10, gave 4.87 inches of rain at Black Birch on 31 May 1962. Heavy rain also fell over the Travers Range, as 2 to 3 inches were recorded at low level stations in the vicinity.

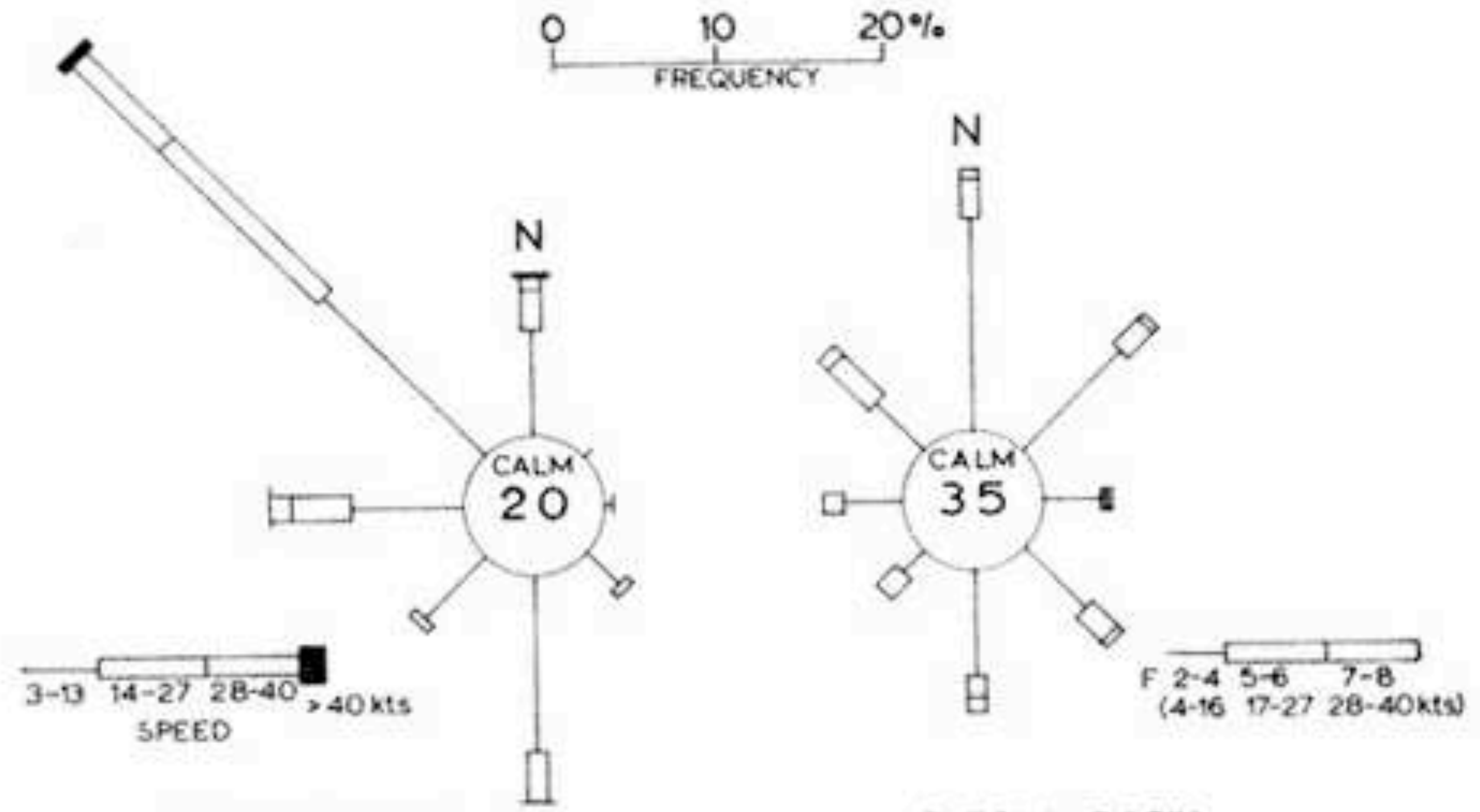


FIGURE 11. *Frequency (%) of winds at Black Birch based on 3-hourly observations (Feb. '62–April '63); and at Cupola Basin, based on non-instrumental observations at 9 a.m. of wind force (F) on Beaufort scale (April '63–April '66).*

Although the mountains to the northwest and west give some rain shadow effect at Black Birch they do not prevent strong winds and cloud from influencing the range in northwesterlies. The station at Black Birch was located on the crest of a broad-topped gently-sloping ridge which rises about 1,000 ft. to Altimarlock summit a mile and a half to the west. Hence the surface wind regime at Black Birch (Fig. 11) closely resembles that of the free air, as may be seen by comparison with the Wellington wind roses for 3,000 and 7,000 ft. (Fig. 8b). The average wind speed at Black Basin during February 1962 to March 1963 was 13.0 kts (6.6 m./s.). Comparison with Wellington records suggests that the long period average is probably about 14 kts (cf. Wellington (Kelburn) 8 kts, Wellington Airport (Rongotai) 14 kts). The average wind speed at approximately the same altitude in the free air above Wellington is 22 kts (11.1 m./s.).

Cupola Basin is situated in a higher mountain range, of more alpine character than Black Birch. It is surrounded by peaks and ridges rising to over 7,000 ft. These are within a mile or two to the north and south, and even closer to the west (Fig. 9). Hence local sheltering effects are important and dominate the surface wind distribution as shown in Figure 11. The average speed is approximately half that at Black Birch; the frequency of calms is much greater (Table 3), and very few gales were reported. (Cupola observations were non-instrumental estimates of wind force on the Beaufort scale. The average speeds given are approximate equivalents of the average Beaufort force.)

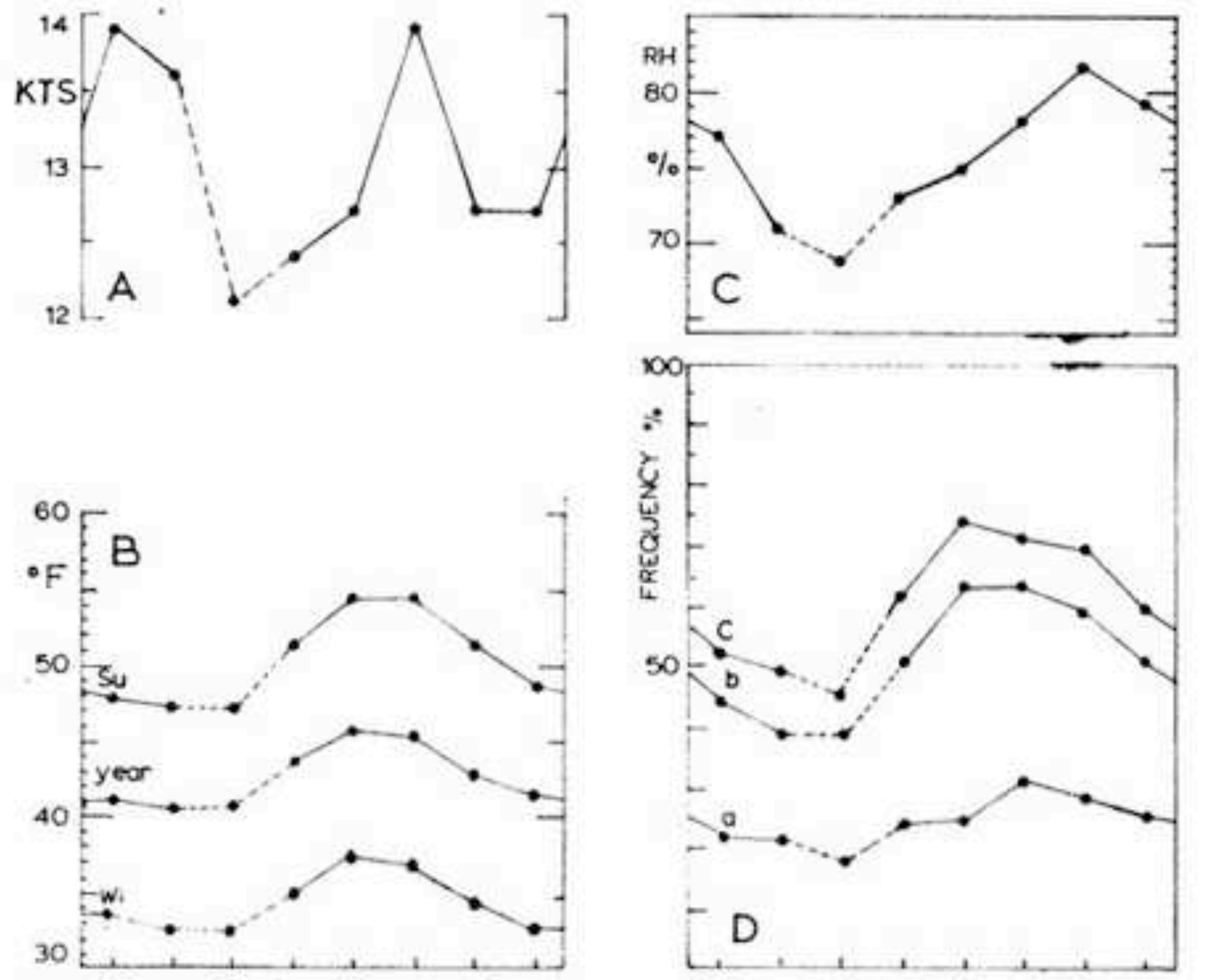


FIGURE 12. *Diurnal variations at Black Birch: (A) average wind speed, (B) average temperatures, (C) average relative humidity, (D) frequency (%) of (a) fogs, (b) cloud amounts (N) more than 5/8, and (c) cloud amounts more than 2/8. (Temp. July '61–March '63; otherwise Feb. '62–March '63.)*

TABLE 3. *Seasonal variation of surface wind at Black Birch (BB) and Cupola Basin (CB).*

		Summer		Autumn		Winter		Spring		Year	
		BB	CB	BB	CB	BB	CB	BB	CB	BB	CB
Frequency of calm and force 1 at 9 a.m. (%)	(a)	29	34	27	50	23	26	17	29	22	35
Average speed at 9 a.m. (knots)	(a)	11	6	12	6	11	8	13	8	12	7
Average speed from 3-hourly ob. (knots)	(b)	12.7	—	12.4	—	13.5	—	13.6	—	13.0	—

(Black Birch: (a) June 1961–March 1963, (b) Feb. 1962–March 1963. Cupola: April 1963–April 1966, 414 ob.).

At Black Birch there is a small diurnal variation in average wind speed (Fig. 12A) which nevertheless appears fairly consistently in individual months. The range from minimum to maximum is 1.8 kts or 14% of the average speed. There are two maxima, one near midnight and one in the afternoon, and two minima, the major one probably near 6 a.m. and the lesser in the evening. The characteristic diurnal variation of wind speed at lowland sites is a mid-day or afternoon maximum and a night-time minimum, reversing in phase at a height of a few hundred metres above the surface (Geiger 1965, p. 114). An evening maximum has been reported at a number of hilltop stations in New England (Putnam 1948, p. 91). Black Birch is interesting in that both effects appear to be present.

The records are too short to establish seasonal trends with accuracy. Table 2 gives monthly averages of 9 a.m. wind speeds at Black Birch for the full period of observations. Table 3 gives seasonal data for both stations.

Whereas calms were considerably more frequent in summer and autumn at both stations the average speed in the four seasons was not much different, winter and spring being windier than summer and autumn on the whole. However, at Black Birch, October 1962 was a month of particularly strong winds and the months October to February experienced many more gales than the rest of the year. Some seasonal differences were evident in the wind directions recorded at Black Birch. Although west to north winds predominated in all seasons — over a third of night-time winds were from 310 degrees to 340 degrees in spring, summer, and autumn — there was a relatively greater proportion (35%) of southerly to westerly winds in winter. In other seasons 19–23% were from 170 degrees to 250 degrees (Bateson 1964, p. 125).

Although the period of observations at Black Birch is too short for these differences to be accepted as entirely representative, their validity is supported by the somewhat similar differences in the upper wind distributions in July and January at Wellington illustrated in Figure 8b.

There is a marked relationship between wind direction and average cloud cover as shown in Table 4 which also gives the distribution of night-time wind directions and the associated average wind speed.

Southwest to west-southwest winds and calms have the smallest average cloudiness (2.7 to 3.3 oktas or eighths of sky covered) whereas northerlies and easterlies have the most (6–7 oktas). Cupola Basin shows no distinct relationship between surface wind direction and cloud cover, and this reflects the local nature of the winds observed there.

Precipitation

There is much greater precipitation at Cupola than at Black Birch, nevertheless Black Birch receives substantially more than the surrounding valleys. Annual "normals" (i.e., estimates for a standard period, 1921–50, based on comparison with nearby long period stations) are as follows:

Cupola Basin	135 inches
Black Birch	50 inches

and may be compared with the valley stations at Lake Rotoiti (2,080 ft., 13 miles NNE of Cupola) and Welds Hill (950 ft., 3 miles SE of Black Birch, see Fig. 9) which have normals of 61 and 32 inches respectively. Both the number of rain days

TABLE 4. *Frequency (%) of wind directions and associated average wind speed (knots) and amount of cloud (oktas) at night at Black Birch (after Bateson 1964, p. 124).*

Direction (degrees)	Calm	350 to 030	040 to 070	080 to 120	130 to 160	170 to 210	220 to 250	260 to 300	310 to 340
Frequency	12	3	0.2	0.5	6	16	9	21	32
Av. speed	0	10	8	6	0.5	10	7	14	17
Av. amount of cloud	3.3	6.7	7.0	6.6	6.0	4.3	2.7	3.5	5.1

(June 1961–March 1963)

TABLE 5. *Frequency (days per year) of (A) daily rainfalls at least 0.01, 0.1, 1.0 and 2.0 inches, and (B) days in dry periods of duration at least 1, 5 and 10 days.*

	A				B		
	Daily rainfall amount (inches)				Duration of dry period (days)		
	0.01+	0.1+	1.0+	2.0+	1+	5+	10+
	Average frequencies (days per year)						
Cupola Basin	235	135	42	16	130	60	17
Black Birch	145	90	15	2	220	145	32

and the intensity of individual falls are greater at Cupola and the number and duration of dry periods correspondingly less, as shown in Table 5.

The storage rain-gauge at the summit of the Black Birch Range collected, overall, somewhat less precipitation than the observatory gauge; the lower station totals were approximately the same as at the observatory. "Normals" have been tentatively estimated at 45 inches and 50 inches for "Summit" and "Lower" respectively but longer records and, perhaps, more effective gauges are needed for reliable results. The deficiency at the summit may be real since the exposure of the three gauges was similar, all being in some degree over-exposed, that on the summit rather more so than the others. However, as the deficit at the summit was greater in winter than in other seasons it may have been partly because of less efficient catch there, especially of snowfalls. Seasonal ratios amongst the various gauges are given in Table 6. The seasonal distribution of precipitation appears to be similar at Black Birch to that of the surrounding lowland areas.

TABLE 6. *Ratios of seasonal rainfall totals.*

	Summer	Autumn	Winter	Spring	Year
Summit/Observatory	0.9	0.9	0.8	1.0	0.89
Observatory/Welds Hill	1.57	—	1.55	—	1.56

(Based on all records to March 1967)

Snow falls in all seasons at both Black Birch and Cupola Basin. The average depth of snow cover was never very great at Black Birch, the greatest reported being one of 1–2 ft. with up to 9 ft. in drifts. Cupola, on the other hand, has had snowfalls of several feet on a number of occasions. The difference arises partly from the smaller amounts of precipitation at Black Birch and partly from its more exposed situation from which snow is often blown away during the fall or soon afterwards. An indication of the frequency of snowfalls and of snow cover is given by the figures in Table 2, but as snowfalls vary greatly from year to year, they should not be given too much weight as representative values. (In June to September 1961 there were 32 days with snowfall, 82 days with snow cover; in the same months in 1962 there were only 23 and 16 days respectively.) There were many days reported as having snow cover (i.e., more than half the ground covered) in which much bare ground was exposed. Blowing snow not only makes measurement of precipitation difficult but also affects other measurements, e.g., thermometer screens become packed with snow and recording instruments fail.

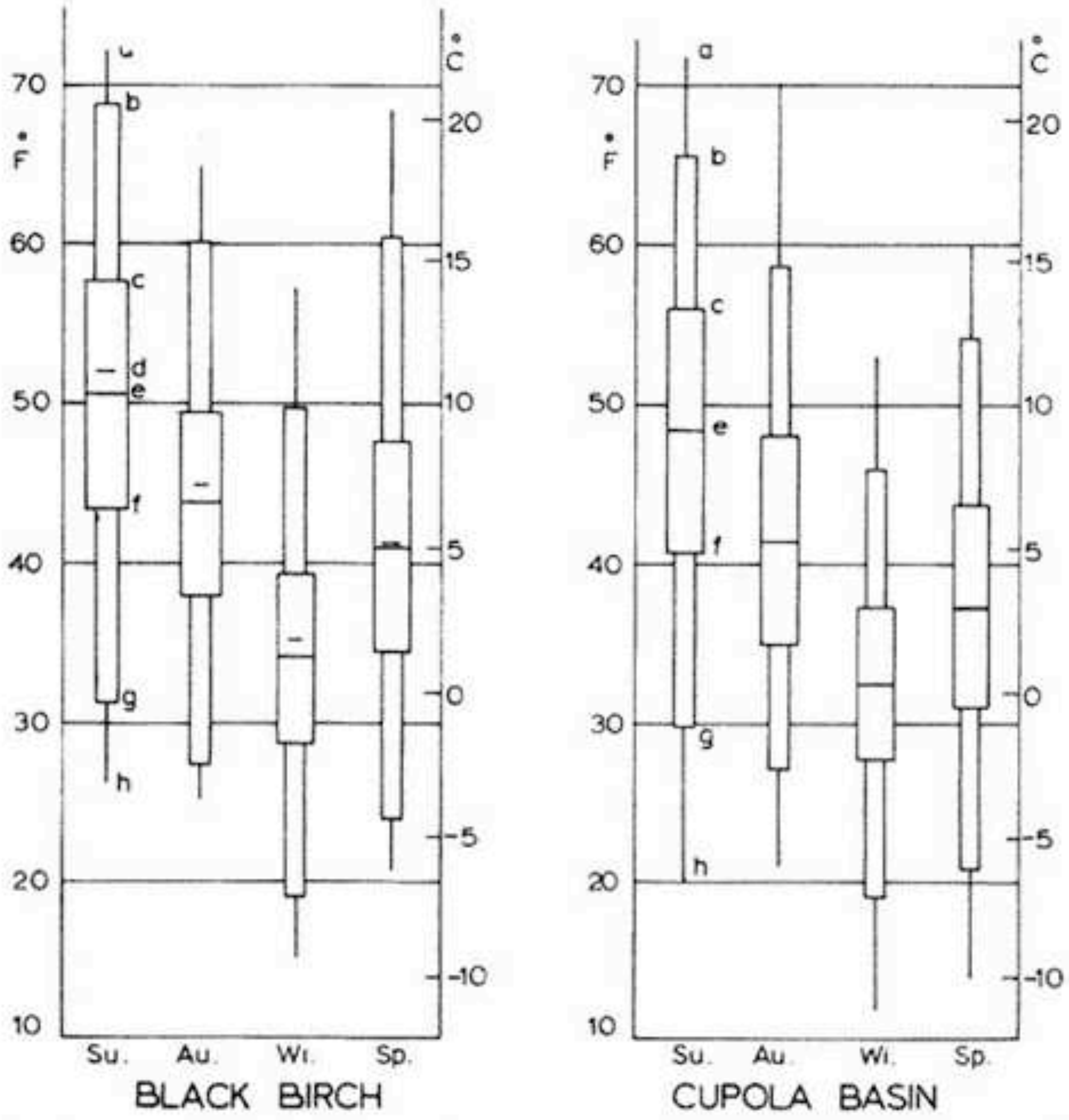


FIGURE 13. *Seasonal averages and extremes of temperature: (a) highest maximum, (b) mean monthly maximum, (c) mean daily maximum, (d) mean 1 ft. earth temperature at 9 a.m., (e) mean: (max.+min.)/2, (f) mean daily minimum, (g) mean monthly minimum, (h) lowest minimum. (Black Birch June '61–April '63, August '63–March '64. Cupola April '63–April '66.)*

Air temperature

Temperature data for Black Birch are summarised in Table 2 for each month. For comparison with Cupola Basin, because of the short period, seasonal temperatures have been illustrated in Figure 13. The mean temperatures are above

TABLE 7. *Average departure from daily mean of 3-hourly temperature at Black Birch.*

Time NZST (hrs)	00	03	06	09	12	15	18	21
Departure from Mean (°F.)	—1.7	—2.4	—2.4	+1.0	+3.3	+2.8	+0.2	—1.2

(Mean = 42.6°F. Feb. 1962–March 1963)

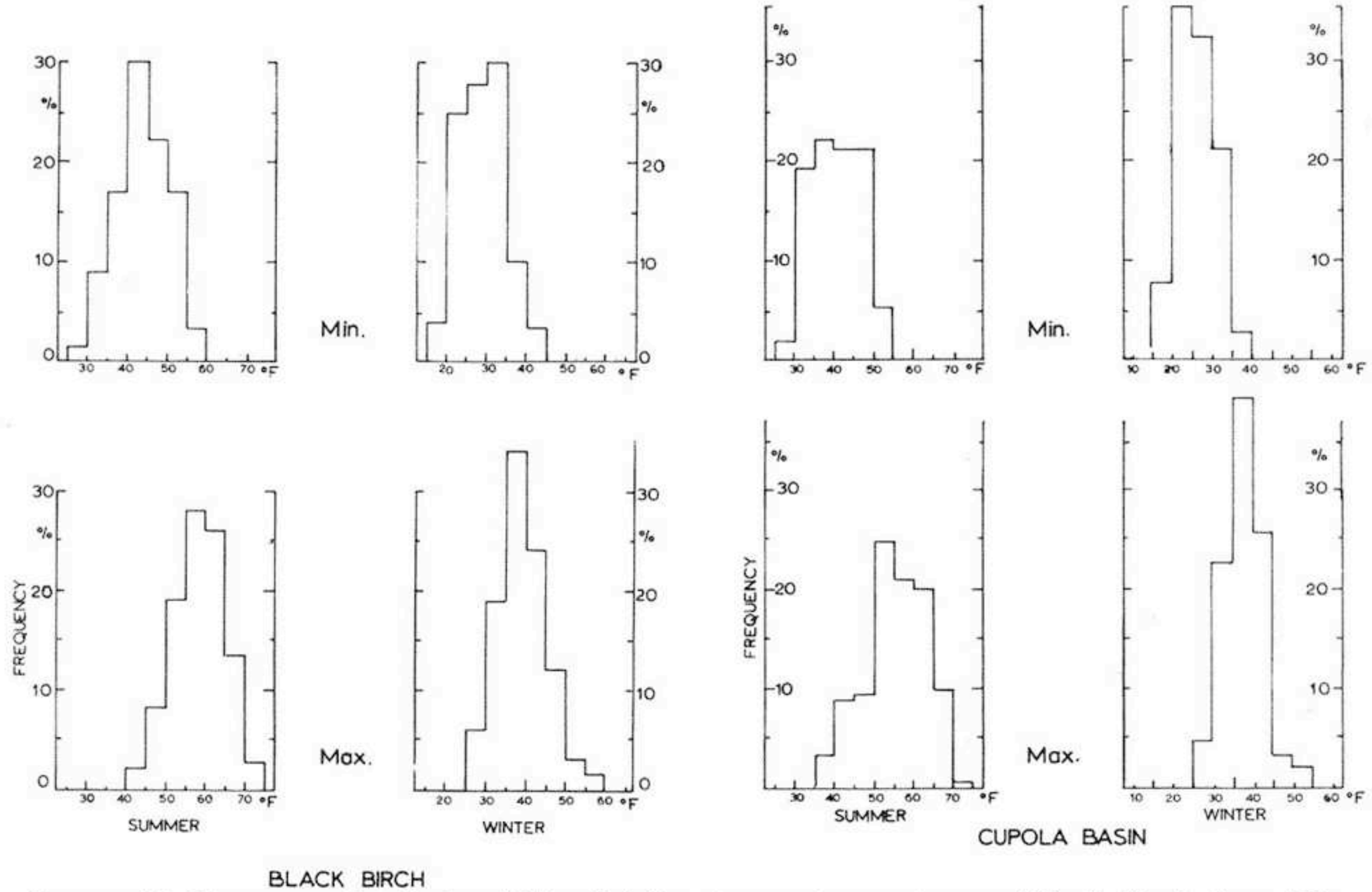


FIGURE 14. *Frequency distribution (%) of daily temperature extremes (Black Birch June '61–April '63, Cupola April '63–April '66.)*

freezing point in all seasons, but in July 1961 the mean at Black Birch was 31.6°F., and at Cupola the seasonal mean for winter was not far above freezing point (32.5°F.). On the average Black Birch is about 3°F. warmer than Cupola. This is a greater difference than would be expected from the difference in altitude. It probably reflects a true difference in climate but may partly reflect the different period of observations. The mean daily range of temperature is slightly greater at Cupola, at least in summer and autumn. The average daily range (12.4°F. at Black Birch, 13°F. at Cupola Basin) may be compared with that of 19.7°F. at Blenheim, 21.5°F. at Molesworth, 14.5°F. at Lake Grassmere, i.e., it is low for an inland station. It is greatest in summer.

The diurnal variation of temperature in winter and summer at Black Birch is shown in Table 7 and Figure 12B. Because few observations were made at 3 a.m. and 6 a.m. the values are uncertain at these hours.

Figure 14 gives the frequency distribution of daily (9 a.m. to 9 a.m.) temperature extremes for winter and summer for the two stations. At both, summer maxima are commonly in the fifties or sixties, and occasionally are above 70°F. In winter they are generally in the thirties or low forties.

Frosts, i.e., days with screen minimum temperature below freezing point, occur in all seasons. Ice days, i.e., days in which the maximum temperature remains below freezing point, occur in autumn and winter (Table 8).

Thus at Black Birch, freeze-thaw changes (i.e., minimum less than 32°F. and maximum above 32°F. on the same day) occurred on about 4% of summer days, and 60% of winter days. Corres-

TABLE 8. *Frequency (%) of frost days and ice days at Black Birch and Cupola Basin.*

	Summer		Autumn		Winter		Spring	
	BB	CB	BB	CB	BB	CB	BB	CB
Frost days	4	10	11	20	72	90	32	50
Ice days	0	0	0	0	13	10	2	5

(Black Birch: June 1961–March 1963, Cupola Basin: April 1963–April 1966)

ponding figures for Cupola Basin are 10% and 80%. This gives a rough indication of the frequency of freeze-thaw cycles experienced at the soil surface. However, because the diurnal temperature cycle has larger amplitude as the surface is approached, bare ground would experience many more freezings and thawings than would the air at screen level. On the other hand snow cover and vegetation protect the soil surface from temperature changes and extremes, thus tending to reduce the number of freeze-thaw changes (Gradwell 1955, 1960).

Some observations of microclimate have been made at Black Birch by Gradwell (1962) and by O'Connor and Macarthur (O'Connor and Lambrechtsen 1967) in connection with studies of soil movement caused by frost and of the re-establishment of plants on eroded areas.

Extreme minimum temperatures recorded at Cupola have been appreciably lower than those at Black Birch, especially in winter and spring, no doubt because of the more sheltered site. The lowest temperatures recorded were 15°F. at Black Birch in June, 12°F. at Cupola in June. These values are not particularly low in comparison with extreme minima at inland valley stations in the South Island, e.g., −3.5°F. at Ophir, 9°F. at Molesworth.

The lapse rate of temperature between Black Birch and Jordan (a climatological station in the Awatere Valley, 5.5 miles SSW of Black Birch and at 1,000 ft. altitude, i.e., 3,580 ft. lower) had a mean of 3.3°F. per 1,000 ft. The difference is greater in summer than in winter and very much greater for temperature maxima than for minima, the lapse rate (in °F./1,000 ft.) being respectively 4.7 and 4.2 for maxima and minima in summer and 4.2 and 1.7 in winter.

A comparison between mean monthly temperatures at Black Birch and those of the free air for the same height and latitude (interpolated from monthly mean radiosonde data) showed an approximate equality in spring, summer and autumn but in winter Black Birch was appreciably colder. The seasonal average differences (free air — Black Birch in °F.) were: summer −0.6, autumn +0.5, winter +3.3, spring +0.4, year +0.9. Finkelstein (1962) derived a similar result from part of the data used here.

Humidity

The mean (9 a.m.) relative humidity at Black Birch (Table 2) was 70% which is similar to that of lowland stations in the area (Blenheim 73%, Molesworth 67%). At Cupola it was higher (82%). Two features of the relative humidity regime at Black Birch may be characteristic of many mountain top stations. The occurrences of occasional very low humidities (below 20%) was noted by Finkelstein (1962). They occur at all hours, usually with clear skies, but with varying winds, e.g., fresh westerly, light southwest, and calm. Bateson (1964) pointed out that average relative humidity values fell during the night, a decrease in average water content of the air more than offsetting the drop in temperature. At lowland stations relative humidity usually has a maximum at night or in the early morning when the temperature is at its minimum.

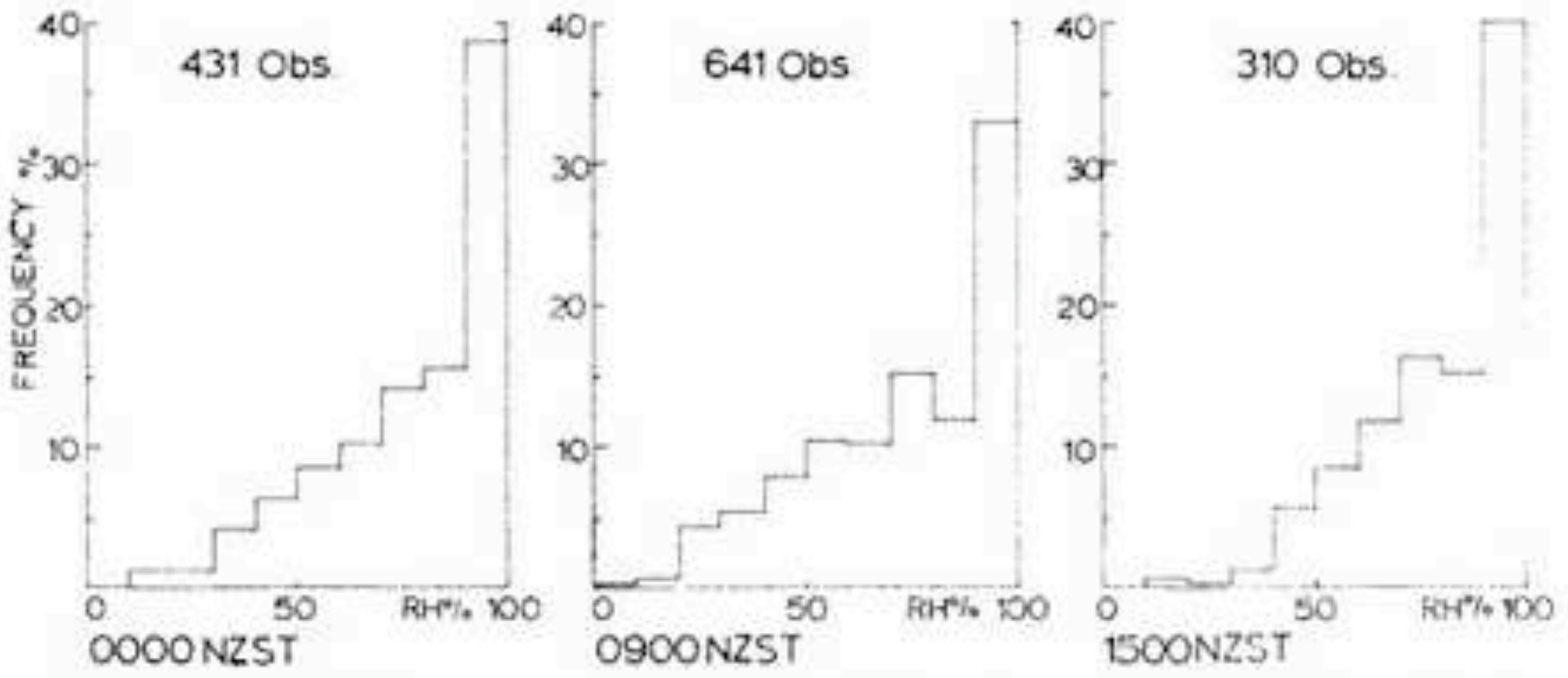


FIGURE 15. *Frequency distribution (%) of relative humidity values at Black Birch (0900 June '61–April '63; otherwise Feb. '62–April '63.)*

In the histograms of relative humidity distribution (Fig. 15) although there is a strong preponderance of high humidities there are an appreciable number of very low ones (nearly a quarter below 40% R.H. at 9 a.m.). There is a suggestion of two peaks in the frequency distribution, one in the 95–100% R.H. class, the other at 70–80% R.H. The distribution thus tends to some extent to resemble that characteristic of the free air (Fig. 5).

Figure 12 (C) shows the diurnal variations of average relative humidity. Values for 3 a.m. and, more especially, 6 a.m. are uncertain for lack of data, but there is no doubt concerning the general form of the curve with a maximum in the late afternoon and a minimum probably near 6 a.m. (Note: The data in the Figures are means of individual R.H. values. Those in Table 2 were derived, as is customary in climatological summaries prepared by the Meteorological Service, from monthly means of dry bulb and wet bulb temperatures. Appreciable differences may arise when there is a wide range of relative humidity and temperature over the month.)

These features (low humidities and night-time decrease in humidity) are a result of vertical motions of the air around the mountains. Descending motion brings dry air from aloft into close proximity to the surface of projecting peaks and ridges. Descending motion is promoted at night near the cooling mountain surface, whereas ascending motion along slopes heated during the day brings moister air up from the valleys.

Fog

On mountains fogs occur when cloud envelops them, frequently with strong winds, in day time or at night. On the plains most fogs are produced by radiative cooling of the surface and the air layer near it on calm clear nights. Bateson (1964) contrasted the behaviour of fogs at Black Birch in different types of weather. Following the onset of strong northwest winds fog commonly envelops the summit of the range and gradually spreads down over the station as the general cloud base lowers. In calm spells there is a tendency for fog bands to lie below the station in the evening and rise over it in the morning, influenced by diurnal mountain-valley wind circulations. Fog may persist for long periods on the mountain tops. Bateson listed five occasions of continuous fog of more than 48 hours duration, the longest being 94 hours in May 1962. Fog was most common in autumn and spring (in the period February 1962–April 1963, which may not be representative). The average frequency was 26% of the (3-hourly) observations, and was slightly higher in daylight hours (27%) than at night (24%). Further details of fog frequency and cloud cover are given in Table 2 and Figure 12 (D) for Black Birch, and in Table 9 and Figure 16 for Cupola Basin and Black Birch.

Bateson (1964, p. 30) tabulated the following percentages of the time Black Birch was in fog at night from data on the duration of individual fog periods: summer 19.7, autumn 27.5, winter 11.2, spring 27.5. (Winter 1961 was apparently unusually free of fog; winter 1962 had a percentage of 21.) Corresponding day-time values cannot be got from the data available, but these night-time figures may be compared with the percentage of observations at fixed (3-hourly) night hours given in Table 2 for February 1962 to April 1963, viz., summer 21, autumn 29, winter 19, spring 28. The similarity between the two series indicates that fixed hour data give a valid approximation of duration.

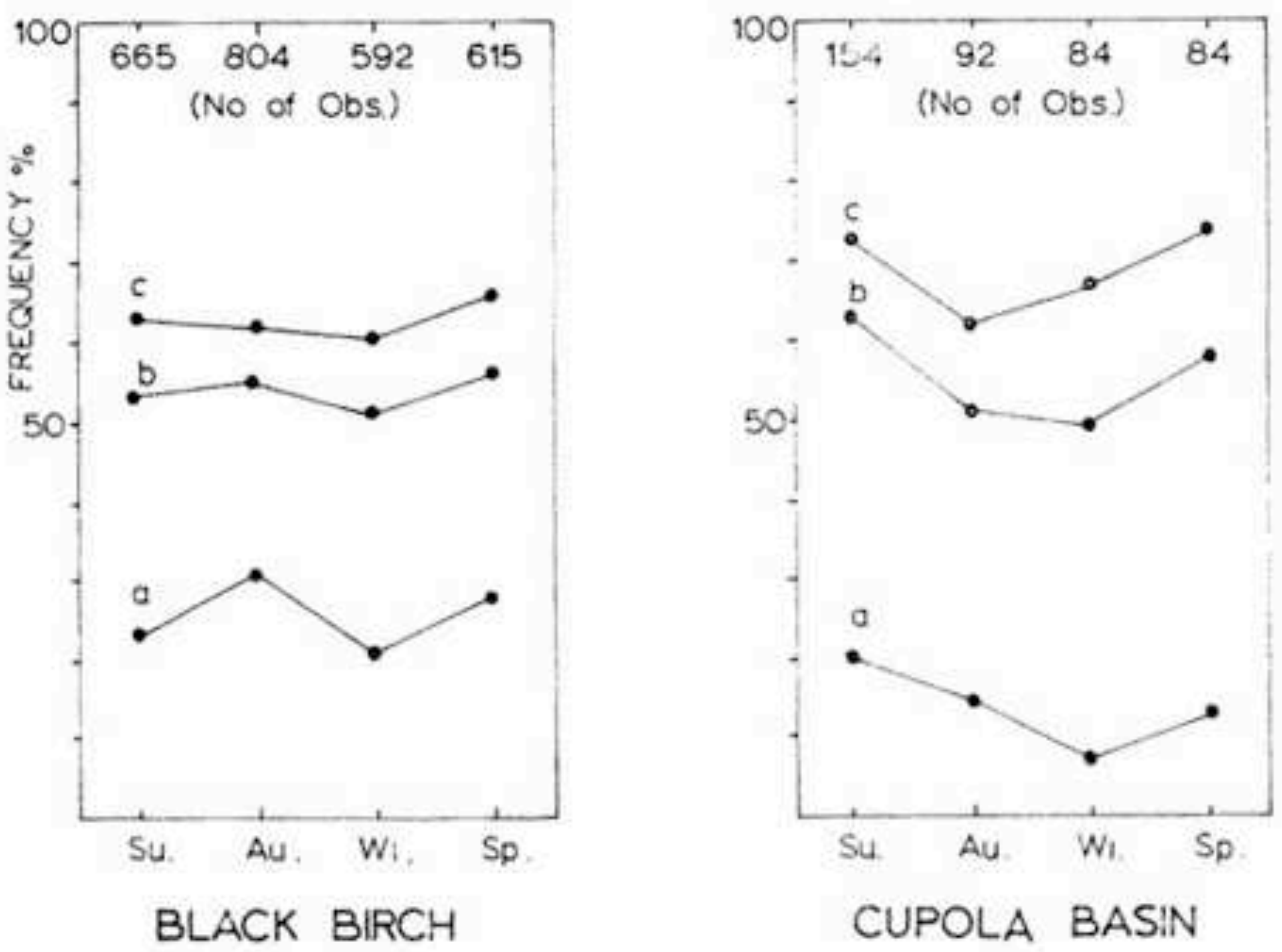


FIGURE 16. *Seasonal frequency distributions (%) of (a) fogs, (b) cloud amounts (N) more than 5/8, (c) (N) more than 2/8. (Black Birch, 3-hourly obs. Feb. '62–April '63; Cupola 9 a.m. obs. April '63–April '66.)*

Sunshine, evaporation, dust, dry periods

Duration of sunshine at Black Birch is relatively great by New Zealand standards. The total for the year of 2,141 hrs (1962–63) was 52% of the total possible at the site. From comparison with neighbouring stations this was probably somewhat greater than the long period average which is estimated to be approximately 2,080 hrs (or 50% of the possible). The months January to April appear to be relatively the sunniest (with 55–60% of possible sunshine); those for May to December, in particular October and November, are proportionately the least sunny (45–50% of possible).

Evaporation was measured by means of a raised pan evaporimeter for a short period (Jan.–April) in 1963. The total evaporation during this period averaged 0.20 inches per day, equal to that at Wither Hills (Blenheim), but about 10% more than at Wellington. Thus, annual average evaporation at Black Birch is probably similar to that in the Marlborough lowlands or the Canterbury Plains but more than that in the Wellington-Manawatu area, for example.

During fine periods, long sunshine hours, especially when combined with strong winds and low relative humidity, cause rapid evapotranspiration; and the soil surface becomes very dry, particularly when bare soil is exposed. Wind-blown dust of

TABLE 9. *Seasonal frequency (%) of fog and cloud amount at 9 a.m.*

	Summer		Autumn		Winter		Spring		Year	
	BB	CB	BB	CB	BB	CB	BB	CB	BB	CB
Fog	26	20	32	14	17	7	19	13	23	15
6, 7, 8/8 or Fog	49	63	54	51	47	49	50	58	50	57
3, 4, 5/8	14	10	7	11	11	18	14	16	11	13
0, 1, 2/8	37	27	39	38	42	33	36	26	39	30

(Black Birch: June 1961–March 1963, Cupola Basin April 1963–April 1966)

local origin was often observed at Black Birch, and in strong winds grit and small stones were often raised from the surface. Depletion of soil moisture to a degree which would adversely affect seedlings and shallowly-rooted plants probably occurs not infrequently in rainless periods in summer and autumn. The records are too short to enable the frequency of severe dry periods to be assessed.

The Black Birch climate can probably be taken as approximately representative of much of the Marlborough mountain country but it is probably more windy than most. The ranges further to the south would be less influenced by the westerlies and northwesterlies, but the Seaward Kaikoura Range is much more exposed to southerlies and probably receives more precipitation. The Richmond Ranges north of the Wairau are more exposed to northerlies and northwesterlies and they receive a much higher rainfall. Drying periods are probably of considerable importance to vegetation in the Marlborough Ranges as in other eastern ranges of both islands.

CONCLUSION

The physical elements of climate that are significant as environmental factors to plants, animals and soil are, of course, the same in the mountains as elsewhere. They include radiation levels (which largely determine the overall energy balance and the photosynthetically active radiation), temperature levels (in particular the frequency and duration of temperatures outside tolerances for plant growth and survival at various stages of growth), water relationships and the occurrence of damaging wind, frost, intense rainfall, drought and other severe storms. The features peculiar to mountains arise from the generally reduced temperatures, the greater ventilation (which reduces the "continentality" of mountain climates), the effects of angle of slope and aspect (especially on temperatures near the surface, evapotranspiration and soil moisture), the changed radiation balance and the generally increased amounts of precipitation, fog and cloud cover. In many New Zealand mountains a rather large average lapse rate of temperature with height and occasional periods of low temperatures in summer appear to be of particular significance ecologically. Frequent fog and cloud cover may significantly reduce light levels and maintain high humidity for long periods. Furthermore, water intercepted by vegetation from fog is likely to be important.

In the absence of excess cloudiness the income of short wave radiation from the sun is greater at high altitudes. Hence, relative to ambient air temperatures, the temperatures of surfaces in the sun tend to be high in the mountains but they fall rapidly at night causing frequent freeze-thaw cycles on bare ground.

A knowledge of the climate of the free air surrounding New Zealand mountains provides a basis for the study of their surface climates. Direct observations of mountain climate are needed for at least a selection of representative areas. The complex topography and wide range of local climate and microclimates resulting from it make it impossible to measure many mountain climates in detail; and the scope of investigation is governed by inaccessibility and limitations of available instruments.

There have been a number of studies of mountain climate in New Zealand in recent years, and some at least of the above-mentioned significant parameters have been measured. Rainfall studies excepted, most have been in the drier eastern mountains which are not only more accessible but also contain perhaps the most urgent ecological problems requiring climatic data for practical applications.

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