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STUDIES OF SNOW CHARACTERISTICS IN THE NORTH-EASTERN BEN OHAU MOUNTAINS, NEW ZEALAND

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ABSTRACT

Seasonal snow characteristics were studied during the winter and spring of 1966 and 1967 in the subalpine and alpine zones of the north-eastern Ben Ohau Range. Five snow courses were established at altitudes of 3,200 ft, 4,100 ft, 4,500 ft, 5,000 ft, and 5,400 ft. Snow depths, snow density and water equivalents were measured along each snow course. A positive linear regression was established of increasing water equivalents with altitude. Temperatures were also recorded 16 in. above ground surface at 3,200 ft, 4,100 ft, and 5,000 ft, and an index of snow melt was compiled at 5,000 ft from screen temperatures and ablation rates. Characteristic slow net accumulation and rapid ablation are discussed in relation to weather phenomena.

INTRODUCTION

Detailed knowledge of the effects of snow upon the hydrology, soils and vegetation of the subalpine and alpine zones was, until recently, limited to Europe and North America. The earliest studies in Europe by Heer (1836) and Braun-Blanquet (1932) and the observations in New Zealand by Cockayne (1928) revealed that in areas where snow lay for considerable periods of time the distribution pattern of certain plant communities was closely related to the duration of the snow cover. Soils were also affected, particularly with regard to temperature and moisture.

Preliminary observations in the Ben Ohau Mountains indicated that snow lay for a considerable period of time, especially on the shaded south and east faces. As a first stage to a comprehensive ecological study of this region, it was necessary to obtain detailed knowledge of the distribution and characteristics of the snow in areas where plant and soil studies were to be made.

REGION OF STUDY

In November 1965, Grasslands Division of the Department of Scientific and Industrial Research established a research field

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station at 2,800 ft on Glentanner Station, 17 miles south from Mount Cook, on the Pukaki-Hermitage Road (Fig. 1).

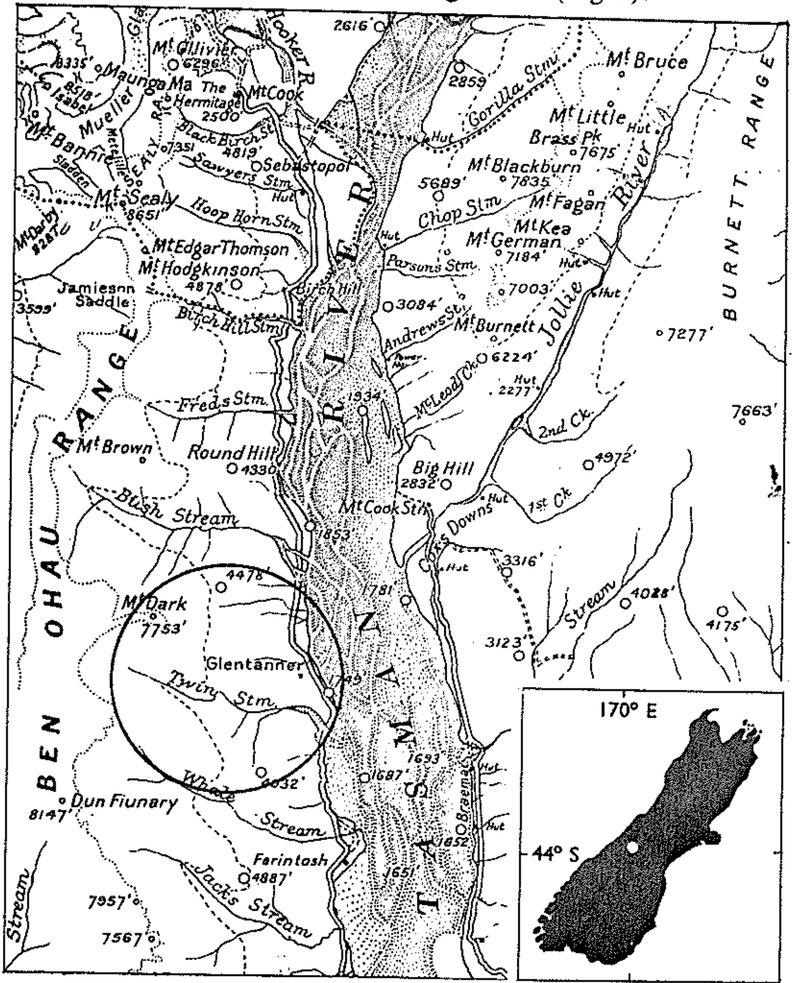

FIG. 1 — Location of research area at Twin Stream. Scale: 4 miles to 1 inch. *Base map: L & S Dept.*

The catchment chosen was that of Twin Stream (Fig. 1), which covers an area of 16.4 square miles (10,500 acres). This area consists of 300 acres of perennial snow and ice, 3,500 acres of sunny northerly and westerly aspects, and 6,700 acres of shaded southerly and easterly aspects. The catchment is typical of the transverse valleys dissecting the eastern slopes of the Ben Ohau Mountains. It has a very marked relief, being deeply incised into the bedrock and superficial deposits.

In April and May 1966, two localities within this catchment were selected for snow sampling (Table 1 and Fig. 2).

TABLE 1 — Topographical and environmental characteristics on snow courses.

Location	*Altitude (ft)*	*Length of course (yd)*	*Mean slope (deg.)*	*Aspect*	*Vegetation*
Scots	3,200	185	25	SE	*Chionochloa rigida* with *Agrostis tenuis* Sibth.
Scots	4,100	109	35	SE	*Agrostis tenuis* with *Chionochloa rigida*
Pyramid Basin	4,500	150	20	ESE	*Chionochloa rigida* with low shrubs
Pyramid Basin	5,000	150	35	ESE	*Celmisia lyallii* community
Pyramid Basin	5,400	150	150	ESE	*Celmisia lyallii* community

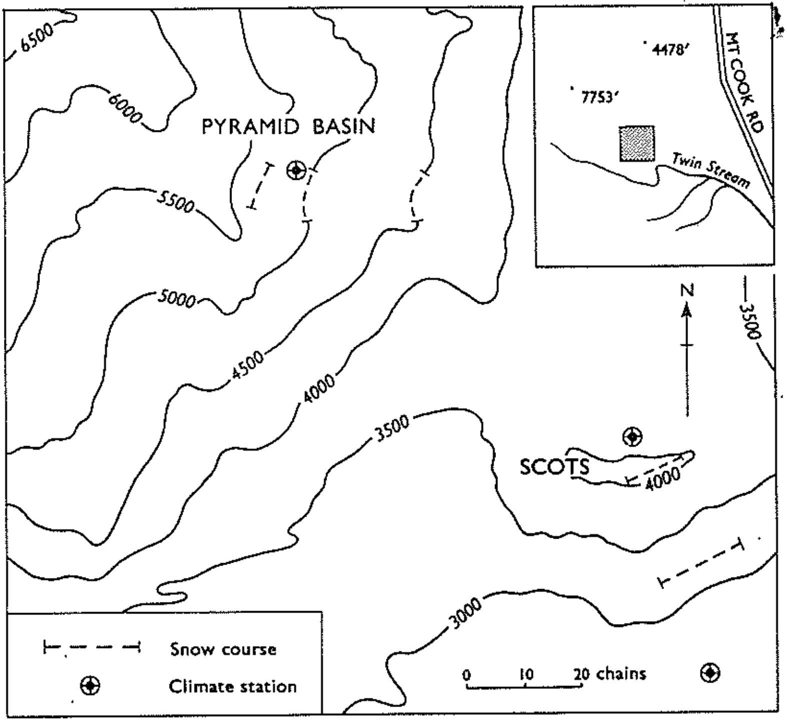

FIG. 2 — Snow sampling localities. Elevations are shown in feet.

Locality 1

A concave slope, known locally as Scots, rising 1,200 ft directly above the outwash terrace upon which the field station is situated, was chosen as an area representing the possible lower limit of the seasonal snow line. This slope has a south-easterly aspect and connects the lower 2,800-ft terraces with the higher subalpine and alpine basins at 3,800 ft and 5,000 ft. The vegetation on this slope consists predominantly of a *Chionochloa rigida* (Raoul) Zotov community with inter-tussock species of low herbaceous and shrubby plants.

Locality 2

This was a small cirque of 200 acres, known locally as Pyramid Basin, with an east-south-easterly aspect. The cirque ranges in altitude from 4,500 ft at its base to a low headwall at 5,800 ft. The floor of the cirque is strewn with ablation moraine and solifluct which lie in a series of ridges and terraces, the result of former ice pressure and nivation and later periglacial mass movement. The northern part of the cirque consists of block scree, but across the southern part a complete cover of vegetation has developed. The lower parts consist of stunted *Chionochloa rigida* and low shrubs of *Dracophyllum kirkii* Bergg., *D. uniflorum* Hook. f., *Hebe subalpina* (Ckn.) Ckn. et Allan, and *H. odora* (Hook. f.) Ckn. Above 4,800 ft to the higher slopes of the basin the dominant vegetation is *Celmisia lyallii* Hook. f.

METHODS

Survey Procedure

Five snow courses (Table 1) were surveyed and marked with snow poles along specified contours in April 1966, two in the locality of Scots and three in Pyramid Basin (Fig. 2). The siting and overall length of each snow course was determined by physiography and the distribution of rocks and vegetation, as well as accessibility. Along each course a more or less constant slope was necessary to obtain representative samples, and the slope had to be clear of avalanche debris likely to disturb the actual snowpack and to give readings distorted by excessive compaction of the snow. Because of the abundance of rocks and discrete patches of low shrubs, it was necessary to restrict the length of the snow courses. Investigations by the U.S. Army Engineers (1956) showed that quality of sampling is greatly improved if snow courses are clear of rocks and brush.

Some attempts were made to site the snow courses where there was no excessive amount of wind-dumped snow. In winter the effects of winds are greatly reduced, but the upper snow courses were still to some extent affected by wind-blown snow from the north-west.

Snow characteristics were measured using standard Italian snow-sampling tubes and methods evolved previously in Europe by Bader *et al.* (1939) and in North America by Church (1933) and Marr (1940).

TABLE 2 — Climatic characteristics at field station (2,800 ft) and 4,100-ft snow course.

Location	*Year*	*Mean of monthly max. and min. air temp. (°F)*				*Mean precipitation (in.)*				*Mean solar insolation (langleys/day)*			
		Jan	*Apr*	*Jul*	*Oct*	*Jan*	*Apr*	*Jul*	*Oct*	*Jan*	*Apr*	*Jul*	*Oct*
Field station (2,800 ft)	1966	no data		34.73	47.25	no data	5.10	4.05	4.09	no data			399
	1967	55.25	49.00	35.60	50.30	6.56	12.39	5.19	5.67	576	214	88	442
4,100-ft snow course (Scots)	1966	no data		28.80*	38.73	no data				no data			
	1967	44.08	38.66	33.88	44.90	no data				no data			

* incomplete month (15 days).

TABLE 3 — Comparison of mean temperatures and relative humidities during north-westerly and southerly weather.

	Mean maximum temperature (°F)			*Mean minimum temperature (°F)*			*Relative humidity (%)*		
	NW weather	*Southerly weather*	*Diff. (±s.e.)*	*NW weather*	*Southerly weather*	*Diff. (±s.e.)*	*NW weather*	*Southerly weather*	*Diff. (±s.e.)*
Aug 1966	48.16	41.00	7.16±2.33*	38.00	28.89	9.11±2.59*	no data		
Aug 1967	50.30	45.25	5.05±2.90	36.64	30.60	6.04±2.15†	73.73	78.40	4.67±5.26
Sep 1967	48.00	44.33	3.67±2.66	34.91	30.33	4.58±2.38	70.00	74.00	4.00±3.17
Oct 1967	63.29	55.38	7.91±2.15*	44.43	38.44	5.99±3.12	52.43	67.00	14.57±10.11
Nov 1967	53.91	55.00	1.09±2.62	37.67	39.00	1.33±2.81	56.73	67.00	10.27±10.12
Overall mean Aug–Nov 1967	53.87	49.99	$F=5.33$†	38.41	34.59	$F=5.77$†	63.22	71.60	$F=3.47$ ns

* $P<0.01$ † $P<0.05$ s.e.: standard error F: variance ratio ns: non-significant

and density were determined from cores taken in the snow tubes and weighed on a beam balance. Water equivalent was taken as the quantity of water within a sample which would result from snow melt. Density was derived from weight and volume of snow, and was expressed as g/cm^3.

The term 'accumulation' is used to describe the phases in which additions of snow were surplus to snow wastage. The term 'ablation' is used to describe the phases in which wastage of the snowpack by melting, sublimation and evaporation (Flint, 1957) was greater than snow additions.

Instrumentation

In the autumn of 1966 a climatological station was established adjacent to the field station at 2,800 ft. Mean solar insolation was measured by a Casella and later a Fuess actinograph, and air and ground-surface temperatures and relative humidities were recorded daily. Precipitation was also recorded at the field station.

In March and August of 1966, Edney thermographs and standard maximum and minimum thermometers were installed 16 in. above ground level at 4,100 ft on Scots and at 5,000 ft in Pyramid Basin. Spot recordings were made from maximum and minimum thermometers at the 3,200-ft snow course.

RESULTS

Meteorological Conditions

A summary of temperature, insolation and precipitation data from the research field station at 2,800 ft and from the snow course at 4,100 ft is given in Table 2. During the winter of 1967, precipitation was generally higher than that recorded in the previous year.

Thermal conditions were influenced by source of air mass. Analysis of mean maximum and minimum temperatures and relative humidities in spells of north-westerly and southerly weather (Table 3) compiled from daily observations at the Twin Stream station, indicates that in August 1966 maximum and minimum temperatures during north-westerly weather were significantly higher than those during southerly weather. Overall comparisons of north-westerly and southerly weather patterns in August to November 1967 (Table 3) reveal significantly higher maximum and minimum temperatures in north-westerly conditions. However, analysis for individual months of 1967 (Table 3) indicates that north-westerly weather produced significantly higher maximum temperatures only during October. Minimum temperature was

Snow was sampled at intervals of 10 yd between snow poles by two men on skis, once or twice a month. Depth of snow was measured with a steel probe normal to the slope. Water equivalent

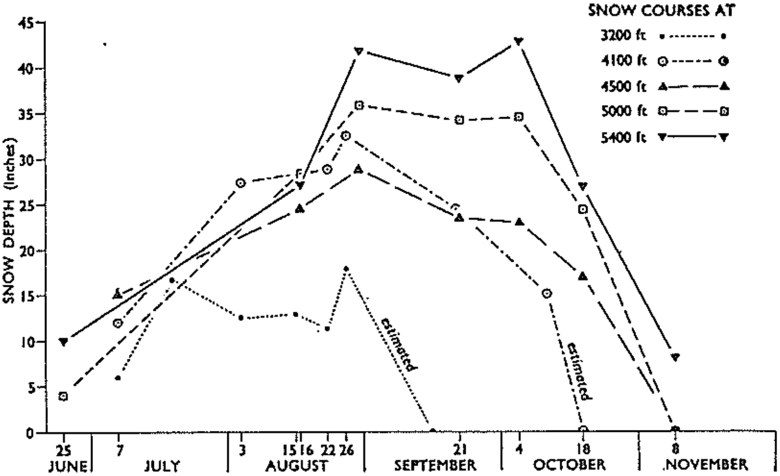

FIG. 3 — Trends in accumulation and ablation during 1966, indicated by snow depth at sampling date.

significantly lower in southerly weather only during August of 1967. Between weather patterns there was no significant difference in relative humidity, which tended to decrease during late spring (Table 3).

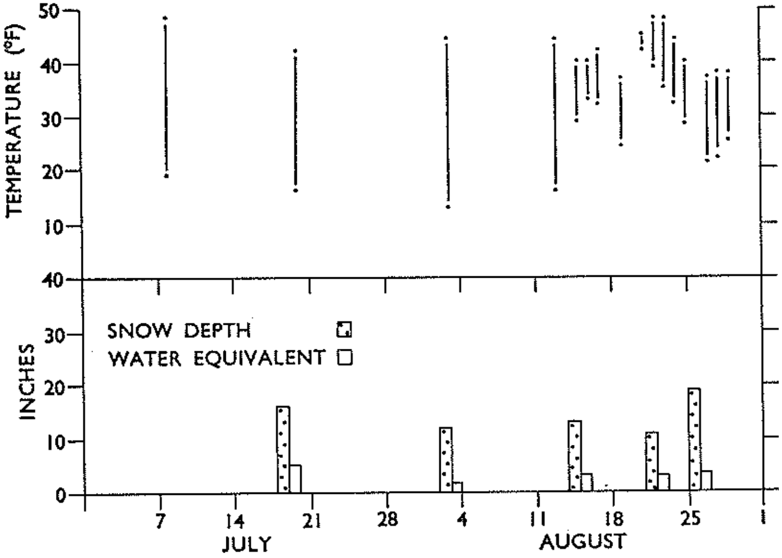

FIG. 4 — 3,200-ft snow course, 1966. Spot readings from thermometers 16 in. above ground and snow depth and water equivalent.

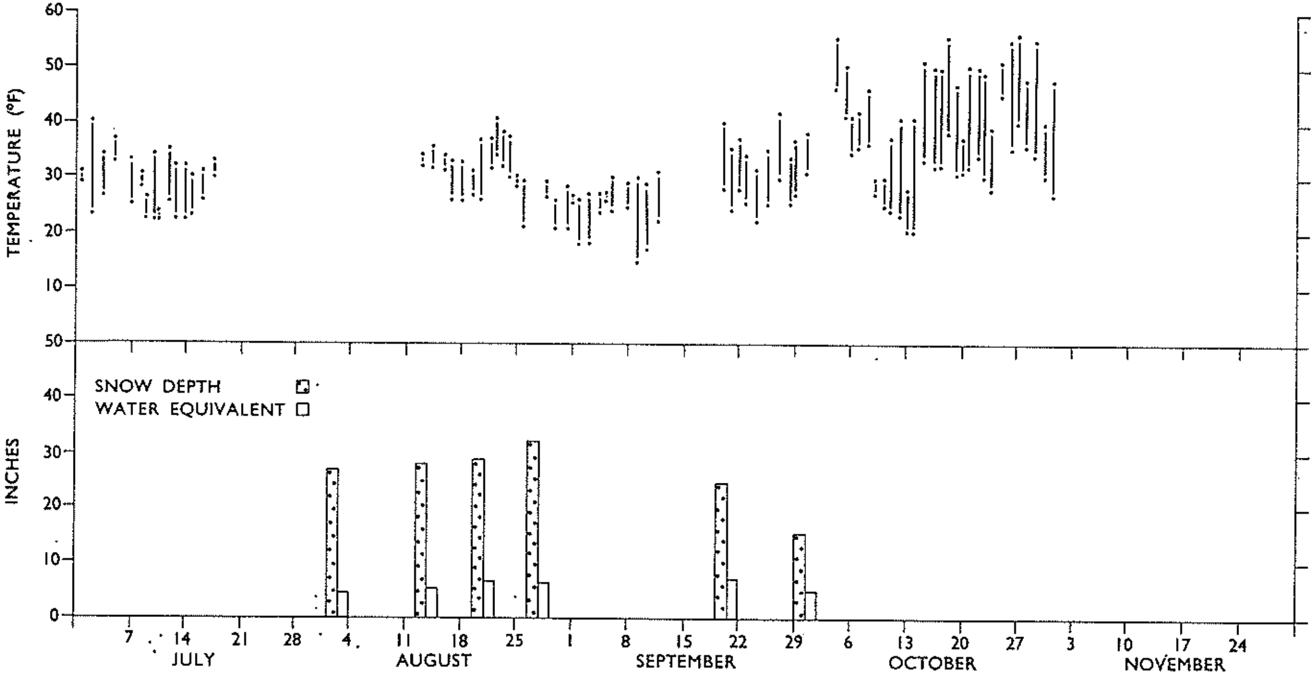

FIG. 5 — 4,100-ft snow course, 1956. Screen maximum and minimum temperatures 16 in. above ground and snow depth and water equivalent.

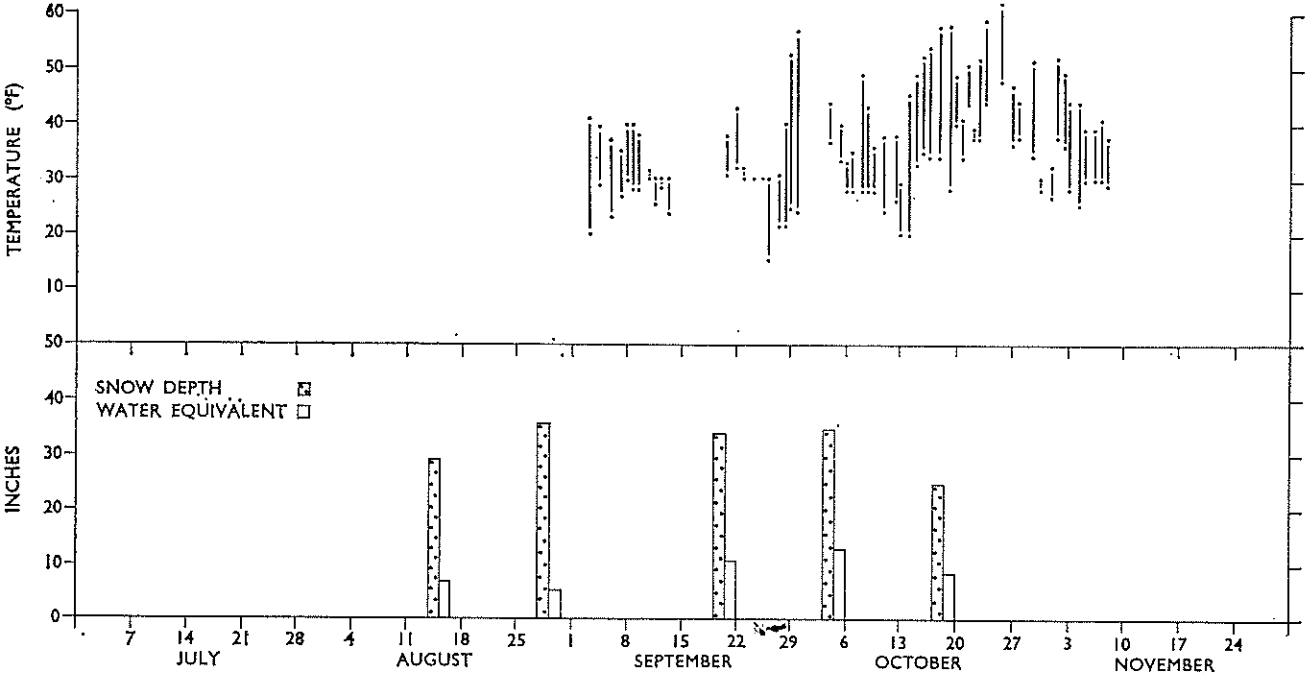

FIG. 6 — 5,000-ft snow course, 1966. Screen maximum and minimum temperatures 16 in. above ground and snow depth and water equivalent.

Seasonal Snow Accumulation and Ablation

Fig. 3 indicates the average snow depths that were measured between the beginning of the accumulation of snow from 25 June to the time when it had virtually disappeared in November. Each sampling date represents the net result of both snow additions and wastage, as it was impossible to record these factors between the periods of sampling. The general trend shows gradual accumulation of snow followed by rapid ablation.

Snow depths at the 3,200-ft snow course never exceeded 18 in., and the snowpack was of short duration. At the 4,500-ft snow course the greatest depth of snow was recorded at the end of August. Throughout September the wastage of the snowpack was greater than the additions. At the two highest snow courses seasonal ablation was delayed until early October when rapid wastage of the snowpack occurred.

Temperatures recorded at the 3,200-ft, 4,100-ft and 5,000-ft snow courses (Figs 4, 5 and 6) indicated that the diurnal range was generally large. The amount of insolation at 44° latitude has considerable effect on wastage of the snowpack. During August at 3,200 ft, little snow fell to replenish the snowpack, diurnal temperatures were high and wastage occurred. At the end of August, however, there was a general drop in temperature and a fall of snow, which increased the snowpack before a final rapid thaw set in (Figs 3 and 4). At the 4,100-ft snow course, both the mean and diurnal range of temperatures were relatively low because of lower insolation on the shaded aspects. From the beginning of October, however, a marked rise in temperature led to accelerated ablation (Fig. 5).

Although the high snow courses received considerable insolation, and although temperatures began to show a marked rise in late September, effective ablation did not begin until the middle of October (Fig. 6).

The 1967 snow season was of short duration. No snowpack formed at the 3,200-ft and 4,100-ft snow courses, and it was not until August that measurable snow appeared at the highest snow course.

A comparison has been made between the snow seasons of 1966 and 1967 for the 4,500-ft and 5,400-ft courses in Figs. 7 and 8. No measurable snow lay at lower altitudes in 1967. The duration of the 1967 winter snow was relatively short. Although mid-September snow depths were similar in 1966 and 1967 at the 5,400-ft snow course, general seasonal ablation commenced much earlier in 1967. The contrast between the two seasons was further accentuated by a heavy snowfall in mid-November 1967 (Figs. 7 and 8).

TABLE 4 — Accumulation of snowpack (water equivalents).

Locality	*Dates*	*No. of days*	*Total water equiv. (in.)*	*Rate per day (in.)*
1966				
3,200 ft	6 Jul–26 Aug	51	3.92	0.076
4,100 ft	6 Jul–20 Sep	76	7.42	0.097
4,500 ft	25 Jun–21 Sep	88	8.53	0.096
5,000 ft	25 Jun– 4 Oct	101	12.50	0.123
5,400 ft	25 Jun– 4 Oct	101	15.83	0.156
1967				
3,200 ft	no measurable snow			
4,100 ft	no measurable snow			
4,500 ft	23 Aug–20 Sep	28	1.70	0.060
5,000 ft	23 Aug–20 Sep	28	2.80	0.100
5,400 ft	1 Aug–20 Sep	51	8.80	0.172

TABLE 5 — Ablation of snowpack (water equivalents).

Locality	*Dates*	*No. of days*	*Total water equiv. (in.)*	*Rate per day (in.)*
1966				
3,200 ft	27 Aug–14 Sep	18	3.92	0.217
4,100 ft	21 Sep–18 Oct	27	7.42	0.274
4,500 ft	22 Sep– 8 Nov	47	8.55	0.181
5,000 ft	5 Oct– 8 Nov	34	12.50	0.367
5,400 ft	5 Oct– 8 Nov	34	12.86	0.378
1967				
3,200 ft		no data		
4,100 ft		no data		
4,500 ft		no data		
5,000 ft	21 Sep–17 Oct	26	5.54	0.213
5,400 ft	21 Sep–17 Oct	26	8.08	0.310

Snowpack Water Equivalents

During 1966 and 1967 no snow or rain gauges were installed on the snow courses. Total precipitation as rain or snow and total water losses in whatever form are not known. In Tables 4 and 5 accumulation and ablation have been represented in water equivalents. Over the whole range of snow courses the net accumulation period lasted from 51 days at the 3,200-ft snow course to 101 days at the highest courses. With the increase in altitude there was a general increase of water equivalents and rates per day. Comparison between the net accumulation periods of the 1966 and 1967 seasons shows that this period was reduced by 50 percent in 1967 at the 5,400-ft snow course, but that the accumulation rate per day was higher in 1967. An exceptionally heavy snowfall with very high water equivalence occurred in mid-November 1967. On 26 and 27 November at the 4,100-ft and 5,000-ft snow courses, water equivalents of 5.22 in. and 6.86 in. respectively were recorded.

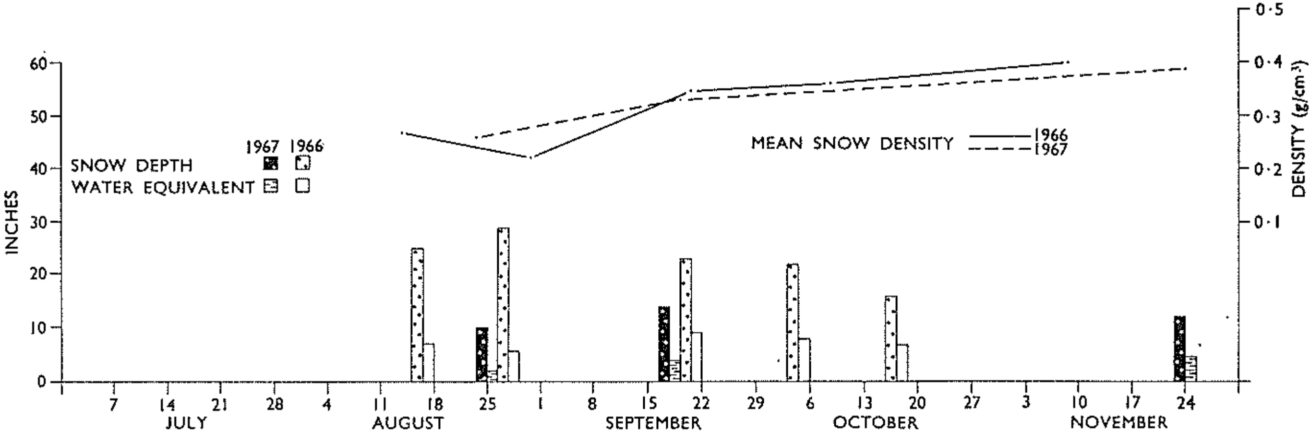

FIG. 7 — Mean snow depths, water equivalents, and snow densities during 1966 and 1967 at the 4,500-ft snow course.

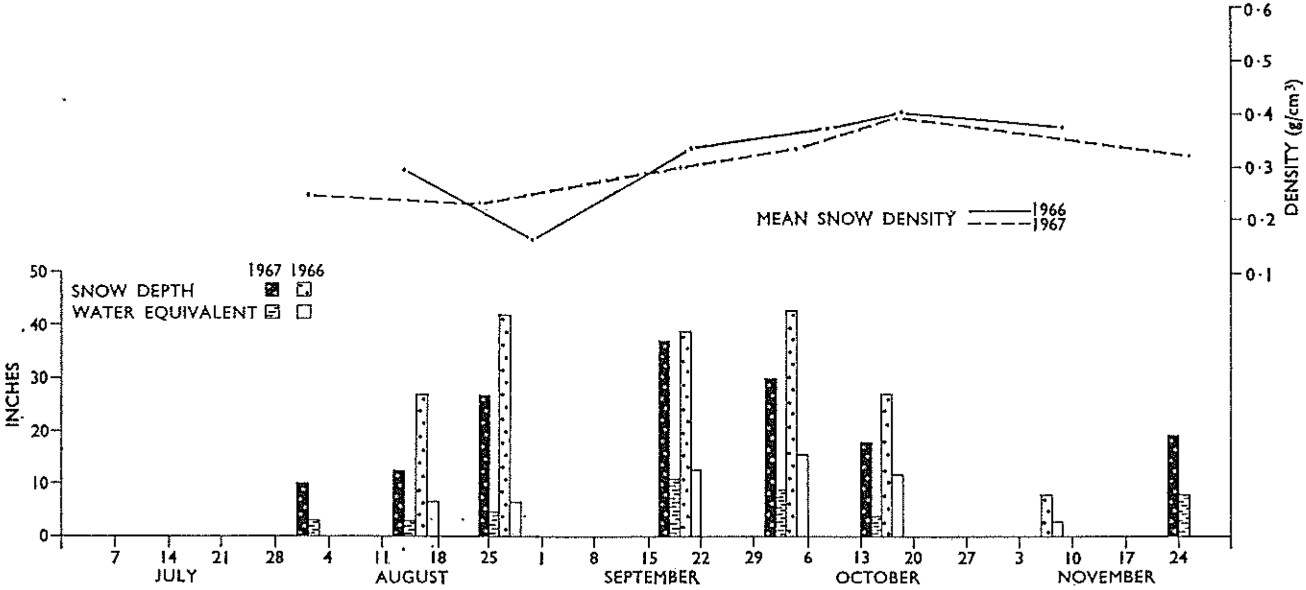

FIG. 8 — Mean snow depths, water equivalents, and snow densities during 1966 and 1967 at the 5,400-ft snow course.

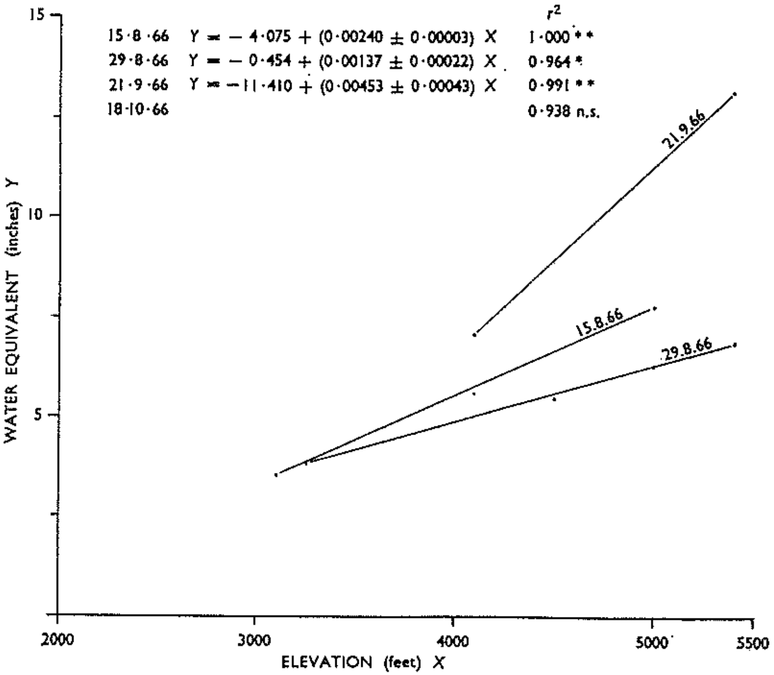

FIG. 9 — Regressions of water equivalents on elevation at several dates.

The period of net ablation has been tabulated for 1966 and 1967 in Table 5. The most noticeable factor is the short duration of the ablation period as shown already in Fig. 3. The rates of ablation are higher in areas of greater snow depths, if one considers the total period of ablation in 1966. The ablation rate per day at the 4,500-ft course was relatively low during the period 22 September to 5 October owing to an equilibrium between addition and wastage of snow at the end of September (see Fig. 3).

Positive linear regressions ($P < 0.05$) of water equivalents $(Y) = b + K$ altitude (X) were established for two sampling periods in August 1966 and one in September 1966 (Fig. 9). These regressions are significantly heterogeneous ($P < 0.01$). Some care must be taken in the interpretation of the correlations. The duration of snowpack on a shaded aspect is far greater than that on a sunny aspect. Therefore, if snow charts were constructed on the basis of these correlations for the purpose of forecasting snow depths at a certain altitude, the exact locality must be specified. At the beginning of the spring thaw, in October, no significant correlations could be established. This may have been caused by the rapid rate of ablation which took place over a short period of time. More extensive snow sampling at smaller altitudinal intervals will also give greater accuracy in forecasting water equivalents at different altitudes.

Snow Density

The seasonal trends of the snowpack and snow density for 1966 and 1967 at the 4,500-ft and 5,400-ft contours have been compared in Figs. 7 and 8. Average densities during 1966 dropped during early snow accumulation in July and August, but then followed a linear increase as the season progressed. The lowest densities at both contours occurred during the establishment of the snowpack. There was a decline in density at the 5,400-ft course during November 1967, probably from the addition of fresh snow at this higher level.

At the 5,400-ft snow course in 1966 the lowest mean winter snow density recorded was 0.164 (±0.0515) g/cm^3. At the beginning of October this increased to 0.350 (±0.423) g/cm^3. A maximum was reached in November when 0.405 (±0.0088) g/cm^3 was recorded.

During winter and early spring the snow profile contained forms of snow which had very variable densities. Marked temperature variation occurred at the snow surface. Surface snow was subjected to a vigorous freeze-thaw cycle, which rapidly reconstituted the newly fallen snow into a granular or ice form. After a period of time, this snow surface would be further covered by a fresh layer of snow of lower density. These conditions resulted in a series of ice lenses or layers of granulated snow within the snow profile. The mean density of surface snow on such a profile was recorded as 0.193 (±0.019) g/cm^3 and the lower lenses of denser snow were 0.444 (±0.033) g/cm^3. Although the winter and spring of 1966 were relatively wind-free, the various phenomena resulting from wind-dumped snow — such as wind slab — also led to considerable variability within the snow profile. When the spring thaw began, the water content of the snow increased and the snow profile tended to become more homogeneous, because of the permation of water throughout the snowpack.

Day-Degree Factor

Screen temperatures were recorded during the winter snowpack at the 5,000-ft snow course until it disintegrated on 8 November 1966 and 17 October 1967. These temperatures were used to compile an index of snow melt. The intervals between maximum daily temperatures and 32°F have been averaged during periods of ablation in 1966 and 1967. From daily rates of ablation obtained from Table 5 and from the averaged number of degrees above freezing point a day-degree factor has been calculated (Table 6).

TABLE 6 — Comparison of ablation rate at 5,000-ft snow course in spring 1966 and 1967.

Period of ablation	*Mean of daily max. temp. above freezing point (°F)*	*Ablation rate (in./day)*	*Day-degree factor*
5 Oct–8 Nov 1966	15.50	0.367	0.024
21 Sep–17 Oct 1967	8.49	0.213	0.025

For the 1966 and 1967 periods of ablation the calculated day-degree factors in Table 6 are of similar magnitude.

DISCUSSION

It is difficult to compare the snow characteristics in north-eastern Ben Ohau Range and in other parts of the subalpine and alpine zones in New Zealand. The only other published data are from the Craigieburn Range (Morris and O'Loughlin, 1965). Both that data and the present indicate slow accumulation followed by rapid ablation. This can be seen in the alpine-zone snow courses at 5,000 ft and 5,400 ft in Fig. 3, where there is a marked inflexion in the snow-depth curve when ablation starts in October. The water-equivalent values during accumulation and ablation at Alans Basin and Camp Stream (Morris and O'Loughlin, 1965) are also similar to those presented in Tables 4 and 5. This pattern of slow accumulation and rapid ablation in New Zealand samplings is characteristic of some continental regions where snow depths are not great and spring ablation is intense (Bader *et al.*, 1939). On the western seaboard of southern Canada and the United States, where greater depths of snow occur, the snow-depth curve is more symmetrical. At an altitude of 3,900 ft in the subalpine zone in southern British Columbia, Brooke (1965) recorded a maximum snow depth up to 173 in. and a snowpack which persisted until July. In such regions the rate of increase of snow is much greater than those experienced in the areas studied in New Zealand. For example, in Fig. 9 it will be seen that the rate of increase of water equivalents per 100 ft of elevation ranges from 0.13 in. to 0.24 in. in August. In September this increases to 0.45 in. For similar periods, water equivalents of 1.4 and 2.5 in. per 100 ft have been recorded in the Yuba River Basin, California, in 1952 (U.S. Army Engineers, 1956).

North-westerly weather in the South Island seems to be something of a paradox. The heaviest snowfalls have been recorded from the north-west by Morris and O'Loughlin (1965) and also in this study. Although neither snowmelt nor the quantity of snowfall in precipitation have been measured, observations indicate that as north-westerly conditions are associated with relatively mild temperatures and high winds, considerable quantities of snow are melted soon after fall, particularly at the lower levels of the seasonal snow line.

Snow densities recorded by Heine (1962), Gillies (1964), Morris and O'Loughlin (1965) and in this study, indicate that winter densities in New Zealand are higher than those recorded in the continental alpine regions by Bader *et al.* (1939) and at the higher latitudes in Scandinavia as reported by Church (1942). The spring snow densities recorded at the 4,500-ft and 5,000-ft snow courses (Figs. 7 and 8) correspond to those measured by Bader *et al.* (1939) in Upper Davos, Switzerland. They recorded means of 0.35 g/cm^3 at the end of March and 0.43 g/cm^3 at the beginning of May. The most significant factor affecting snow densities in the eastern Ben Ohau Range is the large range of diurnal temperatures. This is particularly so during the winter months and leads to seasonal snow profiles which have a wide range of density values.

Although the day-degree factors established at the 5,000-ft snow course are closely similar during 1966 and 1967, they have been based on limited snow sampling during ablation seasons of relatively short duration. Nonetheless, these values are similar to minimum values compiled by the U.S. Army Engineers (1956) throughout the western United States, where day-degree factors range from 0.021 in. to 0.052 in.

From sampling once or twice a month it has been possible to approximate the distribution of the snow in certain localities and also the relative duration of snow accumulation and ablation. It has been found that the quality of the snow in the north-eastern Ben Ohau Range is very variable because of rapid temperature changes and probably because of strong winds. Although melt may occur at any time during the snow season, net ablation is confined to a short period of spring when the wastage of the snow-pack is very rapid. The value of further work on snow characteristics will, therefore, depend upon more intensive sampling combined with more precise instrumentation at particular times of the year. It will also be necessary to establish a further snow course at 6,000 ft, closer to the perennial snow line on the southern aspect. This will give a more satisfactory range for the study of the accumulation, duration, and ablation of snow at higher altitudes and for the preparation of snow charts for forecasting the relationship between water equivalents and altitude.

ACKNOWLEDGMENTS

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