Ten-metre Snow Studies at Grunehogna Base, western Dronning Maud Land

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Fifteen accumulation years (1956 to 1970) were recognized in a 10 m core by detailed study of the depth/density profile. The mean annual accumulation at Grunehogna base (72°02,3'S, 02°48,5'W) over this period was 34,5 g cm^{-2} yr^{-1} with a local temporal variability of 8,3 g cm^{-2} yr^{-1}.

The variation of density with depth was calculated as a straight line with equation:

$$s = 0{,}0241\ h + 0{,}442.$$

where s = density in g cm^{-3} and h = depth in metres (h − 10 m)

During calm weather, the snow temperature at depths as shallow as 4 m is constant, independent of surface temperature fluctuations and equal to the 10 m temperature. This temperature, which is considered to be the annual mean for Grunehogna base, is −20,0°C.

Vyftien jaar se akkumulasie (1956 tot 1970) is in 'n 10m-kern waargeneem deur 'n noukeurige ondersoek van die diepte/digtheid-profiel. Die gemiddelde jaarlikes akkumulasie by Grunehogna-basis (72°02,3' 02°48,5'W) oor hierdie tydperk was 34,5 g cm^{-2} jr^{-1}, met 'n plaaslike tydsafwyking van 8,3 g cm^{-2} jr^{-1}.

Die variasie in digtheid met diepte is bereken as 'n reguit lyn met vergelyking:

$$s = 0{,}0241\ h + 0{,}422$$

waarin s = digtheid in g cm^{-3} en h = diepte in meter (h − 10 m)

In kalm weer is die sneeutemperatuur op dieptes van slegs 4 m konstant, onafhanklik van fluktuasies in oppervlaktemperatuur en gelyk aan die temperatuur op 10 m. Hierdie temperatuur, wat as die jaarlikse gemiddelde vir Grunehogna-basis beskou word, is −20,0°C.

Introduction

Grunehogna base (72° 02,3'S, 02° 48,5'W) lies at an elevation of appoximately 1100 m, halfway between peaks 1285 and 1390 of the Grunehogna group of nunataks. The prevailing wind direction is between SSW and SE and wind is often accompanied by drift snow. Snowstoms invariably come from the east and are characterized by severe gusts. Temperatures measured 15 cm above the snow surface during 1971-72 ranged from −17°C in January to −51, 5°C in July.

Immediately after the erection of the base on 30 April 1971, a 10-m hole was drilled by means of a SIPRE coring auger on a completely undisturbed level surface approximately 20 m south of the hut. The object was to determine the mean annual accumulation stratigraphically and to investigate the influence of surface temperatures on snow temperatures at various depths.

Detailed glaciological investigations by previous South African expeditions were limited mainly to the ice shelf (Fimbulisen) (*Neethling*, 1970). Accumulation studies on the inland ice consisted of stake measurements and observations in shallow pits and SIPRE-boreholes. A 5 m pit study by *Lunde* (1961), in which accumulation was traced for a period of eight years (1950–1957), is the only available information regarding accumulation during a longer period in the mountainous areas of western Dronning Maud Land. It was undertaken at more or less the same latitude as Grunehogna, but approximately 300 km to the east, in the HU Sverdrupfjella.

Accumulation

Stratigraphy

The stratigraphy of the firn differs completely from that encountered on the ice-shelf. In contrast to the easily detectable textural differences between winter and summer accumulation which are so characteristic of the shelf ice, the Grunehogna core is completely devoid of stratification (Fig. 1). This in fact is also the case in all the holes drilled on the inland ice in the Ahlmannryggen area to the south of Grunehogna, and is undoubtedly the main reason why so few attempts have been made at stratigraphic determination of annual accumulation in this region.

Thin wind crusts (some straight, some undulating) are about the only visible features that break the monotony of the firn profile. They are spaced at irregular intervals and apparently have no relation to seasonal accumulation (Fig. 1). The texture of the firn is identical to typical winter accumulation as observed in shelf-ice, i.e. fine-grained and compact. A slight increase in grain size was, however, detected from 7,5 m downwards, but this can be attributed to aggregation of grains due to pressure.

It is clear therefore that unless an intensive microscopic study of grain size is performed (which is difficult to accomplish under conditions in the field), no information regarding annual accumulation can be obtained from textural variations in the firn.

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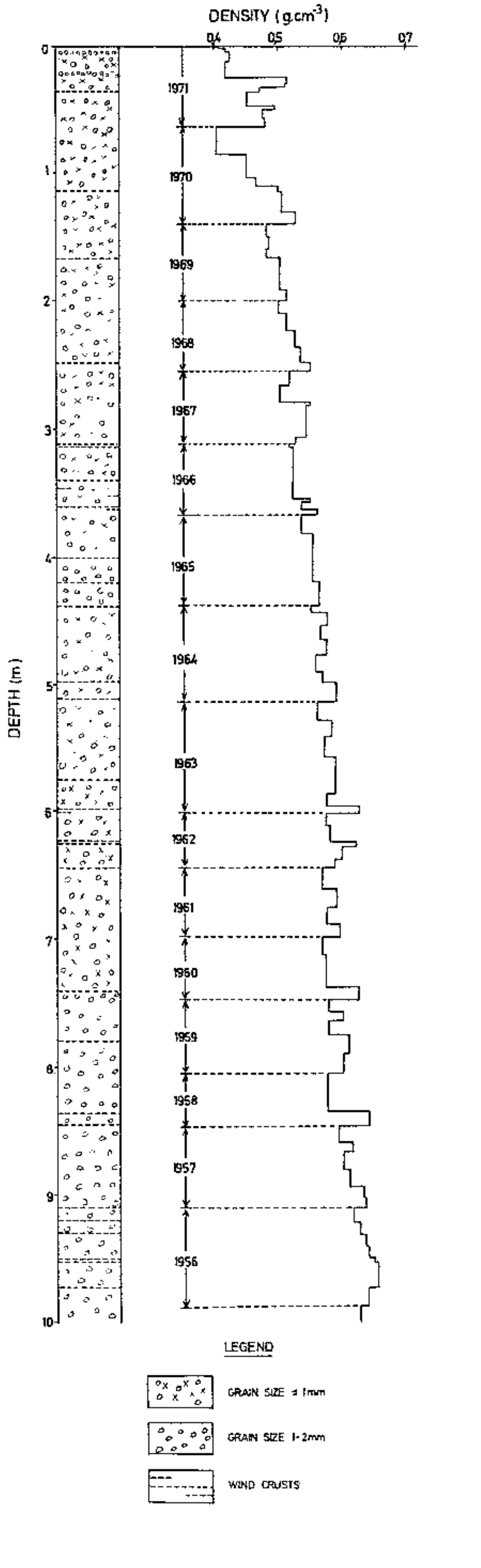

Fig. 1. Stratigraphic section and density profile of the firn in a 10 m borehole at Grunehogna base.

The density/depth profile

A total of 93 density measurements was made in which 8,28 m of core was utilized. On the average a density determination was obtained for every 10,7 cm of the core. The smallest piece was 5 ($\pm$ 0,1) cm long, 7,3 ($\pm$ 0,1) cm in diameter and had a mass of 97,5 ($\pm$ 0,5) g. The maximum error caused by measuring is therefore $\pm$ 0,01 g cm^{-3} (2,1%). The majority of core pieces were, however, of the order of 10 cm long, in which case the maximum error is only $\pm$ 0,005 g cm^{-3} (1%).

The variation of density with depth is shown in Fig. 1. In order to obtain a smoothed density-depth curve which can be used for comparison with the variation of density with depth at other localities, the mean density of every 50 cm of core was calculated. A straight line through these points was then calculated by the method of least squares (Fig. 2).

The following equation for the line was obtained:

$$s = 0{,}0241\,h + 0{,}442$$

where s = density in g cm^{-3}
h = depth in metres (h = 0–10 m).

If this equation is compared with that obtained by *Lunde* (1961) for Norway Station (s = 0,0106 h + 0,452), it is clear that the increase of density with depth at Grunehogna is much more rapid (0,0241 g cm^{-3} m^{-1} compared with 0,0106 g cm^{-3} m^{-1}).

The rate of increase determined by Lunde from a 5-m pit on the inland ice in the HU Sverdrupfjella agrees more closely with the results obtained at Grunehogna (0,0188 g cm^{-3} m^{-1}). This is in perfect agreement with Lunde's observation that the rate of increase of density with depth is greater on the inland ice than on the shelf-ice.

Determination of annual accumulation from the density profile

In the mountainous areas temperatures are not high enough during summer to cause melting and recrystallization of the firn. Some degree of metamorphism does, however, occur and although the effects are not clearly displayed in the form of a coarse-grained texture and ice layers, the firn that was subjected to higher temperatures has a markedly lower density than the surrounding firn. The density profile (Fig. 1) shows these differences clearly.

The general pattern appears to be a steady increase in density to a peak value, after which an abrupt decrease follows which is clearly detectable in most cases. Every sudden decrease in density represents a summer surface and marks the end of each accumulation year.

By this method 15 accumulation years were recognized (1956–1970). The error of interpretation is difficult to determine, but if the 1963 and 1964 summer surfaces are considered as doubtful, the estimated error is approximately 13%. This is slightly lower than the 15% estimated by *Neethling* (1970) for core interpretations.

The water equivalent for each year's accumulation was calculated by adding the water equivalents of the individual sections of different density of which the

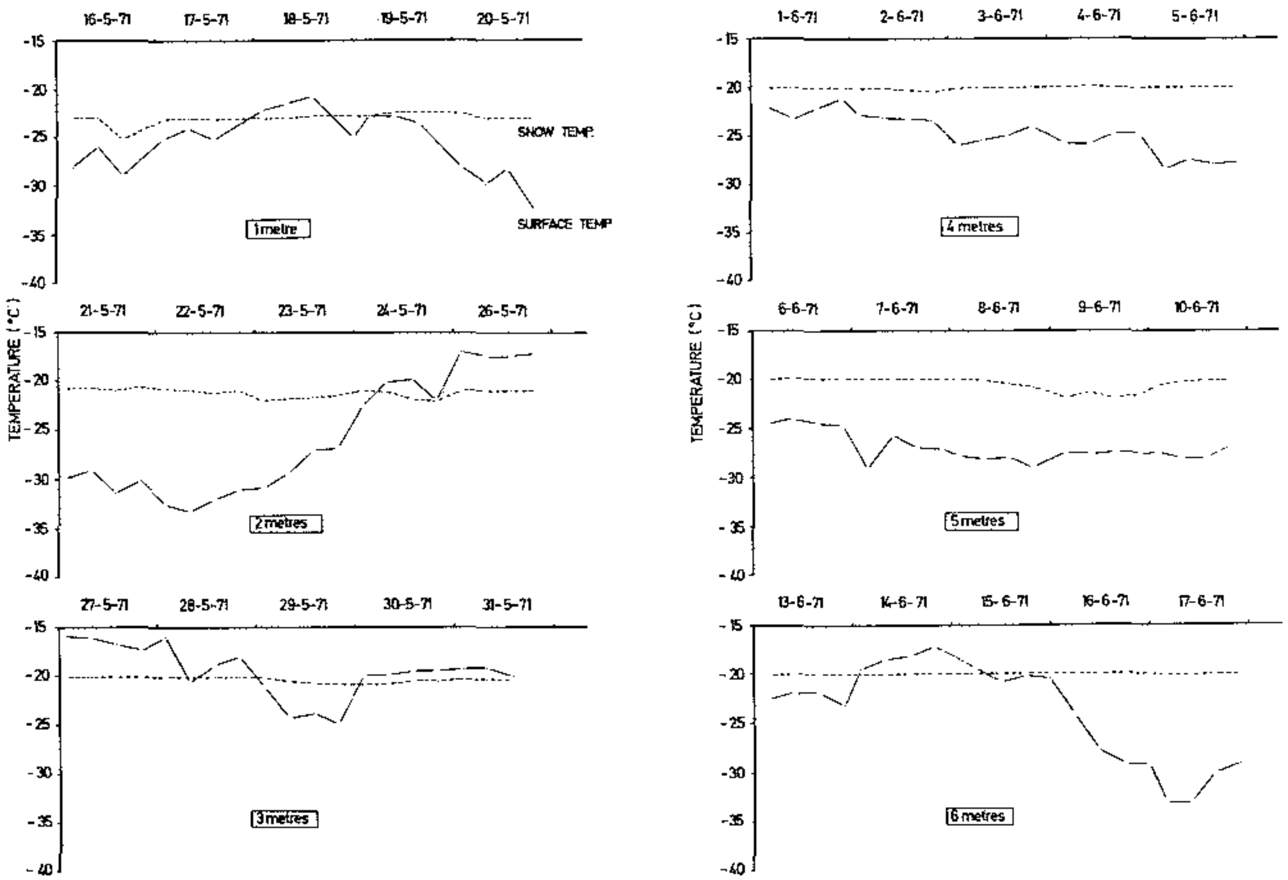

Fig. 3. Graphs showing the differences between surface temperatures (taken 15 cm above the snow surface) and snow temperatures at depths from 1 - 6 m.

considered to be the mean annual temperature of the area (*Schytt*, 1960). This implies that even at a depth of 6 m a fairly accurate mean annual temperature can be obtained.

If weather conditions are taken into account, this depth can be reduced to 4 m, where the only deviation from —20,0°C was caused by winds between 15 and 20 knots (Table 3). The quite unexpected and anomalous deviation of the snow temperature from the constant —20,0°C at 5 m depth during 8th and 9th June can be explained in a similar way. During this period, katabatic winds of approximately 35 knots were experienced and in spite of the fact that the hole was covered, a certain amount of cold air must have been forced down the hole.

If care is therefore taken that the hole is properly covered and readings are taken on a fairly calm day, the mean annual temperature can be obtained at a depth of 4 m.

As the experiment was conducted during winter, surface temperatures were generally lower than the mean annual temperature and also lower than the snow temperatures. During conditions of snowfall and complete cloud cover, however, surface temperatures rose to above that of the firn. For depths between 4 and 10 m, the average temperature is the annual mean (—20,0°C), but at 1, 2 and 3 m depths, the average snow temperature was found to be somewhat lower (—22,8°C at 1 m, —21,1°C at 2 m and —20,3°C at 3 m). There is therefore a gradual shift in the direction of the constant annual mean. It is to be expected that during summer when surface temperatures exceed the annual mean, average snow temperatures at depths shallower than 4 m will be higher than the annual mean.

From this experiment it can therefore be concluded that when use is made of lagged alcohol thermometers a reliable mean annual temperature can be obtained at a depth of only 4 m. These thermometers can usually be read accurately only to 0,2° and an additional error of approximately 0,2°C is introduced while taking the instrument from the hole. The inherent instrumental error is therefore more than the small deviation of snow temperature at 4 m from the annual mean.

Whether this constant 4 m temperature is also valid for areas with a mean annual temperature other than —20,0° C is something that can be established only through further experiment. Further investigation could definitely prove to be worth while, as much time and effort could be saved on traverses by obtaining mean annual temperatues at depths shallower than 10 m.

Conclusions

A detailed study of the depth/density profile can be used to identify summer layers in cores without any visible textural stratification.

The variation of density with depth was calculated as a straight line with equation

$$s = 0,0241\ h + 0,442.$$

This is in agreement with the observations by *Lunde* (1961) that the increase of density with depth on the inland ice is more rapid than on the shelf-ice.

The mean annual accumulation for the 15-year period 1956 to 1970 at Grunehogna base is 34,5 g cm^{-2} yr^{-1}. The local temporal variability is 8,3 cm^{-2} yr^{-1} which agrees with the linear relationship between local temporal variability and accumulation (*Giovinetto,* 1964).

During calm weather conditions, the snow temperature at depths as shallow as 4 m is constant, independent of surface temperature fluctuations and equal to the 10-m temperature (−20,0°C). The validity of these observations should be investigated in other areas.

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