WEATHER AND ABLATION OBSERVATIONS AT SERMIKAVSAK IN UMANAK DISTRICT

By Hans Kuhlman

CONTENTS

Introduction.

This publication will describe some of the glaciological and meteorological observations made in the summer of 1957 at Sermikavsak glacier on Upernivik Ø in the district of Umanak.

The observation work was performed as part of the working programme of the glaciological expedition sent out from the Copenhagen University Geographical Laboratory in 1957. The organization and objects of the expedition were described in J.T. Møller's paper (1959), in connection with which the following report should be read.

For almost nine weeks, from June 24th to August 24th, detail studies were made of ablation and micro-meteorology at a fixed observation station on the glacier. By means of a steel mast 12 metres in height, simultaneous measurements were made of wind and temperature profiles over the ice. The measurements at this mast station are the subject of the following description. The observations on the glacier were correlated with the macro-meteorological conditions recorded at the Sermikavsak expedition camp. It should be pointed out that the results submitted originate solely from the mid-summer period stated above.

The objects of the studies were 1) to describe the glacio-meteorology and the ablation at Sermikavsak, and 2) to test certain measuring methods for analyzing the dynamics of the ablation.

Analogous measurements of glacier meteorology have been undertaken recently in several countries, e.g. in Canada (S. Orvig, 1951 and 1954), Sweden (Wallen, 1949, and E. Sjödin, 1957) and Austria (Hoinkes, 1952 and 1955).

The local morphology.

The essentials of Sermikavsak's appearance and surroundings are given in J.T. Møller's report, and he also describes the exact position of the glacier in the Umanak district; nevertheless, a few remarks should be added for the purpose of visualizing the environment of the mast-station on the glacier.

From the West coast of Upernivik Ø, from Igdlorssuit Sund, four deep valleys cut their way into the granite and gneiss 1000-metre-mountains. The bottom of each of these valleys is covered by a glacier; the southernmost valley contains Sermikavsak. The shadow of the steep slopes of the valley may not actually condition, but at any rate exert a pronouncedly conserving effect upon the island's conspicuous, isolated glaciation in the fiord complex of the Umanak district. The mountain peaks and the high plateaux, lying from 1000 to 2000 metres above sea level, produce the source material of the firn-region from which the ice tongues descend; but we do not know if these supplies of snow and avalanche material suffice to form ice-lobes of such a size as we see today. In comparison with the actual glacier retreat observed elsewhere in Greenland (A.WEIDICK, 1958), it would be natural to think that the glaciers on Upernivik island are of a "relict" character.

Sermikavsak is a valley glacier of alpine type and, in accordance with AHLMANN's morphological classification (1948, pp. 60—62), must be described as Type CI. It is possible to form a schematic idea of the place by likening it to a gigantic, open canal, 10—15 km long, with a cross-section of about 1000 metres on each side. The valley bottom consists of light-reflecting ice, its sides of almost naked rock and talus which readily absorb the solar heat. The southwest corner of the valley is rounded and relatively low, allowing the wind to sweep transversally down to its mouth, whereas the air in its movement at the other parts of the valley bottom is compelled to follow the longitudinal axis of the deep ravine.

We concentrated our attention on the lower part of Sermikavsak, that is to say the 5-kilometre stretch from the glacier front to the first ice-fall encountered on the ascent up the valley. As far as could be observed this almost uncrevassed part of the glacier was inactive and its front constantly retreating from the sea, which was separated from the ice by an outwash plain almost 1 km in length. The situations of these topographical elements will be seen on J.T.MØLLER's fig. 3 and Pl. 1. Except at the front the longitudinal slope of the glacier surface was constant and it averaged no more than 5°—7°. The cross-section of the surface of the ice was almost horizontal except for a few large meltwater streams cutting down into the ice parallel with the valley. The tongue end of the glacier was flanked by two enormous "lateral moraines", of which the southern one is more correctly named by J.T.MØLLER: moraine-covered ice lobe. There were no particularly developed medial moraines, but length-wise oriented "impurities" in the form of coverings of stones, gravel and dust were very frequent, though sporadic: as a consequence, glacier tables and cryonites were numerous. At most places the many foreign bodies, from dust to stone, characterized the surface of the ice, a feature which Sermikavsak had in common with many other valley glaciers in Umanak district.

The glacier must be called sub-polar on account of the temperature of the ice: measurements showed that there were a few degrees of frost at a depth of from 2 to 8 metres below the constantly wet surface. The internal structure revealed conditions exactly similar to those observed in the glacier ice of temperate climate zones, being compact and of high density.

On the lower part of the glacier, 1 km. behind the front, the fixed observation station was established at a height of about 180 m. above sea level. The station consisted of a tent with instruments and the 12-metre telescopic aerial-mast. The station was located upon a representative area of the glacier surface so close to the ice-front that the glaciological and meteorological processes would presumably be distinct, but sufficiently far up the ice-lobe to avoid purely frontal phenomena. The station is indicated by "mast" on J.T. Møller's fig. 3, from which it will also be seen that at a distance of 2 km the expedition camp was situated right on the coast of Igdlorssuit Sund. On account of the short distance to the camp the records of the glacier station are easily compared with the macro-meteorological observations made there.

Weather Conditions in the Summer of 1957.

Method.

Normal, regular meteorological observations were taken at the expedition camp. They were intended to form a valid record of the weather at the South part of Igdlorssuit Sund and Upernivik Ø. There were ample reasons for presuming that this camp at the mouth of the valley would be under the influence of special conditions; but, apart from the shadows cast by the mountains, nothing unusual was noticed that could be attributed to any unfavourable placing of the observation post; not even any particular on-shore or off-shore wind was observed.

A check was made of the volume of wind at the camp in order to see if the wind depended upon a "draught" from the valley. To make this check a cup-anemometer with built-in counter, similar to that at the camp, was set up on one of the freely exposed sandstone peaks 7—800 m. above Upernivik Næs (the Southwest corner of the island). These two wind-gauges showed that the wind-way recorded per time-unit at the camp was an always constant percentage of the wind-way recorded on the free peak. Regardless of the wind direction the difference in wind force could always be explained by the difference between the levels, and no observation was made suggesting any wind concentration at the mouth of the valley.

Besides the wind-gauges the camp was equipped with the following continuously working instruments: a rain-gauge, a heliograph consisting of glass ball and recording paper, two thermographs, working on the principle of temperature recordings via the changes in a metal bow; one of these thermographs was built together with a barograph, the other with a hair-hygrograph, and both were placed in a specimen of the familiar "English hut" which is also employed normally at Danish meteorological stations. In the thermometer hut, set up at a height of 2 metres, there were also a maximum and a minimum thermometer as well as a fine-scale mercury thermometer. Every three hours in the 24 up to August 5th, when midnight observations plus those immediately following were omitted, the recordings of the self-registering instruments were supplemented by a number of short-period observations. This included visual evaluation of cloud and visibility, determination of wind velocity for a period of 5 minutes, and determination of temperature and humidity with an Assmann psychrometer. At the same time the automatic instruments were checked and their readings noted.

Discussion.

During a period of calm, sunny weather it was imperative for us to ascertain how much the inevitable heating of the thermohut affected the temperature readings. If the dry thermometer of the psychrometer could be assumed to show a true air temperature it looked as if the hut might be one or two degrees too warm inside; however, in spite of the intense radiation of the sun and the ground it was not always possible to demonstrate any such recording errors. We were soon forced to recognize that the air temperature there, as at so many other places in Greenland, was of doubtful value, because the predominating heat exchange proceeded by radiation.

Moreover, the nine weeks' observation material from the camp macro-meteorological station presents a more general problem. It is possible to set up and calculate the very large number of measuring units in many different ways, but without obtaining an exhaustive and perspicuous characterization. However, this representative characterization was our essential task; serving up the primary numerical material would be presenting an almost useless and inaccessible assemblage, despite its being correct objectively.

The difficult approach to the problem of the systematics of meteorological data is the same as that of general climatology; in Denmark this has been clearly indicated by HELGE PETERSEN (1934) and K. M. JENSEN (1953). The problem is more epistemological than objective.

In the following I shall endeavour to solve the problems by subdividing the weather into more or less precisely formulated "species" or "types". The weather may be described in qualitative terms, thus providing a vague characteristic as a starting point. In plain language one may say of the weather at Upernivik Ø that it had two conspicuous features; in the first place the weather was very often calm and dry, and in the second place, it was interspersed with periods of what Greenland-farers familiarly call "southeaster", a føhn (cf. Helge Petersen 1950, p. 140). In the course of a few minutes it would change from calm to windy, the air simultaneously becoming warm and dry. And the føhn dropped just as suddenly as it had come. This marked discontinuity of the weather made calculations, especially a general calculation of averages, inexpedient; on the other hand it was indicative of a division into weather types whose frequency it might be possible to find.

Results: Weather types.

It was practicable for the summer period to determine four weather types that are definable by certain of the meteorological elements. The total duration of these four types covered almost the entire time interval. In classifying the types I have endeavoured to draw lines between weather conditions with different forms of dominant heat supply to the ground, such as radiation, flow, conduction or condensation.

The first type I have called "radiation weather" (*VR*), which is defined as clear, calm weather with an almost cloudless sky. "Calm" here means wind forces not precisely measurable at a height of 2 metres with a normal cup-anemometer; it corresponds approximately to ≤ 2 Beaufort.

The second type is "føhn weather" (*VF*), in which a dry, relatively warm air current passes at a wind velocity of ≥ 4 Beaufort. Cloud may vary a good deal.

The third type is designated by the word "overcast" (*VL*), which means that the sky is covered with dark, high, rainless clouds through which the sun cannot shine. There is no wind, or it is ≤ 3 Beaufort.

The fourth type I have called "condensation weather" (*VK*), which signifies calm with mist or rain with moisture-saturated air. Very little solar radiation can reach the surface of the ground.

There were some weather conditions which evaded this classification; there were also doubtful intermediate forms, so that the above type division is only rough; but a further description will show that in the rubricated days the types appeared as "good species".

Radiation weather was dominated completely by the direct rays of the sun and the ground's reflection and re-radiation of heat. As there was sometimes insolation for 60—75 $^0/_0$ of the 24 hours, protracted periods of *VR* were very complicated and uncertain as to temperature. The false night of the mountain shadow caused high temperature amplitudes in case of days of that kind of weather. It may roughly be said that at a height of 2 metres, period classified as *VR* had an air temperature which oscillated around 9° C., with a variation of $\pm$ 3.5° C. Pressure was evenly distributed in the interval. 1015 $\pm$ 10 millibar, often with a falling tendency. The air humidity was practically "normal" with a variation of $\pm$ 15 % around 65 %, depending on the duration of sunshine on the camp.

During characteristic føhn weather (*VF*) humidity was 40 %, perhaps even less, but the air temperature (a term which owing to the high wind is employed in its proper sense), was over 10° C., normally about 14° C., with a variation of $\pm$ 2.5° C. It was obvious that the *VF* weather had a considerable drying effect, observable for instance in the curious fact that our clothing smelled as if it were newly-ironed. It was nothing uncommon for a few drops of rain to fall from cigar-shaped clouds during a føhn, but the rainwater, which seemed foreign in relation to the air, evaporated almost totally before reaching the ground, and this raised the humidity to about 60 %. In conjunction with a føhn, usually before, there was a relative barometer fall, but the absolute pressure might vary a great deal, from 996 to 1020 mb. Fig. 1 shows a thermohygrogram for a protracted føhn period about July 19th to 20th. The dryness referred to will appear from the figure, which also shows how sporadic and abrupt the changes were. Sometimes the føhn was also gusty, the wind coming in distinct blasts approaching gale force.

It was possible to discern some regularity in the weather changes: after days of insolation (*VR*) and falling pressure came the føhns which, the barometer having risen, were succeeded by condensation weather (*VK*), during which the calm and now cooled føhn air shed its surplus moisture, causing the recording instruments to become dripping wet. Humidity measured from 80 to 100 %. The mist or the low rain clouds prevented insolation of any importance, for which reason the modal values of the air temperature were 5°—7° C. and the temperature amplitude rarely exceeded 2°. Under these conditions the atmospheric pressure was almost always rising and for the greater part of the time remained in the interval from 1015 to 1020 mb.

A sort of "offshoot" from the føhn-condensation weather change was the overcast type (*VL*), which in wind, pressure and temperature values was very similar to *VR*, but somewhat colder. On account of the dense strato-cumulus cloud the air was moist: 70—80 %.

On fig. 2 the occurrence and duration of the various weather types are shown in relation to a time scale for the period of June 24th—August 24th. The durations are determined approximately by means of a time unit of half-an-hour, but it is difficult to indicate the actual accuracy of the calculations. The weather of some periods is timed with considerable exactness, whereas the placing of the others on the time-scale is doubtless open to adjustment within a margin of 2—3 hours;

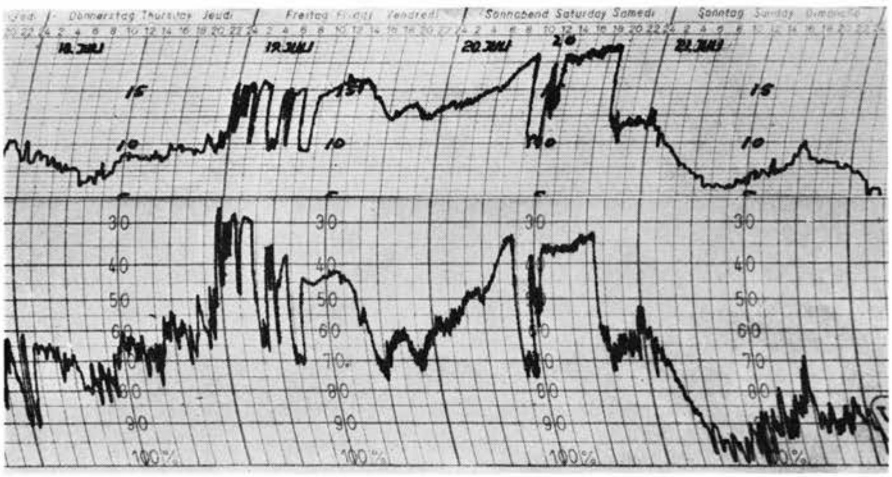

Fig. 1. The recorded continuous variation of temperature and humidity for the days July 18th—21st 1957 near Sermikavsak on Igdlorssuit Sund. The upper curve represents the temperatures, the interval between the heavy horizontal lines corresponding to $2^1/_2$ °C. The lower curve gives the relative humidity. The times are G.M.T. July 19th and 20th have abrupt, leaping increases of temperature and dryness owing to a strong føhn, "south-easter".

all the same, the maximum adjustment of the total occurrence of the weather type would not alter it more than 2—3 %.

The four weather types are distributable as follows: *VR* for 61.0 % of the time period, *VF* 6.9 %, *VK* 17.7 % and *VL* 11.9 %; 2.5 % of the time could not be classified under this system: there were two periods, one of which was an uncharacteristic føhn; in the second, there was sunshine with a strong, cold wind—the sole instance of strong, non—føhn wind within the entire summer. On the other hand, in October and November cold wind and gale are not uncommon in Umanak district.

It will be seen from fig. 2 and the type description that periods without rain and with calm weather were extraordinarily frequent; biologists would say the locality was "continental" in character (T.W. Böcher, 1949). During at least three-fourths of the period the weather was practically calm; one cannot help comparing this quality with the corresponding data from West European coastal areas, where much greater amounts of wind are observable at all seasons. A parallel should also be drawn with the recordings from Peary Land (Børge Fristrup 1953).

One might think that after all special weather conditions prevailed at the observation post, considering that "calm" was so common a state; in addition to what has already been said on this point, another argument is the natural assurance with which the local people sailed out to sea in small open boats. The value and variation of the calm frequency must have a bearing upon the occupational development of the region, inasmuch as the high frequency of dead calm is in favour of the people's hunting and fishing.

The information extractable from fig. 2 may be summarized as follows: fine, calm sunshine (*VR*) was the predominating weather at Igdlorssuit Sund whereas the obtrusive, dry air current of the "south-easter" (*VF*) was the unusual, differing radically from the normal. The cloudy, wet weather following in the wake of the føhn lasted a couple of days and was prominent especially during misty weather (*VK*). The weather changes at the passage of cyclones familiar in Western Europe were not observed. August had very uniform weather, whereas July had sudden changes of weather about twice a week on account of the føhn.

From what has been said above, it is presumable that the main cause of the summer melting at Sermikavsak is direct insolation. In order to approach this problem more closely it was necessary to investigate the micro-meteorology over the glacier ice.

Wind Profiles above the Glacier Ice.

The 12-metre steel mast at the Sermikavsak fixed glaciological station was also used for simultaneous recordings with four contact-cup-anemometers at heights of 150, 345, 640 and 1160 cm. above its foot, which was placed on a base let down into the ice. The recording heights had to be corrected incessantly for the changes of level caused by the considerable ablation, for the reason that the mast grew out of the ice, relatively speaking. As a result, our recordings were made at many different levels above the ice, because in the course of three weeks the recording height of each anemometer was increased by approximately three-fourths of a metre. The wind gauges operated with a current pause for every 100 metres of wind-way; the impulses were totalized in four counters placed in a box inside the tent and connected by a multiple cable from the mast. The necessary calibration curves for the apparatus were subsequently tested in the wind-tunnel at the Danish Technical University. The wind velocities were always found as the mean of a ten-minute recording period. About 120 wind profiles were recorded, representing 110 hours distributed evenly during the summer period (June 24th—August 24th), though the majority date from the early part of the period (and very few in the mornings). The total test percentage, i. e. observation time as a percentage of the maximum possible, was only 7.6. In the first three weeks the test percentage was 11, but in the last three weeks only 4 %. During insolation weather (*VR*) the

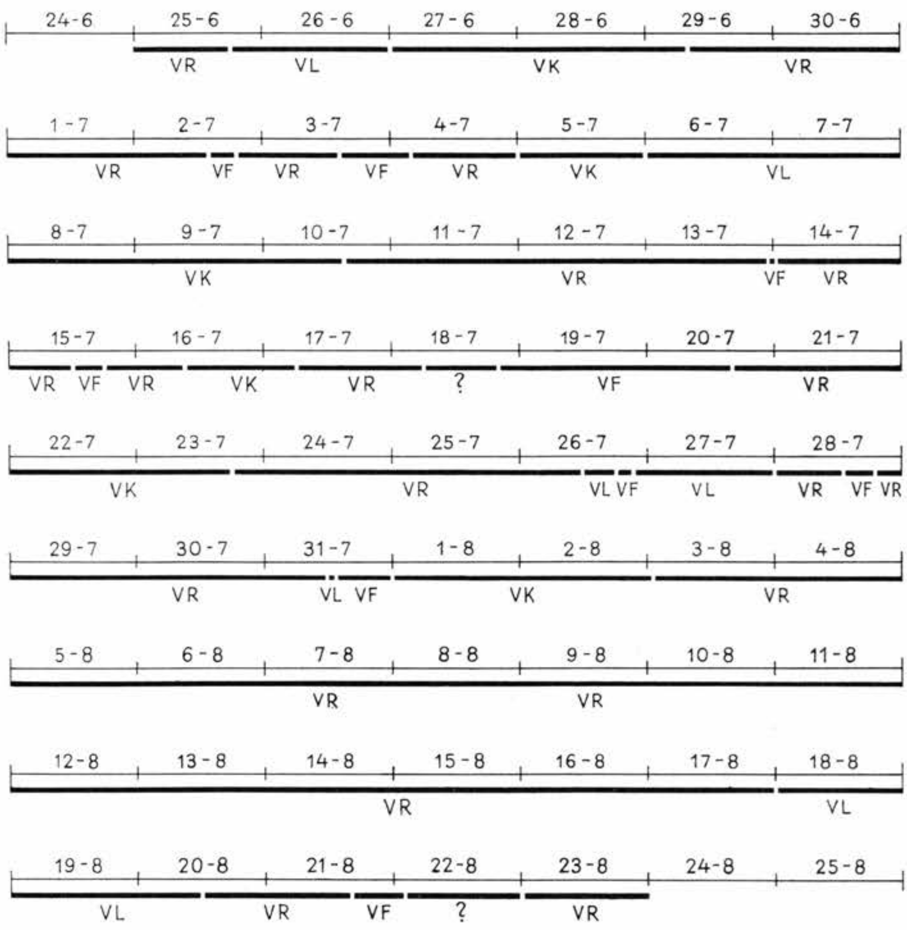

Fig. 2. Occurrence and duration of weather types for the period from June 24th to August 24th 1957 at Sermikavtak. *VR* signifies clear weather with almost cloudless sky and scarcely any wind. *VL* is overcast weather with dense strato-cumulus cloud and slight or no wind. *VK* means rainy-misty weather almost devoid of insolation and wind. *VF* marks the southeaster (the føhn) with its dry, relatively warm air, blowing with a force of $\geqq 4$ Beaufort. ? signifies unclassified weather. The descriptions are amplified in the text.

wind profile above the glacier was analyzed for 6.2 % of the time; in føhn weather (*VF*) the test percentage was 17.1, in overcast weather (*VL*) 12.2 %, whereas in condensation weather (*VK*) wind analyses were made in 7.1 % of the time. It may perhaps be thought—no doubt with some justification—that readings were not taken often enough; but on considering the monotony of the weather types and the test material it seems warrantable to us to draw a limited number of inductive conclusions.

Results: Wind species.

The material from the wind recordings above the ice soon made it evident that it would be reasonable to present the results in the form of a type-division similar to that employed in analyzing the macro-meteorology. There was a question of four "wind species" over the lower part of Sermikavsak, bearing in mind that we are confined to the "adjacent" air strata, "adjacent" here meaning a height zone of from 0 to 15—20 metres above the glacier.

The first wind species is called "*gravity wind*" and corresponds to what is normally spoken of as glacier wind and katabatic wind (see R. GEIGER 1950 and HOINKES 1954). It is characterized by the fact that the wind velocity increases with the height above the ice up to a certain level, in our case 1—2 metres, whereafter it decreases with additional height. It was paradoxical to observe the recording mast in such a situation, the uppermost wind-gauge being motionless whilst the cups of the instrument at face height were rotating at high speed. A gravity wind forms in calm weather by the rapid cooling of the air near the ice and increasing in density especially compared with the air outside the ice; and as the air over the ice lies upon an incline, it begins to glide down it. The movement of the cooled air current towards the sea along the longitudinal axis of the glacier was recorded as gravitational wind. Glacier winds of this kind are known in many parts of the world (see H. PETERSEN 1950, GEIGER 1950, WALLEN 1949, SJÖDIN 1957), although dimensions and frequency vary from one place to another.

Gravity winds are often distinctly pulsating in their occurrence accompanied by gusts (cf. GEIGER), and the glacier wind of Sermikavsak was no exception. O. G. SUTTON 1953, pp. 268—271, reproduces a theoretic analysis by PRANDTL of this kind of wind, which is there called "slope wind". According to that analysis, the profile of a gravitational wind has the form of a subdued oscillation about the velocity zero with an amplitude rapidly decreasing with the height. The velocity of the wind will be zero at a height four times the height at which the velocity reached its maximum.

On fig. 3 are plotted two curved lines surrounding two typical gravitational-wind profiles from Sermikavsak; or rather, only the upper part of the profiles is shown, it being difficult to construct a complete profile because lower recording heights than 150 cm. were not easy to define owing to the uneven and undulating surface of the ice. Clear registration was also hampered by the fact that the wind-gauges were often insufficiently accurate for measuring the generally slight air current. Nevertheless, fig. 3 provides a useful picture of the gravitational

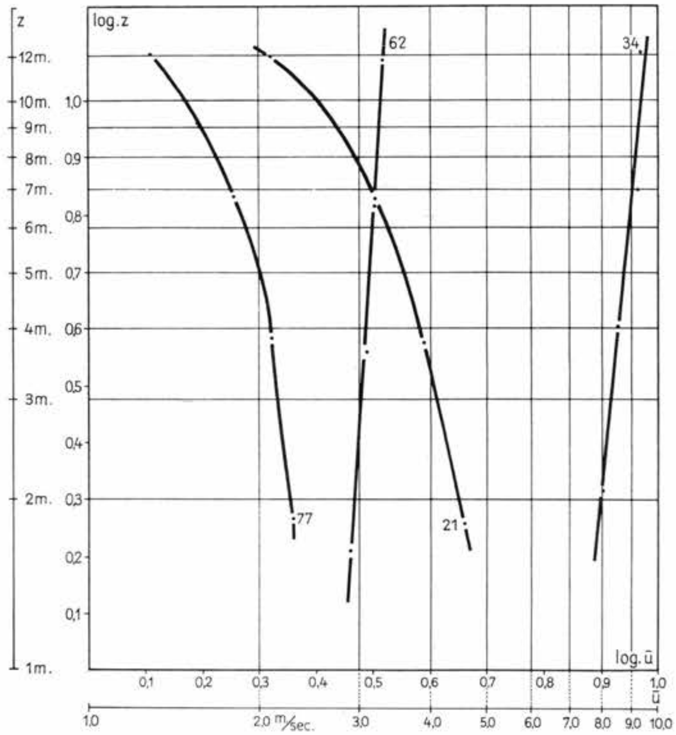

Fig. 3. Four typical wind profiles over the glacier ice. 77 and 21 show the velocity profile of the gravitational wind ("glacier wind"), 62 and 34 the føhn wind. The abscissa is the logarithm of the wind velocity, the ordinate the logarithm of the height above the ice.

wind, whose profile has a rough but recognizable similarity to the theoretic one sketched by PRANDTL.

It is possible to give a further description of all the recorded gravitational winds, of which about half were measurable. The distribution of the velocities of all gravitational winds at a height of 2 metres is shown approximately in fig. 4; the section of the curve to the left of 2 m/sec. is a very rough estimate. The velocities at the height of 11 m, as far as they could be recorded, were fairly constantly 50—60 % of the velocities at 2 m. This description was arrived at—after plotting the wind profiles—by graphically determining the velocities at 2 m and 11 m above the glacier ice for these profiles. It will be seen that the gravitational wind was slight, usually with a maximum velocity of about 2 m/sec., very rarely higher than 5 m/sec.

The second type of wind was the *føhn* (a name which signifies a strong and dry wind as in the usual terminology), whose profile was normalized in the sense that the velocities increased with the height.

On watching the mast during a føhn wind it was observed that the uppermost wind-gauge was rotating at least as rapidly as the others. In fig. 3, two føhn profiles are plotted in relation to the logarithmic scales; by this means they closely approximate two straight lines. The drawn føhn profiles are two observed values, whereas the others, which were of the same shape, were distributed in between. It is doubtful if one can extrapolate outside the height interval within which the recorded profiles were measured, viz. 1.5—12.5 metres. The graphic illustration in fig. 3 suggests that the velocity of the føhn wind varied with the height in accordance with a power law. In ordinary aerodynamics use is also made of an empirical power-law profile, often called "the seventh root profile" (cf. R. GEIGER 1950, O. G. SUTTON 1955, pp. 21—22, and M. JENSEN 1954, p. 23). The formula of the profile may be written thus:

$$\bar{u} = \bar{u}_1 \left(\frac{z}{z_1}\right)^{p'} \qquad p' \geqq 0 \qquad 1.$$

where $\bar{u}$ is the mean wind velocity at the variable height z, and $\bar{u}_1$ is the mean wind at the constant reference height z_1. In the føhn profiles of fig. 3, p' may be read from the slope; the two drawn profiles have the power values of 0.10 (34) and 0.07 (62). All twenty recorded føhn-wind power values had a central tendency around 0.10; the highest p' value found was 0.14 (the seventh root profile). These powers are equal to those usually found (cf. O. G. SUTTON, M. JENSEN).

Wind profile formulae of the same type as Equation 1 have been a conspicuous feature in many calculations of a theoretical ablation (see S. ORVIG 1954, pp. 286—289); but it should be borne in mind that, in the first place, p' is constant only in narrow temperature intervals and limited height zones; in the second place, the formula is not applicable to low and high z values. At Sermikavsak the føhn wind either came down the glacier towards the sea, exactly as the gravity wind did, or it blew from the SE down across the mouth of the valley; the two directions, however, often interchanged at intervals of minutes.

Only one other wind direction besides these two was observed: one from the sea up into the valley; this valley-ascending air stream was the glacier's third type of wind, which may be called the *sea wind*.

With sea winds the profile, on the few occasions when the air flow was of any strength, was a normal one in the sense of increasing velocity with the height above the ice; but it was impossible to find any regularity in the profiles. In the few that were observed the wind force at 2 m. height was 2—3 m./sec., whereas at 11 m. it was about 150 % of that value.

The last form of wind stated is here called the *zero wind*, which signifies velocities so low as to evade measurement by the anemometers, of which the cups were either motionless or turning a few revolutions in 10 minutes. It was impossible to discern any particular height at which the air movement was greatest. If the wind direction was perceptible it was always along the valley. The zero wind, or "calm", is probably always closely associated with either the gravity wind or the sea wind, but the affinity of this wind was impossible to identify by technical measurement. Quite motionless air was seldom observed in that sloping terrain, where the zero wind was an extreme variety of unknown winds.

The four wind types set up above covered the entire period of observation. The fact that only three wind directions were observed illustrates the great influence of the terrain upon the micro-climate of Sermikavsak. It was evident that the føhn and gravitational winds were specifically different and manifested themselves as contrasts.

Weather and wind species.

The duration of the wind species observed may be expressed as a percentage of the aggregate, real recording time; this percentage may be called the "observation frequency". For the gravitational wind it was 73 %, for the føhn wind 15 %, the zero wind (calm) 8 % and the sea wind 4 %. As the observations on the glacier were not made systematically as to time, these observation frequencies provide no reliable picture of the true duration of the wind species in the actual summer period. The total duration of a wind species in the summer, expressed as a percentage, may be termed the occurrence percentage; for its calculation a study of the interplay between the macro-meteorological weather types and the micro-meteorological wind species of the glacier is required. A co-variation can be found, because even rough observation showed that the mast station and the camp had the same type of weather at the same time, allowing for a margin of uncertainty of half an hour.

The føhn wind of course was observed during føhn weather (*VF*) and only then; but sea wind and gravitational wind were also observed in *VF* weather; this was due to the spasmodic interchange of the wind types at the close of a føhn period. During føhn weather, the sea and gravity winds each represented 6 % of the tested time; the remainder was occupied by the regular føhn wind. In radiation weather (*VR*), gravity and zero winds predominated at the glacier and represented 87 % and 10.2 % of the time respectively; sea wind: 2.8 %.

In overcast situations (*VL*) 97.6 % of the time had gravity wind, the remainder sea wind. In condensation weather (*VK*) it was characteristic that zero wind and sea wind were relatively frequent: 16.7 and 8.3 % of the time; on such occasions sea mist and clouds drifting sluggishly in the valley could be seen. Otherwise this form of weather was also dominated by the gravitational wind (75 $^0/_0$ of the time).

If we grant that the test period was long enough to provide a picture of the whole summer period, the true occurrence percentages of the various forms of wind can be calculated by "weighting" their observation frequency within each type of weather with the duration of the type in the total period. The result will then be that gravitational wind had a true occurrence percentage of 78.4, whilst føhn winds occupied

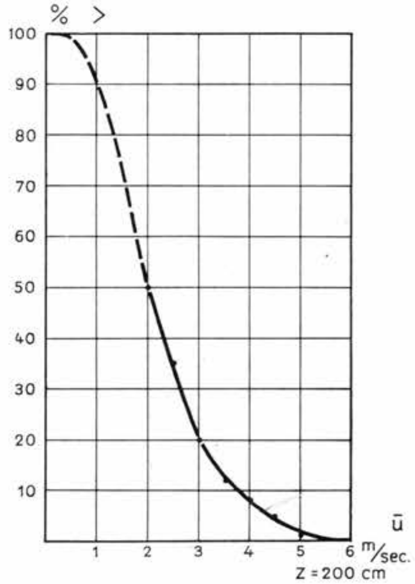

Fig. 4. The approximate distribution of gravitational-wind velocities at 2 metres above the glacier, 1 km from the glacier front. The abscissa shows the wind velocity in m/sec., the ordinate the relative number of velocities recorded.

6.1 $^0/_0$ of the time, zero winds 9.2 $^0/_0$ and sea winds 3.9 $^0/_0$; the remaining percentages correspond to the undefined types of weather (see fig. 2). It will be seen that the wind conditions over the glacier were of a simple character.

The gravitational wind was markedly prominent among three of the weather types and for the entire period was displaced distinctly in only 10—12 $^0/_0$ of the time. In this respect Sermikavsak seems peculiar in relation to what we know of the valley glaciers of Europe, where the "glacier wind" appears less distinctly and is not nearly so frequent. But when we recall how often the weather is calm round about Upernivik Ø, and how Sermikavsak is hemmed in by sheltering mountains, it seems natural that the cooling effect of the ice dominates the movement of the air over the glacier. It was nearly always the case, no matter at what time and at which place we were working on Sermikavsak, we had the cooling current of the gravity wind to mitigate the physical exertion.

HOINKES (1954) makes a distinction between air "foreign" to and "peculiar" to glaciers; the same distinction may also be drawn as regards Sermikavsak, but without simplifying our theoretical considerations of the thermal economy because it is no help in clarifying the mathematical analysis of the structure of the gravitational wind. The influence of that wind on the ablation must be complicated.

Temperature profiles above the glacier ice.

Method.

Our recording of wind profiles proceeded simultaneously with recording the temperatures at four different levels, each about 25 cm. below one of the wind-gauges. At each height was a platinum thermometer, whose electrical resistance changes resulting from the temperature were recorded by a Wheatston bridge placed in the same box as the counters of the wind-gauges. Each platinum wire was fused within a glass rod which was enclosed within a bright metal case with ventilation holes. On account of the frequent calm periods of sunshine and the long insolation period it was found that the platinum thermometers had to be protected more carefully from direct radiation heat. A number of tests were made to find efficient protection, in the course of which it transpired that errors in reading of up to 10°C. could be made even in the "shade".

The problem was to construct a sunshade with natural ventilation and isolated from ice reflection and radiation heat from the shade. A close approach to an ideal shade of this kind was constructed with two bright metal boxes, one suspended freely within the other and with the platinum thermometer likewise freely suspended within the inner box. Cut into both boxes were slots to allow the air to contact and ventilate the instrument. This protection worked well as long as the air moved more than 1.5 m./sec., but as lower velocities were usual at the mast top the temperature tests were incomplete. On account of the marked thermal stratification of the air near the ice, which we particularly intended to study, the use of the Assmann psychrometer in recording the temperatures was soon abandoned, though it is often employed in glacial meteorology (cf. ORVIG, SJÖDIN).

About 400 temperature profiles were recorded, corresponding to a total recording time of 120 hours. On account of the radiation weather and the relatively slight gravity wind, barely one third of the recordings could be used. Observations were made at most times of the 24 hours, at both minimum and maximum insolation. The temperature profiles suitable for our purpose were all recorded during føhn or gravity winds, whereas conditions associated with sea and zero winds are known only approximately.

Results.

The chief result of the test was that during the summer period there was constant temperature inversion over the wet ice, and that no negative air temperatures were recorded; similar summer obser-

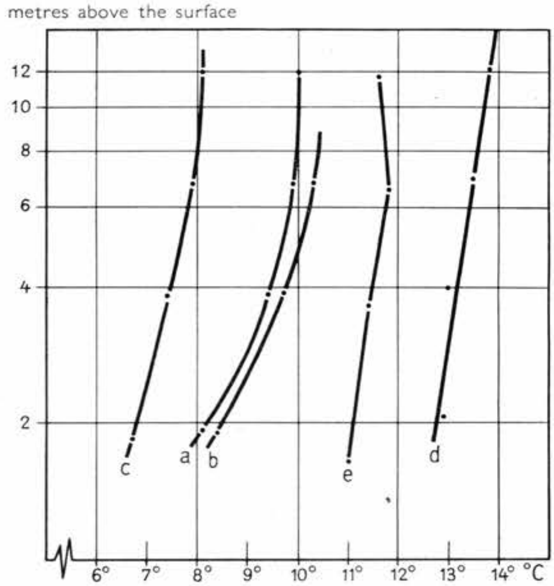

Fig. 5. Typical air-temperature profiles over Sermikavsak, 1 km. from the glacier front. a, b and c recorded in gravitational wind, e and d in føhn wind. The abscissa shows the thermal degrees in Celsius; the ordinate is plotted with the logarithm of the height above the ice. Bearing in mind that the glacier surface was 0° C. it will be seen that the føhn wind caused unusually great temperature differences in the air strata near the ice.

vations have been made at European glaciers (cf. WALLEN, SJÖDIN). The temperature profile for gravitational wind differed perceptibly from that for føhn wind. The profiles for both wind types are shown in fig. 5 by means of characteristic specimens; *a*, *b* and *c* correspond to gravitational wind, whose temperatures were only recorded with certainty during *VR* weather; *d* and *e* are temperature profiles for føhn. It was impossible to find any constant regularity in the form of the profiles, so that extrapolation is doubtful. Strictly speaking, only part of the total profile is accounted for. Profile *a* in fig. 5 was recorded at mid "night" on July 2nd, whilst *b* dates from 14.00 on August 16th. It will be seen that these different occasions showed almost similar temperatures during gravity wind; this homogeneity was universal, for all definite temperature profiles for gravity wind had analogous forms and values which seemed independent of the time of day. It was characteristic that the rise of air temperature with height was most marked near the surface. The following Table I also reveals this homogeneity and gives the distribution of the temperatures at 2 metres for 32 hours (spread over the summer) for gravity wind.

Table 1.

Temperature interval. °C.	Distribution %
< 6.5	0.0
6.5—7.0	15.6
7.0—7.5	15.6
7.5—8.0	31.2
8.0—8.5	21.9
8.5—9.0	15.6
> 9.0	0.0

It appears from the table that approximately 8° C. was the "normal" at the height of 2 m. and that the entire range of variation was no more than 2.5° C. At 11 m. the temperature was always from 1° to 3° C. above that at 2 m. No closer co-variation between the temperatures of the two heights could be found. The slight temperature variability of the gravity wind must be assumed to be characteristic and in so far is comprehensible, because this wind is a creation of the cold/heat relation of the glacier surface and the latter's slope.

On several occasions the temperature profiles of the føhn wind described almost an exponential curve (see fig. 5), but the differences were too numerous for a definite hypothesis. The føhn temperatures were higher than is usual in the case of glacier winds; at 11 m. they varied between 11.5° and 14.0° C., whereas at 2 m they were irregularly 0°—2° C. lower. It will be observed that with a føhn wind there was a considerable difference between the temperatures of ice and air; from 0 cm to 200 cm above the glacier surface there was usually a rise of about 12° C. in the temperature. As that air was in rapid movement it was only to be expected that the føhn would increase the melting of the ice.

Ablation at the mast.

Method.

Parallel with the recording of temperature and wind profiles the gross ablation, or the reduction of the surface level, was measured at the permanent station on the glacier. The usual method was employed: recording the relative height increase of bamboo poles fixed down in bored holes in the ice.

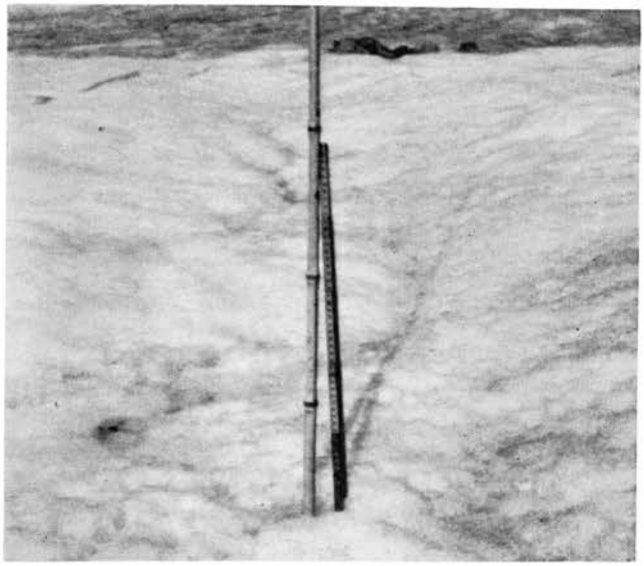

Fig. 6. An ablation pole placed in the normal glacier surface near the recording mast. A ruler is resting against the bamboo pole.

Two poles were set up near the mast, one at a representative spot with an almost clean ice surface (fig. 6), the other at a more special place where the ice was almost hidden by boulders, stones and coarse sand (fig. 7). This covering of stones lay in the form of a superficial medial moraine about 2 m. wide, extending from the mast to some distance down the glacier. The ablation at this special spot was tested for the sake of comparison.

When glacier surfaces are dirty it may be difficult to decide which place may be called representative. The surface may be shaped in metre-wide undulations which in turn are pitted with cryconites and meltwater streams. Even the placing of many poles will not ensure the solving of the problem.

However, it was not only the siting of the poles that sometimes caused difficulty; the actual reading of the ablation also gave trouble. It may seem simple to measure the distance from the mark on a bamboo pole down to the ice; but if the surface has become uneven and sloping since the previous inspection, owing to a meltwater stream having changed its course, it may be difficult to determine the level of 0.0 cm. In the end we took the readings by measuring several distances down to a straight rod which, lying on the ice and touching the gauging pole, was moved round the compass. An approximate mean of the many values was taken as the final reading. When the surface became very

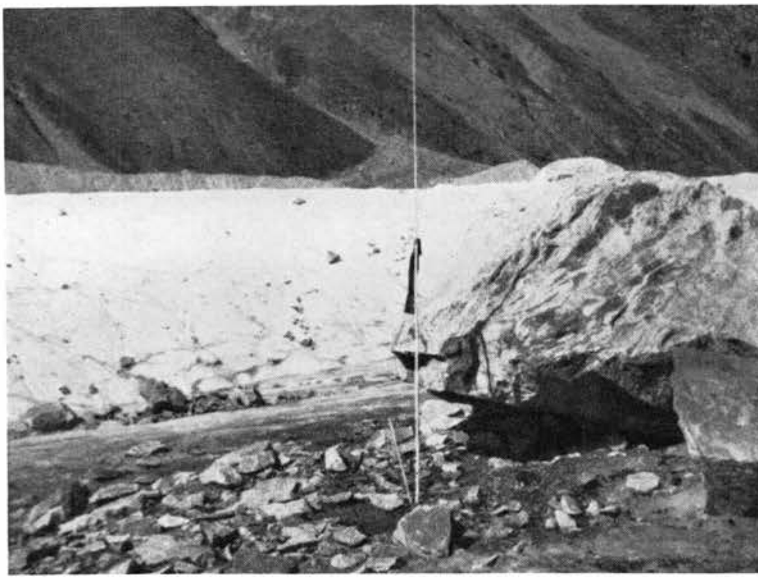

Fig. 7. A bamboo pole placed in a special area of the glacier surface, consisting of a heterogeneous covering of stones, "a thin medial moraine". The large boulder moved in jerks towards the left each time it fell from its self-created glacier table. In the background a section of the normal glacier surface and the northern mountain wall of the valley.

rugged the uncertainty increased to decimetres, whereas normally it was from a half to one centimetre; in such cases the pole was moved to a fresh recording spot.

Relative ablation.

For the purpose of ascertaining the effect of detritus on the ablation we made one or two primitive tests. An ice area of 2×5 m. was cleared of stones, sand and dust, leaving the ice surface as clean and shining as possible. On this clean area we selected five small areas of 50×50 cm. and on four of them laid uniformly-sized small stones and chips packed in different densities; the fifth small area was kept clear of foreign bodies. This cleared spot with the small areas, the "stone beds", will be seen on fig. 8; it will also be seen from the picture that the natural surface of the ice was dusty.

Fig. 9a, b and c show three beds with different stone packings. In the first, fig. 9a, we laid so many small stones evenly distributed that the mean corresponded to 1 g of stones to 1 sq.cm ice surface. In the second stone bed (fig. 9b) the mean was 1.9 g/sq.cm, and in the third (fig. 9c) it was 4.2 g/sq.cm. The fourth stone bed, seen in the background

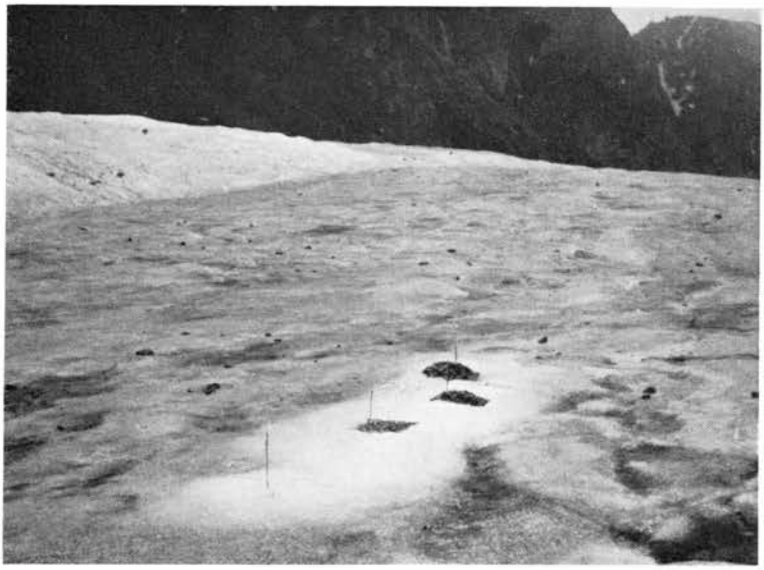

Fig. 8. A piece of the natural surface of the ice has been cleared artificially so that in the picture it contrasts with its surroundings. Four small areas have been laid out with small stones in "stone beds" of different packings.

of fig. 8, contained 8.6 g of stones per sq.cm. Having been arranged, these stone beds were left for 36 hours, whereafter the ablation of the stony parts and of the clean area was measured. They were then left for 18 hours more, whereafter further ablation measurement had to cease because of distinct effects observable between adjacent margins.

There proved to be considerable differences in the melting of the five beds, which of course also depended upon the weather changes. On placing the ablation of each bed in relation to that of the artificially clean ice we obtained the following proportions (Table 2):

Table 2.

gm. stones/cm^2	relative ablation 18—19/7	relative ablation 19—20/7
0	1.0	1.0
1	1.2	1.3
1.9	1.35	1.6
4.2	0.85	0.8
8.6	0.7	0.6

Too much importance need not be attached to this experiment, which may be regarded merely as an instructive demonstration; the conditions are more complicated than can be explained here, because both size and nature of the foreign bodies as well as the extent of the

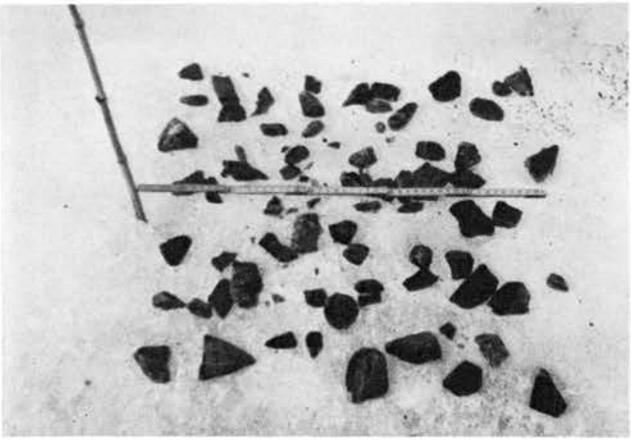

Fig. 9a. An area with small stones placed on cleared ice, one of the stone beds in fig. 8. The ruler lying across the stones is a half metre in length. The average in the "bed" is 1 g of stones per sq.cm.

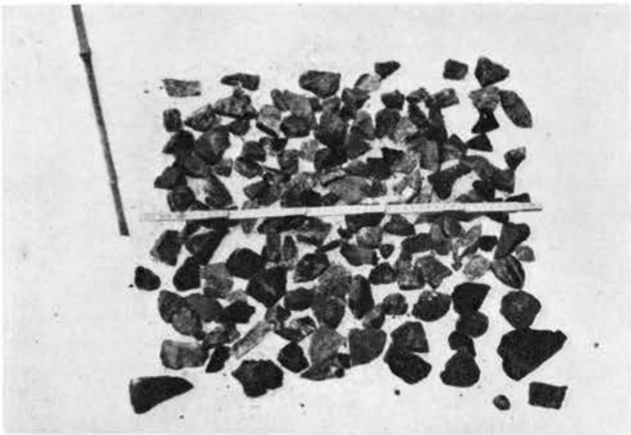

Fig. 9b. Similar to 9a, except that there are 2 g of stones per sq.cm of surface.

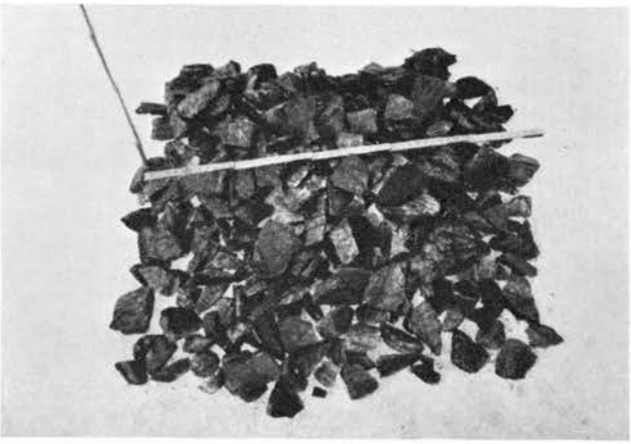

Fig. 9c. An arranged area with about 4 g of stones to the sq.cm. Cf. fig. 9a.

Fig. 10. A gravel cone, 9 m high, in front of a moraine-covered ice lobe just south of Sermikavsak's glacier front. In the background is a glimpse of Upernivik Ø's "sandstone mountains".

"dirty" area have an influence on the problem, which may be called the Relative Ablation. The many aspects of the problem may be gathered from the fact that after the test each of the four stone beds developed degrees of coverage that were almost equal; the explanation of this must be the small size of the areas and the relative mobility of the stones. The test pointed in the same direction as the general observation thesis that the rate of melting advances with increasing quantities of impurities up to a certain limit, whereafter more foreign bodies cause less melting. On Sermikavsak it could readily be seen that the relative ablation had a morphological effect, elevated parts being either very clean or very dirty. The existence of the moraine-covered lobe and the gravel cone, both of which are shown in J.T. MØLLER's fig. 3 and Pl. 1, illustrates this problem. MØLLER's sketch map may be supplemented with fig. 10, showing the 9-metre gravel cone with the dirty lobe in the background.

The contribution made by the specially placed bamboo pole at the mast to the problem of the significance of these foreign bodies also illustrated its complicated nature. On placing the melting of the narrow medial moraine in relation to the "normal" ice, we arrive at the following relative ablations: for the period June 29th—July 11th: 0.9; July 15th—August 1st: 1.3. The ablation of these periods amounted to about 0.75 m water per sq.cm, so it was possible to establish the local differences of ablation. It was a fact that the ablation rate of the thin medial moraine rose during the summer, and that the rate at first was lower, later on higher than the "normal". Whether the cause of this was accumulated heat in the stones or something else, cannot be decided; but theoretically it is difficult to imagine such a *narrow* stone covering to be *stable* unless its melting rate is approximately the same as that of its surroundings; cf. the marginal effects in the test with stone beds.

Cumulated ablation.

By means of the "representative" bamboo pole it was possible to make a complete series of ablation recordings in the period from June 24th to August 1st. The total ablation for the period was measured, and at the same time the melting rate for brief periods was determined, readings being taken at intervals of one or two days. We were interested in ascertaining the 24-hour ablation, to enable us to observe the influence of the weather upon the melting intensity. The periodic fluctuation of the ablation within 24 hours could not be measured with any reasonable accuracy. All theoretic calculations of the ablation will be omitted in the following, firstly because we lacked good records of the humidity and radiation over the ice; secondly, it is my opinion that the usual equation for the heat balance of the ice surface (see S. Orvig 1954, p. 285) cannot be applied direct to dirty, stony glacier surfaces like those at Sermikavsak. The same must be relevant more or less to other localities (see i. a. G. Norling's pictures, 1957).

In fig. 11 the recorded, cumulated ablation as from June 24th is shown as a function of the time elapsed from June 24th to and including August 1st; each dot marks a reading. The ablation is indicated in cm. water per area unit, the gravity of the ice being reckoned as 0.9 (cf. Hoinkes, Norling). Rough checks suggested that the true gravity of the ice was rather lower and somewhat variable, but nevertheless the structure of the ice made it natural to employ 0.9, the figure used in corresponding measurements in Europe. In fig. 11 the function curve is split up into linear elements signifying continuous days with almost the same ablation rate. The total ablation for the 40 days was about 1.8 metres of water. If the observed values of the cumulated ablation are groupable about straight directrices, the ablation intensities indicated by the directrices must be representative values, because both recording uncertainty and 24-hour fluctuation become evened out by this graphic determination. The ablation rate cannot be indicated in relation to time units of less than 24 hours.

Fig. 11 permits of a study of the influence of the types of weather on the melting of the glacier; in the course of the forty days there is relatively little difference in the optimum insolation; for this study it

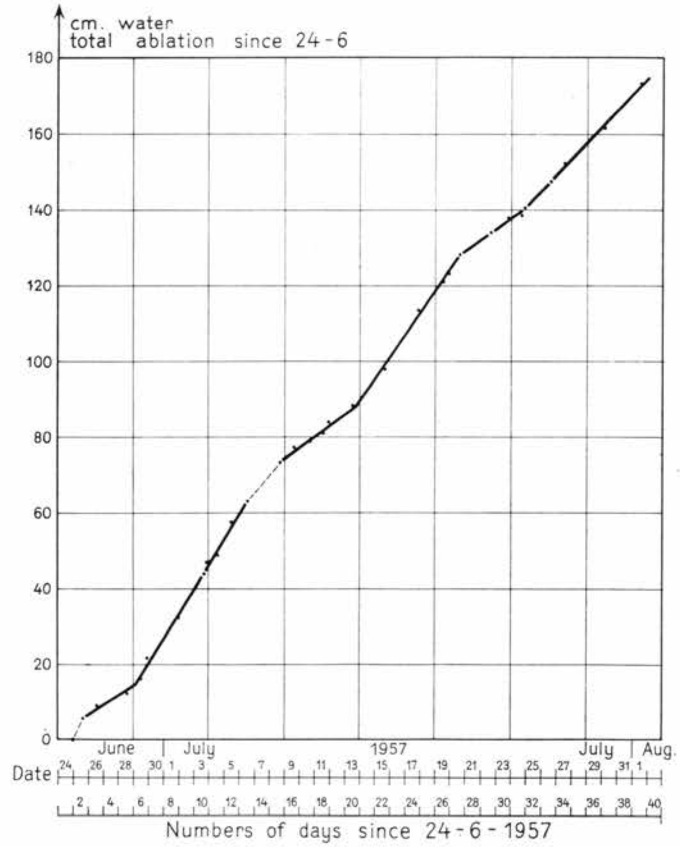

Fig. 11. The cumulated gross ablation since June 24th 1957 at the recording mast on Sermikavsak, placed in relation to the time elapsed from that date till August 3rd of the same year. Each dot marks the ablation measured at the time after June 24th. The recorded ablation values are gathered into groups by directrices; there are six continuous 24-hour groups. The incline of the directrices shows the ablation intensity. The abscissa is the period with the dates showing; the ordinate gives the cm of water melted since the test began.

may be useful to make a comparison between the 24-hour groups in fig. 11, and the indication of weather types in fig. 2. The first 24-hour group, from noon on June 25th to noon on June 29th, had an ablation rate of 2.5 cm per diem (the rate cannot be expressed in units of less than a half centimetre). This period had overcast weather (*VL*), succeeded by misty weather (*VK*). A large portion of the supply of heat came via conduction and condensation when the low or dense cloud reduced insolation to less than half the optimum.

In the next ablation period, June 29th to July 6th, see fig. 11, insolation was optimum right up to July 5th, and the effects of the sun were intensified by two føhn periods. On July 5th—6th there were dense fog-rain clouds which prevented radiation, the result apparently being a kind of "greenhouse effect". The ablation intensity, 6.5 cm per 24 hours per area unit, was distinctly greater than in the first 24-hour group and it was clearly recognizable from many indirect observations, such as the shape of glacier tables and the position of the mast.

In the third 24-hour group, from noon of July 8th to noon of July 13th, there was a steady ablation of 3 cm per 24 hours. In the first half of this period the weather was distinctly of the condensation type (*VK*) which greatly diminished insolation for a couple of days or so; in the latter part of the period the sun returned with optimum strength, but most of the heat seems to have gone to waste because the light reflection of the ice had increased in many places after the surface had been washed clean by the rain. The third 24-hour group resembled the first, both in the intensity of the ablation and in the weather, which was characterized by days of dense, low cloud.

From noon of July 13th and seven days onwards the ablation proceeded uniformly; this fourth 24-hour group had a per diem ablation of 6 cm, which was almost the same as that of the second group but twice as much as that of the foregoing days. The weather consisted of three føhns following upon radiation weather. On July 16th and 19th it was cloudy, but the absence of sunshine was compensated for by the warm føhn air. When discussing wind and temperature profiles over the ice it was mentioned that the recordings would lead one to expect heavy ablation in føhn weather; observations seem to have satisfied these expectations to the full.

At Sermikavsak the "glacier-foreign" air (Hoinkes) definitely brought the greatest amount of convection heat to the ice.

The fifth 24-hour group, July 20th—July 24th, had an ablation of 3 cm/diem. For two days insolation was prevented by condensation weather (*VK*), whose very moist air acted as a buffer to changes in the temperature of the atmosphere. It will be seen once again that protracted condensation weather is succeeded by slight ablation.

The final ablation period, July 25th—August 1st, presented a 24-hour melting of 4.5 cm water. The weather was mostly fine and sunny (*VR*), interrupted by three brief føhns (*VF*), but the low position of the sun in the sky and the brief duration of the føhn must explain why the ablation failed to reach the earlier maximum values.

During the constant radiation weather from August 5th till August 17th the ablation rate (not shown in fig. 11) apparently fell from 4 to 3 cm water/diem, but this determination is only uncertain.

From this examination of fig. 11 we must conclude that the prin cipal cause of the melting was the heat transmitted to the ice by direct sunshine. It is also to be seen that radiation days (*VR*) with interruptions of føhn at mid-summer gave an ablation of 6—7 cm of water/diem, whereas calm, foggy rain (*VK*) at the same time gave only 2—3 cm melting in the 24 hours. The difference does not come under the heading of recording inaccuracy; it is a reality.

A rough estimate shows that about 80 % of the ablation was the result of radiation heat. The heat convected from the air was only of importance in føhn weather, whereas the frequent gravitational wind may be interpreted as an expression of the fact that for most of the time the ice affected the thermics and dynamics of the air near the ground, and not the opposite. Condensation heat from the air to the ice had no effect whatever; indeed in føhn winds much heat was expended on evaporation.

I would rather not compare the observed quantitative ablation rates with corresponding values from either Sermikavsak or other glaciers. The figures presented above are real for that particular period and that locality, but drawing general conclusions from them would be a dubious undertaking, because the shape of the ice surface and its content of foreign bodies influence the recordings in a manner not yet clarified. On Sermikavsak, working in the same height zone I could have found ablation values differing 50 % from those given, and perhaps those figures would also be "representatively descriptive". If notwithstanding the uncertainty the melting of Sermikavsak glacier were placed in relation to the glacier ablations of other countries, it would be warrantable to say that it seems to have a particularly intensive gross ablation, from 4 to 7 cm water per 24-hours per area unit, lasting from 2 to $2^1/_2$ months of the year.

To be in a better position to compare ablation values from various regions it would be advisable in future to set up—in addition to the normally placed poles—accessory bamboos with artificially cleared ice surroundings. It would then be possible to give both the absolute and the relative ablations.

Summary.

From June 24th to August 24th 1957 a detailed survey was made of the weather conditions and ablation on the lower part of the glacier Sermikavsak, Upernivik Ø, Umanak District. The survey was based upon observations from two fixed recording stations, one at the coast, the other 1 km up the glacier.

Prefatorily it is mentioned that Sermikavsak is a narrow valley glacier (Type CI; AHLMANN 1948), surrounded by tall, steep mountain

sides. It was already assumed that the mountainous landscape had a dominating effect upon the weather and climate of the region (Geiger, Sjödin).

The weather of the summer period studied has been classified (as in the case of the observations in Igdlorssuit Sund) experimentally into four weather types whose duration and changes are shown in fig. 2. Both rain and strong winds (>3 Beaufort) were rare. Clear, calm weather with almost cloudless sky reigned for 61 $^0/_0$ of the time, and was especially common in August. In July brief spells of føhns (*VF*: 7 $^0/_0$) were frequent. The weather conditions were uniform and local, governed by the great energy exchange caused by radiation. Biologists would have called the local weather "continental" (T. W. Böcher).

A gravitational wind (cf. Wallen, Geiger, Sjödin) blew almost incessantly, calculated at 78 $^0/_0$ of the time, over the glacier at a height of from 0 to 15 m. Fig. 3 shows a part of the curious profile of this wind; from a height of 1—2 m the wind velocity fell with increasing height above the ice; its velocity was never greater than 5—6 m/sec., but 2 m/sec. was the usual rate (fig. 4). The temperature profile of the gravitational wind always revealed inversion and was only slightly variable at all times (see fig. 5); but it was very difficult to record the air temperature owing to tricky radiation heating. In føhn weather (*VF*) the wind profile over the ice was mostly "normal" in the sense that the velocity increased with height (fig. 3). The føhn wind, whose strong air current was 6—8° C. warmer than the normal, was the only wind over the ice that sometimes blew across the valley. Two other "wind species" were observed over the glacier. One was the zero wind (9 $^0/_0$ of the time), i. e. calm or almost calm; the other was called the sea wind (4 $^0/_0$); its wind profile was also "normalized" and revealed little velocity.

The ablation of the chosen summer period was measured by means of bamboo poles; their placing is discussed. I attach particular importance to the impurities on the glacier surface, which a primitive test showed were capable of causing enormous variations in the ablation (see figs. 8 and 9). Direct observation also showed that foreign bodies have an evident morphological effect (see fig. 10). The relation between a locality's real ablation and what would be measured if the ice were quite clean, is called the relative ablation.

Ablation rates (g.water/diem/area unit) at the glacier station are determined approximately in fig. 11. It appears that in July, periods with radiation weather and føhn had 6—7 cm. ablation in 24-hours, whereas corresponding values in condensation weather were the half of that figure. With uninterrupted radiation weather (*VR*) in August the ablation rate was 4—3 cm per 24 hours.

By far the most important cause of the glacier melting was the transmission of heat by radiation from sun and surroundings (about 80 %). But how the abnormal weather situations, føhn and condensation weather, occur and vary must have a bearing upon the annual, unknown gross ablation. Even slight changes in the frequency of "the uncommon" may have a radical morphological effect (cf. K. M. JENSEN 1953); for example, a short, powerful spring føhn may prepare the way for the sun's attack, whereas condensation weather (*VK*) causes developments to stagnate.

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Abbreviations:

G. = Geographica. Skrifter från Uppsala Universitets Geografiska Institution. Uppsala.
G.Ann. = Geografiska Annaler. Stockholm.
G.T. = Geografisk Tidsskrift. København.
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