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A WEST GREENLAND GLACIER FRONT

A SURVEY OF SERMIKAVSAK NEAR UMANAK IN 1957

BY
JENS TYGE MØLLER

WITH 4 FIGURES IN THE TEXT AND 1 PLATE

WEATHER AND ABLATION OBSERVATIONS AT SERMIKAVSAK IN UMANAK DISTRICT

BY
HANS KUHLMAN

WITH 11 FIGURES IN THE TEXT

DER RÜCKGANG DES JAKOBSHAVNS ISBRÆ (WEST-GRÖNLAND 69° N)

VON
J. GEORGI

MIT 6 FIGUREN IM TEXT

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A WEST GREENLAND GLACIER FRONT

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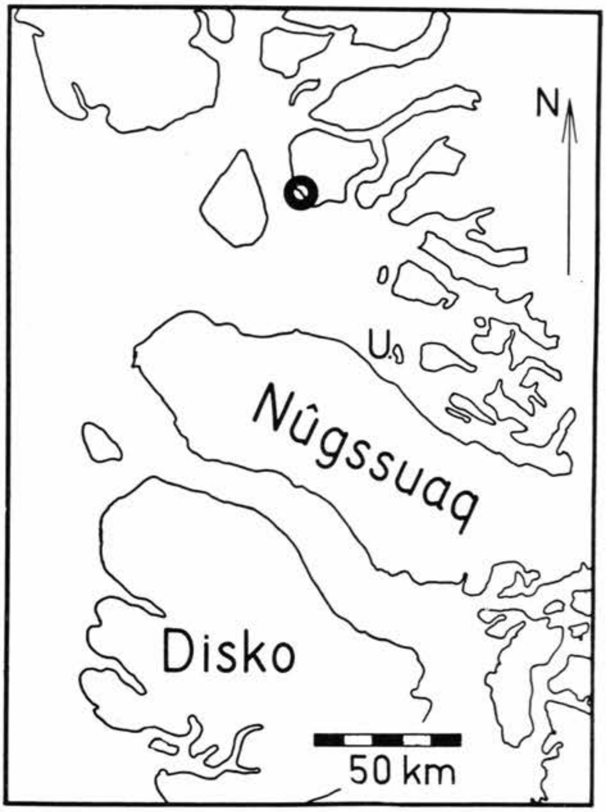


Fig. 1. The camp at Upernivik Næs (marked by a ring). U. indicates the town of Umanak.

A glaciological expedition of three teams was sent out to West Greenland in the summer months of the years 1956 and 1957. It was under the direction of the Copenhagen University Geographical Laboratory and had financial support from The Carlsberg Foundation and the Rask-Ørsted Foundation. The expedition was in charge of Professor NIELS NIELSEN and Assistant Professor B. FRISTRUP, the occasion being The International Geophysical Year. The three teams, whose glaciological researches will not be reported on here, devoted their attention to the Hurlburt Gletscher at Thule, Sermikavsak at Umanak and Sermersoq at Nanortalik respectively. One section of their programme comprised the production of a reliable, large-scale map of the glaciers for use during The Geophysical Year and also to serve as a foundation for establishing the fact of any changes in the glacier surfaces and their extent. It was therefore natural to devote particular attention to drawing a large-scale map of the glacier fronts (fig. 1).

The following is a brief account of the survey of Sermikavsak and of the problems requiring to be solved in conjunction with that geographical field-work. The description is compiled on the background of the fact that the survey is merely a small part of a wider investigation and was carried out by a team which had constantly to bear the total task in mind. From a purely technical point of view, of course, a survey of this nature could be made much more rationally.

The glacier named Sermikavsak (meaning "the paltry glacier") is situated about 70 kilometres northwest of Umanak on the west coast of the small Upernivik Ø (fig. 2. Ø = island). The position of its front may be given approximately as long. 71°12′ N. and lat. 53°03′ W. of Greenwich. It may be mentioned here that there appears to be some vagueness—among the local population too—concerning the name of Sermikavsak, for it is also used of the small glacier (Serminguaq) whose valley debouches into the sea just east of Upernivik Næs, the southwest corner of that island. On the other hand, our glacier is sometimes called Serminguaq ("the little glacier").

Sermikavsak, which is surrounded by chains of mountains 1300—2000 metres in height, extends about 15 kilometres northeastwards into the island, where its highest parts lie at about 1500 metres. The interior part of the valley is in the form of a trough about 2—3 kilometres wide, from which there is a narrower section, about 10 kilometres long and a good kilometre in width, running southwestwards. There is no more than this one outlet, to which the team confined its operations.

Upernivik Ø is occupied entirely by very high mountain ranges which divided it chiefly from northeast to southwest. For the most part the mountains consist of gneiss and other metamorphic rocks. Its southwest corner, Upernivik Næs, forms a stark contrast by being a rounded, relatively low (700 m) hill area consisting of Cretaceous sediments, with sandstone predominating. As a consequence of the shape of the land the glacier has several ice-falls some hundreds of metres in height. At these places the presence of enormous crevasses formed a serious obstacle to the work. The ground ahead of the glacier, whose front lies about a kilometre from the shore, is dominated by a fluvial plain cut up by the ever-changing beds of melt-water streams. Here and there on this plain are very small "islands", no doubt old moraines dating from the period when the glacier last reached out to the sea.

In selecting the glacier to be investigated the following desiderata were set up: It was to be complete in itself. This meant that it was not to be connected with large masses of ice with several tongues, as the size of the expedition prevented the establishment of several stations within the same region; and, as far as possible, the entire glacier was to be under inspection. Furthermore, it should preferably not reach out to the sea, which would make it difficult to measure its outflow. For the same reason there should be as few melt-water streams from the front as possible. Lastly, the glacier should be scalable, with few elements of risk. On Upernivik Island it was very difficult to satisfy these conditions in the very rugged terrain. Sermikavsak complies with them all, but only on the lowest section of the lobe as far as the last-named condition is concerned. That part ascends very evenly and presents hardly any great difficulty at all. It is quite easy to climb and there are but few, insignificant, crevassed areas. But about 5 kilometres northeast of the front there is the first ice-fall, whereafter the difficulties grow immensely, so much so that the work had to be confined to the lower, regular part of the glacier. In particular, the inner parts of Sermikavsak will be very hard to map, for the reason that it is impossible to obtain a view of the glacier without climbing to the mountain tops of the valley sides, and they are so far away from the area as to make a large-scale detail survey almost impracticable. Maps compiled on the basis of aerial photographs could only be on a small scale, as the existing photographs were taken from such a long distance that the pictures are on a scale of about 1:40,000. Another reason why the only map pre-

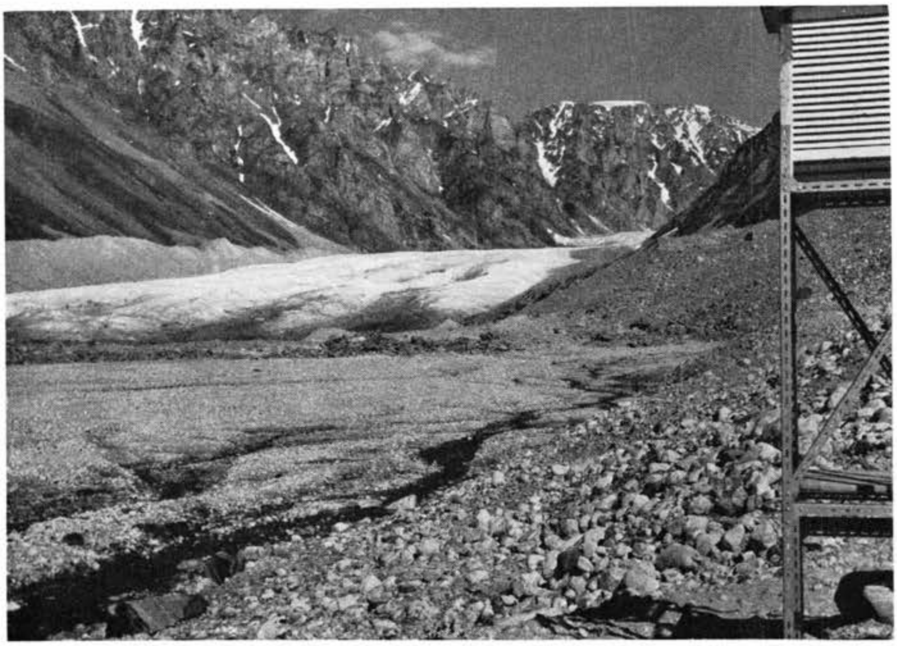


Fig. 2. The glacier front viewed from the camp. In the foreground a glaciofluvial plain. One lateral moraine is clearly visible. A moraine-covered ice tongue to the southeast is partly hidden behind the weather station, of which the left leg only just touches a large stone used as one of the points for detail survey. In the background a glimpse of the westernmost icefall, where the glacier bends eastwards.

pared is of the glacier front is, partly, that the team consisted of only four members, of whom only one could be spared for map-work and only for a short period of the three months of the sojourn on Upernivik Ø.

The survey was planned in July 1956 by a reconnoitring expedition. At the very outset it was found natural to draw a base-line on the flat plain in front of the glacier (fig. 3) and to lay a network of triangles with the apices on the two "lateral moraines" which on both sides separate the glacier from the flanking mountains. It was quickly found, however, that establishing the fixed points was going to be a matter of considerable difficulty, because the lateral moraines are so full of ice as to be quite unstable. Actually, the only real lateral moraine lies on the northwest side of the glacier. Otherwise the margin consists of lobes that are concealed by gravel and stones, on which there could be no question of placing fixed points if they were to be stable. Moreover, the northwest lateral moraine extends only to a point just west of the lowest ice-fall. At the glacier front its highest point lies about two hundred metres above the ice surface, and from there the distance to the top of the moraine diminishes until it disappears at the aforesaid ice-fall. On the southwest side of the glacier and east of the ice-fall the glacier reaches right out to the mountain side, which rises so precipitously as to rule out any possibility of control points there. The tops of the mountains could not be climbed, as the team had neither the equipment nor the technique. In addition, the tops of these flanking heights were so far away from the glacier that, as already stated, a detail survey for a map of such a large scale was impossible. Owing to the differences of the elevations all the sights would run almost parallel with the mountain sides and would thus be obstructed by the shimmer, which already gave rise to many problems.

Fig. 4 is a sketch map showing the glacier front, the glaciological observation post (mast) and some of the poles. The map was compiled on the scale of 1:10,000 from aerial photographs and the map drawn by the expedition. It also shows the situation of the coast ahead of the glacier. The expedition camp was at Point 1. The majority of the control points were established in 1956. The base-line was laid at right-angles to the coast in front of the glacier between Points 9 and 10. Finding an area sufficiently level for a base-line was rather difficult. True, the greater part of the area in front of Sermikavsak may be regarded as a plain, but it is full of moraine blocks and also intersected by melt-water streams which are constantly changing their beds. The base-line was made rather long, 230 metres, as we could not rely upon measurements sufficiently exact to permit of the base being much extended. The distance was measured off with a subsequently verified steel tape with undirectional terminals. The measured line was divided into lengths of just under 20 metres, and the points between these lengths were indicated by a small moraine boulder with the point marked as a cross. The fall was measured with a clinometer (it did not exceed 5° anywhere), and the fall correction was calculated for every length. The base-line was remeasured four times, the greatest deviation between the measurements being 11 millimetres. The mean error of the various measurements of the base-line as a whole was 5 mm. The surveyors took turns in holding the initial point of the tape over the initial point of the various lengths. Moreover, both terminal points of the tape were used as zero.

The base-line was then extended up to the first side in the main system of triangles. It started at Point 1 at the camp to a point (2) on a terminal moraine at the northwest side of the glacier valley. In 1956 at that side four other fixed points were established, all on the aforesaid lateral moraine. Of these, the most easterly one had disappeared in 1957 and it was not re-established later. On the southeast side of the glacier three other points were established in 1956, in addition to Point 1. Point 4 of these had to be set up on the moraine-covered ice-lobe, whereas

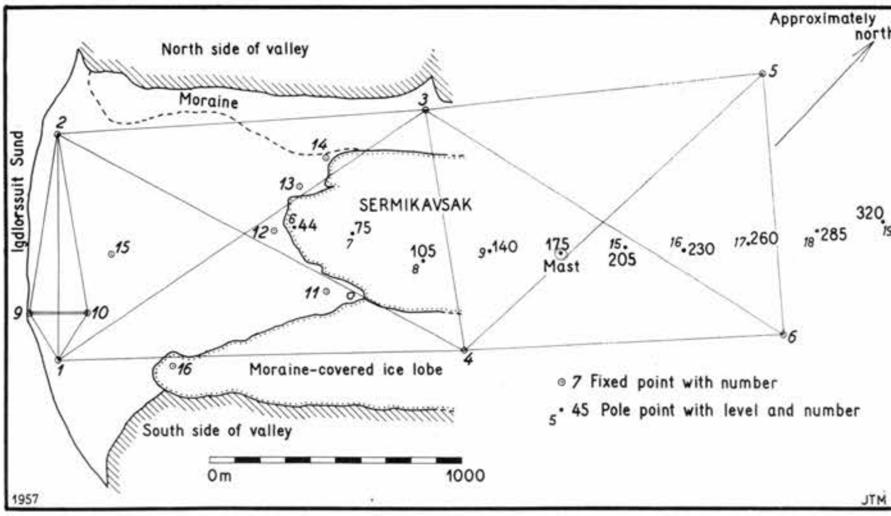


Fig. 3. Map showing the main system of triangles on the lower part of Sermikavsak. The camp was situated at Point 1.

it was possible to place Point 6 on a small rock shelf about two hundred metres up the mountain side. There again the most easterly point was found to have disappeared in 1957. In this latter year a number of fixed points were established ahead of the glacier front to be used in the detail surveys: Points 11, 12, 13, 14 and 16. Point 15 was determined only because from it—on the top of a moraine block four metres high, there is a completely free view of the glacier front; it was employed for photography.

Siting the fixed points proved to be a knotty problem. For the purpose of checking the future movement of the glacier it was highly desirable that they should be recognizable and therefore of a more or less permanent character. At no place was it possible to establish a point on firm rock. Wherever there were outcrops they provided no view over the region, and in addition the rock here is of such a nature that it is doubtful if a bolt driven into would hold very long owing to severe weathering and erosion. Therefore we endeavoured to pick out sites where the ground seemed to be fairly stable, such as old moraines covered with vegetation, with no visible sign of movement at the surface, such as cracks or subsidence. We also tried placing the points upon large moraine boulders lying on nearly horizontal ground and away from slopes. It has to be borne in mind the whole time that we were working in a perma-frost region, where the substratum is very unstable unless it is permanent rock. On the other hand, as long as the points could be sited in a terrain free of steep slopes any movement would mostly be confined to the vertical, unless the glacier advanced at that particular point. But where there is glacier ice below the surface the latter will be anything but stable. Unfortunately, as already stated it was necessary to place some of the fixed points under just these conditions, i. e. in the lateral moraines which, on the northwest side of the glacier valley, lie at a much steeper angle than would have been possible if the moraine had not contained very large quantities of ice. At several places, in fact, the ice is visible where the moraine has slipped. In other words, the lateral moraines are just as unstable as the glacier itself, where in fact one point had to be placed: on the southeast, moraine-covered ice tongue (Point 4).

The fixed points everywhere were established by hewing a copper bolt into the largest moraine block on the spot. At Points 1, 2, 12 and 15 round bronze plates marked "GGU-Maalepunkt" were added. These plates were laid loose over the fixed point and the whole was then covered with heavy stones. At Points 1 and 2 we also built small cairns about one metre in height. Centered pickets with flags were set up at the fixed points during the 1957 survey.

As to the durability of the points established it is possible to say briefly that Points 2, 5, 12 and 15 alone will be stable for a period of ten years or so, and of these only Point 15 can be counted upon for several years more, unless the glacier advances that far.

But even if all points except these four should be lost, it will still be possible to restore the network of triangles, because in that case there will be at least one fixed point and one direction to a known point to build upon. For the purpose of orienting the network and if possible connecting it up with the Geodetic Institute network, resections were carried out in 1956 to points on the island of Ubekendt Ejland west of Upernivik Ø. On the former there are three coordinated points to which observations were made from both Points 1 and 2, whereby their positions and the orienting of the network should be determinable. Resection to the points on Ubekendt Ejland alone will not suffice to restore the network for a map on such a large scale, the distance between Points 1 and 2 being too short in proportion to the distance between the trigonometric stations on Ubekendt Ejland.

The network of triangles was arranged as a frame-work (fig. 4) which, in addition to the base-line network, consists of triangles with their apices at Points 1, 2, 3, 4, 5, 6 and 7. That frame-work was then supplemented with the detail points 11 to 16. Of these, Points 12, 13 and 14 were observed with the side 1—4 as the base, whereas Points 11 and 16 were observed with the side 1—12 as the base. Point 15 has the side 1—2 as its base. At no place does the length of the triangle sides exceed 2 kilometres, whereas the distance from the shore to Point 5 is

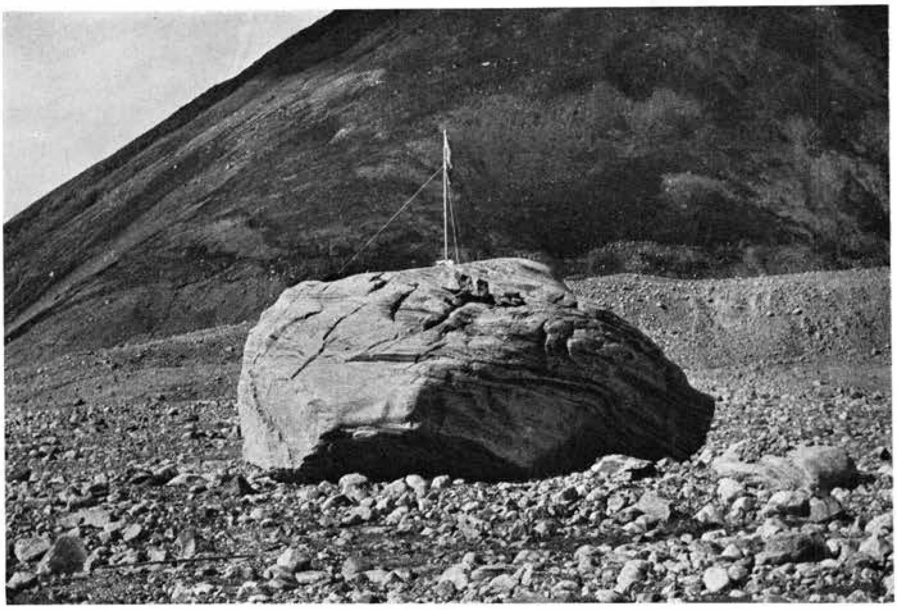


Fig. 4. Point 15 with flag. In the background the lateral moraine to the northwest of Sermikavsak.

only just under 3 kilometres. The little used Point 7 northeast of Point 5 is not plotted on the map.

In order to take the observations farther up the glacier the plan was to carry them out as polygonal surveys with the polygon points situated on the northwest part of the glacier, which in places there is covered with moraine. In the southeast part of the valley the ice as already mentioned is eroding right into the mountain side. It is impossible to establish trigonometric points with any certainty from Point 7 and in any case up to 7 kilometres to the northeast, where the northwest side of the valley is readily accessible with many shelves some way up the mountain side. However, owing to lack of time and labour Point 7 was the most easterly point determined, and the only detail surveys made were in the frontal area.

In the summer of 1956 the whole of the network then established with its base-line was surveyed, so that it should have been possible to build out from it during the following year. In 1957, however, sample observations showed that the angles in the fully measured triangles differed from those of the year before, in some cases by more than half a minute. For the present map these deviations were of no significance; but as it was evident that some of the points must have moved (the entire deviation was one of directions to and from the aforesaid uncertain points), the angle observations and the base-line measurements were carried out afresh. It may just be mentioned that the ultimate length of the base-line, measured in the same manner as in 1956, differed by only 5 mm from the previous one, the terminal points of the base being intact on the fluvial plain.

The angles were observed with a Wild T2 universal theodolite with single second readings. This would seem to be a large instrument to use for so small a network, where one with 1/10th minute readings would have sufficed; but in advance it was impossible to know what problems the surveys would present. If the glacier had had the form of a cap rising up above the surrounding country, much longer sights would probably have been necessary. The same would apply if it had been possible to carry the network of triangles into the inner part of Sermikavsak, which there is much wider than in the more westerly outflow part. In every case angular measurement was carried out as series measurement. All directions to triangle points were measured with three full series. In 1957 the only trigonometrical levellings were made to Points 11, 13 and 14, these points being utilized in the detail survey and there was only time to determine their level by trigonometric levelling. In 1956 trigonometrical levellings were made from all stations in all observed directions, but this was abandoned in 1957 on account of the very strong shimmer whenever the sights were beyond a few hundred metres. This shimmer, which of course also affected horizontal angular measurement, was very difficult to avoid. Owing to the midnight sun and the fact that in point of climate Sermikavsak lies in a region with little cloud, irradiation is very intense, and moreover there is the very sharp reflection from the surface of the ice. At night the glacier lies in the shadow of the northwest chain of mountains, but then the radiation is strong, and into the bargain the valley is so dark that it is impossible to see any signal.

One of the objects of the expedition was to put up a row of bamboo poles in the longitudinal direction of the glacier to assist in measuring the melting and movement of the ice. Poles were accordingly set up in 1956, the first down by the glacier front and the last a short distance northeast of the lower ice-fall, about 6 kilometres from the front. All the poles up to the ice-fall were plotted in the triangulation and were to have been observed again in 1957 for the purpose of obtaining an impression of any movement made by the glacier. However, the glacier melted so much in the late summer of 1956 and early summer of 1957 that all the poles, which had been bored 2 metres down into the ice, had disappeared. Some of them were found in depressions in the surface of the glacier, having been washed or blown there. Thus all chance of measuring the ice movement was lost, there being no time to observe the poles set up at the beginning and the end of the summer work in 1957. As a matter of fact, however, the movement of Sermikavsak is too slight to be registered within so short a period, and therefore the sole purpose of observing the poles that summer was to record their position. It proceeded in the same manner as the other angle observations. It has to be carried out by intersection, because it turned out that stationing on the ice itself was impossible, the tripod feet sinking down into the ice even when the observations were made after the sun had gone and the temperature was just above zero. For the purpose of avoiding serious errors, however, rapid observations were made from each bamboo point but not included in any of the computations.

As stated, in the system of triangles the directions were observed with three full series and all triangles were fully measured. When measuring the angles the degree of accuracy aimed at was such as to permit of a triangle side in the frame-work being determined to a mean error of 10 centimetres. In practice the mean error of the mean of an observed direction was less than 5 seconds everywhere. This was a greater accuracy than was required for the present map, but that standard was maintained for the benefit of any future survey of the glacier. By that time there may be only few fixed points remaining, and at least it should be possible to reconstruct the original network as nearly as possible. It may be added that working to this accuracy of observation cost nothing in the way of time and trouble.

As the cartographic plan had to be carried through in the course of the three months, from triangulation to detail survey, the results had to be worked up continuously as they were arrived at. The computations of the framework itself of course might with advantage have been put off until our return home from Greenland; but as a detail survey in addition to the actual observations had necessarily to be supplemented with the surveyor's personal evaluation of the physical features the map had to be drawn in the field. In other words, the foundation work had to be complete when the detail survey began. As the value of the previous year's observations had proved to be somewhat uncertain the work had to be done against time. Triangulation having been completed and the base-line established, the network of triangles was computed. The expedition had with it a five-place logarithmic table with which all the computations were made. As all sights are less than 2 km the table thus provides a computation accuracy of 0.1 m, which is adequate for a map on the present scale (equal to 0.03 mm). In order to facilitate matters the network was plotted into a co-ordinate system with Point 1 as zero, the ordinate axis coinciding with the side 1—2 and positive direction northeastwards, i. e. in the working direction. The orientation of the co-ordinate system in relation to north is only approximate, being estimated on the basis of rough angular measurements to known points. If necessary it may be determined more exactly by computing the resection to the trigonometric stations on Ubekendt Ejland. The network was calculated by computing the lengths of unknown sides from a known side after distributing the error of the sum of the angles over all three angles. For the base triangle this error is less than 20″ and for the detail network under 30″. No other adjustment was made, because such values as might be arrived at would be so small as to be without significance, with the very short sights and the accuracy of computation employed. Two determinations on the same side were utilized for control wherever possible. For example, side 3—4 was calculated with both side 1—4 and side 2—3 as the base. In no case was there any deviation between the results thus arrived at. The framework (solid line in fig. 4) was computed separately, whereafter the detail points were computed with the sides of the framework as the base. After all sides were computed the co-ordinates of the points were calculated, for each point on the basis of both sides of the triangle as a check on arithmetical errors. The pole points, intended merely for indicating the placing of the poles were plotted with a station pointer with minute readings. As stated, all pole points were checked by means of an orienting observation of the angle from the pole point to the base terminal points employed for the point. In this there were no deviations measurable in the map scale (fig. 4).

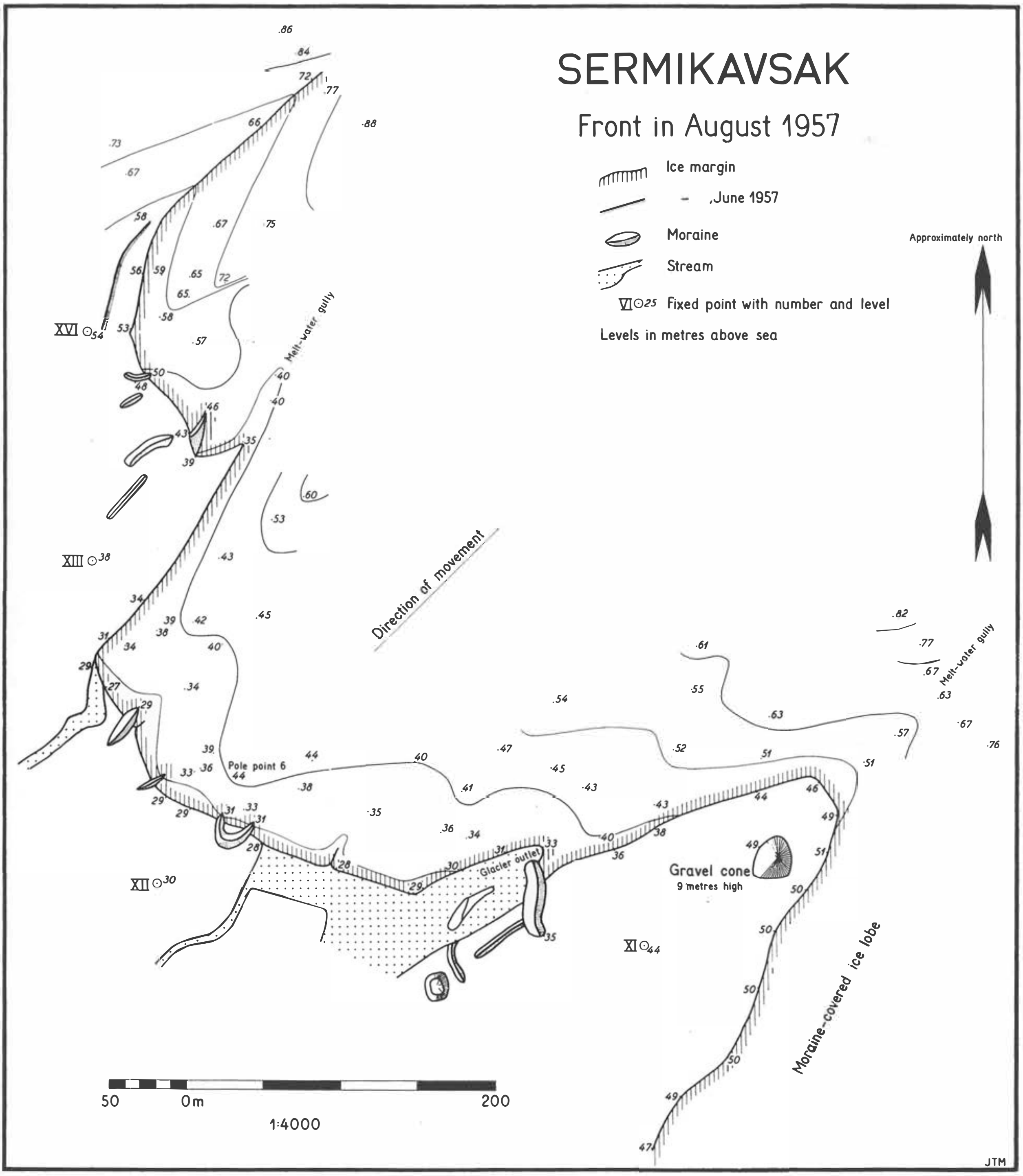
It is a matter of importance to be able to measure not only changes in the extent of a glacier but also variations in heights and relief. The plan therefore included levelling along and across Sermikavsak. Quite apart from the brief time available, it proved to be completely impossible to do any geometric levelling on the ice with the equipment at hand. As was stated in describing the triangulation, the feet of the tripod continued to sink while the instrument was being set up, no matter how well they were stamped down into the ice. In all probability, levelling will be possible if the tripod is provided with a plate on which the entire equipment can be set; the plate could be furnished with small cogs on the underside to prevent slipping. Establishing fixed points should be fairly simple, even if they will scarcely be very durable. The light bamboo poles used for measuring the ice melt could be employed as rods, or short pickets could be bored down into the ice to such a depth as to be frozen fast only as long as the observations are being taken. In the summer of 1957 a number of poles were experimentally fixed in this manner on Sermikavsak right at the front (at Pole 6, figs. 1 and 4). Then for some days, when the temperatures were highly variable, measurements of zenith distances were taken to a permanent mark on each of the five pickets from the very stable Point 12 about 100 metres ahead of the glacier front. It was found that the pickets did actually remain stable as long as they were frozen hard in the ice. There were no deviations whatever between the readings, which were made without removing the tripod between observations. The experiment could not be made to last more than three days, however, the pickets thereafter being loose in the rapidly melting ice. Trigonometric levelling would of course encounter the same difficulties, but it would be possible to set the instrument up at a few permanent stations away from the glacier; from there one could always observe horizontal and vertical angles to selected points on the surface of the ice and thus have the latter's movements under control. However, it would scarcely be practicable by this means to level so many points as to form a working basis for a contour map of the glacier, as the observations must be made with meticulous care if they are at all to show the relatively small movements in question. At any rate it would be necessary to have a tripod permanently set up at each point. It may be stated here that the melting rate for Sermikavsak in the summer of 1957 was 2—3 metres. The levels shown in fig. 4 were observed by means of two aneroid barometers. It was found that the accuracy of these observations had to be rated at ± 5 metres.

As part of the plan (subsequently abandoned) to carry out geometric levelling up on the ice a line was levelled from the sea at the camp back to Point 12 at the glacier front. This latter point was used as the datum for the detail survey. In order to have a datum for the levelling we had to have a zero. There was no time for making immediate water-level observations and therefore the datum point was assumed to be midway between the highest and lowest observed water level within a tidal period. In order to correct this selected datum point a tide staff was later put up in the sea in front of the camp, but its functioning time was only brief, it being impossible to keep it free of drift-ice. However, the observations showed that the level of the selected datum point may very reasonably be put at 0 ± 0.25 metre. Levelling itself was carried out twice with proper observance of the accuracy required of a technical line levelling, with the kilometer error put at 5 mm.

The detail survey was made by tachymetry, this being the only method employable on this very hilly ground, which more over is full of large boulders. The universal theodolite was used as a tachymeter, the second values being immediately converted to tenths of a minute to facilitate computation. The map had to be ready drawn on leaving the locality, especially having regard to the determination of how many details and how large an area were to be included. In addition there was the circumstance that observations of this kind are open to more than one interpretation. If for example the draughtsman who is to construct the map is ignorant of the terrain, he could do it quite correctly from the figures supplied to him and yet the map might not conform to all the details on the spot. Ignorance of the locality requires a very large number of definite points to give the same result as a much smaller number when the map is compiled gradually as the results of the observations are forthcoming. As only one member of the team could be spared for the survey work, it had to be simplified as much as possible. There was no time, for instance, for calculating co-ordinates for the various fixed points, which had to be plotted from the azimuths and the distance from the station. The only aid available was a primitive protractor, but half degrees could be plotted from it without significant error. In order to reduce the uncertainty to a minimum all sights were kept short; only very few were over 150 metres and not one was over 180 metres. Moreover, the directions to the fixed points were selected in advance wherever possible, so that they were in whole or half degrees. The avoidance of long sights made it necessary to supplement the four detail survey points at the glacier front with a number of intermediate points, which were also determined tachymetrically. For control purposes they were determined in relation to two detail survey points and their co-ordinates were computed from the logarithm table. Moreover, at several places the same fixed point was determined from two different stations. When constructing the map it was found that there was no difference of more than 1 mm in these control observations of fixed points.

The tachymetric observations had to be computed with a slide rule. As the inclination of the sights everywhere is under 12° and their lengths under 180 m, the distance from the station to the fixed points concerned could be computed to an accuracy of 1 m, which on the present scale corresponds to 0.3 mm. The elevation differences could be calculated to a similar degree of accuracy, which at first glance seems rather poor. It should be recalled, however, that these are points on an ice surface that is extremely rugged and hummocky. Moreover, during the expedition's working period the ice was melting rapidly, which made the surface very unstable. Consequently, a map, at any rate compiled in summer, can be nothing more than a snapshot. On Sermikavsak it was sometimes possible to see changes from one day to another; as stated above, melting that summer caused the surface of the ice to subside 2—3 m. Therefore the map includes only 10 m contours. A smaller equidistance such as that employed on some glacier surveys right down to 1 m would give a false impression of exactness unless the map were compiled from aerial photographs on a large scale. Determining the levels to the fixed points was done by taking mutual measurements of the vertical angle between the points and the computations were made with the aid of the logarithm table. The map was drawn to the scale of 1:1000 and then reduced to 1:4000, the error at that scale being estimatable at under 1 mm, which corresponds to 4 m on the ground. Care was taken not to include other details than those observed with such certainty as to preclude errors demonstrable in a map on this scale. All summits were plotted and there are many more plotted points than the elevation figures indicate. In the northwest part of the map is a reproduction of the position of the ice margin two months before the actual detail survey. The retreat, very considerable at this spot, was due to the melting from the northwest lateral moraine. There was also a marked retreat at the glacier port, the front in June 1957 reaching right forward to the northeast point of the small island in the meltwater river. The water areas, indicated by stippling, comprise those within which the water flowed. Outlining the courses more precisely was impossible, because they changed from day to day. The term "moraine" comprises the small stone and gravel-covered mounds in front of the ice which probably were not the result of meltwater erosion. They all grew smaller in the course of the summer as their ice content melted. On the map they have a suggestion of shadow, as if the light came from a westerly direction. The many mounds and slopes left as erosion remains by the meltwater streams are not included.

The purpose of this brief description has been to provide an impression of geographical fieldwork in which the task set required more or less ignoring solutions which normally might have been applied. Methods and opinions will be open to many objections, but the possibilities everywhere have been restricted by the short time and labour available and the instruments at hand. For example, a plane-table would have provided possibilities for surveying much larger areas within the same period, but in advance it was not certain that the plane-table could be used at all, and of course equipping the expedition with a complete outfit of instruments would have meant an unreasonable enhancement of the cost. Moreover, it is the intention with this description to make it possible to evaluate the survey with a view to future surveys of Sermikavsak; at that time it might be possible to investigate changes in the glacier surface and extent on a fairly solid foundation.


SERMIKAVSAK
Front in August 1957
Ice margin
- ,June 1957
Moraine
Stream
VI ⊙25 Fixed point with number and level
Levels in metres above sea
Approximately north
Melt-water gully
Direction of movement
Pole point 6
Glacier outlet
Gravel cone
9 metres high
Moraine-covered ice lobe
XVI ⊙54
XIII ⊙38
XII ⊙30
XI ⊙44
50 0m 200
1:4000
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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;

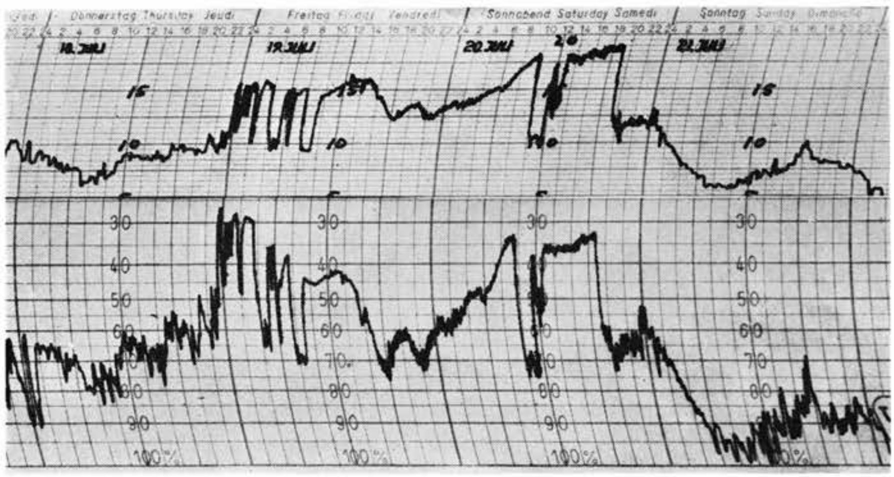

Fig. 1. The recorded continuous variation of temperature and humidity for the days July 18th—21st 1957 near Sermikavsak on Igdlorssuit Sund. The upper curve represents the temperatures, the interval between the heavy horizontal lines corresponding to $2^1/_2$°C. The lower curve gives the relative humidity. 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

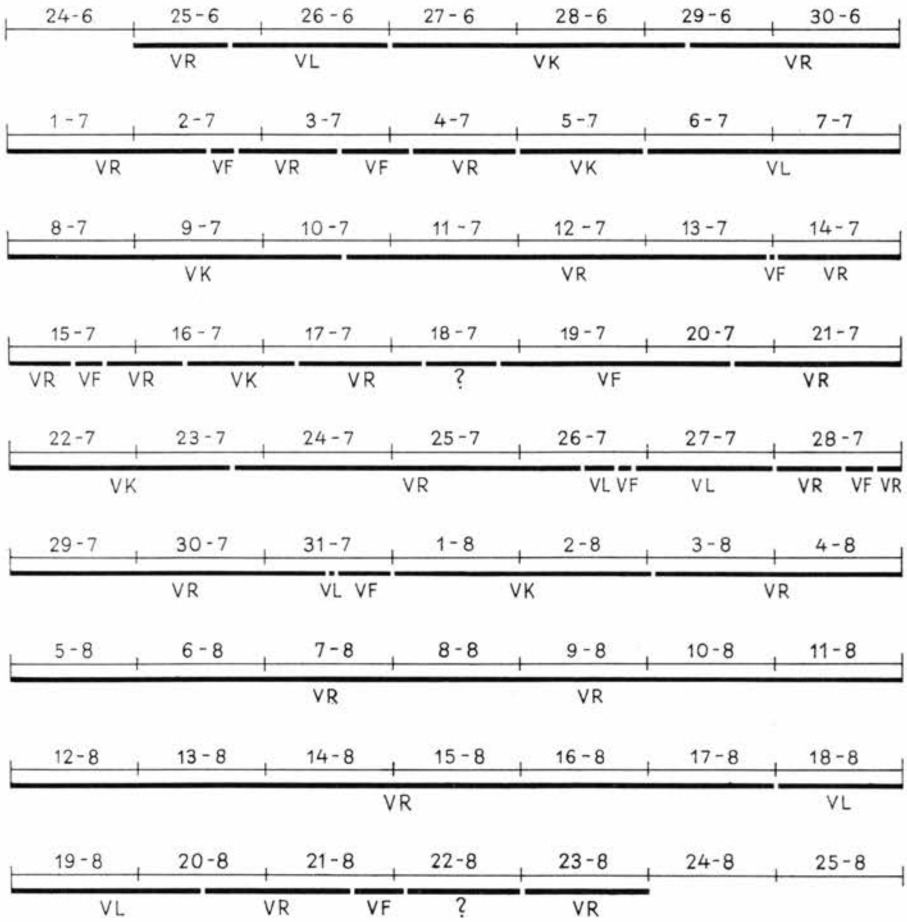

Fig. 2. Occurrence and duration of weather types for the period from June 24th to August 24th 1957 at Sermikavtak. *VR* signifies clear weather with almost cloudless sky and scarcely any wind. *VL* is overcast weather with dense strato-cumulus cloud and slight or no wind. *VK* means rainy-misty weather 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 $^0/_0$ of the time; in føhn weather (*VF*) the test percentage was 17.1, in overcast weather (*VL*) 12.2 $^0/_0$, whereas in condensation weather (*VK*) wind analyses were made in 7.1 $^0/_0$ 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

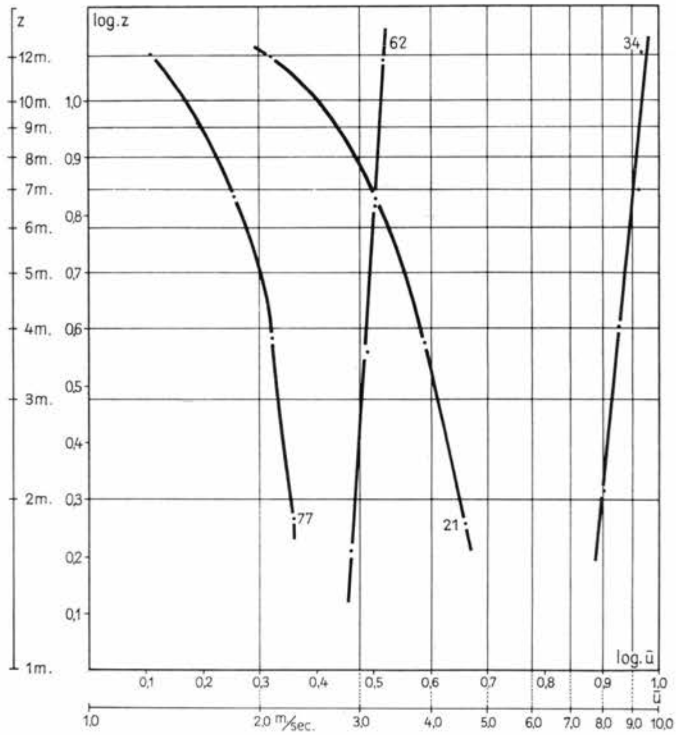

Fig. 3. Four typical wind profiles over the glacier ice. 77 and 21 show the velocity profile of the gravitational wind ("glacier wind"), 62 and 34 the føhn wind. The abscissa is the logarithm of the wind velocity, the ordinate the logarithm of the height above the ice.

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 $^0/_0$ 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

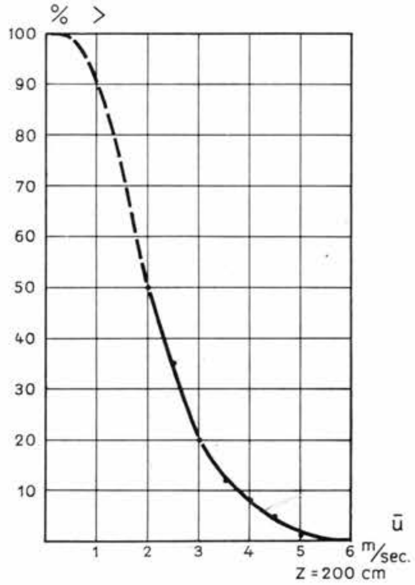

Fig. 4. The approximate distribution of gravitational-wind velocities at 2 metres above the glacier, 1 km from the glacier front. The abscissa shows the wind velocity in m/sec., the ordinate the relative number of velocities recorded.

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-

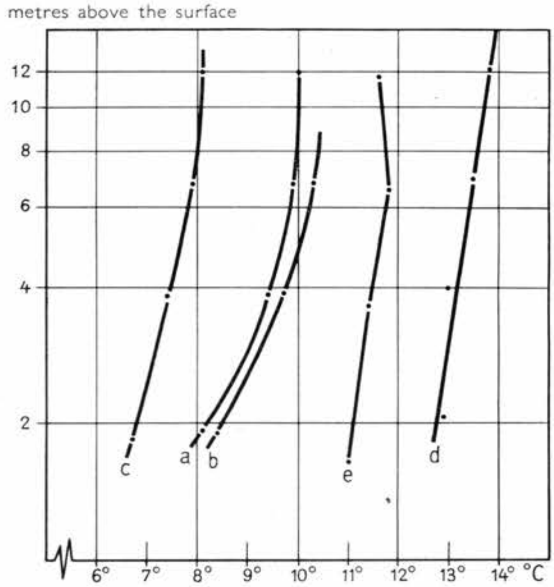

Fig. 5. Typical air-temperature profiles over Sermikavsak, 1 km. from the glacier front. a, b and c recorded in gravitational wind, e and d in føhn wind. The abscissa shows the thermal degrees in Celsius; the ordinate is plotted with the logarithm of the height above the ice. Bearing in mind that the 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.

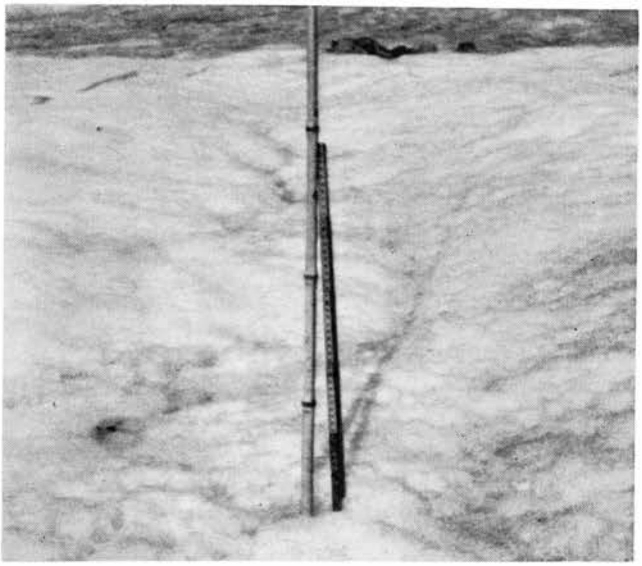

Fig. 6. An ablation pole placed in the normal glacier surface near the recording mast. A ruler is resting against the bamboo pole.

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

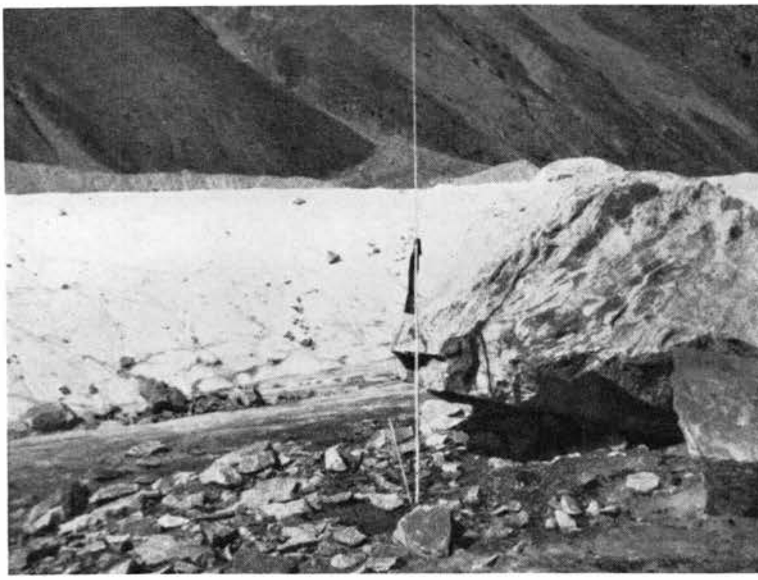

Fig. 7. A bamboo pole placed in a special area of the glacier surface, consisting of a heterogeneous covering of stones, "a thin medial moraine". The large boulder moved in jerks towards the left each time it fell from its self-created glacier table. In the background a section of the normal glacier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

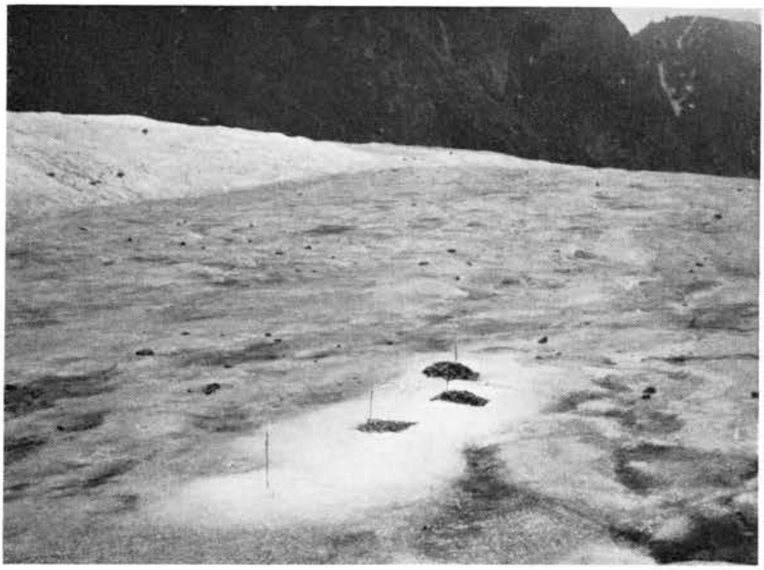

Fig. 8. A piece of the natural surface of the ice has been cleared artificially so that in the picture it contrasts with its surroundings. Four small areas have been laid out with small stones in "stone beds" of different packings.

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/cm²	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

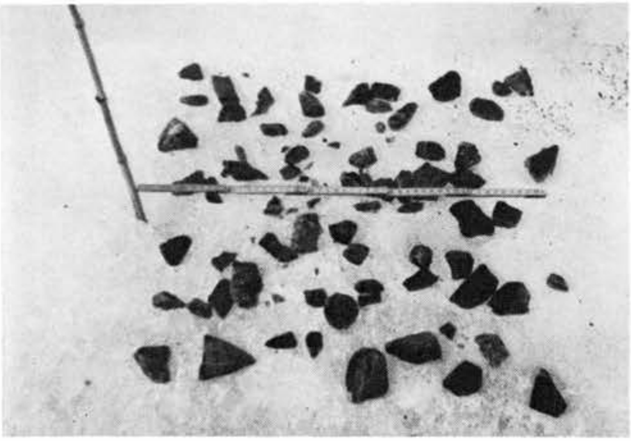

Fig. 9a. An area with small stones placed on cleared ice, one of the stone beds in fig. 8. The ruler lying across the stones is a half metre in length. The average in the "bed" is 1 g of stones per sq.cm.

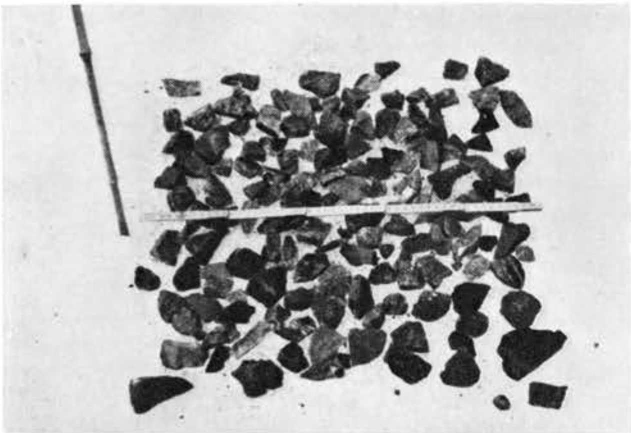

Fig. 9b. Similar to 9a, except that there are 2 g of stones per sq.cm of surface.

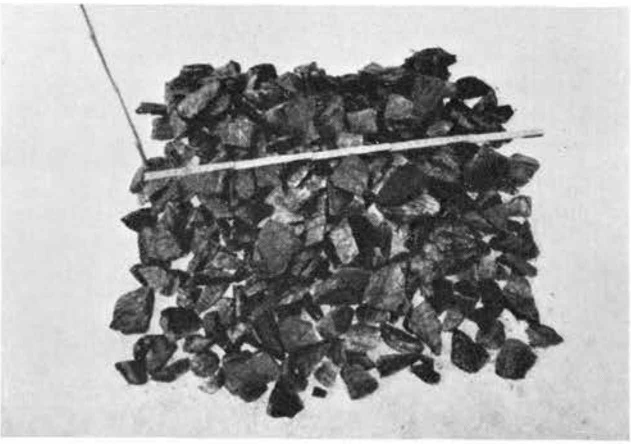

Fig. 9c. An arranged area with about 4 g of stones to the sq.cm. Cf. fig. 9a.

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

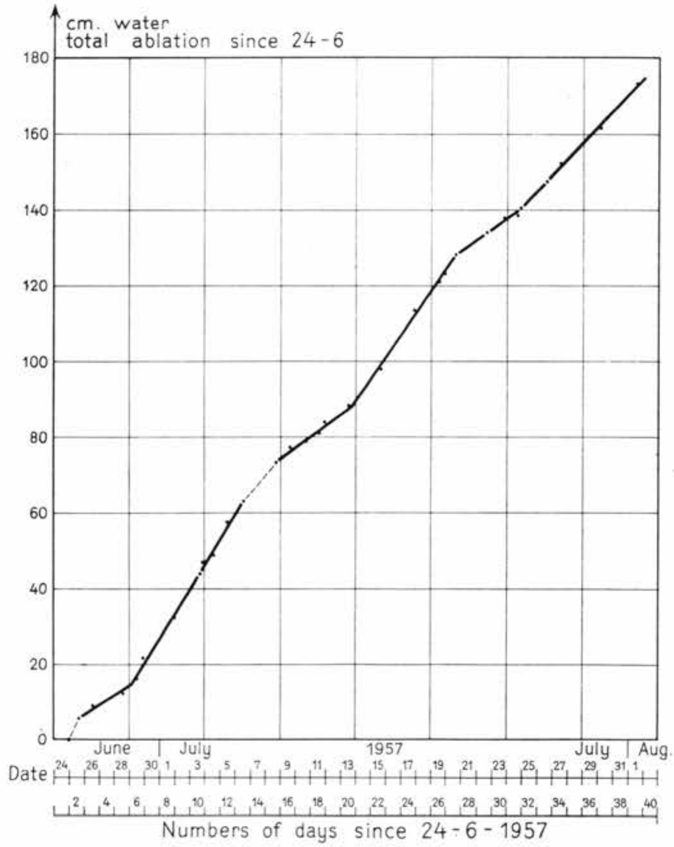

Fig. 11. The cumulated gross ablation since June 24th 1957 at the recording mast on Sermikavsak, placed in relation to the time elapsed from that date till August 3rd of the same year. Each dot marks the ablation measured at the time after June 24th. The recorded ablation values are gathered into groups 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 % of the time, and was especially common in August. In July brief spells of føhns (*VF*: 7 %) 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 % 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 % of the time), i. e. calm or almost calm; the other was called the sea wind (4 %); 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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DER RÜCKGANG DES JACOBSHAVNS ISBRÆ (WEST-GRÖNLAND 69° N)

Von J. GEORGI

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Von J. GEORGI

Anlass zu dieser Bemerkung gab eine kürzlich an zwei Stellen (1, 2) veröffentlichte Karte des Jakobshavns Isfjord mit den Lagen der Gletscherfront zwischen 1850 und 1953, worin drei nicht unwichtige Front-Bestimmungen vermisst wurden. Deren Berücksichtigung erlaubt, ein sehr anschauliches Diagramm des Gletscher-Rückganges in den letzten 100 Jahren in (3) weiter ins Einzelne auszuführen und daraus Andeutungen für eine Periodizität der Stillstände und damit abwechselnden, stärkeren Rückzüge von etwa 30 Jahren zu gewinnen.

»Der Jakobshavner Eisstrom ist der König unter den grönländischen Gletschern«, sagte ALFRED WEGENER in (4, S. 154); er hatte ihn 1913 zusammen mit dem dänischen Hauptmann J. P. KOCH nach ihrer beider erfolgreichen, ersten Durchquerung des nördlichen Teiles des Inlandeises besucht (7, I S. 283) und gibt hier eine kurze Schilderung als Einleitung zu der neuen Vermessung der Gletscherfront 1929 durch E. SORGE. Selbst für die Grönländer hatte dieser gewaltige Gletscher und Eisfjord mit seinen unmotivierten Kalbungswellen und periodischen Ausstössen (dän.: udskydning) riesiger Mengen von Eisbergen besondere Bedeutung als angebliche Mündung eines, das Inlandeis bis zur Ostküste unterfahrenden Kanals, wie u. a. A. E. NORDENSKJÖLD (10a) berichtet, der diesen Gletscher eine »gewaltige Eisberg-Fabrik« (Ofantliga isbergsverkstad) nennt. Für den Grönland-Geologen Dr. LAUGE KOCH schien ebendort eine gewaltige Verwerfung des Felsmassives angedeutet zu sein. Neuerdings bildete es eine der grössten, geophysikalischen Überraschungen, als die seismischen Eisdickenmessungen der »Expéditions Polaires Françaises, Missions Paul Emile Victor« (5, Fig. 18) im Untergrund des grönländischen Felssockels ein System flacher Mulden und Rinnen bis 250 m unter Meeresspiegel enthüllten, die zum Jakobshavner Gletscher zu konvergieren scheinen, wodurch diesem eine überragende Rolle bei der Drainage des Inlandeises zugesprochen werden müsste, siehe (11, S. 23—24): »Die Karte der seismischen Querschnitte (der E.P.F. im Sommer 1951) gibt die Meereshöhen des Erdbodens unterhalb des Inlandeises. Wenn es erlaubt ist, die Lotungen auf vier Profilen in einer 400 km breiten Zone mit einander in Verbindung zu bringen, dann lassen die negativen Meereshöhen im Osten des Jakobshavn-Gletschers die Existenz eines unter dem Eise verlaufenden Tales dieses Gletschers von gleicher Länge annehmen . . . Wir dürfen also annehmen, dass der Gletscher von Jakobshavn ein Eisstrom ist, der dank seiner Länge und der Länge des darunter verlaufenden Tales das Eis einer riesigen Zone abführt, wodurch seine grosse Produktivität bedingt ist.« Zeugnisse für die Majestät dieses Gletschers, zumal in einer Zeit des Vorrückens, sind nach Berichten bekannter Forscher seit 1747 in (1) wiedergeben. Alle

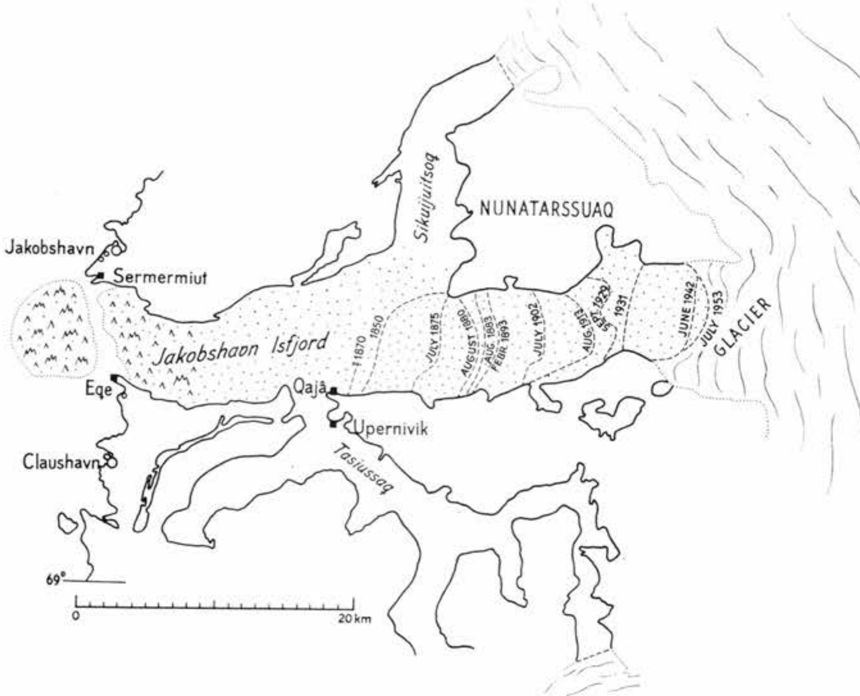


Abb. 1. Karte des Jakobshavn Isfjord mit Lage der Gletscherfront in den letzten 100 Jahren, dargestellt von J. Meldgaard (1, 2) nach M. C. Engell, dem Geodætisk Institut und Luftaufnahmen; sie wurde vom Verf. ergänzt, wie im Text dargelegt. Die Frontlagen von links nach rechts entsprechen den Jahren 1870, 1850, 1875, 1880, 1883, 1893, 1902, 1913, 1929, 1931, 1942, 1953. Masstab der Karte ca. 1:500.000.

diese alten und neuen Beobachtungen sind heute besonders aktuell, während die »Expédition Glaciologique Internationale du Grœnland« (EGIG, 6) für 1959—60 begonnen hat, die mit den neuesten wissenschaftlichen Hilfsmitteln auch den Problemen dieses Riesengletschers zuleibe gehen wird.

Abb. 1 zeigt die erwähnte Karte aus (1) und (2), aber ergänzt durch Einbeziehung der, aus unbekanntem Grunde dort fehlenden Frontlagen vom 3. August 1883 und vom 10. August 1913. Die erstere ist mitgeteilt von J. P. Koch und A. Wegener (7, Fig. 218, S. 387); diese Darstellung dürfte sich zur Hauptsache stützen auf die zusammenfassenden Darstellungen des verdienten dänischen Geodäten M. C. ENGELL (7a, 7b). Die letztgenannte Frontlage, in der gleichen Figur 218 dargestellt, wurde von KOCH-WEGENER selbst beobachtet. Die dritte, in der ursprünglichen Karte fehlende Frontlage wurde gemessen durch ERNST SORGE im Rahmen von ALFRED WEGENER's Vor-Expedition 1929 (27. und 28. September 1929) und veröffentlicht in (8) Band IV_2 Leipzig 1939 356—362 mit 3 Abb. Hingegen ist die, wie aus dem Späteren hervorgeht, irrige Frontangabe von 1888 unberücksichtigt geblieben. Schon KOCH-WEGENER bemerkten dazu: »nach Engell unsicher«. Es sei hier noch erwähnt, dass die bei KOCH-WEGENER mit Nummern bezeichneten Frontlagen zurückgehen auf: 1 H. RINK 1850; 2 A. HELLAND 1875; 3—5 R. R. J. HAMMER 1879, 1880, 1883; 8 M. C. ENGELL 1902. Die vorderste Frontlage geht nach (1) auf E. A. NORDENSKJÖLD zurück. Aus der Tatsache, dass nach Beobachtungen durch CARL FLEISCHER, den dänischen Beamten (Bestyrer) der Siedlung Claushavn, die Relikte der alten, wegen des vordrängenden Eises aufgegebenen Siedlung Qajâ an der Südküste des Eisfjordes in ihrer ursprünglichen Lagerung vorgefunden wurden, zieht J. MELDGAARD (1 und 2) den sehr wichtigen Schluss, »dass Jakobshavn Isbræ seit mehr als 3000 Jahren zu keiner Zeit weiter vorgerückt war, als in der Mitte des 19. Jahrhunderts.«

Zur ausgemerzten Frontlage 1888 sei noch bemerkt, dass ja, wie A. WEGENER (4) schildert, »der ganze, fast 35 km lange Eisfjord zu jeder Jahreszeit so mit Eisbergen und Kalbeisstücken gefüllt ist, dass seit Menschengedenken kein Boot jemals in ihn hineingekommen ist. Aber der Gletscher entleert auch jedes Jahr... etwa 20 Milliarden Tonnen (E. SORGE (8) schätzt nach seinen Geschwindigkeitsmessungen 24 Mrd. m^3) Eis in diesen Fjord. Die grösseren Eisberge kommen auf der Fjordschwelle vor der Ausmündung in die Disko Bugt, der »Eisbergbank« durch Grundberührung fest und hindern die kleineren am Herauskommen. Nur einige Male im Jahre, wenn einige dieser Riesen wieder flott werden, wandern durch die entstandene Bresche ungeheure Eis-Mengen auf die Disko Bugt hinaus, die dann über und über mit Eisbergen übersät erscheint. Wenn also hiernach meistens der Fjord mit Eisbergen und Kalbeis vollgestopft ist, andererseits, wie E. SORGE (8) besonders betont, der Gletscher in der Nähe der Front ohne merkliches Gefälle fliesst, so ist zu verstehen, dass zuzeiten die eigentliche Gletscherfront schwer auszumachen ist. Wenn hiernach der überaus zerklüftete Gletscher sich horizontal in den Fjord hinausschiebt, ist es wahrscheinlich, dass der Kalbungs-Vorgang beim Abbrechen eines mehr oder weniger umfangreichen Frontstückes sich weniger in einem Herabstürzen ungeheurer Eismassen zeigt, wie es E. SORGE (9) 1932 am Rinks Isbræ (W. Grönland $71^3/_4$° N.) beobachten und durch Reihenbilder dokumentieren konnte, als vielmehr in einem Abschwimmen der durch Gezeitenwirkung abbrechenden Stücke, die sich unter vielfachem Wälzen in ihre Einzelteile — Eisberge und Kalbeis — auflösen. Wenn ein Tourist, der 1954 Gelegenheit zum Besuch des Eisfjords hatte (10), eine angeblich während seiner Anwesenheit erfolgte Kalbung so beschreibt: ». . . Unter Getöse, das schwerstem Artilleriefeuer glich, riss ein kilometerlanges Eisplateau los. Mehrere hundert Meter schiessen Wasserdampf-Fontänen aus den Bruchstellen hoch. Dann steigen Zacken und Eistürme mit dem Plateau bis 300 m empor. Eislawinen prasseln über die schrägen Hänge in den eiserfüllten Fjord. Der Koloss kentert; und dunkelblaue bis meergrüne, bisher unterseeische Sockel tauchen auf. Kalbungswellen durchrasen den 50 km langen Fjord und lassen die Eismassen wie bei einem Bombardement zusammenkrachen. Der Gneisboden unter unseren Füssen bebt bedrohlich . . .«, so scheint es dem gegenüber nunmehr unerlässlich, dass ernsthafte Versuche gemacht werden, eine grössere Kalbung dieses Gletschers sorgfältig zu beobachten und in ihren Phasen photographisch oder zeichnerisch zu dokumentieren. Hier scheint eine besondere Aufgabe für das Dänische Geodätische Institut und die bereits in Tätigkeit begriffene Internationale Glaziologische Grönland-Expedition vorzuliegen. Diese Erzählung ist auch schwer zu vereinigen mit der eingehenden Darstellung, die ein so hervorragender Beobachter wie A. E. Nordenskjöld (10a) von der, aus nächster Nähe im Juli 1870 eingesehenen Front unseres Gletschers gibt. Dort zeichnet er in Abb. 5 S. 1009 das von ihm angenommene Profil, worin er den hier »Isblink« d.h. Inlandeis genannten Gletscher auf seinem schwach geneigten Bett sich allmählich in den Fjord vorschieben lässt, und sagt dazu (S. 1021): »Hieraus sieht man, dass keine scharfe Grenze zwischen Inlandeis und Meer anzugeben ist. Der Isblink ist nämlich schon weiter oben, wie das zackige Profil ausweist, wahrscheinlich Meilen weit vor seiner Kante, zu Eisbergen zerklüftet . . . Noch im Anfang des Fjordes sind diese so dicht gepackt, dass sie einen Teil des Gletschers bilden und vielleicht die meisten grundfest bleiben. Erst eine beträchtliche Strecke seewärts lockern sie sich so weit, dass zwischen ihnen hin und wieder die Meeresfläche sichtbar wird.«

Obwohl Nordenskjöld die Eismasse aus nächster Nähe, sowohl vom Strand, wie von den höheren Uferfelsen oberhalb Qajâ aus beobachten konnte, »wäre es mir unmöglich gewesen anzugeben, wie viele hundert Alen (je 0,7 m) der hier von uns besuchte Wohnplatz wirklich von der Stelle entfernt ist, wo sich der Fjord und das Inlandeis treffen. Sicher ist, dass es bis dahin nicht besonders weit, nicht viele hundert Alen war, und viel anders musste die Umgebung ausgesehen haben zu jener Zeit, als Kaja (Qajâ), wie dieser Ort früher genannt wurde, ein bewohnter Platz war.« Eine Erklärung für das Auftreten einer Schein-Front bieten Koch-Wegener (7, S. 387) an. Sie schildern den vorwiegend mit kleineren Kalbeisbrocken dicht gepackten Fjord. »Ganz draussen im äussersten Teil des Eisfjordes . . . sind die grossen Eisberge dicht gepackt und scheinen eine zusammenhängende Masse zu bilden, d. h. der Gletscher ist hier »regeneriert«, ungefähr wie der Storström (NE.-Grönland 77° N.) im äusseren Teil des Borg-Fjordes . . .« Eine solche, tatsächlich durch Druck wiedervereinigte Eismasse könnte ja auch zufällig an anderer Stelle des Fjordes auftreten, z. B. durch eine vorübergehende, später wieder ausgeräumte Bank von Moränenschutt. Wie rasch eine Frontmoräne entstehen und wieder beseitigt werden kann, hat A. Bauer (11) durch Vergleich seiner Beobachtungen 1948 am Eqip Sermia mit denjenigen von A. Wegener's Vor-Expedition 1929 gezeigt. So mag auch die Frontbeobachtung von 1888 zustande gekommen sein. Jedenfalls zeigt schon die punktierte Kurve (3) Fig. 4 S. 143, dass die angebliche Frontlage 1888 einen Vorstoss von 5,8 km in 8 Jahren, und sofort anschliessend einen noch extremeren Rückzug von 6,8 km in 5 Jahren bedeutete. Auch aus der genaueren Rückzugskurve in Abb. 2, wo der für 1888 angegebene Frontstand durch ein Kreuz angedeutet ist, muss die Unmöglichkeit einer derartigen Gletscherbewegung gefolgert werden.

Auch die in (1, 2) dargestellte Frontlage von März 1880 fehlt in unserer Darstellung. Wird die Frontlage von August 1880 übereinstimmend mit (7) als zuverlässig betrachtet, so ergibt März—August einen Rückgang von 1,3 km in etwa 5 Monaten. Der mittlere Rückgang von 1850—1953 beträgt 0,24 km/Jahr; selbst während des stärksten Rückzuges 1870—1880 wurden nur 0,8 km/Jahr oder 0,35 km in 5 Monaten gemessen. Ausserdem fehlt eine Frontlage März 1880 bei (7), während hier ein ganz ähnlicher Frontverlauf von September 1879 datiert ist; diese Frage ist also noch zu klären. Schliesslich ist zu bedenken, dass im März 1880 wahrscheinlich Gletscher und Eisfjord noch tief verschneit waren, was die einwandfreie Feststellung der Grenze zwischen Gletscher und vor der Front eingepressten Eisbergen sehr erschweren muss. Aus diesen Gründen hielten wir uns für berechtigt, auch von dieser Frontlage März 1880 vorläufig abzusehen.

Mit diesen Ergänzungen umgezeichnet, erlaubt das Bewegungs-Diagramm des Gletschers recht interessante Einzelheiten zu erkennen. Hierfür wurden Zurückweichen oder Vorstoss gegenüber der von H. Rink 1850 erstmals festgestellten Frontlage ausgemessen, was freilich angesichts der unterschiedlichen Frontgestaltung über die Fjordbreite von etwa 6 km nur in grober Annäherung möglich war (+ Vorstoss, — Rückzug):

Jahr......	1850	1870	1875	1880	1883	1893	1902	1913
km.......	0	+1,1	—4,2	—7,0	—7,6	—8,4	—12	—15,6

Jahr......	1929	1931	1942	1953
km.......	—17	—18	—23	—24

Das hiernach als Abb. 2 gezeichnete Diagramm zeigt rhythmische Folgen langsameren und rascheren Rückganges mit einer Periode von etwa 30 Jahren, Stillstandszeiten um 1862, 1892, 1922 und 1952 (Pfeile v. o.), die drei ersten Stillstände jeweils gefolgt von stärkeren Rückzügen mit Höchstwerten um 1870—77, 1896—1906, 1934—40.

Dass die Zungenlänge kleinerer Gletscher den klimatischen Temperaturschwankungen mit gewisser Verzögerung parallel geht, ist bekannt und verständlich (20). Aber kann dieselbe Einwirkung erwartet werden bei diesem Riesengletscher, dessen Einzugsgebiet noch über die Mitte Grönlands hinausgreift ((5), Fig. 40, S. 53) und auf mehr als 100.000

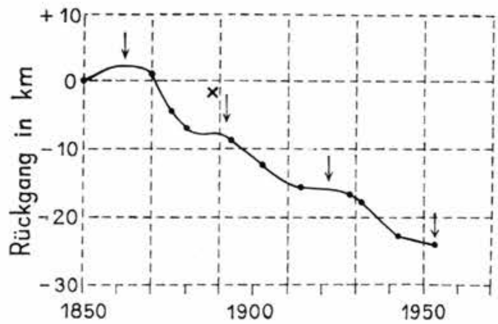


Abb. 2. Lage-Änderung der Front des Jakobshavn-Gletschers von 1850 bis 1953. Zeichnerische Darstellung der Zahlen-Tabelle auf S. 4.

km² mit Eismächtigkeiten von weit über 1000 m veranschlagt werden muss? Sind die in Abb. 2 so deutlich sichtbaren Schwankungen im Rückgang nur eine Erscheinung des kleineren, eigentlichen Zungengebietes, oder etwa des gewaltigen Einzugsgebietes?

In beiden Fällen sollte eine Parellität von Erwärmung und Gletscher-Rückgang beobachtet werden können, doch mit wachsender Verzögerung und abnehmender Amplitude, je weiter im Inneren des Inlandeises das eigentliche Aktionszentrum liegt. Im klimatologischen Anhang wird die Änderung der Bewegung des Jakobshavns Isbræ mit derjenigen der Luft an Hand verschiedener Beobachtungsreihen in Verbindung gesetzt, mit dem Ergebnis, dass ein Zusammenhang zwischen beiden vorläufig nicht erweisbar ist.

Daher sollte eine andere Möglichkeit für solche Perioden eines »Inlandeis-Gletschers« wenigstens versuchsweise zur Erörterung gestellt werden. Als wiederholt beschriebenen Fall einer, wenn auch auf die Oberflächenschicht des Inlandeises beschränkten, unstetigen Bewegung nennen wir den »Firnstoss« (15). Hierbei bilden sich mehrere Dezimeter oder Meter unter der Oberfläche Lockerschichten, vermutlich durch Diffusion von Wasserdampf von den kleineren zu den grösseren Firnkörnern, die aber, oft über grossen Flächen zugleich, erst zusammenbrechen, sobald, z. B. infolge zunehmender Schneebelastung, die Bruchgrenze überschritten wird. Dieses Spiel wiederholt sich ins Unendliche.

Hier erscheint noch eine glaziologische Bemerkung angebracht über die Berechnung des Temperaturganges im Grönlandfirn nach der Poisson'schen Gleichung, etwa zur Feststellung der Eindringtiefe und geschwindigkeit der Temperaturextreme an der Oberfläche. Hierfür ist die Kenntnis des Beiwertes der Wärmeleitung wesentlich, ein für die meisten Stoffe zuverlässig bekannter, individueller Wert. Anders im Firn, wo nach einer von A. Wegener (7, S. 332) angegebenen Methode dieser Wert aus der jeweiligen Dichte bestimmt wird, wobei *homogene* Materialbeschaffenheit vorausgesetzt wird. Wie die »Firnstösse« verschiedener Grössenordnung beweisen, ist im Grönlandfirn jedenfalls in der Vertikalen diese Voraussetzung nicht erfüllt. Wir werden also, wenn die natürliche Schichtung berücksichtigt wird, senkrecht nach unten wahrscheinlich kleinere Werte der Wärmeleitung finden. Ein solcher Wert, der auf 10—100 m mächtige Firnschichten anwendbar sein soll, kann nur *in situ* über die darin enthaltenen Lockerschichten hinweg bestimmt werden, keinesfalls auf Grund einer mittleren Dichte. Wir müssen dem Grönlandfirn ein dreifaches Wärmeleitvermögen zuschreiben: a) bei allseitig gleichmässiger Packung der Firnkristalle das »molekulare« WLV nach A. Wegener's Methode; b) dasselbe horizontal längs der betrachteten Schicht, und c) vertikal zu der tatsächlich vorhandenen Schichtung. Die »strukturellen« Wärmeleitungs-Beiwerte b) und c), wovon der erstere wohl etwas, der letztere ev. erheblich niedriger sein kann als a), können nur in ungestörter Lagerung gemessen werden, der Wert c) im besonderen muss tatsächlich über die Tiefe hin gemessen werden, worauf sich die Rechnung erstrecken soll. Da durch Bohrung oder Schachtanlage die ursprüngliche Textur vermutlich gestört werden wird, bedarf es für diese Messungen der, vom Verf. (12b) und schon früher vorgeschlagenen »Säkularen Inlandeis-Station«.

Erwägen wir die Möglichkeiten einer Periodizität für die gewaltige Masse des Inlandeises, die dem Einzugsgebiet des Jakobshavner Eisstromes angehört, so besteht zunächst ein wesentlicher Unterschied gegenüber den alpinen Gletschern darin, dass diese sich mit dem grössten Teil ihrer Masse auf einer Temperatur nahe dem Gefrierpunkt befinden, wobei das Eis einen hohen Grad von Plastizität besitzt, sodass es verhältnismässig rasch und genau auf die wirkenden Kräfte antwortet. Im Inlandeis dagegen ergaben die Messungen der Temperatur in Schächten und Bohrlöchern, zuerst angedeutet durch E. Sorge's Messungen in seinem 16 m-Schacht in »Eismitte« I 1930—31 (12), um ein Vielfaches ausgedehnt durch Schacht und Tiefbohrung der französischen »Station Centrale« (= Eismitte II) 1950, und wiederum bis in den Boden unter dem 3000 m mächtigen Inlandeis vorgetrieben durch die seismischen Refraktionsmessungen der Expéditions Polaires Françaises 1950 und 1951 (5) nicht den erwarteten positiven Temperaturgradienten mit der Tiefe, endigend mit dem (um etwa 2,2° C druckerniedrigten) Schmelzpunkt in der dem Felsen aufliegenden Unterfläche, sondern in der ganzen Eismasse unerwartet niedrige Temperaturen mit negativem Temperaturgradienten oder Isothermie auf grosse Strecken, ja sogar negative Temperaturen noch einige hundert Meter tief im unterliegenden Moränenboden: kalter Gletscher. Dies bedeutet, dass der Firn und das aus ihm sich bildende Eis im kristallographisch ungeordneten Zustand eine sehr hohe Festigkeit gegen Verschiebung (Scherung) aufweist. Sobald jedoch einmal die Kristallflächen sich parallel zu der Richtung einer Scherungskraft eingestellt haben, ist die zur seitlichen Verschiebung erforderliche Kraft um ein Vielfaches geringer. Solche Scherungsflächen mit einheitlicher Lage der Kristallflächen finden sich u. a. in den bekannten Blaubändern.

Wir lessen bei Lewis (16, S. 149 und 157): »In einer Probe von gefrorenem Schnee ohne bevorzugte Kristall-Orientierung ergab sich die scheinbare Viskosität 70 mal grösser, als in einem multikristallinen Block, worin alle Kristall-Gleitflächen zur Scherungs-Richtung parallel angeordnet waren ... Eine viskose Substanz ist dadurch gekennzeichnet, dass sie schon sehr geringen Kräften folgt. Eis verhält sich nicht derartig, vielleicht mit Ausnahme nicht verfestigten Schnees (s. Perutz und Seligman 1939). Im allgemeinen verhält sich Eis wie eine plastische Substanz, die einer Bewegung Widerstand leistet, bis die verformenden Kräfte die Druckfestigkeit (yield stress) überwiegen. Jede weitere Zunahme der verformenden Kräfte führt zu einer raschen Zunahme der Fliessgeschwindigkeit (Orowan 1949)«. — Auch Seligman (16a, S. 236) betont, »dass Eis kein Material konstanter Viskosität ist, ... sondern dass seine scheinbare Viskosität eine Funktion mehrerer Faktoren ist, so der auftretenden Schubspannung, der Temperatur und des Kristallgefüges. Die Entdeckung, dass die scheinbare Viskosität mit einer hohen Potenz der auftretenden Spannung abnimmt, mit anderen Worten, dass das Eis zunehmend plastisch wird, je grösser die Schubspannung wird, (und doch wohl auch vice versa, G.), ist geeignet, unsere Anschauungen über die Natur des Gletscherfliessens zu revolutionieren. Beiläufig: Die Wirkung der Schubspannung (shear-stress) darf nicht verwechselt werden mit derjenigen des hydrostatischen Druckes; letztere mag ebenfalls die scheinbare Viskosität verringern, doch konnte dies bis jetzt noch nicht experimentell bewiesen werden.« »Apparent« viscosity darf vielleicht übersetzt werden anstatt des unbestimmten Ausdruckes scheinbar mit »virtuelle« Viskosität, in Analogie zu der, ebenfalls von der molekularen Reibung wesentlich verschiedenen virtuellen Reibung der Luft.

Der hier ins Auge gefasste Zyklus in der Produktivität dieses und anderer Gross-Gletscher in Grönland würde nach der schematischen Abb. 3 so vor sich gehen: Figur 1, das Inlandeis empfängt während einer Reihe von Jahren den üblichen Schnee-Auftrag, ohne dass, mangels eingespielter Gleitflächen, die entsprechende, grössere Eismenge aus dem Inneren, speziell aus dem Einzugsgebiet der Gross-Gletscher oder Eis-

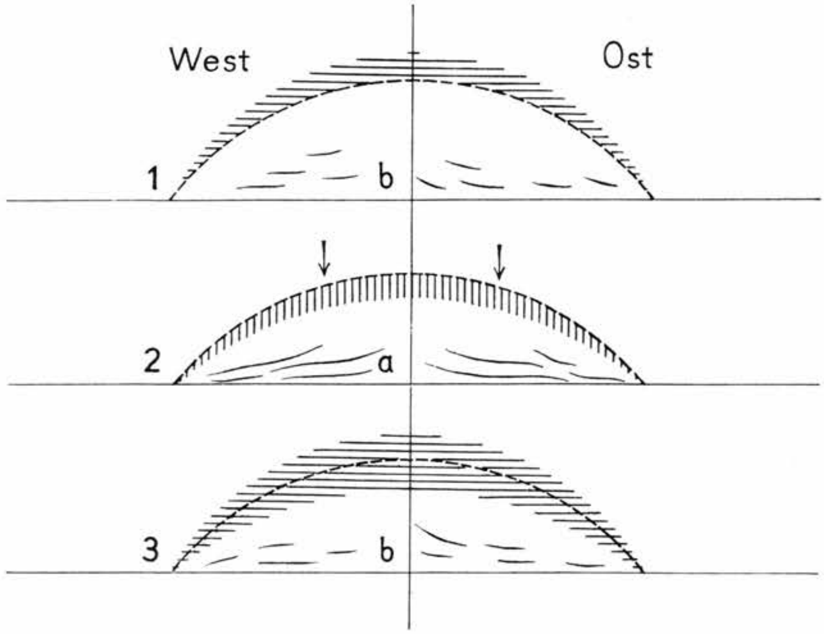


Abb. 3. Schema eines Produktivitäts-Zyklus des Grönländischen Inlandeises. a: aktive, b: abgestorbene Gleitflächen.
Horizontale Schraffur = Akkumulation ohne Absinken; vertikale Schraffur = Absinken.

Ströme (»fleuves de glace« nach A. Bauer (11, S. 14—15) küstenwärts verfrachtet wird.

In einem gewissen Stadium des Zuwachses an der Firnoberfläche erreicht der statische Druck eine solche Höhe, dass sich zunächst in den untersten, am wenigsten kalten Schichten des Inlandeises längs gewisser Flächen die Moleküle parallel anordnen und so Gleitflächen entstehen. Unterstützt durch die Reibungswärme, die die Beweglichkeit erhöht und die Bildung weiterer Blaubänder erleichtert, erfährt das Inlandeis einen rasch zunehmenden, auf dem Höhepunkt den gleichzeitigen Schnee-Auftrag an der Oberfläche weit übertreffenden Aderlass, der sich, wenn nicht in einem Vorstoss, so doch im Stehenbleiben der Gletscherfronten ausprägen wird.

Ist das Spiel dank der »geschmierten« Gleitflächen erst einmal in vollem Gang, so wird das Inlandeis weit stärker abnehmen, als dem, in Abb. 3 gestrichelt angedeuteten Gleichgewichtszustand für kaltes Inlandeis ohne Gleitflächen entspricht, siehe Abb. 3, Figur 2. Aber dieser Vorgang findet sein Ende dadurch, dass die auch während der schnellsten Eisbewegung noch vorhandene Reibung schliesslich durch den verringerten statischen Druck der Eis- und Firnmasse nicht mehr überwunden werden kann, sodass die ausfliessende Bewegung mehr oder weniger zum Stillstand kommt und (als einzige, ad hoc eingeführte Hypothese) die Gleitflächen selbst degenerieren; dabei werden selbstverständlich die schwächer gefütterten Gletscherzungen stärker zurückweichen.

Jetzt überwiegt für Jahre oder Jahrzehnte wieder der Auftrag; er wird die theoretische Gleichgewichtsfigur des Inlandeises aufs neue überschreiten, bis wiederum das Stadium 3,1 erreicht ist und derselbe Zyklus aufs neue beginnt.

Unter den tatsächlichen Verhältnissen mag sich dieser Vorgang mannigfaltig variieren. So wird der Umstand, dass das Einzugsgebiet des Jakobshavner Eisstromes (5, Fig. 40) weit über die geometrische Mitte des Inlandeises nach Osten hinüberreicht, sich dahin auswirken, dass sich auch die Eisscheide im Laufe der Jahrhunderte nach Osten verschiebt; deren heutige asymmetrische Lage hätte also nicht von Anfang an bestanden, was zu berücksichtigen wäre, wenn die erste Bildung des Inlandeises aus Schneewehengletschern an der Westflanke der ostgrönländischen Randberge abgeleitet wird.

Da mit dem Schnee-Auftrag zugleich auch die jeweilige Lufttemperatur den dadurch gebildeten Firnschichten aufgeprägt wird, werden sich diesem geschilderten Normal-Vorgang die säkularen Temperatur-Änderungen überlagern; denn mit zunehmender Temperatur wird die Schubfestigkeit des Firns und Eises verringert und unter sonst gleichen Umständen die Bildung von Gleitflächen in den wärmsten Lagern erleichtert. Wäre eine allgemeine Erwärmung des Inlandeises auf diese Weise anzunehmen, so würde sich die Amplitude des gedachten Vorganges verringern, d. h. die Verstärkung des Eis-Ausstosses schon bei geringerem Schnee-Auftrag in Gang kommen. Gleichzeitig würde sich, — gleichbleibenden Auftrag an der Oberfläche vorausgesetzt, — auch die Länge der Periode verkürzen. —

Diese, wegen der Ungenauigkeit unserer heutigen Unterlagen über die Bewegung der grönländischen Gross-Gletscher naturgemäss fragmentarischen Andeutungen hätten ihren Zweck erfüllt, wenn sie die dänische und internationale Geophysik zu Massnahmen veranlassten, um sowohl die Gletscherzustände in Küstennähe, wie auch die geophysikalischen Verhältnisse in der Mitte Grönlands mit mindestens gleichbleibender Messgenauigkeit für die folgenden Jahrzehnte festzustellen[1]). Die säkulare Bedeutung aller geophysikalischen Messungen auf und am Inlandeise wurde ja bereits von ALFRED WEGENER (19) in seinem heute noch aktuellen Plan einer Inlandeis-Expedition nach Grönland von 1928 hervorgehoben, wo er unter Zif. 2 feststellt, dass es mittels barometrischer Höhenmessung »nicht möglich ist, bei späterer Wiederholung der Messung ein zuverlässiges Urteil zu gewinnen, ob die Höhe des Inlandeises im Wachsen oder im Abnehmen begriffen ist. Wird dagegen die Höhe des Inlandeises . . . auf trigonometrischem Wege ermittelt, so ist damit eine Genauigkeit von schätzungsweise 10 m zu erreichen, was für die genannte Frage ausreichend ist.« Wie der folgende klimatologische Anhang zeigt, ist ja auch wenigstens für gewisse Zeiträume ein Gleichgang zwischen Klima und Gletschertätigkeit nicht ganz ausgeschlossen. Neben Durchforschung der Literatur und der Archive nach etwa existierenden, weiteren Frontbeobachtungen vom Jakobshavns Isbræ[2]) erscheint die möglichst häufige, photographische Aufnahme dieses und anderer grönländischer Gross-Gletscher wichtig, die zweifellos auch Aufschlüsse über die individuelle Art der Kalbung liefern wird. Verf. konnte z. B. im Sommer 1929 am Kangerdlugssuaq (71,4° N.) beobachten und photographieren, wie sich an dessen Front zwei grosse Eisberge ablösten, die, ohne abzustürzen oder zu kentern, in ihrer ursprünglichen Lage durch den Inlandeiswind und den Ablationsstrom in den Fjord hinausgetrieben wurden, — was auch für den ähnlich flach in den Fjord mündenden Jakobshavns Isbræ wahrscheinlicher ist, als die angebliche, auf S. 56 wiedergegebene Beobachtung.

[1]) "Année Géophysique Internationale 1957–58, Comité Special du Conseil Internat. des Unions Scientifiques (CSAGI), Bruxelles 7–14 Septembre 1955. Recommendation:

Objet: Observations continues à la station centrale du Groenland.

Le groupe de travail de Glaciologie reconnait l'importance de la proposition faite par le Dr. J. GEORGI, datée du 31 juillet 1955, portant sur l'organisations continues faites à intervales réguliers dans la région de la Station Centrale du Grœnland des Expéditions Polaires Françaises (oder Eismitte I—III. G.)

Il recommande au Comité National danois pour l'AGI de prendre cette proposition en considération. Dans le cas où il serait impossible aux scientifiques danois d'assurer les observations proposées, le groupe de travail recommande que considération soit prise de permettre à une autre organisation autorisée à travailler au Grœnland, de continuer ces observations. Ce programme pourrait être entrepris par l'Expédition Glaciologique Internationale projettée par la Commission des Neiges et des Glaces et les Expéditions Polaires Françaises à l'occasion de l'AGI. Ces observations assureraient la continuation de celles commencées dans cette région par l'Expédition Wegener 1930—31 et par les Expéditions Polaires Françaises de 1949 à 1951. Il est de plus recommandé à la Commission des Neiges et des Glaces, en coopération avec les autorités danoises de faire assurer la continuation de ces observations après la période couverte par l'AGI.«

[2]) So soll eine amerikanische Expedition im Sommer 1954 sogar eine Kalbung des Jakobshavns Isbræ vom Hubschrauber aus photographiert haben. Als Geograph und Photograph wird Stud. Rat P. Diebold aus Viernheim genannt, doch konnte leider nichts näheres erfahren werden.

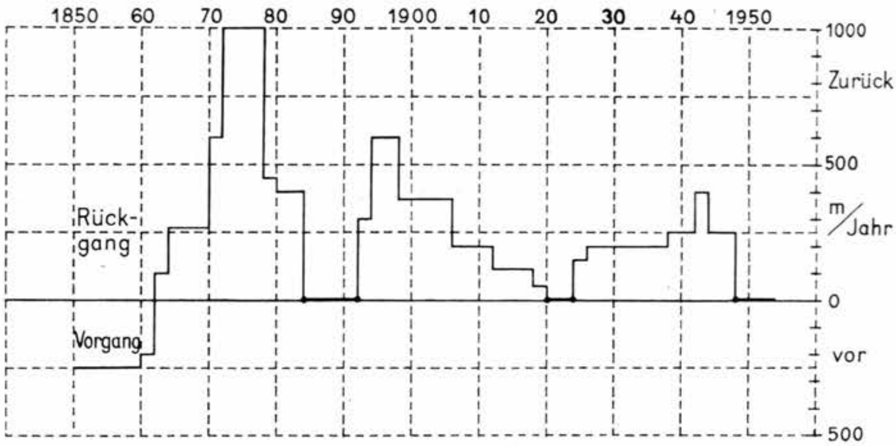


Abb. 4. Vor- und Rückzugs-Geschwindigkeit des Jakobshavns Isbræ in m/Jahr, 1850—1954.

Klimatologischer Anhang.

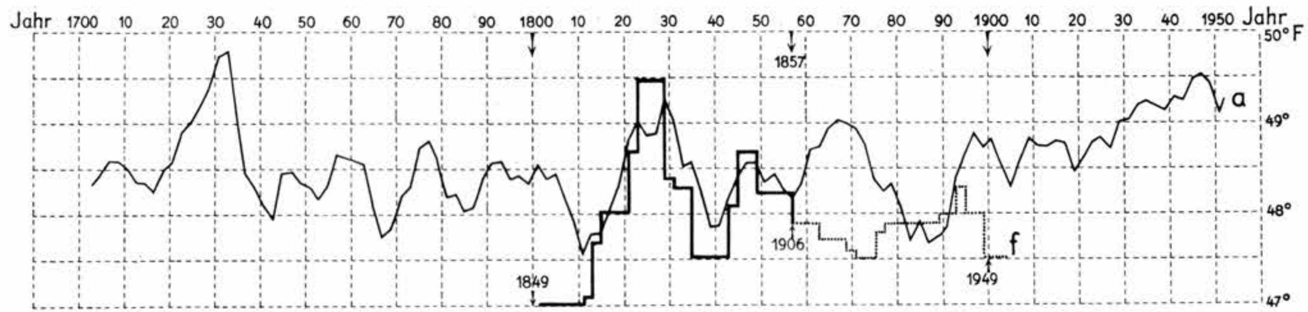
Zum besseren Vergleich der Gletscherbewegungen mit den Temperaturänderungen wurde aus Abb. 2 die Änderungsgeschwindigkeit der Gletscherfront bestimmt (— bedeutet Vorrücken, + Rückgang, 0 Stillstand), woraus sich die folgende Tabelle und deren Darstellung in Abb. 4 ergibt:

Jahr......	1850/60	60/62	62/64	64/70	70/72	72/78	78/80	80/84
km.......	—2,5	—0,4	+0,2	1,6	1,2	6,0	0,9	0,8
m/Jahr...	—250	—200	+100	270	600	1000	450	200
Jahr......	84/92	92/94	94/98	1898/1906	06/12	12/18	18/20	20/24
km.......	0	0,6	2,4	3,0	1,2	0,7	0,1	0
m/Jahr...	0	300	600	375	200	110	50	0
Jahr......	24/26	26/38	38/42	42/44	44/48	48/54		
km.......	0,3	6,0	1,0	0,8	1,0	0		
m/Jahr...	150	200	250	400	250	0		

Das Vorzeichen in Abb. 4 ist so gewählt, dass die Spitzen, also die Perioden mit starkem Rückgang, mit den Höchstwerten der Temperaturkurve in Beziehung gesetzt werden können.

In Abb. 5 sind folgende Temperaturkurven dargestellt:

a) Lufttemperatur über Mittel-England nach G. Manley (17); aus dessen homogenisierter Reihe der Jahresmittel 1698—1952 (handschriftlich ergänzt bis 1957) wurden übergreifende Zehnjahrs-Mittel für jedes zweite Jahr berechnet, von 1799—1808 bis 1847—56, jeweils bezogen auf die Intervall-Mitte von 1803 bis 1951. Obwohl die Frontbeobachtungen in Grönland erst 1850 beginnen, wurde diese Temperaturkurve



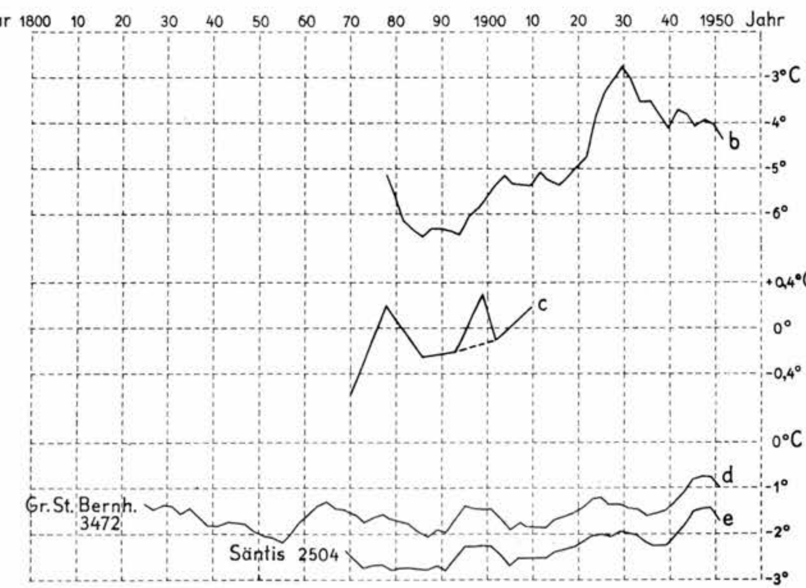


Abb. 5. Temperaturkurven zum Vergleich mit Vor- und Rückzug-Geschwindigkeit des Jakobshavns Isbræ.

a) Lufttemperatur in Mittelengland,
b) dieselbe in Jakobshavn (Westgrönland);
c) Temperaturgang in der nördlichen »kälteren gemässigten Zone«
d, e) Lufttemperatur auf dem Grossen St. Bernhard-Pass und dem Säntis;
f) Gletschergeschwindigkeit wie in Abb. 4, dem 49 Jahre früheren Gang der Lufttemperatur zugeordnet.

in voller Länge wiedergegeben, um dem Leser selbst ein Urteil über irgendwelche Paralellisierungs-Möglichkeit zu erlauben.

b) Lufttemperatur von Jakobshavn (W.-Grönland 69°13′ N.) 1873—1957. Die übergreifenden Zehnjahres-Mittel wurden berechnet von Herrn Richard Lange vom Seewetteramt Hamburg und dankenswerter Weise aus dem Manuskript einer im Druck befindlichen Arbeit zur Verfügung gestellt. Zur weiteren Glättung unwichtiger, kleiner Zacken wurden die Werte zweier, aufeinander folgender Jahre zu einem Mittelwert zusammengefasst, sodass die wiedergegebene Kurve, ebenso wie a, d und e die übergreifenden Zehnjahrs-Mittel für je zwei folgende Jahre darstellt.

c) Mittlere Lufttemperatur für den nördlichen »kälteren gemässigten Gürtel« von 1870—1910 nach W. Köppen 1914 auf Grund der Berechnungen von J. Mielke 1913, entnommen aus Hann, J. v. Hdb. d. Klimatologie, 4. Aufl. v. K. Knoch Stuttgart 1932, Bd. 1 Teil 6 S. 400, Abb. 25. Die dortige Zeichnung wurde für unseren Zweck graphisch ausgeglichen. Punktiert ist der abweichende Kurvenverlauf für den »kalten Gürtel« angedeutet, dem der Höchstwert bei 1900 fehlt.

d) und e) Lufttemperatur vom Grossen St. Bernhard (2472 m) und vom Säntis (2504 m) in den Walliser bzw. Appenzeller Alpen für 1821—1956 bzw. 1864—1956. Die Jahresmittel wurden mir freundlicher Weise von Herrn Dr. H. v. Rudloff, Freiburg i. B. zur Verfügung gestellt; ich berechnete die übergreifenden Zehnjahrsmittel für jedes zweite Jahr.

f) Schliesslich wurde die Geschwindigkeitskurve der Gletscherbewegung aus Abb. 4 willkürlich verschoben unter Kurve a) eingezeichnet, was im Text näher ausgeführt ist.

Zunächst soll die Zusammenstellung mehrerer langer Temperaturreihen, die durch andere lange Reihen, wie diejenige von Prag, Berlin oder New Haven beliebig hätte erweitert werden können, lediglich dartun, dass diese Reihen in ihren wesentlichen Eigenarten übereinstimmen. Dass sich häufig Abweichungen im kleinen finden, ist nur zu erwarten, da sich die langsamen Wechsel zwischen verschiedenen Zirkulationsformen örtlich verschiedenartig auswirken müssen. Man wird sich daher nicht daran stossen dürfen, dass sich etwa der Beginn einer Richtungsänderung zeitlich verschiebt, oder dass die Amplituden nicht übereinstimmen, ja dass irgend ein Buckel oder Tal hier gut ausgebildet ist, dort aber fast ganz verschwindet. Oft zeigt sich die Übereinstimmung nur an den Wendepunkten der Kurven. Auch zonale Unterschiede machen sich bemerkbar, wie dies bereits oben anlässlich der Köppen'schen Kurven c) erwähnt wurde, wobei in der nördlichsten Zone ein in der südlich benachbarten Zone gut ausgeprägtes Maximum kurz vor dem Jahre 1900 ganz fehlt.

Da leider die Temperaturkurve von Jakobshavn nicht weit genug zurückreicht, halten wir uns hiernach für berechtigt, die Manley'sche Temperaturkurve für Mittel-England zum Vergleich mit der Kurve der Geschwindigkeitsänderungen des Jakobshavns Isbræ zu benutzen. Wir haben also in der Temperaturkurve eine Sequenz zu suchen mit Wärmetälern in den Jahren 0, 33, 67 and 97, und mit Wärmebuckeln in den Jahren 20, 41 und 89, zugleich mit langsamem Abfall vom mittleren und langsamem Anstieg zum jüngsten Höchstwert. Würden wir dann noch finden, dass die Wärmebuckel, entsprechend dem Gletscher-Diagramm, jedes Mal niedriger werden, so wäre die Annahme eines realen Zusammenhanges nicht unbegründet.

Freilich ist schon die letztgenannte Bedingung absteigender Höchstwerte der Temperatur nicht zwingend, solange wir über die Gletscheränderungen noch so gut wie nichts wissen. Denn falls eine Temperatur-Einwirkung zur Hauptsache an der Gletscher**zunge** angreift, was erkennbar sein würde an einem verh. geringen, zeitlichen Nachhinken der Gletscherbewegung, könnte diese bei gleichen Temperatur-Höchstwerten immer geringer beeinflusst werden, je kürzer die Gletscherzunge inzwischen geworden ist, siehe unsere Abb. 1. Ferner darf man nicht aus dem Auge verlieren, dass unsere Gletscherkurve auf recht wenigen Einzelbeobachtungen beruht, sodass ihr tatsächlicher Verlauf noch weitere, uns unbekannte Schwankungen enthalten haben kann.

Der Vergleich der Temperatur- und Gletscherkurve fällt enttäuschend aus: Es findet sich in der ganzen, englischen Temperaturreihe keine Entsprechung zu unseren vier Wärmetälern und drei-buckeln. Die einzige, teilweise Vergleichbarkeit entstand, wenn die Gletscherkurve um 49 Jahre nach links verschoben wurde, d. h. bei einem angenommenen Nachhinken des Gletschers gegen die Temperatur von 49 Jahren. In dieser Lage ist in Abb. 5 die Gletscherkurve gestrichelt eingezeichnet. Das stärkste Vorrücken des Gletschers in bekannter Zeit (um 1860) trifft dann zusammen mit dem tiefsten Wärmetal der ganzen Manley-Reihe (1811), und ebenso der stärkste Rückgang 1870—80 mit dem höchsten, vor 1935 beobachteten Wärmebuckel, und so fort. Leider ist aber diese schöne Übereinstimmung bereits nach 60 Jahren zu Ende, sodass das Urteil wohl auf »zufällige Übereinstimmung« lauten muss, selbst wenn man nicht ausschliessen kann, dass der so »störende« Wärmebuckel in England um 1870 in nördlicheren Breiten vielleicht nicht aufgetreten sein mag.

Bei der Suche nach weiteren, vergleichbaren Temperaturreihen fand sich ein Beispiel, woran sich die besonders von J. Bartels-Göttingen mehrfach ausgesprochene Warnung vor unberechtigten Parallelisierungen exemplifizieren lässt. In einer ausgezeichneten Studie über Temperaturschwankungen bringt G. Liljequist (18) einerseits eine Kurve

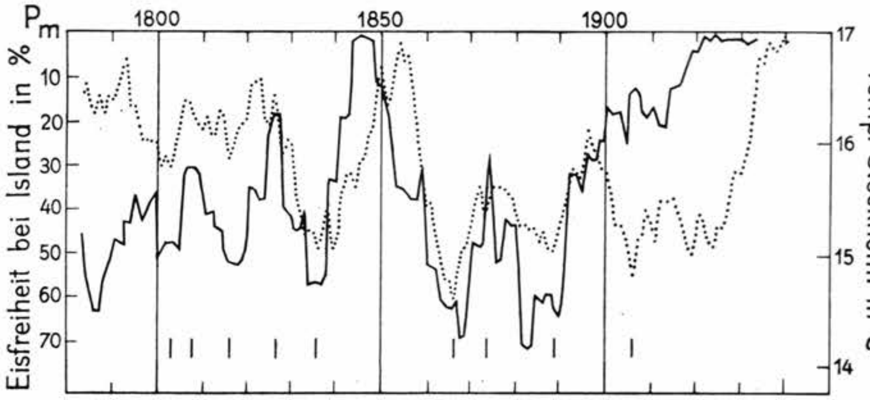


Abb. 6. Eisfreiheit bei Island (—) und Sommer-Mitteltemperatur der Luft in Stockholm (....) in zehnjährigem übergreifenden Mittel. Erklärung unten.

der Eisverhältnisse um Island von G. HOVMÖLLER, andererseits eine solche der Lufttemperatur in Stockholm, beide in Gestalt übergreifender Zehnjahrs-Mittel. Auf den ersten Blick scheinen beide Kurven bis in Einzelheiten so genau übereinzustimmen, wie man es sich nur wünschen kann, um eine reale Abhängigkeit zu beweisen. Zeichnet man beide Kurven übereinander, so ergeben sich in Abb. 6 nicht weniger als 9 unzweifelhafte Übereinstimmungen, die durch kleine Striche unter den Kurven angedeutet wurden. Aber gerade bei der um 1850 beobachteten, höchsten Spitze sowohl der Eisfreiheit bei Island wie der Temperatur in Stockholm für die 150 Jahre zwischen 1780 und 1930 tritt das Optimum der Eisfreiheit etwa 5 Jahre vor demjenigen der Temperatur ein! Bringt man dagegen durch seitliches Verschieben die beiden markanten Höchstwerte zur Deckung, so fallen offensichtlich alle anderen, früher gefundenen Übereinstimmungen fort. Es bedarf jedenfalls eingehender Untersuchungen, um etwa nachzuweisen, dass gerade und allein die beiden Höchstwerte auf einem ganz anderen, physikalischen Zusammenhang beruhen, als die zahlreichen, übrigen Übereinstimmungen, doch würde dies den Rahmen und Zweck dieser Darstellung überschreiten.

Auf jeden Fall hat auch dieser Versuch es als höchst wünschenswert gezeigt, dass alle zuverlässigen, langen Messreihen über Luft- und Wassertemperatur an einer, international bestimmten Stelle gesammelt, fortlaufend auf den neuesten Stand ergänzt und auf Anfrage mitgeteilt werden möchten. Das Gleiche gilt für Frontbeobachtungen von Gletschern und anderen säkularen, geophysikalischen Messwerten, für Jahresringbeobachtungen usw. Diese Messwerte dürften auf das 19. und 20. Jahrhundert beschränkt sein; ihre Bearbeitung, zwischen der aktuellen Klimatologie und der Paläoklimatologie, würde etwa der Stellung der Mittelfrist-Synoptik entsprechen zwischen der aktuellen und Langfrist-Synoptik, und würde ein wichtiges Arbeitsgebiet sui generis darstellen.

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