Johnson, P. G. (1984b): Rock glacier formation by high-magnitude low-frequency slope processes in the southwest Yukon. Annal. Ass. Amer. Geograph. 74(3):408-419.
Martin, H. E. and Whalley, W. B. (1987): Rock glaciers. Part 1. Rock glacier morphology: classification and distribution. Progress in Phys. Geograph. 11(2):260-282.
Outcalt, S. I. and Benedict, J. B. (1965): Photo- interpretation of two types of rock glaciers in the Colorado Front Range, USA. Journ. Glaciol. 5(42):849-856.
Pillewizer, W. (1969): Untersuchungen an Blockströmen der Otzaler Alpen. Abh. d. Geograph. Inst. d. Freie Univ. Berlins 5:37-50.
Potter, N. (1972): Ice-cored rock glacier, Galena Creek, Northern Absaroka Mountains, Wyoming. Bull. Geol. Soc. Amer. 83(10):3025-3058.
Rohn, O. (1900): A reconnaissance of the Chitna River and Skolai Mountains, Alaska. In "U.S. Geological Survey" 21st Ann. Rep. Pt. 2:399-440.
Shakesby, R. A., Dawson, A. G. and Matthews, J. A. (1987): Rock glaciers, protalus ramparts and related phenomena, Rondane, Norway: a continuum of large-scale talus derived landforms. Boreas 16(3):305-317.
Spencer, A. C. (1900): A peculiar form of talus (abstract). Science 11:188.
Thompson, W. F. (1962): Preliminar notes on the nature and distribution of rock glaciers relative to true glaciers and other effects of the climate on the ground in North America. Internat. Associat. Scient. Hydrol. (IASH), Comm. Snow Ice, Symposium Obergurgl, Publ. 58:212-219.
Vernon, P. and Hughes, O. L. (1966): Surficial geology, Dawson, Larsen Creek map-areas, Yukon Territory. Geol. Surv. Canada Bull. 136, 25 pp.
Wahrhaftig, C. and Cox, A. (1959): Rock glaciers in the Alaska range. Geol. Surv. Amer. Bull. 70:383-436.
Whalley, B. (1974a): Rock glaciers and their formation. Reading Geographical Papers, eds. D. Bonnar, C. Chartres, M. Ebery, and P. Williams, University of Reading, Reading, England, No 24, 60 pp.
Whalley, B. (1947b): Origin of rock glaciers (correspondence). Journ. Glaciol. 13(68):323-324.
Whalley, B. (1983): Rock glaciers – permafrost features or glacial relics? Proc. Fourth Int. Conf. Permafrost, National Academy Press, Washington, D.C. 1:1396-1401.
White, S. E. (1981): Alpine Mass Movement Forms (Noncatastrophic): Classification, Description and Significance. Arctic and Alpine Research 13(2):127-137.

Massbalance studies of the Mitdluagkat Glacier, Eastern Greenland

Bent Hasholt

Hasholt, Bent: Massbalance studies of the Mitdluagkat Glacier, Eastern Greenland, Geografisk Tidsskrift 88: 82-85. Copenhagen 1988.

Changes in volume of the Mitdluagkat Glacier in Eastern Greenland are studied by comparison of maps based on aerial photos from 1972 and 1981. The results are compared with detailed measurements at the terminus and at ablation stakes.

Keywords: *Glaciology, Hydrology.*

Bent Hasholt, M.Sc., associate professor, Institute of Geography, University of Copenhagen, Øster Voldgade 10, DK-1350 Copenhagen K.

Large variations in the recent behavior of glaciers within and around the North Atlantic area are reported within recent years, Bjørnsson (1979), Knudsen and Theakstone (1981), Gordon (1981), Liestøl (1983), Anda et al. (1985), and Humlum pers.com. (1987). This paper contributes to the knowledge of the overall pattern in delivering new data from an area where very few data exist.

The Mitdluagkat Glacier was described earlier by Fristrup (1960, 1962, and 1970) and Valeur (1959); it was shown that the glacier has retreated since the first observations in 1933. These results are based mainly on observations of the terminus, but a few measurements at stakes in the upper part indicated a negative net-balance for larger parts of the glacier. In 1972 the glacier was photographed from the air, and a triangulation network was made at the same time. In 1976 a map based on the 1972 aerial photos was drawn; the map did not cover the whole glacier, the scale was 1:5000 with 5 m contour intervals. This map was evaluated by Hasholt (1986) on the basis of new triangulations and hydro-glaciological observation. A comparison with older maps showed an accumulation of volume above the 350 m level contradicting the older observations; the conclusion was, however, that it was most likely that the accumulation found was due to errors in the map from 1932-33.

In 1981 the area was photographed again by Geodetic Institute in scale 1:150,000. As an experiment a new map based on these aerial photos covering the whole glacier was drawn in scale 1:20,000 with 10 m contour intervals. An evaluation of this map was published by Hasholt (1987). The evaluation indicated that the new map of the

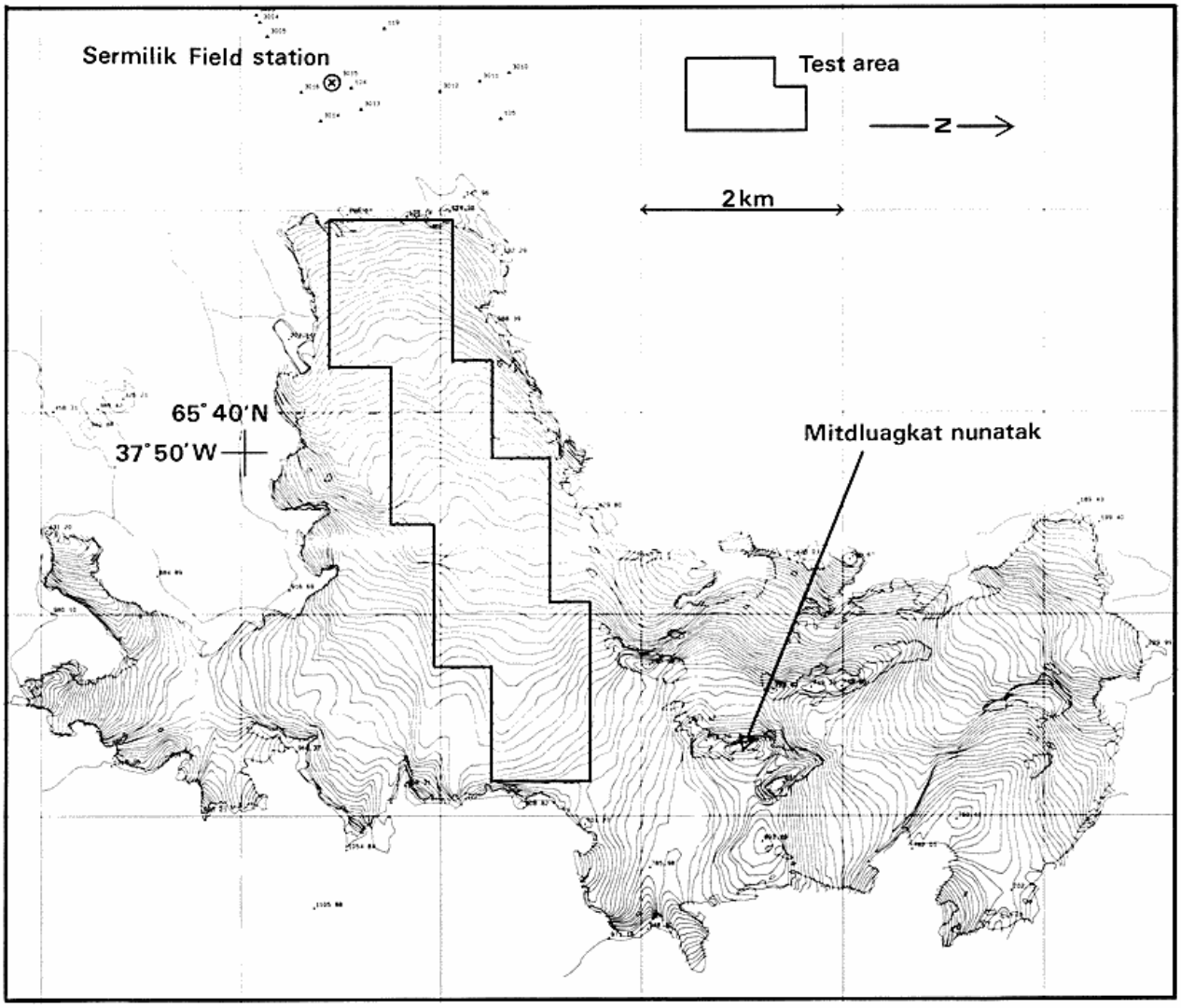

Fig. 1. Map of the Mitdluagkat Glacier and the investigation area.

1981 surface was so accurate that a comparison with the map of the 1972 surface was meaningful; it also supported the hypothesis that the accumulation in the upper parts of the glacier, described by Hasholt (1986), was due to inaccuracies in the old map from Geodetic Institute. The purpose of this investigation is to evaluate the changes of the surface of the glacier from 1972 to 1981 by comparing the two maps based on aerial photos. The result of this comparison is to be tested against field surveys of the terminus carried out since 1979, and measurements in a stake network from 1986-87.

METHODS

As mentioned above there is not complete overlap between the two maps. The southern part of the glacier situated south of the nunatak Mitdluagkat and the area around the nunatak is missing in the 1972 surface map. A rather steep sloping north-facing margin zone is also omitted in the area chosen for the comparison, because it is believed that it has been especially difficult for the cartographers to draw the contour lines here.

The selected area is mainly sloping towards southwest and west with a rather even surface. It should be stressed that the missing area of the glacier consists of the uppermost parts and areas lying in shade along the south margin. The two lakes along the the ice margin having rock thresholds are used as base level for the two surfaces, because it is shown that the level difference is the same on the two maps, Hasholt (1987). The height difference between the two surfaces is measured at grid points spaced at 200 m intervals. A spacing at 100 m intervals is also tested, the test square shows a lowering of the surface by 16.8 m with a standard-deviation of 4.2 m for 16 points in a 200 m grid, the lowering and standard-deviation for a

Height m a.s.l.	Area km^2	Grid Points N	Surface change, m 1972-81 Max	$\bar{X}$	Min	St. dev. m	Density t/m^3	Net balance 1986-87 $*10^6 m^3$
-250	0.58	13	-4.1	-9.0	-14.0	2.7	0.9	-1.04
250-350	1.10	30	-2.4	-5.4	-8.5	1.8	0.9	-1.54
350-450	1.13	29	+3.8	-0.9	-4.4	2.0	0.7	-0.31
450-550	1.81	42	+2.9	-3.4	-13.8	4.1	0.6	+0.65
550-650	1.58	42	+11.3	-10.4	-24.6	8.6	0.6	+0.95
650-	0.52	12	+12.0	-6.2	-25.0	11.5	0.6	+0.47
	6.72	168		-5.8				-0.82

Table 1. Net balance of the Mitdluagkat Glacier.

100 m grid interval is 17.2 m and 4.7 m respectively; therefore a grid size of 200 m is chosen.

The selected area is shown in fig. 1. The grid point's height differences are also sorted in 100 m intervals above sea level on the 1981 surface, i.e. grid points lying between 350 and 450 m are allotted to the level of 400 m a.s.l.

The surveying of the terminus area is carried out by trigonometric levelling using a theodolite with an electrooptic distance meter, the surveyed area is 200 x 200 m.

The stake network is established in 1986, it consists of 17 stakes spaced at 100 m contour intervals from 500 to 200 m a.s.l., there are 4 stakes distributed along each contour. The movement of 4 stakes is monitored by trigonometric levelling from fixed points. Three pits are dug in the accumulation area in 1986.

RESULTS

The area of the glacier sloping from the nunatak Mitdluagkat towards southwest/west is about 20 km^2. The runoff from about 9.3 km^2 drainage area as delimitated by surface contours runs through the valley at the Sermilik field station, Bertelsen et al. (1987), while the rest, from 10.7 km^2, drains northwards along the margin of the glacier. The overlap area covers approx. 23 % of the drainage basin draining west, and approx. 43 % of the basin draining north. The figures are approximate, because the drainage pattern on the surface and within the glacier is not fully known. The changes in volume from 1972 to 1981 are shown in table 1. The volume is diminished by 39 x 10^6 m^3, the corresponding average lowering of the surface during the period is 5.8 m in the overlap area (6.72 km^2). It is, however, seen from table 1 that the distribution of the loss of volume is very uneven, the largest losses are found below 250 m a.s.l. and between 550 and 650 m a.s.l. By use of measured density values the loss of water could be computed, the total loss of water from 1972 to 1981 is approx. 26 x 10^6 m^3, corresponding to a yearly average of approx. 430 mm. It is also seen that there is a considerable variation in the results from one grid point to another; although positive volume changes are found, the standard deviations show that the diminishing of the volume is significant. The vertical lowering of the surface at the terminus (area below 250 m a.s.l.) is found to be approx. 1 m per year.

DISCUSSION

The changes of volume found by comparison of the two maps should be evaluated against other indications of what is happening to the glacier to strengthen the conclusions.

The change of volume at the terminus could be found by comparing surveys from different years since 1979. At 200 m a.s.l. the average lowering of the surface is approx. 1.4 m, varying between 0.5 and 2.0 m per year. 1986-87 the lowering is 1-2 m. The exact lowering from year to year is not known, because the surface is surveyed within circa 14 days of yearly minimum at the end of the summer season. The values found are, however, in good accordance with the average value (1972-81) mentioned above, indicating that the terminus is retreating in a rather uniform way.

The net-balance between ablation and accumulation measured at stakes once a year at the end of the summer shows a negative balance in all cases below 400 m a.s.l. Net ablation is found in some years up to 565 m, Hasholt (1986). Values from the stake network 1986-87, see table 1, show a net ablation of 2 m at 200 m a.s.l. and a net accumulation of 0.8 m at 500 m a.s.l., in good accordance with newer measurements showing a positive balance at this height. Measurements in pits situated 700-800 m a.s.l., carried out in 1986 indicate a yearly net accumulation of 1.3-2.0 m with a density of 0.5-0.6 t/m^3; measurements of dust content carried out by the Geophysic Isotope Laboratory show a spacing of 0.4-1 m between layers with larger dust content, indicating an order of magnitude of the minimum yearly accumulation. During a severe storm (piteraq) in 1986 the pits were covered with windblown snow, this indicates that the surface of the upper part of the glacier could change significantly due to wind

drifting of snow, this could possibly explain the large standard deviations of the volume changes found here.

The change of volume is a function of net accumulation, compression, and downward movement by the glacier in the upper part of the glacier and of net ablation and upward movement in the lower part. The yearly lowering of the surface above 500 m a.s.l. varies from 0.4 to 1.2 m in the period 1972-81, if the net accumulation rates from the recent pit investigations are used; the resulting downward movement caused by compression and glacier movement should be in the order of 1-3 m per year.

Triangulation of stakes at the terminus 1987, together with ablation measurements, shows a vertical movement of 0.5-1 m/year and a horizontal movement of 3-5 m/year. Measurements of stakes situated near the equilibrium line (500 m a.s.l.) show horizontal velocities of 23 m/year near the center of the glacier and 5 m/year near the margin.

A computation of the net balance for the overlap area, based on the field observations 1986-87 and the hypsographic curve shows a negative balance of -0.82 x 10^6 m^3, or 200 mm per year. These results stress the fact that the Mitdluagkat Glacier is complex, and more research is needed, especially in the higher parts and of the bottom topography before a final conclusion on the trend in the massbalance could be drawn.

CONCLUSION

A comparison between two maps based on aerial photos from 1972 and 1981 shows that there is a net loss of volume from an area of 6.72 km^2 on the Mitdluagkat Glacier. The distribution of the volume loss causes a change of the form so that areas above 600 m become more concave and areas below 400 m become steeper. The trend is a continuation of the retreat of the terminus that has been going on since 1933. The results are not contradicted by field observations carried out after 1981, although the field observations indicate that a net accumulation takes place in the upper part of the glacier which is not included in this study.

The results indicate that maps based on rather small scale aerial photos (1:150,000) taken at time intervals of 10-20 years could be a valuable tool in the determination of the massbalance of glaciers in Eastern Greenland, if there is established a triangulation network for testing in key areas.

ACKNOWLEDGMENTS

The Commission for Scientific Investigations in Greenland and the National Science Council are thanked for supporting the project. Geophysic Isotope Laboratory with Professor W. Dansgaard is thanked for advice and analysis of snow samples, and GGU for logistic support. My colleague O. Humlum is thanked for valuable discussion.

Summary

Studies of the Mitdluagkat Glacier have been carried out since 1933; this is the longest record of a retreating terminus from this part of Greenland. Until 1970 only the terminus was followed. In 1976 a map based on aerial photos from 1972 was drawn with a scale 1:5000 and 5 m contour intervals. In 1986 a new map, based on small scale (1:150,000) aerial photos from 1981, covering the whole glacier in scale 1:20,000 with 10 m contour intervals was drawn.

A comparison between the two maps shows that the glacier in the period 1972-81 has lost 5.8 m^3/m^2 as an average over an area of 6.7 km^2 (approx. 35 % of the glacier lobe), or0.64 m per year, the corresponding loss of waterequivalent will vary depending on the density of snow and ice, approx. 0.3-0.6 m per year. The loss of volume is very uneven distributed indicating a flattening of the area above approx. the 500 m level and steepening below. The retreat of the lower part of the glacier is confirmed by manual observations from 1979 to 1987. Measurement at stakes 1986-87 indicates a positive net-balance above approx. 400 m a.s.l. Measurements of stake movements indicate that the accumulation could be compensated by the downward ice movement.

While the development in the lower part of the glacier is well documented, more triangulation in the upper part is needed to give a definite proof of the trend indicated by the comparison of the two maps.

References

Anda, E., Orheim, O. & Magnerud, J. (1985): Late Holocene glacier variations and climate of Jan Mayen. Polar Research 3:129-140.

Bertelsen, L. og Kleist, P. (1987): Energibalancen på Mitdluagkat, en østgrønlandsk gletscher. (Unpubl., internal report).

Björnsson, H. (1979): Glaciers in Iceland. Jökull, 29:74-80.

Fristrup, B. (1960): Studies of Four Glaciers in Greenland. Geografisk Tidsskrift 59:89-102.

Fristrup, B. (1962): Dänische glaziologische Untersuchungen im Internationalen Geophysikalischen Jahr. Polarforschung, Band V, Heft 1/2:3-11.

Fristrup, B. (1970): Ny geografisk Station i Grønland. Geografisk Tidsskrift 69:192-204.

Gordon, J. E. (1981): Glacier margin fluctuations during the 19th and 20th centuries in the Ikamiut Kangerdluarssuat area, West Greenland. Arctic and Alpine Research 13(1):47-62.

Hasholt, B. (1986): Kortlægning af Mitdluagkat gletscheren og nogle hydro-glaciologiske observationer. Geografisk Tidsskrift 86:9-16.

Hasholt, B. (1987): A new map of the Mitdluagkat Glacier. A preliminary report. Geografisk Tidsskrift 87:19-21.

Knudsen, N. T. & Theakstone, W. H. (1981): Recent changes of the glacier Østerdalsisen, Svartisen, Norway. Geografiske Annaler, 63A(1-2): 23-30.

Liestøl, O. (1983): Glaciological work in 1983. Norsk Polarinstitutt Årbok 1983:35-45.

Valeur, H. (1959): Run-off Studies from the Mitdluagkat Gletscher in SE-Greenland during the Late Summer 1958. Geografisk Tidsskrift 58:54-65.

drifting of snow, this could possibly explain the large standard deviations of the volume changes found here.

The change of volume is a function of net accumulation, compression, and downward movement by the glacier in the upper part of the glacier and of net ablation and upward movement in the lower part. The yearly lowering of the surface above 500 m a.s.l. varies from 0.4 to 1.2 m in the period 1972-81, if the net accumulation rates from the recent pit investigations are used; the resulting downward movement caused by compression and glacier movement should be in the order of 1-3 m per year.

Triangulation of stakes at the terminus 1987, together with ablation measurements, shows a vertical movement of 0.5-1 m/year and a horizontal movement of 3-5 m/year. Measurements of stakes situated near the equilibrium line (500 m a.s.l.) show horizontal velocities of 23 m/year near the center of the glacier and 5 m/year near the margin.

A computation of the net balance for the overlap area, based on the field observations 1986-87 and the hypsographic curve shows a negative balance of -0.82 x 10^6 m^3, or 200 mm per year. These results stress the fact that the Mitdluagkat Glacier is complex, and more research is needed, especially in the higher parts and of the bottom topography before a final conclusion on the trend in the massbalance could be drawn.

CONCLUSION

A comparison between two maps based on aerial photos from 1972 and 1981 shows that there is a net loss of volume from an area of 6.72 km^2 on the Mitdluagkat Glacier. The distribution of the volume loss causes a change of the form so that areas above 600 m become more concave and areas below 400 m become steeper. The trend is a continuation of the retreat of the terminus that has been going on since 1933. The results are not contradicted by field observations carried out after 1981, although the field observations indicate that a net accumulation takes place in the upper part of the glacier which is not included in this study.

The results indicate that maps based on rather small scale aerial photos (1:150,000) taken at time intervals of 10-20 years could be a valuable tool in the determination of the massbalance of glaciers in Eastern Greenland, if there is established a triangulation network for testing in key areas.

ACKNOWLEDGMENTS

The Commission for Scientific Investigations in Greenland and the National Science Council are thanked for supporting the project. Geophysic Isotope Laboratory with Professor W. Dansgaard is thanked for advice and analysis of snow samples, and GGU for logistic support. My colleague O. Humlum is thanked for valuable discussion.

Summary

Studies of the Mitdluagkat Glacier have been carried out since 1933; this is the longest record of a retreating terminus from this part of Greenland. Until 1970 only the terminus was followed. In 1976 a map based on aerial photos from 1972 was drawn with a scale 1:5000 and 5 m contour intervals. In 1986 a new map, based on small scale (1:150,000) aerial photos from 1981, covering the whole glacier in scale 1:20,000 with 10 m contour intervals was drawn.

A comparison between the two maps shows that the glacier in the period 1972-81 has lost 5.8 m^3/m^2 as an average over an area of 6.7 km^2 (approx. 35 % of the glacier lobe), or0.64 m per year, the corresponding loss of waterequivalent will vary depending on the density of snow and ice, approx. 0.3-0.6 m per year. The loss of volume is very uneven distributed indicating a flattening of the area above approx. the 500 m level and steepening below. The retreat of the lower part of the glacier is confirmed by manual observations from 1979 to 1987. Measurement at stakes 1986-87 indicates a positive net-balance above approx. 400 m a.s.l. Measurements of stake movements indicate that the accumulation could be compensated by the downward ice movement.

While the development in the lower part of the glacier is well documented, more triangulation in the upper part is needed to give a definite proof of the trend indicated by the comparison of the two maps.

References

Anda, E., Orheim, O. & Magnerud, J. (1985): Late Holocene glacier variations and climate of Jan Mayen. Polar Research 3:129-140.

Bertelsen, L. og Kleist, P. (1987): Energibalancen på Mitdluagkat, en østgrønlandsk gletscher. (Unpubl., internal report).

Björnsson, H. (1979): Glaciers in Iceland. Jökull, 29:74-80.

Fristrup, B. (1960): Studies of Four Glaciers in Greenland. Geografisk Tidsskrift 59:89-102.

Fristrup, B. (1962): Dänische glaziologische Untersuchungen im Internationalen Geophysikalischen Jahr. Polarforschung, Band V, Heft 1/2:3-11.

Fristrup, B. (1970): Ny geografisk Station i Grønland. Geografisk Tidsskrift 69:192-204.

Gordon, J. E. (1981): Glacier margin fluctuations during the 19th and 20th centuries in the Ikamiut Kangerdluarssuat area, West Greenland. Arctic and Alpine Research 13(1):47-62.

Hasholt, B. (1986): Kortlægning af Mitdluagkat gletscheren og nogle hydro-glaciologiske observationer. Geografisk Tidsskrift 86:9-16.

Hasholt, B. (1987): A new map of the Mitdluagkat Glacier. A preliminary report. Geografisk Tidsskrift 87:19-21.

Knudsen, N. T. & Theakstone, W. H. (1981): Recent changes of the glacier Østerdalsisen, Svartisen, Norway. Geografiske Annaler, 63A(1-2): 23-30.

Liestøl, O. (1983): Glaciological work in 1983. Norsk Polarinstitutt Årbok 1983:35-45.

Valeur, H. (1959): Run-off Studies from the Mitdluagkat Gletscher in SE-Greenland during the Late Summer 1958. Geografisk Tidsskrift 58:54-65.