MEDDELELSER OM GRØNLAND
UDGIVNE AF
KOMMISSIONEN FOR VIDENSKABELIGE UNDERSØGELSER I GRØNLAND
Bd. **194** · Nr. **6**

MICROTHERMIC OBSERVATIONS IN ARCTIC VEGETATION

BY

KJELD HANSEN

WITH 14 FIGURES AND 12 TABLES IN THE TEXT

KØBENHAVN
C. A. REITZELS FORLAG
BIANCO LUNOS BOGTRYKKERI A/S
1973

Abstract

In July–August 1965 concurrent microthermic measurements were made at 4 stations in the low-arctic South Greenland (3 in the lowland and 1 in the mountains 610 m a.s.l.) on several biotopes varying in altitude a.s.l., exposure, and vegetation; a transportable thermistor and several stationary thermometers were used in the process.

Measurements of daily maxima and minima on the surface of the ground show a close correlation with macroclimatic conditions, exposure, and type of vegetation. In various southward-facing types of scrubs in the lowland maxima up to 52°–57° C were measured in clear weather. Under overcast, possibly rainy conditions the maxima are much lower, especially on northward-facing biotopes (most frequently 20°–25°).

Observations of microthermic gradients above ground and below ground (from – 10 cm to + 200 cm) show, however, that these extreme maxima mainly occur in the lower layers of the vegetation (5–10 cm), where the vertical difference can be very high (10°–20° C).

Evidently, under favourable macroclimatic conditions approximately the same microthermic conditions can prevail in the mountain (610 m a.s.l.) as in the lowland (maximum up to 48° C), whereas when the weather is unfavourable the temperature in the mountain is distinctly lower (8° C).

ISBN 87 421 0086 0

CONTENTS

INTRODUCTION

In Arctic regions the temperature is often considered the most significant factor affecting the plant growth, and therefore also determining where the individual species are capable of occurring (WARREN WILSON, 1957). The distribution of the species, and especially their occurrence within a limited area are not, however, solely dependent on the macroclimatic factors; but in particular, as far as the frequently low Arctic plants, including the often dominant mosses and lichens, are concerned, the microthermic conditions also determine the species' occurrence in the terrain. There are some earlier observations of microthermic conditions in Arctic vegetation (see e.g. BIEBL, 1968; BILLINGS & BLISS, 1959; BLISS, 1956, 1962; HANSEN & HAGEMANN, 1967; SØRENSEN, 1941; WARREN WILSON, 1957, 1959).

The investigation under report has had as its purpose an endeavour to answer the following questions:

1. The dependence of the microthermic conditions on macroclimatic factors, partly with respect to daily maxima and minima on the surface of the ground, partly with respect to vertical gradients above the surface and underground.
2. Differences between microthermic conditions in the lowland and in the mountain.
3. The influence of exposure on the microthermic conditions.
4. The microthermic differences between different plant communities.

I have tried to answer the above-mentioned questions by making concurrent observations on many biotopes that vary as much as possible with respect to altitude a.s.l., exposure, and vegetation, as well as by conducting these concurrent observations in twenty-four hour periods having as different macroclimates as possible.

KJELD HANSEN
Botanical Institute
The Royal Veterinary and Agricultural University
Copenhagen

Acknowledgements

The present paper is one of the results of the work carried out in the summer of 1965 by the Greenland Botanical Survey, the University of Copenhagen. The author wishes to express his gratitude to Professor THORV. SØRENSEN, the head of this institution, for inviting me to take part in this work.

During the field work the Geological Survey of Greenland contributed valuable help by providing transportation; for this I am most thankful to K. ELLITSGAARD-RASMUSSEN, the director of this institution.

The collection of mosses from vegetation analyses was kindly identified by K. HOLMEN.

The manuscript was translated from the Danish by Mrs. KARIN FENNOW.

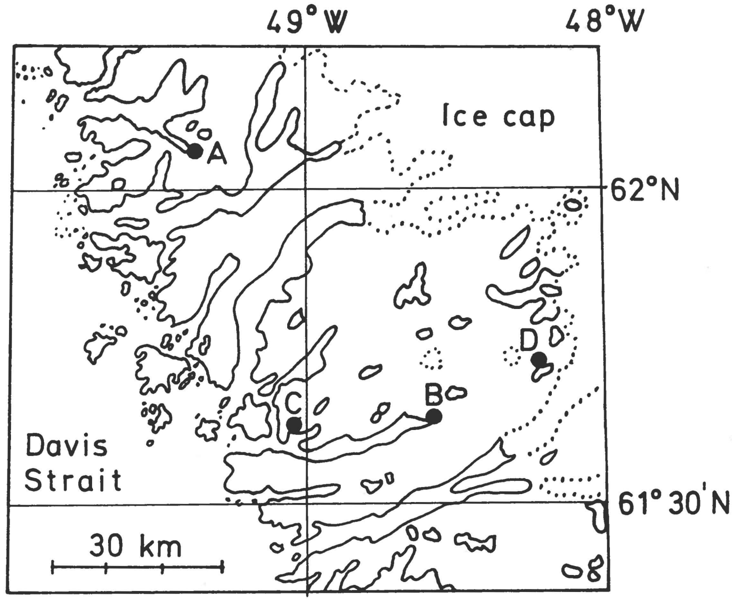

Fig. 1. Location of the 4 stations (A, B, C, D) with microthermic observations, cf. also Table 1.

LOCATION OF THE INVESTIGATED STATIONS

Observations were made at 4 stations, all located in the southernmost part of the westcoast of Greenland (Fig. 1, p. 7 and Table 1, p. 7). At stations A, B, and C the observations were made on biotopes in valleys at the bottom of the fjords, i.e. close to sea level (5–25 m a.s.l.). Station D was selected far from the outer coast and close to the inland ice at 610 m a.s.l.

Table 1. *The 4 stations where microthermic observations took place, cf. also Fig. 1.*

Station	Lat. N.	Long. W.	Altitude of observ., m a.s.l.	Period of observations
A. Nigerdleq	62°04′	49°20′	20– 25	6.–12. 7. 1965
B. Neria	61°38′	48°34′	5– 10	16.–19. 7. 1965
C. Tasiussakasik .	61°38′	49°00′	5– 10	1.– 4. 8. 1965
D. 610 m lake . . .	61°43′	48°08′	615–625	21.–24. 7. 1965

Macroclimatic conditions in the area

There is no information available concerning macroclimatic observations at the 4 investigated stations. The nearest comparable stations are Narssarssuaq, Narssaq, Grønnedal, and Simiutaq, all of which are close to sea level, cf. Table 2 (p. 8), which indicates that temperature and precipitation depend on distance from the outer coast.

Table 2. *Macroclimatic conditions at 4 meteorological stations in South Greenland located at various distances from the outer coast (according to* BLINKENBERG, *1952). Warmest month: July or August. Coldest month: January or February.*

Meteorological station	Lat. N.	Long. W.	Distance from outer coast line	Temperature, °C			Annual temp. ampl., °C	Annual precip., cm	Period of observ.
				Year	Warmest month	Coldest month			
Narssarssuaq . .	61°11′	45°25′	70 km	1.8	10.4	− 6.3	16.7	69.6	1941–48
Narssaq.	60°54′	46°00′	35 km	1.0	7.9	− 4.4	12.3	71.2	1944–48
Grønnedal.	61°13′	48°07′	25 km	0.9	8.3	− 5.9	14.2	113.2	1943–48
Simiutaq	60°41′	46°33′	0 km	0.2	6.2	− 5.4	11.6	77.9	1942–48

The location of the investigated stations (Fig. 1, p. 7) is such that Station B is situated farthest from the outer coast and can therefore best be compared with the meteorological station Narssarssuaq. Station A is most comparable to Narssaq and Grønnedal, and Station C, closest to the sea, with Simiutaq. No meteorological observations are available from stations at altitudes comparable to Station D.

Accordingly, it can be assumed that at station B the mean temperature for the warmest month (July or August) is ca. 10° C, and at stations A and C ca. 7°–9° C. The microthermic observations took place in the warmest periods (July or early August). The annual precipitation at the investigated stations is more uncertain, but probably amounts to 70–110 cm, depending on the distance from the outer coast and the local orographic conditions.

Instrumentation and methods

The microthermic observations were made partly with a transportable thermistor (Neo-Pyro, type C) for the measurement of the actual temperature, partly with a number of stationary liquid thermometers with a remote probe for measuring the maximum and minimum temperature every twenty-four hours.

Thermistor measurements of the actual temperature were made at that point in the twenty-four hour period which normally can be expected to have the highest air temperature (14 o'clock). These measurements were made at depth of 5 and 10 cm under the surface, in the surface of the ground (or in the midst of a possible moss-, lichen- or litter-layer), and at altitudes of 5, 20, and 200 cm above the surface. These thermistor measurements prevent the observations from being affected by solar radiation. An observed vertical gradient is therefore realistic.

During measurements of maximum and minimum temperatures the probe was permanently placed in the surface of the ground, concealed by mosses, lichens, or dead parts of plants; thus, the probe was not exposed to direct solar radiation.

In order to compare the dependence of the microthermic conditions on macroclimatic conditions, the following observations were made daily:

1. Cloudiness. Estimated on the basis of a scale ranging from 0 = clear to 10 = overcast.
2. Precipitation. Estimated on the basis of a scale ranging from 0 = no precipitation to 10 = constant precipitation.
3. Wind force. Estimated on the basis of the usual scale from 1–12.

At each of the 4 stations observations were made on biotopes chosen as different as possible with respect to exposure, location in the terrain, and type of vegetation. In addition, the observations took place on days having as varying a macroclimate as possible.

All temperatures are given in centigrades.

DAILY MAXIMUM AND MINIMUM TEMPERATURES

Station A. Nigerdleq

With respect to maxima, Fig. 5 shows that on totally overcast days with precipitation there is only a slight difference among the 3 biotopes, all of which have maxima between 16° and 19°. On clear days without precipitation (especially 8 and 9 July) there is a considerable difference among the biotopes, for A 1 (scrub including i. a. *Juniperus* and *Salix*

Table 3. *Station A (Nigerdleq). Characteristics of 3 biotopes (A 1, A 2, A 3) with observations of max. and min. temperatures (see Fig. 5, p. 13). Altitude: 20–25 m a.s.l.*

Biotope No. Expos., slope:	A 1 (Fig. 2) South, 20°	A 2 (Fig. 3) West, 10°	A 3 (Fig. 4) South-West, 5°
Situation in terrain:	Half-way up 5 m high dry, sandy slope	Bottom of narrow valley; tussocky terrain with pools and brook.	In the middle of large, flat, alluvial terrace
Vegetation type:	Scrub, 0.5 m high	Bog, 0.2 m high	Lichen heath, 0.1 m high
Degree of cover, 1 m²:	4: *Juniperus comm. alp.* 4: *Salix glauca call.* 3: *Deschampsia flex.* 1: *Empetrum hermaphr.* 1: *Carex bigelowii* 1: *Lycopodium dubium* 1: *Rumex acetosa* 1: *Peltigera aphthosa* 1: *Pleurozium schreb.* 1: *Brachythec. reflex.*	4: *Vaccinium uligin.* 4: *Empetrum hermaphr.* 4: *Salix arctophila* 3: *Carex bigelowii* 1: *Ledum groenland.* 1: *Pleurozium schr.* 1: *Dicranum scopar.* 1: *Drepanocladus unc.* 1: *Calliergon stram.* 1: *Polytrichum com.* 1: *Sphagnum rob.* 1: *Spagnum theres*	4: *Cladonia rangifer.* 3: *Cladonia alpestris* 3: *Betula glandulosa* 2: *Cladonia mitis* 1: *Stereocaulon pasc.* 1: *Cetraria nivalis* 1: *Carex bigelowii*
Placement of probe:	Hidden in moss-layer among *Deschampsia flex.*	Hidden in moss-layer beneath *Vaccinium*	Hidden at 5 cm depth in the lichen-mat

Fig. 2. Biotope A 1, cf. Table 3 (p. 10). Close-up of placement of probe (at the base of the pole, concealed in layers of moss among *Deschampsia flexuosa*).

Fig. 3. Biotope A 2, cf. Table 3 (p. 20). Probe placed at the base of the pole (10 cm intervals) concealed under *Vaccinium uliginosum*.

Fig. 4. Biotope A 3, cf. Table 3 (p. 10). Close-up of placement of proble (concealed at the base of the pole among *Cladonia alpestris*). Intervals on the pole: 10 cm.

glauca on a southward-facing slope) shows the highest maxima (55°–57°), whereas A 2 (westward-facing bog including i. a. *Vaccinium uliginosum*, *Empetrum hermaphroditum* and *Salix arctophila*) shows the lowest maxima (31°–32°). Biotope A 3 (an almost horizontal lichen heath) shows intermediary maxima (39°–45°). On slightly cloudy days, but with no precipitation, the maxima are somewhat lower on all 3 biotopes, but the mutual proportions are approximately the same (55°, 25°, and 37°–39°, respectively).

As far as minima are concerned, Fig. 5 indicates that all 3 biotopes have the highest minimum (4°–9°) during nights following totally overcast days, and the lowest minimum (1°–6°) during nights following clear or only slightly cloudy days.

It was observed that in periods with clear weather and no precipitation the 24-hour temperature amplitude was very high, yet the amplitude nevertheless is different on the 3 biotopes (A 1: 52°; A 2: 26°; A 3: 43°). On the other hand, the amplitude is very small and almost the same in periods with total cloudiness and precipitation (A 1: 10°; A 2: 8°; A 3: 11°).

A comparison of the 3 biotopes shows that Biotope A 1 has relatively highest maxima on all days, and Biotope A 2 relatively lowest maxima

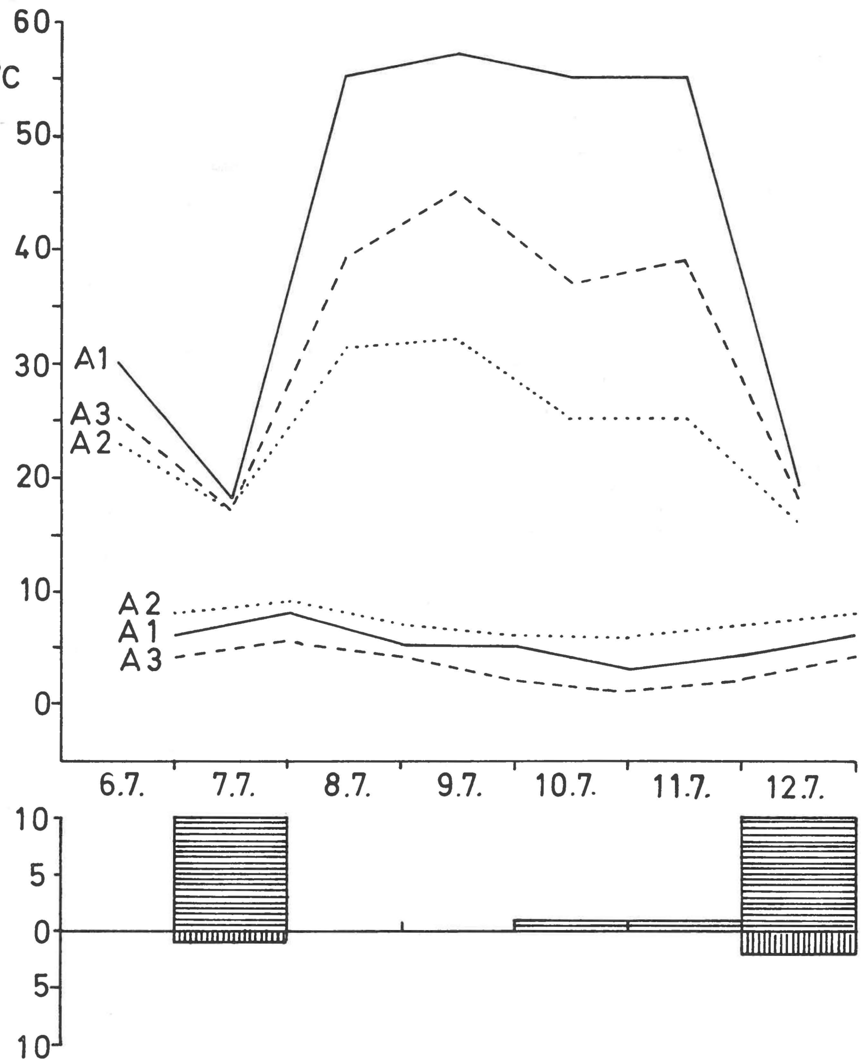

Fig. 5. Station A (Nigerdleq). Observations of maximum temperatures (3 uppermost curves) and minimum temperatures (3 lowest curves) on biotopes A 1, A 2, A 3 (cf. Table 3, p. 10) every 24-hours from 6 July–12 July. Below, indication of cloudiness (horizontally hatched) and precipitation (vertically hatched), cf. p. 9.

throughout the period. Biotope A 3 has a constantly intermediary maximum. With respect to minimum, Biotope A 2 shows the highest minima and A 3 the lowest minima throughout the period. Biotope A 1 has intermediary values during the entire period.

As will be seen, at Station A, which is located midway between the outer coast and the inland ice, on clear days quite high temperatures (45°–57°) can be reached on the 2 warmest biotopes, measured in the bottom layer of the vegetation.

Table 4. *Station B (Neria). Characteristics of 3 biotopes (B 1, B 2, B 3) with observations of max. and min. temperatures (see Fig. 6, p. 15). Altitude: 5–10 m a.s.l.*

Biotope No. Expos., slope	B 1 South, 20°	B 2 South, 50°	B 3 North, 30°
Situation in terrain:	At the top of 3 m high slope, bordering on small valley	On narrow, dry ledge in the middle of steep talus slope	In the middle of 4 m high slope
Vegetation type:	Birch-scrub, 1 m high	Scrub, 0.5–1.0 m high	Dwarf-shrub heath 0.2 –0.3 m high
Degree of cover, 1 m²:	5: *Betula pubescens* 5: *Deschampsia flex.* 1: *Salix glauca call.* 1: *Poa glauca* 1: *Carex bigelowii* *Dicranum scoparium*	3: *Betula pubescens* 2: *Juniperus comm.* 1: *Woodsia ilvensis* 1: *Poa glauca* 1: *Campanula gies.* 1: *Cerastium alpin.* 1: *Peltigera malacea* 1: *Cladonia rangifer.* 1: *Cladonia uncialis* 1: *Cladonia mitis* 1: *Umbilicaria cylind.*	5: *Empetrum herm.* 3: *Lycopodium dubium* 2: *Salix glauca call.* 1: *Betula glandulosa* 1: *Deschampsia flex.* 1: *Carex bigelowii* 1: *Nephroma arcticum* 1: *Stereocaulon alpin.*
Placement of probe:	Hidden at bottom, among *Deschampsia*	Beneath *Poa glauca* and *Peltigera*	Beneath *Empetrum* and *Nephroma*

Station B. Neria

With respect to maxima, Fig. 6 shows that all 3 biotopes have the highest daily maxima on only slightly cloudy days with no precipitation (22°–52°) and a considerably lower maxima on totally overcast days with precipitation (15°–31°). During the entire period the highest daily maxima were measured on biotopes B 1 (southward-facing scrub of *Betula pubescens*; 31°–52° C) and B 2 (southward-facing low scrub of *Betula pubescens* and *Juniperus communis*; 23°–43° C). Biotope B 3 (northward-facing dwarf-shrub heath with *Empetrum hermaphroditum*) shows considerably lower maxima during the whole period (15°–22°); furthermore, B 3 is less affected by the macroclimatic conditions.

As far as minima are concerned, there is only a slight difference among the 3 biotopes, and there are but small changes in the course of the measuring period. Fig. 6 shows, however, that throughout the period Biotope B 2 had the highest minima in the 24-hours (8°–11°), B 3 the lowest minima (2°–5°) and B 1 intermediary minima (5°–8°). Accordingly, Biotope B 3 shows the lowest temperatures with respect to both maximum and minimum.

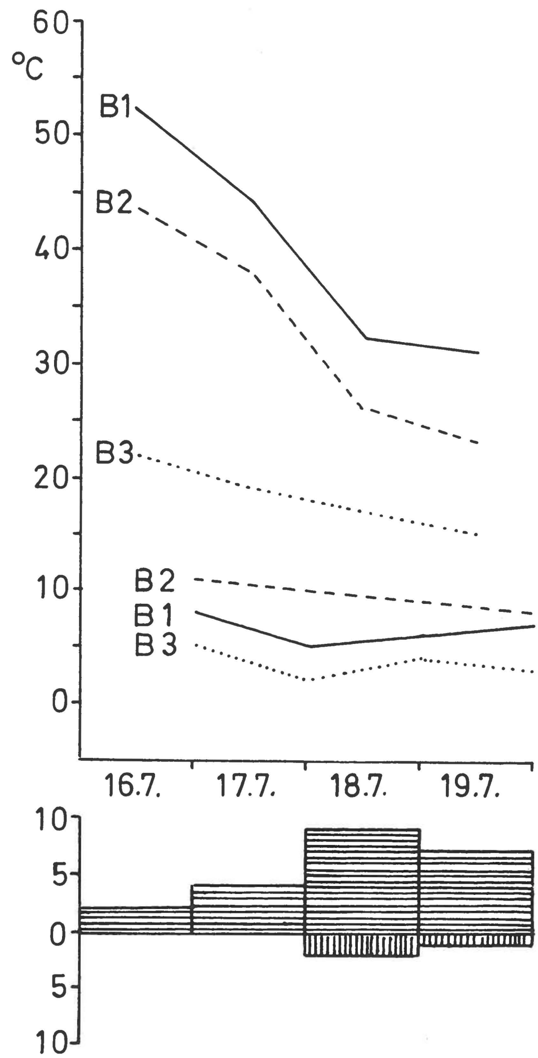

Fig. 6. Station B (Neria). Observations of maximum temperatures (3 uppermost curves) and minimum temperatures (3 lowest curves) on biotopes B 1, B 2, B 3 (cf. Table 4, p. 14) every 24-hours from 16 July–19 July. Below, indication of cloudiness (horizontally hatched) and precipitation (vertically hatched), cf. p. 9.

The 24-hour temperature amplitude was greatest in the least cloudy period (B 1: 46°; B 2: 32°; B 3: 17°). In the almost totally overcast period with precipitation the 24-hour temperature amplitude is most frequently lesser (24°, 15°, and 12°, respectively). The amplitude is always greatest for B 1, lesser for B 2, and least for B 3.

It is evident that on almost clear days the temperature at Station B, which is located relatively close to the inland ice, can almost become just as high on the 2 warmest biotopes (43°–52°) as at Station A in clear weather (55°–57°).

Station C. Tasiussakasik

In regard to maxima, Fig. 10 shows that biotopes C 1 (southward-facing, low scrub of *Juniperus communis* and *Betula glandulosa*) and C 3 (horizontal dwarf-shrub heath and lichen heath) have the highest maxima on days that are almost clear (44° and 34°, respectively), whereas on nearly totally overcast days with some precipitation the maximum is lowest on these 2 biotopes (30° and 25°, respectively). On the other hand, Biotope C 2 (northward-facing dwarf-shrub heath) has maxima that appear to be more independent on the macroclimatic variation (17°–21°). Fig. 10 shows that Biotope C 1 has the greatest maxima and C 2 the lowest maxima during the entire period, but with a decreasing mutual difference when cloudiness increases. Biotope C 3 has intermediary maxima throughout the period.

As far as minima are concerned, there is but slight variation among the 3 biotopes, since all of them have the lowest minima in 24-hour

Table 5. *Station C (Tasiussakasik). Characteristics of 3 biotopes (C 1, C 2, C 3) with observations of max. and min. temperatures (see Fig. 10, p. 19). Altitude: 5–10 m a.s.l.*

Biotope No. Expos., slope:	C 1 (Fig. 7) South, 45°	C 2 (Fig. 8) North, 45°	C 3 (Fig. 9) 0°
Situation in terrain:	Beneath top of 5 m high slope	Upper part of 2 m high slope near brook	In the middle of large, flat alluvial terrace
Vegetation type:	Scrub, 0.3–0.5 m	Dwarf-shrub heath, 0.1 –0.2 m high	Dwarf-shrub and lichen heath, 0.2 m high
Degree of cover, 1 m²:	5: *Juniperus comm. alp.* 3: *Betula glandulosa* 2: *Empetrum hermaphr.* 1: *Vaccinium uligin.* 1: *Campanula gieseck.* 1: *Deschampsia flex.* 1: *Salix glauca call.* 1: *Peltigera malacea* 1: *Cladonia rangifer.* 1: *Stereocaulon pasch.* *Dicranum scoparium*	5: *Empetrum hermaphr.* 2: *Betula glandulosa* 1: *Vaccinium uligin.* 1: *Salix glauca call.* 2: *Peltigera canina* 2: *Peltigera aphth.* 1: *Cetraria island.* 1: *Stereocaulon pas.* *Drepanocl. uncinat.* *Hylocomium splend.* *Dicranum fuscesc.* *Barbiloph. lycop.*	4: *Betula glandulosa* 3: *Cladonia rangifer.* 2: *Empetrum hermaphr* 1: *Deschampsia flex.* 1: *Cetraria islandica* 1: *Cladonia deformis* 1: *Cladonia bellidif.* 1: *Cladonia cornuta* 1: *Cladonia cyanipes* 1: *Cladonia pleurota* 1: *Cladonia chloroph.*
Placement of probe:	Hidden beneath *Peltigera malacea*	Hidden beneath *Peltigera* ssp.	Hidden beside *Cladonia cornuta*

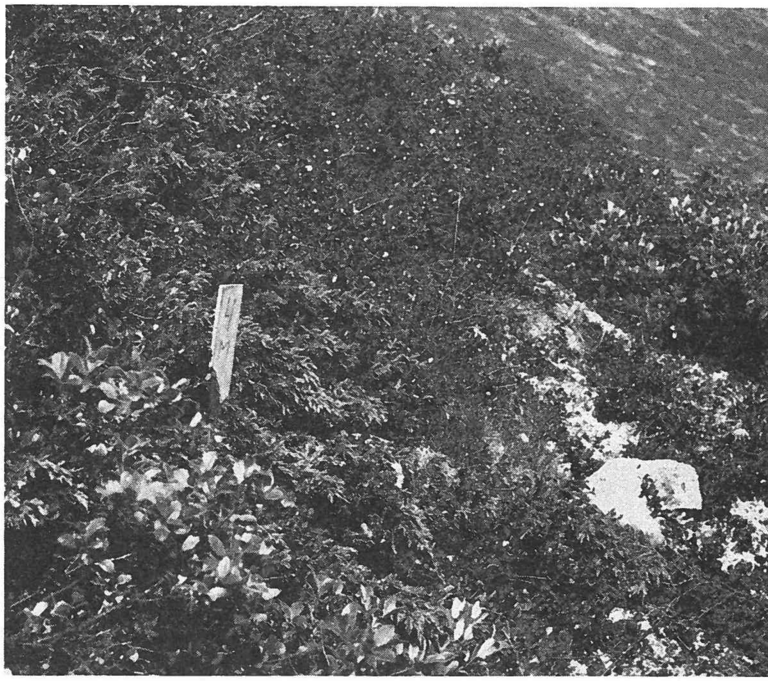

Fig. 7. Biotope C 1, Table 5 (p. 16). Probe placed at base of the pole, among *Juniperus*, concealed under *Peltigera malacea* (visible part of pole: 30 cm).

Fig. 8. Biotope C 2, cf. Table 5 (p. 16). Close-up of placement of probe, concealed at base of the pole (20 cm), under *Peltigera* spp.

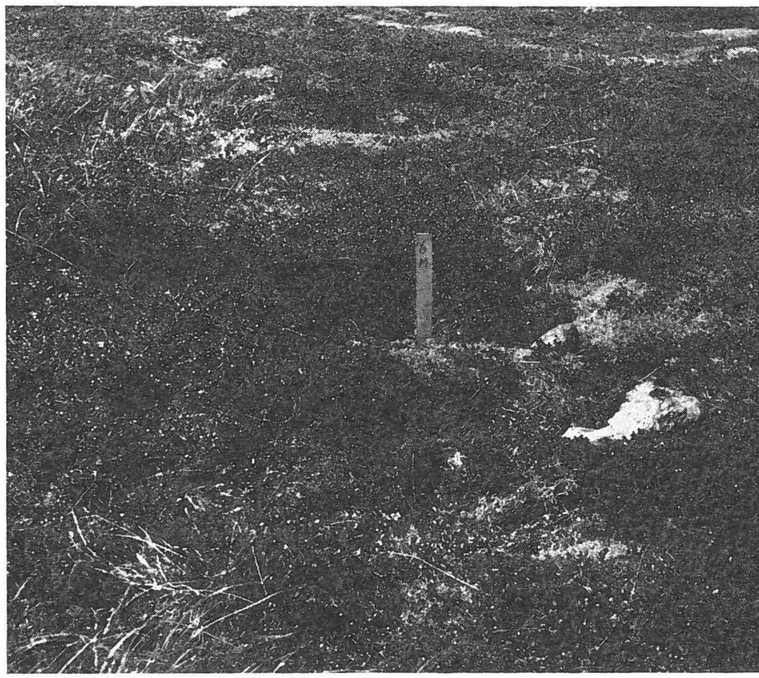

Fig. 9. Biotope C 3, cf. Table 5 (p. 16). Probe placed at the base of the pole (30 cm), hidden under lichens.

periods when cloudiness is least (– 1°–0°), and the highest minima following an extensively overcast day (9°–10°).

The 24-hour temperature amplitude evidently is greatest for Biotope C 1, especially given little cloudiness (44°), and least for Biotope C 2, in particular given extensive cloudiness (12°).

A comparison with Station B shows that on biotopes which resemble one another and on comparable days (with little cloudiness) on Station C close to the outer coast lower microthermic maxima (44°) were measured than at Station B, which is located at a distance from the outer coast (52°).

Station D. 610 m lake

With respect to maxima, Fig. 14 shows that Biotope D 2 (southward-facing dwarf-shrub heath and lichen heath) is very dependent on the macroclimatic conditions, as there are very high maxima on clear days (43°–48°), somewhat lower (39°) on partly overcast days, and a very low maximum on totally overcast days and much precipitation (8°). At Biotope D 1 (northward-facing snow-patch) the daily maxima are also dis-

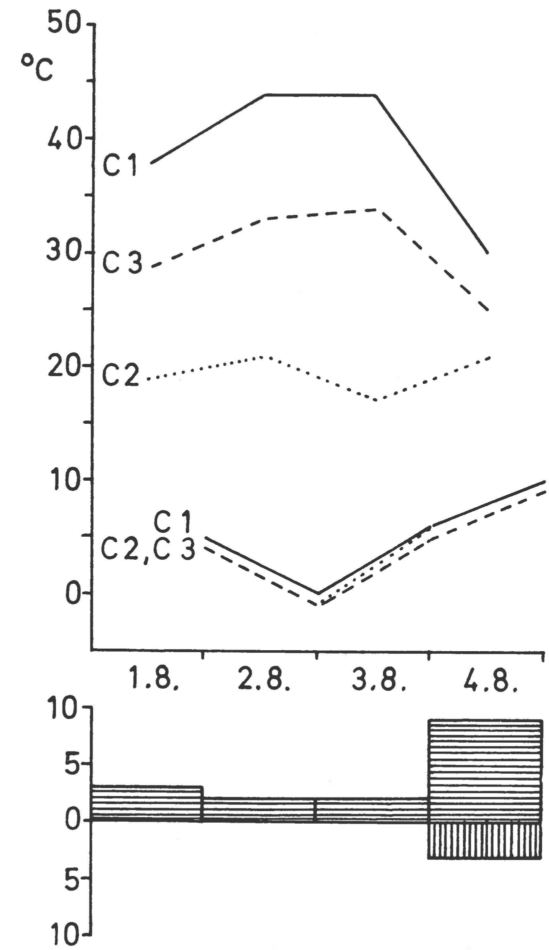

Fig. 10. Station C (Tasiussakasik). Observations of maximum temperatures (3 uppermost curves) and minimum temperatures (3 lowest curves) on biotopes C 1, C 2, C 3 (cf. Table 5, p. 16) every 24-hours from 1 August–4 August. Below, indication of cloudiness (horizontally hatched) and precipitation (vertically hatched), cf. p. 9.

tinctly highest on clear days (30°–37°). Biotope D 3 (horizontal fell-field) shows relatively lower maxima (24°–27°) on clear days.

As for minima, Fig. 14 does not show any distinct difference among the 3 biotopes throughout the period (lowest minima 0°–1°; highest minima 8°–9°).

It was found that the 24-hour temperature amplitude was greatest for Biotope D 2, especially during the clear period (42°–45°), somewhat less for Biotope D 1, and least for Biotope D 3, in particular in an extensively overcast 24-hour period (21°).

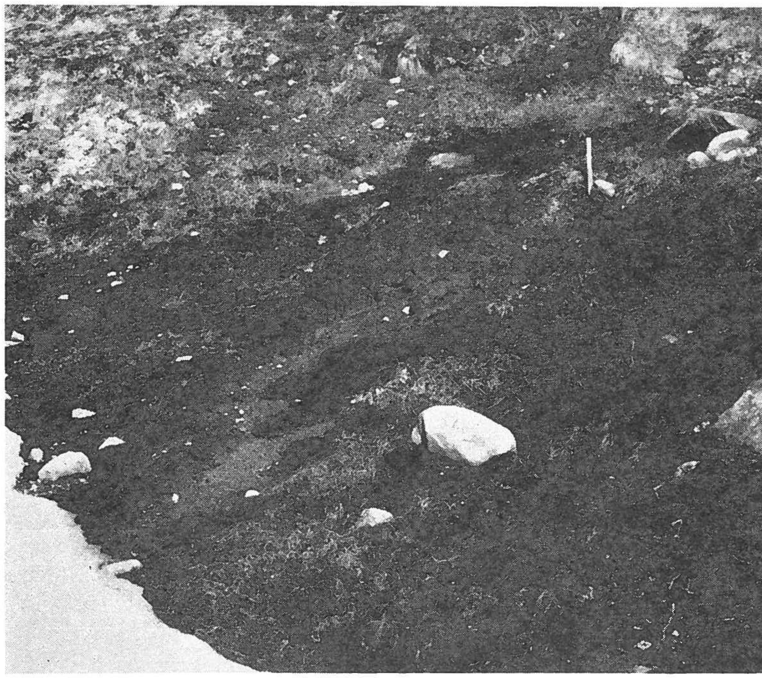

Fig. 11. Biotope D 1, cf. Table 6 (p. 20). Probe placed at the base of the pole (20, cm) in the uppermost right corner, concealed by *Salix herbacea*. Lowest, on the left, snow.

Table 6. *Station D (610 m lake). Characteristics of 3 biotopes (D 1, D 2, D 3) with observations of max. and min. temperatures (see Fig. 14, p. 22). Altitude: 615–625 m a.s.l.*

Biotope No. Expos., slope:	D 1 (Fig. 11) North, 30°	D 2 (Fig. 12) South, 10°	D 3 (Fig. 13) 0°
Situation in terrain:	On a slope, 2 m above depression with permanent snow	In the middle of large, flat area	In the middle of protruding, stony, gravelly area
Vegetation type:	Snow-patch, 1–3 cm high	Dwarf-shrub and lichen heath, 10–20 cm high	Fell-field, 5 cm high
Degree of cover, 1 m²:	5: *Salix herbacea* 2: *Harrimanella hypn.* 2: *Carex bigelowii* 2: *Solorina crocea* 1: *Cladonia ecmocyna* 1: *Cladonia bellidif.* *Conostomum tetr.* *Polytrichum pilif.* *Polytrichum norveg.* *Pohlia* sp.	4: *Stereocaulon pasch.* 2: *Betula glandulosa* 2: *Cladonia mitis* 2: *Carex arctogena* 2: *Juncus trifidus* 1: *Potentilla trident.* 1: *Viscaria alpina* 1: *Cladonia rangifer.* 1: *Cladonia grac. chord.* 1: *Cladonia amaurocr.* 1: *Cetraria nivalis* *Polytrichum strict.* *Ptilidium ciliare*	2: *Loiseleuria proc.* 1: *Salix uva-ursi* 1: *Diapensia lapp.* 1: *Luzula spicata* 1: *Agrostis borealis* 1: *Juncus trifidus* 1: *Cetraria nivalis* 1: *Cetraria nigric.* 1: *Alectoria ochrol.* 1: *Alectoria nigric.* 1: *Thamnolia subul.* 1: *Stereocaulon ves.* *Gymnomitr. concin.*
Placement of probe:	Hidden beneath *Salix herbacea*	Hidden in the lichen mat (*Cladonia*)	Beneath *Salix u.-u.* and *Loiseleuria*

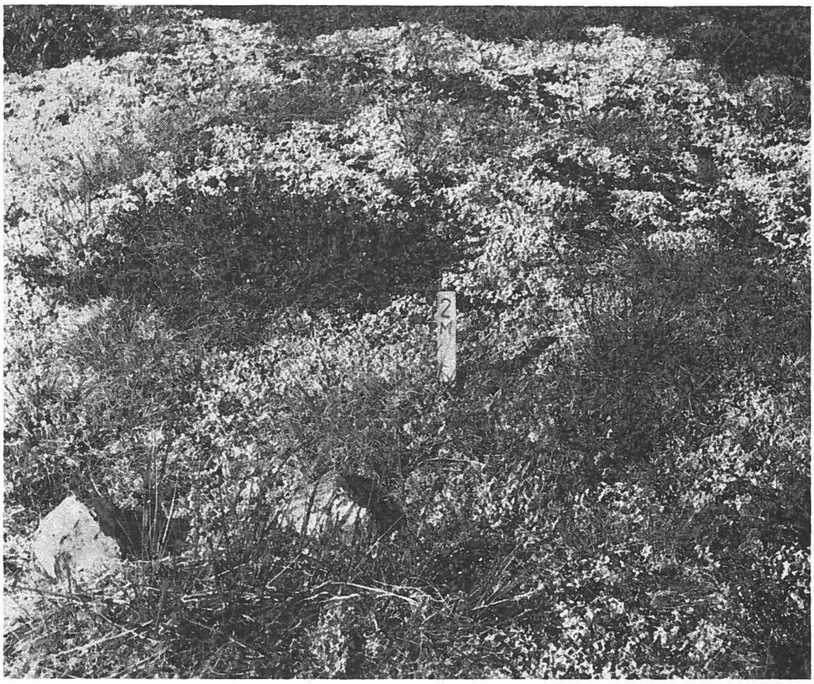

Fig. 12. Biotope D 2, cf. Table 6 (p. 20), Probe placed at the base of the pole (20 cm), concealed by lichens.

Fig. 13. Biotope D 3, cf. Table 6 (p. 20). Probe placed at the base of the pole (30 cm) ca in the middle of the photograph, concealed by *Salix uva-ursi* and *Loiseleuria procumbens*.

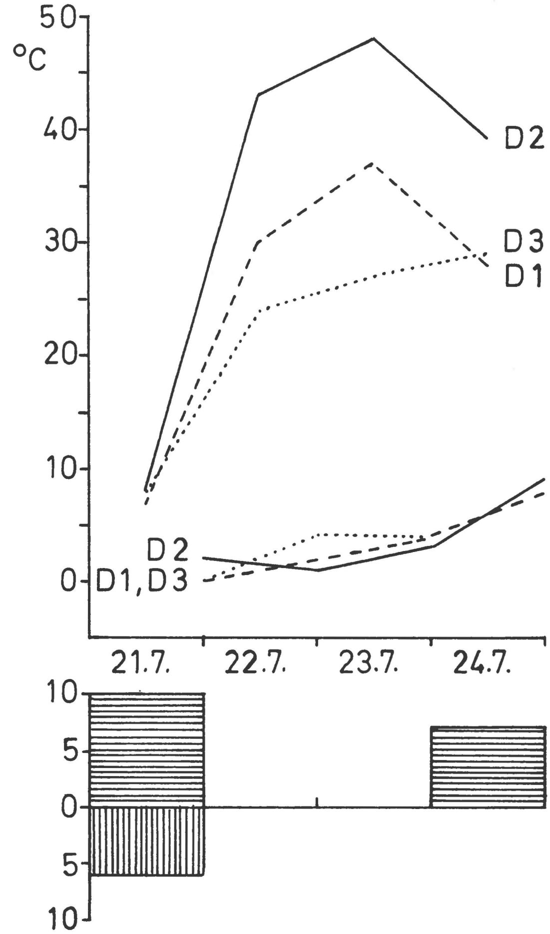

Fig. 14. Station D (610 m lake). Observations of maximum temperatures (3 uppermost curves) and minimum temperatures (3 lowest curves) on biotopes D 1, D 2, D 3 (cf. Table 6, p. 20) every 24-hours from 21 July–24 July. Below, indication of cloudiness (horizontally hatched) and precipitation (vertically hatched), cf. p. 9.

It has thus become apparent that at a station located 610 m a. s. l., when the sky is completely overcast and there is much precipitation (rain), there are low maxima on all 3 biotopes (7°–8°), whereas on clear days the maxima can become quite high, especially on a southward-facing biotope (43°–48°). Even on a biotope 2 meters distant from permanent snow (D 1) considerably high microthermic maxima (30°–37°) can be reached on clear days.

VERTICAL MICROTHERMIC GRADIENTS

Station A. Nigerdleq

Table 8 shows that on the two first-mentioned days, clear (9 July), and with very slight cloudiness but no precipitation (11 July), respectively, there is a very distinct gradient on the southward-facing Biotope A 4 (low scrub with, i. a. *Salix glauca* and *Betula glandulosa*) with temperatures amounting, respectively, to 19° and 12° at a height of 200 cm, 38° and 31° at 0 cm, and 12° and 8° at – 10 cm. It can be seen that the difference between 0 cm and 200 cm is 19° on both days, and that the difference between 0 cm and – 10 cm is between 26° and 23°. It can furthermore be seen that the largest decline in temperature above ground on both days takes place in the lowest layers of the vegetation (lowest 5 cm: decline of 9°; lowest 20 cm: decline of 14°–15°). The largest underground declines also occur in the upper 5 cm (declines 21° and 14°, respectively).

On the same two days (9 and 11 July) there are but slight gradients above the ground on the two northward-facing biotopes A 5 (low scrub with i. a. *Salix glauca* and *Betula glandulosa*) and A 6 (snow-patch with i. a. *Salix herbacea* and *Harrimanella hypnoides*), for the difference between 0 cm and 200 cm is only from 1° to 5°. The underground gradient is somewhat steeper, as there is a difference between 0 cm and – 10 cm of 6°–10°.

On the third day when measurements were made (totally overcast with a little precipitation; 12 July) approximately the same slight gradient was observed on all 3 biotopes, both above ground (0 cm–200 cm: 2°–3°) and below ground (0 cm–10 cm: 2°–5°).

The measurements of the temperature in the ground have shown that macroclimatic conditions (cloudiness) affect the temperature of the soil to at least a depth of 10 cm. Under clear conditions 12°, 9°, and 13°, were measured, respectively, at this depth on the three biotopes A 4, A 5, and A 6, whereas given total cloudiness the temperatures are lower (8°, 9°, and 11°, respectively).

Table 7. *Station A (Nigerdleq). Characteristics of 3 biotopes (A 4, A 5, A 6) with observations of vertical microthermic gradient (see Table 8, p. 24). Altitude: 20–25 m a.s.l.*

Biotope No.	A 4	A 5	A 6
Expos., slope	South, 20°	North, 30°	North, 30°
Situation in terrain:	South-facing side of tussock (1 m) in bottom of valley	North-facing side of same tussock as in biotope A 4	Lower part of steep slope, 4 m high
Vegetation type:	Scrub, 0.5 m high	Scrub, 0.5 m high	Snow-patch, 2–5 cm high
Flora, 1 m²:	*Salix glauca call.* *Betula glandulosa* *Empetrum hermaphr.* *Ledum groenlandicum* *Rumex acetosa* *Pyrola minor* *Veronica wormskiold.* *Pleurozium schreberi* *Drepanoclad. uncinat.* *Polytrichum alpinum*	*Salix glauca call.* *Betula glandulosa* *Empetrum hermaphr.* *Polygonum viviparum* *Deschampsia flex.* *Peltigera aphthosa* *Pleurozium schreberi* *Hylocomium splendens*	*Salix herbacea* *Harrimanella hypn.* *Empetrum hermaphr.* *Loiseleuria proc.* *Solorina crocea* *Cladonia bellidifl.* *Peltigera scabrosa* *Drepanoclad. uncin.* *Conostomum tetrag.* *Pleuroclada alb.* *Anthelia juratz.*

Table 8. *Station A (Nigerdleq). Temperature (°C) at varying level (0 = surface). Observations on 3 biotopes (A 4, A 5, A 6) on 3 days (14 o'clock) with various macroclimatic conditions. Biotopes: see Table 7 (p. 24).*

Date (1965):	9.7.			11.7.			12.7.		
Cloudiness (0–10):	0			1			10		
Rain (0–10):	0			0			2		
Wind force (0–12):	1			3			3		
Biotope No:	A 4	A 5	A 6	A 4	A 5	A 6	A 4	A 5	A 6
+ 200 cm	19	18	18	12	13	13	11	11	11
+ 20 cm	23	21	20	17	15	14	12	11	11
+ 5 cm	29	21	21	22	16	15	12	12	12
0 cm	38	19	21	31	16	18	13	14	13
− 5 cm	17	15	15	17	13	14	11	13	12
− 10 cm	12	9	13	8	9	12	8	9	11

Station B. Neria

Table 10 shows that on an almost cloudless day with no precipitation (16 July) there are the most distinct microthermic gradients on the southward-facing Biotope B 4 (scrub with i.a. *Betula pubescens* and *Salix glauca*), where the difference between 0 cm and 200 cm is 11°, and the

Table 9. *Station B (Neria). Characteristics of 3 biotopes (B 4, B 5, B 6) with observations of vertical microthermic gradient (see Table 10, p. 25). Altitude: 5–10 m a.s.l.*

Biotope No.	B 4	B 5	B 6
Expos., slope:	South, 30°	0°	North, 40°
Situation in terrain:	In the middle of south-facing side of 5 m wide ravine, 5 m deep	Bottom of 5 m wide ravine, near a brook, between B 4 and B 6	In the middle of north-facing side of 5 m wide ravine, 5 m deep
Vegetation type:	Birch-scrub, 1–1.5 m high	Bog, 0.2–0.3 m high	Dwarf-shrub heath, 0.2 m high
Flora, 1 m²:	*Betula pubescens* *Salix glauca call.* *Ledum groenland.* *Vaccinium uligin.* *Empetrum hermaphr.* *Deschampsia flex.* *Campanula gieseck.* *Lycopodium dubium* *Thalictrum alpinum*	*Vaccinium uligin.* *Empetrum hermaphr.* *Salix arctophila* *Carex rariflora* *Polygonum vivipar.* *Sphagnum* sp.	*Empetrum hermaphr.* *Salix glauca call.* *Vaccinium uligin.* *Salix arctophila* *Lycopodium dubium* *Carex bigelowii* *Equisetum arvense* *Peltigera scabrosa*

Table 10. *Station B (Neria). Temperature (°C) at varying level 0 = surface). Observations on 3 biotopes (B 4, B 5, B 6) on 3 days (14 o'clock) with various macroclimatic conditions. Biotopes: See Table 9 (p. 25).*

Date (1965):	16.7.			17.7.			18.7.		
Cloudiness (0–10):	2			4			9		
Rain (0–10):	0			0			2		
Wind force (0–12):	2			4			6		
Biotope no.:	B 4	B 5	B 6	B 4	B 5	B 6	B 4	B 5	B 6
+ 200 cm	18	19	17	11	11	12	13	12	13
+ 20 cm	21	20	20	14	13	16	13	12	13
+ 5 cm	24	22	20	16	15	16	14	12	13
0 cm	29	25	19	20	21	16	14	12	14
− 5 cm	19	22	16	16	16	11	13	11	10
− 10 cm	15	13	13	12	12	9	11	10	9

difference between 0 cm and − 10 cm is 14°. On the opposite, northward-facing side of the ravine (Biotope B 6, dwarf-shrub heath with i.a. *Empetrum hermaphroditum* and *Salix glauca*) the corresponding differences are considerably smaller, 2° above the ground and 6° under the ground, respectively. The intermediately located horizontal Biotope B 5 (bog with i. a. *Vaccinium uliginosum* and *Salix arctophila*) has intermediary gradients, 6° above the ground and 12° under the ground, respectively).

On an almost totally overcast day with little precipitation (18 July) all 3 biotopes show approximately the same slight gradients, namely, 0°–1° above the ground and 2°–5° under the ground.

On a day with average cloud density (17 July) the gradients measured for all 3 biotopes are intermediary between the measurements made on the first two days mentioned, when the macroclimatic conditions were extreme.

In common with Station A, distinctly higher temperatures also were measured at Station B (B 4, B 5, and B 6) at a depth of 10 cm in the ground, with slight cloudiness (15°, 13°, and 13°, respectively) than with overcast weather (11°, 10°, and 9°, respectively).

Station D. 610 m lake

Table 12 shows that on a clear day (22 July) a very steep gradient was found on the southward-facing Biotope D 4 (low scrub with i. a. *Juniperus*) (0 cm − 200 cm: 18°); in particular the temperature fluctuation was considerable in the lowermost 5 cm (14°). There also were distinct gradients (above ground 0 cm − 200 cm: 11°; underground 0 cm − 10 cm: 12°) on the southward-facing Biotope D 5 (dwarf-shrub heath with *Betula glandulosa* and *Vaccinium uliginosum*). On the nearby, but northward-facing Biotope D 6 (dwarf-shrub heath with i. a. *Empetrum hermaphroditum* and *Vaccinium uliginosum*) the above ground difference is only 5°, but the underground one also is 12°).

On another day (23 July), which was total overcast, but when there was no precipitation, approximately the same slight above ground gradients were found on all 3 biotopes (0 cm − 200 cm: 4°–6°). The largest underground gradient was found on the northward-facing Biotope D 6 (0 cm − 10 cm: 13°).

Table 11. *Station D (610 m lake). Characteristics of 3 biotopes (D 4, D 5,D 6) with observations of vertical microthermic gradient (see Table 12, p. 27). Altitude: 615–625 m a.s.l.*

Biotope No.	D 4	D 5	D 6
Expos., slope:	South, 40°	South, 20°	North, 30°
Situation in terrain:	At the top of steep slope, 5 m high	South-facing side of tussock (0.5 m) in flat terrain	North-facing side of same tussock as in biotope D 5
Vegetation type:	Juniperus-scrub 0.5 m high	Moist dwarf-shrub heath, 0.1–0.2 m high	Moist dwarf-shrub heath, 0.1–0.2 m high
Flora, 1 m^2:	*Juniperus comm alp.* *Betula glandulosa* *Viscaria alpina* *Potentilla trident.*	*Betula glandulosa* *Vaccinium uligin.* *Carex bigelowii* *Cladonia mitis* *Cladonia grac. chord.* *Cladonia crispata*	*Empetrum hermaphr.* *Vaccinium uligin.* *Betula glandulosa* *Cetraria islandica* *Dicranum majus* *Aulacomnium palustre* *Sphagnum girgensoh.* *Drepanoclad. uncin.* *Polytrichum alpinum*

Table 12. *Station D (610 m lake). Temperature (°C) at varying levels (0 = surface). Observations on 3 biotopes (D 4, D 5, D 6) on two days (14 o'clock) with various macroclimatic conditions. Biotopes: see Table 11 (p. 27).*

Date (1965):	22.7.			23.7.		
Cloudiness (0–10):	0			8		
Rain (0–10):	0			0		
Wind force (0–12):	2			2		
Biotope No.:	D 4	D 5	D 6	D 4	D 5	D 6
+ 200 cm	16	15	15	16	17	17
+ 20 cm	18	16	16	17	18	18
+ 5 cm	20	19	20	18	19	21
0 cm	34	26	20	22	21	22
− 5 cm	22	22	17	17	21	16
− 10 cm		14	8		14	9

DISCUSSION

1. Dependence on altitude a.s.l.

The majority of investigations of microthermic conditions in Arctic regions have taken place at altitudes near sea level; only a few measurements made at higher levels exist. On the basis of temperature integrals in the period 6 July–20 August Hansen & Hagemann (1967) calculated the mean surface temperature on some biotopes located 400 m a.s.l. in South Greenland. There was a mean temperature of 26.6° on a fell-field dominated by *Loiseleuria procumbens*, and in a snow-patch dominated by *Salix herbacea* and *Sibbaldia procumbens* the mean temperature was ca. 31°. Anderson et al. (1966) measured air and soil temperatures in northeastern Iceland at a station situated at 350 m a.s.l. Stoutjesdijk (1970) investigated the air and plant temperatures at an altitude of 1.200 m a.s.l. (above the timber line) in southern Norway. Here the temperature was 63° on the southern side of an ant hill, and lichens on top of a tussock had a temperature of 40°.

Accordingly, these earlier investigations have shown that quite high microtemperatures can occur at considerable altitudes. The present investigations make possible a more detailed comparison of the microthermic conditions in the lowland near sea level and in the mountain 610 m a.s.l. On clear days maximum temperatures of 52°–57° (southward-facing scrubs) have been recorded at the two lowland stations A and B, whereas at the mountain Station D (southward-facing dwarf-shrub and lichen heath) a maximum temperature of 48° has been observed under comparable conditions. Very high microtemperatures can accordingly be reached even at an altitude of 610 m; given favourable conditions and in the most vigorous types of vegetation, these are approximately as high as in the lowland.

Under unfavourable conditions (total cloudiness and precipitation) the maximal temperatures in the mountain are very low, however, (7°–8°) in comparison to the maximum in the lowland (16°–18°).

A comparison of biotopes D 2 (mountain) and A 3 (lowland) having approximately the same exposure (S 10° and SW 5°, respectively) shows that in clear periods the maximal temperature in the surface of the ground is about the same (48° and 45°, respectively) on these two biotopes (dwarf-shrub-lichen heath and lichen heath, respectively). On the other hand, when the weather is totally overcast there is a distinct difference between the maximal temperatures (D 2: 8°; A 3: 18°).

With respect to the 24-hour minimum surface temperatures, the lowest minima on the majority of the biotopes in the lowland are between 2° and 6°, and in the mountain most frequently between 0° and 1°.

It can be concluded that given favourable macroclimatic conditions, the microclimatic conditions in the mountain (610 m a. s. l.) are only slightly poorer with respect to daily maxima. Under unfavourable conditions, on the other hand, the situation is a good deal poorer in the mountain as far as the daily maxima are concerned. With respect to the 24-hour minima, these generally are 2°–5° lower in the mountain than in the lowland.

2. Dependence on exposure

The investigations show that the biotope's exposure has a very considerable effect on the microthermic conditions, both with respect to the surface maximum and minimum and with respect to the vertical gradients.

Fig. 5 thus shows that in clear weather significantly higher maxima are reached on the southward-facing Biotope A 1 than on the westward-facing Biotope A 2 (55°–57° as against 31°–32°). On the other hand, given totally overcast weather, the difference is very slight (1°–3°). Similar conditions are indicated by Fig. 6, where the difference between maxima on the southward-facing Biotope B 1 and the northward-facing Biotope B 3 is particularly great in slightly cloudy weather (30°) and lesser when the sky is nearly totally overcast (15°). Fig. 10 also shows that under all kinds of weather the daily maxima on the horizontal Biotope C 3 are intermediary between the values on the southward-facing Biotope C 1 and the northward-facing Biotope C 2.

With respect to vertical microthermic gradients, it has been found that both the above-ground and the underground gradients are steepest on southward-facing biotopes, as the maxima on the surface is highest on biotopes of this kind. Thus, Table 8 shows that in clear weather there is a great difference (19°) between 200 cm and 0 cm on the southward-facing Biotope A 4, whereas the difference on the northward-facing Biotope A 5 is only 1°. The underground gradient (0 cm – 10 cm) is 26° and 10°, respectively. Similar conditions were found with respect to the proportion between biotopes B 4 and B 6 (Table 10) and between D 4 and D 6 (Table 12).

3. Relation to vegetation

There have been some earlier observations of microthermic conditions in various types of Arctic vegetation, including measurements of the temperature of the ground, the air, and the individual plant species (BLISS, 1956; WARREN WILSON, 1957). There also are earlier microthermic observations from Greenland, namely from the central part of West Greenland (BIEBL, 1968; T. W. BÖCHER, 1949), as well as a series of comprehensive measurements from the northern part of East Greenland (SØRENSEN 1941). From South Greenland there are microclimatic observations in a vegetation resembling that on the steppes, with *Potentilla tridentata* (J. BÖCHER, 1971), as well as measurements and calculations of the mean temperature in the majority of the growth period in 10 different plant communities (HANSEN & HAGEMANN, 1967).

The investigations under report show that the plant communities vary to a considerable extent, both with respect to daily maxima and minima and to the vertical gradient. A comparison of the biotopes on the stations in the lowland indicates that when the weather is clear or slightly cloudy the highest daily maxima on the surface were measured in various types of scrubs. Maxima of 57° and 44° were measured in two *Juniperus* scrubs (A 1 and C 1) and maxima of 52° and 44° were noted in two low birch-scrubs (B 1 and B 2). Lower maxima were found in all other types of vegetation under the same weather conditions (more or less clear). In lichen heaths or in dwarf-shrub-lichen heaths there are surface maxima of 32°–45° (A 3, Fig. 5) and 33°–34° (C 3, Fig. 10). The daily maxima in dwarf-shrub heaths are still lower, namely 22° in B 3 (Fig. 6) and 21° in C 2 (Fig. 10). In a bog (A 2) the maximum is 25° in the same, slightly cloudy weather (Fig. 5).

As shown in the previous chapter, these surface maxima are conditioned i.a. by the biotope's exposure. In addition, the height and the density of the vegetation affect the microthermic conditions, since the vertical gradient is steepest among the highest types of vegetation, namely the scrubs, partly as a result of the influence of wind (WARREN WILSON, 1959).

In the mountain the maxima are highest (43°–48°) in clear weather in the dwarf-shrub-lichen heath (D 2), whereas the maxima are considerably lower (24°–27°) on the same days in the windswept fell-field (D 3). It is also remarkable that surface maxima of 30°–37° have been measured in snow-patch vegetation 2 m distant from permanent snow.

A comparison of the curves in each of Figs 5, 6, and 10 shows that with more or less total cloudiness there is little difference among the plant communities.

It must be kept in mind, however, that in evaluating the abovementioned maxima these values are only valid as far as the surface of the ground is concerned; furthermore, as pointed out in a previous chapter dealing with the vertical gradients, the temperature decreases considerably along with increased height above the surface, especially in the lowest 5–10 cm. Consequently, mainly the lower layers of vegetation (especially mosses and lichens) are exposed to these extreme maxima. In the higher vegetational layers (herbaceous and shrub layers) the temperatures are, as indicated, considerably lower (often 10°–20°), e. g. Biotope A 4 (Table 8) and Biotope D 4 (Table 12). Therefore it is difficult to determine precisely which microthermic conditions prevail with respect to each individual species on a biotope.

LITERATURE

ANDERSON, D. J., COOKE, R. C., ELKINGTON, T. T. & READ, D. J., 1966: Studies on structure in plant communities. II. The structure of some dwarf-heath and birch-copse communities in Skjaldfannardalur, North-West Iceland. – *J. Ecol.* **54,3**: 781–793. Oxford.

BIEBL, R., 1968: Über Wärmehaushalt und Temperaturresistenz arktischer Pflanzen in Westgrönland. – *Flora* B **157**: 327–354. Jena.

BILLINGS, W. D. & BLISS, L. C., 1959: An alpine snowbank environment and its effects on vegetation, plant development, and productivity. – *Ecology* **40**:388–397. DURHAM, N. C.

BLINKENBERG, H., 1952: Vejrforholdene over de grønlandske kystområder. – *Beretninger vedrørende Grønland*, **2**. København.

BLISS, L. C., 1956: A comparison of plant development in micro-environments of arctic and alpine tundras. – *Ecol. Monogr.* **26**: 303–337. DURHAM, N. C.

BÖCHER, J., 1971: Preliminary studies on the biology and ecology of *Chlamydatus pullus* (REUTER) (Heteroptera: Miridae) in Greenland. – *Meddr Grønland* **191**,3.

BÖCHER, T. W., 1949: Climate, soil, and lakes in continental West Greenland in relation to plant life. – *Meddr Grønland* **147**,2.

HANSEN, KJELD & HAGEMANN, K., 1967: Micro-thermic measurements in Arctic vegetation with a transistor-probe and integrating Cu-voltameter. – *Oikos* **18**: 14–24. København.

STOUTJESDIJK, P., 1970: A note on vegetation temperatures above the timber line in Southern Norway. – *Acta Bot. Neerl.* **19** (6): 918–925. Leiden.

SØRENSEN, THORV., 1941: Temperature relations and phenology of the northeast Greenland flowering plants. – *Meddr Grønland* **125**,9.

WILSON, J. WARREN, 1957: Observations on the temperatures of arctic plants and their environment. – *J. Ecol.* **45**: 499–531. Oxford.

— 1959: Notes on wind and its effect in arctic-alpine vegetation. – *J. Ecol.* **47**: 415–427. Oxford.

Færdig fra trykkeriet den 11. oktober 1973.