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Ground temperature of main ecotopes of Kaffiöyra, Spitsbergen, summer 1978

ABSTRACT: Ground temperature measurement results in main ecotopes of the Kaffiöyra coastal plain (Oscar II Land, northwestern Spitsbergen): sea beach, tundra and morainic plateau, are presented and discussed in the paper. The spatial distribution of thermal conditions is discussed with particular regard to temperature of the active surface and vertical gradients of temperature dependent on daytime and weather conditions.

Key words: Arctic, Spitsbergen, climatology, thermal conditions.

Introduction

Ground temperature investigations are carried out in Spitsbergen in regularly working meteorological stations, as at Barentsburg. These investigations are carried out also in other regions, mainly in summer, by scientific expeditions, including also the Polish expeditions (Czeppe 1961, Jahn 1961, Baranowski 1963, 1968; Kamiński 1982, Jahn and Walker 1983, Grześ 1984). Wide range of the ground temperature measurements have been carried out at Kaffiöyra since 1975 by the Toruń polar expeditions (Leszkiewicz 1977, Wójcik 1982, Marciniak and Przybylak 1983, Wójcik and Marciniak 1983).

Investigations of thermal properties, and thermal regime of ground in polar countries have been dynamized during the last 20 years by international permafrost conferences. Four such conferences were held up to now [1], the fifth being announced in Norway in 1988, already under the auspicies of the International Permafrost Association having its seat in Canada.

The physico-geographic exploration carried out by the 3rd Toruń Polar Expedition to Spitsbergen comprised also the ground temperature conditions within the active layer of permafrost. The research works were located in the northern part of the Kaffiöyra coastal plain (Oscar II Land) at the Research Station of N. Copernicus University of Toruń ($\varphi = 78° 41'N$, $\lambda = 11°51'E$, $H = 71.5$ m a.s.l.), at the distance of about 200 m from the shoreline of Forlandsundet.

The investigations were carried out at three points representative for main ground material types, different with physical and chemical properties and character of the surfaces (Fig. 1), *viz.*: sandy seashore beach (B), tundra (T) and moraine (M). They were located nearby the meteorological station. In our opinion, the ecologic terminology in relation to these selected measuring places, could be adapted, so we can say about 3 ecotopes of beach, tundra and moraine. Their general characteristic is as follows:

a) The sea beach is narrow, widening near the station to 200 m; the observation point was located at the distance of about 150 m from the coastline, beyond the extent of the present storm ridge. The beach is composed of light fine-grained sands of more than 1 m thick. The depth of summer thawing reaches 1.1—1.2 m (Wójcik 1982, Marciniak and Szczepanik 1983). The sand layer is always very moist what is connected, among other things, with sea tides. During a low-tide the sea water inflows into a shallow abandoned stream channel surrounding with an arch a plot of the beach, on which measurements were performed, and infiltrates in abundance into well permeable sand. Capillary rise of this water saturates the whole layer above the permafrost.

During a wet weather with precipitations, the sand layer over the permafrost is strongly saturated with water, whereas during a dry weather, particularly at more intensive insolation, the thin outer layer (to 5 cm) is dried. The occurrence of this layer, which has a reduced thermal capacity and weakened heat conductivity, affects significantly the heat movement in the vertical profile. It makes the beach surface reach, in spite of its light colour, the highest temperature in the daytime and the lowest one at night as compared with other ecotopes. The thermal capacity and the heat conductivity are the highest there. The thermal regime of the beach is formed, similarly as that of the other ecotopes, in connection with a shallow occurrence of the permafrost.

b) The tundra has been formed on a small flat sandur fan located in the forefield of the main terminal moraine of the Aavatsmark Glacier. The outwash consists of fine gravel, mostly of 1—2 cm in diameter, mixed up with sands and muds. A thickness of the thawing layer amounts there as in the beach, to about 1.0—1.2 m. The whole layer is, however, less moist than on the beach so the thermal capacity and heat conductivity are there adequately less. The ground surface is covered by the tundra vegetation, at prevalence of cup-moss (*Cladonia rangiferina*). Plants form bunches covering about 70% of the area. The plant cover, though thin and discontinous, affects to a certain degree the ground temperature formation.

c) The third ecotope consists of a terminal moraine. The measuring point was located on a flattened surface of the external, the oldest moraine rampart composed of coarse waste mixed up with fine-grained and silty material. The occurrence of the active melting niches within the same moraine ridge near the measuring point indicates an occurrence of a buried

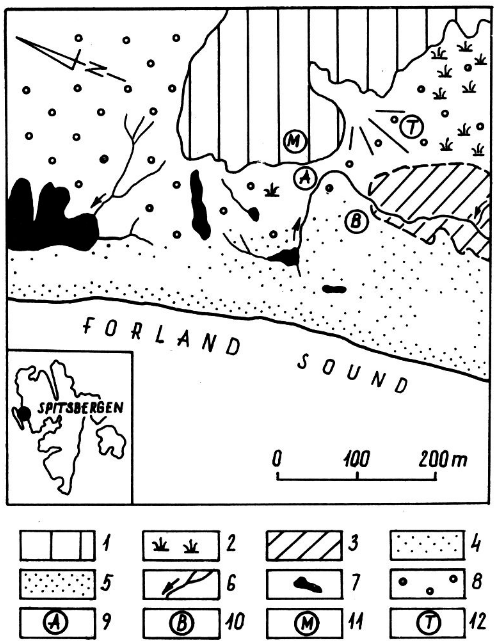

Fig. 1. Morphologic sketch of the area of the Research Station of the N. Copernicus University, Toruń and location of measurement stands
1 — moraine, 2 — tundra, 3 — area periodically flooded during tides, 4 — storm ridges, 5 — area of the beach flooded during tides, 6 — streams, 7 — lakes, 8 — outwash plain, 9 — Research Station, 10 — ground temperature measuring stand "Beach" (B), 11 — ground temperature measuring stand "Moraine" (M), 12 — ground temperature measuring stand "Tundra" (T)

dead ice. The grain-size composition of the moraine (blocks and waste-rocks) made it difficult to sound the depth of summer thawing which has been only estimated for at least 1.5 m. Water content of the active layer is still lower than in the tundra and so, the thermal volumetric capacity and the heat conductivity coefficient are the least in this ecotope.

The deglaciated areas are gradually occupied by vegetation. Single flowers start growing on the moraine surface. This pioneer plant cover does not affect thermal conditions of the ground.

Research methods

The ground temperature has been measured using the mercury-in-glass thermometers placed at the depth of 1, 5, 10, 20 and 50 cm. Thus the measurements comprised such a part of the active layer, in which temperature fluctuations were perceptible by the used measuring instruments. The thermometer indications were read during standard meteorologic observations performed at 01, 07, 13 and 19 LMT. Synchronic observations at all measuring points were carried out from July 24 to September 5, 1978. The data for this period constitute a basis of the present work.

The measurements performed at 4 terms enabled to calculate mean daily temperatures for each depth (Table 1, Figs. 2 and 3) as well as means for decades and for the whole period (Tables 1 and 2). Also the mean temperature of the whole 1—50 cm layer was calculated using the formula:

$$t = \frac{t_1 + t_5 + t_{10} + t_{20} + t_{50}}{5}$$

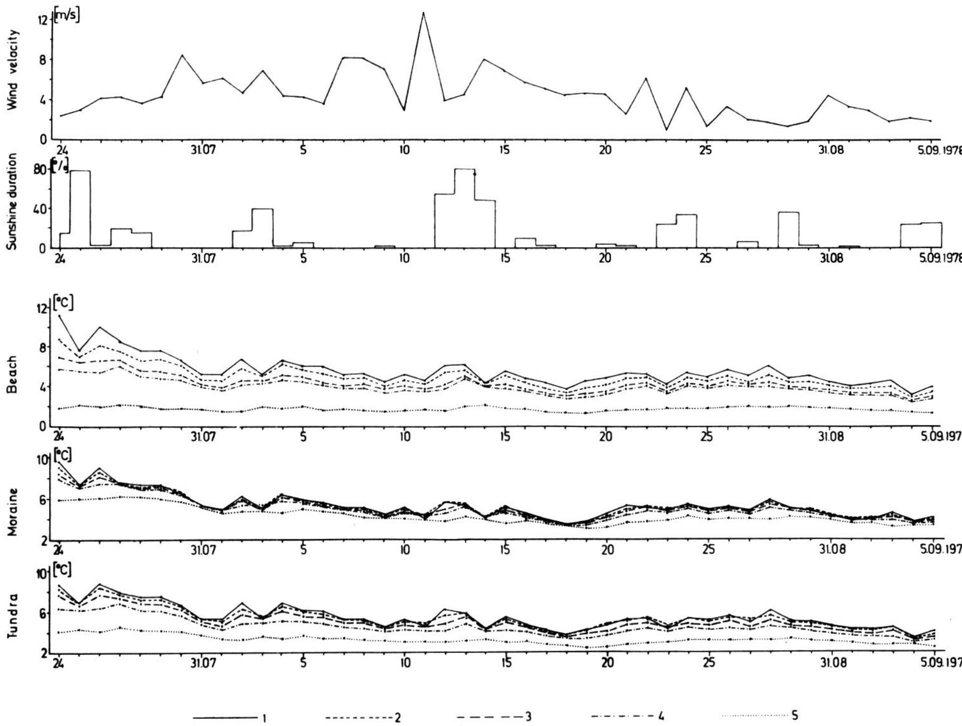

Fig. 2. Course of mean daily ground temperature values for the period July 24 — September 5, 1978 against the background of wind velocity and relative insolation in the Kaffiöyra plain 1 — 1 cm, 2 — 5 cm, 3 — 10 cm, 4 — 20 cm, 5 — 50 cm

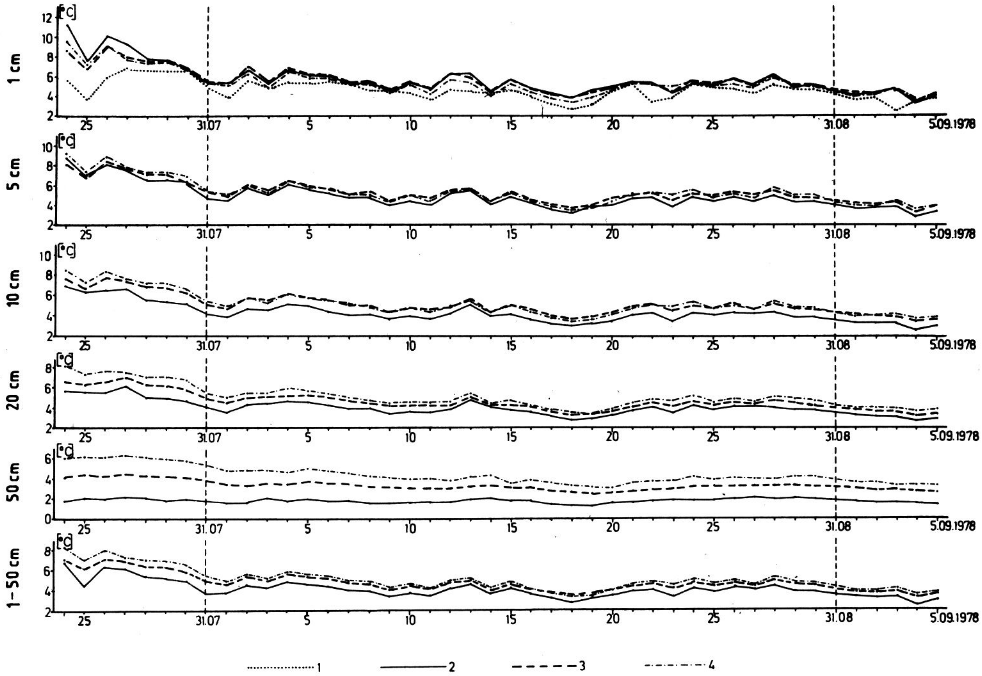

Fig. 3. Courses of mean daily values of air and ground temperature for the period July 24 — September 5, 1978 in the Kaffiöyra plain

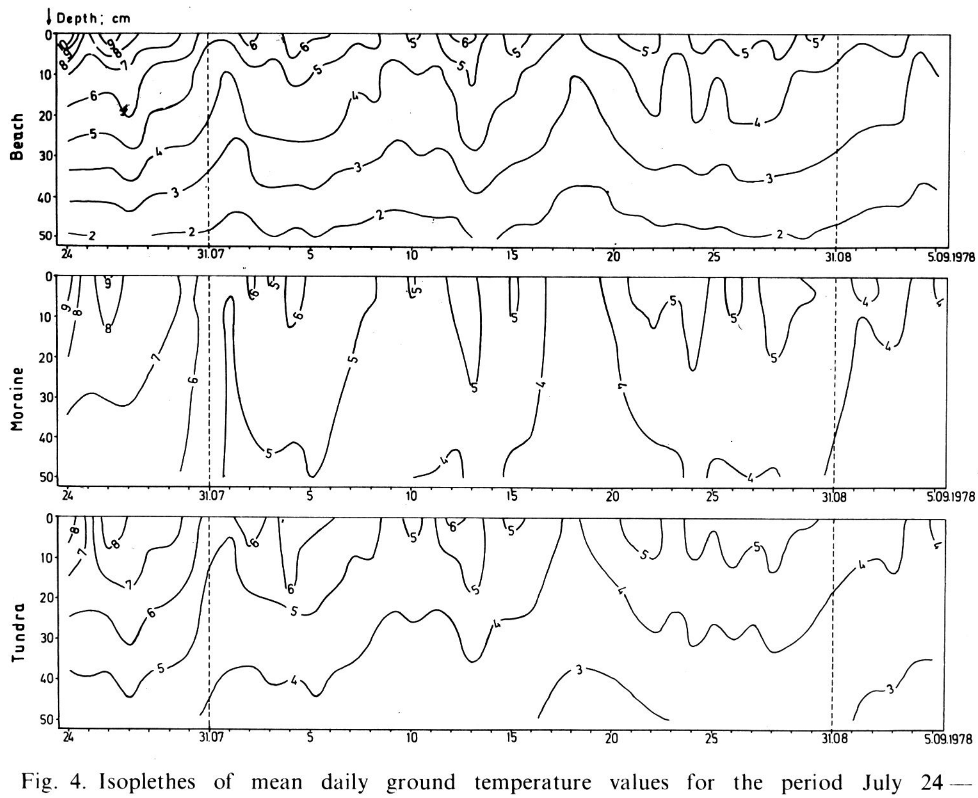

Fig. 4. Isoplethes of mean daily ground temperature values for the period July 24 — September 5, 1978 in selected ecotopes in the Kaffiöyra plain

Table 1

Mean daily values of the ground temperature in the period from 21st July to 5th September 1978 on the Kaffiöyra Plain, Spitsbergen

Date	Beach						Moraine						Tundra					
	Depth (cm)																	
	1	5	10	20	50	mˣ	1	5	10	20	50	mˣ						
21.07							8,7	8,6	8,6	7,7	5,9	7.9						
22.							8,8	8,6	8,0	7,4	5,9	7.7						
23.							7,6	7,5	7,4	7,2	6,1	7.2						
24.	11,2	8,8	7.0	5,8	1,9	6,9	9,6	9,2	8,5	8,0	6,0	8,3	8,7	8,2	7,7	6,4	4,1	7,0
25.	7,6	7,0	6,5	5,6	2,1	5.8	7,2	7,3	7,3	7,4	6,1	7,1	6,7	6,9	6,7	6,2	4,4	6,2
26.	10,0	8,1	6,6	5,5	2,0	6,4	9,1	8,8	8,2	7,6	6,1	8,0	8,9	8,4	7,7	6,4	4,2	7,1
27.	8,6	7,6	6,7	6,1	2,2	6,2	7,6	7,7	7,6	7,5	6,3	7,3	7,9	7,7	7,4	6,9	4,6	6,9
28.	7,6	6,6	5,6	5,0	2,1	5,4	7,3	7,2	7,2	7,0	6,2	7,0	7,5	7,2	6,9	6,2	4,3	6,4
29.	7,6	6,7	5,5	4,9	1,9	5,3	7,4	7,3	7,2	7,0	6,0	7,0	7,6	7,2	6,8	6,1	4,2	6,4
30.	6,6	6,1	5,2	4,7	1,9	4,9	6,6	6,8	6,6	6,6	5,8	6,5	6,7	6,5	6,3	5,7	4,1	5,9
31.	5,2	4,7	4,2	4,0	1,8	3,6	5,2	5,3	5,3	5,4	5,4	5,3	5,4	5,3	5,1	4,8	3,8	4,9
01.08	5,2	4,6	3,9	3,6	1,6	3,8	5,0	5,0	4,9	4,9	4,8	4,9	5,3	5,0	4,8	4,4	3,4	4,6
02.	6,6	5,8	4,7	4,2	1,6	4,6	6,2	6,0	5,8	5,4	4,8	5,6	6,9	6,2	5,8	4,9	3,3	5,4
0.3	5,2	5,1	4,6	4,4	2,0	4,3	4,9	5,1	5,2	5,4	4,9	5,1	5,4	5,5	5,4	5,0	3,6	5,0
04.	6,6	6,2	5,2	4,6	1,8	4,9	6,4	6,4	6,1	5,8	4,7	5,9	6,8	6,5	6,2	5,2	3,4	5,6
05.	6,0	5,6	5,0	4,5	2,0	4,6	5,8	5,8	5,7	5,6	5,0	5,6	6,1	6,0	5,7	5,2	3,7	5,3
06.	6,0	5,3	4,5	4,2	1,8	4,4	5,7	5,6	5,5	5,3	4,8	5,4	6,1	5,8	5,6	4,9	3,5	5,2
07.	5,2	4,8	4,1	3,9	1,8	4,0	5,1	5,1	5,1	5,0	4,6	5,0	5,3	5,2	5,0	4,6	3,5	4,7
08.	5,3	4,9	4,2	3,9	1,6	4,0	5,1	5,1	4,9	4,7	4,2	4,8	5,4	5,3	5,0	4,4	3,2	4,7
09.	4,5	4,1	3,7	3,4	1,6	3,5	4,3	4,4	4,4	4,4	4,2	4,3	4,6	4,5	4,4	4,1	3,2	4,2
10.	5,2	4,6	4,0	3,6	1,6	3,8	5,1	5,0	4,8	4,6	4,0	4,7	5,3	5,0	4,8	4,2	3,1	4,5
11.	4,6	4,2	3,8	3,5	1,7	3,6	4,1	4,4	4,4	4,4	4,0	4,3	4,7	4,8	4,6	4,1	3,1	4,3
12.	6,1	5,4	4,2	3,8	1,6	4,2	5,6	5,6	5,0	4,6	3,8	4,9	6,2	5,6	4,9	4,2	3,0	4,8
13.	6,2	5,6	5,1	4,8	2,0	4,7	5,5	5,6	5,5	5,3	4,2	5,2	5,9	5,8	5,6	4,9	3,2	5,1
14.	4,4	4,2	4,0	4,0	2,1	3,7	4,0	4,2	4,3	4,3	4,3	4,2	4,4	4,4	4,3	4,2	3,3	4,1
15.	5,6	5,0	4,2	3,8	1,8	4,1	5,2	5,2	5,0	4,6	3,8	4,8	5,6	5,3	5,0	4,2	3,0	4,6
16.	4,8	4,3	3,7	3,6	1,8	3,6	4,4	4,3	4,3	4,2	3,9	4,2	4,7	4,6	4,6	4,1	3,1	4,2
17.	4,3	3,7	3,2	3,1	1,5	3,2	3,7	3,8	3,8	3,8	3,6	3,7	4,2	4,1	4,0	3,6	2,8	3,7
18.	3,7	3,3	3,0	2,8	1,4	2,8	3,3	3,4	3,4	3,5	3,4	3,4	3,8	3,8	3,6	3,4	3,7	3,5
19.	4,6	3,9	3,2	2,9	1,3	3,2	3,8	3,7	3,6	3,4	3,1	3,5	4,3	4,1	3,9	3,4	2,5	3,6
20.	4,9	4,1	3,5	3,2	1,6	3,5	4,5	4,3	4,1	3,8	3,1	4,0	4,7	4,8	4,2	3,7	2,6	4,0

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21.	5,4	4,8	4,1	3,7	1,6	3,9	5,3	5,1	4,8	4,4	3,6	4,6	5,4	5,1	4,8	4,1	2,8	4,4
22.	5,2	4,9	4,3	4,0	1,7	4,0	5,1	5,2	5,1	4,7	3,7	4,8	5,4	5,3	5,0	4,4	2,9	4,6
23.	4,3	3,9	3,5	3,4	1,8	3,4	4,8	5,0	4,8	4,6	3,8	4,6	4,5	4,6	4,5	4,1	3,0	4,1
24.	5,3	4,9	4,3	4,1	1,8	4,1	5,4	5,4	5,3	5,1	4,2	5,1	5,4	5,3	5,0	4,5	3,2	4,7
25.	5,0	4,5	4,0	3,8	1,8	3,8	4,9	4,8	4,7	4,5	3,9	4,6	5,1	4,9	4,7	4,2	3,2	4,4
26.	5,7	5,0	4,3	4,1	1,9	4,2	5,1	5,2	5,0	4,8	4,0	4,8	5,7	5,4	5,2	4,4	3,2	4,8
27.	5,1	4,5	4,2	4,1	2,0	4,0	4,8	4,7	4,6	4,5	4,0	4,5	5,0	5,1	4,6	4,2	3,2	4,4
28.	6,1	5,1	4,4	4,0	1,9	4,3	5,8	5,8	5,4	5,0	3,9	5,2	6,1	5,6	5,2	4,6	3,2	4,9
29.	4,9	4,4	3,9	3,8	2,0	3,8	5,1	5,0	4,8	4,9	4,2	4,8	5,1	4,9	4,7	4,4	3,3	4,5
30.	5,1	4,5	3,9	3,7	1,9	3,8	4,8	5,0	4,8	4,7	4,1	4,7	5,1	4,9	4,7	4,2	3,2	4,4
31.	4,5	4,1	3,6	3,5	1,8	3,5	4,2	4,4	4,3	4,2	3,9	4,2	4,6	4,5	4,3	3,9	3,1	4,1
01.09	4,1	3,8	3,3	3,2	1,7	3,2	3,9	4,0	4,0	3,9	3,6	3,9	4,3	4,2	4,1	3,8	3,0	3,9
02.	4,3	3,9	3,3	3,1	1,6	3,2	4,0	4,0	4,1	3,9	3,6	3,9	4,3	4,1	4,0	3,6	2,8	3,8
03.	4,6	4,0	3,3	3,1	1,6	3,3	4,6	4,5	4,2	3,9	3,3	4,1	4,6	4,5	4,2	3,6	2,8	3,9
04.	3,2	2,9	2,5	2,6	1,5	2,5	3,6	3,6	3,7	3,6	3,4	3,6	3,5	3,4	3,4	3,2	2,8	3,3
05.	4,0	3,5	3,0	2,9	1,4	3,0	4,1	4,0	3,9	3,8	3,3	3,8	4,1	4,0	3,7	3,4	2,6	3,6
24—31.07	8,1	7,0	6,0	5,2	2,0	5,7	7,7	7,7	7,4	7,1	6,0	7,2	7,4	7,2	6,8	6,1	4,2	6,3
01—10.08	5,6	5,1	4,4	4,0	1,8	4,2	5,4	5,3	5,2	5,1	4,6	5,1	5,7	5,5	5,2	4,7	3,4	4,9
11—20.08	4,9	4,4	3,8	3,6	1,7	3,7	4,4	4,4	4,3	4,2	3,7	4,2	4,8	4,7	4,4	4,0	2,9	4,2
21—31.08	5,1	4,6	4,0	3,8	1,8	3,9	5,0	5,0	4,9	4,7	3,9	4,7	5,2	5,1	4,8	4,3	3,1	4,5
01—05.09	4,0	3,6	3,1	3,0	1,6	3,1	3,7	3,7	3,7	3,6	3,3	3,6	4,2	4,0	3,9	3,5	2,8	3,7
01—31.08	5,2	4,7	4,1	3,8	1,8	3,9	4,9	4,9	4,8	4,6	4,1	4,7	5,2	5,1	4,8	4,3	3,2	4,5
24.07—05.09	5,7	5,0	4,3	4,0	1,8	4,2	5,3	5,3	5,2	5,0	4,3	5,0	5,5	5,3	5,1	4,5	3,3	4,7

— mean temperature of the ground layer 1—50 cm according to measurements at depth of 1, 5, 10, 20 and 50 cm.

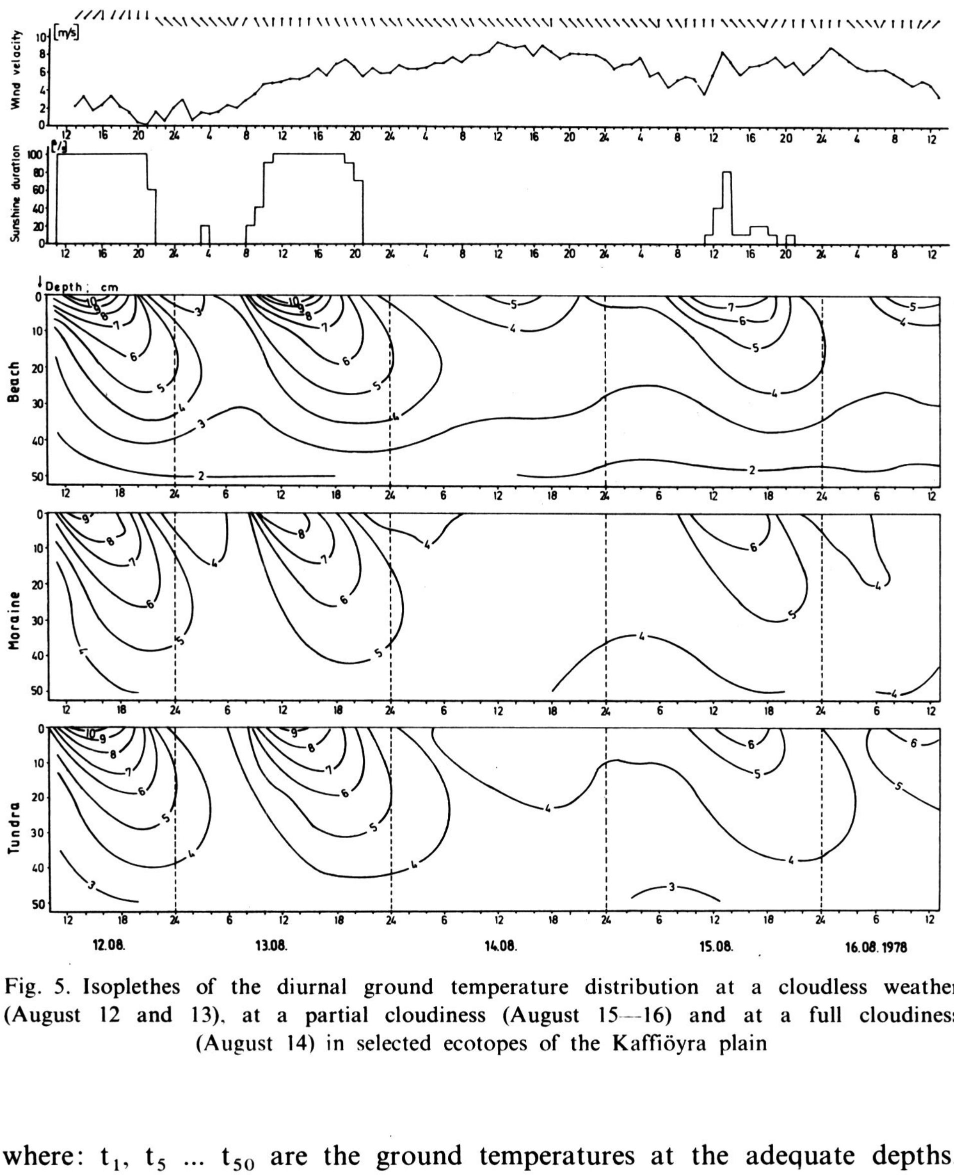


Fig. 5. Isoplethes of the diurnal ground temperature distribution at a cloudless weather (August 12 and 13), at a partial cloudiness (August 15—16) and at a full cloudiness (August 14) in selected ecotopes of the Kaffiöyra plain

where: t_1, t_5 ... t_{50} are the ground temperatures at the adequate depths.

On the basis of the collected material, dynamics of the spatial temperature distribution from day to day and in the diurnal cycle was investigated and discussed (Figs. 4 and 5). Vertical temperature distributions in particular ecotopes, dependent on weather conditions, were also analyzed (Figs. 6 and 7). Thermal properties of the background of the investigated ecotopes were finally compared by means of a simple complex index (t) of the mean temperature of the whole measured 1—50 cm layer (Tables 1 and 2).

During the investigations the cyclonic, *i.e.* windy weather with frequent precipitations and fogs, prevailed; it was described in another paper (Wójcik and Marciniak 1983). The weather (insolation, wind velocity, air temperature) is presented in Figs. 2 and 3.

Spatial differentiation of ground temperatures

Vertical distribution of the ground temperature in selected ecotopes (*see* Fig. 6) allows to distinguish 2 layers:

a) outer and thinner layer with a varying thickness, in which thermal differences between the investigated ecotopes decrease with the depth and sometimes vanish at all. Such an equalized or almost equalized temperature is defined by us as a monothermy and its stabilization depth as the level or depth of monothermy. This layer is situated between the active surface and the monothermy. Its thickness is thus determined by the monothermy depth and varies, depending on weather conditions, from 0 at a cloudy weather (*e.g.* on August 15 at 01 h) to about 17 cm at a cloudless weather (*e.g.* on August 13 at 01 and 19 h) or at a light overcast (*e.g.* on August 14 at 01 h), whereas its average thickness amounts to about 5 cm (Fig. 6). In the diurnal cycle, at least at a light overcast, the thickness of this layer is smaller within the daytime and greater at night (Fig. 6).

The upper part of the investigated profile is always the warmest on the beach and the coolest on the moraine, occupying an intermediate place on the tundra (*cf.* Figs. 3, 6). Only at night (Fig. 6, graphs for 01 h, means for the whole period July 24 — September 5) and at a light overcast (August 13), the tundra was the warmest, the beach was the coolest, while the moraine occupied an intermediate place.

In the outer layer the greatest thermal differences between particular ecotopes were marked on the active surface. The thermal conditions of this surface are to be discussed somewhat more detailed due to their significance for the processes within the atmosphere boundary layer. The temperature of the active surface was measured by thermometers, the reservoirs *i.e.* receptors of which were plunged about 1 cm into the ground.

Investigations were carried out already after the summer solstice, in the regression phase of the annual solar cycle. The ground temperature gradually dropped, showing sufficiently considerable oscillations from day to day in accordance with changing weather conditions, particularly the cloudiness. Therefore, the mean daily temperature of the beach at the depth of 1 cm decreased from 11.2°C at the beginning of measurement start (July 24) to 4.0°C on the last day (September 5). The average temperature for the whole period amounted to 5.7°C (Table 1). The highest mean daily temperature occurred at the beginning of the measuring period, at still most favourable astronomic parameters and at a cloudless weather, whereas the lowest one occurred at the end of the measuring period, at the beginning of the arctic autumn and at a cloudy weather with precipitations (mean daily cloudiness on September 4 was 7.8 in the 0—10 scale), whereas the total precipitation was 4.4 mm (Table 1, Figs. 2 and 3).

The general decreasing trend of mean daily temperatures of the active surface of three ecotopes is presented by the following equations and graphs in Figs. 2 and 3:

— for the beach (B) $y_i = -0.087\,x_i + 7.56$
— for the tundra (T) $y_i = -0.072x_i + 7.12$
— for the moraine (M) $y_i = -0.077x_i + 7.03$,

where:

x_i — subsequent day of the period July 24 — September 5 ($i = 1, 2, 3 \ldots 44$)

y_i — mean daily temperature on the i-th day.

A general trend of decreasing temperature is noted for the considered period, but its oscillations from day to day, dependent on weather conditions, were clearly marked. Short-term, interdiurnal changes of the mean temperature were small, mainly within the limits of 0.5—1.5°C. The maximum of 3.6°C occurred on the beach while the mean for the whole period amounted to 0.9°C (Table 1).

The highest interdiurnal change of temperature on the beach occurred between 24th and 25th July and has been caused by a radical change in the cloudiness degree (3.5 and 9.0, adequately) and consequently in insolation (77.9% and 1.2%). Weaker oscillations from day to day showed night temperatures, stronger — diurnal ones. So *e.g.*, on the beach at the depth of 1 cm at 01 h the mean temperature variability amounted to 0.87°C at the highest temperature of 4.1°C, whereas at 13 h the adequate values amounted to 1.86°C and 6.8°C.

The thermal spottiness of the active surface depends on its character and ground properties, depends also on weather and changes in the diurnal cycle. Mean temperature at the depth of 1 cm for the period of investigations (Table 1) amounted to 5.7°C on the beach, to 5.5°C on the tundra and to 5.3°C on the moraine. The temperature differentiation increased at the sunny weather. The widest differences occurred at a cloudless sky, particularly at still high astronomic parameters as *e.g.* on July 24 when daily means amounted to 11.2°C on the beach, to 9.6°C on the moraine and to 8.7°C on the tundra (Table 1, Fig. 2). During a cloudy weather, particularly when joined with rainfalls, the thermal differences disappeared, as *e.g.* on July 30, when mean daily temperatures in the investigated ecotopes were almost the same and equal 6.6—6.7°C.

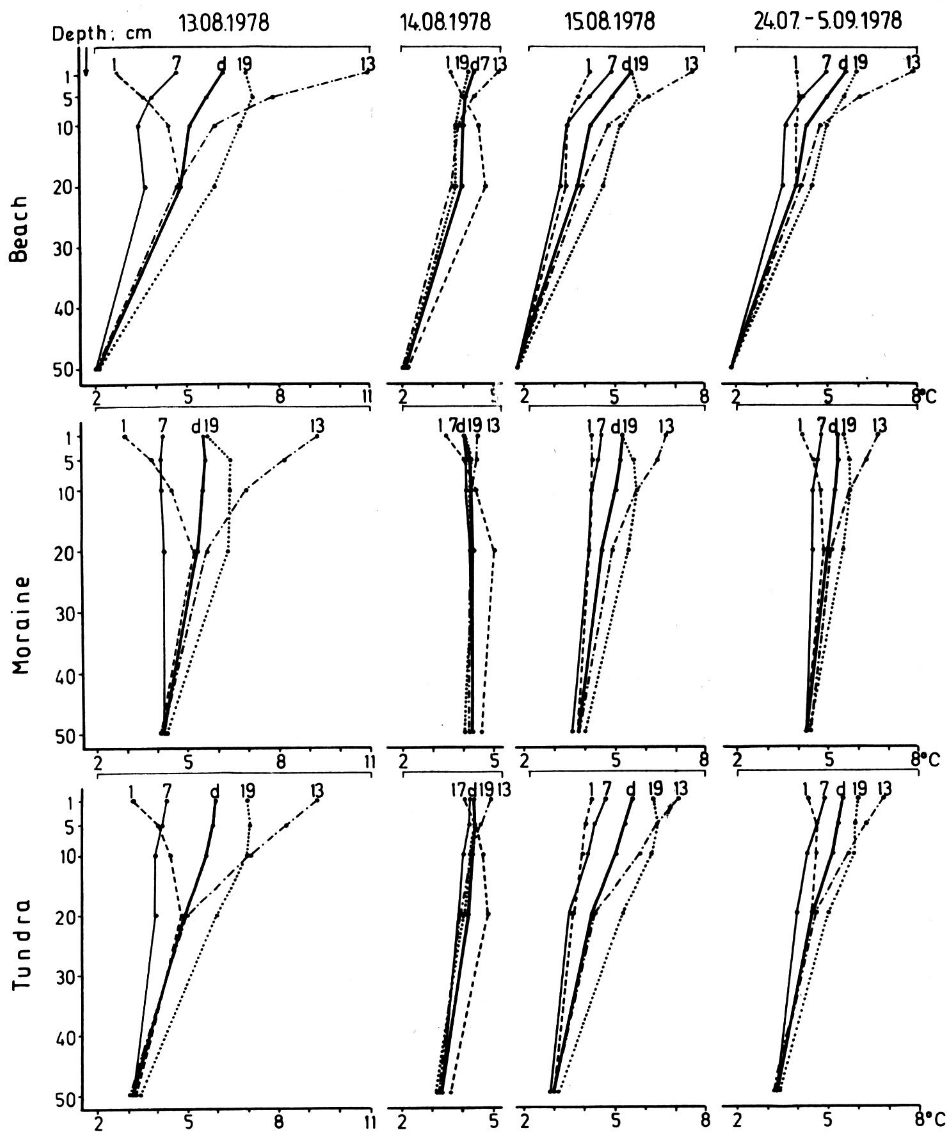


Fig. 6. Vertical ground temperature distribution in the diurnal cycle on selected ecotopes at a cloudless weather (August 13), at a partial cloudiness (August 15), at a full cloudiness (August 14), and mean in the period July 24 — September 5, 1978 in the Kaffiöyra plain

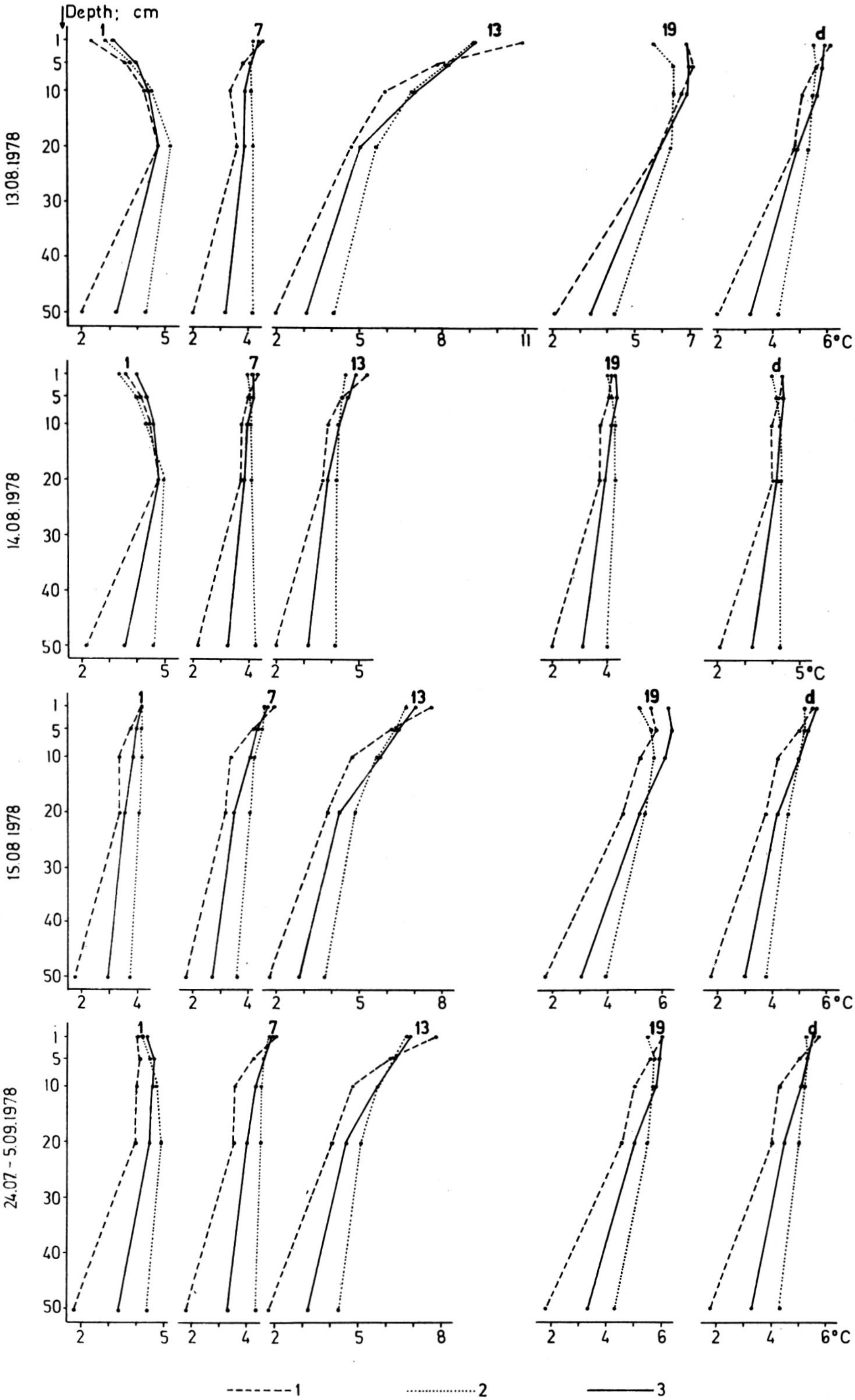
The thermal spottiness changed in the diurnal cycle and its highest intensity appeared at the most intensive insolation *i.e.* at noon, at a cloudless weather. Thus on July 24 at 13 h the temperature at the depth of 1 cm on the beach amounted to 17.0°C, to 14.0°C on the moraine and to

12.8°C on the tundra (Fig. 7). The night cooling of the active surface depends only slightly on its character and in this connection the thermal spottiness disappears at night, particularly at a cloudy weather as *e.g.* on July 30 when at 01 h the temperature of the tundra surface amounted to 6.8°C, to 6.6°C on the beach and to 6.5°C on the moraine. At a fine weather these differences were greater however still did not exceed 1°C, and *e.g.* on July 24 at 01 h temperature amounted to 5.2°C on the moraine, to 4.9°C on the beach and to 4.5°C on the tundra.

b) In the lower layer located below the monothermy the temperature differentiation between particular ecotopes keeps increasing with the depth (*cf.* Fig. 6). The beach is always the coolest, the moraine is the warmest (inversely as in the outer layer) and the tundra occupies an intermediary place. Means for the whole period of investigations at the depth of 50 cm amounted to 1.8°C on the beach, to 3.3°C on the tundra and to 4.3°C on the moraine. The horizontal differentiation of temperature at this depth is several times higher than on the active surface. This fact is closely connected with the permafrost depth, shallow on the beach, deeper on the tundra and still deeper on the moraine.

The horizontal differentiation of temperature at the depth of 50 cm changed in the period of investigations. The greatest differences appeared at the beginning and gradually decreased till the end of this period. Mean daily temperatures at this depth (Table 1) amounted on July 24 to 1.9°C on the beach, to 4.1°C on the tundra and to 6.0°C on the moraine. On August 11 they amounted adequately to 1.7°C, 3.1°C and 4.0°C and on September 5 to 1.4°C, 2.6°C and 3.3°C. Equalization of temperatures was connected on the one hand with a reduced inflow of heat from outside into the ground (due to the decreased insolation and shortened the daylength), and on the other one with a growth of permafrost from below at a cost of winter cold reserves stored in the permafrost. The growth of the permafrost at the end of summer was proved by Marciniak and Szczepanik (1983). Therefore, the temperature at the depth of 50 cm began to differentiate in spring in connection with a varying thawing rate, the slowest on the beach and the quickest on

Fig. 7. Vertical ground temperature distribution in the Kaffiöyra plain, for particular observation terms (1, 7, 13, 19 h) and daily means (d) during a sunny weather (August 13), at a partial cloudiness (August 15) and at a full cloudiness (August 14) and means for the period July 24 — September 5, 1978 on the beach (1), the moraine (2) and the tundra (3)



Depth; cm
13.08.1978
14.08.1978
15.08.1978
24.07 - 5.09.1978
1
7
13
19
d
6°C
5°C
1
2
3

the moraine, however only when the thawing moves beyond a depth of 50 cm. On the beach the shallower occurrence of permafrost than in other ecotopes resulted in the most intensive decrease of temperature. In addition, the lowest temperature in the layer below the monothermy depends on a higher thermal capacity and reduced heat conductivity in the outer 2—3 cm thick layer of the beach due to its easy drying up. It happened at the weather with a light overcast, otherwise most effective for heating up the ground.

In the period of investigations the temperature inside the ground systematically decreased as on the surface. The deeper the slower decrease rate occurred. At the depth of 50 cm the daily temperatures decreased from 2.2°C on the beach at the beginning of investigations to 1.4°C at the end of this period, whereas from 4.6°C to 2.6°C on the tundra and from 6.3°C to 3.3°C on the moraine. The mean drop of temperature amounted adequately to 0.02, 0.05 and 0.08°C a day. These coefficients are, therefore, more differentiated than those referring to the ground surface. It indicates then a depth increase of thermal differences between particular environments.

c) Remarks concerning the both primary layers, particularly the monothermy, allow consequently to distinguish another one, the third transitional layer situated between the two mentioned above and comprising the lower part of the (a) layer and the upper part of the (b) layer. For the predominant occurrence of the monothermy in this layer, it is characterized by the least differentiation of temperature between particular ecotopes.

Daily course of ground temperature

The daily course of ground temperature was considered mainly on the basis of observations at 4 terms and more detailed every-hour observations performed on several selected days with different weather conditions.

Ground temperature in the warm season is characterized, on the whole, by a well-marked diurnal course. The daily amplitudes, determined as distinctions between the highest and the lowest measured temperature at 4 observation terms correlate with the weather conditions. At a sunny weather the amplitudes are high and *e.g.* on July 24 on the beach surface the amplitude was equal 12.1°C whereas at a cloudy and rainy weather the differences almost disappeared, *e.g.* on August 7 the amplitude was 0.9°C at the mean amplitude for the whole period amounted to 3.5°C.

The daily courses of the ground surface temperature are marked somewhat weaker in the other sites. In comparison with the beach, daily temperatures are lower on the moraine and still lower on the tundra.

They changed from 0.3°C (August 7) to 8.8.°C (July 24) on the moraine at the mean amounting to 2.6°C, whereas from 0.6°C to 8.3°C on the tundra at the same mean value.

Daily amplitudes decrease with the ground depth in accordance with the second Fourier's law. At the depth of 50 cm its highest value reached 0.3°C on the beach at the mean amounting to 0.0°C, 0.7°C on the moraine at the mean of 0.1°C and 0.4°C on the tundra at the mean of 0.2°C. It could be estimated on the basis of the performed measurements and their analysis that the daily amplitude vanished at the depth of 60 cm on the beach, at 75 cm on the moraine and the tundra. These values marked out the constant daily temperature level. Its average depths are smaller, amounting 50 cm on the beach, 57 cm on the moraine and 60 cm on the tundra.

According to measurements at 4 climatologic terms, the lowest temperature in the diurnal cycle on the ground surface occurred at 01 h, the highest one — at 13 h LMT. These terms slow down with the depth in accordance with the third Fourier's law, and at the depth of 20 cm, they occurred 6 hours later. Therefore, the slowing down of terms of extreme temperatures in the diurnal cycle amounts to 3 hours per 10 cm of the depth.

The above every-hour observations for several selected days allowed to determine more correctly the terms of the diurnal extreme. The daily maximum at the ground surface occurs always at noon (differences between the temperature values at 12 and 13 h are not high), the minimum before a sunrise above the mountains.

Vertical distribution of ground temperatures

The temperature penetration into the ground depends on physical properties of the latter *i.e.* on the heat conductivity (direct relation) and on the thermal capacity (inverse relation). The performed measurements proved that in Spitsbergen rapid diurnal temperature changes occurred in the outer ground layer and they were modified by weather conditions whereas their quantitative characteristics depend on the ecotope. In the light of the collected data and the calculations (Tables 1 and 2, Figs. 6 and 7), the highest vertical temperature differentiation occurs on the beach, lower on the tundra and the lowest on the moraine. Mean vertical gradients from July 24 to September 5 in the layer of 1–50 cm were equal −0.80, −0.40 and −0.20°C per 10 cm, respectively. The vertical differentiation of temperature in ground changes in the diurnal cycle: the highest gradients occur at 13 h and, on the average amount to

−1.20°C on the beach, to −0.74°C on the tundra and to −0.50°C per 10 cm on the moraine, while the lowest ones at 01 h amounted adequately to −0.44, −0.18 and −0.06°C per 10 cm.

The vertical gradients depend on weather conditions. The highest ones occur by day at a sunny weather (Fig. 6), *e.g.* on August 13 the vertical gradient on the beach in the layer 1—50 cm amounted to −1.80°C per 10 cm and in the outer layer 1—10 cm it reached −6.20°C per 10 cm. The adequate values on the tundra amounted to −1.22° and −2.20°C and on the moraine to −1.02°C and −2.30°C per 10 cm. In summer 1977 during three-day sunny weather, complex an extremely strong vertical differentiation of temperature took place, and *e.g.* on July 26 at 13 h on the beach in the 1—50 cm layer the gradient amounted to −2.98°C and in the 1—10 cm layer it was almost the same as in 1978, amounting to −6.10°C per 10 cm (Wójcik 1982). At a cloudy and rainy weather the temperature in the vertical profile of the 1—50 cm layer was equalized, the vertical gradients at all terms being small, *e.g.* on August 14, 1978 at 13 h (Figs. 6 and 7) the gradient amounted to −0.66°C on the beach, to −0.34°C on the tundra and to −0.06°C per 10 cm on the moraine, whereas in the evening at 19 h a further smoothing of vertical temperature took place: the gradients amounted adequately to −0.49, −0.24 and 0.00°C per 10 cm.

The investigations allowed to note that under conditions of the polar summer with absence of a snow cover, 3 types of vertical stratification of temperature in ground occurred, *viz.*:

a) The summer, *i.e.* insolation type predominates (temperature decreases with the depth). In the diurnal cycle this type occurs in the day-time and, as it has been shown (Fig. 7) for the whole period (July 24 — September 5), forms early in the morning being noted as early as at 07 h, and is marked most clearly at noon disappearing towards the evening and at 19 h is still marked only on the beach and on the tundra.

b) Radiation-insolation type (temperature grows in the upper part of the section, decreases in the lower part with the depth. This type occurs in the diurnal cycle at night due to georadiation. It occurs (although only on the moraine) usually at about 19 h and is most clearly visible, as at 01 h (*cf.* Figs. 6, 7). However, the night cooling does not reach too deep and *e.g.* at a cloudless weather on August 13 at 01 h the vertical gradient in the 1—20 cm layer amounted to +1.25°C per 10 cm while the daily mean on the same day amounted to −0.80°C per 10 cm.

The radiation-insolation type of the temperature distribution divides the investigated ground section into three thermicly different layers, two of which — upper and lower are cool, separated by a warm middle layer (Figs. 6 and 7, graphs for August 13 at 01 h). The latter layer corresponds

Mean ground temperature in the period from 24th July to 5th September 1978 on the Kaffiöyra Plain, Spitsbergen

Period	Depth 1 cm, hours 01	07	13	19	m	5 cm, hours 01	07	13	19	m	10 cm, hours 01	07	13	19	m	20 cm, hours 01	07	13	19	m	50 cm, hours 01	07	13	19	m	1 — 50 cm, hours 01	07	13	19	m
A. Beach																														
24—31.07	5,8	7,7	10,2	8,4	8,1	6,0	6,4	8,1	7,6	7,0	5,6	5,3	6,4	6,5	6,0	5,3	4,8	5,3	5,6	5,2	2,0	2,0	2,0	2,0	2,0	4,9	5,2	6,4	6,0	5,6
01—10.08	4,4	5,2	7,1	5,6	5,6	4,3	4,6	5,9	5,6	5,1	4,0	3,8	4,8	4,9	4,4	3,9	3,6	4,2	4,4	4,0	1,8	1,7	1,8	1,8	1,8	3,7	3,8	4,8	4,5	4,2
11—20.08	3,0	4,3	6,9	5,4	4,9	3,3	3,6	5,4	5,2	4,4	3,4	3,0	4,2	4,5	3,8	3,6	3,0	3,5	4,1	3,6	1,7	1,7	1,6	1,7	1,7	3,0	3,1	4,3	4,2	3,7
21—31.08	3,7	4,5	7,0	5,4	5,1	3,8	3,7	5,6	5,2	4,6	3,7	3,2	4,5	4,7	4,0	3,8	3,2	3,9	4,3	3,8	1,9	1,8	1,8	1,8	1,8	3,4	3,3	4,6	4,3	3,9
01—05.09	2,8	2,9	6,5	4,0	4,0	2,9	2,5	5,1	4,0	3,6	2,8	2,3	3,6	3,7	3,1	3,0	2,5	3,0	3,5	3,0	1,6	1,6	1,5	1,5	1,6	2,6	2,4	3,9	3,3	3,1
01—31.08	3,7	4,6	7,0	5,5	5,2	3,8	4,0	5,6	5,3	4,7	3,7	3,3	4,5	4,7	4,1	3,8	3,3	3,9	4,4	3,8	1,8	1,8	1,7	1,8	1,8	3,4	3,4	4,5	4,3	3,9
24.07—05.09	4,0	5,0	7,8	6,0	5,7	4,1	4,2	6,1	5,6	5,0	4,0	3,6	4,8	5,0	4,3	4,0	3,5	4,1	4,5	4,0	1,8	1,8	1,8	1,8	1,8	3,6	3,6	4,9	4,6	4,2
B. Moraine																														
24—31.07	6,2	7,3	9,3	8,1	7,7	6,8	6,9	8,8	8,2	7,7	7,1	6,6	7,9	8,1	7,4	7,2	6,6	7,1	7,7	7,1	6,0	6,0	5,9	6,0	6,0	6,7	6,7	7,8	7,6	7,2
01—10.08	4,5	5,1	6,3	5,5	5,4	4,7	5,0	6,0	5,7	5,3	4,8	4,8	5,7	5,7	5,2	5,0	4,7	5,2	5,5	5,1	4,7	4,6	4,5	4,6	4,6	4,7	4,8	5,5	5,4	5,1
11—20.08	3,1	3,9	5,8	4,8	4,4	3,5	3,8	5,5	5,0	4,4	3,8	3,6	4,9	5,0	4,3	4,1	3,7	4,3	4,8	4,2	3,8	3,7	3,6	3,6	3,7	3,7	3,7	4,8	4,6	4,2
21—31.08	4,0	4,4	6,4	5,3	5,0	4,3	4,3	6,1	5,5	5,0	4,4	4,2	5,4	5,4	4,9	4,6	4,2	4,8	5,2	4,7	4,0	3,9	3,9	4,0	3,9	4,3	4,2	5,3	5,1	4,7
01—05.09	2,5	2,9	5,6	3,6	3,7	3,0	2,9	5,0	4,0	3,7	3,2	3,0	4,4	4,1	3,7	3,4	3,1	3,8	4,1	3,6	3,4	3,3	3,2	3,2	3,3	3,1	3,0	4,4	3,8	3,6
01—31.08	3,8	4,5	6,2	5,2	4,9	4,2	4,4	5,8	5,4	4,9	4,4	4,2	5,3	5,4	4,8	4,5	4,2	4,8	5,1	4,6	4,1	4,1	4,0	4,1	4,1	4,2	4,3	5,2	5,0	4,7
	4,1	4,8	6,7	5,5	5,3	4,5	4,6	6,3	5,7	5,3	4,7	4,5	5,7	5,7	5,2	4,9	4,5	5,1	5,5	5,0	4,4	4,3	4,3	4,3	4,3	4,5	4,5	5,6	5,3	5,0
C. Tundra																														
24—31.07	5,9	7,0	8,8	8,0	7,4	6,3	6,5	8,1	7,8	7,2	6,3	6,2	7,4	7,6	6,8	6,1	5,6	6,1	6,6	6,1	4,3	4,2	4,1	4,2	4,2	5,8	5,9	6,9	6,8	6,4
01—10.08	4,7	5,4	6,7	6,1	5,7	4,8	5,0	6,2	6,0	5,5	4,7	4,7	5,8	5,8	5,2	4,6	4,2	4,8	5,1	4,7	3,5	3,4	3,4	3,4	3,4	4,5	4,5	5,4	5,3	4,9
11—20.08	3,3	4,1	6,4	5,6	4,8	3,7	3,9	5,7	5,5	4,7	3,8	3,6	5,1	5,3	4,4	3,9	3,4	4,0	4,6	4,0	3,0	2,9	2,8	2,9	2.9	3,5	3,6	4,8	4,8	4,2
21—31.08	4,2	4,4	6,5	5,7	5,2	4,4	4,2	6,0	5,6	5,1	4,4	3,9	5,4	5,5	4,8	4,3	3,7	4,3	4,8	4,3	3,2	3,1	3,0	3,3	3,1	4,1	3,9	5,0	5,0	4,5
01—05.09	3,2	3,0	6,0	4,5	4,2	3,4	2,9	5,4	4,5	4,0	3,4	2,9	4,7	4,4	3,9	3,5	2,9	3,6	4,0	3,5	2,9	2,8	2,7	2,7	2,8	3,3	2,9	4,5	4,0	3,7
01—31.08	4,1	4,6	6,5	5,8	5,2	4,3	4,4	6,0	5,7	5,1	4,3	4,1	5,4	5,5	4,8	4,2	3,8	4,4	4,8	4,3	3,2	3,1	3,1	3,2	3,2	4,0	4,0	5,1	5,0	4,5
24.07—05.09	4,3	4,9	6,9	6,0	5,5	4,6	4,6	6,3	5,9	5,3	4,6	4,3	5,7	5,8	5,1	4,5	4,0	4,6	5,0	4,5	3,4	3,3	3,2	3,3	3,3	4,3	4,2	5,3	5,2	4,8

to the monothermic layer, which has been mentioned in the paragraph 2.

c) Insolation-radiation type (temperature decreases in the upper part of the section and grows in the lower part with the depth) occurs in single days, mainly at a cloudless or slightly cloudy sky, as *e.g.* on August 13 in the morning (Fig. 7). This type does not comprise the whole investigated profile, confining only to its outer part, about 20 cm thick. This layer is divided into three thermal layers. Two of them, upper and lower ones are warm, separated by a cooler layer. Below, the temperature keeps decreasing with the depth due to a close vicinity of the permafrost.

Mean temperature of ground layer of 1—50 cm

The mean temperature of the 1—50 cm layer is the complex index used in comparison of thermal relations in the three analyzed ecotopes (Tables 1 and 2, Fig. 3). We are conscious of the physical limitations of this index; however, it seems to be applied for a determination of thermal differences between particular ecotopes.

In the light of mean values of this index, the beach forms the coolest environment, the moraine is the warmest one, which only slightly differs in this respect from the tundra. Such relations between ecotopes maintained, in principle, throughout the whole period of measurements, whereas the differences between them changed in particular days. The greatest thermal differences between ecotopes occurred at the start of the measuring period (July 24 — September 5) at a sunny weather. On July 29 these differences reached, in the light of daily means for the 1—50 cm layer, the maximum value, amounting between the beach and the moraine to 1.7°C and between the tundra and the moraine to 0.6°C. The least differences occurred between the beach and the moraine, amounted to 0.3°C (August 19). It should be underlined that within 6 days of the second decade of August the mean daily temperature of the tundra came up to the analogic temperature of the moraine, and even within 2 days exceeded temperature of the latter by 0.1°C.

The fluctuations of mean daily temperatures in the measurement period were the highest on the moraine (4.7°C), then on the beach (4.4°C) and the lowest ones on the tundra (3.8°C). Much higher values are reached by fluctuations of mean temperature of the 1—50 cm layer determined on the basis of field measurements. The highest values of this index on all the ecotopes occurred on July 24 at 13 h and the lowest on September 4 at 07 h. The extreme values amounted to 9.0°C and 1.2°C on the beach, to 10.3°C and 2.4°C on the moraine and to 10.0°C and 2.0°C on the tundra. So, the temperature fluctuations determined by the measurements for the period July 24 — September 5 amounted to 7.8°C on the beach, to 7.9°C on the moraine and to 8.0°C on the tundra.

Against the background of the general decreasing trend of the mean daily temperature values of the ground layer 1—50 cm, the gradual decrease of thermal differences between the ecotopes have been also observed. At the beginning of the measuring period the greatest interdiurnal temperature changes of the whole layer have been marked. They reached 1.3°C on the beach (July 24—25). The mean daily temperature run of the 1—50 cm layer was only slightly varying (Table 2). The highest mean daily temperature calculated on the basis of performed measurements occurred on the beach (1.3°C), varying only slightly in this respect from the moraine and the tundra (by 1.1°C). In all three ecotopes the diurnal mean maximum temperature occurred at 13 h, and next at 19 h. The maximum temperatures occurred at 01 and 07 h whereas the mean has been the same in the given site. The comparison of a mean temperature of 1—50 cm layer in the analyzed ecotopes at particular observation terms has proved that the spatial differences between them were the highest at night and in the morning, decreasing during the day and the evening.

The above spatial differences are mainly caused by physical properties of the ground of the investigated ecotopes because the influence of thermal energy from outside is the same. There are either no significant differences in the value of absorbed solar radiation dependent on the albedo of their surfaces. For instance the superficial layer of the beach, in spite of the light colour of sand, is heated stronger than on the moraine and tundra. No significant differences occur, either, in the night cooling of these sites. Therefore, one should assume that the heat conductivity and the thermal capacity of a ground are the main factors that influence the thermal conditions of these ecotopes.

Final remarks

The general qualitative model of the annual and diurnal thermal regime of the land ground corresponds to the theory of molecular heat conductivity of J. B. B. Fourier. Quantitative indices of this model under natural conditions depend on the physical properties of ground, being disturbed by meteorologic factors, mainly by cloudiness and atmospheric precipitation.

In Spitsbergen the permafrost occurring beneath the active layer is an additional disturbing factor. A more detailed recognition of the thermal regime of the outer ground layer in Spitsbergen against the background of meteorologic conditions requires additional investigations of the section, concerning the ground compactness and dynamics of water content, thermal capcity, heat and temperature conductivity. These investigations will be carried out during the next polar expedition.

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[1] International conferences on the problem of permafrost:
First International Conference on Permafrost at Purdue University, Lafayette, Indiana, USA, 17—19th July 1963.
Second International Conference on Permafrost at Yakutsk, Siberia, USSR, 16—20th July 1973.
Third International Conference on Permafrost at Edmonton, Alberta, Canada, July 10—13, 1978.
Fourth Permafrost International Conference, Fairbanks, Alaska, USA, July 17—22, 1983.

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Резюме

1. Исследования термики грунта проводились во время III-ей Торуньской полярной экспедиции „Шпицберген 1978” на приморской низмеенности Каффиейра (земля Оскара II-го) в период 24 июля — 5 сентября 1978 г. Измерения температуры грунта проводились на 3 постах представительных для основных экотопов полярной среды (рис. 1): песчаного

приморского пляжа (B), тундры (T) и морены (M). Эти экотопы разнились друг от друга термической ёмкостью и теплопроводимостью грунта.

2. Температуру измеряли с помощью ртутных термометров на глубине 1, 5, 10, 20 и 50 см. Показания термометров отсчитывали во время стандартных метеорологических наблюдений в 01, 07, 13 и 19 часов LMT. На основании измерений в 4 срока исчисляли среднесуточные температуры для отдельных глубин (табл. 1, рис. 2 и 3), а также средние декадные и средние для всего периода (табл. 1 и 2). В качестве комплексного показателя была принята средняя температура (t) всего слоя 1—50 см, которую исчисляли по формуле: $t = (t_1 + t_5 + t_{10} + t_{20} + t_{50}) : 5$. На основе собранного материала и результатов исследований изучали динамику пространственного распределения температуры со дня на день (рис. 4 и 5), а также в суточном цикле. Анализировали также вертикальное распределение температуры в отдельных экотопах, а также среднее распределение и зависящее от условий погоды (рис. 6 и 7). Термические разницы материнской породы исследуемых экотопов сравнивали в конечном счете с помощью вышеуказанного комплексного показателя.

В период исследований преобладала циклонная (т.е. ветряная) погода с частыми атмосферными осадками и туманами. Она иллюстрируется кривыми (рис. 2 и 3) хода инсоляции, скорости ветра и температуры воздуха.

3. В исследуемых экотопах, в вертикальном профиле, обозначаются два слоя: а) Внешний, более тонкий слой изменчивой толщины, в котором термические разницы между исследуемыми экотопами уменьшаются с глубиной, а иногда даже совершенно исчезают. Такую выровненную, или почти выровненную температуру называем монотермией, а глубину ее стабилизации — уровнем или глубиной монотермии. Указанный слой помещается между активной поверхностью и монотермней. Эта верхня часть исследуемого профиля была всегда наиболее теплой на пляже, а наиболее холодной на морене. В этом слое самые большие термические разницы между отдельными экотопами обозначались на активной поверхности. Температуру этой поверхности измеряли на глубине 1 см. Термическая пятнистость активной поверхности обусловленная ее характером зависит также от погоды и изменяется в суточном цикле (табл. 1, рис. 2). Ее наивысшая интенсивность появляется при наиболее интенсивной инсоляции, т.е. в полдень при безоблачном небе, затухая ночью, особенно при пасмурной погоде. б) Нижний слой, расположенный ниже монотермии, в котором с глубиной увеличивается термическая дифференциация между экотопами (рис. 6). В этом секторе вертикального профиля наиболее холодным является всегда пляж, а наиболее теплой морена (обратно чем во внешнем слое). На глубине 50 см вертикальная дифференциация температуры несколько раз больше, чем на активной поверхности, что связано с глубиной залегания пермафроста, наиболее мелкой на пляже, а постепенно более глубокой на тундре и морене. Вертикальные распределения температуры в грунте позволяют выделить еще третий, переходный слой между двумя предыдущими слоями. [н охватывает нижнюю часть слоя (а) и верхнюю часть слоя (б), в которой чаще всего выступает монотермия, в связи с чем он характеризуется наименьшей дифференциацией уровня температуры.

4. В теплом сезоне хорошо обозначается суточный ход температуры. Он коррелирует с характером погоды и видом материнской породы. Наиболее четко он обозначается на пляже, а более слабо на морене и тундре (рис. 6 и 7).

5. Проникание температуры вглубь грунта зависит от физических свойств последнего, т.е. от теплопроводимости (прямо пропорционально) и от термической ёмкости. В связи с этим в вертикалбном профиле наиболее сильно дифференцированы температуры на пляже, а наиболее слабо на морене (табл. 1 и 2, рис. 6 и 7).

Проведенные исследования показали, что в условиях полярного лета, при отсутствии снежнего покрова, в грунте выступают три типа вертикальной стратификации температуры: а) Преобладает летний, инсоляционный тип (температира падает с глубиной). В суточном цикле он выступает в пределе дня и в среднем для всего периода (рис. 7).

Он появляется рано утром обозначаясь наиболее четко в полдень. б) Радиационно-инсоляционный тип (в верхней части профиля температура растет, а в нижней падает с глубиной), который в суточном цикле выступает под влиянием георадиации. Он появляется вечером, обозначаясь наиболее четко в полночь. Этот тип разделяет исследуемый профиль грунта на три слоя, из которых два холодные — верхний и нижний, разделены средним тонким слоем (рис. 7, а также 6, чертежи для 13 августа 01 час). Этот последний слой покрывается с монотермией, в) Инсоляционно-радиационный тип (в верхней части профиля температура падает, а в нижней растет с глубиной), который выступает в отдельные дни при небе безоблачном или с малой облачностью (как напр. 13 августа, 07 час. — рис. 7) и не. охватывает всего исследуемого профиля, ограничиваясь только его внешней частью до около 20 см. Эта часть разделена на три слоя: два теплые — верхний и нижний, разделенные тонким более холодным слоем. Ниже температура падает с глубиной в связи с близостью пермафроста.

Комплексный показатель (средняя температура слоя 1—50 см), несмотря на свою физическую ограниченность, обнаруживает термические различия между отдельными экотопами. В свете средних величин этого показателя (табл. 1 и 2, рис. 3) наиболее холодным является пляж, а наиболее теплой морена, которой лишь в небольшой степени уступает тундра.

7. Более подробное изучение термического режима внешнего слоя грунта на Шпицбергене требует профильных исследований по определению густоты грунта, динамики его увлажнения, термической ёмкости, а также тепло- и температуропроводимости.

Streszczenie

Badania termiki gruntu prowadzono podczas III Toruńskiej Wyprawy Polarnej "Spitsbergen 1978" na nadmorskiej nizinie Kaffiöyra (Ziemia Oskara II) w okresie od 24.07—5.09.1978 r. Pomiary temperatury gruntu wykonywano w 3 punktach reprezentujących zasadnicze ekotopy środowiska polarnego (fig. 1): piaszczystą nadmorską plażę (B), tundrę (T) i morenę (M). Ekotopy te różniły się między sobą pojemnością cieplną i przewodnictwem cieplnym gruntu.

Temperaturę mierzono przy pomocy termometrów rtęciowych na głębokości 1, 5, 10, 20 i 50 cm. Wskazania termometrów odczytywano podczas standardowych obserwacji meteorologicznych o godz. 01, 07, 13 i 19 LMT. Na podstawie pomiarów w 4 terminach obliczono średnie dobowe z poszczególnych głębokości (tab. 1, fig. 2—3) oraz średnie dekadowe i z całego okresu (tab. 1—2). Obliczono, jako wskaźnik kompleksowy, średnią temperaturę (t) całej warstwy 1—50 cm wg wzoru: $t = (t_1 + t_5 + t_{10} + t_{20} + t_{50})/5$. Na podstawie zebranego materiału i wyliczeń przebadano i omówiono dynamikę przestrzennego rozkładu temperatury z dnia na dzień (fig. 4—5) i w cyklu dobowym. Przeanalizowano także pionowe rozkłady temperatury w poszczególnych ekotopach, średnie i w zależności od sytuacji pogodowej (fig. 6—7). Różnice termiczne podłoża badanych ekotopów porównano na koniec przy pomocy wspomnianego kompleksowego wskaźnika.

W okresie badań przeważała pogoda cyklonalna, tj. wietrzna z częstymi opadami atmosferycznymi i mgłami. Ilustrują ją krzywe (fig. 2—3) przebiegu usłonecznienia, prędkości wiatru i temperatury powietrza.

W badanych ekotopach, w profilu pionowym, zaznaczają się dwie warstwy: a) Warstwa zewnętrzna, cieńsza, o zmiennej grubości, w której różnice termiczne między badanymi ekotopami maleją wraz z głębokością, a czasami nawet zupełnie zanikają. Tę wyrównaną lub prawie wyrównaną temperaturę nazywamy monotermią, a głębokość, na której się

ustala, poziomem lub głębokością monotermii. Omawiana warstwa mieści się pomiędzy powierzchnią czynną i monotermią. Ta górna część badanego profilu prawie zawsze była najcieplejsza na plaży, najchłodniejsza zaś na morenie. W tej warstwie największe różnice termiczne pomiędzy poszczególnymi ekotopami zaznaczały się na powierzchni czynnej. Temperaturę tej powierzchni reprezentują pomiary na głębokości 1 cm. Termiczna plamistość powierzchni czynnej, uwarunkowana jej charakterem zależy także od pogody i zmienia się w cyklu dobowym (tab. 1, fig. 2). Największe jej natężenie pojawia się przy największej insolacji, a więc w południe przy niebie bezchmurnym. Zanika ono nocą, szczególnie przy pogodzie pochmurnej. b) Warstwa dolna, leżąca poniżej monotermii, w której wraz z głębokością narasta termiczne zróżnicowanie między ekotopami (Fig. 6). W tym odcinku profilu pionowego najchłodniejsza jest zawsze plaża, a najcieplejsza morena (odwrotnie niż w warstwie zewnętrznej). Na głębokości 50 cm zróżnicowanie poziome temperatury jest parokrotnie większe niż na powierzchni czynnej, co pozostaje w związku z głębokością zalegania zmarzliny, która na plaży występuje najpłycej, na tundrze i morenie stopniowo coraz głębiej. Pionowe rozkłady temperatury w gruncie pozwalają wyróżnić trzecią warstwę, przejściową pomiędzy dwoma poprzednimi. Obejmuje ona dolną część warstwy *a* i górną część warstwy *b*, w której najczęściej występuje monotermia, i w związku z tym jej cechą jest najmniejsze zróżnicowanie poziome temperatury.

W sezonie ciepłym dobrze jest zarysowany dobowy przebieg temperatury. Koreluje on z charakterem pogody i rodzajem podłoża. Najlepiej wyrażony jest na plaży, słabiej na morenie i na tundrze (fig. 6—7).

Przenikanie temperatury w głąb gruntu zależy od jego właściwości fizycznych, tj. od przewodnictwa cieplnego (wprost proporcjonalnie) i od pojemności cieplnej. W związku z tym w profilu pionowym najbardziej są zróżnicowane temperatury na plaży, a najmniej na morenie (tab. 1—2, fig. 6—7). Z przeprowadzonych badań wynika, że w warunkach polarnego lata i przy braku pokrywy śnieżnej w gruncie występują trzy typy pionowej stratyfikacji temperatury: a) Dominuje letni, insolacyjny typ (temperatura maleje wraz z głębokością). W cyklu dobowym występuje w przedziale dnia i przeciętnie w całym okresie (fig. 7), formuje się wcześnie rano, w południe jest wyrażony najpełniej, a ku wieczorowi zanika. b) Typ radiacyjno-insolacyjny (w górnej części profilu temperatura rośnie, w dolnej maleje wraz z głębokością), który w cyklu dobowym występuje wskutek georadiacji. Pojawia się wieczorem, najwyraźniejszy jest o północy. Typ ten dzieli badany profil gruntu na trzy warstwy, z których dwie chłodne — górna i dolna — przedzielone są warstwą środkową ciepłą (fig. 7, a także 6, wykresy z dnia 13.08, godz. 01). Ta ostatnia warstwa pokrywa się z warstwą monotermiczną. c) Typ insolacyjno-radiacyjny (w górnej części profilu temperatura maleje, w dolnej rośnie z głębokością), który występuje w pojedynczych dniach przy niebie bezchmurnym lub z małym zachmurzeniem (jak np. 13.08, godz. 07, fig. 7) i nie obejmuje on całego badanego profilu, a ogranicza się tylko do jego części zewnętrznej do około 20 cm. Dzieli się ona na trzy warstwy, dwie ciepłe — górna i dolna — przedzielone warstewką chłodniejszą. Poniżej temperatura maleje wraz z głębokością na skutek bliskiej obecności wieloletniej zmarzliny.

Kompleksowy wskaźnik (średnia temperatura warstwy 1—50 cm), pomimo swej fizycznej ograniczoności, ujawnia różnice termiczne między poszczególnymi ekotopami. W świetle średnich wartości tego wskaźnika (tab. 1—2, fig. 3), najchłodniejszym środowiskiem jest plaża, a najcieplejszym morena, której niewiele pod tym względem ustępuje tundra.

Pełniejsze rozpatrzenie ustroju termicznego zewnętrznej warstwy gruntu na Spitsbergenie wymaga badań profilowych dotyczących gęstości gruntu, dynamiki uwilgotnienia, pojemności cieplnej i przewodnictwa cieplnego i temperaturowego.

Praca została wykonana w ramach problemu MR.I.29, B. 14.