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Heat exchange in the subsurface soil layer in the Hornsund area (Spitsbergen)*

ABSTRACT: On the basis of the results of direct measurements, the conduction properties of the yearly behaviour of the heat flux conducted in the tundra soil (S) are determined. In general, the cooling period of the soil profile lasted from August to January, with highest intensity in October ($S = -4.8$ Wm^{-2}). A rapid intensification of the heat exchange in the soil occurred in July ($S = 7.4$ Wm^{-2}). The 24-hour values of S were found to vary greatly (from -19 Wm^{-2} to 32 Wm^{-2}). For chosen days, relationships were determined among the particular elements of the heat balance of the active layer.

Key words: Arctic Spitsbergen meteorology, heat exchange with the underlying layer

Introduction

For many years the problems related to the heat relationships in tundra soil have attracted a large interest among the specialists carrying out research on the phenomena and processes occurring in the active layer of permafrost. The previous investigations carried out in the Hornsund area were devoted above all to the problem of heat distribution in the soil profile and its time variations (Czeppe 1966, Baranowski 1968), and also the analysis of the behaviour and depth of the summer soil thawing (Jahn 1982, Grześ 1984).

The purpose of the present elaboration is to characterise quantitatively the exchange of heat conducted in the subsurface soil layer, in an environment representative of the tundra Hornsund coast.

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The investigation results given in the paper involve the analysis of an almost yearlong series of continuous measurements of the heat flux density, conducted in the ground, carried out by the author from 1 August, 1980, to 20 July, 1981, in the vicinity of the Polish Polar Station at Hornsund ($\varphi = 77°00'$ N, $\lambda = 15°33'$ E).

2. Method of the experimental investigations

The measurement post was localised within a raised sea terrace (9 m over the sea level). The typical tundra soil, about 50 cm thick, occurring here, arose from sea sand (Szerszeń 1965). Sand fractions with a large addition of gravel and stones dominate in the mechanical composition of the soil. The sparse soil cover is composed of single clusters of moss and saxifrage. Some physical properties of this soil, determined by the author in a laboratory, are given in Table I.

Table I

Some physical properties of the tundra soil at the measurement post (mean values from August 1980)

Soil layer cm	Soil specific weight $10^3 . kg \cdot m^{-3}$	General porosity %	Solid phase volume %	Current bulk humidity %	Bulk soil heateapacity $MJ.m^{-3}{}^{0}C^{-1}$
0—5	2.54	57	43	20	1.710
5—10	2.59	44	56	17	1.871
10—20	2.60	42	58	16	1.875
20—50	2.62	40	60	20	2.094

The heat flux conducted in the ground was measured directly by means of a system of 4 Middleton fluxmeters linked in series. The measurement sensors were set up at a depth of 2 cm under the ground surface and connected to a TZ 21S type recorder. Such a composition of the equipment provided analog recording of the magnitude and direction of the heat flux conducted just under the ground surface. The positive values of the flux corresponded to the conditions of heat flow towards the deeper layers of the base (soil heating), whereas the negative ones were characteristic of the heat flow from the base to the ground surface (giving up of heat by the base).

3. Results and discussion

The heat exchange in the subsurface layer of the tundra soil depends on the amount of energy reaching the active surface (the ground surface) or that leaving it, and also of the physical properties of the base. Both the direction and the density of the heat flux conducted in the ground are subject to periodic variations, related above all to the conditions of heat energy transformation on the active layer. The very distinct yearly cycle of variations in the heat flux conducted in the ground, reflecting approximately the behaviour of the net radiation, plays a deciding role in the shaping of a large number of periglacial phenomena. The 24-hour variations, although very high, occur only in the Arctic summer.

It follows from Table II that from August to January, in the Hornsund area, the giving up of heat from the ground, by way of molecular con-

Table II

Chosen components of the heat balance of the active layer of the periglacial tundra and the temperatures of the air and soil at the meteorological station at Hornsund (mean monthly values in the research period 1980/1981)

Month	O* $W \cdot m^{-2}$	S $W \cdot m^{-2}$	Ta °C	Tg °C
August 1980	39.2	−0.2	3.8	3.8
September	10.8	−1.1	1.8	1.1
October	−24.9	−4.8	−5.5	−4.3
November	−34.0	−3.6	−13.4	−9.6
December	−33.7	−1.8	−16.2	−16.2
January 1981	—	−4.1	−17.9	−17.8
February	—	2.2	−9.0	−10.8
March	—	−0.3	−16.8	−12.0
April	—	0.2	−11.3	−10.8
May	—	1.0	−4.3	−6.5
June	—	1.2	0.4	−1.4
July 1—20	—	7.4	3.6	2.3

O* — net radiation,
S — density of the heat flux conducted in the ground,
Ta — air temperature,
Tg — ground temperature at 5 cm depth

duction ($S < O$), dominated. This led to a systematic decrease in the soil temperature throughout the profile (Fig. 1). This process was the most intense in October, synchronously with the progressive freezing of the successively deeper layers of the soil profile. The mean density of the heat flux conducted in the ground was then — 4.8 Wm^{-2}.

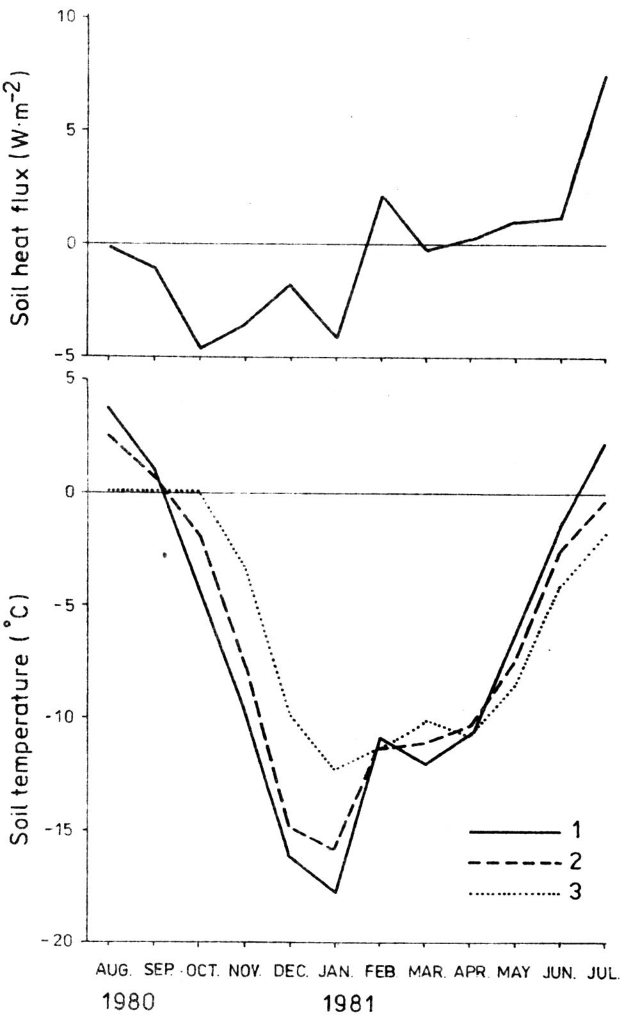

Fig. 1. Yearly behaviour of the conducted heat flux and soil temperatures in the Hornsund area in the research period 1980/1981

1 — depth of 5 cm, 2 — depth of 50 cm, 3 — depth of 150 cm

In Poland (Warsaw — Bielany) the autumn maximum heat loss from the ground is also observed, while the respective value of the flux in October is $-5.5\ Wm^{-2}$ (Grzybowski and Paszyński 1981).

A rather high variability of the general weather conditions, characteristic of the Hornsund area, is reflected in the regime of heat exchange in the ground over shorter time intervals. This is so both in the last days of the polar summer (1 — 18 August), autumn and the whole period of the polar night.

It can be seen in Fig. 2 that at the end of the polar summer, 24-hour changes in the heat flux conducted in the ground correspond distinctly to changes in the net radiation of the active surface. In periods of anticyclonic weather, conditions favourable to heat accumulation in the

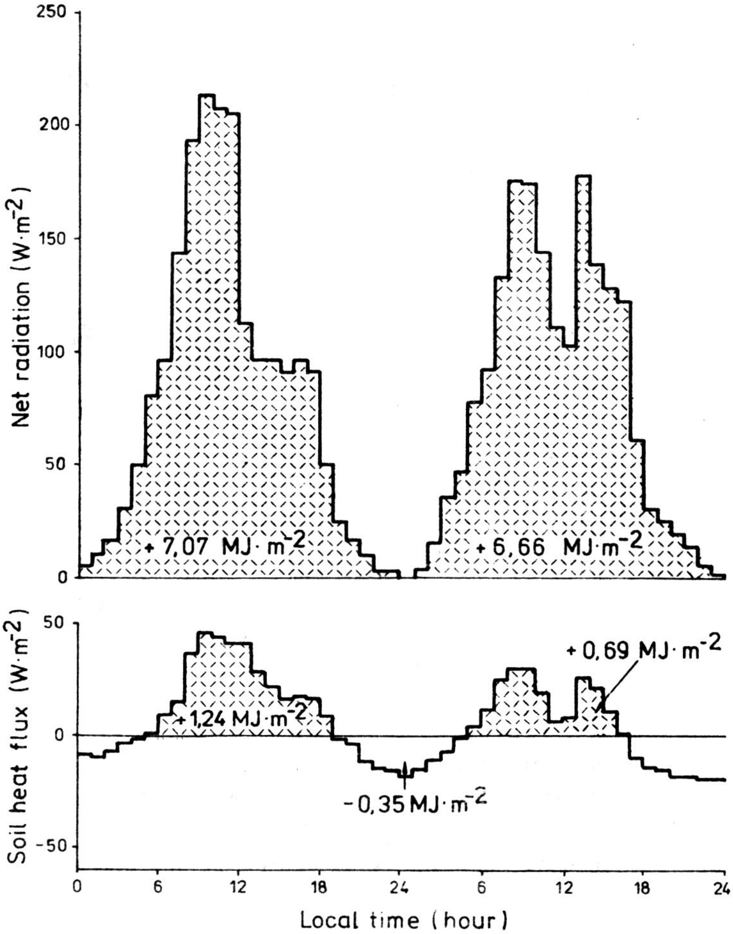

Fig. 2. Mean hourly values of the net radiation and of the density of the heat flux conducted in the tundra soil in the Hornsund area during the polar day (1—2 August, 1980)

base can be observed. Then, almost 15% of radiation energy, absorbed by the ground surface over 24 hours, can be used to heat the deeper layers of the base (Fig. 3). The strong wind contributes to a weakening of the heat exchange in the ground to the advantage of increased sensible heat transport from the ground surface to the atmosphere (convection exchange) and used up for evaporation. This occurred distinetly on 2 August (Fig. 2).

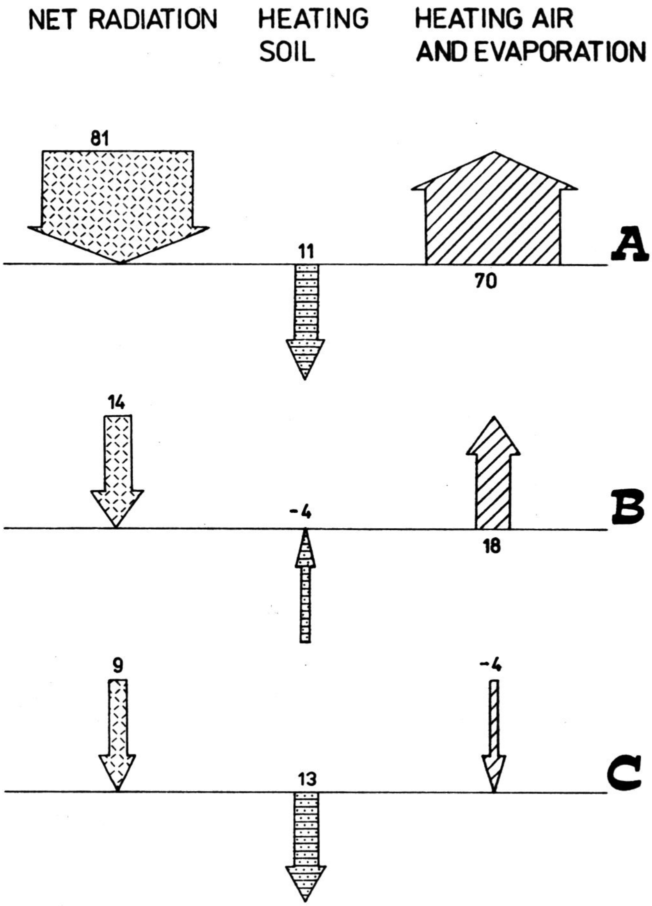

Fig. 3. Schematic diagram of the heat balance of the active surface of the periglacial tundra for chosen days in the summer and autumn seasons of 1980 (numbers represent mean 24-hour energy values)

A — centre of anticyclone (1 August), B — cool advection in the cyclone (20 August), C — intense advection of hot air from the south (25 September)

The negative 24-hour values of the heat flux conducted in the ground (down to $-13\,\mathrm{Wm}^{-2}$), dominating at the turn of summer and autumn, were mainly conditioned by low values of the net radiation (related to a high degree of cloudiness), particularly in periods of advection of cool air from the central Arctic regions. In these conditions the surplus of solar radiation energy and of heat flowing up from the deeper soil layers were used up almost entirely for convection (Fig. 3). Exceptions were sporadic, 1–2 days long, periods of intense advection of heat and humidity at noon, when the energy transported to the ground surface, as a result of still positive net radiation and turbulent fluxes of sensible and latent heat (condensation), were used up to heat the deeper soil layers (Fig. 3).

Neither in October, nor in the following 3.5 — month period of the polar night, the 24-hour behaviour of the heat flux conducted in the ground was observed. For the most part of days, as a result of negative net radiation, the ground surface lost a large amount of heat intermediated in its transport from the deeper layer to the surface. In anticyclonic conditions, the extreme value of the density of the heat flux conducted in the ground was — 19 Wm^{-2}. Only short–term advections of hot air from the south caused a change in the direction of the flux and sometimes rather intense heating of the base (up to 18 Wm^{-2}), which was reflected by an increase in the temperature of the ground surface up to as much as 0°C. The sporadic thin layer of snow cover did not affect significantly the regime of heat exchange in the ground.

The long–term cooling process in the soil profile, dominating from August on, stopped rapidly at the end of the polar night (the 1st decade of February). A high frequency of hot air advection in February brought about high temperatures of the air and the subsurface soil layer (Table II). It was then that a rather intense heat flux, directed from the ground surface to the deeper layers of the base, dominated, with a maximum 24-hour value of 13 Wm^{-2}. In the extremely freezing and windy March, with snow cover often reduced from the base, mainly a not too intense cooling of the subsurface soil layer was observed (Fig. 1).

The heat relationships in the tundra soil in the spring period (April — June) were related almost exclusively to the conditions of shaping of the heat balance of the already stabilized and rather thick (about 40 cm) snow cover. As a result of slow generation of the heat wave (molecular conduction) from the surface of the snow cover to the soil and absorption of slight energy of the penetrating direct solar radiation, a slightly positive heat flux conducted in the ground dominated. Increased heating of the soil occurred only in the thawing periods, in relation to the processes of exchange of mass and energy, and to phase transitions of water, occurring then. At that time, the density of the heat flux conducted in the ground increased to 10 Wm^{-2}. However, the advection thaws were sporadic.

It was not until the disappearance of snow cover (2 July), in general, thet there was a rapid intensification of exchange of heat conducted in the ground. In relation to high absorption of solar radiation by the ground surface (low albedo), there occurred very intense heat accumulation in the base, with a very distinct 24-hour cyclic character. The mean density of the heat flux conducted in July was 7.4 Wm^{-2}, while on some days with good weather it varied between 20 and 32 Wm^{-2}. These values are close to those given by Thompson and Fahey (1977) for the initial days of the summer season in the Canadian Arctic. The maximum soil heating in Poland occurs in May, when the mean density of the soil heat flux is 8—9 Wm^{-2} (Grzybowski and Paszyński 1981).

As snow cover receded from the measurement post at Hornsund, there occurred permanent thawing of the successive lower layers of the soil profile. It was delayed by almost a whole month compared with the prewious year. The process of soil thawing in 1981 was, however, more intense. The "progress" of the 0°C isothermal line in the 5—50 cm soil layer lasted then 11 days, compared with 23 in the previous one. At the end of the research season (20 July, 1981), the temperature of the soil profile was, however, still lower by 0.3 — 1.3°C than the value on the analogous day the previous year. This comparison shows high variability of the thermal relationships for the tundra soil (the climate of the soil) in the Hornsund area. This is so both in terms of a yearly cycle and over longer intervals. This factor must not be neglected in constructing empirical models of the effect of the physical properties of the active layer of permafrost on the behaviour of morphological processes. It also indicates the significant role of meteorological conditions in the Arctic ecosystem.

4. Резюме

В основании работы лежат результаты непосредственных измерений теплового потока в грунте, проведенные вблизи Польской полярной станции в Горнзунде в период от 1 августа 1980 до 20 июля 1981 года.

Охарактеризованы физические свойства тундровой почвы (табл. I), проведен анализ годового и суточного хода теплового потока в грунте (S).

В рассматриваемой период средние месячные величины S изменялись от $-4{,}8$ $W\,m^{-2}$. в октябре до $+7{,}4$ $W\,m^{-2}$ в июле (табл. II). Период охлаждения профиля почвы продолжался от августа до января. Интенсивное накопление тепла в грунте наступило только в июле (фиг. 1).

Установлено, что суточные величины S сильно меняются в течение года. Они умещались в границах от -19 $W\,m^{-2}$ до $+32$ $W\,m^{-2}$.

Суточные колебания S в течение полярного дна явно соответствуют изменениям радиационного баланса солнечной радиации (фиг. 2).

В определенные дни с характерным типом погоды была определена структура теплового баланса подстилающей поверхности (фиг. 3).

Установлено запаздывание размерзания почвенного профиля в сравнении с предыдущим годом.

5. Streszczenie

Podstawę opracowania stanowią wyniki bezpośrednich pomiarów strumienia ciepła przewodzonego w gruncie, przeprowadzone w pobliżu Polskiej Stacji Polarnej w Hornsundzie w okresie od 1 sierpnia 1980 roku do 20 lipca 1981 roku.

Przedstawiono właściwości fizyczne gleby tundrowej (tab. I) oraz przeprowadzono analizę rocznego i dobowego przebiegu strumienia ciepła przewodzonego w glebie (S).

W rozpatrywanym okresie średnie miesięczne wartości S zmieniały się od $-4.8\ W \cdot m^{-2}$ w październiku do $+7.4\ W \cdot m^{-2}$ w lipcu (tab. II). Okres wychładzania profilu glebowego trwał od sierpnia do stycznia. Intensywna akumulacja ciepła w gruncie wystąpiła tylko w lipcu (fig. 1).

Stwierdzono dużą zmienność dobowych wartości S w ciągu całego roku. Mieściły się one w przedziale od $-19\ W \cdot m^{-2}$ do $+32\ W \cdot m^{-2}$.

Dobowe zmiany S w okresie dnia polarnego korespondują wyraźnie ze zmianami całkowitego bilansu promieniowania (fig. 2).

Dla wybranych dni, reprezentujących charakterystyczne typy pogody, określono strukturę bilansu cieplnego powierzchni czynnej (fig. 3).

Stwierdzono miesięczne opóźnienie odmarzania profilu glebowego w stosunku do roku poprzedniego.

6. References

1. Baranowski S. 1968 — Thermics of the periglacial tundra, SW Spitsbergen (in Polish) — Acta Univ. Wratisl. 68, Stud. Geogr. 10, Wrocław, 74 pp.
2. Czeppe Z. 1966 — Behaviour of the major morphogenetic processes in Southwest Spitsbergen (in Polish) — Scientific Reports, Jagiellonian University, Geogr. Reports, 13: 1 - 129.
3. Grześ M. 1984 — Characteristic of the active layer of the long-term permafrost in Spitsbergen (in Polish) — XIth Polar Symposium. Papers and communiqués. Poznań: 65 - 83.
4. Grzybowski J., Paszyński J. 1981 — Heast exchange between the active surface and the ground in the Polish territory (in Polish) — Przegl. Geogr., 53: 711 - 724.
5. Jahn A. 1982 — Soil thawing and active layer of permafrost in Spitsbergen — Acta. Univ. Wratisl. (Results of investigations of the Polish Scientific Expeditions) 4, 525: 57 - 76.
6. Oke T. R. 1982 — Klimaty pogranichnogo sloya — Gidrometeoizdat, Leningrad, 358 pp.
7. Szerszeń L. 1965 — Studies on the soils in the Arctic climate zone in the case of Southwest Spitsbergen (in Polish) — Scientific Reports WSR Wrocław, 60: 39 - 79.
8. Thompson R. D., Fakey B. D. 1977 — Energy Balance and Thermal Regime Studies, Broughton Island, Northwest Territories, Canada — Arch. Met. Geoph. Biokl., Ser. A, 25: 251 - 272.

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