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Short period changes of soil temperature against advective changes of air temperature in Hornsund, Spitsbergen

ABSTRACT: On the ground of continuous records of air and soil temperature at standard levels, changes of soil temperature against changes of air temperature have been analyzed at thick and without snow cover. The first example concerns a six-day winter thaw, and the second one a four-day autumn cooling. A particular influence of energy advection has been noted. A delay of changes of soil temperature was found to increase with depth in relation to air temperature. A hypothesis on correlation between air temperature at a height of 5 cm and soil temperature at a depth of 5 cm has been verified.

Key words: Arctic, Spitsbergen, soil temperature.

Introduction

Several scientists have been already engaged since 1957 in research of soil thermal conditions in Hornsund near the Polar Station of the Polish Academy of Sciences. Among them Baranowski (1968) and Czeppe (1960a, b, 1966) extensively described soil thermal conditions, mainly soil congelation and thawing, on the basis of yearly data from the season 1957—58. Baranowski paid moreover attention to the fact that run of air temperatures at a height of 2 m characterized rightly soil thermal conditions at a depth of 5 cm.

Głowicki (1985) described quantitatively and qualitatively a heat exchange between soil and near-ground atmospheric layer on the basis of expedition materials from 1980—81. Soil temperature measurements in the Polar Station area were done in different sites by members of several summer expeditions.

Wójcik and Marciniak (1984) paid attention to influence of insolation and soil moisture on changes of soil temperature. A heat-insulation role of organic layer (turf or peat) in soil thawing was described among others by Czeppe (1966), Jahn (1970, 1982), Grześ (1984) and Szmyrka et al. (1986). Jahn (1982) considered the occurrence of first-year and old snow patches for a dilatory agent in soil thawing. Szponar (1974), Kozarski (1974) and Grześ (1986) joined a discussion on heat-insulating role of ablation moraine. Moreover Grześ (1984) noted also that structural soil dissimilarities in Hornsund as well as varying physical and chemical properties cause the soil thawing to occur with varying rate and to various depths.

Szerszeń (1965) was the first one who noted the uncommon variety of soils near the Polar Station. In previous works measurements of soil temperature have been mostly done with a use of conventional mercury thermometers and readings were taken at depths of 5 to 50 cm, three or four times a day as well as once a day with a use of extension thermometer at depth of 100 cm.

Similar standard measurements of soil temperature have been systematically made since 1978, all the time in the same site, by the meteorological staff of the yearly expeditions organized by the Institute of Geophysics, Polish Academy of Sciences.

All these data enable to calculate mean many-years' values as well as mean annual variation of soil temperature at different levels with application of the Fourier analysis (Miętus *unpubl.*). They form also the basis for basic statistical characteristics (Miętus *unpubl.*).

The present paper presents examples of dependence of soil temperature upon warm or cool air advection, and also an insulation role of snow cover.

Results and discussion

Simultaneous measurements of soil temperature with a use of mercury and platinum thermometers have been made since 1st November, 1982 to 31st October, 1983. Air temperature was also recorded in the same way. Application of electric thermometers enabled to record constantly the temperature at individual levels and to observe short-period temperature oscillations which could escape at traditional methods of recording. Continuous temperature records of both, air and soil, are particularly useful at examinations of their mutual thermal influence.

Two examples are described in this paper. They are selected from the above mentioned period and enable to investigate soil temperature changes as a result of changes of atmospheric parameters, mainly the air temperature.

The first example comes from the turn of February, 1983 and represents a several-days' mid-winter warming (Fig. 1). Winter of the Hornsund area commonly indicates sudden warmings, often accompanied by abundant snow and rain. The greatest thaw in the West Arctic of winter 1982/83 occurred between February 27 and March 4 due to a strong zonal circulation over the northwestern Atlantic Ocean which transferred warm and humid air from southwestern regions up the Arctic Zone. A displacement of subsequent warm sectors caused also a rapid change of weather over Hornsund.

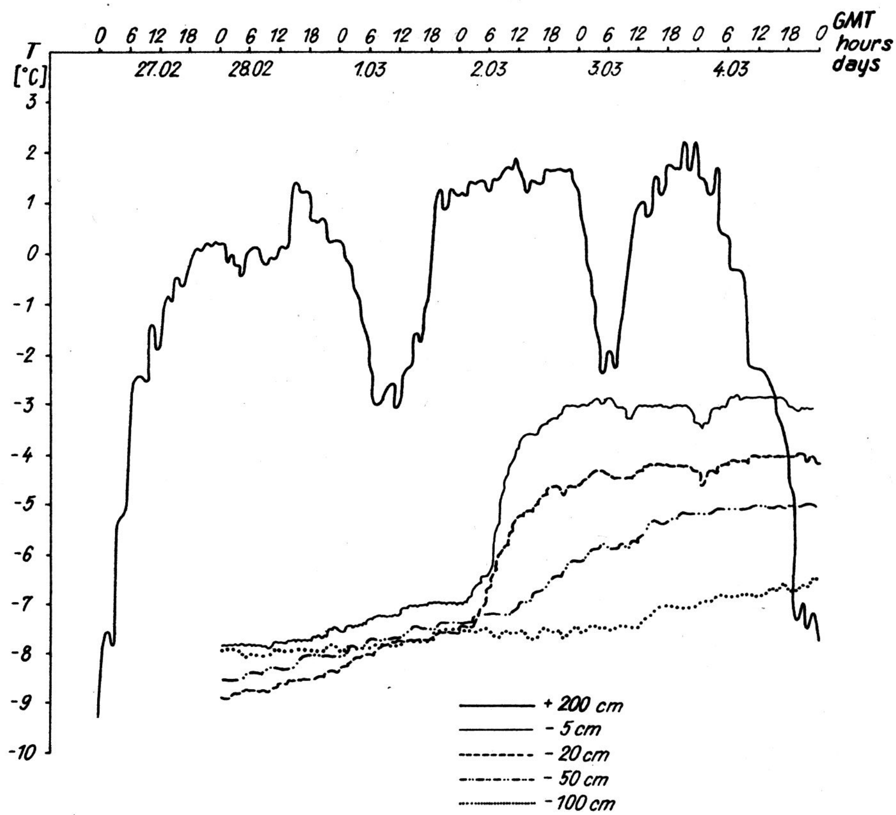

Fig. 1. Variation of soil temperature at depths of 5, 20, 50 and 100 cm against changes of air temperature at height of 200 cm in Hornsund, February 27 — March 4, 1983

During a single day (February 27) the air temperature rose from −11°C to 0°C, and in the next days to +2°C. There was no sunshine though already on February 12 the polar night was over. On March 1 an abundant snowfall and then rain appeared. A thickness of the snow cover (dry at first) dropped from 54 cm on February 27 to 42 cm on March 4.

Unfortunately temperature has not been measured inside a snow cover. However we can most certainly find that it acted as heat-insulating layer for the soil but only during the first three days. In that time a rise of air temperature caused a very slow but systematic rise of soil temperature at levels of 5, 20 and 50 cm (Fig. 1). Only the temperature at a depth of 100 cm which was formed by long cold periods in January-February (mean monthly air temperatures equal −8.9°C and −13.5°C respectively) did not indicate explicit upward trend and kept to about −8°C.

Abundant rainfall starting at 7 GMT on March 1 and lasting until afternoon next day (29.3 mm of liquid fall) caused intensive infiltration of water through a snow cover and its degradation. Degradated snow cover enabled a direct contact of warm air with soil surface. Furthermore the water seems probable to have infiltrated deeper into the soil. A deterministic role of these factors is proved by a sudden rise of soil temperature in shallower levels since March 2. The level at −5 cm responsed the first as its temperature rose between 00 to 09 GMT from −7°C to −3°C, and the rise rate amounted to $V_t = 0.19°Ch^{-1}$. About an hour later the gauge at a depth of 20 cm recorded a dynamic rise of temperature. A warming of soil at this level was 3—4 hours retarded and occurred in the rate of $V_t = 0.13°Ch^{-1}$. Still a greater delay, i.e. 12 hours after the gauge at a depth of 5 cm, was noted by temperature changes at a depth of 50 cm. Warming of this level lasted about 1.5 day and rate of temperature rise was equal $V_t = 0.07°Ch^{-1}$.

Beginning of the temperature rise at a depth of 100 cm has been recorded about noon on March 3 i.e. about 36 hours later than at a depth of 5 cm. Therefore, a heat wave reached 1 m in depth of soil with a rate of $w = 2.63$ cm h^{-1}. Heating at 100 cm was very slow, within 1.5 day the temperature rose only about 1°C what makes an average rate of $V_t = 0.03°Ch^{-1}$.

Insulating properties of the non-degradated snow cover for a soil have been confirmed by examples of air warming when no sudden rise of soil temperature was noted, even in the shallowest layer (Fig. 2).

Changes of soil temperature from February 28 to March 4, 1983 are also presented by analysis of vertical profile of soil temperature (Fig. 3). The profile shape is here similar at 00, 06, 12 and 18 GMT. There are only small temperature oscillations at individual levels. On March 2 we already observe changes of a profile shape. During a single day, temperatures at depths of 5, 20 and 50 cm rise distinctly. The profile shapes of 12 and 18 GMT indicate a distinct heat transfer into a soil, however with different rates at individual layers.

Profiles of March 4 are already distinctly misshapen to a depth of 50 cm and speed of heat transfer at individual levels is being delayed. Only at a depth of 100 cm the temperature keeps rising.

The second example presents four days between October 7—10, 1983, indicating distinct changes of air and soil temperatures. During this time

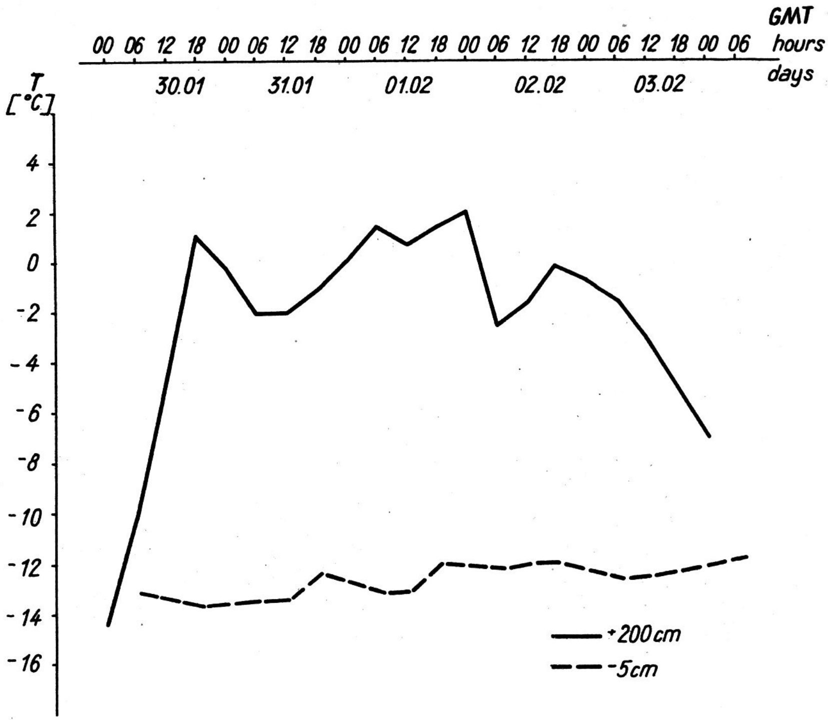

Fig. 2. Variation of soil temperature at depth of 5 cm against changes of air temperature at height of 200 cm in Hornsund, December 30, 1982 to January 3, 1983

Spitsbergen occurred at a border of filling low, replaced then by developing high-pressure area from Greenland with a little cooler air. Varying and periodical small cloudiness enabled during a day an insolation for a couple of hours (on October 7, 9 and 10) but at nights facilitated backradiation. A snow cover formed firstly only thin sheets, then became compact on October 9 but of a depth of only 1 cm and therefore did not acted as essential insulation layer. There were mostly moderate winds with speed of 4 to 10 ms^{-1} from NE and E. On October 7—8 a calm lasted for almost 24 hours.

During this period a great conformity occurs in curves of air and soil temperatures (Fig. 4). A characteristic time-shift of about three hours is noted between changes of soil and air temperature. Amplitudes of soil temperature changes are restrained: one or two-hour air temperature oscillatons are smoothed in soil and not indicated by changes of its temperature. From October 8 to 9 air temperature decreased at a rate of $-0.26°Ch^{-1}$ while soil temperature only at a rate of $-0.18°Ch^{-1}$. However from October 9 to 10 temperature has risen in both media at rates of $0.5°Ch^{-1}$ and $0.2°Ch^{-1}$ respectively.

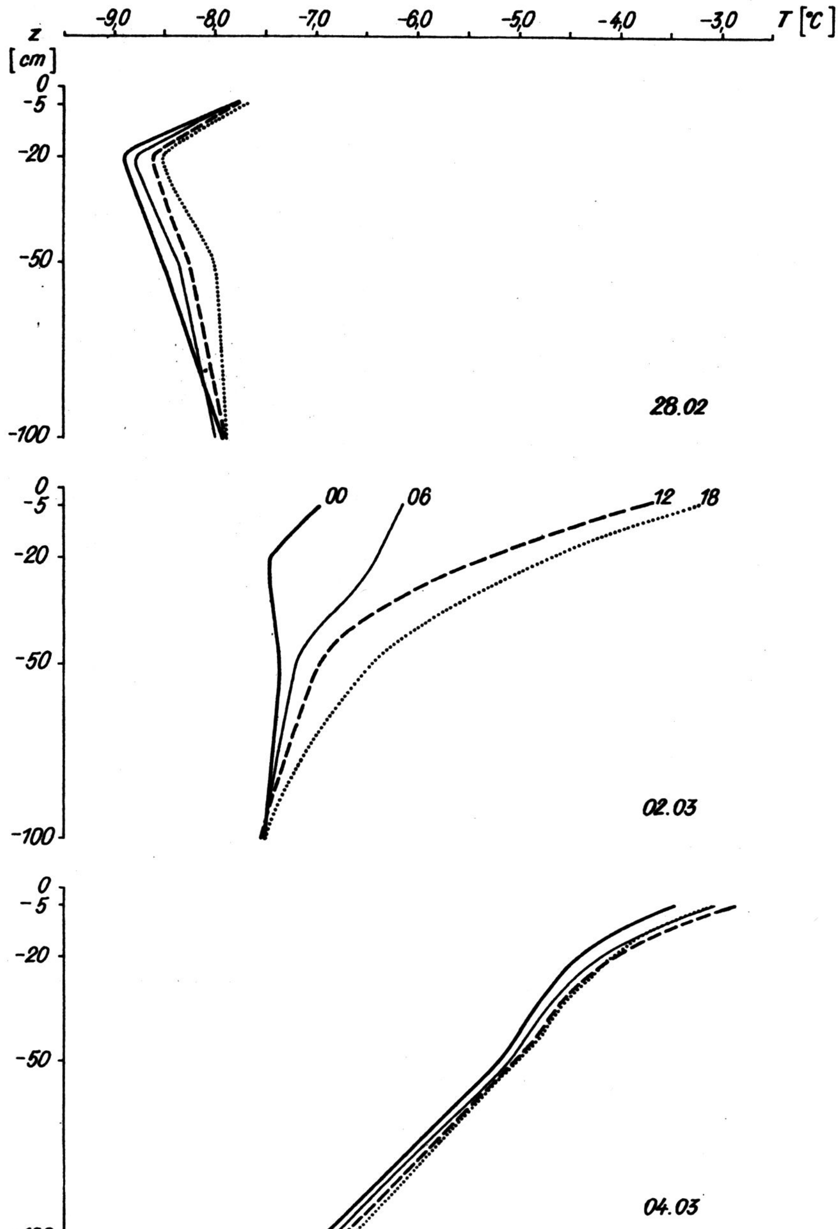

Fig. 3. Vertical profiles of soil temperature during a warming. Curve for March 2 supplied with steady observation hours

If considering a three-hour delay of soil temperature reaction at a depth of 5 cm due to changes of air temperature at a height of 5 cm, we can speak about a strong correlation between these temperatures (values of correlation coefficients $r \geqslant 0.83$ in individual time intervals).

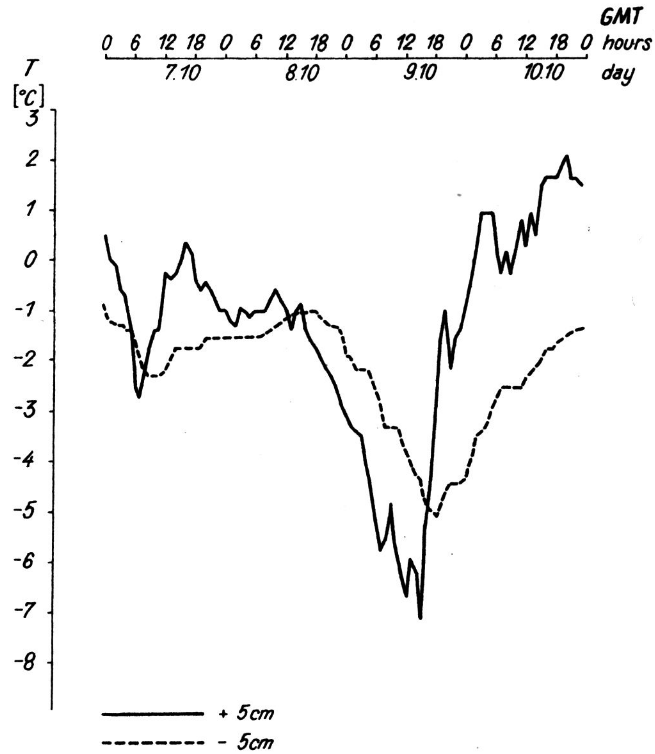

Fig. 4. Variation of soil temperature at depth of 5 cm against changes of air temperature at height of 5 cm in Hornsund, October 7 to 10, 1983.

Zero hypothesis has been verified that no correlation dependence was found in the whole general population $(R/t_p,\ t_g/ = 0)$ upon the alternative that such a dependence exists $(R/t_p,\ t_g \neq 0)$. Computed value of a variable $t = 4.88$ of Student distribution with n-2 degrees of freedom is greater than critical value for a confidence level $\alpha = 0.05$ and 94 degrees of freedom (calculations were made for the whole period on the basis of 96 values of air and soil temperature). Therefore in the case of thin snow cover a dependence of soil temperature (5 cm under the surface) on air temperature (5 cm above it) is true for the whole population.

Conclusions

Analysis of main meteorological parameters during selected periods and particularly changes of air and soil temperatures, resulted in the following conclusions:

— advection of energy intensively increases a heat exchange between the soil and the air above it;

— dry, homogeneous and sufficiently thick snow cover results in a good heat insulation for a soil whereas degraded and wet cover does not protect from exchange of heat energy;
— delay in soil heating depends on depth;
— heating rate is different for individual levels;
— there is a strong correlation between air and soil temperatures at levels of +5 cm and −5 cm respectively with regard to adequate delay at a thin snow cover;
— dependence between these temperatures exists for the entire population.

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Streszczenie

Analizując zmiany temperatury gruntu na tle zmian temperatury powietrza na stacji PAN w Hornsundzie w okresie 1983.02.27—03.04 (fig. 1) należy podkreślić znaczenie adwekcji ciepłego powietrza dla wymiany energii między gruntem a zalegającym nad nim powietrzem. Wystąpiło duże opóźniene w nagrzaniu się gruntu pomimo wysokiego skoku temperatury od $-11°C$ do $+2°C$ w krótkim okresie czasu i utrzymywanie się jej powyżej zera przez parę dni. Zaleganie grubej, nietkniętej pokrywy śnieżnej pozwoliło jedynie na niewielkie ogrzanie się gruntu. Dopiero opad deszczu (29,3 mm w ciągu około 20 godzin), zniszczenie pokrywy oraz jej przesiąknięcie spowodowało intensywne ogrzewanie się gruntu. Dynamika ogrzewania słabła od $0.19°Ch^{-1}$ na poziomie -5 cm do $0.03°Ch^{-1}$ na poziomie -1000 cm. Prędkość przenikania fali ciepła do głębokości 100 cm wynosiła 2,63 $cm \cdot h^{-1}$; co daje 1,5 dobowe przesunięcie między gwałtownym wzrostem temperatury na głębokości 5 cm i jej wyraźnym wzrostem na poziomie -100 cm. Fakt termoizolacyjnej roli grubej, jednorodnej pokrywy śnieżnej dla gruntu potwierdzają inne, liczne przykłady zimowych ociepleń, w których nie wystąpiły opady deszczu (fig. 2). Chwilowe profile temperatury gruntu z przełomu lutego i marca 1983 roku zmieniają kształt w miarę zmiany warunków atmosferycznych (fig. 3). Zmiany temperatury gruntu tuż pod powierzchnią, na głębokości -5 cm, na tle zmian temperatury powietrza na wysokości $+5$ cm omówiono na przykładzie krótkiego okresu o wyraźnych zmianach temperatury powietrza (fig. 4), gdy na powierzchni gruntu zalegała świeża pokrywa śnieżna o grubości 1 cm. Zaobserwowano 3 godzinne opóźnienie reakcji gruntu na zmiany temperatury powietrza.

Występuje silny związek korelacyjny pomiędzy temperaturami obu ośrodków na poziomach odpowiednio $+5$ cm i -5 cm przy uwzględnieniu 3 godzinnego przesunięcia czasowego. Z prawdopodobieństwem 0,95 można przyjąć hipotezę o istnieniu zależności między tymi temperaturami w całej populacji.

Praca została wykonana w ramach tematu CPBP 03.03. B.13.