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*GEOTHERMAL FIELDS AND THERMAL PROCESSES IN CRYOSPHERE*

# INFLUENCE OF METEOROLOGICAL CONDITIONS ON THE THERMAL INSULATION PROPERTIES OF MOSS COVER ACCORDING TO MEASUREMENTS ON SVALBARD

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On the basis of experimental studies, an assessment of the influence of air temperature and weather type on the heat-shielding properties of the moss cover has been given. It has been revealed that in sunny weather with light cloudiness, the highest temperature of the soil surface under 1 cm thick moss is almost by 13 °C higher than under 5 cm thick moss, while in cloudy weather that difference is 3 °C. The measurements has demonstrated that for the period of 06.07 to 08.08.2016, the average temperature of the 70 cm thick soil layer under the 5 cm thick moss cover was by 1.5 °C lower than that under the 1 cm thick one.

***Key words:*** *meteorological conditions, moss cover, ground temperature, Svalbard.*

## INTRODUCTION

To study the response of permafrost to modern climate changes and to develop methods to reduce the negative consequences of the permafrost degradation, it is necessary to study the effect of ground cover on the soil thermal regime. Ground covers have a significant effect on soil temperature [*Novikova, 2016; Kaverin et al., 2019*]. The most common ground cover in the permafrost zone is moss, which is a natural heat insulator. Thermal insulation properties of moss and their year-round dynamics are not studied enough. That is due to large species diversity of mosses and insufficient studies of their thermophysical parameters. The heat-insulating role of the ground covers of the Arctic tundra is considered in the monograph [*Pavlov, 2008*], which presents the results of studies of ground covers effect on the soil surface temperature. A review of studies of thermal conductivity of mosses is presented in [*Tishkov et al., 2013*].

Moss cover, as well as snow cover, reduces heat transfer between the surface air and the underlying substate. However, in contrast to the snow cover, which insulating role is revealed mainly in the period with negative air temperatures, the effect of the moss cover is year-round. The moss cover protects the surface soil layer from summer heating during the period with positive surface air temperatures and from winter cooling, especially under small snow thickness. The snow cover protects the ground from warming-up to positive temperatures only during winter thaws and snowmelt period. In the summer, the moss cover is the main factor which reduces ground heating and thawing, and in the cold season it serves only as an addition to the insulating effect of the snow cover.

To determine the effect of moss cover on the soil thermal regime in the warm season, the authors carried out field measurements for 30 days in July–August in the area of the hydrometeorological station (HMS) in Barentsburg (West Spitsbergen island). The purpose was to study the effect of moss cover on the soil temperature regime, depending on the air temperature and weather type. Previous studies have shown [*Tishkov et al., 2013*] that in mid-August near the Barentsburg settlement the soil surface temperature under 8 cm thick moss cover is by 4 °C lower than in its absence. The depth of loam thaw under 8 cm thick moss cover was 0.98 m with a 0 °C ground temperature at that depth. At the adjacent site without a moss cover, the loam temperature at a depth of 0.98 m was 4 °C with 1.9 m depth of thaw. According to the measurements, the depth of daily temperature changes was 0.1 m under the moss cover and 0.3 m without it. During the period of positive air temperatures, the presence of a moss cover lowers the soil temperature and significantly reduces the depth of thaw.

In the cold period of the year, the thermal conductivity of the frozen moss *Hylocomium splendens* var. *alascanum* is 3–4 times higher than in the summer [*Tishkov et al., 2013*]. This is because the thermal conductivity of ice is approximately four times more than that of water, and the moss water content increases before freezing due to autumn rainfalls. The frozen moss cover is a solid moss-ice monolith. Therefore, the frozen moss cover is not a significant obstacle to soil cooling in the cold season.

The begining time of residual thaw layer formation depends on climatic changes, the parameters of snow and moss cover, and soil water content [*Kudryavtsev, 1978; Pavlov, 2008*]. Our calculations have revealed [*Sosnovsky, Osokin, 2018*] that for the conditions of the Svalbard Archipelago with 1-m thick snow cover and a sandy-loam with 18 % gravimetric water content, the presence of a 5 cm thick moss cover of *Hylocomium splendens* var. *alascanum* shifts the beginning of of residual thaw layer formation by 24 years, taking into account the data of the regional climate change model [*Forland et al., 2011*]. Thus, under conditions of low (4–5 °C) positive mean daily air temperatures on Svalbard, a decrease in the soil mean annual temperature under the moss cover by several degrees can compensate for a possible increase in air temperature during warming, which protects permafrost from degradation. In [*Cable et al., 2016*] it is noted that in some landscapes of Western Alaska, the absence of a moss layer indicates the absence of permafrost near the surface. Therefore, when calculating the effect of climatic changes on the state of permafrost, it is necessary to take into account the thermal insulation role of the moss cover.

The heat insulation properties of moss are characterized by its thermal resistance and depend both on its thermal conductivity and on features of exact species that determine its water content, density, and structure. The heat insulation role of moss determines the temperature difference between the surface and the moss layer base. It depends on thermal resistance of moss, meteorological conditions and underlying soil properties. In [*Alekseev, 2014*], it is noted that warming in the Arctic is associated with changes in incoming solar radiation regime. During sunny weather, the heat insulation role of moss increases compared to cloudy weather. That is due, in particular, to the different albedo values of the sediment surface and moss. The albedo of soil without vegetation is 17 %, those of black moss and green moss (solid cover) are correspondingly 18 % and 32 % (*http://www.ifaran.ru/...reports/Artamonov.pdf*), while in clear weather the total solar radiation is several times higher than in cloudy weather. As a result, the moss-covered sites will reflect significantly more solar radiation than the sites without moss cover. In cloudy weather, the difference in the temperature regime of these sites will be much smaller.

Water content of the moss and, as a consequence, its thermal conductivity [*Tishkov et al., 2013*] depend on meteorological conditions. Therefore, the variability of meteorological parameters under climate change will affect the heat-insulating role of moss and heat transfer in the ‘atmosphere–soil’ system.

Under the conditions of climate change, the number of hazardous meteorological phenomena increases [*A report..., 2020*], which include heavy precipitation. Over the past 20 years, its amount has been almost tripled. A decrease in the number of rainy days has been recorded on most of the land around the earth, except for high latitudes in the Northern Hemisphere. In the period of 2000–2099 an increase in the average intensity of precipitation is predicted throughout the land. Analysis of the mean annual precipitation for 1900–1999 has revealed positive trends over continental regions [*Semenov, Bengtsson, 2002*]. A disproportionate increase in heavy precipitation on land, including local maxima in Europe and the Eastern United States, has been identified. For Svalbard, the amount of the mean annual precipitation in most of the archipelago has increased by 10–20 % from 1915 to 2005 [*Forland et al., 2011*]. In rainy weather, part of the precipitation accumulates in the moss cover, increasing its water content and thermal conductivity.

The work [*Pokrovsky, 2019*] presents the results of the analysis of global and regional cloud cover for 1983–2009 obtained within the framework of the International Satellite Cloud Climatology Project (ISCCP). The results of the analysis have demonstrated a decrease in global and regional cloud cover by 2–6 %.

Thus, as a result of climate change and meteorological parameters, the heat-insulating role of the moss cover may change. Therefore, the study of the influence of air temperature dynamics, solar radiation, cloud cover and precipitation on the soil thermal regime under the moss cover will help to make more accurate predictions of permafrost degradation.

The aim of the research is to assess the influence of meteorological conditions on the thermal insulation properties of the moss cover and on the thermal regime the active layer of Arctic soils based on measurement data from Svalbard.

## THERMAL PROPERTIES OF MOSS

There are dozens of moss species on Svalbard. They differ both in the thickness of the moss cover and in structural features. *Hylocomium splendens* var. *alascanum* is one of the most common moss species in the area of Barentsburg settlement (Spitsbergen). Its thickness is 5–8 cm and its density is 176 kg/m$^3$ with water content of 200 %. The moss cover affects near-surface permafrost thawing through the thermal state of the soil and its reaction to meteorological conditions changes, especially in summer. In that case, an important factor is the thermophysical properties of moss, which determine its heat insulation ability. A review of studies of the thermophysical properties of moss is given in [*Tishkov et al., 2013*]. The review presents the values of thermal conductivity of some types of moss obtained during field studies.

The thermal conductivity coefficients of *Hylocomium splendens* var. *alascanum* are calculated for the warm and cold periods of the year according to the formulas obtained in [*Tishkov et al., 2013*]:

$$\lambda_t = 0.0003w + 0.0645, \lambda_c = 0.0014w + 0.0645,$$

where $w$ is water content of moss cover (%).

With a water content of 200 %, moss thermal conductivity coefficients in summer and winter are correspondingly 0.12 and 0.34 W/(m·K), and the thermal resistance of a 5-cm thick layer of moss is 0.40 and 0.15 ($m^2$·K)/W, correspondingly. In winter the thermal resistance of a 5-cm thick layer of moss with 200 % water content corresponds approximately to the thermal resistance of a 2.5-cm thick layer of snow with a density of 200 kg/$m^3$. Note that the consequence of these formulas is an increase in the coefficient of thermal conductivity of moss with an increase of its water content. Therefore, in sunny weather, when the water content of moss decreases, its thermal conductivity is lower. Thermal insulation properties of moss are enhanced compared to rainy weather.

The thermal conductivity of thawed moss varies within 0.1–0.2 W/(m·K) and depends on its species and water content [*Tishkov et al., 2013*]. The thermal conductivity of frozen moss increases 2–3 times with water content growth.

According to P.N. Skryabin [*Pavlov, 1980*], in the summer of 1978 at the Syrdakh station (Yakutia) for brie mosses, which are distinguished by a large species diversity, with a moisture content of 74–350 %, the values of thermal conductivity coefficient were 0.08–0.30 W/(m·K). At an average water content of 200 %, the thermal conductivity of moss was 0.14 W/(m·K).

## RESEARCH AREA AND METEOROLOGICAL CONDITIONS DURING THE MEASUREMENT PERIOD

Soil temperature was measured in the Arctic tundra on the coast of Grönfjord Bay (Spitsbergen island) in the immediate vicinity of the Barentsburg hydrometeorological station (Barentsburg settlement) in the period from July 6 to August 8, 2016.

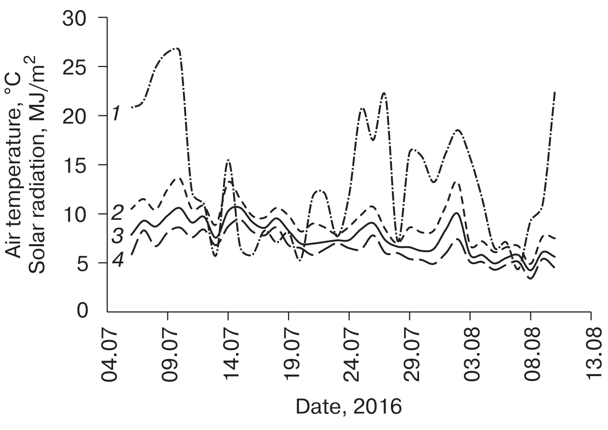


**Fig. 1. Dynamics of total solar radiation (*1*) and air temperature.**

Air temperature: *2* – maximum, *3* – average daily, *4* – minimum.

Spitsbergen is a mountainous area half of which is covered with glaciers. In the coastal zone, there are flat areas free of ice and occupied by Arctic tundra with poorly developed soil cover, low air temperatures, low soil organic matter content and frequent freeze-thaw cycles.

For the Spitsbergen island near Svalbard Airport, the mean-annual air temperature from 1961–1990 to 1981–2010 has increased from –6.7 to –4.6 °C. Over the calendar summer and winter months, the air temperature during these periods has increased from 4.2 to 5.2 °C and from –15.1 to –11.7 °C [*Forland et al., 2011*]. An increase in air temperature leads to an increase in the thickness of the seasonally thawed layer (STL). Monitoring of the STL thickness in a well drilled in Janssonhaugen 20 km from Longyear, the capital of Svalbard (*http://www.mosj.no/...*), has revealed that over 20 years (from 1998 to 2017), the STL thickness has increased 1.2 times, from 154 to 185 cm.

To measure the soil temperature, two sites with 1 cm thick (*Gymnomitrion* sp., liverwort with a dark surface) and 5 cm thick (*Hylocomium splendens* var. of green color) moss cover, with a diameter of at least 5 m each have been selected. Temperature sensors have been placed in sandy loam with a water content of 18 % to a depth of 0 to 90 cm with an interval of 10–20 cm and at a height of 10 cm above the moss surface. The STL thickness varied from 120 to 250 cm. The temperature recording interval was 30 minutes, which made it possible to track the influence of weather conditions variability on the temperature of STL. The air temperature (data from the website *http://rp5.ru/archive.php?wmo_id=20107*) during the observation period varied from 13.6 °C on July 10, 2016 to 3.4 °C on August 8, 2016 (Fig. 1). At the same time, the maximum daily temperature range was 5.8 °C and was recorded on August 2, 2016. During the measurement period, there were both days with low cloudiness and maximum total daily solar radiation and days with 100% cloudiness and showers with an intensity of up to 20 mm of precipitation have been recorded for several hours (Fig. 1).

Air temperature is largely determined by solar radiation. Thus, the daily maximum air temperature falls mainly on the maximums of the total daily solar radiation (Fig. 1). The maximum total daily solar radiation falls on July 9 and 10, 2016 and is equal to 26.5 MJ/$m^2$. The minimum total daily solar radiation was recorded on August 7, 2016 and is equal to 4.4 MJ/$m^2$. On this day, 26 mm of precipitation fell.

Small values of solar radiation fall on July 13, 16 and 20, 2016 (showers and drizzle) and amount to 5.3–5.8 MJ/$m^2$. The average value of the total solar radiation for the period from July 6 to August 8, 2016 is 13.3 MJ/$m^2$.

## Influence of dayly dynamics of weather conditions on the thermal regime of the active layer under moss cover of different thickness

Let us consider the influence of meteorological conditions (air temperature, solar radiation, cloudiness and precipitation) on the thermal regime of active layer under moss cover of different thickness.

Figure 2, *a* shows the air temperature on July 9, 2016 according to the Barentsburg hydrometeorological station (73 m a.s.l.), air temperature at a height of 10 cm above the moss surface, temperature on soil surface and at depths of 10 and 20 cm under moss cover of 1 and 5 cm thick in clear weather, maximum daily radiation and an average wind speed of 3 m/s.

The measurements have demonstrated that in sunny weather with light cloud cover, the air temperature at a height of 10 cm above the surface of 1 cm thick moss (curve *2*) is higher than above 5 cm thick moss (curve *3*). After 9:00 this difference reaches 2 °C. At the same time, the highest air temperature at a height of 10 cm reaches 22 °C at 18:30. The highest air temperature at the Barentsburg HMS was 12.5 °C at 21:00.

Soil surface temperature under 1 cm thick moss (curve *4*) constantly increases due to solar radiation up to 23.4 °C at 16:00. At the same time, under 5 cm thick moss cover, the highest soil surface temperature reaches 10.6 °C at 17:00 (curve *5*), which is by 12.8 °C lower than under 1 cm thick moss. The measurements revealed that the maximum temperature difference of the soil surface under 1 cm thick moss and soil at 10 cm depth was 14 °C. The highest soil temperature at 10 and 20 cm depths under 1 cm thick moss was 9.6 and 7.2 °C, respectively. The soil temperature at 20 cm depth under 1 and 5 cm thick moss differed by approximately 1.5 °C (curves *6* and *7*).

Clear sunny weather was also observed on other days. On August 2, 2016, the maximum values of the soil surface temperature under 1 cm thick moss (at 16:30) and 5-cm thick moss (at 18:30) were 22 and 11 °C, respectively. The maximum soil surface temperature under 5 cm thick moss was recorded 2 hours later. The maximum air temperature at the Barentsburg hydrometeorological station on this day reached 13.2 °C at 15:00.

On a sunny day on July 26, 2016, with a total cloudiness of 10 %, the air temperature at 19:00 at a height of 10 cm above moss 1 cm thick and 5 cm thick was 18.5 and 16.9 °C, respectively. Note that on a cloudy and rainy day on August 07, 2016, with a heavy railfall (21 mm of precipitation) and total cloudiness of 100 %, the air temperature at 6:00 at a height of 10 cm above moss 1 cm thick and 5 cm thick was almost equal and amounted to 5.4 °C.

The difference between the soil surface temperature and the air temperature (on a sunny day on July 26, 2016) at a height of 10 cm above the moss cover 1 cm thick was 3.5 °C, while at a moss thickness of 5 cm it was 7.2 °C. The soil surface temperature under 1 cm thick moss was 5.2 °C higher than under 5 cm thick moss. The soil surface temperature under 5 cm thick moss basically does not differ from the air temperature at the hydrometeorological station.

The measurement results on a cloudy rainy day on July 13, 2016 (at an average wind speed of 2 m/s) of air temperature, soil surface temperature under moss 1 and 5 cm thick and the soil temperature at a depth of 10 and 20 cm are shown in Fig. 2, *b*.

On this day (July 13, 2016), 100% cloudiness and minimal daily solar radiation were noted. At the same time, 2 mm of precipitation fell at 6:00 and 9:00. After heavy rainfall occurred between 18:00 and 23:00 the soil surface temperature under 1 cm thick moss dropped by 2.5 °C (from 11.0 to 8.5 °C), and under a 5 cm thick moss it decreased by 0.7 °C (from 7.9 to 7.2 °C). At the same time, the soil surface temperature under the moss 1 cm thick was 3 °C higher than under the moss 5 cm thick, mainly in the daytime, while at night the difference was 2 times less. The soil

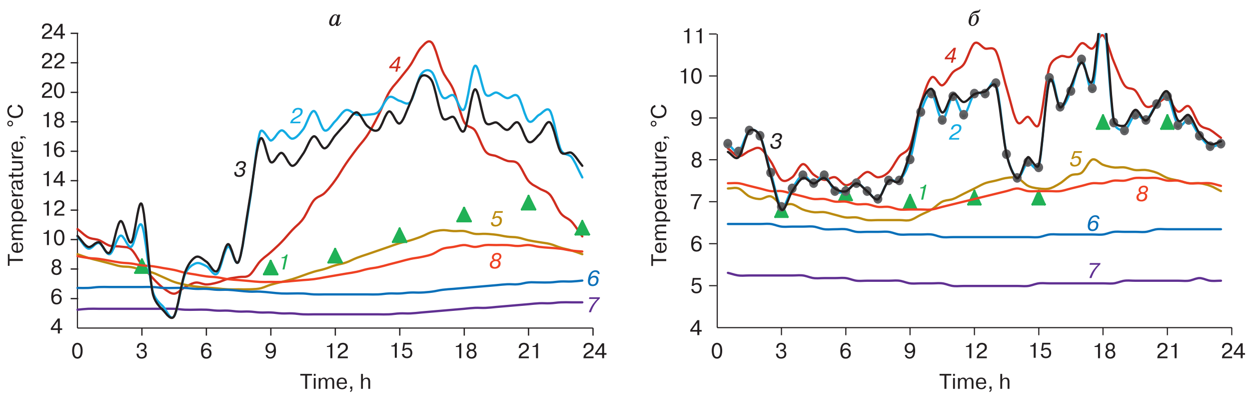


**Fig. 2. Air and soil temperature on July 9, 2016 under clear weather and maximum daily radiation (*a*) and on July 13, 2016 under 100 % cloud cover and precipitation (*b*).**

Air temperature: *1* – according to the data of the Barentsburg HMS; *2*, *3* – at a height of 10 cm above the moss surface. Soil temperature: *4*, *5* – on the surface; *6*, *7* – at a depth of 20 cm; 8 – at a depth of 10 cm. Moss thickness: 1 cm (*2*, *4*, *6*, *8*) and 5 cm (*3*, *5*, *7*).

temperature at a depth of 20 cm under moss 1 and 5 cm thick differed by approximately 1 °C. The soil surface temperature under the moss 5 cm thick (curve *5*) and the soil temperature at a depth of 10 cm under 1 cm thick moss (curve *8*) are quite close to the air temperature in the period up to 16:00.

A similar picture took place on August 7, 2016 under 100 % cloudiness and precipitation. At night, according to the data from the Barentsburg hydrometeorological station, the air temperature was 0.5 °C higher than above the moss surface, while in the daytime this difference changed sign and increased to 1 °C. At the same time, in the daytime, the soil surface temperature under a layer of moss 1 cm thick exceeded the air temperature above the moss (at a height of 10 cm) by almost 1.5 °C.

The amount of precipitation on August 07, 2016 was 10 and 11 mm at 6:00 and 9:00 and 3 and 2 mm at 18:00 and 21:00, respectively, with 100 % cloudiness. One hour after the shower began, at 18:00 the soil surface temperature under the moss 1 cm thick dropped from 8.6 to 5.8 °C, and under the moss 5 cm thick it lowered from 7.0 to 6.2 °C. Measurements have demonstrated that in cloudy weather the air temperature at a height of 10 cm above the moss cover 5 and 1 cm thick basically coincides (Fig. 2, *b*). The average daily difference between these temperatures was 0.2 °C. Under light cloudiness, as a result of the difference in moss albedo (due to its color), the temperature above moss 1 cm thick is 1 °C higher than that above moss 5 cm thick (Fig. 2, *a*). The air temperature at the Barentsburg hydrometeorological station (at a height of 2 m) is lower than the air temperature above the moss. The largest daily difference of those temperatures was about 4 °C (Fig. 2, *a*), with an average daily value of 2.7 °C.

Measurements of the soil temperature under the moss 1 and 5 cm thick on the coldest and warmest days along with the air temperature at a height of 10 cm above the moss have revealed the following. On a warm day of July 15, 2016 (mean daily air temperature $T_a$ = 10.8 °C), the average soil temperature at a depth of 20–70 cm under a 1 cm thick layer of moss was 1.6 °C higher than under a 5 cm thick one. On a cold day of August 8, 2016 ($T_a$ = 4.4 °C) this excess was 0.5 °C. The mean daily air temperature at a height of 10 cm above the moss 1 and 5 cm thick was 14.3 and 11.6 °C respectively on the warmest day, and 6.8 and 5.7 °C on the coldest day.

Let us consider the effect of the type of weather on the thermal insulation capacity of the moss cover. In clear weather at 16:00 the temperature on the soil surface and at a depth of 20 cm under a 5 cm thick moss cover is 10.5 and 5.1 °C, respectively (Fig. 2, *a*). In this case, the temperature difference will be 5.4 °C, while under the moss cover 1 cm thick this difference is 16.9 °C. The temperature gradient at a depth of 0–20 cm, which determines the heat fluxes into the soil, in these cases is equal to 27°C/m and 88°C/m, respectively. The heat-insulating effect of a moss cover 5 cm thick in sunny weather is 3.3 times greater than that of a moss cover 1 cm thick, which significantly reduces the heat flux into the soil.

In cloudy weather at the same time (Fig. 2, *b*) these gradients are equal to 13 and 22 °C/m, and the heat-insulating effecta moss cover 5 cm thick is 1.7 times greater than that of a moss cover 1 cm thick. Thus, in clear sunny weather, the heat-insulating effect of a moss cover 5 cm thick is almost twice higher that in cloudy weather. This is due to the greater role of the albedo of the moss cover in sunny weather (because of the greater value of the total solar radiation on a cloudless day, see Fig. 1) and a possible change in the moss water content. In sunny weather, there is a slight decrease in a moisture content of moss when it is heated under the sun, and a decrease in the coefficient of thermal conductivity.

The largest difference in soil surface temperature under a moss cover 1 cm thick on clear (Fig. 2, *a*) and cloudy (Fig. 2, *b*) days was 12.4 °C, while under a moss cover 5 cm thick that difference is almost 5 times less and equal to 2.6 °C.

**Effect of moss cover on soil temperature during the observation period**

The change in the mean daily temperature of air and soil under the moss 1 and 5 cm thick for the observation period from July 6 to August 8, 2016 is shown in Fig. 3. The average wind speed for this period was 2.7 m/s. The measurements have demonstrated that at local air temperature maxima, its values at a height of 10 cm above a 1 cm thick moss (curve *2*) are greater than those above 5 cm thick moss (curve *3*). Moreover, these values are higher than the air temperature according to the data from the Barentsburg hydrometeorological station (curve *1*). The largest temperature difference between the soil surface under the moss 1 and 5 cm thick (curves *4* and 5) fell on July 9, 2016 and amounted to 4.2 °C.

The average soil surface temperature over the period of measurements was 7.4 °C under moss 5 cm thick and 9.6 °C under moss 1 cm thick, with mean air temperature at the Barentsburg station equal to 7.9 °C. The mean soil temperature at a depth of 20 cm under moss 1 cm thick (curve *6*) was by 2.2 °C higher than that under moss 5 cm thick (curve *7*).

The largest difference in soil temperature at a depth of 20 cm under moss 1 and 5 cm thick, equal to 2.2 °C, fell on July 21, 2016. At an average air temperature of 7.9 °C, the average soil temperature at a depth of 20 cm was 5.4 °C (under 5 cm thick moss) and 6.6 °C (under 1 cm thick moss).

At the beginning of the measurement period on July 6, 2016, the soil temperature at a depth of 50 cm under moss cover 1 and 5 cm thick was 3.2 and 1.3 °C,

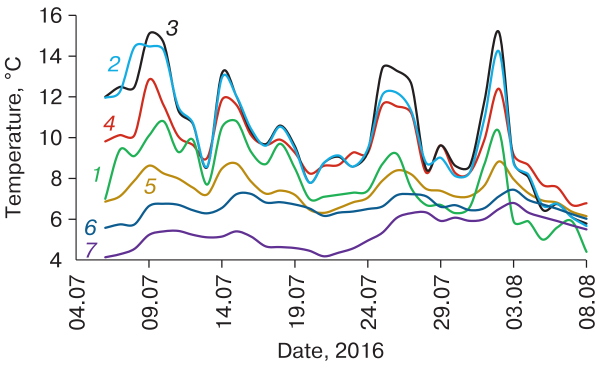


**Fig. 3. Dynamics of air and soil temperature.**

Air temperature: *1* – according to the data of the Barentsburg HMS; *2*, *3* – at a height of 10 cm above the moss surface. Soil temperature: *4*, *5* – on the surface; *6*, *7* – at a depth of 20 cm. Moss thickness: 1 cm (*2*, *4*, *6*) and 5 cm (*3*, *5*, *7*).

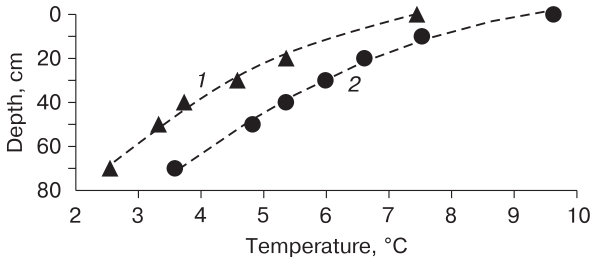


**Fig. 4. Depth distribution of the average soil temperature for the period July 6 – August 8, 2016 under 5 cm (1) and 1 cm (2) moss cover.**

respectively. The largest difference in soil temperature fell on July 16, 2016 and was 2.8 °C. The average soil temperature difference at a depth of 50 cm under the 1 and 5 cm thick moss was 1.5 °C.

The depth distribution of the soil temperature averaged over the period of July 6–August 8, 2016 at the depth of 0 to 70 cm under the moss 1 and 5 cm thick is shown in Fig. 4. The depth-averaged soil temperature under a 5 cm thick moss layer was 1.5 °C lower than under a 1 cm thick one. Thus, the removal of a moss cover 5 cm thick during the land development can lead to an increase in the active layer temperature by 1.5 °C. The mean soil temperature under the 1 and 5 cm thick moss cover over the measurement period at the depth of 70 cm, 40 cm and on the surface was respectively 3.6 and 2.5 °C, 5.4 and 3.7 °C, and 9.6 and 7.4 °C.

### Air temperature influence on soil temperature under moss cover

Studies have demonstrated that at different air temperatures, the heat insulating role of the moss cover can be different. The soil surface temperature for moss 1 cm and 5 cm thick, depending on the mean daily air temperature at the Barentsburg hydrometeorological station, is shown in Fig. 5, *a*. The approximation of mean daily soil surface temperature ($T_s$) depending on the mean daily air temperature at the hydrometeorological station ($T_a$) for moss 1 cm thick is

$$T_s = 0.740\ T_a + 3.745,\ R^2 = 0.717,$$

and for the moss 5 cm thick is

$$T_s = 0.304\ T_a + 5.031,\ R^2 = 0.542,$$

where $R^2$ is the coefficient of determination.

These dependencies are statistically significant at a significance level of 5 %. With an increase in air temperature (at the Barentsburg HMS), the temperature difference of the soil surface under the moss of different thicknesses increases. At mean daily air temperature $T_a$ = 4.4 °C, the mean daily temperature of the soil surface under the moss 1 and 5 cm thick is 6.8 and 6.1 °C, respectively, while at an air temperature of 10.8 °C these values were already 11.6 and 8.2 °C, respectively (Fig. 5, *a*). As a result, as the air temperature rises from 4.4 to 10.8 °C, the temperature difference between the soil surface under the moss cover 1 and 5 cm thick increases from 0.7 to 3.4 °C (Fig. 5, *a*).

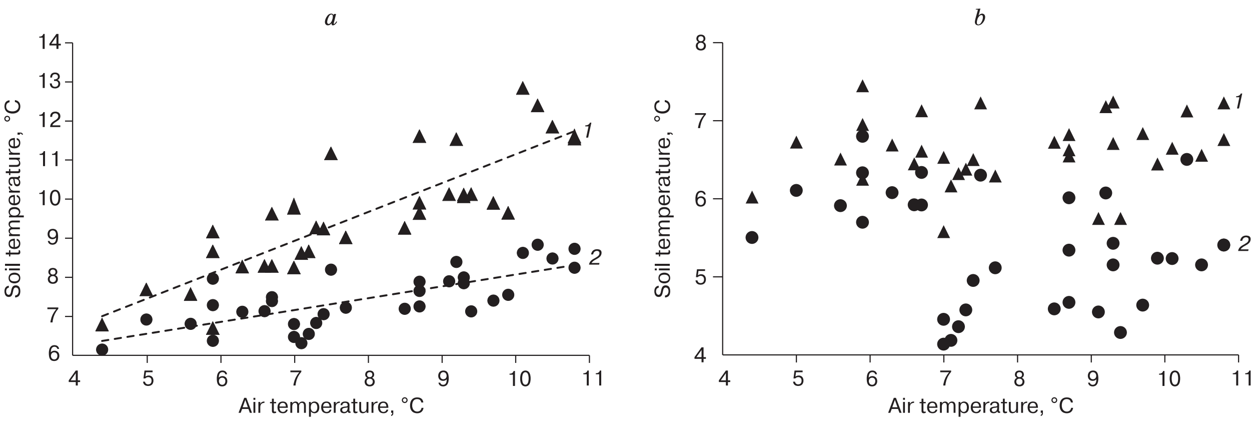


**Fig. 5. Dependences of the soil surface temperature (*a*) and soil temperature at a depth of 20 cm (*b*) on the air temperature for moss with a thickness of 1 cm (*1*) and 5 cm (*2*).**

The dependence of the soil temperature at a depth of 20 cm under the moss cover 1 and 5 cm thick on the air temperature is shown in Fig. 5, *b*. The figure demonstrates that at an air temperature of more than 7 °C, the average soil temperature at a depth of 20 cm under a moss cover 1 cm thick is 1.5 °C higher than that under a 5 cm thick moss cover. At an air temperature of less than 7 °C, the temperature difference between the soil under moss cover of 1 or 5 cm is almost two times smaller. Thus, with an increase in air temperature, the heat-insulating effect of the moss cover increases. In the presence of significant cloudiness and precipitation, the effect of moss cover on the soil surface temperature regime is much weaker.

This is due to the fact that the increase in air temperature by more than 7 °C occurs mainly due to solar radiation, which leads to the greatest temperature differentiation under the moss cover (Fig. 2, *a*). In cloudy weather, the air temperature and total solar radiation are lower (Fig. 1), and the temperature difference of the soil under the moss cover of different thickness and of different albedo values is smaller (Fig. 2, *b*). Another factor is the difference in the dynamics of soil temperature changes under the moss cover as the air temperature changes. So, with a decrease in air temperature, the initially warmer soil layer under the 1 cm thick moss (compared to moss 5 cm thick) will cool down faster than the soil layer protected by a 5 cm thick moss cover. As a result, the soil surface temperature under the 1 cm thick moss may temporarily become even lower than that under the 5 cm thick moss layer.

## CONCLUSION

Under conditions of climate warming, both global and regional cloud cover changes, the number of rainy days decreases due to an increase in the intensity of showers and an increase in the number of days with extreme precipitation, and changes in the mode of incoming solar radiation occur.

The research results have revealed that depending on the type of weather and air temperature, the heat-insulating effect of moss cover changes.

In sunny weather with light cloudiness, the soil surface temperature under the moss *Gymnomitrion* sp. 1 cm thick with dark surface (the albedo of moss and soil are close) increases to 23.4 °C, while under the green moss cover of *Hylocomium splendens* var. 5 cm thick (the moss albedo is twice as high as soil albedo), the highest soil surface temperature is lower by 12.8 °C. In cloudy weather, the soil surface temperature under the 1 cm thick moss did not exceed 11 °C, which is almost by 12 °C lower than that in sunny weather, while the maximum air temperature according to the Barentsburg HMS is 12.5 °C (in sunny weather) and 8.9 °C (in cloudy weather), differed only by 3.6 °C.

The effect of moss cover on soil temperature is determined both by its thickness and by the albedo value. In addition, in rainy weather, part of the precipitation is accumulated in the moss cover, increasing its water content and thermal conductivity. Therefore, after rain, the rapid heating of soil under the moss cover can occur.

The measurements have revealed that with an increase in air temperature, the difference in the temperature of soil surface under the moss cover 1 and 5 cm thick increases, the soil surface temperature under a 5 cm thick moss cover increases grows much more slowly than that under a 1 cm thick moss cover.

In clear sunny weather, the heat insulating effect of the moss cover is almost twice stronger that in cloudy weather. That is mainly due to the greater role of the moss cover albedo in sunny weather as compared to cloudy weather.

It has been determined that for the period from July 6 to August 8, 2016, the temperature of the 70 cm thick soil layer under the 5 cm thick moss cover was, on average, by 1.5 °C lower than that under the 1 cm thick moss cover. As a result, under the 5 cm thick moss cover, the soil thawing depth will be much shallower and the permafrost will last longer.

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