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Mirosław MIĘTUS

Institute of Meteorology
and Water Management
Marine Branch
Waszyngtona 42
81–342 Gdynia, POLAND

Statistical characteristics of soil temperature at the depth of 5 cm in thermal seasons, Hornsund, Spitsbergen

ABSTRACT: Average duration of a thermal winter in Hornsund has been determined for 216 days. Average soil temperature at depth of 5 cm in winter is equal —9.8°C. During a spring that lasts 35 days only, soil temperatures at depth of 5 cm indicate distribution nearest to a normal one. Soil temperature distribution in winter substantially differs from the one in spring.

Key words: Arctic, Spitsbergen, soil temperature.

Introduction

The region of Hornsund has been an area of intensive exploration by Polish scientists for many years. In 1988 the tenth anniversary of a continuous activity of the Polish Polar Station in Hornsund occurred. This event induces to undertake wider elaboration, covering the longest possible period of available measurements. During the last years quite a number of papers appeared on selected meteorological problems, being the syntheses for more than a single expedition season. Rodzik and Stepko (1985) described climatic conditions in Hornsund in 1978–1983. Niedźwiedź (*unpubl.*) studied influence of synoptic situation upon thermal conditions in Hornsund. Skrzypczak and Wielbińska (1988) presented distribution of wind speed and directions, and air temperatures. The author submittet Fourier analysis of average monthly and dekad values of soil temperatures at depths of 5, 10, 20, 50, 80 and 100 cm from 1978 to 1986 (Miętus 1988a).

Data and method

Soil temperature measurements belong to the standard program of meteorological investigations at the station in Hornsund. They have been carried out continuously by the staff members of IMWM since the Station was established, by means of mercury soil theremometers, three times a day. Only in the 1981/82 expedition the meteorological observations, including soil temperature measurements, were carried out by the scientists of Wrocław University. The data got stored on magnetic data carriers of IBM PC/XT microcomputer in Polar Research Laboratory of the IMWM. The analysed data set covers full 8 years. Differentiated conditions during this period, above all different degree of winters severity and different length of the seasons of the year allow to use the data set as sufficiently representative for soil thermal studies. Estimation of the length of the seasons in Hornsund given by Rodzik and Stepko (1985) till summer 1983, was expanded till summer 1986, according to Baranowski's (1968) criterion. Mean time of beginning and the end of each season were found. In each „mean season" soil temperature at the depth of 5 cm was statistically analysed. Estimated were: mean value, standard deviation, skewness and excess coefficient, median and model value.

The main aim of this work is to complete hitherto state of knowledge on the length of thermal seasons in Hornsund. Further, to find statistical characteristics of soil temperature at the depth of 5 cm in these seasons. Limitation of the analysis to soil temperatures at this one depth only refers to Baranowski's (1968) opinion that mean soil temperatures at 5 cm are close to corresponding air temperatures at the height of 200 cm and that these both quantities characterize thermal conditions in the contact layer soil-atmosphere. Basides, soil temperature at this depth is an indicator of intensity and advancement of vegetational processes and for this reason it is interesting to biology and ecology.

Results and discussion

Winter is the longest season in Hornsund (Table 1). It begins on October 18 and comes to an end on May 20. It lasts 216 days which makes 59% of a year time. Spring on the average lasts 35 days up to June 24. Only 8 days longer is autumn, from September 5 to October 17. Summer on the average begins on June 25 and lasts till September 4, which is close to 20% of a year time. A comparison of these results with the data of Norwegian Station Isfjord Radio from the period 1947—1968 reveals that duration of respective thermal seasons is quite close to each other. However, at Isfjord Radio situated more northwards, winter is longer whereas spring and autumn are shorter than in Hornsund.

Table 1

Duration of thermal seasons, in number of days and as fraction (%) of calendar year at the station in Hornsund (1978–1986) and in Isfjord Radio (1947–1968)

SEASON	HORNSUND			ISFJORD RADIO		
WINTER	Oct.18 – May 20	216	59.0%	Oct. 10 – May 21	224	61.4%
SPRING	May 21 – June 24	35	9.5%	May 22 – June 21	31	8.5%
SUMMER	June 25 – Sept. 4	72	19.6%	June 22 – Sept. 2	74	20.0%
AUTUMN	Sept. 5 – Oct. 17	43	11.7%	Sept. 3 – Oct. 9	37	10.1%

Table 2

Length of thermal seasons in Hornsund in 1978–1986

	AUTUMN		WINTER	
	DATE	NO. OF DAYS	DATE	NO. OF DAYS
1978/79	Sept. 1 – Sept. 18	18	Sept. 19 – May 30	254
1979/80	Sept. 1 – Nov. 9	70	Nov. 10 – May 18	190
1980/81	Sept. 5 – Oct. 9	35	Oct. 10 – May 14	217
1981/82	Sept. 11 – Oct. 30	50	Oct. 31 – May 29	211
1982/83	August 22 – Oct. 9	49	Oct. 10 – May 18	221
1983/84	Sept. 12 – Oct. 19	38	Oct. 20 – May 12	206
1984/85	Sept. 20 – Oct. 20	31	Oct. 21 – May 29	221
1985/86	August 23 – Oct. 14	53	Oct. 15 – May 10	208

	SPRING		SUMMER	
	DATE	NO. OF DAYS	DATE	NO. OF DAYS
1978/79	May 31 – June 28	29	June 29 – August 31	64
1979/80	May 19 – June 18	31	June 29 – Sept. 4	78
1980/81	May 15 – June 28	45	June 29 – Sept. 10	74
1981/82	May 30 – July 1	33	July 2 – August 21	51
1982/83	May 19 – June 22	35	June 23 – Sept. 11	81
1983/84	May 13 – June 21	40	June 23 – Sept. 19	89
1984/85	May 30 – June 20	22	June 21 – August 22	63
1985/86	May 11 – June 23	45	June 24 – Sept. 6	76

Winter

The longest winter was in the season 1978/79 (Table 2). It began on September 19 and got finished on May 30, so it lasted as long as 254 days. On the other hand the shortest winter was in the next season 1979/80. It lasted only 190 days from November 10 to May 18. The lowest soil temperature T_{-5i}=-26.7°C was recorded on January 16,1981, while the mean daily soil temperature was -26.1°C (Table 3). On the same day the absolute air temperature minimum was recorded in the screen (-35.9°C). Daily mean soil temperatures T_{-5} during all the winters of the considered period varied within the range from -26.1°C to 0.6°C. During the 216 days of mean thermal winter a soil at the depth of 5 cm is on average frozen for 215 days, and only one day with soil temperature $T_{-5} \geqslant 0$°C is observed. This is an important indicator of tundra soil development, dependent on recurrent freezing, *i.e.* with number of cases, when the soil temperature passes 0°C. Average soil temperature at 5 cm in winter 1978–86 was -9.78°C. The frostiest winter was observed in 1980/81 with average soil temperature at 5 cm equal to -12.1°C. The calmest one was in 1984/85 with average soil temperature -4.2°C.

Table 3

Soil temperature at the depth of 5 cm in thermal winter in Hornsund in 1978–1986

	$\overline{T}_i$ (°C)	$\overline{T}_{i\,max}$ (°C) AND DATE	$\overline{T}_{i\,min}$(°C) AND DATE	NUMBER OF DAYS WITH $\overline{T}_i<0°$	$\overline{T}_i\geqslant 0°$
1978/79	-10.3	0.0 Nov. 11	-19.0 Febr. 9	253	1
1979/80	-10.6	-3.1 Nov. 18	-20.1 Febr. 14	190	0
1980/81	-12.1	-1.5 Oct. 10	-26.1 Jan. 16	217	0
1981/82	-10.8	-0.6 Nov. 9	-25.6 Jan. 28	211	0
1982/83	-9.1	-0.8 Oct. 24	-17.2 Febr. 20	221	0
1983/84	-10.4	-2.4 Oct. 21	-20.4 Dec. 25	206	0
1984/85	-4.2	0.6 Nov. 6	-11.7 Febr. 17	218	3
1985/86	-10.5	-0.5 Oct. 19	-20.5 March 4	208	0

Standard deviation of winter soil temperatures was as high as ± 4.6°C and the asymmetry was equal to -0.87°C (Table 7). Negative sign of the last factor indicates that the majority of the probability mass is concentrated to the right of the mean value.

Very large negative value of the excess, -12.64°C, reveals that the distribution is much more flattened in comparison to normal distribution. The modal value amounts to -8.33°C. Close to this value concentrates the biggest number of the results. The median value is equal to -8.94°C. Adoption of the three sigma rule for the winter population of T_{-5i} allows to confirm that nearly 70% of all values are concentrated within the range $\pm\sigma$ and almost 100% of the results within the range $\pm 3\sigma$. Relatively high value of standard deviation is caused by factors by which particular winters substantially differ from one another. Most important of them are: average air temperatures (Niedźwiedź *unpubl.*, Rodzik and Stepko 1985), depth of snow and persistence of snow cover (Miętus 1991), density of snow and its thermo-insulating properties (Migała 1988, Pereyma 1988, Miętus 1991), frequency of rapid temperature changes due to warm or cold air advection and rainfall (Miętus 1988). Essential effect on the standard deviation have also the air temperature oscillations in March—June when the most intensive insolation in Hornsund is observed, so that snow cover of relatively great snow density towards the end of winter allows for markedly warming of the surface soil during a day, but it does not protect it from night cooling and from cooling caused by invasion of cold air. Moreover, in 1976—86, on 280 out of 1728 winter days the mean soil temperature T_{-5} was lower than -15°C. Adopting Kosiba's (1958) criterion, which was originally used for air temperatures, to soil temperature, we find that more than 16% winter days were peculiarly frosty in the upper soil layers.

Spring

Length of thermal spring varies from 22 days in 1985 to 45 days in 1981 and 1986 (Table 2). Mean soil temperature in spring was -0.47°C and varied from -2.9°C in 1979 to +1.4°C in 1982 (Tables 4 and 7). As the spring comes after a long and frosty winter, on 22 out of 35 spring days mean soil temperature

Table 4

Soil temperature at the depth of 5 cm in thermal spring in Hornsund in the years 1978—1986

	$\overline{T}_i$ (°C)	$\overline{T}_{i\,max}$ (°C) AND DATE	$\overline{T}_{i\,min}$ (°C) AND DATE	NUMBER OF DAYS WITH $\overline{T}_i<0°$	NUMBER OF DAYS WITH $\overline{T}_i\geq0°$
1978/79	-2.9	2.3 June 28	-6.3 May 31	26	3
1979/80	-0.2	3.0 June 13	-5.6 May 19	15	16
1980/81	-2.4	-0.6 June 26—28	-7.0 May 15	45	0
1981/82	1.4	5.4 June 27	-3.9 May 30	13	20
1982/83	-0.7	3.6 June 21	-4.3 May 19	28	7
1983/84	0.0	4.7 June 14	-6.7 May 13	20	20
1984/85	-0.3	2.5 June 19	-2.8 May 31	13	9
1985/86	1.0	6.1 June 20	-7.1 May 11	15	30

at the depth of 5 cm is negative and on only 13 days it is positive or equal zero. Nevertheless, mean soil temperature at this depth is relatively high. This is connected with distinct increase of insolation (Stanisławczyk and Kratke

Table 5

Soil temperature at the depth of 5 cm in thermal summer in Hornsund in 1978–1986

	$\overline{T}_i$ (°C)	$\overline{T}_{i\,max}$ (°C) AND DATE	$\overline{T}_{i\,min}$ (°C) AND DATE	NUMBER OF DAYS WITH $\overline{T}_i>0°$	$\overline{T}_i\leq 0°$
1978/79	5.1	8.5 July 17	1.8 August 31	64	0
1979/80	4.4	6.8 July 12	1.9 August 23	78	0
1980/81	3.7	6.4 July 29	-0.5 June 29	69	5
1981/82	4.7	7.0 July 10	2.5 August 15	51	0
1982/83	4.6	7.5 July 20	1.3 Sept. 2	81	0
1983/84	4.7	7.9 July 1	1.2 Sept. 7, 14	89	0
1984/85	5.8	8.2 June 30	3.1 June 21	63	0
1985/86	5.1	7.3 July 21	3.0 June 26 Sept. 1	76	0

Table 6

Soil temperature at the depth of 5 cm in thermal autumn in Hornsund in 1978–1986

	$\overline{T}_i$ (°C)	$\overline{T}_{i\,max}$ (°C) AND DATE	$\overline{T}_{i\,min}$ (°C) AND DATE	NUMBER OF DAYS WITH $\overline{T}_i<0°$	$\overline{T}_i\geq 0°$
1978/79	1.2	3.3 Sept. 6	-0.4 Sept. 15	6	12
1979/80	-1.5	2.6 Sept. 15, 16	-10.4 Oct. 22	51	19
1980/81	0.7	2.6 Sept. 30	-0.4 Sept. 20	6	29
1981/82	-1.5	1.7 Sept. 19	-5.2 Oct. 11	34	16
1982/83	0.0	4.0 August 22	-2.7 Sept. 25, 29	28	21
1983/84	-0.2	2.4 Sept. 12, 14	-2.2 Oct. 19	26	12
1984/85	0.5	3.3 Oct. 7	-1.3 Oct. 17	10	21
1985/86	0.9	2.8 August 23 Sept. 16	-1.4 Sept. 28, 29	10	43

unpubl.) which in May and June plays a decisive role in forming thermal conditions in Hornsund. Great amount of sunshine hours is favored also by fact that anticyclonal pressure pattern reaches maximum of occurrence in May (25%) and is quite frequent in summer months (Niedźwiedź and Ustrnul *unpubl.*). The standard deviation $\sigma = \pm 2.75°C$, asymmetry factor g_1 equals to 0.03°C. These numbers indicate that the statistical distribution is almost symmetrical with respect to $T_{-5} = -0.47°C$. The excess coefficient slightly differs from zero, $g_2 = -0.22°C$, what means that distribution of T_{-5} is close to normal. Median m_e is equal to -0.55°C, and medal value $m_o = 0.62°C$ is not much smaller than m_e. Within the range of $\pm\sigma$ are concentrated almost 70% of all the results, and the range $\pm 3\sigma$ includes a whole population (Table 7).

Table 7

Statistical characteristics of soil temperature at the depth of 5 cm in thermal seasons in Hornsund in 1978–1986

$\overline{T}$ — mean temperature, σ — standard deviation, g_1 — asymmetry coefficient, g_2 — excess, m_e — median, m_o — modal value, P $(|\overline{T}_i| \leq \overline{T} \pm k \cdot \sigma)$ — probability by rule of 3σ

SEASON	$\overline{T}$ (°C)	σ (°C)	g_1 (°C)	g_2 (°C)	m_e (°C)	m_o (°C)	P $(\|\overline{T}_i\| \leq \overline{T} \pm k \cdot \sigma)$ k=1	k=2	k=3
WINTER	-9.78	4.61	-0.87	12.64	-8.94	-8.33	0.689	0.953	0.996
SPRING	-0.47	2.75	0.03	-0.22	-0.55	-0.62	0.689	0.975	1.000
SUMMER	4.78	1.53	-0.40	0.34	4.95	4.96	0.460	0.962	0.990
AUTUMN	-0.07	1.90	-1.31	4.29	-0.07	-0.06	0.747	0.953	1.000

Summer

Summer, the warmest season, has at average 72 days. The shortest summer lasted only 52 days and occurred in 1982; on the contrary, the longest one, in 1984, lasted as long as 89 days (Table 2). The coolest summer was in 1981, with $T_{-5}=3.7$°C and the warmest one in 1985, when mean soil temperature value was 5.8°C (Table 5). Mean daily soil temperatures T_{-5} exceed 0°C for 71 days. On one day only T_{-5} is lower than 0°C. Daily means of T_{-5} vary from -0.5 in 1981 to 8.5°C in 1979. Mean soil temperature of the whole summer season is 4.78°C (Table 7) and is comparable with mean air summer temperature in meteorological screen at +200 cm which within 1978–85 was 4.1°C. The standard deviation is ± 1.53°C. Its relatively small value in comparison to the σ of other seasons proves a small soil temperature range, similarly to the summer range of air temperatures (Stanisławczyk and Kratke, *unpubl.*). Relatively high value of summer temperatures is connected with air flow from southern directions, frequent in this season (Niedźwiedź 1987) and with insolation, theoretically possible for 24 hours per day. Unfortunately, great amount of clouds in that season prevents greater heating but the same time it does not favour heat emission (Vowinckel and Orwig 1973, Głowicki 1985, Steffenson 1982, Migtus *unpubl.*). All this causes that daily air temperature fluctuations are small (Skrzypczak and Wielbińska 1988, Niedźwiedź 1987) and soil temperature amplitudes are small as well. Asymmetry coefficient g_1 is -0.4°C and excess g_2 is 0.33°C, modal value m_o is 4.95°C and median m_e is 4.96°C. Only 46% of all measurements is comprised within the range $\pm\sigma$ but 99% of them lies within $\pm 3\sigma$.

Autumn

The shortest autumn lasted 18 days and it happened in 1978 (Table 2). The longest autumn, in 1979, lasted as long as 70 days. Variations of the length of this season are quite large. Large are also variations of daily soil temperatures within this season. Daily means of soil temperature at the depth of 5 cm varied from -10.4°C in 1979 to 4.0°C in 1982 (Table 6). Mean autumn temperature in soil on the level 5 cm is -0.072°C with standard deviation ±1.9°C (Table 7), the asymmetry factor $g_1=1.31$°C and excess coefficient $g_2=4.29$°C. It means that distribution is strongly concentrated round the mean value, which is confirmed by the fact that 75% of all measurements are concentrated within $\pm\sigma$ and 100% measurements within $\pm3\sigma$.

Conclusions

Based on the data from 1978–1987 and using Baranowski's criterion we can establish the limits of thermal seasons as follows: winter lasts 216 days from October 18 to May 20, spring lasts 35 days from May 21 to June 24, summer lasts 72 days from June 25 to September 4, autumn lasts 43 days from September 5 to October 17. The days of beginning and end of thermal seasons in Hornsund are analogical to those at Isfjord Radio.

Statistical analysis of soil temperatures at depth of 5 cm in 1978–1986 reveals:

– mean soil temperature in winter, the coldest season, is equal to -9.78°C,

– mean soil temperature in summer, the warmest season is equal to 4.78°C,

– spring and autumn have mean temperature of the season close to each other -0.47°C and -0.07°C respectively,

– statistical distribution of soil temperatures closest to normal is the spring distribution,

– decidedly different from normal distribution is that one for winter of soil temperatures,

– close to 100% of all temperatures are concentrated within $\pm3\sigma$.

Large value of standard deviation at the depth of 5 cm in winter is caused by strong diversification of respective winter seasons with regard to their severity, to the depth and density of snow further to frequency and intensity of thaw occurring in mid-winter and to insolation intensity during March–May. High value of mean daily soil temperature in spring in comparison to the six times longer winter indicates that the main role in forming the thermal characteristic of the upper soil layer plays the insolation in this season. Large insolation is connected with high frequency of anticyclonal pressure pattern, characteristic for spring.

In summer average soil temperature is positive and its value is close to average air temperature. It is due to warm air advection prevailing in this season, and due to polar day permitting for many sunshine hours. The course of mean soil temperature in autumn confirms the fact that also in Hornsund the cooling comes gradually. Each year oscillation around 0°C lasting for several days have been observed and some days with temperature equal to 0°C.

References

Baranowski S. 1968. Thermics of the periglacial tundra of SW Spitsbergen. — Acta Univ. Wratislav., 68: 74 pp.

Głowicki B. 1985. Heat exchange in the subsurface of soil layer in the Hornsund area (Spitsbergen). — Pol. Polar Res., 6: 331—340.

Kosiba A. 1958. O konieczności ujednolicenia skali międzynarodowej podstawowych kryteriów termicznych w klimatologii. — Przegl. Geogr., 3: 27—31.

Migała K. 1988. Snow cover influence on active layer of permafrost (Hornsund region, Spitsbergen). — 15 Sympozjum Polarne, Wrocław: 230—239.

Miętus M. 1988a. Annual variation of the soil temperature in the polar station in Hornsund, Spitsbergen. — Pol. Polar Res., 9: 87—94.

Miętus M. 1988b. Short period changes of soil temperature against advective changes of air temperature in Hornsund, Spitsbergen. — Pol. Polar Res., 9: 95—103.

Miętus M. 1991. Snow depth at the Hornsund, Spitsbergen, in 1978—1986 — Pol. Polar Res., 12: 223—228.

Niedźwiedź T. 1987. Wpływ cyrkulacji atmosfery na temperaturę powietrza w Hornsundzie, Spitsbergen. — 14 Sympozjum Polarne, Lublin: 174—180.

Pereyma J. 1988. Thermal conditions of snow cover at the tundra in the Fugleberget basin (Spitsbergen). — 15 Sympozjum Polarne, Wrocław: 226—229.

Rodzik J. and Stepko W. 1985. Climatic conditions in Hornsund (1978—1983). — Pol. Polar Res., 6, 561—576.

Skrzypczak E. and Wielbińska D. 1988. Mean air temperature at defined wind directions in Hornsund, Spitsbergen. — Pol. Polar Res., 9: 133—145.

Steffensen E.L. 1982. The climate at Norwegian arctic stations. — Klima, 5: 44 pp.

Vowinckel E. and Orving S. 1973. Klimat Arkticheskogo baseyna. — *In*: Klimat polarnykh reyonov. Gidrometeoizdat, Leningrad: 170—317.

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Streszczenie

W oparciu o kryterium Baranowskiego (1968) wyznaczone zostały terminy występowania termicznych pór roku w rejonie stacji PAN w Hornsundzie (Spitsbergen) w okresie 1978—1986. Czasy trwania pór roku w Hornsundzie zostały porównane z norweską stacją Isfjord Radio (tab. 1) i są na obu stacjach zbliżone do siebie. Czasy trwania sezonów termicznych w poszczególnych latach są różne (tab. 2). Najzimniejszą a zarazem najdłuższą porą roku jest zima (tab. 3). Po bardzo

krótkiej, ale ciepłej w porównaniu z zimą wiośnie (tab. 4) następuje najcieplejsza pora roku — termiczne lato (tab. 5). Jesień trwa w Hornsundzie parę dni dłużej od wiosny i jest od niej nieznacznie chłodniejsza (tab. 6). Najbardziej zbliżony do rozkładu normalnego jest rozkład temperatury gruntu wiosną (tab. 7), natomiast zdecydowanie różnym jest rozkład zimowy. Blisko 100% wyników pomiarów temperatury gruntu na głębokości 5 cm zawiera się w przedziale $\pm 3\sigma$ wokół wartości średniej.

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