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Some characteristics of air thermal conditions in Hornsund, Spitsbergen

ABSTRACT: Temporal differentiation of the air thermal conditions in SW part of Spitsbergen has been presented in this paper. Daily meteorological records of the Polish Polar Station of the Polish Academy of Sciences in Hornsund have been used for the period of 1978—1986. Distributions of basic thermal indices based on mean, maximum, minimum air temperatures and minimum temperature at a ground surface have been given. Annual patterns of the above elements of various occurrence probabilities have been also presented and thermal periods have been distinguished.

Key words: Arctic, Spitsbergen, thermal conditions.

Introduction

The purpose of this paper is the characteristics of air thermal conditions of SW Spitsbergen with the Polish Polar Station of the Polish Academy of Sciences in Hornsund as example. A detailed analysis of this element in the area in question is still lacking as it is difficult to consider the analyses of thermal conditions based on short observation periods (consisting of one season usually) as such. Among the other works based on longer record series, the paper dealing with thermal conditions of the periglacial tundra (Baranowski 1968) and the characteristics of climatic conditions (Rodzik and Stepko 1985) are worth to be emphasized in the first place.

The paper has been limited to a presentation of a temporal pattern of main thermal elements while their causal genetic analysis has been disregarded.

Material and method

The initial material for this study consisted of records of daily mean, maximum and minimum temperatures, and of the minimum temperature at a ground surface i.e., at a height of 5 cm above the ground surface (a.g.s.)* of the period of 1978—1986 of the station Hornsund. The Polish Polar Station in Hornsund is located in the SW part of Spitsbergen, 200 m from the Isbjörnhamna coast. It is located at 11 m a.s.l., at the geographical coordinates equal 77°00' N and 15°33' E.

Temperature records originate mainly from meteorological yearbooks. The latter have been prepared in the Marine Branch, Institute of Meterology and Water Management in Gdynia. According to these yearbooks, daily mean temperature was calculated as the average of 8 daily recording times, excluding the period of July 1979 — June 1980 when it has been calculated as an average of 4 values due to records taken only in the main synoptical terms. The material used for computations has come from the period of July 1978 — July 1981 and October 1982 — July 1986. Although the entire period under consideration does not consist of a decade it should present the fundamental air thermal conditions in the area in question. The collected numerical material has been checked with respect to formal conditions and merits. A computation of the frequency of occurrence of given temperature values in 1-degree intervals has been the fundamental stage of the study. The material elaborated this way has been used to construct graphs of annual pattern of particular thermal elements of a given occurrence probability. Moreover, mean and extreme values as well as standard deviations have been calculated for each element. Based on the commonly accepted criteria, the number of days of characteristic temperatures has been also given and thermal periods have been distinguished.

It should be emphasized that the annual mean temperature of the discussed period 1978—1986 in Hornsund was very close to that one of the period 1951—1970 i.e. −5.0 and −5.2°C, respectively (Rodzik and Stepko 1985). Simultaneously, mean temperatures of a year and of particular months were very diversified in this period. Large fluctuations of extreme temperatures have taken place as well. Thus, despite of a short period of records according to a climatological point of view, all values of these elements provide a complete insight into the thermal conditions of Hornsund.

Mean and extreme values of air temperature

Mean annual temperature is considered as one of the main thermal indices. The annual mean temperature of the study period has been 5.0°C and it has been very close to that of the period 1951—1970. However, its value varied in particular years from −2.3°C in 1984 to −7.8°C

* Hereafter, the following abbreviations are used for these elements and for the amplitude: TM — mean temperature, TMAX — maximum temperature, TMIN — minimum temperature, TMIN5 — minimum temperature at a ground, TAMP — temperature amplitude.

Table 1

Annual pattern of monthly mean air temperatures in °C for the period 1978—1986 in Hornsund and standard deviations of a monthly mean temperature

Year	Months												Mean
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
1978							4.3	3.8	−1.0	−3.3	−8.3	−9.5	
1979	−15.4	−16.6	−13.9	−14.1	−7.3	−0.1	4.9	3.7	1.2	−2.8	−4.9	−9.5	−7.8
1980	−12.0	−11.6	−11.7	−8.1	−2.9	2.4	4.4	3.8	1.8	−5.5	−13.4	−16.3	−5.7
1981	−17.9	−9.0	−16.8	−11.3	−4.3	0.4	3.7						
1982										−4.1	−6.8	−11.5	
1983	−8.9	−13.5	−7.8	−9.9	−3.5	0.8	4.2	3.3	1.6	−4.2	−12.7	−15.3	−5.4
1984	−7.2	−6.5	−11.4	−7.2	−2.6	2.1	4.3	4.0	2.0	−0.7	−2.7	−1.2	−2.3
1985	−9.9	−8.2	−9.1	−10.9	−3.1	1.8	5.0	3.9	1.3	−4.1	−7.3	−11.1	−4.3
1986	−13.5	−15.1	−8.6	−10.7	−2.3	2.3	4.1						
TM	−12.1	−11.5	−11.3	−10.3	−3.7	1.4	4.4	3.8	1.2	−3.5	−8.0	−10.6	−5.0
	7.0	7.4	7.4	5.2	3.8	2.0	1.3	1.4	2.4	4.5	6.3	6.9	

in 1979 (Table 1). When analyzing the annual pattern, January is the coldest month (−12.1°C) while July is the warmest one (4.4°C). Monthly mean temperatures below −10°C occur from December until April. Monthly mean temperatures above 0°C are characteristic for June, July, August and September only what has been already emphasized earlier (Pereyma 1983). Differentiation of standard deviation values of the daily temperature proves that the largest variability of the element in question is characteristic for February and March (7.4°C; Table 1). Fairly large standard deviations above 5°C occur from November until April while a large stability is characteristic for a daily mean temperature from June until September, and especially in July and August (±1.3°C and ±1.4°C). The lowest daily mean temperature during the studied period was equal −32.5°C while the highest one 10.1°C (Table 3). It is worth mentioning that the discussed mean value has never been below 0°C in July and August only.

When characterizing the thermal regime it is also important to present a differentiation of extreme values. It is of crucial importance in the case of climates with strong daily temperature contrasts.

Average annual maximum temperature in Hornsund is −2.5°C while the monthly means of this value vary from −8.7°C in January to 6.5°C in July (Table 2). Based on standard deviations of maximum temperatures it can be stated that the largest variability of the latter occurs from November until March (above ±6°C) like in the case of daily mean temperatures. The smallest variability is noticed from June until September, and especially in July and August (±1.7°C). Recorded extreme values of maximum temperatures in particular months are given in Table 3. It is worth to be noticed that the absolute maximum occurred in July (13.4°C) while the lowest maximum temperature occurred in January (−28.4°C).

Average annual minimum temperature of the Hornsund station is −7.7°C. Monthly averages of minimum temperatures differentiate from −16.0°C in January to 2.5°C in July (Table 2). The period from November until April has monthly means of minimum temperatures below −10.0°C. It should be emphasized here that a mean minimum temperature is not below 0°C in July and August only. A minimum temperature indicates the largest variability in February and March (±7.7°C) while the lowest one in July and August (±1.1°C and ±1.2°C). The lowest annual minimum temperature has been recorded in January (−35.9°C) while the highest one in July (7.5°C).

The presented above fundamental charactetistics of minimum temperatures which are usually used to evaluate air thermal conditions in a given area, are based on measurements of the air temperature at a standard height of 2 m. For numerous purposes, e.g. geomorphological studies, however, the minimum air temperature at a ground surface is much more important. Therefore, the fundamental properties of the minimum temperature at 5 cm

Table 2

Monthly means of selected thermal elements and standard deviations of monthly values of these elements in °C in Hornsund (data of 1978—1986)

Element	Months												Year
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
TMAX	−8.7	−7.7	−8.3	−7.4	−1.4	3.3	6.5	5.6	3.0	−1.4	−5.5	−7.5	−2.5
	6.9	6.9	7.2	5.1	3.5	2.3	1.7	1.7	2.4	4.3	6.0	6.5	
TMIN	−16.0	−15.2	−14.7	−13.5	−6.0	−0.3	2.5	2.0	−0.7	−5.9	−10.9	−14.1	−7.7
	7.4	7.7	7.7	5.5	4.5	2.1	1.1	1.2	2.6	5.1	6.6	7.2	
TMIN5	−18.0	−16.9	−16.5	−15.2	−7.1	−1.0	2.5	1.7	−2.1	−7.4	−12.2	−15.7	−9.0
	8.1	8.3	8.3	6.4	5.0	2.9	1.4	1.7	4.2	5.9	7.4	8.1	
TAMP	7.3	7.5	6.4	6.1	4.5	3.6	4.0	3.7	3.7	4.6	5.4	6.6	5.3
	3.8	4.1	3.1	2.7	2.4	1.4	1.4	1.3	1.4	2.2	2.8	3.3	

Table 3

Application of extreme values of selected thermal elements in °C in particular months in Hornsund (data of 1978—1986)

Element		Months												Year
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
TM	MAX	1.5	0.7	2.0	1.1	2.1	7.3	10.1	8.2	5.8	5.6	1.6	3.0	10.1
	MIN	−32.5	−30.2	−30.5	−21.6	−15.3	−3.3	0.4	0.7	−5.4	−14.6	−25.8	−26.0	−32.5
TMAX	MAX	2.6	2.6	3.0	2.6	5.0	11.3	13.4	11.5	9.2	7.6	3.9	4.4	13.4
	MIN	−28.4	−26.9	−26.8	−19.4	12.3	−2.0	3.0	2.0	−3.4	−11.4	−23.4	−23.9	−28.4
TMIN	MAX	−0.2	0.6	0.7	0.1	0.8	4.8	7.5	5.8	4.4	4.3	0.8	1.0	7.5
	MIN	35.9	−33.6	−34.2	−25.4	−19.5	−7.4	−0.7	−1.0	−8.9	−17.2	−28.9	−29.4	−35.9
TMIN5	MAX	0.0	−0.5	0.5	−0.1	0.3	4.7	7.5	7.0	3.2	3.6	1.4	1.2	7.5
	MIN	−40.3	−39.0	−35.4	−29.3	−21.6	−14.2	−3.5	−3.2	−19.6	−20.4	−33.1	−34.1	−40.3
TAMP	MAX	20.4	22.5	16.5	16.4	12.4	10.1	8.8	9.0	11.4	16.4	17.2	23.6	23.6
	MIN	2.4	1.7	1.3	1.6	1.1	1.0	1.8	1.3	1.4	1.0	1.5	2.0	1.0

a.g.s. are presented in the paper. Average annual minimum temperature at a ground surface is −9.0°C while monthly means of this element vary from −18.0°C in January to 2.5°C in July. According to Table 2 these minimum air temperatures are lower than monthly means of the temperatures measured at 2 m by 1—2°C on the average in all months, excluding July. Recorded extreme minimum temperatures at a height of 5 cm are as a rule lower than those at 2 m a.g.s. (Table 3).

A daily temperature amplitude is another element which contributes to the thermal characteristics given above. The latter presents some features of a daily pattern of air temperatures (Hess, Niedźwiedź and Obrębska-Starklowa 1977). The annual average of the daily air temperature amplitude is equal 5.3°C in Hornsund. Like the discussed thermal indices mean daily amplitudes vary in particular months, from 3.6°C in June and 3.7°C in August and September to 7.3°C in January and 7.5°C in February. Standard deviations of the monthly mean daily amplitude confirm that the largest stability of these amplitudes occurs from June until September (±1.3°C and ±1.4°C) and so the most uniform daily temperature pattern is also noted in these months. The largest variability of this element occurs from December to March with a maximum in February (±4.1°C). The smallest amplitude in the entire period of 1978—1986 was recorded in June and October (1.0°C) while the largest one in December (23.6°C, Table 3).

Number of days with characteristic temperatures

All the thermal characteristics presented earlier are supplemented well, especially with respect to applicational tasks, by the number of days with characteristic values of temperatures (Table 4).

Number of days with maximum temperature below −10°C is 70 in a year at average. It is the largest subsequently in January (14.7 days), March (13.3), December and February (ca. 11 days each month); from June to September no such days are noted.

Cold days (TMAX <0°C) may occur in all the months excluding July and August. Their annual total is equal 191.

Very severe cold days (TMIN <−20°C) occur 38 times a year on the average. Such days may happen from November until April, while the majority is recorded in January (9.3 days).

There are 140 severe cold days (TMIN <−10°C). Such days occur 20—23 times on the average from December until April.

Cold and frosty days (TMIN <0°C) may occur in any month. All days in January are characterized by a minimum temperature below 0°C while

Table 4

Mean number of days with characteristic values of air temperatures in °C at the Polish Polar Station in Hornsund (data of 1978—1986)

Element	Months												Year
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Days TMAX $< -10°$	14.7	11.1	13.3	10.9	0.3					0.9	7.1	11.0	69.3
Cold days TMAX $< 0°$	26.1	22.7	25.9	27.3	18.3	2.0			3.2	16.9	22.4	25.9	190.7
Very severe cold days TMIN $< -20°$	9.3	8.6	8.7	2.7							2.3	6.9	38.5
Severe cold days TMIN $< -10°$	23.6	19.6	21.4	22.3	6.9					7.7	17.3	21.4	140.2
Cold and frost days TMIN $< 0°$	31.0	27.9	30.3	29.9	29.3	12.6	0.5	1.5	14.5	26.6	29.4	30.4	263.9
Frost days TMAX $> 0°$ and TMIN $< 0°$	4.9	5.2	4.4	2.6	11.0	10.6	0.5	1.5	11.3	9.7	7.0	4.5	73.2
Frost and ground frost days TMAX $> 0°$ and TMIN5 $< 0°$	4.1	5.1	4.1	2.1	11.0	13.4	1.1	4.2	14.5	5.4	4.9	4.6	74.5

there are definitely less such days in July and August (0.5 and 1.5 days, respectively). Almost 264 such days are recorded during a year.

Frost days (TMAX > 0°C and TMIN < 0°C) when the temperature passes a freezing point, are of a very large importance for numerous processes in the upper ground layer, related to water freezing and ice thawing, among others with so called glacial cycles. In Hornsund, 73 such days are recorded a year. The majority of them occur in May, June and September (11 days a month on the average) while the minority in July and August. Usually a few such days occur in the remaining months.

A number of days with a ground frost is occasionally more important then that with frost at a height of a meteorological case. The number of such days during a year and in particular months is very close to that with frost recorded at a standard height. However, certain seasonal differences exist here. In a period from October to April the number of days with frost is larger than that with ground frost while in the remaining part of a year the opposite phenomenon is observed, excluding May when they are the same. It proves probably that a temperature distribution ground surface air layer is more influenced by a compensating effect of the ground than by air advection during a colder season while during a warmer season the advection factor predominates a frost development. A similar phenomenon when the temperature amplitudes at a ground surface in winter were smaller than at a height of 100 cm have been already emphasized by Baranowski (1968). According to him such phenomenon resulted from a larger heat capacity of the ground what decreased temperature amplitudes at a ground surface.

Probability of occurrence of particular temperatures

Very detailed characteristic of thermal differentiation forms the probability of occurrence in every month of the following; daily mean, maximum, minimum temperatures and minimum temperature at a ground as well as the amplitude below and above the given value. The annual pattern of these elements of various probabilities of occurrence in Hornsund is presented (Figs. 1—5). The graphs show a range of variability of considered thermal characteristics and determine a probability of occurrence of given temperatures for the two thermally extreme months, namely January and July.

A mean daily temperature of January in Hornsund varies from −32.5°C to 1.5°C. Then, there is 10% probability that the temperature will be lower than −19.9°C, 50% that it will decrease below −12.7°C, and 90% that it will decrease below −2.1°C. The daily mean will not be below 0°C only in 2% of the cases. However, these temperatures in July can vary within

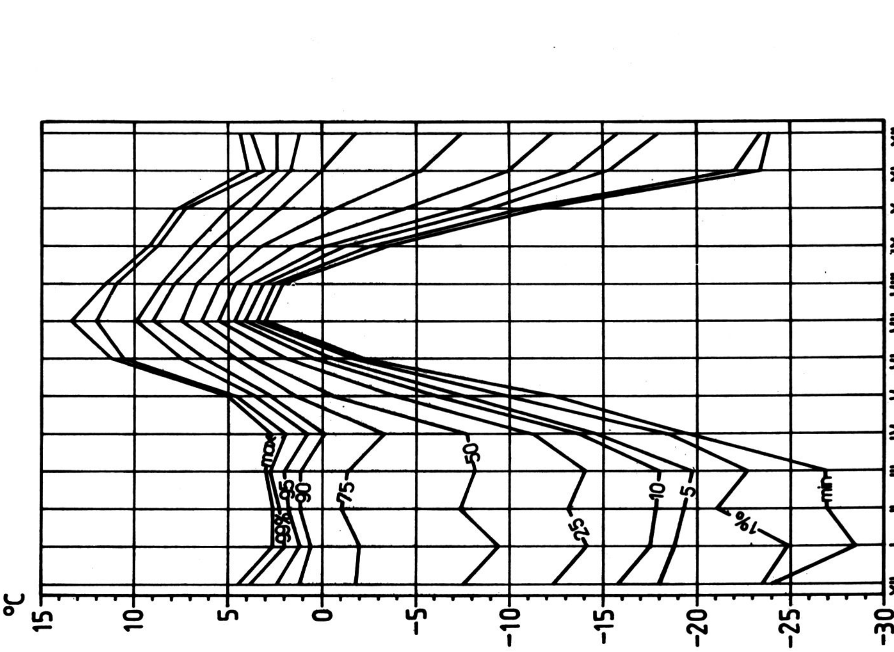

Fig. 2. Annual course of daily maximum temperature characterized by a various probability of its occurrence in Hornsund

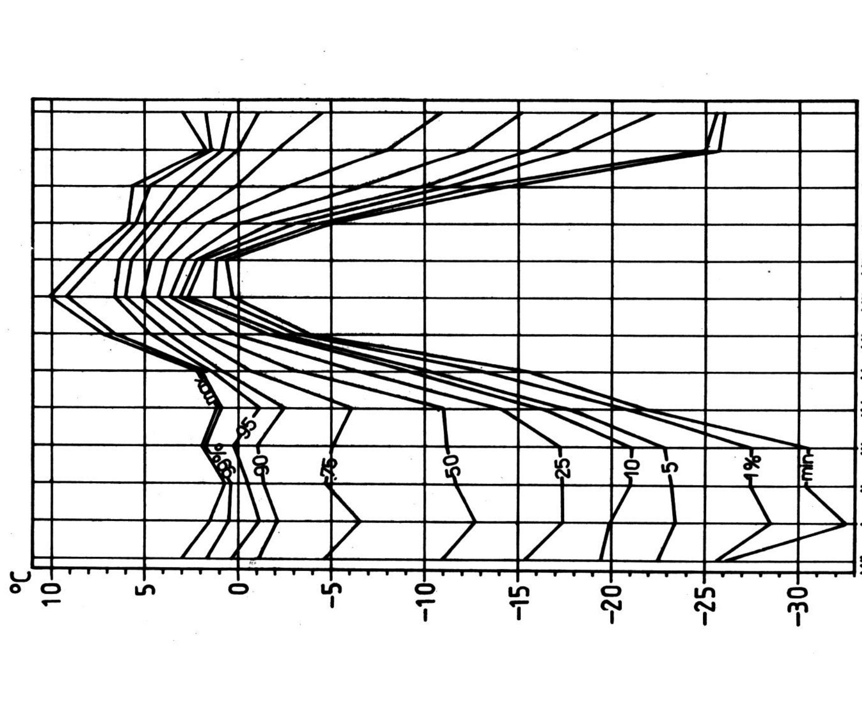

Fig. 1. Annual course of mean daily temperature characterized by a various probability of its occurrence in Hornsund

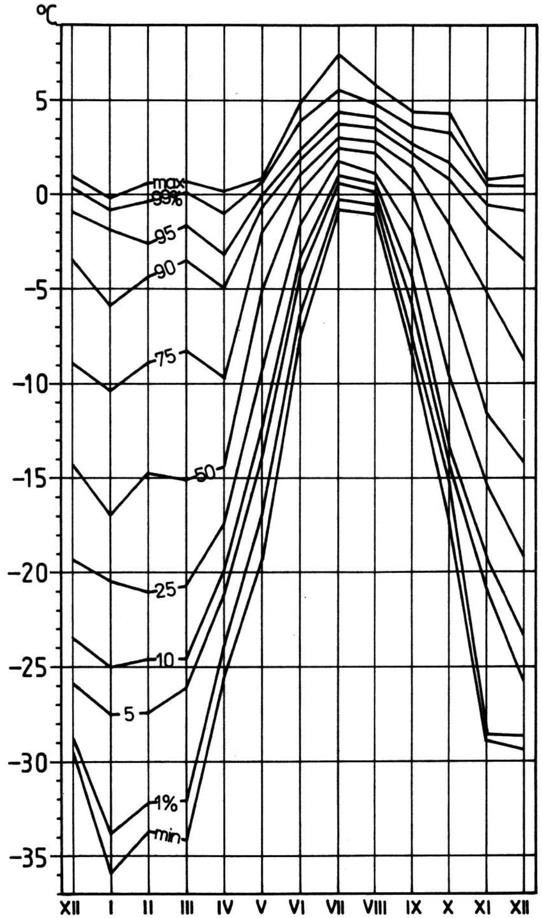

Fig. 3. Annual course of daily minimum temperature characterized by a various probability of its occurrence in Hornsund

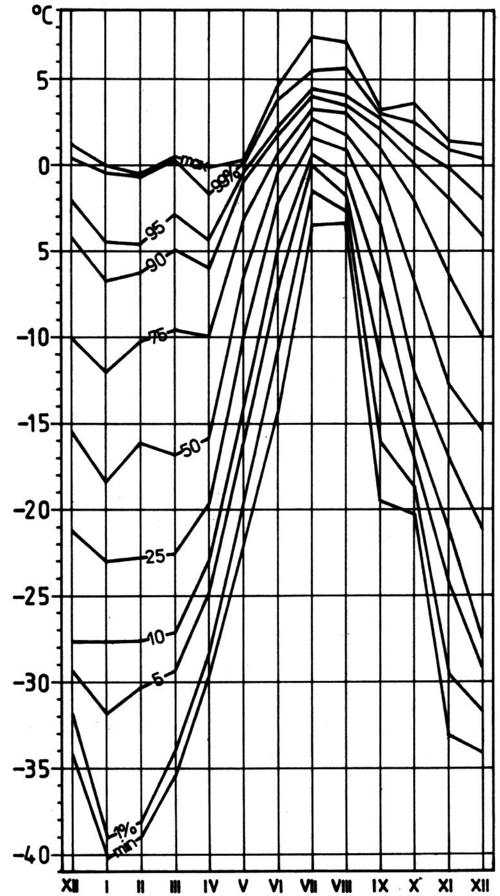

Fig. 4. Annual course of the daily minimum temperature at a ground level characterized by a various probability of its occurrence in Hornsund

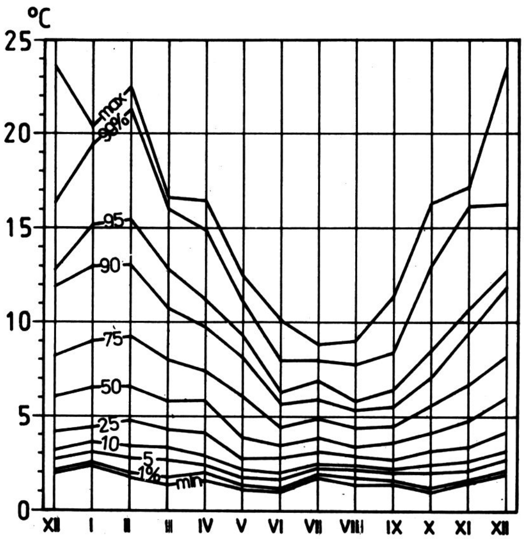

Fig. 5. Annual course of daily temperature amplitude characterized by a various probability of its occurrence in Hornsund

the interval from 0.4°C to 10.1°C. In such case there is a probability of 24% that a daily mean temperature will be over 5°C. Probability of 50% denotes the occurrence of the values below 4.3°C while that of 25% for below 3.6°C.

A daily maximum temperature in January varies from −28.4°C to 2.6°C. Probability of 25% denotes the values below −14.1°C, that of 50% the temperature below −9.4°C and that of 75% the temperature lower than −2.0°C. The temperature below 0°C can occur with a probability of 14%. A maximum temperature in July varies from 3.0°C to 13.4°C. One should expect 50% of cases with the maximum temperature above 6.4°C in this month.

The lowest minimum temperature in January can equal −35.9°C while the highest one −0.2°C. Temperatures below −20.5°C occur with a probability of 25% while those below −17.0°C already with a probability of 50%. A minimum temperature below 0°C in July can occur in 2% of cases, a temperature below 2.5°C with a probability of 50% and that below 3.1°C with a probability of 75%. The highest minimum temperature of this month reaches 8.2°C.

A minimum temperature at a ground can vary in January from −40.3°C to 0.0°C. With a probability of 25% one should expect a temperature below −23.0°C, with that of 50% a temperature below −18.5°C and with that of 75% a temperature below −12.0°C. In July, a probability of 25% denotes the values lower than 1.7°C, that of 25% temperatures below 2.8°C and that of 75% minima lower than 3.3°C. A minimum temperature at a ground below 0°C can occur in 5% of days during this month.

Among the elements presented above, the daily amplitudes of air temperature are characterized by both seasonal and annual differentiations. The latter can vary in January from 2.4°C to 20.4°C while in July can change from 1.8°C to 8.8°C. Daily amplitudes of air temperatures below 5°C occur with a probability of 28% in January and with a probability of 77% in July. Amplitudes above 10°C can occur in any month excluding July and August. The highest probability of their occurrence is in January and February (20%).

Thermal periods in Hornsund

When characterizing climate of a given area, and especially its thermal conditions, it is of a crucial importance to determine the duration of thermal periods. The latter are thermal indicators characterizing fairly equivocally a thermal regime of a given area. Most commonly, a duration of various thermal periods is based on daily mean temperatures passing the particular thermal thresholds. For example, a period with a daily mean temperature below 0°C is accepted as winter. In Hornsund, the latter lasts 257 days, from September 25 to June 8 while the severe winter (TM < -5°C) lasts 194 days — from October 26 to May 7. Thermal thresholds used above are not very suitable for the characteristic of thermal seasons in the Arctic as they do not provide their sufficient division. Therefore, another criterion based on the annual air temperature pattern and the analysis of temperatue classes every 2°C (Baranowski 1968) have been accepted for Spitsbergen. According to this criterion the following thermal seasons can be distinguished in Hornsund, based on data from the period of 1978—1986: spring (-2.5°C$<$TM$<$2.5°C) lasting 26 days (May 25 — June 19), summer (TM$\geqslant$2.5°C) — 76 days (June 20 — September 3), autumn (-2.5°C$<$TM$<$ 2.5°C) — 36 days (September 4 — October 9) and winter (TM$\leqslant -2.5$°C) lasting 227 days (October 10 — May 24).

The presented thermal periods in Hornsund are based on two different criteria. However, they both possess some faults. The first criterion, based on a daily mean temperature passing the thermal thresholds determined every 5°C is rather universal, however it is most useful for a temperate zone. As it has been already mentioned, it does not enable a more detailed division in cold climates. The criterion of Baranowski (1968) is fairly well fitted to the thermal regime of Spitsbergen but it does not allow to compare the length of these periods in various climatic zones.

Therefore, the author proposes to distinguish the thermal periods in

Hornsund based on a magnitude of the changes from month to month of fundamental thermal elements. The author does not accept equivocal quantitative criteria because it would be rather difficult and purposeless when considering numerous elements. Provided above it is possible to subscribe a given month to a particular season. Limits between the seasons are determined as the difference between the neighbouring months is crucial. The fundamental elements used for that purpose are all the values of monthly mean temperatures, including also the extreme ones, number of days with characteristic temperatures and the annual pattern of probabilities of the discussed thermal elements. So, the warm period lasts from June to September with a maximum in July and August. This period coincides fairly well with the daily mean temperature above 0°C i.e. with the so-called winterless period. The winter period is distinguished from November until April (among others it coincides with the daily mean temperature and the minimum one below −10°C) while May and October are typical transitional months. Such approach must not be considered as a method for determination of periods or thermal seasons. That is only a preliminary task for another solution of the problem of division into seasons or thermal periods. A more detailed and objective division into thermal periods would be achieved by pentads application or taxonometric methods, similarly to the procedure used by Woś (1977) for the Wielkopolska Lowland and Pomerania.

Conclusions

1. Mean annual temperature of the period 1978—1986 in Hornsund is very close to the hypothetical one of the longer period and is −5.0°C.

2. Mean annual temperature of the studied period has varied from −2.3°C to −7.8°C. Large monthly and seasonal differences have been also remarkable.

3. The largest variability of a daily mean temperature as well as that of extreme temperatures is recorded in winter.

4. Minimum temperature at a ground surface is characterized by a larger variability in all the months than a minimum temperature measured according to the standard.

5. A largest stability of daily temperature amplitudes has been recorded from June to September.

6. Number of frost days equals 73 a year on the average. Most of them occur in May, June and September. Number of days with a ground frost is almost the same. A seasonal differentiation is noticeable only what is expressed by a larger number of days with a ground frost in winter and by the opposite situation in a warmer season.

7. Graphs of probabilities of occurrence of given temperatures in particular months are the most precise and thorough form of presentation of thermal conditions differentiation.

8. Despite of the possibility to use some criteria to distinguish thermal periods, their detailed division is a very difficult task, especially if a detailed comparative analysis of various regions is to be performed.

9. The presented characteristic of air thermal conditions with the Polish Polar Station in Hornsund as example, should indicate fundamental properties of a thermal differentiation of SW Spitsbergen. However, many problems are to be considered carefully because climatic conditions of Spitsbergen, resulting among the others from orography, sea influence, glaciers and altitude are particularly strongly differentiated (Szczepankiewicz-Szmyrka 1981, Pereyma 1983).

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Streszczenie

Niniejszą pracę oparto na wynikach codziennych pomiarów temperatury średniej dobowej, maksymalnej, minimalnej i minimalnej przy powierzchni gruntu z okresu 1978—1986 ze stacji Polskiej Akademii Nauk w Hornsundzie (SW Spitsbergen). Średnia roczna temperatura

dla Hornsundu z okresu 1978—1986 jest bardzo zbliżona do hipotetycznej z dłuższych okresów i wynosi −5.0°C. W poszczególnych latach wahała się ona od −2.3°C do −2.8°C. Zaznaczyły się też duże różnice miesięczne i sezonowe (tab. 1). Największa zmienność temperatur ekstremalnych i amplitudy dobowej notowana jest w okresie zimowym, natomiast największą stabilność obserwuje się latem. Potwierdzają to odchylenia standardowe tych elementów obliczone dla poszczególnych miesięcy (tab. 2), oraz ich wartości ekstremalne (tab. 3). Liczby dni z przymrozkiem oraz z przymrozkiem przygruntowym są podobne i wynoszą ponad 70 dni w roku. Najwięcej ich przypada na maj, czerwiec i wrzesień (tab. 4). Najdokładniejszą i najpełniejszą formą przedstawiania zróżnicowania stosunków termicznych są wykresy prawdopodobieństwa występowania określonych temperatur w poszczególnych miesiącach (fig. 1—5).

Mimo istnienia wielu kryteriów do wydzielania okresów termicznych, ich szczegółowe wyróżnienie w SW Spitsbergenie nastręcza wiele trudności zwłaszcza jeżeli zachodzi potrzeba dokonania analizy porównawczej z innymi obszarami.