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Temporal and spatial variability of thermal and humidity stimuli in the Hornsund area (Svalbard)

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Abstract: The article presents the biometeorological impact of thermal and humidity conditions on the human body in the Hornsund area in the southern Spitsbergen, Svalbard. This was determined based on diurnal air temperature range, the day-to-day variation in average diurnal air temperature and the average diurnal relative humidity. The temporal variability of thermal and humidity biometeorological stimuli in Hornsund was examined for the period 01.11.1978–31.12.2017. A lessening of biometeorological impact was found in the southern Spitsbergen region, including a statistically significant negative trend in strongly- and severely-felt stimuli (according to diurnal air temperature range), and in significant and severe stimuli (according to day-to-day variation in average diurnal air temperature). A non-significant positive trend was observed in the number of days of relative humidity with humid and very humid air. To analyse the spatial variability of the stimuli around the Hornsund fjord, data were used from seven year-round measuring stations for the period 01.07.2014–31.06.2015. The most unfavourable conditions were found on the Hans Glacier, on the summit of Fugleberget and inside the fjord. The paper presents the role of atmospheric circulation on thermal and humidity stimuli. In the Hornsund region, the highest probability of unfavourable sensible temperatures for humans occurring during the year was mostly in winter and early spring. This was related to the advection of air masses from the north-east sector, regardless of baric regime type. It was found that very humid air (> 85%) flowed over Hornsund for practically the entire year from the S–SW as part of both cyclonic and anti-cyclonic systems.

Key words: Arctic, Spitsbergen, biometeorology, climate change, atmospheric circulation.

Introduction

On Spitsbergen (Svalbard archipelago, Arctic), rapid climatic changes have been occurring at the turn of the 21st century (*e.g.* Marsz and Styszyńska 2007, 2013; Araźny 2008; Nordli 2010; Nordli *et al*. 2014; Araźny *et al*. 2016;

Przybylak 2016; Przybylak and Araźny 2016). The region of the Svalbard archipelago lies is the warmest part of the entire Arctic (Przybylak 2002, 2016). In that part of the Arctic, a significant increase in air temperature occurred in just the last pentad of the 20th century (Tuomenwirta *et al*. 2000; Przybylak 2002). The average annual air temperature in 1898–2012 at the Svalbard Airport station in the centre of Spitsbergen increased by 2.6°C in 100 years (Nordli *et al*. 2014). However, the issue of relative humidity (f) presents differently in the Svalbard region. Since the beginning of instrumental measurement, there has been difficulty in measuring this parameter. This is probably the main reason for rare publications that analysed relative humidity. The few works that exist on this subject for Spitsbergen for longer periods of time include Pereyma (1983), Przybylak (1992), Araźny (2003, 2008), Marsz (2013) and Maturilli *et al*. (2013). As a result of climate change, human living conditions in Svalbard have also changed significantly (Araźny 2008).

Knowledge of the bioclimatic conditions of the Svalbard region has been steadily improving over the last few decades. The first such analysis was the article by Knothe (1931) regarding the Green Harbour station on Spitsbergen. Later, works were published by Wójcik (1963), Szczepankiewicz-Szmyrka (1981, 1988), Marciniak (1983), Szczepankiewicz-Szmyrka and Pereyma (1992), Zawiślak (1986), Gluza (1988) and Nordli *et al*. (2000). In the 21st century, works published on Svalbard bioclimatology have included Przybylak and Araźny (2005), Araźny and Błażejczyk (2007), Araźny (2006, 2008, 2009, 2010, 2012), Araźny *et al*. (2009, 2010), Bednorz and Kolendowicz (2010), Sikora *et al*. (2010, 2011) and Maciejczyk *et al*. (2017). Analysis of selected issues in the field of sensible temperature and humidity in Svalbard had until now only been carried out by Araźny for the entire Svalbard area (2008) and for the Forlandsundet region in Spitsbergen (2012). A small number of studies explaining the impact of atmospheric circulation (AC) on biometeorological conditions on Svalbard have appeared, including Nordli *et al*. (2000), Araźny (2008), Araźny *et al*. (2010) and Sikora *et al*. (2010, 2011).

The aim of this work is to present the temporal and spatial variability of sensible temperature and humidity factors for humans in the Arctic based on the example of the Hornsund region of Spitsbergen. The paper also presents the influence of atmospheric circulation on these factors. Knowledge of actual sensible conditions in the analysed area of the Arctic is of practical significance. The results of the research may be useful to tourists and to scientists conducting field studies. The analysis of thermal and humidity stimuli is very useful for botanic, zoological and other biological studies.

Study area, data and methods

Spitsbergen is in the Svalbard archipelago in the Arctic Ocean. The Hornsund fjord lies in its south-western part (Fig. 1). Hornsund extends latitudinally for about 35 km. It opens to the west, towards the Greenland Sea (Marsz and Styszyńska 2007, 2013). The fjord is surrounded on both sides by longitudinal mountain ranges, including the Sørkappland mountains, where Hornsundtind, the highest peak of southern Spitsbergen (1,431 m a.s.l.), lies.

Investigation of the temporal variability of thermal and humidity biometeorological stimuli employed data from the meteorological stations at the Polish Hornsund Polar Station. Since 1978, meteorological observations have been regularly conducted there as part of the network of Norwegian stations. The station is registered with the WMO (World Meteorological Organisation) as number 01003. The source material includes meteorological data from the Hornsund Meteorological Annals issued by the Institute of Meteorology and Water Management (up to 2000) and the Institute of Geophysics of the Polish Academy of Sciences (in hard copy until 2005, and currently as an electronic database). Additionally, in order to determine the spatial variability of thermal and humidity biometeorological stimuli in the Hornsund region, year-round data was used from air temperature and humidity measurement stations for 1 July

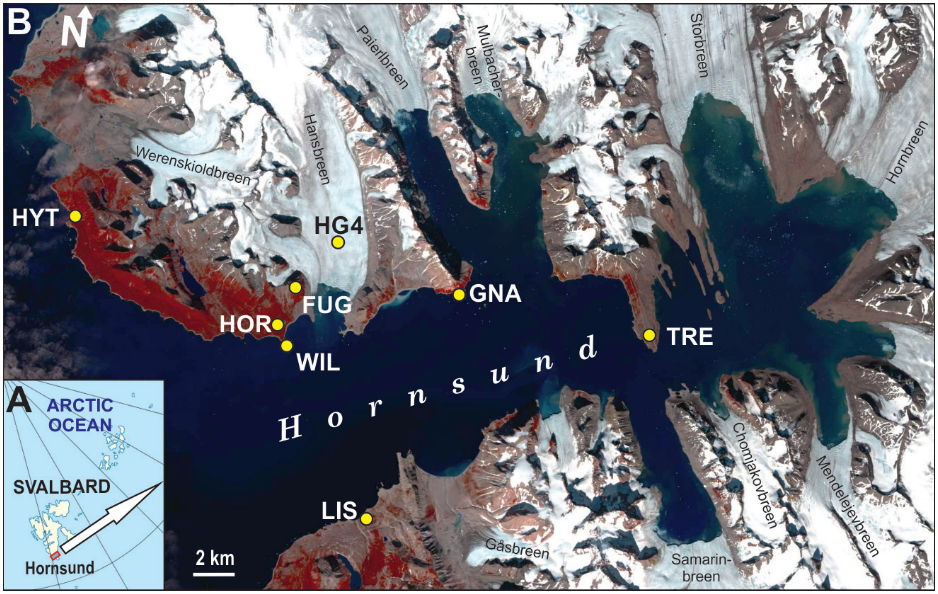

Fig. 1. Research area in Svalbard (**A**) and location of measuring stations used in the Hornsund region (**B**); HOR – Polish Polar Station in Hornsund, HYT – Hyttevika, HG4 – Hans Glacier, FUG – Fugleberget, GNA – Gnålodden, WIL – Wilczekodden, TRE – Treskelodden, LIS – Lisbetdalen, see also Araźny et al. (2018). Based on a Landsat 8 satellite image from August 2016.

2014 to 30 June 2015 (Fig. 1). More information on these stations and the spatial variability of air temperature and f around Hornsund is available in the work by Araźny *et al*. (2018).

To assess sensible temperature and humidity in the Hornsund region, mean daily air temperatures, maximum and minimum daily temperatures, and average daily values of f were used. The stimulating effect of thermal conditions was determined by diurnal air temperature range (DTR). It presents diurnal contrasts between the maximum and minimum air temperature. The following specific values for intensity of thermal stimuli are attributed to Błażejczyk (2004): neutral (< 4.0°C), mildly perceptible (4.0–7.9°C), strongly perceptible (8.0–11.9°C) and severe (≥ 12°C). Another index of thermal stimulus is the day-to-day variation in average diurnal air temperature (ΔT). This was assessed according to Bajbakova *et al*. (1963), who identified thermal stimuli as: neutral (≤ 2.0°C), perceptible (2.1–4.0°C), significant (4.1–6.0°C) and severe (> 6°C). Periods of rapid day-to-day temperature changes negatively affect human health and well-being. The simplest assessment criterion for atmospheric humidity conditions is relative humidity. Bokša and Boguckij (1980) report that f below 56% is dry air, from 56 to 70% moderately dry, from 71 to 85% humid, and above 85% is very humid.

In the literature, it is possible to find different divisions of the year for seasons in the Arctic (Baranowski 1968; Gavrilova and Sokolov 1969; Przybylak 1992). Traditional division into four seasons of equal duration (winter: December–February, spring: March–May, etc.) is not appropriate if we want to describe real climate conditions. This study uses the seasonal divisions of Gavrilova and Sokolov (1969): winter (November–March), spring (April–May), summer (June–August), and autumn (September–October).

To determine the extent of the influence of atmospheric circulation on thermal and humidity stimuli, the calendar of circulation types by Niedźwiedź (2018) was used. The author of the catalogue distinguished 21 main types classified by direction of air advection, or lack of clear inflow, and type of baric regime (Niedźwiedź 2013a; Isaksen *et al*. 2016). Direction of inflow is presented in capital letters (N, S, W and E), while type of baric regime is marked as "a" for anticyclonic or "c" for cyclonic. Baric regimes that are difficult to determine and barometric cols are designated as "X".

Results and discussion

General characteristics of air temperature and relative humidity in Hornsund. — The average annual air temperature in Hornsund in the years 1979–2017 was -3.8°C (Table 1). The lowest average annual temperature (-7.3°C) occurred in 1988, and the highest (0.3°C) in 2016. The lowest seasonal average temperature was recorded in winter (-8.9°C), and the highest in summer (3.6°C).

The smallest variation in the average daily air temperature in Hornsund was recorded in 2012 and 2016, with a standard deviation of 4.9°C. However, the greatest variability of average daily temperature occurred in 1988, with a standard deviation of 9.2°C.

Table 1

Average seasonal and annual air temperature (Ta) and relative humidity (f) and their trends (respectively, °C and % per 10 years) in Hornsund in 1979–2017. Trends statistically significant at $p < 0.05$ are shown in bold.

Parameter	Winter	Spring	Summer	Autumn	Year
Ta (°C)	-8.9	-5.4	3.6	-0.4	-3.8
f (%)	77	78	85	80	80
Ta (°C/10 years)	**1.7**	**0.9**	**0.4**	**0.9**	**1.1**
f (%/10 years)	0.5	-0.1	-0.1	**1.0**	0.3

In the annual course of air temperature in Hornsund, the highest monthly average for the long-term period occurred in March (-10.1°C), while the lowest was in July (-1.1°C). The lowest average daily temperature (-32.5°C) was recorded on 16.01.1981, with advection of air from the north-east in low-pressure circulation conditions. The highest (11.5°C) occurred on 31.07.2015, during easterly anticyclonic conditions.

In Hornsund, while the station was in operation during the period 1979–2017, there was a clear increase in air temperature (Table 1). The statistically significant positive trend in average annual air temperature is 1.1°C per 10 years, while the greatest increase was recorded for winter (1.7°C for 10 years). Meanwhile, in the longer term, *i.e.* for 1898–2012, the largest increase (3.9°C per 100 years) occurred in the centre of Spitsbergen at the Svalbard Airport station in the spring (Nordli *et al*. 2014). The station in Hornsund is warmer than the stations in the north of Spitsbergen, more distant from the influence of the Greenland Sea (Ny-Ålesund, Svalbard-Lufthavn), and cooler than Bjørnøya located to the south (Araźny 2008; Marsz and Styszyńska 2013).

The annual average f in Hornsund in the years 1979–2017 was 80% (Table 1). The lowest annual average f (76%) occurred in 2003, and the highest annual average (83%) in 1994. The lowest f was in winter (77%), and the highest in summer (85%). The standard deviation of the daily average f in Hornsund was smallest in 1991 (8%), while its greatest variability was in 1980 and 1981 (13%).

In the annual course of f in Hornsund for the study period, the lowest monthly average was for November and December (76%), and the highest for July (87%). Average monthly and seasonal f values indicate the dominance of only slightly transformed masses of marine air or fresh masses of marine air over Hornsund (Marsz and Styszyńska 2007, 2013). The lowest daily average value of f (39%) occurred on 16.01.1981 during the polar night, with a large advection of cooled air. However, the highest value of f (100%) was recorded on multiple occasions.

As Table 1 shows, f increased slightly year-on-year in Hornsund (0.3% per 10 years). Of the individual seasons, this increase is highest in winter and autumn (0.5 and 1.0% per 10 years, respectively). In the second case, the trend is statistically significant.

The lowest f in Svalbard is in the middle of the western coast of Spitsbergen (Svalbard Lufthavn), while the highest is on the Bjørnøya and Hopen islands, which are strongly influenced by the marine climate (Araźny 2003, 2008). This is the result of the impact of humid sea air masses from a south-westerly direction being transported from the Atlantic by cyclonic activity (Araźny 2008).

The biometeorological impact of diurnal air temperature range in Hornsund. — The DTR reflects daily thermal contrasts. It significantly affects human well-being during a long stay in the open air (Błażejczyk 2004; Araźny 2008). In Hornsund, this parameter has a clear annual course (Fig. 2). The lowest average values occur in June (3.4°C) and the highest in February (6.0°C). There were instances of DTR ≥ 20.0°C from January to March. The highest DTR (22.5°C) was recorded on 16.02.1980. The temperature on that day fell from -7.7°C to -30.2°C as a result of the inflow of cold air masses from the north.

In Hornsund according to DTR, on average, neutral and mildly perceptible stimuli occur most frequently (90%). These stimuli occur most often in summer (99%), and least frequently in winter (82%). Strongly perceptible stimuli were recorded for 8% of days in the year. They occurred most often in winter (14%) and least often in summer (1%). Very severe, high-intensity stimuli are very significant to humans, as they are distressing. From June to September, severe stimuli do not occur (Figs 3 and 4), while in winter they account for > 4% of all days.

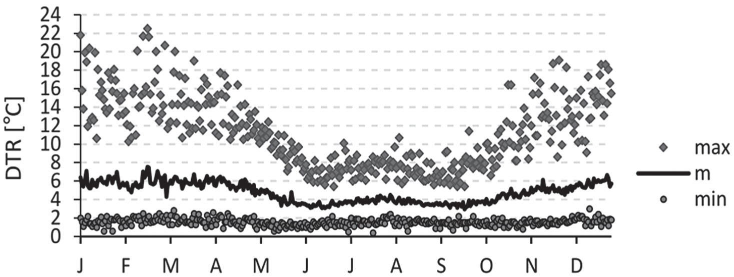

Fig. 2. Annual course of mean (m), maximum (max) and minimum (min) diurnal air temperature range (DTR) in Hornsund in 1978–2017.

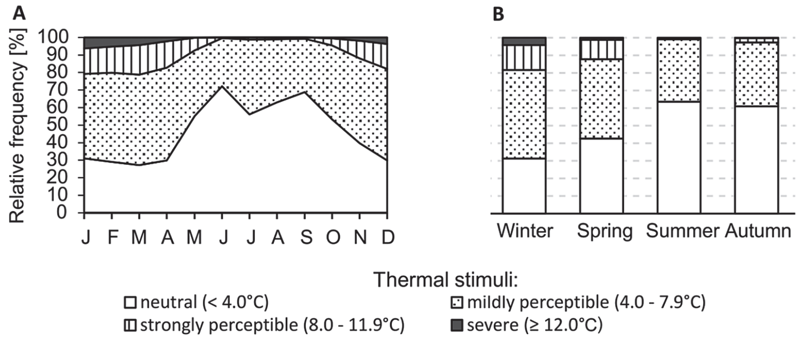

Fig. 3. Relative frequency of thermal stimuli based on diurnal air temperature range (DTR) in the annual course (**A**) and in particular seasons (**B**) in Hornsund, 1978–2017.

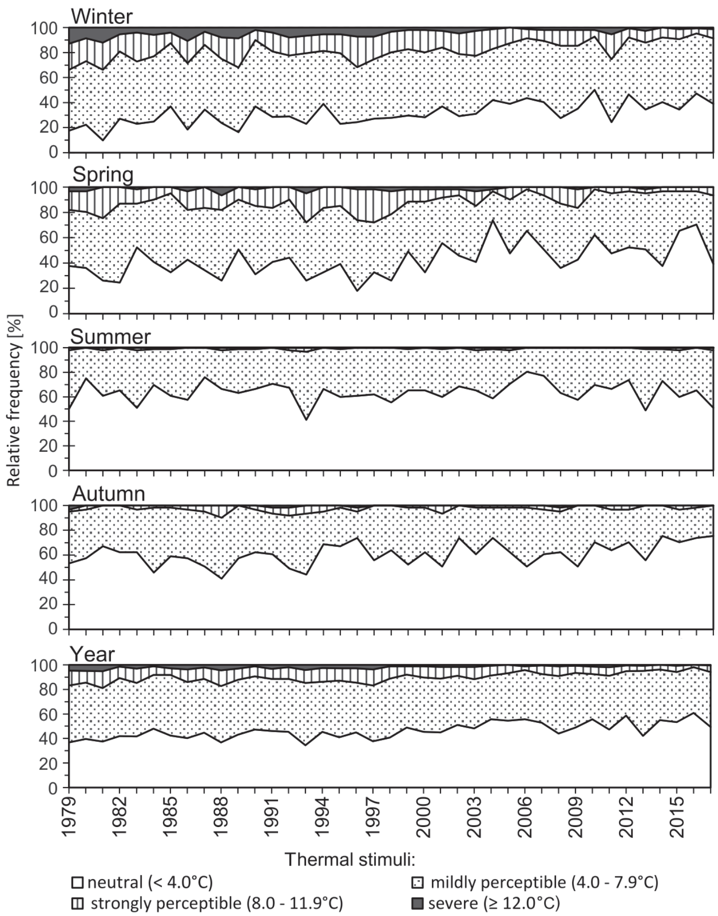

Fig. 4. Year-to-year course of the relative frequency of thermal stimuli based on diurnal air temperature range (DTR) in Hornsund, 1978–2017.

Table 2

Seasonal and annual trends of thermal stimulus categories by DTR value (number of days/10 years) in Hornsund in 1978–2017. Trends statistically significant at $p<0.05$ are shown in bold.

Thermal stimuli	Winter	Spring	Summer	Autumn	Year
neutral	**8.3**	**3.7**	0.5	**2.2**	**14.9**
mildly perceptible	-0.8	-1.4	-0.4	**-1.8**	**-4.8**
strongly perceptible	**-4.1**	**-2.1**	-0.1	-0.3	**-6.6**
severe	**-3.2**	-0.3	0.0	-0.1	**-3.5**

During the study period in Hornsund, the structure of thermal stimuli according to DTR transformed significantly. The number of days of neutral stimuli increased by 14.9 days per 10 years on avarage. Meanwhile, there was a downward trend in strongly and mildly perceptible and severe stimuli. All annual changes in the four categories of biometeorological stimuli are statistically significant (Table 2). In the course of the year, the biggest changes took place in winter. There was, among other trends, a systematic increase in neutral stimuli (8.3 days/10 years) and a decrease in perceptible and severe stimuli of about 4 and 3 days per 10 years. The analysis of DTR shows that we observe a weakening of thermal biometeorological impact in southern Spitsbergen.

Day-to-day variability of average diurnal air temperature in Hornsund. — Another characteristic of the thermal stimulus is the day-to-day variability of average diurnal air temperature, which, along with other factors, determines human well-being. Large day-to-day changes in temperature are considered to be a severe and highly distressing thermal stimulus (Błażejczyk 2004).

In Hornsund in the years 1978–2017, neutral stimuli predominated for 242 days a year (Figs 5 and 6). Changes perceptible to the human body occurred on an average of 74 days per year, while significant changes occurred on 29. Severe, distressing stimuli occurred in Hornsund on about 20 days per year. In the annual course, the largest differences in ΔT were recorded between winter and summer. For example, the strongest stimuli ("severe"), occurred for about 11% of winter. These stimuli were practically absent in summer (Fig. 5).

The largest increase in ΔT (20.0°C) in Hornsund occurred in 1986 (from -22.0°C on February 12 to -2.0°C the following day), while the largest decrease (16.0°C) was recorded in 2011 (-0.5°C on February 21 to 16.5°C the following day) (Fig. 7). In the first case, atmospheric circulation (AC) changed from a central anticyclonic situation to advection from the south-west in a cyclonic

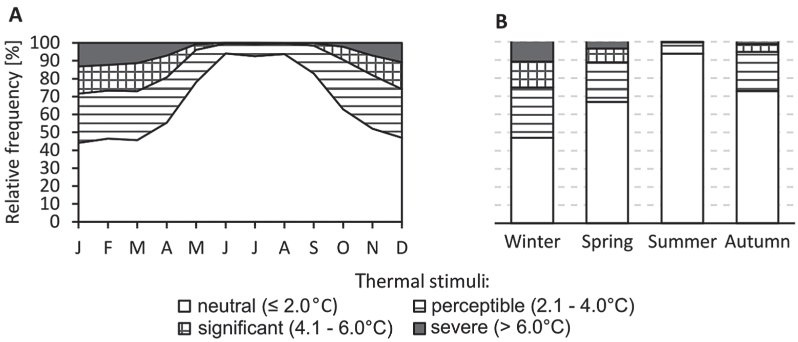

Fig. 5. Relative frequency of thermal stimuli based on day-to-day changes in average diurnal air temperature in the annual course (**A**) and in particular seasons (**B**) in Hornsund, 1978–2017.

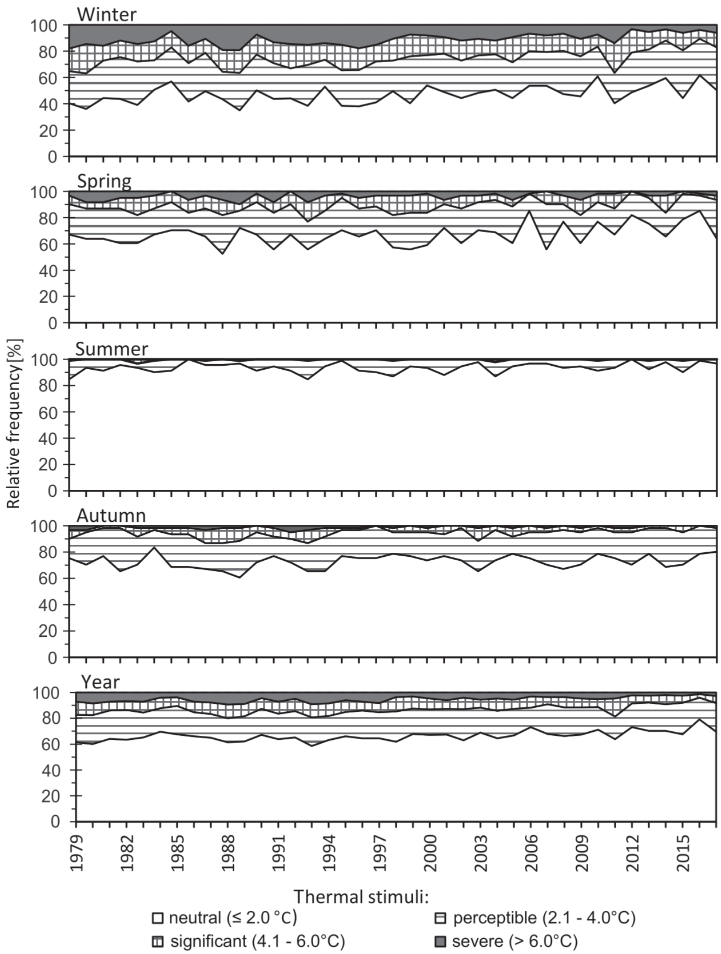

Fig. 6. Year-to-year course of the relative frequency of day-to-day changes of average diurnal air temperature in Hornsund, 1978–2017.

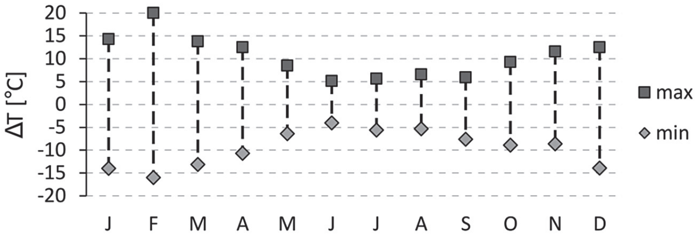

Fig. 7. Annual course of absolute maximum (max) and minimum (min) increases and decreases in average diurnal air temperature in Hornsund, 1978–2017.

situation. However, a record drop was registered during cyclonic AC (from a central cyclonic situation to advection from the SE).

In Hornsund, during the analysed period, ΔT showed a reduction in thermal stimuli. A statistically significant year-to-year increase in changes perceived as neutral was observed of about 8 days for 10 years on average. There was a slight decrease in perceptible stimuli. In the case of significant and severe stimuli, there were also statistically significant downward trends (2.6 and 5.0 days/10 years, respectively), see Table 3. In the seasonal structure of sensible changes, the biggest changes in ΔT occurred in the winter. From 1978 onwards, there was an increase of about 4 days per year in neutral stimuli and a drop of about 4 days/10 years in severe stimuli, those least trends were favourable for humans.

Table 3

Seasonal and annual trends of thermal stimuli by day-to-day changes of average diurnal air temperature (number of days/10 years) in Hornsund, 1978–2017. Trends statistically significant at $p < 0.05$ are shown in bold.

Thermal perception	Winter	Spring	Summer	Autumn	Year
neutral	**4.4**	**1.7**	0.8	0.7	**7.9**
perceptible	1.0	-0.4	-0.7	0.1	-0.3
significant	-1.2	-0.7	-0.1	-0.5	**-2.6**
severe	**-4.1**	**-0.6**	0.0	**-0.3**	**-5.0**

The perception of relative humidity in Hornsund. — In environmental conditions when f is high, sweating is not effective. The human body needs to generate more sweat, because evaporation is slowed by the water vapour already present in the air. Thus, the human body feels hotter. The occurrence of a high f exacerbates biometeorological conditions, especially at low air temperatures and high wind speeds (Błażejczyk 2004; Araźny 2008; Araźny 2012). Meanwhile, low f can intensify the loss of water from the body (Błażejczyk 2004).

Based on daily values of relative humidity, the frequency of days of different characteristic values was examined. In individual months, seasons and years, sensible humidity is very diverse (Figs 8 and 9). Dry air in Hornsund occurred very sporadically, averaging only 2% of the year. It was most often recorded in winter (4%). From July to September, no day with dry air was found. Moderately dry air occurred in the south of Spitsbergen more often than dry air. It was recorded for 17% of the days of the year. It was the least frequent in summer (5%), and most frequent in winter (23%). In Hornsund, on average, humid air was recorded the most frequently in the year (47%). It occurred least often in summer (41%), and most often in spring (55%). The air was very humid for 34% of the year. In the Hornsund region, very humid air was least frequent in winter and spring (25%), and most frequent in summer (54%), Fig. 8.

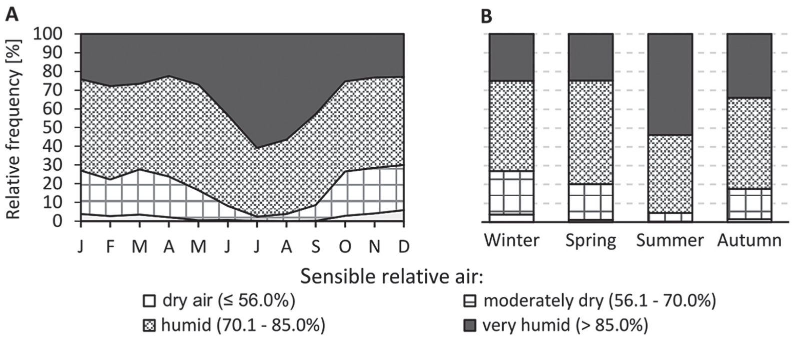

Fig. 8. Relative frequency of days of different sensible relative humidity in the annual course (**A**) and in particular seasons (**B**) in Hornsund, 1978–2017.

In Hornsund, year-to-year, days with different categories of f values are highly variable (Fig. 9). The linear annual trends of days with varying degrees of humidity showed a rising tendency for very humid and humid air (2.4 and 3.5 days/10 years, respectively). Conversely, days with dry and moderately dry air show a downward trend (1.2 and 4.6 days/10 years, respectively), see Table 4. In the case of the number of dry days, the average seasonal trends are negative and low, except for spring when no trend is observed. There was a downward trend in the number of moderately dry-air days (from 0.4 days/10 years in summer to 2.7 in winter). Gradually, the number of humid days in Hornsund in winter, spring and summer is rising (around 1.4–1.5 days/10 years), and slightly decreasing for autumn. In the analysed period, the number of days with very humid air trended upwards in winter and autumn (2.2 and 2.3 days/10 years, respectively), while the autumn increase was statistically significant. In the remaining seasons, there was a systematic decrease in the number of very humid days (Table 4). The change in the structure of sensible humidity in the studied period is related to the observed increase in air temperature and the more frequent inflow of humid air masses from the south-west.

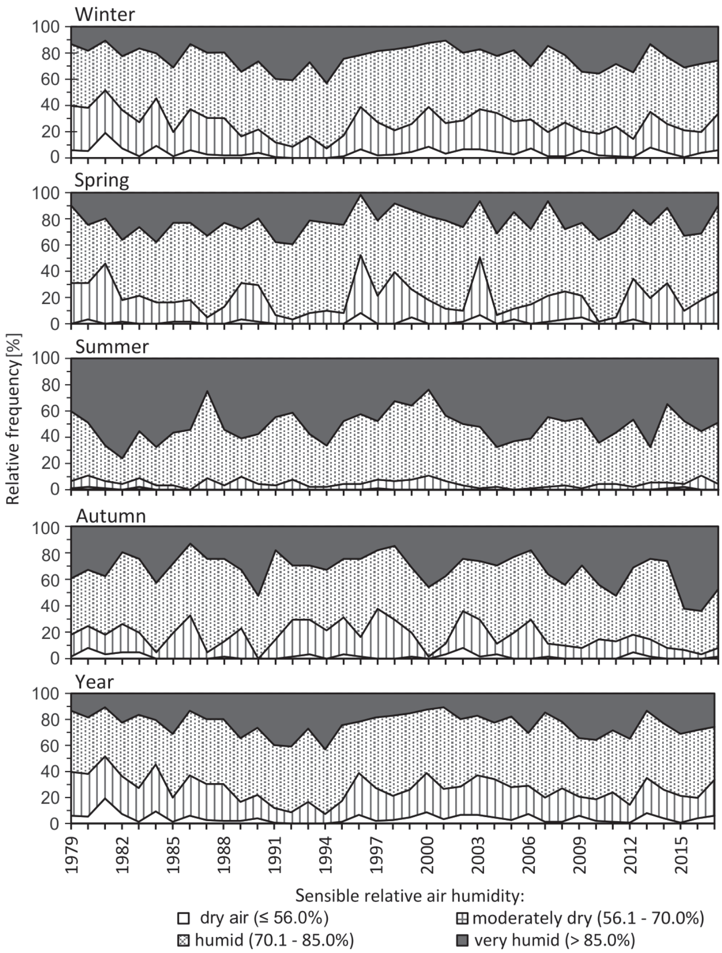

Fig. 9. Year-on-year course of the relative frequency of different sensible relative humidity in Hornsund, 1978–2017.

Table 4

Seasonal and annual trends of stimulus categories according to differing perception of relative humidity (days/10 years) in Hornsund, 1978–2017. Trends statistically significant at $p < 0.05$ are shown in bold.

Sensible relative humidity	Winter	Spring	Summer	Autumn	Year
dry air	-0.9	0.0	-0.1	-0.3	-1.2
moderately dry air	-2.7	-0.8	-0.4	-1.2	-4.6
humid air	1.4	1.5	1.5	-0.8	3.5
very humid air	2.2	-0.8	-1.0	**2.3**	2.4

The influence of atmospheric circulation on thermal and humidity conditions and their sensations in Hornsund. — Atmospheric circulation plays a much greater role over Svalbard in the Arctic than in other areas of the globe. Its greatest impact is noted during the polar night, when solar radiation does not reach the ground in this region (Araźny 2008). Radiation factors are stable for a significant part of the year, so they are not of primary impact (Niedźwiedź 1993). In this situation, AC is the key determinant of the variability of bioclimatic conditions in the Svalbard region.

AC in Hornsund was analysed based on the frequency of occurrence of circulation types (Fig. 10). In the period 1978–2017, on average, cyclonic AC predominated during the year (60.0%). Anticyclonic regimes shaped the weather in this region for 36.6% of days. Situations not classified into the 20 designated types accounted for 3.4% of all cases. In winter, the most commonly occurring type (14.7%) was eastern cyclonic (Ec), followed closely by NEc (11.3%). Least frequent, at less than 1%, were anticyclonic types with W and NW advection of air masses, and Ca. A similar distribution of circulation type prevalences was recorded for autumn (Fig. 10). The situation was different for summer and spring. In these seasons the Ka type was the most observed (15.2 and 12.8%, respectively), and the least observed were NWa in spring (1.1%) and Sa in summer (1.9%).

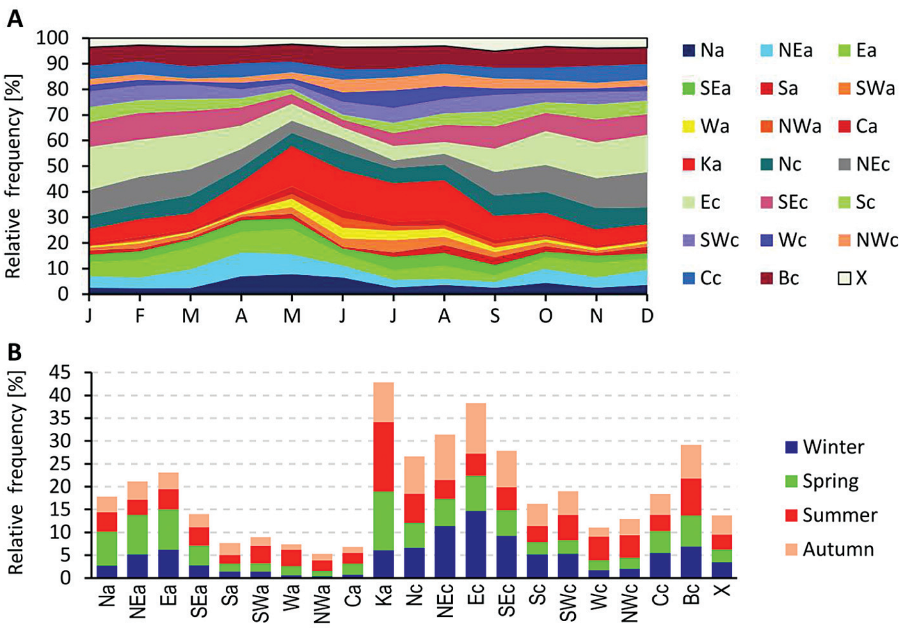

Fig. 10. Relative frequency of atmospheric circulation types in individual months (**A**), and seasons (**B**), for 01.11.1978–31.12.2017 on Spitsbergen.

In the 21st century, changes in the character of AC took place in the Svalbard region, which corresponds with some of the warming that occurred in this period (Niedźwiedź 2013a; Isaksen *et al*. 2016; Przybylak *et al*. 2018). This has resulted from the more frequent inflow of air from the south, which brings very warm air in winter. Conversely, the inflow of air masses from the north in the summer brings cool air from the Central Arctic region (Niedźwiedź 2013a).

In Hornsund, over the course of the year, the highest average air temperature was recorded for types SWa and Wa (1.8 and 1.4°C, respectively), and the lowest for NEa and NEc (-9.6 and -8.2°C, respectively). The thermal characteristics of AC types are similar across all seasons. The warmest air masses come from the south-western sector. Baric regime type is less important, as suggested also by Przybylak (1992), Przybylak *et al*. (2012) and Niedźwiedź (2013b). In the annual course, the range of changes in average daily air temperature under the influence of AC types was the smallest in July (1.7°C) and largest in February (17.6°C) (Fig. 11A). The smallest of the above range of variability in mean daily temperature was recorded in summer (2.0°C) (Fig. 12A). It varied from 2.8°C for Na type to 4.8°C for Sa. By contrast, the highest amplitude (14.8°C) was in winter, *i.e*. from 1.6°C for SWa to -16.4°C for NEa.

AC significantly shapes DTR in various Arctic regions (Przybylak 1992, 2000, 2016; Stafford *et al*. 2000; Tuomenvirta *et al*. 2000; Przybylak *et al*. 2014, 2018). In Hornsund, its average values in the annual course range from 3.4°C in June to 6.0°C in February. On the annual scale, changes in DTR for individual AC types were the smallest in August at 1.1°C, ranging from 3.2°C for SWc to 4.3°C for NWa and Sc, and the largest in March at 6.7°C, ranging from 3.8°C for SWa up to 10.4°C for NWa (Fig. 11B). The smallest range of DTR variability (1.3°C) was recorded for summer (Fig. 12B), when it changed from 3.2°C (for Wc) to 4.5°C (for NWa). The largest range (3.1°C) occurred in winter, ranging from 4.6°C (for SEa and SEc) to 7.7°C (for NWa). Its highest seasonal average values > 6°C, perceived as severe stimuli, were noted only in winter with inflow of air masses from the NW sector, for types without advection (Ka, Ca and Cc), and for unspecified types (X). In summer, slightly higher DTR was noted for anticyclonic regimes. In winter, greater variations in DTR are often caused by changes in air mass inflow direction during low-pressure (Niedźwiedź 2013b).

Human well-being in polar regions is also affected by the size of ΔT. The scale of these temperature changes is mainly determined by AC. The advection of thermally diverse air masses causes significant ΔT. In the annual course, the lowest mean ΔT (0.8°C) was recorded in June and August, and the highest (3.0°C) in January and February. During the year, the range of changes in ΔT for individual AC types was smallest in July at 0.5°C, ranging from 0.7°C for SWc, Wc and Nc to 1.2°C for Sa and SEc. Conversely, the largest range (2.9°C) occurred in February, from 2.0°C for Wa to 4.9°C for Na. ΔT also

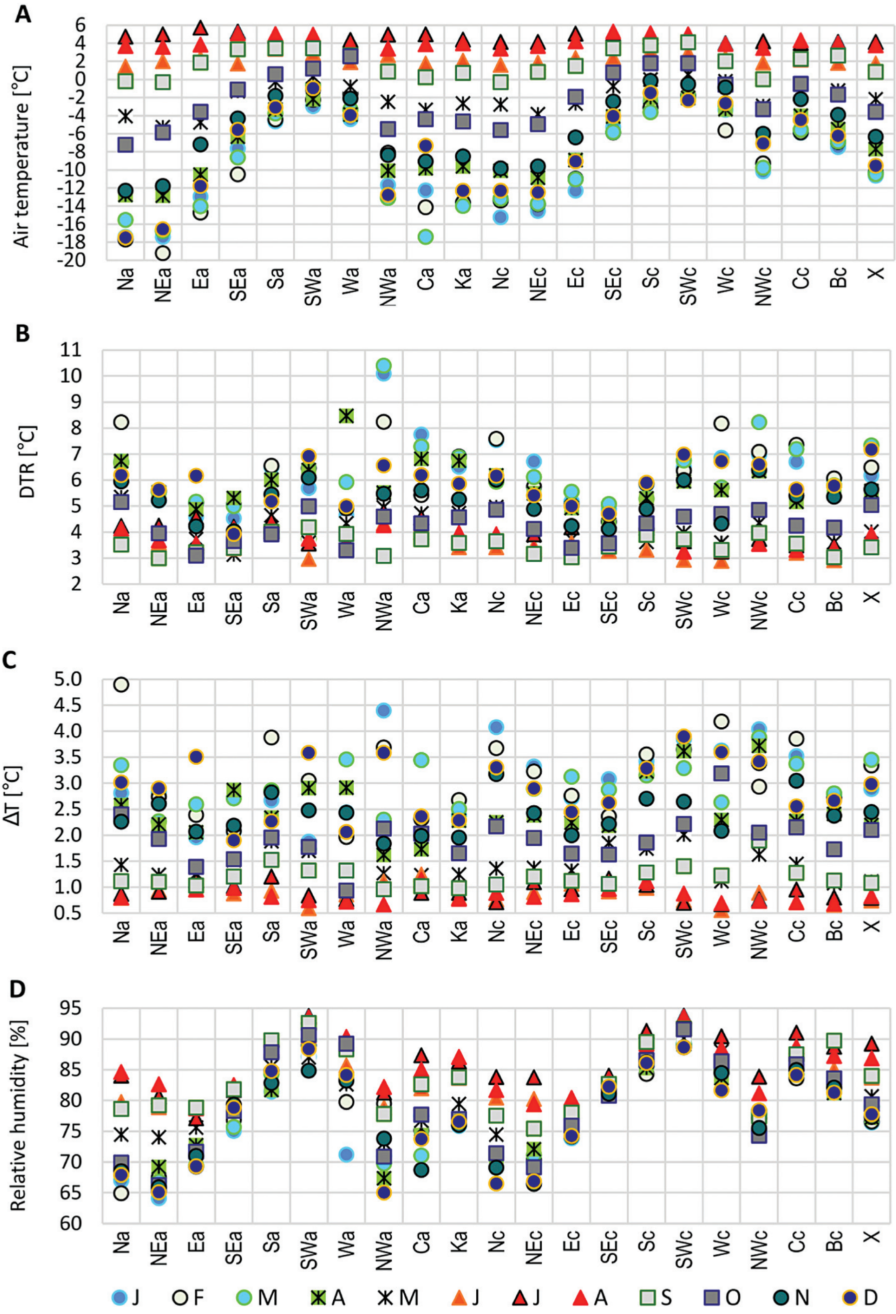

Fig. 11. Average air temperature (**A**), diurnal air temperature range (**B**), day-to-day values of the variability of average daily air temperature (**C**) and average relative humidity (**D**) on Spitsbergen for individual atmospheric circulation types in individual months, for 01.11.1978–31.12.2017.

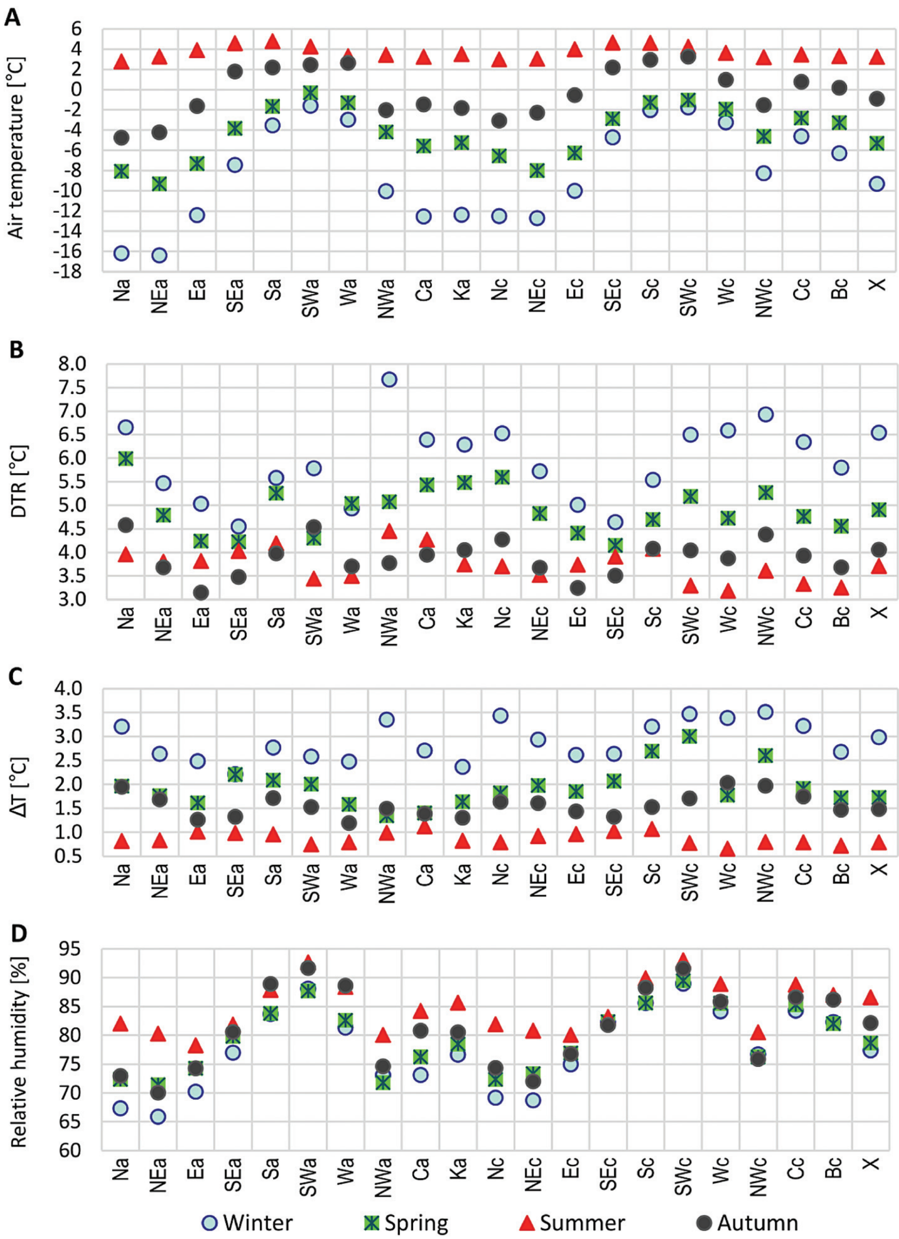

Fig. 12. Average air temperature (**A**), diurnal air temperature range (**B**), day-to-day values of the variability of average daily air temperature (**C**) and average relative humidity (**D**) on Spitsbergen for individual atmospheric circulation types in seasons, for 01.11.1978–31.12.2017.

varied significantly in particular seasons seasons (Fig. 12C). The smallest range of ΔT (0.5°C) was recorded for summer, when it fluctuated from 0.7°C (SWa, Wc and Bc) to 1.1°C (Ca and Sc). The largest ΔT (1.3°C) was in winter, when it ranged from 2.2°C (for SEa) to 3.5°C (for SWc). In Hornsund, according to ΔT, stimuli of significance to humans (> 4°C) occurred mainly in January and February during the advection of air from the N, NW and W in both cyclonic and anticyclonic systems (Fig. 11C).

In the annual course of f in Hornsund, the highest (91%) average was measured during inflow of air masses from the SW under cyclonic and anticyclonic AC conditions, while the lowest (70%) was for NEa with the inflow of Arctic air masses. Throughout the entire year, very humid air (> 85%) was recorded in Hornsund for SWc, Sc (except February) and SWa (except November), refer to Fig. 11D. Over the year, the range of changes in *f* for individual AC types was smallest (15%) in June, ranging from 76% for NWc to 92% for SWc, and in August, from 79% for NEc and Ea to 94% for SWc. Conversely, the largest range of 25% was observed in January. In particular seasons, the smallest range of variability in f was in summer at 15%, ranging from 78% for Ea to 93% for SWa and SWc (Fig. 12D). The largest range between AC types was found in winter at 23%, ranging from 66% for NEa to 89% for SWc.

Spatial variability of thermal and humidity sensation in the Hornsund region. — The main aim of this subsection is to present the spatial variability of thermal and humidity sensations in the Hornsund region. In the introduction, general characteristics of thermal and humidity conditions are outlined. In the period from July 2014 to June 2015, for the first time, studies were carried out on the spatial variability of thermal and humidity conditions around the Hornsund fjord. The most important results of these measurements are presented in the work by Araźny *et al*. (2018).

They indicated that during the year, in the fjord region relative to the Hornsund base station (HOR), the areas around Hyttevika (HYT) and the Wilczekodden peninsula (WIL) proved to be the warmest (by 1.1 and 0.3°C, respectively) (Fig. 13A). These two stations are located on the west coast of the Hornsund fjord. HYT had the most favourable thermal conditions, being sheltered orographically to the east from where mainly cold and dry air masses flow in. Average air temperatures were the lowest, *i.e*. lower than in HOR by 3.7 and 2.1°C, at the top of Fugleberget (FUG) and on the Hans Glacier (HG4), respectively (Araźny *et al*. 2018). The low temperature at FUG was affected by its altitude (568 m a.s.l.), and at HG4 by its altitude (180 m a.s.l.) and its location on a glacier (Fig. 1).

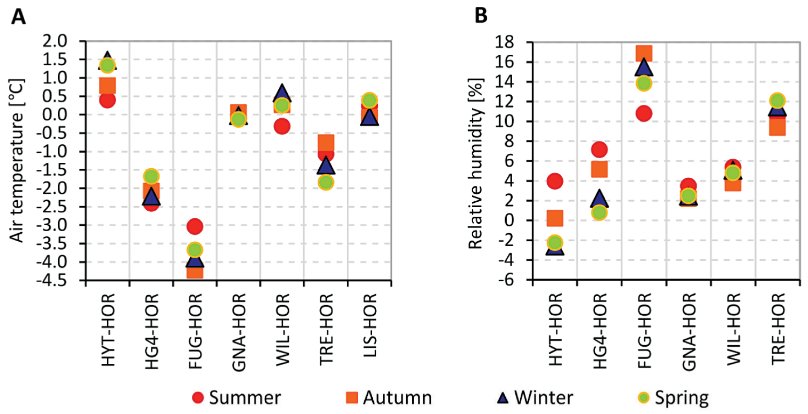

Fig. 13. Differences in average air temperature (**A**) and relative humidity (**B**) between individual measuring stations around the Hornsund fjord (HYT, HG4 etc.) and the Hornsund station (HYT–HOR *etc.*), 01.07.2014–31.06.2015.

Meanwhile, over the year, f differs most from Hornsund on the top of FUG and on the Treskelen peninsula (TRE), where it is on average approximately 14% and 11% higher (Fig. 13B). In the case of FUG, the increase in f is caused by the site being located at the level of low cloud occurrence, while TRE is located in the middle of the eastern part of Hornsund fjord (Araźny *et al*. 2018).

Thermal stimuli in the Hornsund region, as determined by DTR values showed high seasonal variability (Fig. 14). Neutral stimuli were most frequently recorded in summer (on average 85% of days for the entire area), ranging from 73% at FUG (a mountain peak) to 95% in WIL (the Wilczekodden peninsula). In winter, they appeared least often, *i.e*. around 50%, in the Hornsund region, including only 30% of days on the Hans Glacier (HG4). Mildly perceptible thermal stimuli were recorded most frequently in winter, while in the other seasons the frequency of occurrence was stable. Strongly perceptible and sharp stimuli were not recorded in summer around the fjord (Fig. 14). For the entire Hornsund region, these stimuli occur only in winter. In that season, severe changes in DTR then appeared most often on the Hans Glacier (HG4) and in the east of the fjord (TRE), at 9% and 6%, respectively.

Neutral day-to-day changes in average diurnal air temperature, which do not affect human well-being, are most frequently recorded in summer (Fig. 15). Their frequency ranged from 82% (the FUG mountain peak) to 99% (the WIL coastal environment). In winter, neutral changes appeared less frequently, at < 50% for all measuring stations. Sensible changes around the fjord were most frequently recorded in winter, from 30% to 37% at various locations. These changes are fewest in summer. Significant changes most often affected human well-being in winter, *i.e*. from 9% on WIL to 18% on TRE. Severe changes, which are determined as distressing stimuli, are typical for the entire region

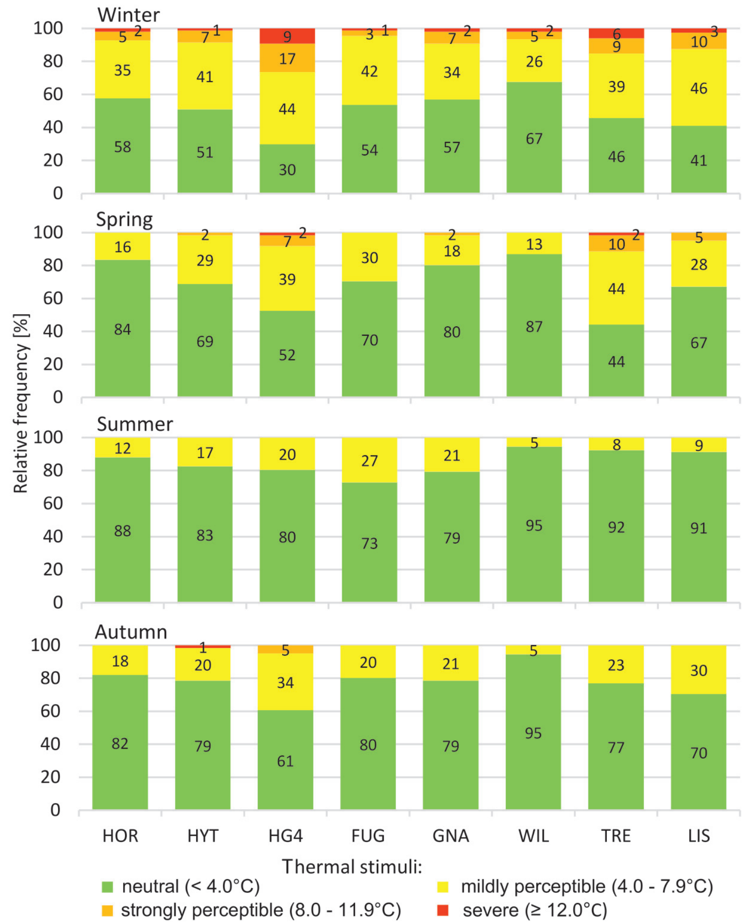

Fig. 14. Relative frequency of thermal stimuli determined on the basis of diurnal air temperature range in the Hornsund region, 01.07.2014–31.06.2015.

in winter and spring, and then only on the glacier and in the mountain), see Fig. 15. In winter, the frequency of such changes ranges from 5–7% right on the fjord to 15% on the Hans Glacier.

In the Hornsund region, the structure of humanly sensible air in terms of f remained at a generally stable level at individual measurement points in winter, spring and autumn (Fig. 16). However, summer was clearly more humid than the other seasons. In summer, the frequency of occurrence of very humid air ranged from 37% at HOR (a sea-coast terrace) to 95% at TRE, in the inner part of the fjord. In the Hornsund region, in the places with the highest average annual relative humidity, *i.e*. FUG and TRE, the frequency of very humid air was > 50% in all seasons (Fig. 16). The sensation of dry air was observed very sporadically.

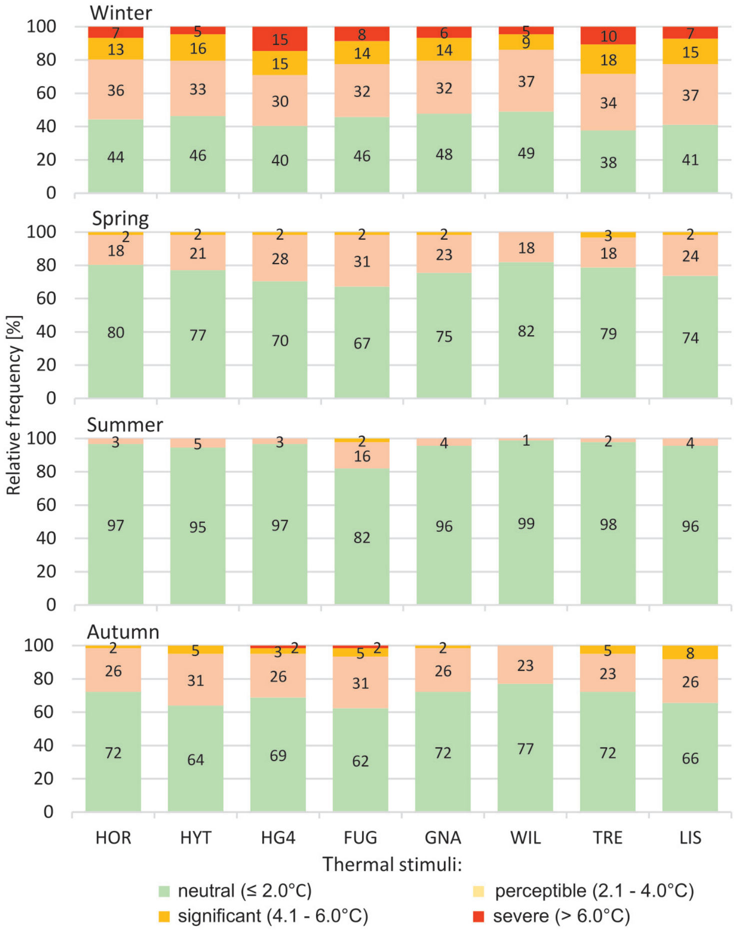

Fig. 15. Relative frequency of thermal stimuli in the Hornsund region, determined by day-to-day variation in average diurnal air temperature, 01.07.2014–31.06.2015.

Summary

The article presents the biometeorological impact of thermal and humidity conditions in the Hornsund region, and their relationship with atmospheric circulation. The temporal (1978–2017) and spatial variability across the Hornsund fjord region of thermal and humidity biometeorological stimuli were investigated. They allowed the following to be concluded.

In the period of 1978–2017, the Hornsund region became warmer in all seasons. These changes are statistically significant. The positive trend in average annual air temperature was 1.1°C per 10 years, and the highest increase was recorded in winter (1.7°C/10 years). In the examined multi-year period, a slight increase in relative humidity of 0.3%/10 years was noted.

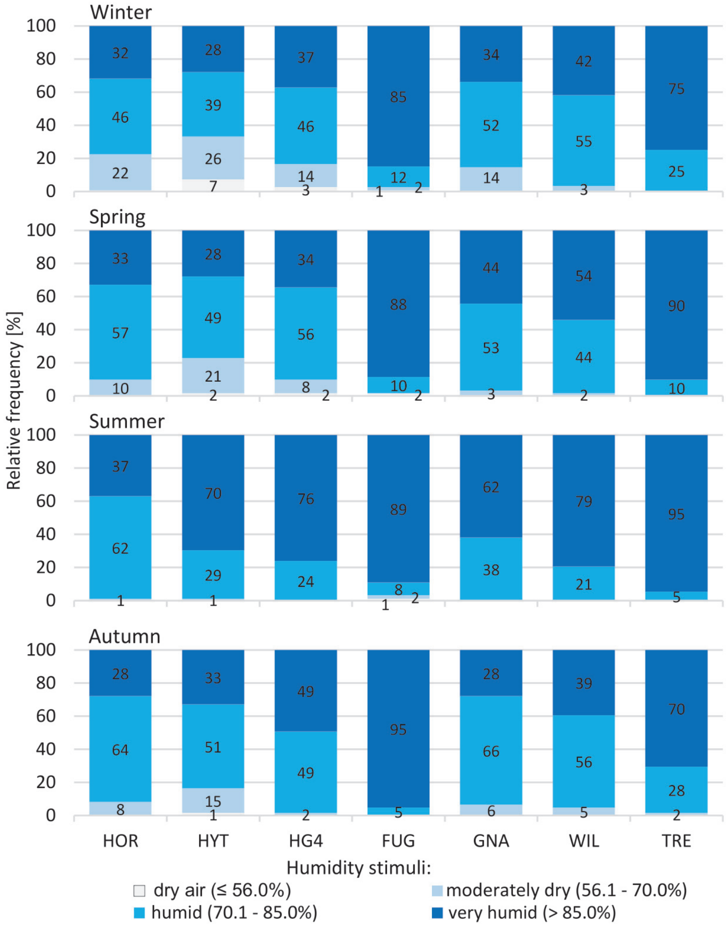

Fig. 16. Relative frequency of humidity stimuli based in relative humidity categories in the Hornsund region, 01.07.2014–31.06.2015.

Assessment of the biometeorological impact of thermal conditions based on day-to-day changes in average diurnal air temperature and diurnal air temperature range showed a decrease in thermal stimuli for humans. A statistically significant positive trend in neutral stimuli was found in DTR of about 15 days/10 years, but there were decreases in strongly perceptible and severe stimuli. A similar situation was found in the analysis of thermal stimuli according to ΔT. There was a statistically significant increase in the number of neutral days, by about 8 days/10 years, while the number of days of significant and severe sensations decreased.

In the assessment of the biometeorological impact of humidity conditions in the years 1978–2017, an increase in the frequency of humid and very humid air inflow was observed, *i.e*. 3.5 and 2.4 days/10 years, respectively, which took place at the expense of a drop in the number of days of dry and moderately dry air.

A significant spatial differentiation of thermal and humidity stimuli was found in the period 2014–2015. The thermal stimulus as assessed in terms of both DTR and ΔT was most conducive to human well-being in the western part of the Hornsund fjord. Conversely, thermal sensations more distressing to the human body were found at stations on glaciers, far inside the fjord and in mountainous areas. Meanwhile, in terms of the biometeorological impact of humidity conditions, humid and very humid air were definitely prevalent through the year. In the Hornsund region, in the places with the highest average annual relative humidity, *i.e.* on the summit of Fugleberget and the Treskelen peninsula, the frequency of very humid air was > 50% in all seasons.

The most important role in AC shaping air temperature sensation and relative humidity in the Hornsund region is played by the direction of incoming air masses. During the advection of air masses from the north-east sector, regardless of type of baric regime, a worsening of thermal stimuli was observed. However, throughout practically the entire year, very humid air (f > 85%) came in over Hornsund from the S–SW with cyclonic and anticyclonic systems. The studied thermal and humidity stimuli occurred with the greatest variability in winter and spring, and with the lowest in summer.

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References

ARAŹNY A. 2003. Annual course of relative air humidity in the Norwegian Arctic from 1971 to 2000. *Problemy Klimatologii Polarnej* 13: 107–115 (in Polish).

ARAŹNY A. 2006. Variability of the predicted insulation index of clothing in the Norwegian Arctic for the period 1971–2000. *Polish Polar Research* 27: 341–357.

ARAŹNY A. 2008. *Bioclimatic conditions and their variability in the Norwegian Arctic for the period 1971–2000*. Wydawnictwo Uniwersytetu Mikołaja Kopernika, Toruń: 215 pp. (in Polish).

ARAŹNY A. 2009. Weather types in the Norwegian Arctic. *Bulletin of Geography. Physical Geography Series* 2: 107–120.

ARAŹNY A. 2010. Biometeorological conditions in the Arctic during the First International Polar Year, 1882–1883. *Bulletin of Geography. Physical Geography Series* 3: 47–64.

ARAŹNY A. 2012. Biometeorological conditions in the Forlandsundet area (NW Spitsbergen) from 11 July to 31 August 2010. *Przegląd Geograficzny* 84: 357–371 (in Polish).

Araźny A. and Błażejczyk K. 2007. Bioclimatic conditions on Kaffiøyra Plain and Waldemar Glacier (NW Spitsbergen) from 16th July to 20th September 2005. *In*: R. Przybylak, M. Kejna, A. Araźny and P. Głowacki (eds) *Abiotyczne środowisko Spitsbergenu w latach 2005–2006 w warunkach globalnego ocieplenia*. Wydawnictwo Uniwersytetu Mikołaja Kopernika: 67–87 (in Polish).

Araźny A., Migała K., Sikora S., Budzik T. and Puczko D. 2009. Biometeorological and meteorological conditions in the Hornsund region during the warm season of 2007 and 2008. *Problemy Klimatologii Polarnej* 19: 203–222 (in Polish).

Araźny A., Migała K., Sikora S. and Budzik T. 2010. Meteorological and biometeorological conditions in the Hornsund area (Spitsbergen) during the warm season. *Polish Polar Research* 31: 217–238.

Araźny A., Przybylak R. and Kejna M. 2016. Ground temperature changes on the Kaffiøyra Plain (Spitsbergen) in the summer seasons, 1975-2014. *Polish Polar Research* 37: 1–21.

Araźny A., Przybylak R., Wyszyński P., Wawrzyniak T., Nawrot A. and Budzik T. 2018. Spatial variations in air temperature and humidity over Hornsund fjord (Spitsbergen) from 1 July 2014 to 30 June 2015. *Geografiska Annaler: Series A, Physical Geography* 100: 27–43.

Bajbakowa E.M., Niewrajew G.A. and Czubukow L.A. 1963. Methods of climate analysis of resorts and meteorological conditions for climatotherapy. *In*: *Study in climate resorts*, Moskwa: 5–42 (in Russian).

Baranowski S. 1968. Thermal conditions of the periglacial tundra, SW Spitsbergen. *Studia Geograficzne 10*. *Acta Universitatis Wratislaviensis* 68: 1–77 (in Polish).

Bednorz E. and Kolendowicz L. 2010. Summer 2009 thermal and bioclimatic conditions in the Ebba Valey region. *Polish Polar Research* 31: 327–348.

Błażejczyk K. 2004. Bioclimatic principles of recreation and tourism in Poland. *Prace Geograficzne* 5: 291 pp. (in Polish).

Bokša V.G. and Boguckij B.V. 1980. *Medical climatology and climatotherapy*. Health, Kiev: 264 pp. (in Russian).

Gavrilova L.A. and Sokolov S.I. 1969. Temporal variability of air temperature in the Arctic. *Proceedings of the Arctic and Antarctic Research Institute* 287: 59–68 (in Russian).

Gluza A.F. 1988. Results of investigation of kata thermometer cooling power in July and August 1986 in Calypsobyen (West Spitsbergen). *In*: *XV Sympozjum Polarne*, Wrocław, 19–21.05, Wydawnictwo Uniwersytetu Wrocławskiego, Wrocław: 207–211. (in Polish).

Isaksen K., Nordli Ø., Førland E.J., Łupikasza E., Eastwood S. and Niedźwiedź T. 2016. Recent warming on Spitsbergen—Influence of atmospheric circulation and sea ice cover. *Journal of Geophysical Research Atmospheres* 121: 11,913–11,931.

Knothe H. 1931. Spitsbergen a regional study. *Petermanns Geographische Mitteilungen* 211: 1–109 (in German).

Maciejczyk M., Araźny A. and Opyrchał M. 2017. Changes in aerobic performance, body composition and physical activity in polar explorers during a year-long stay at the polar station in the Arctic. *International Journal of Biometeorology* 61: 669–675.

Marciniak K. 1983. Attempt of evolution of thermic conditions perceptible in summer at the Kaffiøyra (NW Spitsbergen). *Acta Universitatis Nicolai Copernici 18, Geografia* 56: 125–145.

Marsz A.A. 2013. Humidity. *In*: A.A. Marsz and A. Styszyńska (eds) *Climate and climate change at Hornsund, Svalbard*. Wydawnictwo Akademii Morskiej, Gdynia: 189–198.

Marsz A.A. and Styszyńska A. 2007. (eds) *The climate of the area of the Polish Polar Station in Hornsund – the state, changes and their causes*. Wydawnictwo Akademii Morskiej, Gdynia: 376 pp. (in Polish).

Marsz A.A. and Styszyńska A. 2013. (eds) *Climate and climate change at Hornsund, Svalbard*. Wydawnictwo Akademii Morskiej, Gdynia: 402 pp.

MATURILLI M., HERBER A. and KÖNIG-LANGLO G. 2013. Climatology and time series of surface meteorology in Ny-Ålesund, Svalbard, *Earth System Science Data* 5: 155–163.

NIEDŹWIEDŹ T. 1993. The main Factors Forming the Climate of the Hornsund (Spitsbergen). *Zeszyty Naukowe UJ – Prace Geograficzne* 94: 49–63.

NIEDŹWIEDŹ T. 2013a. The atmospheric circulation, *In*: A.A. Marsz and A. Styszyńska (eds) *Climate and climate change at Hornsund, Svalbard*. Wydawnictwo Akademii Morskiej, Gdynia: 57–74.

NIEDŹWIEDŹ T. 2013b. Influence of atmospheric circulation on the air temperature at Hornsund, *In*: A.A. Marsz and A. Styszyńska (eds) *Climate and climate change at Hornsund, Svalbard*. Wydawnictwo Akademii Morskiej, Gdynia: 165–171.

NIEDŹWIEDŹ T. 2018. *Catalogue of circulation types above Spitsbergen (1978–2017)*. Department of Climatology, University of Silesia, Sosnowiec, Poland. Computer file. http://www.kk.wnoz.us.edu.pl/nauka/kalendarz-typow-cyrkulacji.

NORDLI Ø. 2010. The Svalbard Airport Temperature Series. *Bulletin of Geography. Physical Geography Series* 3: 5–25.

NORDLI Ø., FØRLAND E.J. and NIEDŹWIEDŹ T. 2000. Wind-chill temperature at Svalbard and Jan Mayen. *Klima*. Report No. 07/00, Det Norske Meteorologiske Institutt, Oslo: 47 pp.

NORDLI Ø., PRZYBYLAK R., OGILVIE A.E.J. and ISAKSEN K. 2014. Long-term temperature trends and variability on Spitsbergen: the extended Svalbard Airport temperature series, 1898-2012. *Polar Research* 33: 21349.

PEREYMA J. 1983. Climatological problems of the Hornsund area – Spitsbergen. *Acta Universitatis Wratislaviensis* 714: 134 pp.

PRZYBYLAK R. 1992. The thermic and humidity relations against a background of the circulations conditions in Hornsund (Spitsbergen) in the period 1978–1983. *Dokumentacja Geograficzna* 2: 1–105 (in Polish).

PRZYBYLAK R. 2000. Diurnal temperature range in the Arctic and its relation to hemispheric and Arctic circulation patterns. *International Journal of Climatology* 20: 231–253.

PRZYBYLAK R. 2002. *Variability of air temperature and atmospheric precipitation in the Arctic*. Atmospheric and Oceanographic Sciences Library, 25, Kluwer Academic Publishers, Dordrecht/Boston/London: 330 pp.

PRZYBYLAK R. 2016. *The climate of the Arctic. 2nd ed*. Atmospheric and Oceanographic Sciences Library 52, Heidelberg: Springer: 287 pp.

PRZYBYLAK R. and ARAŹNY A. 2005. Comparison of climatic and bioclimatic conditions in the northern part of Oscar II Land with other areas of the west coast of Spitsbergen from 1975 to 2000. *Problemy Klimatologii Polarnej* 15: 119–131 (in Polish).

PRZYBYLAK R. and ARAŹNY A. 2016. Warming and drying of tundra and glacier summer climate in NW Spitsbergen from 1975 to 2014. *Polish Polar Research* 37: 173–192.

PRZYBYLAK R., ARAŹNY A. and KEJNA M. 2012. Influence of atmospheric circulation on air temperature in the Kaffiøyra region (NW Spitsbergen) in the period July 2005–August 2010. *In*: Z. Bielec-Bąkowska, E. Łupikasza and A. Widawski (eds) *Rola cyrkulacji atmosfery w kształtowaniu klimatu*. Sosnowiec: 181–194 (in Polish).

PRZYBYLAK R., ARAŹNY A., NORDLI Ø., FINKELNBURG R., KEJNA M., BUDZIK T., MIGAŁA K., SIKORA S., PUCZKO D., RYMER K. and RACHLEWICZ G. 2014. Spatial distribution of air temperature on Svalbard during 1 year with campaign measurements. *International Journal of Climatology* 34: 3702–3719.

PRZYBYLAK R., ARAŹNY A. and ULANDOWSKA-MONARCHA P. 2018. The influence of atmospheric circulation on the spatial diversity of air temperature in the area of Forlandsundet (NW Spitsbergen) during 2010–2013. *International Journal of Climatology* 38: 230–251.

SIKORA S., ARAŹNY A., BUDZIK T., MIGAŁA K. and PUCZKO D. 2010. Meteorological and biometeorological conditions in the Hornsund region (Western Spitsbergen) in 2009. *Problemy Klimatologii Polarnej* 20: 83–101 (in Polish).

SIKORA S., BUDZIK T., MIGAŁA K. and PUCZKO D. 2011. Meteorological and biometeorological conditions of south-west Svalbard in 2010. *Problemy Klimatologii Polarnej* 21: 213–228 (in Polish).

STAFFORD J.M., WENDLER G. and CURTIS J. 2000. Temperature and precipitation of Alaska: 50 year trend analysis. *Theoretical and Applied Climatology* 67: 33–44.

SZCZEPANKIEWICZ-SZMYRKA A. 1981. Biometeorological conditions on the foreland of the Werenskiold Glacier in Summer 1980. *In*: A. Jahn, J. Jania and M. Pulina (eds) *VIII Sympozjum Polarne*, Sosnowiec: 43–48 (in Polish).

SZCZEPANKIEWICZ-SZMYRKA A. 1988. Biometeorological conditions in the summer–autumn period of 1985 in the Werenskiold Glacier region. *In*: R. Brázdil (eds) *Results of Investigation of the Geographical Research Expedition Spitsbergen 1985*. Univerzita Purkyné, Brno: 142–152.

SZCZEPANKIEWICZ-SZMYRKA A. and PEREYMA J. 1992. Biometeorological conditions in Hornsund, in 1979–1980. *In*: K.W. Opaliński, R.Z. Klekowski (eds) *Landscape, Life World and Man in High Arctic*. Institute of Ecology, Polish Academy of Science, Warszawa: 103–111.

TUOMENVIRTA H., ALEXANDERSSON H., DREBS A., FRICH P. and NORDLI Ø. 2000. Trends in Nordic and Arctic Temperature Extremes and Ranges. *Journal of Climate* 13: 977–990.

WÓJCIK G. 1963. On the amount of cooling power of air on Spitsbergen. *Biuletyn Komisji MRG*, 1/32, Warszawa: 73–80 (in Polish).

ZAWIŚLAK T. 1986. Preliminary characteristic of the bioclimatic conditions of the Spitsbergen west coast. *Acta Universitatis Wratislaviensis*. *Results of Investigation of the Polish Scientific Spitsbergen Expeditions* VI: 75–85.

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