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Meteorological and biometeorological conditions in the Hornsund area (Spitsbergen) during the warm season

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Abstract: Meteorological and biometeorological conditions during the warm seasons (June–September) of 1979–2008 are described for the Hornsund area, Spitsbergen. The measurements were taken at four sites: at Hornsund, at the Hans Glacier (at its equilibrium line and in the firn section) and at the summit of Fugleberget. The variation of meteorological and biometeorological conditions was analysed in relation to altitude, distance from the sea and the ground type. In warm seasons, the air temperature at Hornsund was 2.2 °C higher on average than at the Hans Glacier (central section) and by 2.8 °C than at the Hans Glacier (firn section) and at Fugleberget. The average wind speed recorded at Hornsund was higher (0.6 m s^{-1}) than at the Hans Glacier and lower (0.9 m s^{-1}) than at Fugleberget. Four biometeorological indices were used: wind chill index (WCI), predicted insulation of clothing (Iclp), cooling power (H) and subjective temperature index (STI). The strongest thermal stimuli were observed on the Hans Glacier and in the upper mountain areas. The study has found a considerable degree of spatial variation between the meteorological elements investigated and the biometeorological indices in the Hornsund area. The impact of atmospheric circulation on meteorological elements and biometeorological indices is also presented. The mildest biometeorological conditions of the warm season found at Hornsund were associated with air masses arriving from the southwest and west.

Key words: Arctic, South Spitsbergen, meteorology, biometeorology, atmospheric circulation.

Introduction

The main purpose of this study is to investigate the spatial variation in meteorological and biometeorological conditions prevailing in the Hornsund area (SW Spitsbergen) during the warm seasons (June–September) over the period

1979–2008. In addition, the study is intended to evaluate how circulation-related and local factors affect the meteorological and biometeorological conditions in this Arctic area.

Low air temperatures cause the sensation of cold in humans. This occurs when heat loss is greater than the human body's capacity to generate heat. Natural defences against the drop of body temperature include the restriction of heat transfer to the skin (vasoconstriction) and faster rates of heat generation. In Polar areas, however, these physiological mechanisms are not sufficient and we have to look for additional protection, such as special clothing and a high-energy diet.

The history of topoclimatic research in Spitsbergen stretches back more than 50 years to 1957, the 3rd International Geophysical Year. Polish meteorological efforts in glaciated areas produced an extensive set of data at Hornsund as the number of survey sites and the scope of the research gradually expanded (Kosiba 1958, 1960; Głowicki and Baranowski 1974; Baranowski and Głowicki 1975a, b; Baranowski 1977; Pereyma 1983; Brázdil *et al.* 1988; Pereyma and Piasecki 1988; Marsz and Styszyńska 2007; Nasiółkowski and Pereyma 2007; Migała *et al.* 2008). Less published research is available on biometeorology and bioclimatology (Wójcik 1963; Szczepankiewicz-Szmyrka 1981, 1988; Szczepankiewicz-Szmyrka and Pereyma 1992; Zawiślak 1986; Nordli *et al.* 2000; Araźny 2003, 2006, 2008; Przybylak and Araźny 2005; Sikora *et al.* 2007).

Study area

The study shows the variation in meteorological and biometeorological conditions using data from four sites: at Hornsund (HOR), at the Hans Glacier (HT4 and HT9) and on the summit of Fugleberget (FUG) (Fig. 1). This variation was analysed in various weather conditions depending on altitude above sea level, distance to the sea and ground type.

The main local weather station is located on the north bank of the Hornsund fiord (HOR) at Polish Polar Station of the Polish Academy of Sciences. It is located on a marine terrace 10 m.a.s.l. and 300 m from the sea (φ = 77°00'N, λ = 15°33'E). The Hornsund weather station operates as part of the World Meteorological Organisation (WMO) network and conducts systematic 24 h measurements and observations using the basic meteorology according to WMO standards.

Two survey stations were used to determine the local climate of the Hans Glacier. One of them (HT4) is located at 184 m.a.s.l. in a central section of the glacier, near its equilibrium line 3 km from the glacier snout (φ = 77°04' N, λ = 15°63' E). The other station (HT9) is located at 421 m.a.s.l. and 9 km from this glacier's snout (φ = 77°11' N, λ = 15°48' E). The Hans Glacier is 16 km in length and has a surface area of approximately 57 km^2. The positioning of both stations is affected, albeit slowly, by deglaciation and the glacier flow processes.

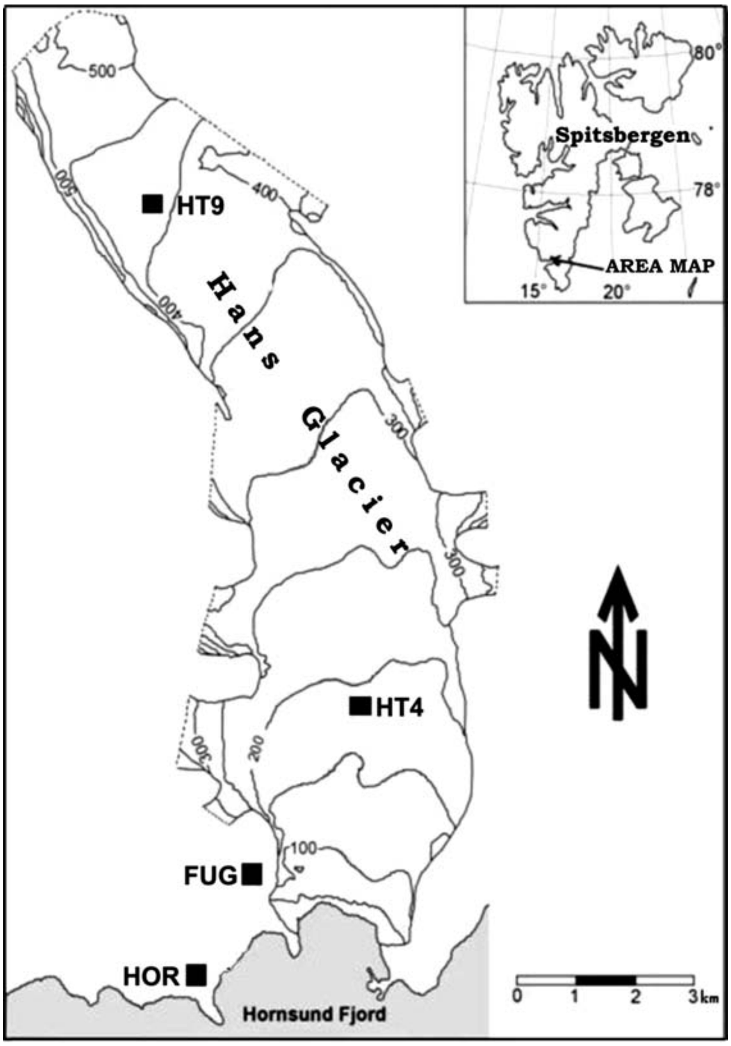

Fig. 1. Location of study area and meteorological stations used in the present study.

The fourth survey point was positioned on the summit of the Fugleberget (FUG) at 568 m asl and 1.5 km from the Hornsund fiord (φ = 77°01'N, λ = 15°34'E).

Data and methods

Standard computational climatological and bioclimatological methods (including Gregory 1968 and Kozłowska-Szczęsna *et al.* 1997) were used to investigate the meteorological and biometeorological conditions. Four biometeorological indexes were analysed: wind chill index (*WCI*), predicted insulation of clothing (*Iclp*), subjective temperature index (*STI*) and cooling power (*H*). Momentary values (10 min.) of meteorological data from the two warm seasons (June–September) of 2007 and 2008 were used. The biometeorological indexes (*WCI, Iclp, STI* and *H*) were determined with empirical formula using the BioKlima 2.5 software package (Błażejczyk and Błażejczyk 2007).

Wind chill index was used to determine the biothermal conditions around the Hornsund station with the assumption of heavy protection by winter clothing for arctic conditions with a 4.0 clo insulation value (Siple and Passel 1945):

$$WCI = (10\, v^{0.5} + 10.45 - v)\,(33.0 - T)\, 1.163$$

where: T – air temperature (°C), v – wind speed (m s^{-1}).

WCI values denote the thermal sensations experienced by humans in contact with air (Kozłowska-Szczęsna *et al.* 1997). Specific *WCI* values include: extremely hot ($WCI \leq 58.2$ Wm^{-2}), hot (58.3–116.3 Wm^{-2}), warm (116.4–232.6 Wm^{-2}), comfortable (232.7–581.5 Wm^{-2}), cool (581.6–930.4 Wm^{-2}), cold (930.5–1628.2 Wm^{-2}), frosty (1628.3–2326.0 Wm^{-2}), extremely frost (> 2326.0 Wm^{-2}).

The predicted insulation of clothing index was proposed by Burton and Edholm (1955) for thermophysiological research in the outdoors. It is calculated with the formula:

$$Iclp = 0.082\,[91.4 - (1.8T + 32)] \,/\, (0.01724M) - 1 \,/\, (0.61 + 1.9\, v^{0.5})$$

where: T – air temperature in °C, v – wind speed in m s^{-1}, M – metabolism in Wm^{-2}.

For the purpose of calculating *Iclp* a metabolism of 135 Wm^{-2} was adopted, typical of a person walking at 4 km per hour. Finally, *Iclp* values were derived for specific weather conditions in clo.

The following descriptions of weather conditions are equivalent to the various *Iclp* values: very warm (< 0.30 clo), warm (0.31–0.80 clo), neutral (0.81–1.20 clo), cool (1.21–2.00 clo), cold (2.01–3.00 clo), very cold (3.01–4.00 clo) and arctic cold (> 4.00 clo).

The subjective temperature index represents the sensation of the human body exposed to the atmosphere elements. It is derived from the human heat balance using the MENEX_2002 model of heat exchange between the human body and its surroundings (Błażejczyk 1993, 2003). *STI* represents subjective sensations of the human body. These sensations are felt as a result of the reaction of hot/cold receptors to thermal stimuli from the body and its environment (Błażejczyk 2003).

The various subjective temperature values are described by the following sensations: very cold (< -38.00 °C), cold (-38.00 – -0.50 °C), cool (-0.49 – 22.50 °C), comfortable (22.51–32.00 °C), warm (32.01–46.00 °C), hot (46.01–55.00 °C), very hot (> 55.00 °C).

The cooling power reflects the loss of heat from the body surface in time. The *H* index is useful in assessing thermal sensations of a walking human wearing appropriate clothing. The index was derived using Hill's empirical formulas (Kozłowska-Szczęsna *et al.* 1997):

$$H = (36.5 - T)\,(0.20 + 0.4v^{\,0.5})\,41.868 \text{ when } v \leq 1 \text{ m s}^{-1}$$

$$H = (36.5 - T)\,(0.13 + 0.47v^{\,0.5})\,41.868 \text{ when } v > 1 \text{ m s}^{-1}$$

where: T – air temperature (°C), v – wind speed (m s^{-1}).

The calculated H values were presented as a frequency distribution against Petrovič and Kacvinsky's thermal sensation scale (after Kozłowska-Szczęsna *et al.* 1997). The scale is as follows: extremely cold and windy (>2100.0 Wm^{-2}); very cold (1680.1–2100.0 Wm^{-2}); cold (1260.1–1680.0 Wm^{-2}); cool (840.1–1260.0 Wm^{-2}); slightly cool (630.1–840.0 Wm^{-2}); neutral (420.1–630.0 Wm^{-2}); hot (210.1–420.0 Wm^{-2}) and very hot (< 210.0 Wm^{-2}).

Meteorological conditions

Air temperature. — Local air temperature distributions depend to a large extent on the orography and exposure, type and properties of the surface, altitude, distance from the sea and the local air circulation. In glaciated areas, temperature is also subject to a strong influence from ice and snow masses where the glacier surface temperature does not rise above 0 °C.

The highest average air temperatures during the warm seasons of 2007 and 2008 were recorded on the sea terrace at HOR (Table 1). The average monthly temperatures on the northern bank of the Hornsund fiord were higher than 0 °C. These were compatible with the average monthly air temperatures recorded at HOR during the period 1979–2006 (Fig. 2). On average, the warmest months of the year at HOR are July and August (4.4 and 4.0 °C, respectively) followed by June and September (1.8 and 1.3 °C, respectively) (Marsz and Styszyńska 2007). During the warm seasons of 2007 and 2008, the August temperature was close to average (3.9–4.2 °C), while July was somewhat cooler (4.1–4.2 °C). The remaining months were warmer than the long-term average: June (2.4–2.7 °C) and September (1.7–2.9 °C). This situation was caused by a more frequent influx of warmer and more humid air masses from the Atlantic than in previous years.

The Hans Glacier is, on average, the coldest place in the Hornsund area. The average temperature difference of over eight months between HOR and the glacial stations (HT4 and HT9) was at 2.5 °C. The average temperature gradient over the measurement period between the upper glacial station HT9 and HOR was 0.70 °C per 100 m. In July and August of 2007 and 2008, the Hans Glacier had a uniform temperature field (0.1–0.6 °C), but in other months the differences between the warmer section of the glacier, located between the snout and the equilibrium line and its firn-snow section were large (Table 1).

Table 1

Mean values of selected meteorological elements (T – mean air temperature, v – wind velocity at 2 m above ground level, f – relative humidity) at HOR in comparison with HT4, HT9 and FUG from 1st June to 30th September 2007 and 2008

Element	Year	2007				2008			
	Station	HOR	HT4 -HOR	HT9 -HOR	FUG -HOR	HOR	HT4 -HOR	HT9 -HOR	FUG -HOR
T [°C]	1–10.06	1.9	-1.6	-2.2	–	1.5	-1.2	-2.0	-2.6
	11–20.06	2.3	-2.3	-2.4	–	2.3	-2.0	-3.5	-4.0
	21–30.06	3.8	-1.6	-3.0	–	3.5	-1.4	-3.3	-4.0
	1–30.06	**2.7**	**-1.9**	**-2.6**	–	**2.4**	**-1.5**	**-2.9**	**-3.5**
	1–10.07	3.8	-2.5	-1.8	-1.1	3.5	-1.5	-1.7	-1.6
	11–20.07	4.2	-2.8	-2.7	-2.5	4.1	-1.3	-2.6	-3.2
	21–31.07	4.6	-2.6	-3.1	-3.0	4.8	-2.3	-1.2	-0.2
	1–31.07	**4.1**	**-2.5**	**-2.4**	**-2.1**	**4.2**	**-1.8**	**-1.9**	**-1.7**
	1–10.08	5.6	-1.9	-3.3	-2.6	3.5	-1.8	-1.2	-0.2
	11–20.08	4.4	-3.4	-3.4	-3.1	4.5	-2.2	-2.7	-3.1
	21–31.08	2.7	-3.2	-3.8	-3.8	3.8	-1.6	-2.6	-2.6
	1–31.08	**4.2**	**-2.9**	**-3.5**	**-3.2**	**3.9**	**-1.8**	**-2.2**	**-1.9**
	1–10.09	2.5	-3.5	-4.8	-4.0	2.8	-1.7	-2.4	-2.5
	11–20.09	2.3	-1.7	-4.3	-4.2	4.9	-1.9	-1.7	-2.0
	21–30.09	0.5	-3.2	-4.0	-3.9	1.0	-2.1	-4.1	-4.7
	1–30.09	**1.7**	**-3.0**	**-4.3**	**-4.0**	**2.9**	**-1.9**	**-2.7**	**-3.0**
v [m/s]	1–10.06	2.6	-0.4	-0.6	–	2.6	-0.5	-0.6	–
	11–20.06	3.3	-0.8	-0.8	–	2.5	0.3	0.5	–
	21–30.06	5.3	-2.7	-2.8	–	5.4	-1.5	-1.3	–
	1–30.06	**3.8**	**-1.4**	**-1.5**	–	**3.5**	**-0.6**	**-0.5**	–
	1–10.07	2.1	-0.4	0.0	-0.1	2.3	-0.1	0.2	1.0
	11–20.07	2.7	-0.7	-0.9	0.6	3.7	-1.1	-1.6	1.2
	21–31.07	4.0	-1.5	-2.2	0.8	1.7	0.3	0.0	0.5
	1–31.07	**2.8**	**-0.7**	**-0.9**	**0.7**	**2.5**	**-0.3**	**-0.4**	**0.9**
	1–10.08	5.8	-1.5	-3.2	3.0	1.6	0.2	0.8	0.7
	11–20.08	2.1	0.3	0.0	0.6	2.5	0.0	0.2	0.4
	21–31.08	3.7	-0.9	-0.9	0.8	2.9	-0.8	-1.2	0.7
	1–31.08	**3.8**	**-0.7**	**-1.3**	**1.6**	**2.4**	**-0.3**	**-0.1**	**0.5**
	1–10.09	2.5	-0.1	-0.2	0.3	1.6	0.0	0.5	1.7
	11–20.09	3.9	-1.1	-1.6	1.7	2.3	-0.2	1.1	1.6
	21–30.09	2.7	0.0	0.2	0.3	4.0	0.2	0.2	2.0
	1–30.09	**3.0**	**-0.4**	**-0.5**	**0.9**	**2.6**	**0.0**	**0.6**	**1.8**

f [%]	1–10.06	85.1	5.3	7.6	–	82.7	1.6	-0.6	–
	11–20.06	79.5	0.8	0.0	–	73.0	6.0	4.2	–
	21–30.06	82.3	-1.6	5.8	–	78.5	-0.6	4.6	–
	1–30.06	**82.0**	**1.9**	**4.7**	–	**78.1**	**2.4**	**2.8**	–
	1–10.07	91.2	2.2	-5.5	–	87.9	1.7	-5.1	-5.2
	11–20.07	88.6	-0.5	-1.3	–	87.4	1.6	2.5	5.8
	21–31.07	87.6	0.3	4.0	–	89.7	2.0	-7.7	-8.8
	1–31.07	**89.5**	**0.2**	**-1.2**	–	**88.4**	**1.7**	**-3.6**	**-2.8**
	1–10.08	84.8	2.2	8.9	–	90.6	-1.0	-11.3	-13.9
	11–20.08	86.2	3.6	2.3	–	88.3	2.8	-0.7	4.1
	21–31.08	77.4	7.4	9.8	–	84.6	1.7	3.8	4.7
	1–31.08	**82.7**	**4.4**	**7.1**	–	**87.7**	**1.2**	**-2.5**	**-1.5**
	1–10.09	81.2	2.0	12.5	–	89.8	1.1	-2.2	-2.3
	11–20.09	89.9	-6.1	-1.4	–	96.9	2.3	-1.9	-1.1
	21–30.09	85.2	2.7	2.4	–	80.3	4.9	9.8	12.3
	1–30.09	**84.7**	**0.4**	**5.2**	–	**89.0**	**2.8**	**1.9**	**3.0**

The FUG station is located on a high mountain peak on the Fugleberget massif. The average air temperature gradient over the measurement period between FUG and HOR was 0.50 °C per 100 m. An identical temperature gradient is reported in other areas of Spitsbergen by Wójcik *et al*. (1998), Araźny (1999) and Kejna (2001).

The warmest periods in the Hornsund area were two first decades of August. For example, the temperatures recorded in the first decade of August 2007 reached 5.6 °C at HOR, between 3.7 and 2.3 °C at the Hans Glacier and 3.0 °C at FUG. The coldest period was definitely the last decade of September 2007 with 0.5 °C at HOR, -2.7 to -3.5 °C at the glacier and -3.4 °C at FUG.

Wind speed. — The windiest of all four weather stations is the mountain-top FUG (Table 1). It is located on the highest summit of the Ariekammen-Fugleberget mountain range (568 m.a.s.l.). The average wind speed over the two periods studied is 1.1 m s^{-1} higher at FUG than at HOR.

The lowest annual wind speeds recorded at HOR occurred between June and September (Fig. 2). According to Araźny (2008) during 1979–2000, the station recorded average wind speeds at 2.7, 2.9, 3.0 and 3.2 m s^{-1} (at 2 m above ground level). Wind speeds observed during the warm seasons of 2007 and 2008 were higher in June by 0.8–1.1 m s^{-1} and lower in September by 0.2–0.6 m s^{-1} in comparison to the long-term values.

The average wind speed recorded at the sheltered Hans Glacier was lower than at the coast (HOR) or in the mountains (FUG). The glacier is surrounded by several mountain ridges, including the Sofiekammen massif with its peaks Wintertinden (925 m) and Fannytoppen (412 m) to the east and the Stryptegga (734 m) and

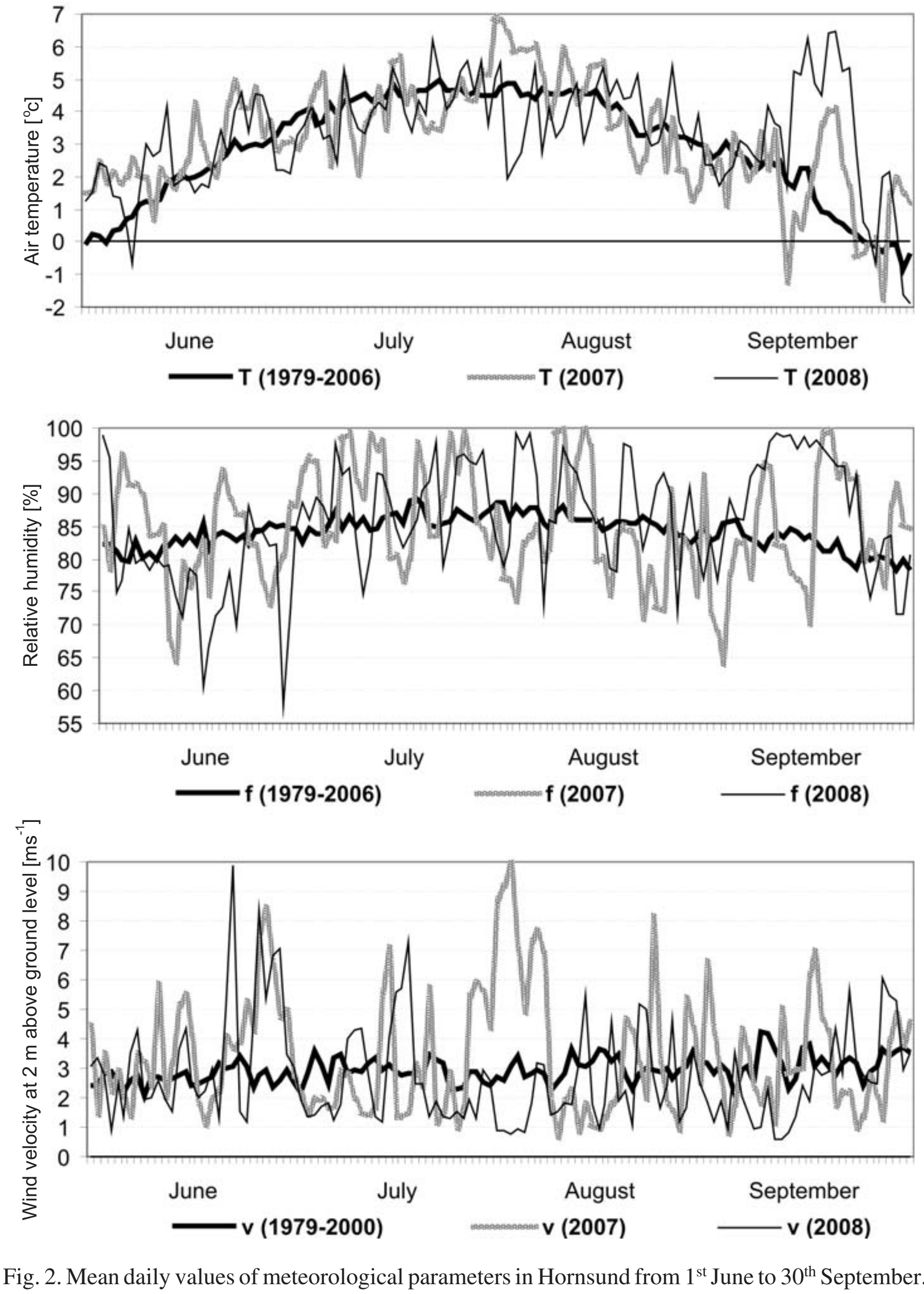

Fig. 2. Mean daily values of meteorological parameters in Hornsund from 1st June to 30th September.

Bergnova (655 m) mountains and also the nearby Fugleberget range (FUG) (568 m) to the west.

During the periods studied, the strongest winds were recorded in the first decade of August 2007. These included average speeds of 8.8 m s^{-1} at FUG, 5.8 m s^{-1}

at HOR, 4.3 m s^{-1} at the central section of the Hans Glacier and 2.6 m s^{-1} at its top section. The lowest wind speeds (1.6 m s^{-1}) recorded at HOR occurred during the first decades of August and September 2008.

Relative air humidity. — SW Spitsbergen has a characteristically high relative air humidity, as a result of a high proportion of warm and humid air blown in by cyclones from moderate latitudes, low air temperatures and the sea in close proximity.

The annual maximum relative air humidity at HOR was recorded in July and August (85.8% and 85.7%, respectively), followed by somewhat lower values in June and September (82.8% and 81.6%, respectively) (Marsz and Styszyńska 2007). In July and September 2007 and 2008 and in August 2008, the average monthly relative humidity was higher than the long term average by 3–7%. In June 2007 and 2008 and in August 2007, it was lower that the long-term average (1–5%). Foehn-type winds had little influence on the relative humidity pattern at HOR, which confirmed earlier records of Marsz and Styszyńska (2007).

There was a slight difference in the relative air humidity between HOR and the other three stations (Hans Glacier and FUG). On the Hans Glacier, relative humidity was mainly influenced by the ice and snow and by katabatic winds.

The wettest period was the second decade of September 2008. At HOR, the relative humidity reached 96.9%, at the Hans Glacier it ranged from 95.0 to 99.2% and at FUG it was 95.8%. The driest period was recorded in the second decade of June 2008 when the relative humidity at HOR was 73.0% and at the glacier between 77.2 and 79.0% (Table 1).

Biometeorological conditions

Wind chill index (*WCI*). — The wind chill is a very useful biometeorological index of thermal conditions at low temperatures (Siple and Passel 1945). The best thermal conditions found in the study were linked to higher temperatures (HOR) or lower wind speeds (glacier stations).

Between June and September of the years 1979–2000, the "cool" category clearly prevailed at HOR (Fig. 3; Araźny 2008). The same category prevailed on monthly average throughout the period at all stations. The only exceptions included "cold" prevailing in September 2007 and 2008 and in August 2007 at FUG and in September 2007 at HT9 (Table 2).

During the eight months analysed in detail, the momentary (10 min.) values ranged from "comfortable" to "extremely frosty" (Fig. 4). At HT4, HOR and HT9 the most frequent sensation was "cool" (69%, 66% and 64%, respectively), while at FUG "cold" occurred more frequently than "cool" (47% *vs*. 44%). During that period, no momentary values likely to cause frostbite to exposed parts of the body were recorded. Over the entire measurement period, "frosty" and "extremely

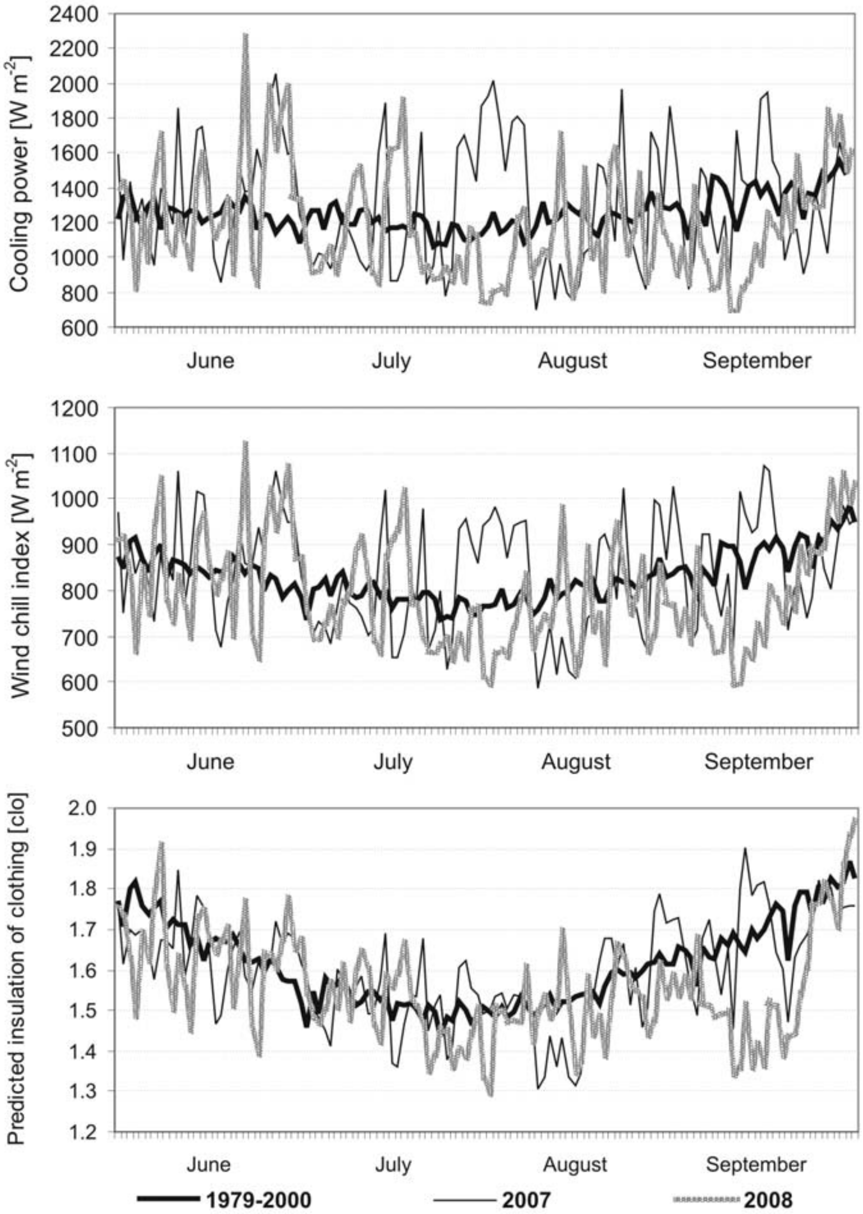

Fig. 3. Mean daily values of biometeorological indexes during moderate (M = 135 Wm^{-2}) physical activity in Hornsund from 1st June to 30th September.

frosty" sensations were only recorded in September 2007 at the upper glacier station HT9, but only constituted 2% of that month's record.

Predicted insulation of clothing (*Iclp*). — The predicted insulation of clothing index was used to assess the biometeorological conditions for the purpose of

Table 2

Mean values of wind chill index (*WCI*) and of predicted insulation of clothing (*Iclp*) during moderate (M = 135 Wm^{-2}) physical activity at HOR in comparison with HT4, HT9 and FUG from 1st June to 30th September 2007 and 2008

Index	Year	2007				2008			
	Station	HOR	HT4 -HOR	HT9 -HOR	FUG -HOR	HOR	HT4 -HOR	HT9 -HOR	FUG -HOR
WCI (Wm^{-2})	1–10.06	834.8	5.1	17.0	–	841.0	-2.8	5.4	–
	11–20.06	859.2	23.9	30.1	–	821.5	75.4	126.3	–
	21–30.06	939.7	-85.5	-74.1	–	921.0	-29.3	49.2	–
	1–30.06	**882.7**	**-23.5**	**-13.8**	–	**861.2**	**14.4**	**60.3**	–
	1–10.07	757.9	64.1	45.3	5.2	766.2	12.6	42.9	53.3
	11–20.07	769.5	39.7	24.5	103.1	835.9	-26.8	-20.1	130.2
	21–31.07	825.0	1.0	-31.4	124.6	684.5	95.8	39.3	47.5
	1–31.07	**785.5**	**33.8**	**11.3**	**86.1**	**759.7**	**29.4**	**21.3**	**76.6**
	1–10.08	855.5	31.9	-13.6	166.2	704.1	66.6	112.1	48.5
	11–20.08	724.2	128.7	99.9	110.9	751.0	63.3	86.5	77.4
	21–31.08	842.8	76.3	95.2	157.5	803.6	-4.6	-23.0	96.6
	1–31.08	**804.5**	**83.0**	**65.8**	**153.4**	**754.6**	**40.2**	**55.8**	**74.8**
	1–10.09	808.4	103.7	125.7	108.6	717.8	47.5	128.0	198.4
	11–20.09	911.3	15.5	4.7	157.8	719.3	44.8	119.0	169.5
	21–30.09	871.9	75.3	452.3	142.1	946.2	70.9	113.3	247.5
	1–30.09	**858.6**	**70.4**	**199.5**	**143.0**	**794.4**	**54.4**	**120.1**	**205.1**
Iclp (clo)	1–10.06	1.7	0.0	0.1	–	1.7	0.0	0.1	–
	11–20.06	1.6	0.2	0.2	–	1.6	0.2	0.3	–
	21–30.06	1.6	0.1	0.1	–	1.6	0.1	0.2	–
	1–30.06	**1.6**	**0.1**	**0.2**	–	**1.6**	**0.1**	**0.2**	–
	1–10.07	1.5	0.2	0.1	0.1	1.5	0.1	0.1	0.1
	11–20.07	1.5	0.2	0.1	0.2	1.6	0.0	0.1	0.2
	21–31.07	1.5	0.2	0.1	0.2	1.4	0.2	0.1	0.0
	1–31.07	**1.5**	**0.2**	**0.1**	**0.2**	**1.5**	**0.1**	**0.1**	**0.1**
	1–10.08	1.5	0.1	0.2	0.2	1.5	0.1	0.1	0.0
	11–20.08	1.5	0.2	0.2	0.2	1.5	0.1	0.2	0.1
	21–31.08	1.6	0.2	0.3	0.3	1.6	0.0	0.1	0.1
	1–31.08	**1.5**	**0.2**	**0.2**	**0.3**	**1.5**	**0.1**	**0.1**	**0.1**
	1–10.09	1.6	0.2	0.3	0.2	1.5	0.1	0.2	0.3
	11–20.09	1.7	0.1	0.2	0.2	1.4	0.2	0.2	0.2
	21–30.09	1.7	0.2	0.3	0.4	1.8	0.1	0.2	0.3
	1–30.09	**1.7**	**0.2**	**0.2**	**0.2**	**1.6**	**0.1**	**0.2**	**0.2**

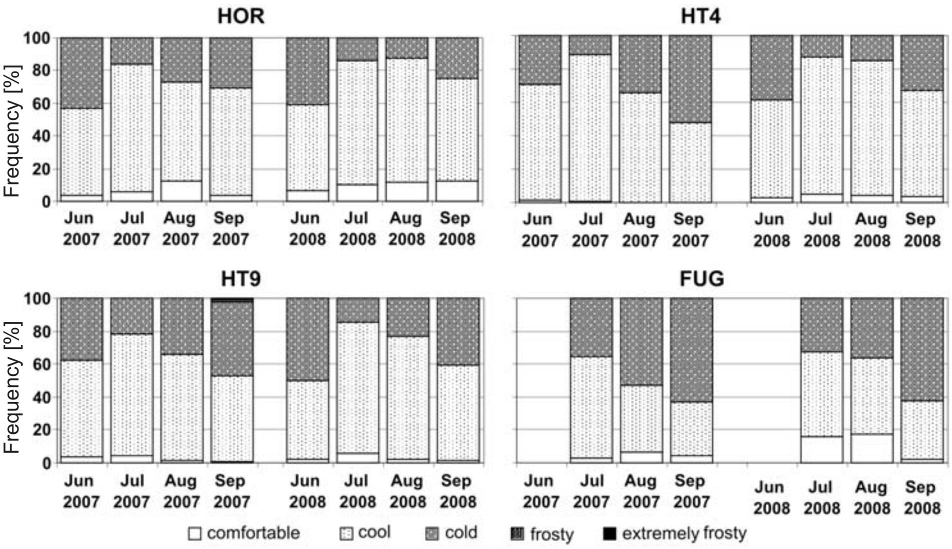

Fig. 4. Frequency of wind chill index from 1st June to 30th September 2007 and 2008.

determining the clothing requirements that would provide thermal comfort to a person walking at 4 km per hour. Between June and September, the optimal insulation clothing for a walking person was a type of clothing intended for transitional periods below the value of 2.5 clo (Fig. 3, Table 2). The values recorded at HOR in individual months were lower by 0.1–0.2 clo than those at the Hans Glacier and lower by 0.1–0.4 clo than at FUG. However, an additional clothing layer, *e.g.* an undershirt or a shirt, is required when the values drop by as slightly as 0.1–0.2 clo.

In addition, a human body needs twice as much clothing insulation for thermal comfort when standing upright as does a body in motion (Araźny 2006, 2008). A standing body produces only 70 Wm^{-2} of heat, which is roughly 50% of that produced by the metabolism of a walking person.

"Cool" thermal conditions, at a moderate rate of physical exercise, prevailed during the entire period. This category accounted for 80–90% of all cases at all survey points (Fig. 5).

Subjective temperature index (*STI*). — Subjective temperature takes into account the human thermophysiological response to changing external conditions. *STI* is derived from the heat balance of the human body (Błażejczyk and Błażejczyk 2007). *STI* was not available at FUG, as solar radiation, an essential variable used to compute *STI*, was not recorded at that station.

At Hornsund and around the Hans Glacier, average *STI* values were highly variable (Table 3). Over the study period, the best biothermal conditions, described as "cool", occurred at the higher section of the glacier (HT9) during the first ten days of July 2008 (11.0 °C). At the same time, the lower part of the glacier recorded a temperature of 4.3 °C and at HOR only 3.7 °C. This *STI* distribution is a

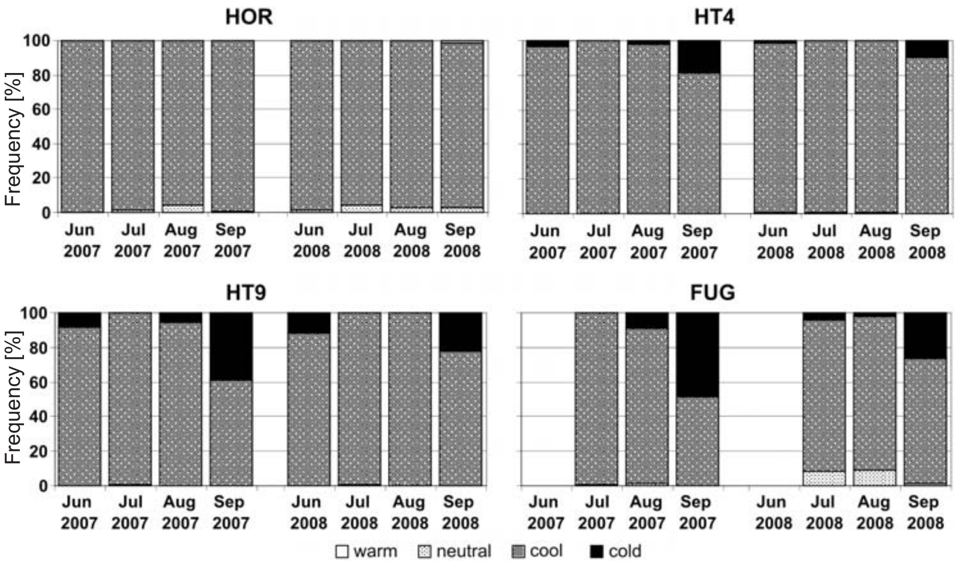

Fig. 5. Frequency of predicted insulation of clothing during moderate (M = 135 Wm^{-2}) physical activity from 1st June to 30th September 2007 and 2008.

result of a local cloud pattern covering the coastal lowland and exposing the glacier, especially its top firn section, to solar radiation. The worst biothermal conditions (-14.7 °C) occurred at the Hans Glacier station HT9 in the third decade of September 2008.

The momentary (10 min.) *STI* values range between "warm" and "very cold" sensations at all stations in 2007 and 2008. "Cold" was the predominant value from this range at all stations, including *ca*. 73–75% of readings at HOR and HT4 and 59% on average at HT9 (Fig. 6). The overall picture of *STI* spatial variation was influenced by the distribution of solar radiation, air temperature, wind speed and air humidity.

Cooling power (*H*). — *H* is useful for assessing thermal sensations in humans while exercising outdoors assuming appropriate clothing. Considerable differences were found in *H* from station to station.

The mildest thermal sensations over the whole study area (especially at HOR), measured on the Petrovič and Kacvinsky scale (after Kozłowska-Szczęsna *et al.* 1997), were obtained in the last ten days of July 2008 (Table 3). The greatest loss of human body heat was observed at FUG in the third decade of September 2008 as a result of very strong winds and low air temperature.

All of the momentary values (10 min.) derived during the two observation periods ranged from "neutral" to "extremely cold and windy" (Fig. 7). The "cool" sensation category was the most frequent over all the readings, including *ca*. 40–44% of readings at the glacier and 34% at HOR. During the eight months covered by the study, cold discomfort conditions ("cold", "very cold" and "extremely cold and

Table 3

Mean values of subjective temperature index (*STI*) and cooling power (*H*) at HOR in comparison with HT4, HT9 and FUG from 1st June to 30th September 2007 and 2008

Index	Year	2007				2008			
	Station	HOR	HT4 -HOR	HT9 -HOR	FUG -HOR	HOR	HT4 -HOR	HT9 -HOR	FUG -HOR
STI [°C]	1-10.06	-3.9	1.0	2.8	-	2.0	2.5	7.1	-
	11-20.06	0.0	1.2	2.8	-	1.6	1.1	6.5	-
	21-30.06	-5.0	1.2	2.2	-	-5.6	0.6	4.8	-
	1-30.06	**-2.8**	**1.0**	**2.4**	**-**	**-0.7**	**1.4**	**6.2**	**-**
	1-10.07	3.2	-1.9	3.0	-	3.7	0.6	7.3	-
	11-20.07	0.4	-4.9	1.3	-	-1.9	0.4	4.1	-
	21-31.07	-3.8	-4.0	-0.7	-	2.0	-1.0	6.3	-
	1-31.07	**0.0**	**-3.6**	**0.9**	**-**	**1.3**	**-0.1**	**5.9**	**-**
	1-10.08	-4.4	-0.7	-1.0	-	-1.6	0.6	5.1	-
	11-20.08	-0.1	-4.9	-4.2	-	-3.3	-2.1	1.7	-
	21-31.08	-4.3	-2.6	-2.8	-	-3.5	-1.2	1.0	-
	1-31.08	**-2.8**	**-2.9**	**-2.8**	**-**	**-2.9**	**-0.8**	**2.6**	**-**
	1-10.09	-5.7	-2.6	-4.3	-	-6.3	-1.6	0.4	-
	11-20.09	-10.2	-1.6	-1.9	-	-5.7	-3.3	-2.3	-
	21-30.09	-11.5	-2.4	-0.5	-	-12.0	-1.8	-2.7	-
	1-30.09	**-9.0**	**-2.3**	**-2.2**	**-**	**-8.0**	**-2.2**	**-1.5**	**-**
H (Wm^{-2})	1-10.06	1229.3	-43.1	-58.0	-	1236.5	-55.8	-62.3	-
	11-20.06	1328.2	-42.4	-49.3	-	1205.9	127.7	214.6	-
	21-30.06	1628.5	-349.2	-378.3	-	1596.9	-170.5	-32.9	-
	1-30.06	**1413.8**	**-164.4**	**-180.3**	**-**	**1346.4**	**-32.8**	**39.8**	**-**
	1-10.07	1079.9	77.3	44.7	-1.9	1100.2	0.0	73.3	168.2
	11-20.07	1146.6	-19.5	-68.2	200.3	1335.7	-142.6	-178.3	292.6
	21-31.07	1335.5	-133.0	-256.7	254.1	935.6	155.6	49.5	124.3
	1-31.07	**1192.1**	**-28.5**	**-98.7**	**172.7**	**1117.8**	**9.2**	**-16.4**	**194.1**
	1-10.08	1520.6	-63.9	-293.3	489.6	951.7	100.2	237.2	141.5
	11-20.08	1030.9	203.7	120.2	208.7	1103.7	82.7	136.8	141.1
	21-31.08	1306.6	56.4	72.5	328.7	1219.2	-86.2	-161.2	199.5
	1-31.08	**1276.9**	**74.9**	**-20.3**	**364.7**	**1095.6**	**28.5**	**63.5**	**162.0**
	1-10.09	1183.9	139.5	116.1	178.6	965.9	57.4	225.3	449.1
	11-20.09	1467.8	-40.9	-192.3	378.0	1041.9	40.3	259.6	388.6
	21-30.09	1287.5	95.6	132.6	215.4	1516.9	116.9	177.0	561.1
	1-30.09	**1295.9**	**74.4**	**36.0**	**290.3**	**1174.9**	**71.6**	**220.6**	**466.3**

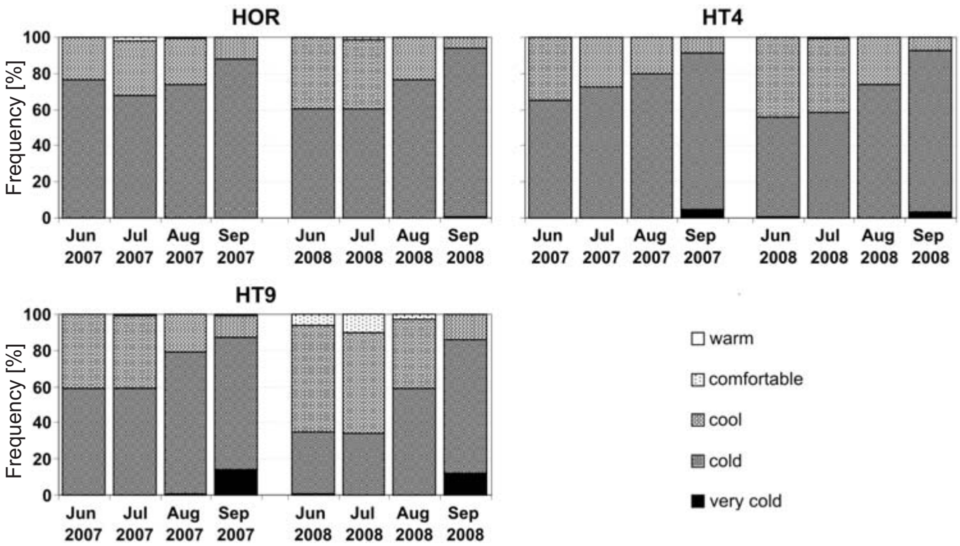

Fig. 6. Frequency of subjective temperature index from 1st June to 30th September 2007 and 2008.

windy") accounted for 42% of values at HT4 and HT9, 45% at HOR and 58% at FUG. The frequency of the comfortable situations ("neutral" and "slightly cool") was 13 to 18% at the glacier and at the summit of Fugleberget and 21% at HOR. This spatial distribution was an effect of the HOR area's privileged position *vis-a-vis* the glacier and the mountains.

The cooling power is the most popular biometeorological index used in Spitsbergen. The "cool" sensible thermal conditions, determined in the area in August 2007 and 2008, were also reported for the same month in 1986 in Calypsobyen (Gluza 1988), in Ny-Ålesund (1981–2000), at Svalbard Airport (1976–2000) and at Hornsund (1979–2000) (Fig. 3; Araźny 2008). "Cold" conditions were also reported in August at the Werenskiold Glacier in 1957 (Wójcik 1963), on the Kaffiøyra in 1979 (Marciniak 1983) and 2005 (Araźny and Błażejczyk 2007) and in Hornsund in 1979 (Szczepankiewicz-Szmyrka and Pereyma 1992).

Flows of heat exchange between the human body and the environment. — An analysis of the character of the heat exchange between the human body and the environment in the Hornsund area shows that loss of sensible heat by convection is dominant. During the warm seasons of 2007 and 2008, the average stream of convection heat loss amounted up to -123.2 Wm^{-2} in HOR, -114.2 Wm^{-2} in HT4 and -116.8 Wm^{-2} in HT9 (Table 4). This heat loss accounted for *ca*. 50% of the total loss of body heat. This was followed in order by latent heat loss resulting from the evaporation of sweat from the skin surface, and through long-wave radiation. These streams fluctuated around 34 Wm^{-2} at all of the stations. The lowest amount of heat loss was in the respiratory stream.

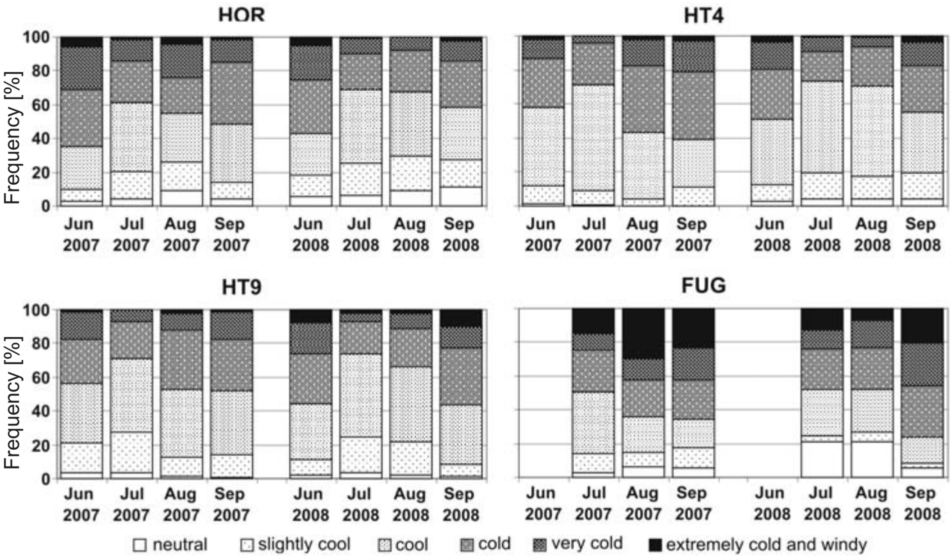

Fig. 7. Frequency of cooling power from 1st June to 30th September 2007 and 2008.

The average balance of the "body-environment" heat exchange over the entire period, amounted to -65.9 Wm^{-2} at HOR, -54.7 Wm^{-2} at HT4 and -55.9 Wm^{-2} at HT9 (Table 4). Between June and September in 2007 and 2008, the overall "body-environment" energy balance in the Hornsund area was negative. A loss of 90 Wm^{-2} of energy per hour lowers the human body temperature by 2 °C and may lead to hypothermia (Błażejczyk 1993). In such a situation, the human body produces additional heat in shivering thermogenesis to compensate the greater heat loss (Błażejczyk *et al.* 2008).

Impact of atmospheric circulation on meteorological and biometeorological conditions

Atmospheric circulation characteristics were obtained using the coastal HOR station data and a calendar of circulation types (Niedźwiedź 2009). Niedźwiedź identified 20 circulation types, taking into account air pressure system types and sectors of advection, and an additional type "x" representing a baric col and other situations that otherwise did not lend themselves to classification. The classification and the type description is found in Niedźwiedź (1997). A simplified version of this classification after Przybylak (1992) was adopted for the purposes of this study to account for the rare occurrence of certain types. The resulting classification comprises six circulation types with well-defined advection sectors, two types with variable advection sectors and one type (x) represented a col and other unclassified situations.

Table 4

Mean monthly values of "man-environment" heat exchange fluxes at Hornsund (HOR) and on the Hans Glacier (HT4 and HT9) from 1st June to 30th September 2007 and 2008

Station	Period	2007							2008						
		mR	mC	mE	mL	mRes	mQ	mS	mR	mC	mE	mL	mRes	mQ	mS
HOR	1–30.06	8.5	-136.6	-34.3	-34.0	-17.8	-25.5	-79.2	11.2	-130.8	-34.2	-35.0	-18.0	-23.8	-71.8
	1–31.07	8.5	-122.1	-34.3	-33.5	-17.2	-24.7	-62.5	9.8	-112.3	-33.9	-33.6	-17.3	-23.8	-52.2
	1–31.08	7.0	-130.4	-35.2	-34.2	-17.3	-27.4	-74.7	5.8	-110.3	-33.5	-33.7	-17.4	-27.9	-54.0
	1–30.09	3.2	-127.7	-32.7	-33.9	-18.1	-30.7	-70.0	2.0	-115.5	-32.8	-33.7	-17.6	-31.6	-62.6
HT4	1–30.06	10.5	-117.8	-32.4	-34.6	-18.3	-24.1	-57.7	13.4	-125.3	-33.0	-35.1	-18.3	-21.8	-63.4
	1–31.07	7.2	-112.6	-46.5	-37.5	-18.0	-26.5	-42.9	12.2	-110.5	-32.8	-35.0	-17.8	-22.8	-48.8
	1–31.08	6.2	-111.0	-32.2	-33.8	-18.1	-27.7	-54.0	7.7	-108.9	-32.3	-34.8	-17.9	-27.1	-51.2
	1–30.09	3.2	-110.0	-30.9	-33.7	-18.9	-30.5	-55.3	2.7	-117.4	-31.8	-34.5	-18.1	-31.8	-64.1
HT9	1–30.06	12.3	-120.3	-32.1	-34.7	-18.5	-22.4	-58.2	18.4	-125.0	-32.4	-34.9	-18.7	-16.4	-57.6
	1–31.07	12.3	-110.9	-32.4	-35.0	-18.0	-22.7	-49.0	18.1	-106.1	-33.0	-35.5	-17.9	-17.4	-39.4
	1–31.08	7.2	-120.5	-32.0	-34.3	-18.3	-27.1	-62.9	11.2	-108.5	-32.5	-34.9	-18.0	-23.7	-47.7
	1–30.09	4.8	-119.7	-30.6	-34.5	-19.1	-29.7	-64.1	4.4	-123.7	-31.8	-34.2	-18.4	-29.8	-68.7

Explanations: mR – absorbed solar radiation; mC – turbulent exchange of sensible heat (convection); mE – turbulent exchange of latent heat (evaporation); mL – heat exchange by long-wave radiation; mRes – respiratory heat loss (respiration); mQ – radiation balance of man; mS – net heat storage. Heat exchange fluxes in Wm^{-2}.

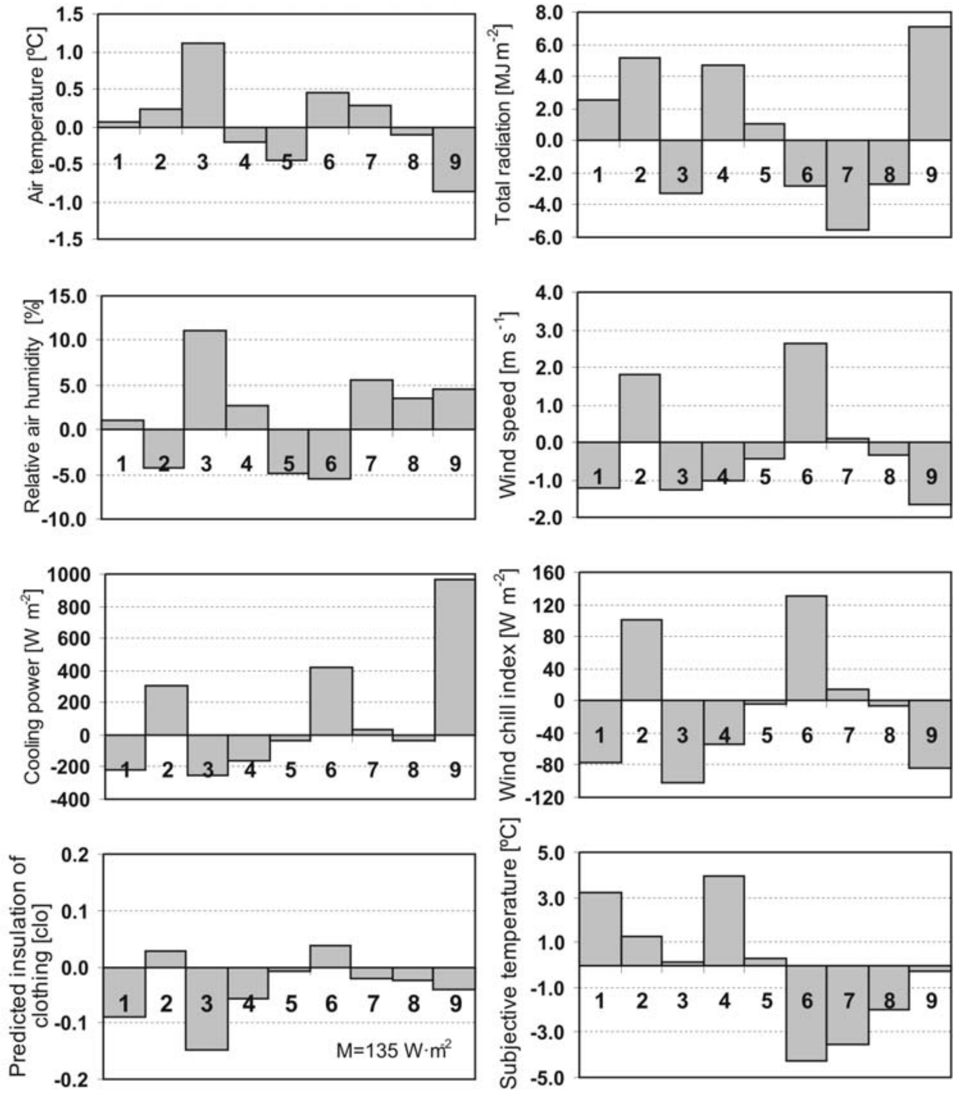

Fig. 8. Mean anomalies of selected meteorological parameters and biometeorological indexes for particular types of circulation in Hornsund from 1st June to 30th September 2007 and 2008. Types of circulation: 1 – NWa+Na+NEa; 2 – Ea+SEa; 3 – Sa+SWa+Wa; 4 – Ca+Ka; 5 – NWc+Nc+NEc; 6 – Ec+SEc; 7 – Sc+SWc+Wc; 8 – Cc+Bc; 9 – X, after Przybylak (1992).

The weather in Spitsbergen during the two measurement periods in 2007 and 2008 was dominated by cyclonic situations (61.9%). The most frequent were the types NWc+Nc+NEc (26.6%), Ca+Ka (14.8%), Ec+SEc (14.3%) and Cc+Bc (11.5%), while the least frequent were Ea+SEa (5.3%), Sa+SWa+Wa (6.6%), Sc+SWc+Wc (9.4%) and NWa+Na+NEa (9.8%). To assess the impact of atmospheric circulation on individual meteorological parameters and on the deviation of biometeorological indices from the average values of these parameters and indices, the indices corresponded to each circulation type group were calculated from the overall average values of those elements and indices (Fig. 8).

The greatest positive deviation of air temperature at HOR occurred during anticyclones Sa+SWa+Wa (1.1 °C), while the lowest deviation was obtained during the NWc+Nc+NEc type (-0.5 °C). This confirms earlier research from the period 1979–2006 (Niedźwiedź 2007). In anticyclonic situations (types 2 and 4), involving higher rates of direct solar radiation, the total radiation received was higher by 4.7–5.2 Wm^{-2}. Cyclonic situations with humid air advection (type 7) reduced solar radiation (-5.6 Wm^{-2}). Relative humidity at HOR depends more on the sector from which air advection occurs than on the type of pressure system. The greatest positive deviation of relative humidity was recorded during Sa+SWa+Wa (11.0%) and Sc+SWc+Wc (5.6%) situations, while the lowest deviation accompanied the advection of dry air masses from the east and north (Fig. 8). The direction of wind recorded at HOR is largely modified by the local topography. The most frequent are strong winds from the eastern sectors when intense cyclones pass over southern Spitsbergen (Marsz and Styszyńska 2007). During the warm seasons of 2007 and 2008, considerable increases in wind speed were recorded during Ea+SEa and Ec+SEc types (by 1.8 and 2.7 m s^{-1}, respectively).

There is a strong relationship between air advection and biometeorological indexes at HOR. An analysis of the cooling power and the wind chill index shows that a deterioration in thermal sensation was associated with Ea+SEa and Ec+SEc types (Fig. 8). These sensations improved with anticyclonic situations (types 1 and 3). The requirement for clothing insulation, measured by the *Iclp* index for a moderate rate of exercise, rose slightly in types 2 and 6, but was lower by up to 0.15 clo under the anticyclonic types Sa+SWa+Wa and NWa+Na+NEa. The largest positive deviations of subjective temperature (3.2–3.9 °C) were found during types 1 and 4. A reverse trend was found during cyclonic situations with air advection from the S-SW-W and E-SE sectors (respectively 3.5 and 4.3 °C). The analysis of the warm seasons of 2007 and 2008 confirms an earlier study by Araźny (2008) on the impact of atmospheric circulation on various biometeorological indices at HOR covering the period 1979–2000.

Conclusions

- A considerable spatial variation of meteorological and biometeorological conditions, caused primarily by the local topography and altitude, was found in the studied area during the summer season spanning June and September.
- The strongest thermal stimuli were discovered on the glacier and in the top mountain areas. The observed high amplitudes of sensible temperature are likely to have an adverse impact on humans in the area.

- The weather stations which received direct solar radiation over most of the day were found to be biothermically superior.
- The overall "human-environment" energy balance in the Hornsund area was found to be negative, which could favour hypothermia and can be compensated by shivering thermogenesis.
- A clear relationship was found linking meteorological parameters and biometeorological indices with types of atmospheric circulation. The mildest biometeorological conditions of the warm season found at Hornsund were associated with air masses arriving from southwest and west. Worst sensations for humans occurred most frequently at advection of air masses from the east in cyclonic situation.

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