BADANIA FIZJOGRAFICZNE
R. V – SERIA A – GEOGRAFIA FIZYCZNA (A65) str. 007–021

DOI 10.14746/bfg.2014.5.1

VARIABILITY OF SUMMER METEOROLOGICAL AND BIOMETEOROLOGICAL CONDITIONS IN THE EBBA VALLEY REGION (CENTRAL SPITSBERGEN)

EWA BEDNORZ[1], LESZEK KOLENDOWICZ[1], JÓZEF SZPIKOWSKI[2], JAKUB MAŁECKI[2]

[1] Adam Mickiewicz University, Department of Climatology,
Institute of Physical Geography and Environmental

Abstract: Variability of summer meteorological and biometeorological conditions on the topoclimatic scale in the 2008–2010 summer season in the Ebba Valley region (Central Spitsbergen) was investigated. Three measurement sites, representing different altitudes and topography, as well as different types of active surfaces typical of Spitsbergen, were chosen, where automatic, hourly recorded, measurements were taken. The mean diurnal course of the basic meteorological and biometeorological parameters (i.e. air surface temperature, relative humidity, wind speed and wind direction, global solar radiation, wind chill temperature, cooling power, etc.), was computed for each of the three sites, which demonstrated spatial and temporal variability of biometeorological and weather conditions. Furthermore, four relevant weather types which may appear in the summer in different environments represented by the three measurement sites were distinguished. They can be defined as follows: type 1 – cold and windy weather, type 2 – cold and wet weather, type 3 – sunny weather (moderately windy and relatively warm), type 4 – warm and cloudy weather. The characteristics and occurrence of each of these types were described.

Keywords: Central Spitsbergen, climate, bioclimate

INTRODUCTION

The 4th International Polar Year showed a growing interest of the scientific community in the biotic and abiotic environments of the Polar Regions (tundra, permafrost, sea ice, glaciers, snow cover, etc.). These areas are considered most vulnerable to climate changes, particularly, to the effects of the global warming observed in recent decades. A number of studies concerning polar climate have been published in recent years (e. g. Moritz *et al*. 2002; Comiso 2003; Polyakov *et al*. 2003; Przybylak 2000, 2003, 2007; Johannesen *et al*. 2004; Styszyńska 2005; Turner *et al*. 2006). At the same time, more intensive human activity (scientific research, tourism, etc.) has been observed in the Arctic in recent years, particularly in the summer season (ACIA Scientific Report 2005). Therefore, there is a need for detailed studies of severe climatic and bioclimatic conditions of the Polar Regions, particularly on a topoclimatic scale.

Bioclimatic studies, considering the chill temperature, which is one of the most commonly used biometeorological indices, were carried out by Nordli *et al.* (2000), Brazdil 1988 and Przybylak, Araźny (2005). Summer biometeorological conditions in the western coast of Spitsbergen (Calypsobyen) were described by Gluza and Siwek (2009). Differences between biometeorological conditions in the area of Kaffiøyra Plain and the Waldemar Glacier area (NW coast of Spitsbergen) in the 2005summer season were worked out by Araźny and Błażejczyk (2007). A comprehensive study of the bioclimatic conditions of the Norwegian Arctic, compiled on the basis of data from 6 meteorological stations, was drawn up by Araźny (2008). However, a majority of the studies do not account for the local (topoclimatic) changeability of bioclimatic conditions. Only Araźny *et al.* (2010) took into consideration the local topography and altitude as factors causing considerable spatial variation of meteorological and biometeorological conditions in the Hornsund area and in NW Spitsbergen.

At a time of growing interest in summer tourism and other activities in the Arctic, the lack of detailed bioclimatic studies of the warmest season, considering changeability in the topoclimatic scale, is strikingly noticeable. Therefore, the aim of this study is to characterize the biometeorological conditions that can be expected in the summer season in Central Spitsbergen, consider the changeability of weather (Ferdynus 2007) and the variability of active surfaces typical of this area.

The summer weather conditions of the Petunia Bay (Fig. 1) developed on the basis of meteorological observations conducted in the vicinity of the Adam Mickiewicz University's research station had already been described (Rachle-

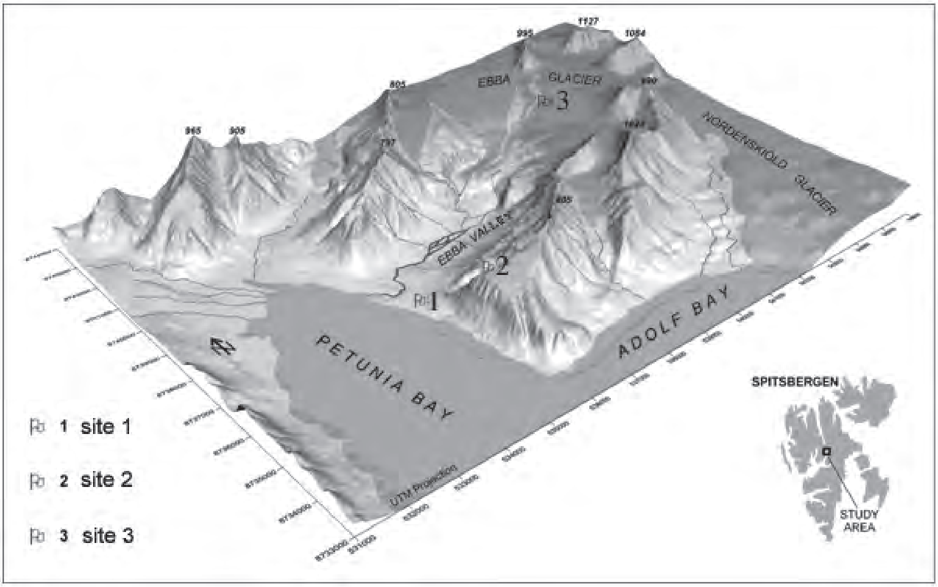

Fig. 1. The study area – Ebba river valley, site 1 – Skottehytta (5 m a.s.l.), site 2 – Wordiekammen (500 m a.s.l.), site 3 – Ebba glacier (550 m a.s.l.)

wicz 2003; Przybylak *et al.* 2006; Rachlewicz, Styszyńska 2007; Rachlewicz 2009). However, the lack of detailed studies of spatial and temporal variability under summer meteorological and biometeorological weather conditions is still noticeable.

AREA OF THE STUDY, DATA AND METHODS

This study is based on measurements conducted in the 2008–2010 summer seasons (July, August) in the Ebba Valley, in the vicinity of the Adam Mickiewicz University field research station (Fig. 1). The River Ebba flows to the Petunia Bay which is an arm of the Billefjorden which merges with the Isfjorden fiord cutting deeply into the land. The research focused on the central part of Spitsbergen Island.

The Ebba Valley is about 5 km long and up to 500 m wide and it merges in its upper part with the tongue of the Ebba valley glacier which originates from the vast glacial fields of Lomonosovfonna. The valley runs from WSW to ENE and is exposed to a free flow of air from the western sector prevailing in the summer in this climatic zone (Niedźwiedź 2006).

Three measurement sites were chosen, representing three different environments characterized by diversified topographic and morphologic conditions and varying active surfaces (Fig. 1). Selected sites relatively well represent the diversification of the topoclimatic conditions on the entire island.

1. Site **1** – Skottehytta, was located in a tundra (lichens with dominating *Dryas octopetala*) region 50 m from the shore of the bay, at an altitude of 5 m a.s.l.
2. Site **2** – Wordiekammen was located on the southern side of the valley, on the top rocky surface of the Wordiekammen mountain, at an altitude of 500 m a.s.l.
3. Site **3** – Ebba, was located on the ice surface of the Ebba glacier gently inclining towards the south-west, 200 m eastward from the stony nunataks, at an absolute altitude of 550 m a.s.l.

The measurements were performed using automatic meteorological stations: Davis Vantage Pro Weather Stations (Davis Instruments Corp. California USA; <http://www.davisnet.com>). The measurements were carried out in half-hour intervals, but only hourly measured data of the following meteorological elements were used in this study:

1. Surface air temperature at 2 m above ground level.
2. Relative humidity at 2 m above ground level.
3. Wind speed (10 minutes mean) and wind direction according to a 16-direction wind rose at 2 m above ground level.
4. Global solar radiation (measured only on site 1).
5. Air pressure.

6. Vapor pressure computed on the basis of values measured at 2 m above ground level, using the BioKlima program (Błażejczyk, Błażejczyk 1996; <http://www.igipz.pan.pl/geoekoklimat/blaz/BioKlima.htm>).

Additionally, the surface air temperature data from Svalbard Lufthavn situated at the inner end of Adventfjorden, a southern branch of Istfjorden, were used in the study. Svalbard Lufthavn is a meteorological station of the Norwegian Meteorological Institute located closest to the studied area. Data for the summer months (July, August) for the years 1981–2010 were collected from the Norwegian Meteorological Institute dataset (available at the eKlima web portal, <http://sharki.oslo.dnmi.no/portal/page?_pageid=73,39035,73_39049&_dad=portal&_schema=PORTAL>).

On the basis of the dataset from the three measurement sites, several biometeorological indices were computed:

1. Wind chill temperature (WCT. in °C), which indicates cold intensity and cold hazard when staying outdoors. WCT is calculated as follows:

$$WCT = 13.12 + 0.6215\, t - 11.37(1.5\, v)^{0.16} + 0.3965\, t\, (1.5\, v)^{0.16}$$

where t – air temperature in °C, v – wind speed in $m \times s^{-1}$ (Nelson *et al*. 2002).

2. Cooling power (H, in $W \times m^{-2}$) is an index assessing thermal sensations of a standing person wearing clothing adequate for the particular seasons. It illustrates dry heat loss from the human body caused by air temperature and air motion. The values of H are not equal to the actual amount of heat loss. The H index is calculated according to the Hill's formulas as follows (Błażejczyk, Błażejczyk 1996):

$$H = (36.5 - t)(0.2 + 0.4\, v^{0.5})41.868 \quad \text{for } v <= 1\ m \times s^{-1}$$

$$H = (36.5 - t)(0.13 + 0.47\, v^{0.5})41.868 \quad \text{for } v > 1\ m \times s^{-1}$$

where t – air temperature in °C, v – wind speed in $m \times s^{-1}$

Thermal sensations of the human body are assessed according to a modified Petrovic-Kacvinski scale (Kozłowska-Szczęsna *et al.* 1997):

above 2100	– extremely cold and windy
from 1680 to 2100	– very cold
from 1260 to 1680	– cold
from 840 to 1260	– cool
from 630 to 840	– slightly cool
from 420 to 630	– neutral
from 210 to 420	– hot
below 210	– very hot.

3. Predicted clothing insulation (Iclp in clo) defines an approximated, predicted value of thermal insulation of clothing which is necessary to maintain thermal comfort for humans. The Iclp index is derived from Burton & Edholm (1955) equation of total insulation of clothing and surrounded air layer as follows:

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

where t – air temperature in °C, v – wind speed in $m \times s^{-1}$, M – metabolism in $W \times m^{-2}$, M equals 70 $W \times m^{-2}$ for a man standing and M equals 135 $W \times m^{-2}$ for a man walking with a speed of 4 km/h (Araźny 2006).
The insulation of clothes is measured with the unit clo, where 1 clo = 0.155 $m^2 \times KW^{-1}$.
Based on Iclp values in clo thermal conditions can be assessed as follows:
below 0.30 – very warm
from 0.3 to 0.8 – warm
from 0.8 to 1.2 – neutral
from 1.2 to 2.0 – cool
from 2.0 to 3.0 – cold
from 3.0 to 4.0 – very cold.
4. Physiological saturation deficit (D in hPa) is an index of evaporation from the upper respiratory tract, calculated according to the following formula:

$$D = E_{36.5} - e$$

where $E_{36.5}$ – saturation pressure in temperature 36.5°C in hPa, e – vapor pressure in hPa.

Values of physiological saturation deficit above 53 hPa are sensed as dry conditions, while values below 45 hPa are considered muggy conditions (Kozłowska-Szczęsna *et al.* 1997).

All biometeorological parameters were computed on the basis of values measured at 2 m above ground level at each measurement site. Graphs of mean diurnal courses of meteorological elements and biometeorological parameters were constructed for each measurement site and shown in graphs, which allowed estimating spatial and temporal variability of these parameters.

Furthermore, data from two hours daily were selected from the whole dataset. These were 02.00 and 14.00 of the Local Mean Time (LMT), 02.00 representing the worst weather conditions and 14.00 representing the time when the optimal parameters prevailed: high temperature, high solar irradiation and relatively small average wind speed (Bednorz, Kolendowicz 2010). The 713 examples of diverse weather conditions at the three measurement sites characterized by 10 meteorological and biometeorological parameters listed above were obtained. In order to distinguish the types of biometeorological conditions, which can be expected in the summer season in different environments, represented by the three measurement sites, the method of hierarchical grouping was applied to the 713 objectives, that is 713 cases of different weather conditions. Standardized values of 4 variables were used in the hierarchical grouping procedure. These were: surface air temperature, relative humidity, wind speed and global solar radiation, which are the main meteorological elements determining bioclimatic conditions. Among many hierarchical techniques the Ward's method was chosen, which is one of the most frequently used clustering techniques for climatic classification (Ward 1963, Kalkstein *et al*. 1987). The groups obtained were characterized by means and by values of the 5th and 95th percentile of the main meteorological and biometeorological parameters.

Additionally, circulation patterns appearing in the studied summer seasons and, particularly, in the four established weather types, were recognized. To this end, the calendar of circulation types of Spitsbergen developed by Niedźwiedź (2011) was applied. In the typology, 21 types of synoptic situations (circulation types) are distinguished, using synoptic maps of Europe and taking into account the direction of air masses advection, as well as the type of pressure pattern (cyclonic, anticyclonic).

RESULTS

Two out of the three summer seasons (2008 and 2010), when the measurements were carried out, were characterized by the surface air temperature close to the multiannual mean of summer temperature in Svalbard Lufthavn, which is the meteorological station closest to the area of the study. Only the summer of 2009 was much warmer than the average (Table 1), July 2009 was warmer by 1.3^{o}C than the 30-year average, which exceeded the value of one standard deviation, and August 2009 was warmer by 1.0^{o}C, which was equal to one standard deviation. Table 3 contains the circulation conditions in the three analyzed summer seasons. In terms of circulation conditions in the warm year 2009 there were approximately 20% more anticyclonic circulation types than the average, according to Niedźwiedź's (2011) classification, particularly with advection from NE (type NEa), SE (type SEa) and with a high pressure ridge without a definite direction of advection (type Ka).

The mean diurnal course of the basic meteorological and biometeorological parameters in the 2008–2010 summer seasons was computed for each of the three sites (Fig. 2). The surface air temperature shows a clear diurnal course at each measurement site with maximum values between 14:00 and 17:00 LMT. However, there are distinct differences between the measurement sites. Definitely, site 1, located at the bottom of the valley not far from the shore (see Fig. 1),

Table 1. Air temperature [°C] in summer months in the Svalbard Lufthavn station. Multiannual average and standard deviation for 1981–2010 and means for years: 2008, 2009, 2010

Month	Mean 1981–2010	Standard dev. 1981–2010	2008	2009	2010
Jul	6.4	0.96	6.2	7.7	6.6
Aug	5.4	1.00	5.0	6.4	4.9
Jul-Aug	5.9	0.91	5.6	7.0	5.7

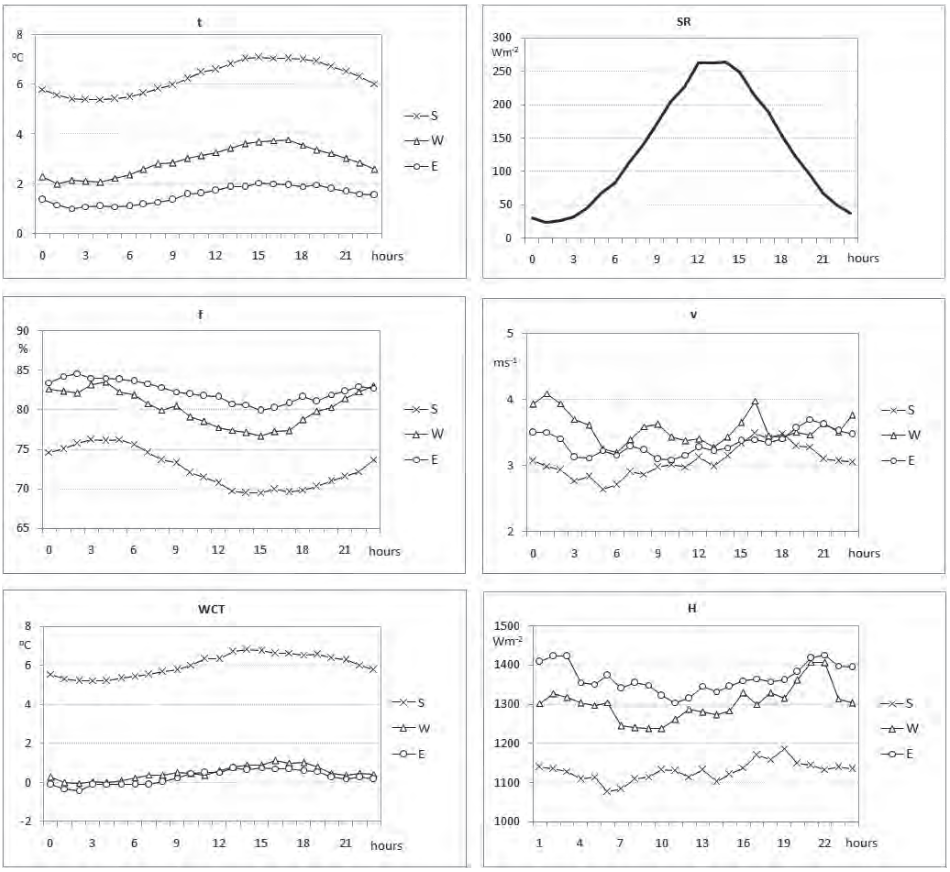

Fig. 2. The average diurnal (by LMT hours) course of the main meteorological and biometeorological parameters for summer seasons 2008–2010. Abbreviations in legends: *S* – site 1 Skottehytta, *W* – site 2 Wordiekammen, *E* – site 3 Ebba glacier, *t* – surface air temperature, *f* – relative humidity, *v* – wind speed, SR – global solar radiation, WCT – wind chill temperature, *H* – cooling power

was the warmest, with the average diurnal temperature ranging from 5.4°C to 7.1°C. The temperature was lowe by some 3°C at the top of Wordiekammen (site 2), where the average diurnal temperature ranged from 2.0°C to 3.8°C. Ebba was the coldest site with the lowest diurnal range of temperature from 1.0°C to 2.1°C on average (Fig. 2). Absolute ranges of surface air temperature recorded in the three summer seasons show the same regularity: an absolute maximum amounting to 15.5°C was noted at site 1 (Skottehytta) on July 28th 2009 at southeastern antycyclonic circulation type (SEa) (Table 2). An absolute minimum of surface air temperature occurred on August 16th 2010 and it amounted to –4.6°C at site 3 (Ebba glacier) and –3.7°C at the top of Wordiekammen on August 15th 2010 at northern cyclonic circulation type (Nc). At the same time the air temperature at Skottehytta did not drop below 0°C.

The highest temperatures often appeared with the high (exceeding 500 W×m^{-2}) values of global solar irradiation during the noon hours. The average diurnal course of global solar irradiation showed the maximum value between 12:00 and 14:00 LMT (above 262 W×m^{-2}) and was at the lowest after midnight (23.5 W×m^{-2}).

Relative humidity, being a function of vapor pressure and air temperature, displayed, just like the temperature itself, a clear diurnal course at all measurement sites (Fig. 2). The daily maximum values occurred in the evening and early morning hours (3:00–5:00 LMT) and the minimum values were observed in the afternoon (14:00–15:00 LMT). The most humid conditions occurred at the coldest site on the glacier (79.9–83.8% on average), while the driest conditions with the widest diurnal range were noted at the Skottehytta site (69.4–76.2%). Absolute minimum of relative humidity amounted to 30% and was recorded at the top of Wordiekammen on July 12th 2009 at eastern anticyclonic circulation (Ea) (Table 2).

Table 2. Mean and extreme values of the main meteorological and biometeorological parameters in the three measurement sites.
Abbreviations: *t* – surface air temperature, *f* – relative humidity, *v* – wind speed, Kglob – global solar radiation, WCT – wind chill temperature

Parameters	Site 1 Skotte			Site 2 Wordie			Site 3 Ebba		
	mean	max	min	mean	max	min	mean	max	min
t [°C]	6.3	15.5	0.2	3.7	14.6	-3.7	1.9	9.9	–4.6
f [%]	73.6	100	38	78.2	100	30	80.9	96	43
v [m×s^{-1}]	2.8	12.1	0	3.2	16.1	0	3.2	19.2	0
Kglob [W×m^{-2}]	134.3	811	0	–	–	–	–	–	–
WCT [°C]	4.4	15.5	–4,6	2.0	14,6	–10.9	–0.9	8.7	–12.8

The wind speed did not show any distinct diurnal course at any measurement site. At the bottom of the valley the average wind speed was the lowest (3.1 m×s^{-1}), with an increase during the afternoon hours, when the spatial differences in the air temperature were the most distinct. Absolute maximum wind speed recorded in the valley amounted to 12.1 m×s^{-1} on August 18th 2009 (Table 2). Higher values were noted on the glacier (3.3 m×s^{-1} on the average), where the wind speed increased in the evening hours. Absolute maximum wind speed recorded on the glacier amounted to 19.2 m×s^{-1} on August 31st 2009 and was highest among all the measurement sites, although, the highest average wind speed was computed for the top of Wordiekammen (3.6 m×s^{-1}).

Both the air temperature and the wind speed influence the most important parameters used to estimate the bioclimatic conditions in the cold climates, namely the wind chill temperature (WCT) and the cooling power of the air (*H*). Site 1 represented the most comfortable conditions, with the average WCT amounting to 6.0°C and the mean diurnal range from 5.2°C, during the night hours, to 6.8°C in the afternoon (Fig. 2). Absolute minimum WCT, dropping below –10.0 °C was recorded at site 3 (–12.8 °C) and at site 2 (–10.9°C), both at the northern cyclonal circulation type (Nc). The mean H value in the bottom of the valley reached 1,129 W×m^{-2} which is classified as "cool" according to the Petrovič and Kacvinski's scale of thermal sensations. The average diurnal range of H with a minimum of about 1075 W×m^{-2} at 5:00 LMT and a maximum of 1186 W×m^{-2} at 18:00 LMT did not exceed the thermal sensation classified as "cool". Worse bioclimatic conditions occurred at two other sites. At the top of Wordiekammen and on the Ebba glacier the average WCT equaled 0.5°C and 0.3°C, respectively. At both measurement sites WCT average diurnal course dropped below 0°C at 02:00 LMT and reached about 1°C at 16:00 LMT. The high values of *H* made biometeorological conditions definitely the most severe on the Ebba glacier, where during the whole day the "cold" sensation, according to the Petrovič and Kacvinski's scale should be expected. The average diurnal range of H on Ebba glacier, with a minimum value 1304 W×m^{-2} and maximum about 1425 W×m^{-2}, did not exceed the thermal sensation deemed "cold". Slightly better conditions prevailed on the top of Wordiekammen, with the average values of H in the morning and noon hours dropping below 1260 W×m^{-2} , which means "cool" thermal sensation.

As it follows from the range of all meteorological and biometeorological parameters, there were diversified weather conditions during the measurement periods in the three summer seasons. They changed spatially and temporally as is shown in the diurnal courses for each measurement site (Fig. 2). In order to classify all possible weather conditions into particular types that may occur in the summer in different environments represented by the three measurement sites, the Ward method of hierarchical grouping was applied. First the data from two hours daily, i.e. 2.00 and 14.00 LMT, were selected from the whole dataset.

Table 3. Frequency of circulation types in summer (July–August) according to Niedźwiedź's (2011) classification; mean for 1981–2010 and for each studied season.

Circulation type	1981–2010	2008	2009	2010
Na	2.6	8.1	3.2	8.1
NEa	2.5	3.2	12.9	6.5
Ea	4.9	3.2	4.8	3.2
SEa	5.0	0.0	9.7	1.6
Sa	2.2	1.6	0.0	0.0
SWa	4.2	3.2	3.2	0.0
Wa	3.4	8.1	0.0	9.7
NWa	1.5	4.8	1.6	1.6
Ca	2.1	4.8	3.2	1.6
Ka	16.2	11.3	27.4	14.5
Nc	5.7	8.1	9.7	9.7
NEc	3.3	1.6	4.8	8.1
Ec	5.3	6.5	4.8	0.0
SEc	5.6	3.2	4.8	1.6
Sc	4.1	3.2	1.6	4.8
SWc	6.0	4.8	0.0	4.8
Wc	5.9	3.2	1.6	8.1
NWc	4.8	4.8	3.2	3.2
Cc	3.0	3.2	0.0	1.6
Bc	8.1	11.3	1.6	3.2
x	3.7	1.6	1.6	8.1

All chosen cases were divided into four groups on the basis of the four variables, being the main weather parameters, used commonly to compute the biometeorological indices, namely: surface air temperature, relative humidity, wind speed and global solar radiation.

Four types, which differ by the weather conditions and biometeorological parameters, were distinguished (Table 4). Types 1 and 2 represent the worst weather conditions with the lowest temperature (2.4°C and 2.0°C. respectively). In the first type the severity of weather conditions is increased by the wind speed, which amounts to 6.3 m×s^{-1} on average, with prevailing direction from the N-E quadrant (over 50%). The wind speed may exceed 10 m×s^{-1} (95 percentile equals to 10.3 m×s^{-1}). Type 1 represents cold and windy weather. Both these features, together with low solar radiation cause adverse bioclimatic conditions, i.e. a negative value of wind chill temperature and high cooling power of the air, classified as "very cold", according to the scale of thermal sensations. Type 1

Table 4. Mean values of meteorological and biometeorological parameters in the four distinguished weather types. Abbreviations: *t* – surface air temperature, *f* – relative humidity, *v* – wind speed, Kglob – global solar radiation, *D* – physiological saturation deficit, WCT – wind chill temperature, *H* – cooling power, Iclp 135 – predicted clothing insulation for a metabolism level 135 W×m⁻2 , clp 70 – predicted clothing insulation for a metabolism level 70 W×m⁻2 .

Parameters	Type 1	Type 2	Type 3	Type 4
T [°C]	2.4	2.0	4.4	6.9
f [%]	73.6	86.0	70.6	79.6
v [m×s^{-1}]	6.3	1.9	3.6	1.3
Kglob [W×m^{-2}]	46.9	54.1	381.2	97.0
D [hPa]	55.5	54.8	55.0	53.0
WCT [°C]	-0.3	2.0	3.2	6.9
H [W×m^{-2}]	1848.7	1077.5	1316.5	784.7
Iclp 135 [clo]	1.7	1.6	1.5	1.2
Iclp 70 [clo]	3.8	3.4	3.2	2.5

appeared mostly in the night hours; about 80% of all cases of this type occurred at 02:00 LMT (Table 5). This kind of cold and windy weather appears mainly at cyclonic circulation from N and NE direction (Nc, NEc).

Type 2 represents cold and wet weather, with temperatures ranging from 5°C to –2°C in 90% of cases. High relative humidity and low solar radiation indicate cloudy conditions (Table 4). Despite the low average wind speed, which does not exceed 2.0 m×s^{-1} on the average, the bioclimatic conditions are severe. Low temperature makes the cooling power exceed 1000 W×m^{-2} , which means “chilly” conditions, according to the Petrovič and Kacvinsky scale. Like the previous type, type 2 occurs more often during the night hours, only about 30% of cases are observed at noon hours (Table 5). Severe conditions represented by type 2 appear most often at the glacier; almost 50% of cases were noted at the third measurement site located on the Ebba glacier (Table 6). Furthermore, such conditions appeared more often in August than in July, despite the latter being warmer in general. Almost half of the cases of type 2 occur together with eastern wind direction (prevailing NE-SE quadrant) and at cyclonal circulation.

Table 5. Frequency of occurrence of each distinguished weather type at two times of a day in percents (LMT – local time)

Hour (LMT)	Type 1	Type 2	Type 3	Type 4
02:00	78.9	71.0	0.0	49.7
14:00	21.1	29.0	100.0	50.3

Table 6. Frequency of occurrence of each distinguished weather type at three measurement sites

Site	Type 1	Type 2	Type 3	Type 4
1 Skotte	39.5	11.4	31.0	64.1
2 Wordie	32.3	39.0	33.9	25.0
3 Ebba	28.3	49.7	35.1	10.9

Type 3, which appears only close to the noon hours (Table 5), represents sunny, rather dry, relatively warm and moderately windy weather. Despite very high global solar radiation (about 380 W×m^{-2}), bioclimatic conditions are moderate and the cooling power exceeds 1300 W×m^{-2} , which means "cold" conditions on the Petrovič and Kacvinsky's scale. Type 3 and its clear sky conditions appear most often at the wind directions from the N–E quadrant and at high pressure conditions (about 1012 hPa on average).

The fourth type is the warmest of all, with the mean temperature amounting to 6.9°C. In 90% of all cases belonging to this type, the air temperature ranges from 4.7°C (5 percentile) to 9.3°C (95 percentile). High temperature and humidity together with a mild wind from southerly direction (over 60% from the ESE-SSW quadrant) make comfortable bioclimatic conditions. The cooling power decreases below 800 W×m^{-2}, which means "slightly cool" on the scale of thermal sensations. Additionally, type 4 is the only one which is not dry from the physiological point of view, as the mean value of saturation deficit does not exceed the critical value of 53 hPa. This kind of weather appears mostly at anticyclonic circulation types Ka (with a high pressure ridge) and SEa. Comfortable weather conditions represented by type 4 appear most frequently at the bottom of the Ebba valley; about 64% of cases belonging to type 4 were noted at the first measurement site – Skottehytta. Only 25% were observed at the top of Wordiekammen and even less (10%) on the Ebba glacier.

DISCUSSION AND CONCLUSIONS

A distinctive spatial and temporal variability of meteorological and biometeorological conditions in the vicinity of the Petunia Bay was observed in the 2008–2010 summer seasons. The three different sites chosen for the measurement and for analysis represent quite different environments with variable active surfaces. These are the most typical environments in the entire area of Central Spitsbergen: 1) a bottom part of the valley covered with tundra, 2) rocky mountains without a glacier, and 3) a vast glacier surface. The results obtained in the study give an idea of the topoclimatic and bioclimatic differences between three different types of surfaces.

In the three summer seasons, two of them (2008 and 2010) being close to climatic normals and 2009 being warmer than average, four types of weather conditions were observed. They were defined as follows: type 1 – cold and windy weather, type 2 – cold and wet weather, type 3 – sunny weather (moderately windy and relatively warm), type 4 – warm and cloudy weather. All types were described with mean values of the main meteorological and biometeorological parameters.

The best meteorological and biometeorological conditions appeared at the bottom of the Ebba Valley, where the optimal fourth weather type occurred most frequently. On the other hand, the Ebba glacier most frequently sees the least favorable conditions represented by weather types 1 and 2. Both on the glacier and on the top of Wordiekammen severe biometeorological conditions may be experienced, despite the summer season. The wind chill temperature (WCT), which is one of the main biometeorological parameters, used to evaluate bioclimate in the polar zones, frequently drops below zero Celsius and the cooling power of the air usually causes the “cold” thermal sensation, according to the Petrovic-Kacvinski’s scale (Kozłowska-Szczęsna *et al.* 1997). The mean summer values of WCT and H computed for site 2 and site 3 are distinctly lower than the mean summer values computed for other locations on the west coast of Spitsbergen (Przybylak, Araźny 2005; Styszyńska 2007).

The study has demonstrated that spatial variability of meteorological and biometeorological conditions during the polar summer is caused mainly by the altitude, local topography and the type of active surface. The most severe bioclimatic conditions and a greatest frequency of the least favorable weather types were discovered on the glacier and in the top mountain areas. Similar findings were recorded by Araźny *et al.* (2010) in the study concerning spatial variation of meteorological and biometeorological conditions in the Hornsund area. Such severe conditions, having an adverse impact on humans, require much better clothing insulation, which is important, while exploring the regions far from the relatively warm valleys. Moreover, it has been demonstrated that atmospheric circulation has an impact on summer weather conditions in central Spitsbergen. Unfavorable conditions appear at cyclonic circulation types, with advection from east and northeast, while the mildest weather prevails under anticyclonic circulation type with southeastern advection or under the high pressure ridge extending over the Svalbard Archipelago.

Acknowledgements: This work was supported by the Polish Committee of Scientific Research under grant number

REFERENCES

ACIA Scientific Report, 2005: Cambridge University Press, Cambridge.

Araźny A. 2006: *Variability of the predicted insulation index of clothing in the Norwegian Arctic for the period 1971–2000*, Polish Polar Research, 27, 4, 341–357.

Araźny A. 2008: *Bioklimat Arktyki Norweskiej i jego zmienność w okresie 1971–2000 (Bioclimate of the Norvegian Arctic)*, Wydawnictwo Naukowe Uniwersytetu Mikołaja Kopernika, Toruń: 215 pp [in Polish].

Araźny A., Błażejczyk K. 2007: *Warunki biometeorologiczne na Równinie Kaffiöyra i w regionie Lodowca Waldemara (NW Spitsbergen) w okresie od 16 lipca do 20 września 2005 r.*, [in:] R. Przybylak, M. Kejna, A. Araźny, P. Głowacki (red.), *Abiotyczne środowisko Spitsbergenu w latach 2005–2006 w warunkach globalnego ocieplenia*, UMK, Toruń, 67–87.

Araźny A., Migała K., Sikora S., Budzik T. 2010: *Meteorological and biometeorological conditions in the Hornsund area (Spitsbergen) during the warm season*, Polish Polar Research, 31(3), 217–238.

Bednorz E., Kolendowicz L. 2010: *Summer 2009 thermal and bioclimatic conditions in the Ebba Valey region*, Polish Polar Research, 31(4), 327–348.

Błażejczyk K., Błażejczyk M. 1996: *BioKlima-un nouvel outil de la recherche bioclimatique*. Publications de l'AIC, 9, pp. 173–177.

Brázdil R. 1988: *Variation of air temperature and atmospheric precipitation in the region of Svalbard*, [in:] R. Brázdil et al. (ed.), *Results of Investigations of the Geographical Research Expedition Sspitsbergen 1985*, University J.E. Purkyne, Brno, pp. 285–323.

Burton A.C., Edholm O.G. 1955: *Man in a cold environment*. E. Arnold Publ., London.

Comiso J.C. 2003: *Warming trends in the Arctic from clear-sky satellite observations*, Journal of Climate, 16, 21, 3498–3510.

Ferdynus J. 2007: *Charakterystyczne dla Hornsundu typy pogody a cyrkulacja atmosfery* (Weather types characteristic for Hornsund versus atmospheric circulation), Problemy Klimatologii Polarnej, 19, 223–231 [in Polish].

Gluza A., Siwek K. 2009: *Odczuwalność cieplna w sezonach letnich 2007 i 2008 w Calypsobyen (Spitsbergen)* (Heat comfort in summer seasons 2007 and 2008 in Calypsobyen), Problemy Klimatologii Polarnej, 17, 105–111 [in Polish].

IPCC Fourth Assessment Report, 2007: Working Group I Report "The Physical Science Basis", Chapter 10, Global Climate Projections.

Johannesen O.M., Bengtsson L., Miles M.W., Kuzmina S.I., Semenov V.A., Alekseev G.V., Nagurnyi A.P., Zakharov V.F., Bobylev L.P., Pettersson L.H., Hasselman K., Cattle H.P. 2004: *Arctic climate change: observed and modeled temperature and sea-ice variability*, Tellus, 56A, 328–341.

Kalkstein L.S., Tan G., Skindlov J.A. 1987: *An evaluation of three clustering procedures for use in synoptic climatological classification*, Journal of Climatology and Applied Meteorology, 26, 717–730.

Kozłowska-Szczęsna T., Błażejczyk K., Krawczyk B. 1997: *Bioklimatologia człowieka, metody i ich zastosowanie* (Human bioclimatology. methods and applications), IGiPZ PAN,Monografie 1, Warszawa, pp. 200 [in Polish].

Moritz R.E., Bitz C.M., Steig E.J. 2002: *Dynamics of recent climate change in the Arctic*, Science, 297, 1497–1502.

Nelson C.A., Tew M., Phetteplace G., Schwerdt R., Maarouf A., Osczevski R., Bluestein M., Shaykewich J., Smarsh D., Derby J.C., Petty R.C., Berger M., Quayle R.G., Santee W.R., O'Lenic E., Lupo A.R., Browne K. 2002: *Joint development and implementation by the United States and Canada of a new Wind Chill Temperature (WCT) index*, Proceedings of the 16th International Congress on Biometeorology, Kansas City, USA, 172–176.

Niedźwiedź T. 2006: *Główne cechy cyrkulacji nad Spitsbergenem (XII 1950–IX 2006)* (The main features of circulation over Spitsbergen), Problemy Klimatologii Polarnej, 16, 91–105 [in Polish].

Niedźwiedź T. 2011: *Calendar of circulation types for territory of Spitsbergen (1951–2011)*, University of Silesia, Department of Climatology, Sosnowiec, Available on-line at <http://klimat.wnoz.us.edu.pl/>.

Nordli P.O., Forland E.J., Niedźwiedź T. 2000: *Wind-chill temperature at Svalbard and Jan Mayen. Klima*, Report No. 07/00. Det Norske Meteorologiske Institutt, Oslo, pp. 47.
Polyakov I.V., Bekryaev R.V., Alekseev G.V., Bhatt U.S. Colony R.L., Johnson M.A., Maskshtas A.P. Walsh D. 2003: *Variability and trends of air temperature and pressure in the maritime Arctic 1875–2000*, Journal of Climate, 16, 12, 2067–2077.
Przybylak R. 2000: *Temporal and spatial variation of surface air temperature over the period of instrumental observations in the Arctic*, International Journal of Climatology, 20, 6, 587–614.
Przybylak R. 2003: *The climate of the Arctic*, Dodrecht etc., Kluwer Academic Publishers.
Przybylak R. 2007: *Recent air-temperature changes in the Arctic*, Annals of Glaciology, 46, 316–324.
Przybylak R., Araźny A. 2005: *Porównanie warunków klimatycznych i bioklimatycznych północnej części Ziemi Oskara II z innymi obszarami zachodniego wybrzeża Spitsbergenu w okresie 1975–2000* (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., Araźny A., Gluza A., Hojan M., Migała K., Sikora S., Siwek K., Zwoliński Z. 2006: *Porównanie warunków meteorologicznych na zachodnim wybrzeżu Spitsbergenu w sezonie letnim 2005* (Comparison of the meteorologic conditions in the western coast of Spitsbergen in the summer season 2005), Problemy Klimatologii Polarnej, 16, 125–138 [in Polish].
Rachlewicz G. 2003: *Warunki meteorologiczne w Zatoce Petunia (Spitsbergen Środkowy) w sezonach letnich 2000–2001* (Meteorological conditions in the Petunia Bay (Central Spitsbergen) in summer seasons 2000–2001), Problemy Klimatologii Polarnej, 13, 127–138 [in Polish].
Rachlewicz G. 2009: *Contemporary sediment fluxes and relief changes in high Arctic glacierized valley systems (Billefjorden. Central Spitsbergen)*, Wydawnictwo Naukowe UAM, Poznań, pp. 203.
Rachlewicz G., Styszyńska A. 2007: *Porównanie przebiegu temperatury powietrza w Petuniabukta i Svalbard-Lufthavn (Isfjord. West Spitsbergen)* (Comparison of the air temperature course in Petunia Bukta and Svalbard-Lufthavn (Isfjord. West Spitsbergen)), Problemy Klimatologii Polarnej, 17, 121–134 [in Polish].
Styszyńska A. 2005: *Przyczyny i mechanizmy współczesnego (1982–2002) ocieplenia atlantyckiej Arktyki* (Causes and mechanisms of present (1982–2002) warming of the Atlantic part of the Arctic), Wydawnictwo Uczelniane Akademii Morskiej w Gdyni, Gdynia, pp. 109.
Styszyńska A. 2007: *Ochładzanie wiatrowe* (Wind chill), [in:] A. Marsz. A. Styszyńska (eds), *Klimat rejonu Polskiej Stacji Polarnej w hornsundzie* (Climate of the region of the Polish Polar Station in Hornsund), Wydawnictwo Akademii Morskiej w Gdyni, Gdynia, 242–248[in Polish].
Turner J., Overland J.E., Walsh J.E. 2006: *An Arctic and Antarctic perspective on recent climate change*, International Journal of Climatology, 27, 3, 277–293.
Ward J.H. 1963: *Hierarchical grouping to optimize an objective function*, Journal of the American Statistical Association, 58, 236–244.