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Summer 2009 thermal and bioclimatic conditions in Ebba Valley, central Spitsbergen

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Abstract: The thermal, anemometric and bioclimatic conditions on the topoclimatic scale were investigated in the summer season in the Ebba Valley region in central Spitsbergen. Eight measurement sites, representing different ecosystems and different types of active surfaces typical of Spitsbergen, were chosen and automatic, hourly recorded, measurements were performed at the sites between 11 and 25 of July 2009. The analysis of the spatial distribution of the air temperature and the wind-chill temperature, both for the days with radiation and non-radiation weather, indicates that the most favorable regions in the interior of Spitsbergen are those situated in the shielded central parts of the valleys and in the lower parts of the slopes with southern exposure. The thermal and wind conditions are definitely less favorable at the tops of elevations and on the glacier. Large differences between the air temperature and the wind-chill temperature were noted, particularly during the unfavorable non-radiation weather, on the glacier and on open peaks due to a large horizontal and vertical wind-chill temperature gradient. The thermal inversions observed in the Ebba Valley in July 2009 were not of the typical, glacier katabatic wind origin. They appeared during the western air circulation, which brings advection of cooled air from above the cold waters of Petunia Bay. The cold air penetrates into the valley and pushes upwards the mass of warmer air in the valley, creating a rather thin inversion layer, whose upper edge is marked with thin *Stratus* clouds.

Key words: Arctic, Spitsbergen, topoclimate, bioclimate, wind-chill.

Introduction

The Svalbard Archipelago, which part is the island of Spitsbergen, is located in the zone of polar climates, specifically in the zone of the tundra climate, ET in Köppen (1900) classification (Kottek *et al*. 2006). The western part of the island is characterized by a very high degree of oceanity index, indicating oceanic conditions. The central part of Spitsbergen has a sub-oceanic climate (Marsz 1995; Førland *et al.* 1997; Rachlewicz 2003, 2009; Przybylak and Araźny 2005). The summer with temperatures above freezing lasts from 3 to 4 months, with the average temperature below 10 °C for the warmest month. July is the warmest month in the central part of the island (Svalbard Lufthavn station) with the average temperature of 6.4 °C during 1975–2009 (http://met.no). However, both the summer and the other seasons are characterized by a considerable variability of weather conditions (Ferdynus 2007), resulting from changes in circulation and insolation. Western and southwestern directions of airflow dominate during summer over the Svalbard Archipelago; however, they do not prevail throughout the entire season. Similarly, cyclonal and anticyclonal patterns of circulation may appear alternately over the island, with almost equal frequency, bringing diversity of weather patterns (Niedźwiedź 2003, 2006, 2007). A great dynamic of cyclogenesis and variability of pressure patterns is typical for the entire Arctic, particularly in summer (Serreze and Barry 1988; Serreze *et al.* 1993; Brümmer *et al.* 2000). Circulation modifies bioclimatic features, for example the wind chill temperature (WCT), which is a function of the air temperature and wind speed. Moreover, it depends on the wind direction. The lowest WCT in Svalbard Archipelago was noted for northerly or northeasterly flow, the highest for southerly flow (Nordli *et al.* 2000).

Polar regions are considered to be most vulnerable to climate changes, particularly, to the global warming observed in recent decades (*e.g.* Przybylak 2000, 2003, 2007; Moritz *et al*. 2002; Comiso 2003; Polyakov *et al*. 2003; Johannesen *et al*. 2004; Styszyńska 2005; Turner *et al*. 2006) Their biotic and abiotic environment (tundra, permafrost, sea-ice, glaciers, snow cover, *etc.*) are very sensitive indicators of climate fluctuations. Several positive feedback mechanisms, like decrease in surface albedo due to ice and snow melt, are well known to enhance the air temperature in the Arctic and they possibly led to the abrupt temperature rise in the mid 1990s. Topo- and microclimate research, conducted in different phisiographic conditions and representing different active surfaces, may show the close relationship between climate and environment in polar regions (Weller and Holmgreen 1974).

A considerable spatial variability of topoclimatic conditions, resulting mainly from the occurrence of diversified active surfaces, prevails in Spitsbergen as well. The topoclimatic-scale surveys of the peculiar and sometimes unique Spitsbergen ecosystems were conducted exclusively in the western part of the island based on research stations operating during the summer (Przybylak 1992). Numerous studies on a topoclimatic scale were conducted in the Kaffiöyra plain, NW Spitsbergen (*e.g.* Wójcik *et al.* 1991, 1993; Przybylak *et al.* 1993). Also, the Hornsund region (SW Spitsbergen) was examined topoclimatically, especially in the peripheries of the Werenskiold Glacier and the Brattegg Valley (Migała *et al.* 2008). Some profiles of the summer weather conditions were developed based on meteorological observations conducted in the region of the Adam Mickiewicz University research station, situated at the shore of the Petunia Bay (Rachlewicz 2003, 2009; Przybylak *et al.* 2006; Rachlewicz and Styszyńska 2007). However, the valleys and glacial regions of central Spitsbergen have not yet been subject to studies showing topoclimatic diversification.

Due to a growing interest in tourism in the polar regions, the lack of detailed bioclimatic studies of the warmest season in the topoclimatic scale is striking. Summer bioclimatic conditions in the western coast of Spitsbergen (Calypsobyen) were described by Gluza and Siwek (2009). The comprehensive study of bioclimatic conditions of the Norwegian Arctic were carried on by Araźny (2008). He compiled data from 6 meteorological stations, but has not accounted for the local topoclimatic variability of bioclimatic conditions.

The aim of this study is to characterize thermal, anemometric and bioclimatic conditions on the topoclimatic scale in the summer season in the glacial valley and in the glacial field in the central part of Spitsbergen. The thermal conditions described represent various summer weather states in a polar climate, while the measurement sites in the valley of the Ebba River and on the Ebba Valley Glacier represent the ecosystems and types of active surfaces typical of Spitsbergen.

Study area

This study utilizes topoclimatic measurements conducted in July 2009 in the glacial valley of the Ebba River, flowing to Petiuna Bay. That bay is a part of Billefjorden, which merges with the Isfjorden cut deeply into the land. Consequently, the research focused on the central part of Spitsbergen (Fig. 1). The Ebba Valley, about 5 km long and up to 500 m wide, is situated longitudinally and it is

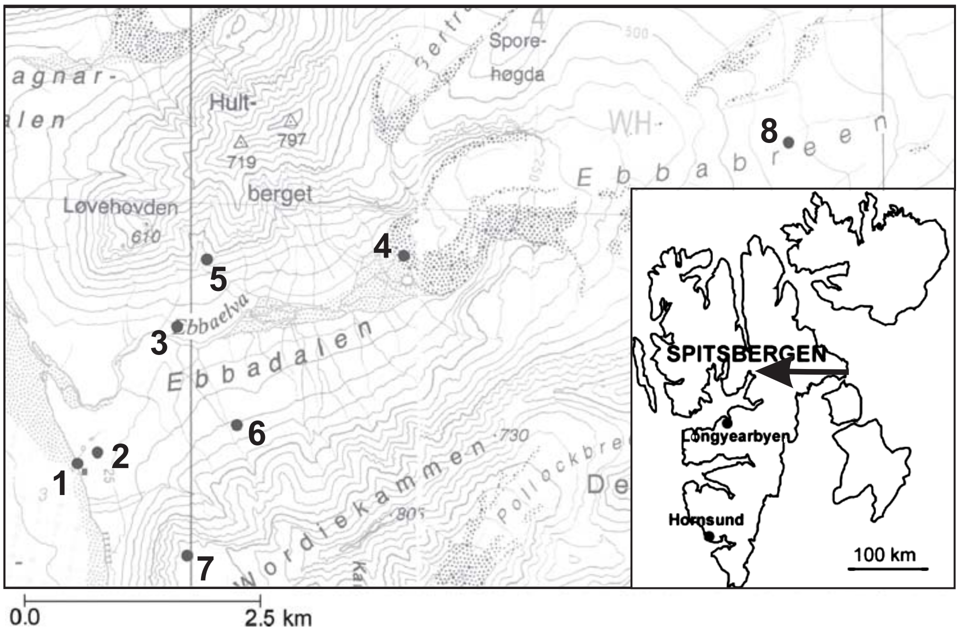

Fig. 1. Location of the measurement sites in the Ebba Valley region in July 2009.

perpendicular to the eastern coast of Petunia Bay. In its upper part, it hosts the Ebba Valley Glacier, while the lower part is covered with poor tundra. The Ebba Valley Glacier originates from the vast glacial fields of Lomonosovfonna.

Running from WSW to ENE, the valley shows diversified insolation conditions on its slopes. Northern and southern rocky slopes of the valley climb to the altitude of 700–800 m a.s.l. A free flow of air from the western sector prevails in the summer (Niedźwiedź 2006). This indicates a frequent transfer of air masses from above the fiord, surrounded by numerous glaciers (Ragnarbreen, Horbyebreen, Svenbreen, Ferdinandbreen and Elsabreen) and with the largest glacier Nordenskjoldbreen flowing down to the neighboring valley of Adolfbukta.

Methods and data selection

Eight measurement sites were located in the Ebba Valley and in its closest vicinity, accounting for diversified topographic and morphologic conditions, varying soil conditions and diverse exposure to insolation (Fig. 1). Therefore, they represent the diverse topoclimatic conditions in the Ebba Valley.

– Site 1 was located on the beach, 2 m from the seashore during the flood tide, on clayey gravel soil.
– Site 2 was located in the tundra (lichens with dominating *Dryas octopetala*) region, 50 m from the shore of the bay, at the elevation of 5 m a.s.l.
– Site 3 was located at the bottom of the valley, in its central part, on the flat scarcely flora-grown sandy soil, several meters from the bank of the Ebba River at 14 m a.s.l.
– Site 4 was located on the mutonized rocky soil at 36 m a.s.l., in the vicinity of the frontal moraine of the Ebba Valley Glacier, which shielded the stand from the glacier edge.
– Site 5 was situated on the northern rocky slope of the valley, well exposed to the solar radiation, in the ravine of the slope of the Lovehovden mountain, at 96 m a.s.l.
– Site 6 was situated on a small stony shelf, scarcely grown with poor tundra, at the elevation of 167 m a.s.l., also well-exposed to the sun and uncovered by the overlying slope. It was located symmetrically to Site 5, on the opposite, southern slope.
– Site 7 was of the highest elevation, on the southern side of the valley and the top surface of the Wordiekammen mountain, at 500 m a.s.l.
– Site 8 was located on the surface of the Ebba Valley Glacier, weakly-inclined towards the south-west, 200 m eastward from nunataks, at the absolute height of 300 m a.s.l.

The measurements were performed by portable weather stations; Sites 1, 3, 4, 5 and 6 with Kestrel 4500 Weather Meter (Nielsen-Kellerman http://www.

nkhome.com/kestrel/), and Sites 2, 7 and 8 with Davis Vantage Pro Weather Stations (Davis Instruments Corp. California USA http://www.davisnet.com). The hourly temperatures and values of the other meteorological parameters measured at Site 2, such as atmospheric pressure, wind speed and direction, and intensity of solar radiation, were all used. Cloud type and quantity were recorded three times a day. The WCT values were measured and calculated automatically by the weather stations, according to the equation:

$$WCT = 13.2 + 0.62t - 11.37(1.5v)^{0.16} + 0.3965t(1.5v)^{0.16},$$

where t indicates air temperature and v indicates wind velocity.

Data series, when the measurements proceeded without disturbances and the full diurnal cycles of data were available, were chosen from a longer observation period. Therefore, days between July 11 and July 25, 2009 were used in the analysis. This period was characterized by changing weather conditions. Groups of days with distinct, especially thermal, characteristics were distinguished using Ward's method (Ward 1963). That is the most frequently used hierarchical clustering technique for climatic classification (Kalkstein *et al*. 1987). Clustering, based on the mean, maximum and minimum daily air temperature at the eight sites, allowed distinguishing different types of weather that appeared during the studied period. The air temperature and WCT for the selected days and periods of time were reconstructed on contour maps, using the Surfer 8.0 software. The diurnal courses of the selected parameters were shown in graphs.

Results

The values of different thermal characteristics were calculated for all the measurement sites (Table 1). The mean air temperature calculated for the entire mea-

Table 1

Characteristics of the air temperature (T in °C) at measurement points in the Ebba Valley region in July 2009

Site number	Mean T	Daily mean T		Absolute		Diurnal T range		
		Max	Min	Max T	Min T	Mean	Max	Min
1	7.5	12.3	3.2	15.4	2.0	4.4	8.3	2.2
2	7.4	12.3	3.0	15.4	1.9	4.1	8.3	2.0
3	7.7	12.1	2.9	14.6	1.5	5.0	9.8	2.2
4	7.5	12.4	2.0	15.1	0.7	4.8	8.3	2.1
5	6.7	11.4	1.4	16.5	-0.4	5.0	8.6	3.0
6	7.3	11.9	2.1	15.1	1.2	5.5	11.5	1.8
7	3.7	9.2	-1.6	12.0	-2.7	4.1	7.0	2.1
8	2.1	6.4	-2.5	9.4	-3.3	3.2	5.3	1.6

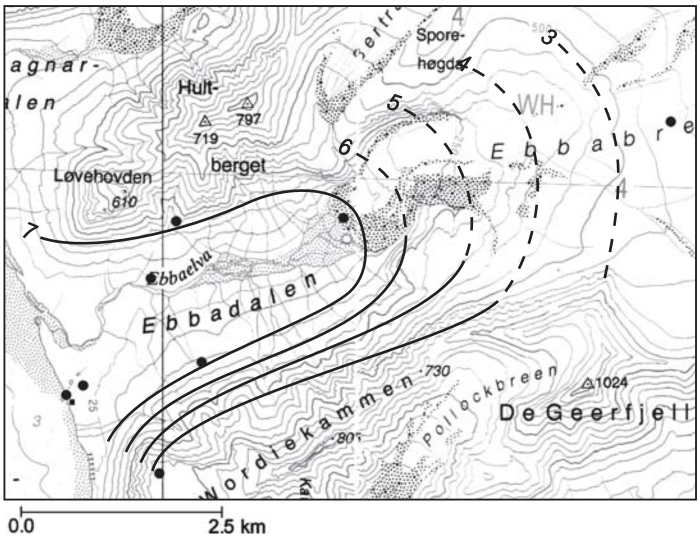

Fig. 2. Mean air temperature (°C) in the Ebba Valley region for all days of the studied period (July 10–25, 2009).

surement period reached the highest values in the lowest parts of the valley and amounted 7.7 °C in the middle part of the valley bottom at Site 3 (Fig. 2). The mean temperature values drop with elevation increase by about 1 °C/100m on the northern slope (Site 2, at the height of 96 m a.s.l.) and by about 4 °C on Wordiekammen (Site 7 at the height of 500 m a.s.l.). This results in a mean drop of about 0.8 °C/100 m – the intermediate value between the dry and wet adiabatic gradient. The drop of temperature over the surface of the Ebba Valley Glacier resulted in the lowest mean temperature at 2.1 °C.

The highest mean daily temperatures (12.1–12.4 °C) occurred along the entire valley, from the beach (Site 1) to the end of the valley (Site 4). However, the absolute temperature maximum (16.5 °C) was noted on the northern slope on the rocky soil with southern exposure. On the other hand, the minimum values of the mean daily temperature occurred over the surface of the glacier (Site 8) and on Wordiekammen (Site 7) and they reached -2.5 °C and -1.6 °C, respectively. The absolute lowest temperatures (-3.3 °C and -2.7 °C) were noted at the same sites. The temperature below freezing occurred also on the northern slope of the valley (Site 5), which, situated at the mouth of the deeply-cut in ravine, was exposed to periodic flows of cool air from the Lovehovden peak. Consequently, the value of the highest absolute amplitude in the examined period – *i.e.* almost 17 °C, was observed at Site 5. Taking into account the daily changes of the height of the sun, from about 10 °C to over 30 °C, the diurnal temperature range amounted on average from about 5°C inside the valley (Sites 3, 4, 5, 6) to about 4°C at the shore of the bay (Sites 1, 2) and 3.2 °C over the surface of the glacier (Site 8). The diurnal temperature ranges rarely exceeded 8 °C, which was related to a short-term shading of the

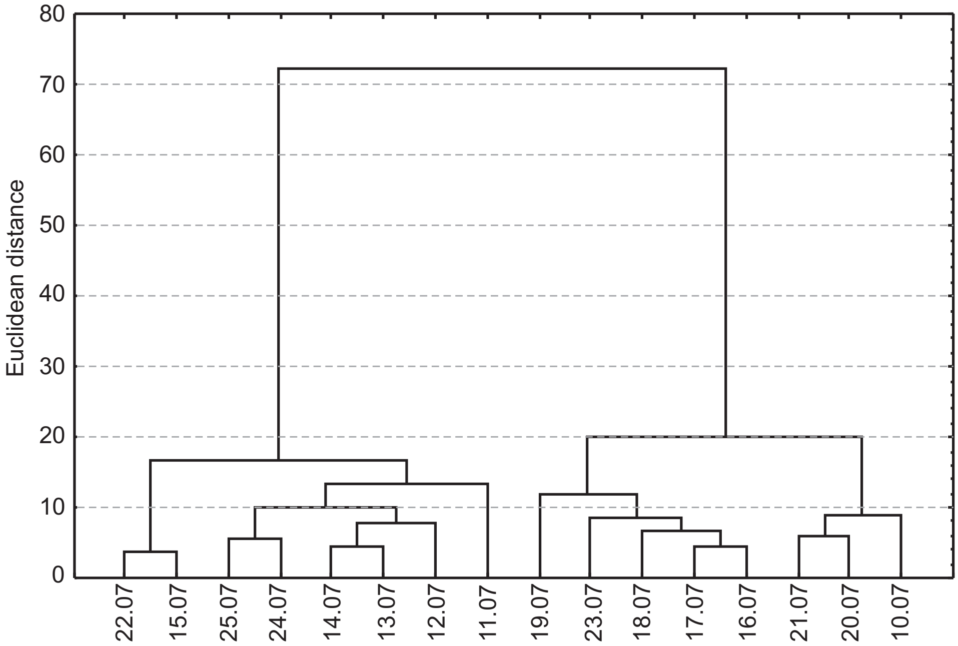

Fig. 3. Dendrogram grouping days using the Ward method, explanations in the text.

measurement sites during the lowest position of the sun or periodically high cloudiness. There were cloudy days as well when the diurnal temperature ranges reached up to about 2 °C at most measurement sites.

According to the temperature range alone, there were days with variable weather conditions. Two groups of days were identified according to Ward's method, based on the mean, maximum and minimum daily air temperature at the eight sites (Fig. 3). The first group, consisting of eight days, was characterized by radiation weather conditions, that is by large connected with little cloudiness, which contributed to higher air temperatures. The daily mean solar radiation was over 200 W/m^2, and at the noon hours exceeding 400 W/m^2 (Fig. 4) The radiation weather was also characterized by low-speed winds of about 2 m/s on average, with the prevailing directions between WSW and WNW. The atmospheric pressure was higher than usual and reached up about 1017 hPa with the long-term July average at the nearby Svalbard Airport station in Longyearbyen at 1012.7 hPa (Araźny 2008). During the non-radiation weather (the second group of days), larger cloudiness limited the supply of solar radiation, especially at the noon hours. The mean wind speed reached up 5 m/s, with the mean speed at gusts at 8 m/s, mainly from the NE quadrant, while the pressure amounted 1009 hPa.

The mean temperature, for radiation days inside the Ebba Valley, was by 4 °C higher than the mean temperature for the non-radiation days, while on the glacier (Site 8) and on the Wordiekammen (Site 7) the difference was greater and it ranged

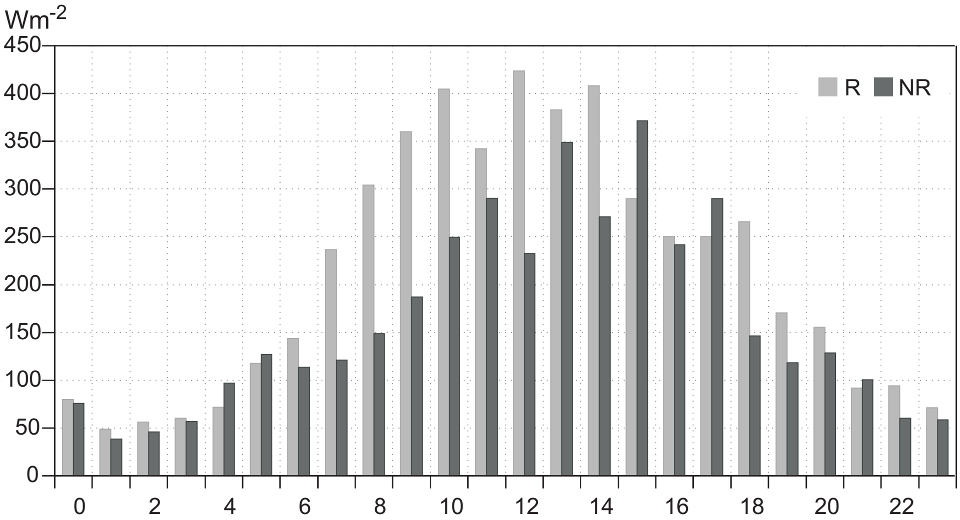

Fig. 4. Mean daily course of solar radiation intensities at the measurement Site 2, averaged for radiation days (R) and non-radiation days (NR), hours of local time on horizontal axis.

between 4.7 °C and 6.2 °C, respectively (Table 2). The spatial distribution of temperature for both day groups is shown on Fig. 5 and the daily mean pattern of temperature for all the sites, during the radiation and non-radiation days as well as the mean for the entire study period, is presented on Fig. 6. Temperature drop with height was smaller for the radiation days (0.56 °C/100 m) than for the non-radiation ones (0.94 °C/100 m), with the mean vertical temperature gradient at about 0.65 °C/100 m. The reduced gradient during radiation days value resulted from frequent thermal inversions during the sunny and windless weather.

The absolute range of temperature variations over the entire examined period exceeds 19 °C. During the radiation weather, very high daily temperature maxima occurred, on average of approximately 12.0 °C in the valley and 6.5 °C on the gla-

Table 2

Characteristics of the air temperature (T in °C) at measurement points in the Ebba Valley region in July 2009 in the radiative weather (R) and non-radiative weather (NR)

Site number	Daily mean T		Mean max daily T		Mean min daily T		Diurnal T range	
	R	NR	R	NR	R	NR	R	NR
1	9.6	5.4	12.5	7.5	7.3	3.9	5.2	3.6
2	9.5	5.3	12.2	7.2	7.2	4.0	5.1	3.2
3	9.6	5.9	11.9	9.1	7.1	3.8	4.8	5.3
4	9.7	5.3	12.0	8.1	7.2	3.4	4.8	4.7
5	9.1	4.3	12.2	6.9	6.7	2.7	5.5	4.5
6	9.2	5.3	11.8	9.0	6.7	3.0	5.1	5.9
7	6.8	0.6	9.2	2.5	4.3	-0.7	4.9	3.2
8	4.5	-0.2	6.5	1.1	2.7	-1.4	3.8	2.5

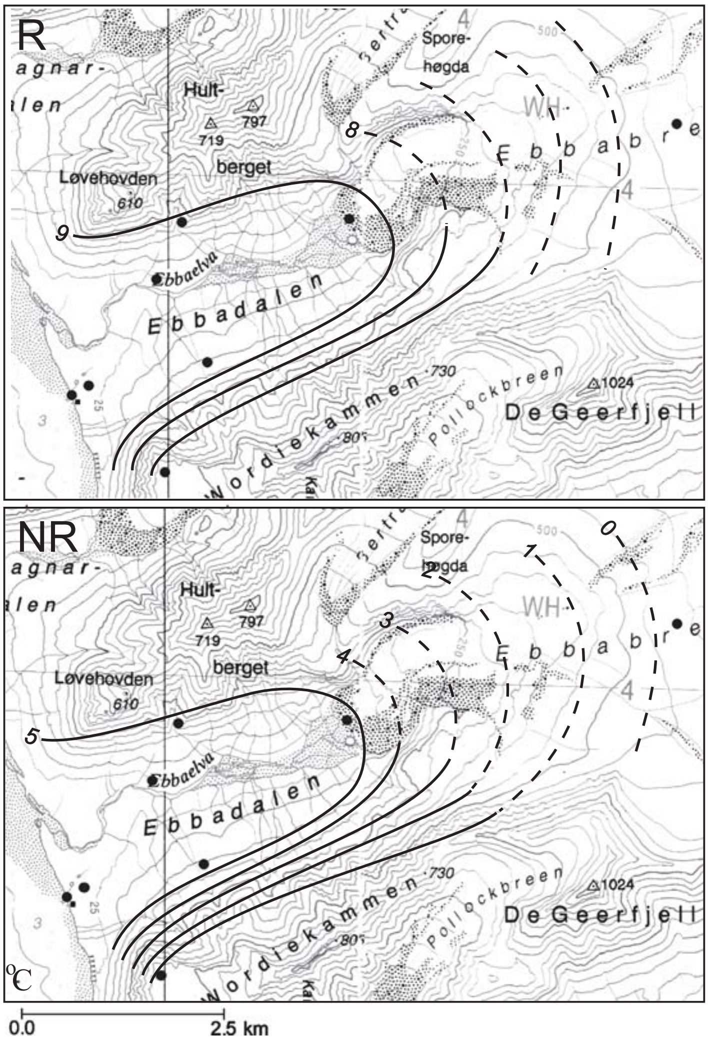

Fig. 5. Air temperature (°C) in the Ebba Valley region averaged for radiation days (R) and non-radiation days (NR).

cier (Site 8). The spatial temperature distribution during the warmest afternoon hours for July 12 is presented on Fig. 7. Sunny and windless weather prevailed in the entire Ebba Valley and the temperature reached 14.5 °C at some places. An exceptionally large temperature difference of 6.7 °C was noted on Wordiekammen. During the radiation weather, the daily temperature minima also proved to be higher, again with an exception of Wordiekammen, where the difference reached up to 5 °C. Diurnal temperature ranges, averaged separately for the radiation and non-radiation days, differed slightly by up to 2 °C.

Thermal inversions, with temperature markedly growing with height, occurred on few occasions during the study period in the Ebba Valley. The inversions in gla-

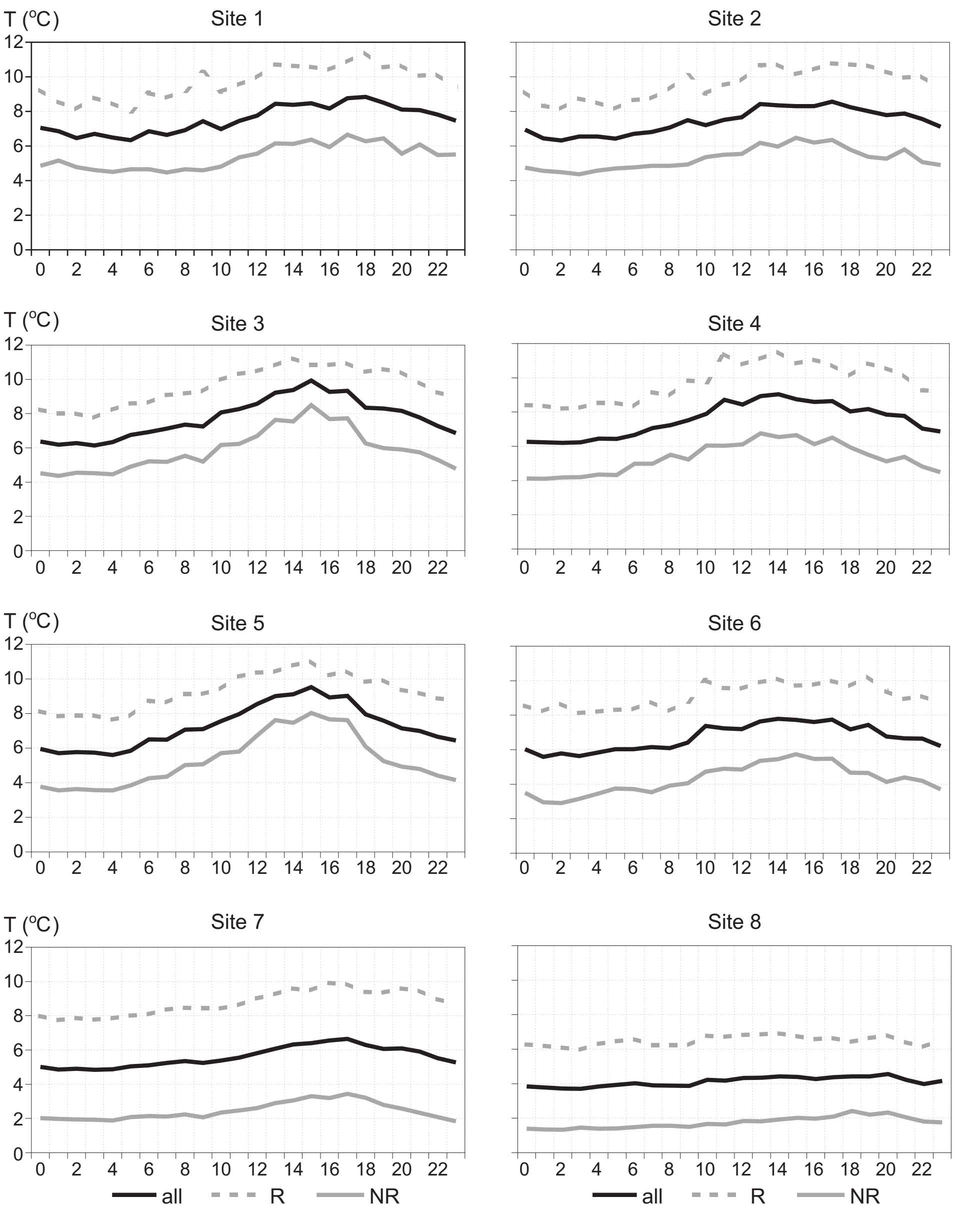

Fig. 6. Mean daily air temperatures at all measurement sites for all days of the studied period, radiation days (R) and non-radiation days (NR), hours of local time on horizontal axis.

cial valleys are usually related to the flow of cold air from above the surface of the glacier with katabatic glacier winds that are sometimes very strong. As it follows from the analysis of the spatial temperature distribution for selected measurement dates (an exemplary distribution in Fig. 8), in the case of the Ebba Valley these include, as a rule, advections of cooled air from above the cold waters of Petunia

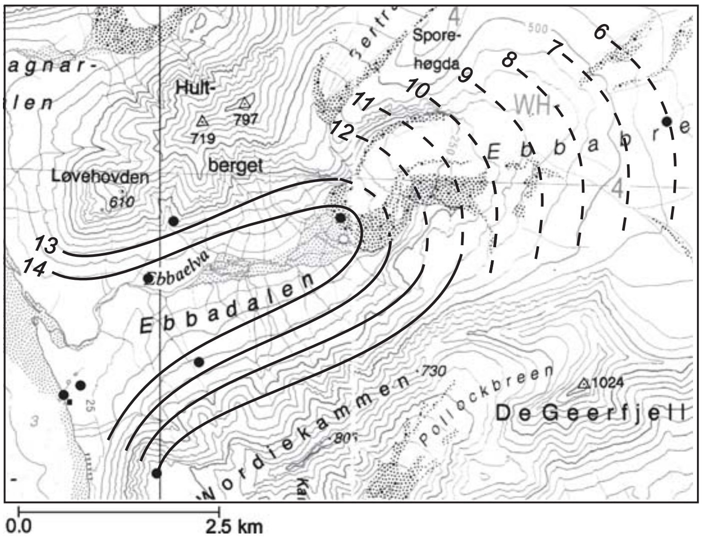

Fig. 7. The highest air temperature (°C) observed in the Ebba valley region during the studied period. Values for July 12, averaged from 16 p.m. to 18 p.m.

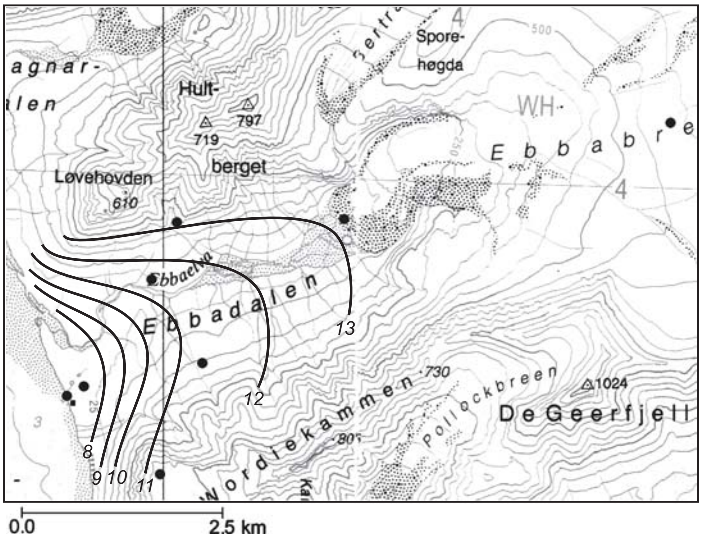

Fig. 8. Inverse air temperature (°C) distribution on July 24, averaged for the period from 10 a.m. to 13 p.m.

Bay. The cold air penetrate into the valley when the wind blows from the western and south-western direction. The thin layer of cool air reaches the height of approximately 250–300 m. It is manifested by a presence of the thin layer of *Stratus* clouds (Fig. 9). The cool air from the bay pushes upwards the mass of warmer air accumulating in the valley. Due to its cooling, the water vapor condensation takes place, developing the thin layer of clouds.

Fig. 9. *Stratus* clouds over the Ebba Valley, with a cloud base at 250–300 m a.s.l.

Fig. 10. *Stratus* (lower level cloud base at about 100–150 m a.s.l.) and *Stratocumulus* with higher level cloud base at about 400 on right side of the picture and at 700 m a.s.l. over Petunia Bay on left side of the picture.

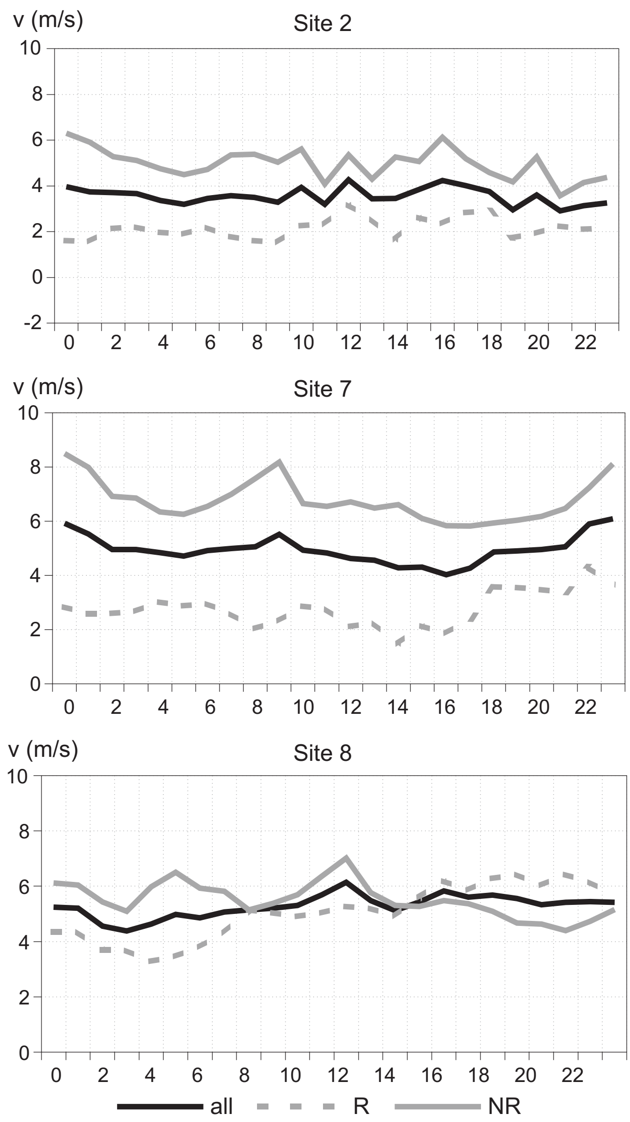

Fig. 11. Daily course of the wind speed at chosen measurement sites in the Ebba Valley region in the period 10–25 July 2009, averaged for all measurement days (all), radiation days (R) and non-radiation days (NR). Hours of local time on horizontal axis.

The thin strands of *Stratus* clouds visible on Fig. 10 provide evidence for the low inversions over Petunia Bay, more than 100 meters above the sea level. Cooling of the lowest air layers may result from the low temperature of the bay waters or/and the flows of cold air from above the neighboring Nordenskjold Glacier, in which vicinity strong katabatic winds are common. The jagged upper surface of the *Stratus* clouds indicates unstable equilibrium with temperature drop with height and with updrafts prevailing above the thin clouds at the border of the inver-

Table 3

The wind speed (v in m/s) at chosen measurement points in the Ebba Valley region in the period 10–25 July 2009 (all – all days, R – radiation days, NR – non-radiation days)

Site number	Mean daily v			Mean max daily v			Absolute max v
	all	R	NR	all	R	NR	
2	3.6	2.1	5.0	4.3	3.2	6.3	10.7
7	5.0	2.8	6.8	6.1	4.3	8.5	16.1
8	5.3	5.0	5.5	6.1	6.4	7.0	16.5

Table 4

The wind chill temperature (WCT in °C) at all measurement sites in the Ebba Valley region in the period 10–25 July 2009 (all – all days, R – days with radiation weather, NR – days with non radiation weather)

Site number	Mean daily WCT			Mean daily maximum WCT			Mean daily minimum WCT			Abs. max WCT	Abs. min WCT
	all	R	NR	all	R	NR	all	R	NR		
1	5.0	8.3	1.7	6.3	10.0	3.3	3.3	6.0	-0.3	16.0	-5.1
2	5.1	8.3	1.8	6.3	10.0	3.3	3.7	6.8	0.3	-16.0	-4.6
3	5.9	7.6	4.2	7.8	9.1	7.1	4.2	5.8	2.2	16.8	-3.8
4	6.0	8.1	3.9	7.8	10.4	5.9	4.1	6.2	1.4	17.9	-6.3
5	4.9	7.3	2.5	6.5	8.9	4.1	3.4	6.1	0.5	15.1	-5.6
6	5.9	8.0	3.9	7.7	9.5	6.7	4.1	6.9	1.2	16.5	-6.7
7	0.9	5.7	-3.9	2.6	7.3	-1.7	-0.4	4.6	-5.6	12.0	-11.0
8	-1.9	1.1	-5.0	-1.3	1.8	-3.7	-2.6	0.3	-6.1	8.3	-12.0

sion zone. Above, there is the second, higher level of condensation, marked by a compact cover of *Stratocumulus*.

The analysis of wind speeds in the region of the Ebba Valley and in its vicinity is based on measurements at Site 2 in the river Ebba Valley, Site 7 in the peak part of Wordiekammen, and at Site 8 on the Ebba Valley Glacier. The days with the radiation weather were characterized by the lowest wind speed. Its mean valued 2.1 m/s in the valley, 2.8 m/s on Wordiekammen, and 5.0 on the glacier. During the days with non-radiation weather, wind speeds were considerably higher and reached up to 5.0 m/s in the valley, 5.5 on the glacier, and 6.8 m/s on Wordiekammen. The mean speed, calculated for the whole period examined, was the highest on the glacier and at the site located at the top of Wordiekammen, where it reached up 5.3 m/s. It was the lowest in the valley, with 3.6 m/s. The absolute highest values of wind speed at the sites located higher (the Ebba Valley Glacier and Wordiekammen) exceeded 16 m/s while in the Ebba Valley wind speed was not much higher than 10 m/s (Table 3). The analysis of the mean daily pattern of wind speeds, for days with radiation and non-radiation days as well as for the entire examined period, is presented on Fig. 11.

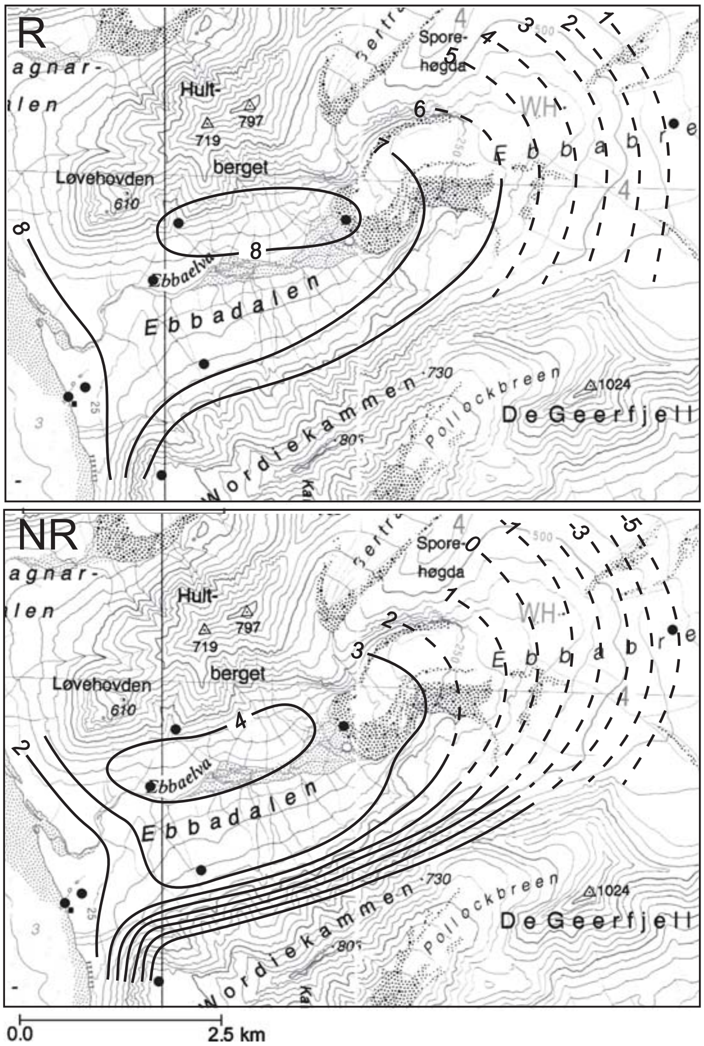

Fig. 12. Wind-chill temperature (°C) in the Ebba Valley region averaged for radiation days (R) and non-radiation days (NR).

At the bottom of the valley and at the peak of Wordiekammen, the mean wind speed during days with radiation weather was lower than during days with non-radiation weather throughout. On the other hand, a reverse situation was observed between 2 p.m. and 12 p.m. on the Ebba Valley Glacier, with a higher wind speed during days with radiation weather. It may be explained by a stronger development of the local pressure centers during the radiation weather and an increased strength of the glacier katabatic wind.

The bioclimatic analysis of the Ebba Valley region was performed for days with radiation and non-radiation weather as well as for the entire examined period. The lowest wind chilling factor was observed during the radiation weather (Table

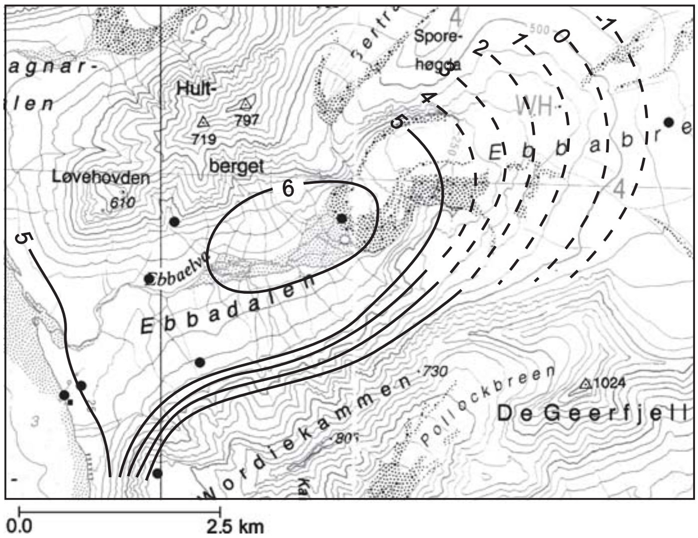

Fig. 13. Wind-chill temperature (°C) in the Ebba Valley region, averaged for all days of the studied period.

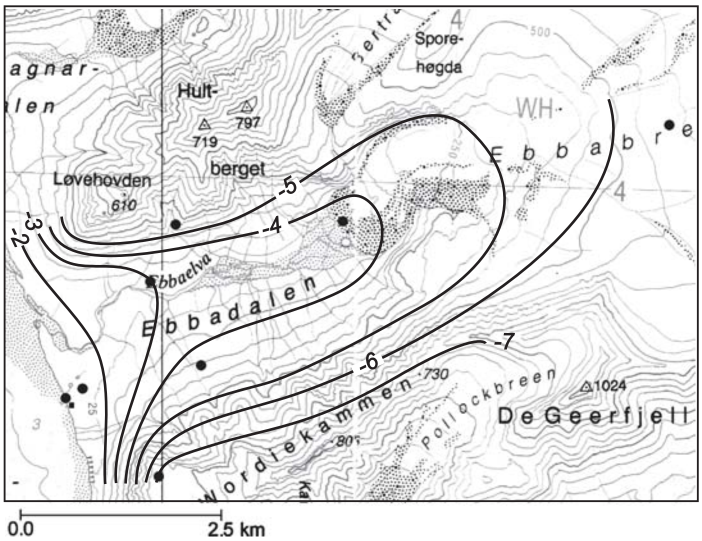

Fig. 14. The lowest wind-chill temperature (°C) observed in the Ebba Valley region during the studied period. Values of July 21 are averaged from 1 a.m. to 3 a.m.

4, Fig. 12). The warmest sites were those on the beach (Site 1) and in the tundra not far away from the shore (Site 2), where the mean WCT reached up 8.3 °C. Slightly lower values were characteristic of Site 4 at the end of the valley and of Site 6 at the slope with southern exposure, where the WCT amounted 8.1 °C and 8.0 °C, respectively. It was cooler at Site 7 at the top of Wordiekammen (5.7 °C). With no doubt, the least favorable bioclimatic conditions prevailed on the Ebba Valley Gla-

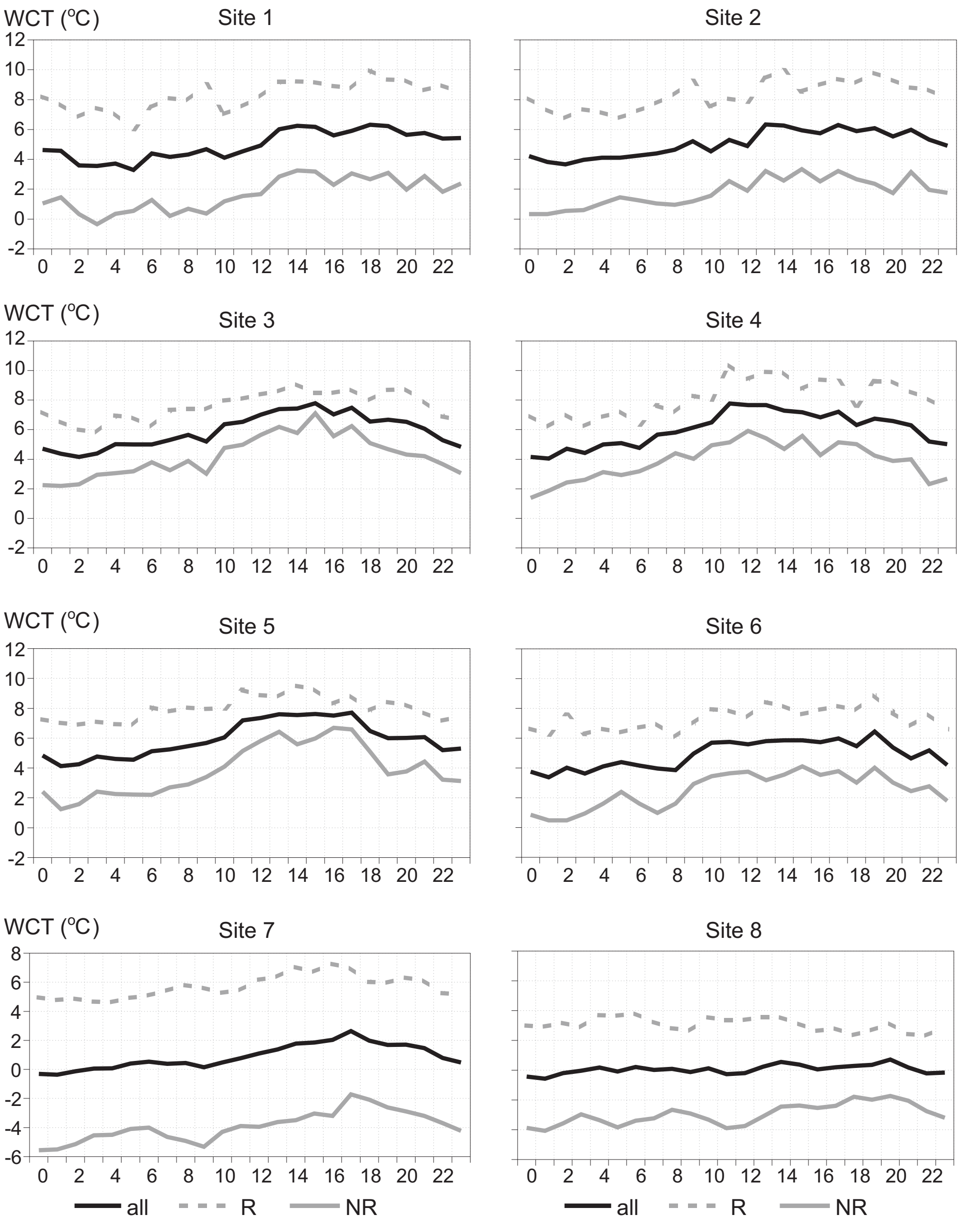

Fig. 15. Mean daily course of wind-chill in all measurement sites (1–8) for all days of the studied period (all), radiation days (R) and non-radiation days (NR). Hours of local time on horizontal axis.

cier, where the mean WCT value was as low as 1.1 °C only. What is peculiar in the spatial distribution of the WCT is its weak vertical gradient on radiation days, *i.e.* lower than the thermal gradient on Fig. 5, and, at the same time, its strong horizontal gradient *i.e.* the difference between the Ebba Valley and the surface of the Ebba

Valley Glacier. It can be explained by the already mentioned high wind speeds during radiation days.

During non-radiation weather, the highest mean WCT value was observed at Site 3, located at the bottom of the valley, and Site 4 at the end of the valley, for which WCT values amounted 4.2 °C and 3.9 °C, respectively. At that time, both the horizontal and vertical WCT gradients were much stronger than during the radiation weather. WTC decreased by approximately 8 °C on average between Site 6 (southern slope) and Site 7 (Wordiekammen) within the distance of about 400 m in altitude. Even greater difference, of about 9 °C, occurred between the surface of the glacier and the secluded bottom of the valley. It was due to an increase of wind speed on the top and on the bare surface of the glacier.

The distribution of mean WCT values on the particular sites calculated for the entire study period is similar to the distribution typical for the days with non-radiation weather (Fig. 13). It was the warmest at the sites located at the bottom of the valley and at its end, before the glacier (Sites 3 and 4), for which the WCT reached up 6.0 °C and 5.9 °C, respectively. The coolest bioclimatic conditions occurred on the glacier and at the peak of Wordiekammen. The WCT for those sites amounted -1.9 °C and 0.9 °C, respectively. The absolute highest WCT values calculated for the analyzed sites ranged between 16.8 °C in the bottom of the valley (Site 3) and 8.3 °C on the Ebba Valley Glacier (Site 8). Such favorable bioclimatic conditions occurred during the windless and sunny radiation weather. The absolute lowest WCT values were characteristic of the same sites as before and ranged between -3.8 °C at the bottom of the valley and -12 °C on the glacier (Table 4). They were observed during non-radiation weather.

The analysis of the WCT distribution, characterized by the lowest mean values for July 21, between 1 a.m. and 3 a.m. (Fig. 14), portrays the situation when the temperature drop below freezing in the whole region. Relatively bearable conditions prevail on the beach and in its immediate neighborhood where the WCT attained the values above -2 °C. However, while moving inside the valley or upwards along its slopes the index values become lower, dropping to -7 °C on Wordiekammen.

The comparison of the mean daily WCT pattern for days with radiation and non-radiation weather (Fig. 15) shows the greatest cooling of the wind throughout the whole day during non-radiation weather at each site. The largest WCT differences, calculated for the two types of weather, was observed at Site 7 (Wordiekammen) and reached 9.6 °C on average. On the other hand, the lowest differences were observed at the bottom of the valley, amounting 3.4 °C on average. The highest WTC values at most of the sites were recorded for afternoon and evening hours, ranging between -1.3 °C on the Ebba Valley Glacier and nearly 8 °C at the bottom of the valley and at its eastern end (Site 4). As a rule, the lowest WCT values took place between 12 p.m. and 6 a.m. ranging between -2.6 °C on the glacier and slightly above 4 °C at the bottom of the valley and at its end (Sites 3 and 4).

Discussion and conclusions

July of 2009 appeared to be slightly warmer than average, with mean monthly temperature in the Svalbard Lufthavn station in Longyearbyen reaching 7.7 °C and 7.6 °C between 10 and 25 of July. That is by 0.6 °C higher than the multiannual average. The difference has not exceed the standard deviation of mean July temperatures, which is as high as 0.9 °C. Concerning the multiannual variability of mean July temperature in Svalbard Lufthavn, the year 2009 was within the normal range between the 10 and 90 percentile, according to limits postulated by IPCC (IPCC Fourth Assessment Report 2007). Thus, the study period can be considered representative for the warmest month of the year in central Spitsbergen.

During the studied period, mean temperatures within the valley were similar to the temperatures in the nearest meteorological station of Svalbard Lufthavn (difference of up to 0.2 °C), and they were considerably lower at higher altitudes and on the glacier (the difference of 5.5 °C and 8.5 °C respectively). The temperature range also corresponded to the mean values occurring at Svalbard Lufthavn (Araźny 2008).

According to atmospheric circulation patterns for Spitsbergen determined by Niedźwiedź (2010), two types of circulation patterns prevailed in the period 10–25 July 2009: anticyclonic from the eastern quadrant: Ea, SEa, NEa, (sum total 7 days, plus 1 Na, plus 1 Ka type, which means anticyclonic wedge or ridge of high pressure) and cyclonic, mainly from the north (Nc, 5 days) and from the east (Ec, 2 days). The days classified in this study as radiation weather days, appeared mainly in the anticyclonic circulation patterns, while non-radiation days corresponded mainly with northern cyclonic situations.

The thermal inversions observed in the Ebba Valley seem to be of a different character than described by Trepińska (2002), suggesting that the flow of cool air from above the surface of the glacier is considered to be the reason for the inversion in glacial valleys. In the case of the Ebba Valley, which stretches latitudinally and it is situated in the far-away cold part of the Isfjorden, the western air circulation brings about advections of cooled air from above the cold waters of Petunia Bay which penetrates into the valley. The cold air pushes upwards the mass of warmer air in the valley, creating a rather thin inversion layer, which upper edge is marked with a thin and non-uniform cover of clouds.

The WCT index measured within the Ebba Valley (5.0 to 6.0 °C) slightly exceeds the mean July values computed by Araźny (2008) for the Svalbard Lufthavn station (4.9 °C), while it is considerably lower on the higher elevations and on the Ebba Valley Glacier (0.9 to -1.9 °C). Much lower July average values (1.3 °C) were calculated for the Polish Polar Station in Hornsund (Styszyńska 2007). The analysis of the spatial distribution of WCT values, both for the days with radiation and non-radiation weather as well as for the mean conditions in the entire study period, indicates that the most favorable regions in the interior of Spitsbergen from a bioclimatic point of view and with respect to the cooling of the wind, are those situated in the shielded central parts of the valleys and in the lower parts of the slopes with southern exposure. On the other hand, the conditions in the regions situated at elevations and on the glacier are definitely less favorable. Especially during unfavorable non-radiation weather, a large difference between the real temperature values and the WCT values occurs. Furthermore, with non-radiation weather, the bioclimatic conditions deteriorate rapidly, especially on the glacier and on open peak surfaces, indicated by strong horizontal and vertical WCT gradients.

Despite the summer season, considerable discomfort and the possibility of cooling (Błażejczyk 2004) should be considered for WCT values, which may decrease below -10 °C as recorded in Wordiekammen and Ebba Valley Glacier. That should be kept in mind while exploring central Spitsbergen and urge explorers to use clothes providing proper protection against unfavorable weather (Araźny 2006).

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