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Weather patterns of the coastal zone of Petuniabukta, central Spitsbergen in the period 2008–2010

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Abstract: This paper presents the first results of measurements of global solar radiation, albedo, ground surface and 2-m air temperature, relative humidity, and wind speed and direction carried out in the central part of Spitsbergen Island in the period 2008–2010. The study site was located on the coastal ice-free zone of Petuniabukta (north-western branch of Billefjorden), which was strongly affected by local topography, character of the ground surface, and sea ice extent. Temporal analysis of the selected meteorological parameters shows both strong seasonal and inter-diurnal variation affected by synoptic-scale weather systems, channelling and drainage effects of the fjords and surrounding glaciers. The prevailing pattern of atmospheric circulation primarily determined the variation in global solar radiation, wind speed, ground surface and 2-m air temperatures. Furthermore, it was found that thermal differences between Petuniabukta and the nearest meteorological station (Svalbard Lufthavn) differ significantly due to differences in sea ice concentrations and ice types in the fjords during the winter and spring months.

Key words: Arctic, Svalbard, climate, temperature, solar radiation.

Introduction

In recent studies, many authors indicated that near-surface air temperature in the Arctic has increased about twice as fast as temperatures in lower latitudes during the past few decades (Przybylak 2000; Knutson *et al.* 2006; Miller *et al.* 2010). The Svalbard archipelago has been also the subject of many studies that confirmed enormous climate warming, reductions in permafrost thickness, glacier retreat, and changes in vegetation and terrestrial animal habitats (Ziaja 2005; Rachlewicz and Szczuciński 2008; Moreau *et al.* 2009; Prach *et al.* 2012 this issue).

It is well known that regional climate change directly affects the local climate on a temporal scale, and, therefore, has a pronounced effect on many aspects of both the abiotic and biotic components of Arctic ecosystems. A local climate (topoclimate) is defined as the climate of a relatively small region with predominantly uniform natural conditions (Barry 2008). A local climate is determined by several environmental factors, *e.g.* topography, active ground surface (soil, vegetation, and glacier), which directly affect water, biota, and snow cover distribution. There are pronounced spatial differences in these features over distances of 100 m to 1–10 km. Topoclimatic effects usually extend to a height of 100 to 1000 m above the ground depending on local topography and its elevation (Barry 2008).

In the case of the Svalbard archipelago, climate differentiation of ice-free zones is mainly influenced by local topography, character of ground surface (*e.g.* patterned ground, tundra zone, and wetland), and distance from an oceanic and/or glacial margin. It is apparent that each of these features is related to the effects of weather systems (atmospheric circulation mode) and microclimatic conditions at the Earth's surface. However, the local topography (slope orientation, slope angle, and other relief characteristics) plays an essential role in modifying airflow and weather systems reaching the Svalbard archipelago. As reported by many authors, airflow transformation and mountain effects lead to a local circulation system and local wind occurrence (*e.g.* Hanssen-Bauer *et al.* 1990; Serreze *et al.* 1993; Førland and Hanssen-Bauer 2003; Niedźwiedź 2007; Kilpeläinen *et al.* 2011; Mäkiranta *et al.* 2011).

One of the first topoclimatic observations on Svalbard was carried out in the region of Treurenberg Bay and Massif Olimp (NE Spitsbergen) in 1899–1900 (Przybylak and Dzierżawski 2004). The second oldest topoclimatic investigations were done by the team led by Kosiba at Werenskiold Glacier during the International Geophysical Year 1957–58 and the years 1959–60 (Kosiba 1960). The spatio-temporal variation of topoclimatic conditions have been furthermore investigated in the region of Hornsund, Calypsobyen (West Spitsbergen), Kaffiøyra (Northwestern Spitsbergen), and Petuniabukta (Central Spitsbergen) by researchers from Wrocław University, Masaryk University (Brno), Maria Curie Skłodowska University (Lublin), Nicolaus Copernicus University (Toruń), and Adam Mickiewicz University (Poznań) during several summer expeditions (*e.g.* Baranowski and Głowicki 1975; Brázdil *et al.* 1988, 1991; Pereyma and Piasecki 1988; Przybylak 1992; Kejna and Dzieniszewski 1993; Rachlewicz 2003). Recently, comprehensive studies of the influence of atmospheric circulation on the local climate have been conducted in Spitsbergen (Przybylak and Arazny 2006; Marsz 2007; Rachlewicz and Styszyńska 2007; Migała *et al.* 2008; Bednorz and Kolendowicz 2010).

Atmospheric and climate research have been carried out primarily in the vicinity of large settlements (Longyearbyen, Ny-Ålesund, Barentsburg, Sveagruva) or research stations (*e.g.* Polish Polar Station "Hornsund", Nicolaus Copernicus University Polar Station "Kaffiøyra") situated along the western and south-western coasts of Spitsbergen. The first meteorological observations in the region of Petuniabukta (central part of Spitsbergen) were carried out during the Polish expedition from Adam Mickiewicz University in 1985 (Kostrzewski *et al*. 1989). Nevertheless, most

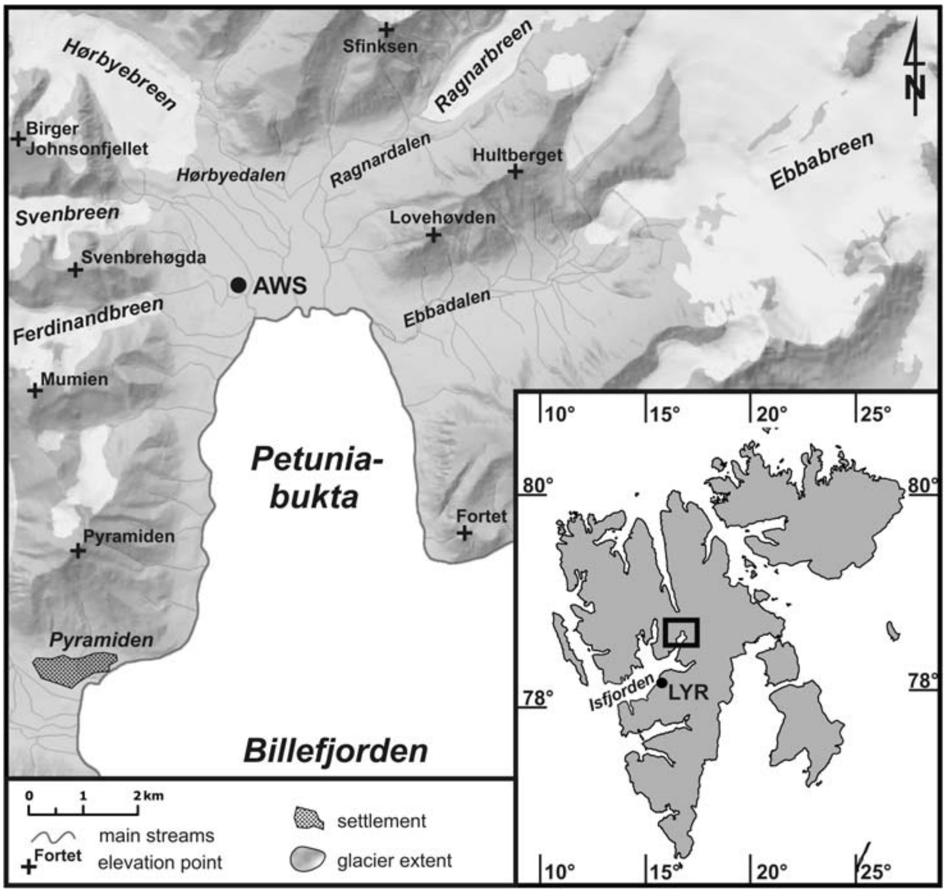

Fig. 1. Location of the study site in Petuniabukta (Billefjorden), central Spitsbergen. Abbreviations: AWS – Automatic Weather Station of the Czech Team, LYR – Svalbard Lufthavn Weather Station (Norwegian Meteorological Institute). Map source: Svalbardkartet, Norwegian Polar Institute.

of the climate studies at Petuniabukta dealt with the analysis of short-term meteorological measurements and observations conducted during single summer seasons only (June–August). It is therefore crucial to obtain further quantitative information about the annual and seasonal variation of weather conditions in the central part of Spitsbergen in order to understand interactions among the components of the climate systems and possible consequences for Arctic ecosystems.

This paper provides the first results of comprehensive meteorological observations conducted in Petuniabukta (Billefjorden, Central Spitsbergen) in the period 2008–2010. Our objectives were, therefore, to evaluate temporal variability of weather conditions of the coastal ice-free zone of Petuniabukta, and evaluate the air temperature differences between the study site and the nearest meteorological station (Svalbard Lufthavn) with regular all-year round observations (Fig. 1). We focused primarily on describing the diurnal and annual regimes of basic meteorological parameters measured at such a remote site as the Petuniabukta, and their assessment in the context of synoptic situations over the Svalbard archipelago. However, the preliminary character of the presented results arises from their general analysis and description on which the authors focused at the beginning. This was mainly due to the quality of the meteorological datasets and partly to a number of missing parameters (air pressure and wind direction). Hence, detailed analyses, in particular evaluation of atmospheric processes (*e.g.* dependence of the selected meteorological parameters on local atmospheric circulation by objective methods), will be the subject of further study.

Study area

The investigated area was located on the western coast of Petuniabukta in the central part of Spitsbergen, the largest island of the Svalbard archipelago (Fig. 1). The Petuniabukta is part of the northern branch of Billefjorden, which is an extension of Isfjorden, the second longest fjord in Spitsbergen. The automatic weather station (AWS) was situated on the flat marine terrace at the geographical coordinates 78°42.11'N, 16°27.64'E and the altitude of 15 m a.s.l. From the southwestern to western sector, it is surrounded by the Pyramiden (935 m a.s.l.), Mumien (770 m a.s.l.), and Svenbrehøgda (620 m a.s.l.) mountain ranges and numerous valley glaciers (Ferdinandbreen, Svenbreen, Hørbyebreen, Ragnarbreen, and Ebbabreen). From the northeastern to southeastern sector, it is close to the hummock tundra, which is regularly flooded with thawing water from snow patches and several glacier rivers. Another important feature of Petuniabukta is the presence of seasonal sea ice cover (mainly fast-ice and open drift ice) usually occurring from December to May (Nilsen *et al.* 2008). As the AWS was located 500 metres from the coastline, winds from the southeast to east represented the airflow from the fjord. An ice-cement type of the permafrost occurs predominantly in the lower part of the coastal zone. During summer, the permafrost table is located at a depth of 40–120 cm depending on *e.g.* altitude, slope and relief exposition (Láska *et al.* 2010). The vicinity of the AWS is covered by permanent tundra vegetation with several dominant species: *Cassiope tetragona*, *Dryas octopetala*, *Carex rupestris*, *Salix polaris*, and *Saxifraga opossitifolia* (J. Gloser, personal communication).

Methods

The first part of the AWS was installed at Petuniabukta in October 2007 and has been operated all-year round since June 2010. Shortwave incoming and reflected solar radiations were measured using two identical Shenk 8101 starpyranometers (Ph. Shenk, Austria), with an accuracy of <5% of the nominal value. Additional errors of the starpyranometers due to ice formation and snow deposition in

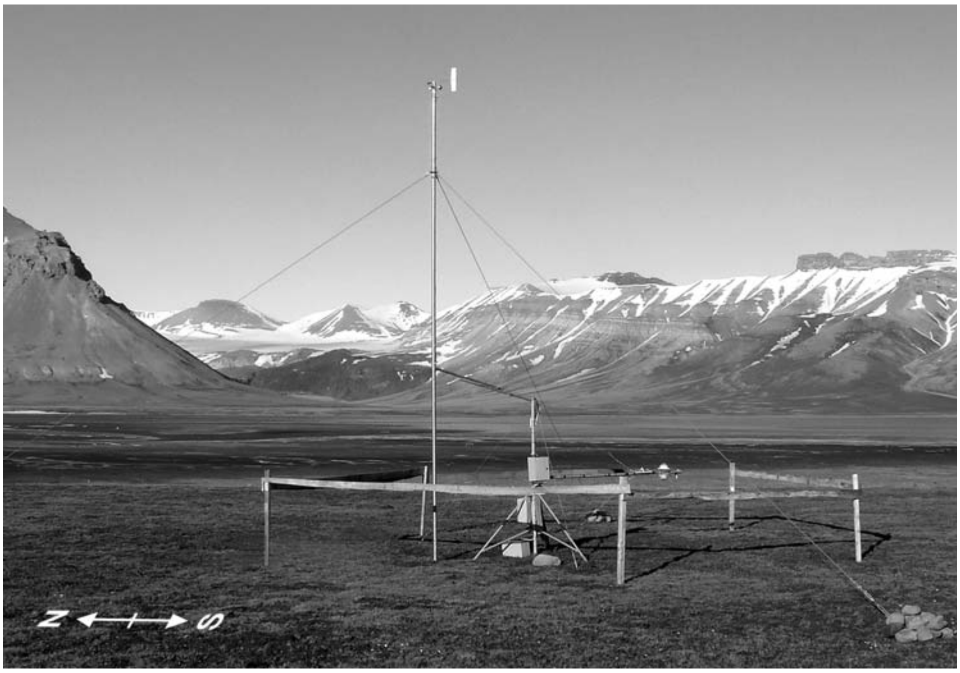

Fig. 2. General view of the automatic weather station located on the marine terrace in the western coast of Petuniabukta with the Ebba Valley and Ebbabreen in the background.

winter and spring may temporarily reduce the daily mean intensity of solar radiation by up to 30%. Ground surface temperature was monitored by an Omega OS-36-2 near-infrared temperature sensor (Omega, USA), with accuracy ±2% of the nominal range (-18 to 85°C) and ±5% outside of the temperature range. The instruments were located at a height of 1.5 m above ground. As the OS-36-2 sensor is sensitive to the emissivity of the measured surface, emissivity values were changed during the year in accordance with the OS36 Operator's Manual (Omega Corp. USA, http://www.omega.com). In most cases, surface emissivity was set in the range of 0.993 (tundra vegetation) to 0.995 (snow) according to the actual ground surface conditions (M. Bartak, personal communication). Air temperature and relative humidity were measured by an EMS33 probe (EMS Brno, Czech Republic) at the height of 2 m above ground. Accuracy of the temperature probe was ±0.15°C, while humidity probe accuracy was 3% of the nominal value. Wind speed and direction were recorded by a MetOne 034B anemometer (MetOne, USA) at a height of 6 m above ground (Fig. 2). Wind speed was monitored with an accuracy of ±0.1 ms^{-1} (starting threshold at 0.4 ms^{-1}), while wind direction accuracy was ±4°. Solar radiation measurements were taken every 10 s and data were stored as 30 min averages in a MiniCube VV/VX Data Logger (EMS Brno, Czech Republic). The other sensors were sampled at 30 min intervals only. High power consumption of the AWS did not allow measurements of precipitation due to its prevailing solid state and the fact that the whole measuring system was supplied by small solar panels. All sensors were thoroughly calibrated before installation at the study site and then regularly every year at the calibration laboratory of the Czech Hydrometerological Institute, EMS Brno (CZ), and during summer expeditions by comparison with a CM-11 pyranometer (Kipp & Zonen, Netherlands).

In this study, we use the term albedo when we are referring to the hemispherical reflection of solar radiation from the Earth's surface, with wavelengths between 300 and 3000 nm. Albedo was evaluated from reflected and incoming solar radiation to determine the occurrence of snow cover at the study site. The albedo (α) was calculated for each 30-min values as

$$\alpha = RR \,/\, GR$$

where GR is the intensity of global shortwave radiation incident on the Earth's surface (Wm^{-2}) and RR the intensity of shortwave radiation intensity reflected from the surface back to the atmosphere (Wm^{-2}). The albedo was not calculated during low solar elevation angle, typically being less than 5° (November–February).

The 30-min, daily and monthly means and extreme values from the AWS were analysed using STATISTICA (2011) and standard statistical methods. This also includes the standard deviation, correlation coefficient, and variation coefficient determined for the selected meteorological parameters according to Storch and Zwiers (1999). Only complete time series of daily mean and extreme values of the selected meteorological parameters corresponding to the period from August 1, 2008 to June 30, 2010 (698 days) were used for the following analyses. Therefore, the wind speed and direction data, which included several malfunctions of the anemometer, were reduced to the period from August 1 to September 30, 2008 and the period from July 1, 2009 to June 30, 2010.

In order to evaluate the weather conditions within the study period, changes in the atmospheric circulation patterns were analysed and compared with the multiyear data (1970–2000). The description of atmospheric circulation was based on the calendar of circulation types for the Spitsbergen area, provided by Niedźwiedź (2012). The principles of the classification are synoptic maps from which direction of the geostrophic wind and the kind of pressure pattern (cyclonic or anticyclonic) is determined (Niedźwiedź 2007). The author of the classification distinguished 21 circulation types according to the common directions of advection, adding the symbol "a" for anticyclonic (high pressure) and "c" for cyclonic (low pressure) systems. Other distinguished types were the anticyclonic centre over Spitsbergen (Ca), anticyclonic wedge (Ka), cyclonic centre over Spitsbergen (Cc), cyclonic trough (Bc), and baric col or synoptic situations which was impossible to classify (X).

The second objective of the analysis was to evaluate air temperature differences between the study site and the nearest all-year round operating the weather station at Svalbard Lufthavn (Fig. 1). The meteorological data for Svalbard Lufthavn were provided by the Norwegian Meteorological Institute in Oslo. The station is situated near the mouth of Adventfjorden, approximately 600 m from the coastline, at an elevation of 28 m a.s.l. Its location in the middle part of Isfjorden (42 km from the open ocean) contributes to different climate conditions in comparison to meteorological stations along the western and south-western coast of Spitsbergen, *e.g.* Ny-Ålesund or Horsund (Przybylak and Araźny 2006). The distance between the Svalbard Lufthavn station and the study site in Petuniabukta is 56 km (Fig. 1). Due to the fact that sea ice occurrence plays an important role in shaping the local climate conditions (Kilpeläinen *et al.* 2011), part of the analysis was devoted to evaluation of the effects of sea ice occurrence on temperature variations between both sites. Sea ice conditions were evaluated according to the high resolution sea ice charts of the Svalbard area provided by the Sea Ice Service of the Norwegian Meteorological Institute (http://polarview.met.no/).

Results and discussion

Atmospheric circulation. — In order to evaluate the effect of atmospheric circulation on local weather conditions in the observed period, the classification of circulation pattern provided by Niedźwiedź (2012) for the Svalbard archipelago was used. We compared the relative frequency of occurrence of circulation types in the period from August 2008 to June 2010 against the long-term average values from 1970 to 2000 (Fig. 3). In the study period (2008–2010), cyclonic activity prevailed on 58.9% of the days, while anticyclonic situations occurred in only 38.1%. The most common circulation types were from the northeastern sector, with frequency of occurrence being 9.6% (Ec type), 9.0% (Nc type), 8.3% (SEc type) and 7.2% (NEc type). Considerably high frequencies were found also for the anticyclonic wedge (Ka type – 9.0%), trough of low pressure (Bc type – 8.6%), and anticyclonic situations from the northeastern sector, Na (5.7%), NEa (5.3%), and Ea (6.3%) in particular. The highest activity of the cyclonic circulation was found in

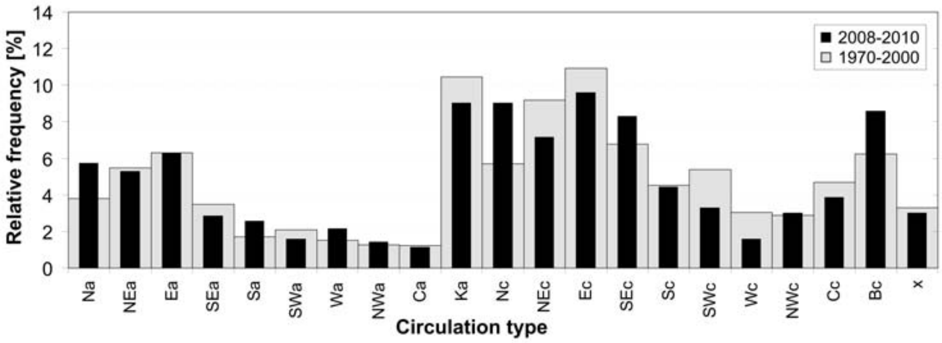

Fig. 3. Relative frequency of occurrence of circulation types over Spitsbergen area in the period from August 2008 to June 2010, as compared with the long-term average from 1970 to 2000.

autumn (88.2%) and winter (86.6%). Conversely, the anticyclonic types were most common in summer (35.3%) and spring (19.0%). A very similar distribution of baric patterns was found from 1970 to 2000, where the cyclonic situations prevailed in 59.4%, while the anticyclonic situations occurred in 37.3% of the days. The remaining types of circulation (X – baric col or other unclassified situations) were recorded at frequencies of 3.0% (2008–2010) and 3.3% (1970–2000) respectively. The highest differences in circulation pattern between the study period and the 1970–2000 period were found during cyclonic situations (Fig. 3). The circulation types Nc, SEc and Bc (troughs of low pressure) showed considerable increases in frequency by +3.3%, +1.5% and +2.3%, compared to the long-term average values. On the other hand, circulation types NEc and SWc, with differences of -2.0% and -2.1%, occurred less frequently compared to the long-term averages. The anticyclonic situations were most frequently represented by type Na, with a difference of +1.9%, while type Ka decreased in frequency by -1.4% compared to the long-term average values (Fig. 3). A similar pattern of atmospheric circulation over the Svalbard area, as well as similar seasonal variation of circulation types, were found by Førland and Hanssen-Bauer (2003), Przybylak and Araźny (2006), Niedźwiedź (2007), and Migała *et al.* (2008).

Surface Wind Field. — The relative frequency of wind direction measured at the 6-m mast was estimated from 30-min data. The effect of local topography on the wind pattern in Petuniabukta is evident in Fig. 4. From July 2009 to June 2010, the prevailing wind directions were observed from the south (9.6%), northeast (8.2%), and northwest (7.8%), which clearly corresponded with the local topography and longitudinal axis of the Billefjorden, Ragnardalen, and Ferdinanddalen valleys. Such a channeling effect in Petuniabukta was confirmed by the studies of Rachlewicz and Styszyńska (2007), and Bednorz and Kolendowicz (2010). On the other hand, northerly winds (2.4%) had the lowest frequency of wind direction. Seasonal variation in the frequency of main drainage flows was apparent between cold and warm periods of the year. Southerly and northeasterly winds were most common in summer (June–August), with a frequency of occurrence representing 16.1% and 14.5% of all cases. Conversely, these winds rarely appeared from October to February, which had frequencies between 6.6% and 5.0% in all cases.

Mean wind speed during the study period was estimated at 3.9 ms^{-1}. The strongest winds were primarily connected to the northeasterly flow from the Ragnardalen and Ebbadalen valleys (Ragnarbreen and Ebbabreen glaciers). In this case, mean wind speed varied between 5.4 ms^{-1} for ENE and 6.4 ms^{-1} for NNE directions Fig. 4. The daily maximal wind speed from these directions exceeded 11.9 ms^{-1}. Due to the blocking effects of the Pyramiden, Mumien, and Svenbrehøgda mountain ranges, the lowest wind speed was observed from the western sector, with mean values ranging from 2.5 ms^{-1} (WSW) to 2.8 ms^{-1} (WNW). Therefore, daily maximal wind speed from western sector was 8 ms^{-1} only. Generally, the westerly winds occurred primarily in autumn and winter (October–February), with a wind

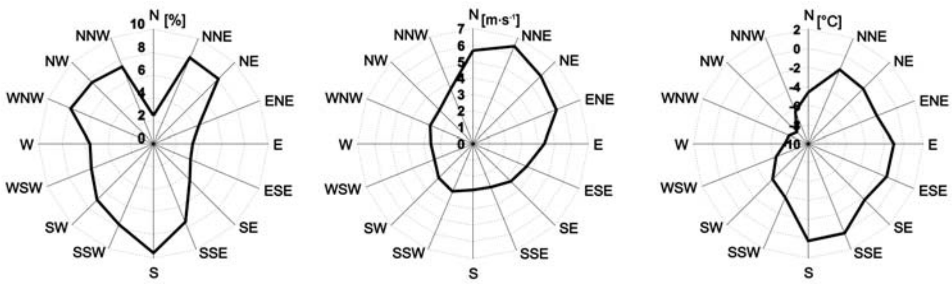

Fig. 4. Relative frequency of wind direction, mean wind speed, and 2-m air temperature, according to the airflow direction at Petuniabukta in the period from July 2009 to June 2010.

frequency of 8.1% for all cases. The highest daily mean wind speed exceeded 12.2 ms^{-1} on April 12, 2010. During this event, a low pressure system passed over Spitsbergen, which was accompanied by changes in atmospheric circulation from types Bc (April 11, 2010), Cc, and Nc to SEc (April 14, 2010). This was also reflected in sudden changes in surface wind direction, turning from westerly to northeasterly and southeasterly flows. A maximum 30-min average wind speed of 23.6 ms^{-1} was measured from the northeast on January 27, 2010. In this situation, circulation type Ec stayed over Spitsbergen until 28 January 2010, while the direction of the geostrophic wind (estimated from an ECMWF analysis) approached more to the southeast. On the other hand, daily mean wind speed was smaller than 1 ms^{-1} for 15.7% of the time between July 2009 and June 2010. The lowest monthly mean wind speed was observed in December 2009 (2.9 ms^{-1}), while the highest monthly wind speed was reached in March 2010 (5.1 ms^{-1}). These results, however, differ from the previous study of Kruszewski (2006), who estimated seasonal variation of geostrophic winds over the Spitsbergen area from 1981–2005, with the highest monthly U-wind values in June and July, while the lowest values occurred in February and March.

In general, the local winds in Petuniabukta were affected mainly by large-scale circulation. As in most fjords in Svalbard, channeling effects and katabatic flows occur in Petuniabukta as well. It is evident that local topography, together with the major driving mechanism of the land-sea breeze circulation driven by horizontal temperature differences between the open water of the fjords and the glaciers, may lead to significant differences in the surface wind pattern (Esau and Repina 2012). Therefore, along-fjord (southern) winds in Petuniabukta were the most frequent in the study period. Similar features were found during the northeasterly drainage flow from the Ragnarbreen glacier, from which the highest wind speed was recorded.

Global solar radiation. — Temporal variability of the selected meteorological elements measured at Petuniabukta from August 1, 2008 to June 30, 2010 is shown in Fig. 5 and Table 1. The seasonal variation of incoming solar radiation intensity ranged from 0 to about 380 Wm^{-2}, which can be expected from the geographic loca-

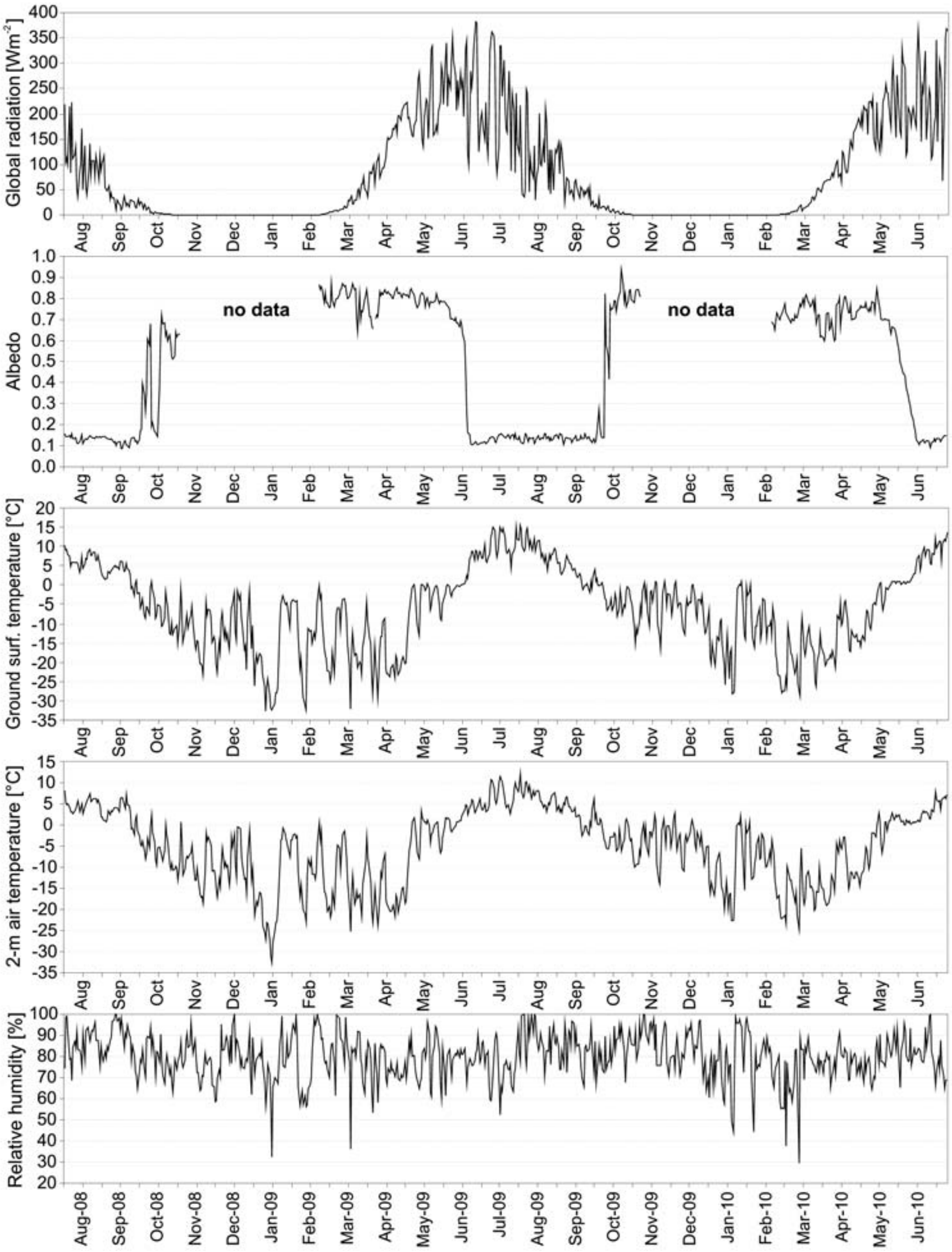

Fig. 5. Time series of daily means of global solar radiation, albedo, ground surface temperature, 2-m air temperature, and relative humidity at Petuniabukta in the period 2008–2010.

tion of the study site, and changes in solar elevation angle and the Earth–Sun distance through the year. The annual course of solar radiation intensity was modified by the phenomena of the polar day and the polar night. The polar day at Petuniabukta

Table 1

Seasonal variation of monthly means and extremes of the selected meteorological parameters at Petuniabukta in the period 2008–2010.

Month -Year	Global radiation	Albedo	Ground surface temperature			2-m air temperature			Relative humidity	Wind speed	Max wind speed
			Mean	Max	Min	Mean	Max	Min			
	[Wm^{-2}]		[°C]	[°C]	[°C]	[°C]	[°C]	[°C]	[%]	[ms^{-1}]	[ms^{-1}]
Aug-2008	108.0	0.14	6.6	18.2	-1.7	4.7	10.9	0.2	86.0	3.0	13.9
Sep-2008	31.3	0.12	2.4	9.5	-8.0	2.5	9.8	-6.2	86.6	3.8	14.5
Oct-2008	5.6	0.47	-7.3	1.5	-20.0	-6.3	4.1	-16.2	78.5	–	–
Nov-2008	0.0	–	-12.3	0.5	-25.8	-9.6	3.4	-20.6	76.7	–	–
Dec-2008	0.0	–	-11.6	0.9	-30.6	-9.6	2.9	-24.2	81.5	–	–
Jan-2009	0.0	–	-16.8	0.7	-36.2	-14.6	1.7	-33.3	78.9	–	–
Feb-2009	1.5	–	-15.8	0.7	-33.4	-12.9	3.0	-27.0	76.8	–	–
Mar-2009	33.2	0.80	-13.9	-1.8	-34.6	-12.3	0.1	-26.3	82.8	–	–
Apr-2009	150.8	0.80	-19.5	-1.8	-33.7	-17.0	-0.6	-26.9	75.1	–	–
May-2009	218.1	0.79	-3.2	1.0	-19.6	-1.4	9.1	-15.0	77.8	–	–
Jun-2009	247.2	0.38	3.5	21.0	-5.9	2.7	10.0	-4.0	79.6	–	–
Jul-2009	199.4	0.14	10.8	26.5	1.6	7.2	16.2	1.2	76.9	4.0	14.6
Aug-2009	114.5	0.14	8.2	23.5	-3.7	6.2	12.6	-0.2	86.1	3.2	13.6
Sep-2009	39.7	0.14	2.1	14.5	-5.6	1.9	9.7	-4.9	83.5	3.4	14.2
Oct-2009	4.8	0.74	-5.6	1.0	-19.5	-4.3	2.7	-13.4	84.7	3.2	14.6
Nov-2009	0.0	–	-4.0	1.0	-18.7	-3.0	4.1	-16.6	85.9	3.4	15.6
Dec-2009	0.0	–	-9.2	0.9	-24.0	-6.7	2.6	-18.3	80.7	2.8	16.0
Jan-2010	0.0	–	-11.4	1.0	-31.1	-9.8	3.5	-24.6	79.9	4.6	23.6
Feb-2010	1.7	–	-15.9	-2.4	-31.3	-12.2	-0.6	-26.6	72.8	3.2	15.7
Mar-2010	39.9	0.72	-18.2	-2.4	-30.6	-15.9	-1.5	-26.2	78.1	5.0	19.5
Apr-2010	148.3	0.74	-11.7	-1.5	-24.8	-9.5	-0.4	-19.6	78.0	4.3	16.4
May-2010	207.0	0.63	-1.2	3.2	-17.8	-0.1	7.0	-12.3	80.9	3.1	12.0
Jun-2010	240.7	0.14	7.9	23.1	-0.7	3.3	9.6	-1.0	80.4	4.0	14.2

lasts from April 17 to August 25 (131 days) and the polar night from October 26 to February 16 (114 days). Zero radiation intensity due to the actual atmospheric conditions and local topography occurred from October 31, 2008 to February 9, 2009 (101 days) and from October 30, 2009 to February 10, 2010 (103 days) respectively. The annual mean solar radiation in 2009 was 84.5 Wm^{-2}, while the maximum monthly means were recorded in July 2009 (247.2 Wm^{-2}) and June 2010 (240.7 Wm^{-2}). The maximum daily means of 381.3 Wm^{-2} and 369.0 Wm^{-2} were measured during clear sky conditions on June 21, 2009 and June 28, 2010 respectively.

Apart from the above-mentioned factors, cloudiness and its optical properties strongly modulate the intensity of solar radiation on the Earth's surface. The diurnal course of solar radiation intensity within two summer days with varied cloudiness is

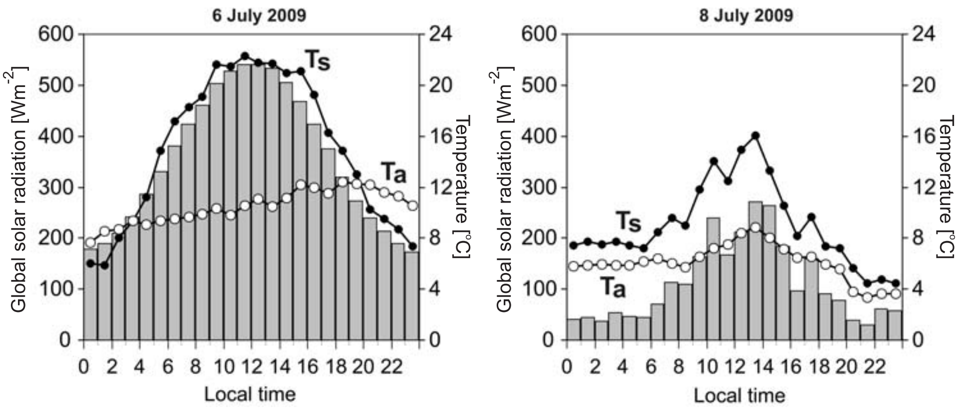

Fig. 6. Diurnal course of global solar radiation intensity (grey bars), 2-m air temperature (Ta) and ground surface temperature (Ts) at Petuniabukta on a clear sky (6 July 2009) and overcast conditions (8 July 2009).

shown in Fig. 6. Clear sky conditions on July 6, 2009 were apparent in the high intensity of incoming radiation, with a 30-min mean maximum of 541 Wm^{-2}, while an overcast sky on July 8, 2009 was pronounced in the low diurnal course with a 30-min mean maximum of 271 Wm^{-2}. High inter-diurnal and diurnal variations of solar radiation were found in the summer period (June–August). The remoteness of Petuniabukta from the nearest settlements, as well as the monitoring systems of the AWS, did not allow year-round observations of cloudiness. Therefore, cloudiness was approximately evaluated using global radiation and its attenuation by the cloud cover. As seen in Figs 5 and 6, there were inter-diurnal changes in the incoming radiative flux, which fluctuated between 90–200 Wm^{-2} per 24 hours depending on cloudiness. The effect of reduced cloudiness on solar radiation was also apparent within the spring periods, with the monthly mean values ranging between 150.8 and 218.1 Wm^{-2} (April–May 2009) and 148.3 and 207.0 Wm^{-2} (April–May 2010).

The significant dependence of solar radiation on cloudiness and prevailing weather systems (air mass origin) was also confirmed by variation coefficients calculated for April–September according to Storch and Zwiers (1999). As seen in Table 2, the variation coefficient of solar radiation gradually increased from spring to autumn 2008 and/or 2009, due to increasing cyclonic activity, cloudiness and its fast changes. Therefore, the highest coefficients of variation were 66.2% (September 2008), 122.7% (October 2008) and 107% (October 2009). During these months, there was an increase in cloudiness due to cyclonic situations represented mainly in higher frequency of the types Nc (25.8% – October 2009), NEc (12.9% – October 2008), and Ec (29.0% – October 2008). This was also confirmed by long-term average values (1970–2000), where the circulation type Ec was the most frequent in September (10.4%) and October (12.4%), while type NEc was dominant in October (10.8%). Moreover, considerably high coefficients in March 2009 (70.6%) and 2010 (61.9%)

Table 2

Seasonal variation of 2-m air temperature, ground surface temperature, global solar radiation intensity, albedo, and relative humidity expressed by the standard deviation and coefficient of variation at Petuniabukta in the period 2008–2010.

Month-Year	Standard deviation [°C]		Coefficient of variation [%]		
	Air temperature	Ground surface temperature	Global solar radiation	Albedo	Relative humidity
Aug-2008	1.5	1.8	44.3	8.8	8.7
Sep-2008	2.9	3.0	66.2	15.3	10.9
Oct-2008	3.6	3.9	122.7	41.9	9.6
Nov-2008	5.1	5.9	–	–	12.3
Dec-2008	5.5	6.2	–	–	10.4
Jan-2009	10.7	11.3	–	–	18.2
Feb-2009	6.6	8.6	–	–	18.8
Mar-2009	6.2	7.0	70.6	7.2	15.6
Apr-2009	4.5	5.3	32.3	6.4	10.9
May-2009	3.0	3.5	27.7	3.1	13.5
Jun-2009	2.3	4.3	31.0	73.8	5.9
Jul-2009	2.8	3.2	51.1	10.2	16.2
Aug-2009	2.0	3.1	50.5	10.2	9.5
Sep-2009	2.5	2.6	45.4	20.7	10.2
Oct-2009	3.0	3.5	107.0	25.5	8.7
Nov-2009	4.2	4.4	–	–	10.3
Dec-2009	5.1	6.0	–	–	12.3
Jan-2010	7.6	8.7	–	–	20.1
Feb-2010	6.5	7.7	–	–	17.2
Mar-2010	3.8	4.5	61.9	8.8	13.8
Apr-2010	3.9	4.4	34.2	7.4	7.1
May-2010	2.5	2.7	28.3	22.9	10.4
Jun-2010	2.4	3.3	36.4	31.1	11.2

were probably caused by the small solar elevation angle and biases of solar radiation measurements. On the other hand, sunny weather, with the smallest changes in cloudiness, was affected by anticyclonic situations, which prevailed in May 2009 and 2010. In these cases, the variation coefficients ranged only from 27.7 to 28.3% due to anticyclonic situations, with the highest occurrence of types Ea (16.1% – May 2010), Ka (16.1% – May 2010), and Wa (19.4% – May 2009). It is supported by the long-term average values (1970–2000), where type Ka (anticyclonic wedge), with a frequency of 17.6%, was one of the most frequent types in May. This is consistent with the findings of previous studies on solar radiation, cloudiness and the surface energy budget in the Ny-Ålesund region (Ørbæk *et al.* 1999; Przybylak and Araźny 2006). In general, the maritime climate of the Svalbard archipelago is formed by a high amount of clouds, large short-term variation in cloudiness, and the high frequency of Arctic sea fog, formed by the advection of relatively warm air over colder surfaces, predominantly in summer (Svendsen *et al.* 2002).

Albedo and snow cover occurrence. — Albedo from reflected and incoming solar radiation intensities was calculated to determine the occurrence of snow cover at the study site. Mean albedo was 0.50 in the period from August 1, 2008 to June 30, 2010. Seasonal variation of albedo was affected by the character of the ground surface (Fig. 5). Therefore, monthly mean albedo varied from 0.12 over tundra (September 2008) to 0.80 during snow accumulation (March–April 2009). Albedo over tundra vegetation in both dry and wet conditions typically ranged from 0.11 to 0.16. On the other hand, albedo of fresh snow in March and April reached up to 0.87. Analysis of the albedo was used to estimate snow cover occurrence near the study site. The first day with snow cover was frequently observed at the beginning of October, while the last day occurred in the first half of June. Permanent snow cover lasted from October 16, 2008 to June 16, 2009 (243 days) and from October 3, 2009 to June 5, 2010 (245 days). The effect of direct solar radiation and thermal advection on snow cover thawing is shown in Fig. 5. From the albedo variation and its spring decline, it was estimated that the last snow cover melted within different time periods: June 13–16, 2009 (4 days) and May 27 – June 16, 2010 (20 days). Apart from a low summer albedo (0.14), high inter-diurnal variation was found in September and October due to the first snowfalls and fast thawing of snow cover (Table 2). Due to this fact, daily mean albedo in autumn varied between 0.11 and 0.94. The snow-free period in Petuniabukta typically lasted from the first half of June to the beginning of October (120 days).

Surface ground temperature. — Surface ground temperature of the tundra vegetation was measured close to the AWS. The annual mean temperature in 2009 was -5.2°C, while monthly mean temperature ranged from -19.5°C (April 2009) to 10.8°C (July 2009). Daily mean temperature varied between -32.6°C to 15.6°C (Fig. 5 and Table 1). The lowest surface temperature of -36.2°C was observed on January 7, 2009 on the snow surface. The highest surface temperature rose to 26.5°C on July 11, 2009 due to the high intensity of incoming radiation that incidents on the dry tundra vegetation surface. These conditions occurred during an eastern advection (circulation type Ea) characterized by a clear sky and wind speed of less than 2 ms^{-1}. The diurnal course of surface temperature during two different days with different weather conditions in July 2009 is shown in Fig. 6. The typical diurnal sinusoidal behavior was found under clear sky conditions (July 6, 2009) with high intensity of solar radiation and a noon-time surface temperature reaching 22.3°C. On the contrary, a rather suppressed diurnal course, with noon-time temperature of 16°C, was caused by an overcast sky and relatively low incoming radiation (July 8, 2009). Differences in the diurnal course were mainly affected by changes in circulation conditions over the Spitsbergen area, where the type NEa (July 6, 2009) was swiftly replaced by the NWc type (July 8, 2009).

Short-term variability of the daily mean surface temperature often exceeded 20°C during winter and spring, with the highest standard deviation between 11.3°C (January 2009) and 8.7°C (January 2010). As seen in Table 2, the lowest deviation was found in August 2008 (1.9°C) and September 2009 (2.6°C). The rapid increase of surface temperature above 0°C was observed in the first half of June after intensive snow melting. The first day with a negative surface temperature occurred on September 4, 2008 and August 16, 2009, while permanent freezing of the ground surface was measured on October 10, 2008 and October 2, 2009. The dependence of surface ground temperature on the snow cover was clearly documented in positive surface temperatures, which followed after the last day with snow cover by a delay of 1–3 days.

Relative air humidity. — In the study period, mean relative humidity at 2 m above the ground surface exceeded 80%. As seen in Table 1, seasonal variation of relative humidity was relatively small, and therefore, monthly mean humidity ranged from 72.8% (February 2010) to 86.6% (September 2008). Daily mean relative humidity varied between 29.6% and 99.9% (Fig. 5). Daily mean humidity was higher than 70% in 84.1% of the study period. The highest variation of humidity and daily minimum values (less than 50%) were typically observed from the beginning of January to mid April (Table 2). On the other hand, the lowest variation occurred from June to August due to weak cyclonic activity and small inter-diurnal variation of the other meteorological parameters such as global solar radiation and 2-m air temperature. This suggests that the high frequency of Arctic sea fog formed by the advection of relatively warm (maritime) air masses over the colder surfaces of the fjords and glaciers significantly influenced the high values of relative humidity also in Petuniabukta.

Air temperature. — The monthly means and extremes of air temperature at 2 m above the ground surface are shown in Table 1. The annual mean temperature in 2009 reached -4.5°C, while monthly mean air temperature ranged from -17.0°C (April 2009) to 7.2°C (July 2009). The lowest air temperature of -33.3°C was observed on January 12, 2009. The highest air temperature rose to 16.2°C on July 28, 2009 during partly cloudy weather with a wind speed less than 4 ms^{-1}. As seen in Fig. 5, daily mean air temperature varied between -32.6°C and 12.2°C. The daily mean temperature was higher than 5°C for 51% of the time between June and August 2009. By contrast to the ground surface temperature, the diurnal course of 2-m air temperature did not tightly follow solar radiation intensity (Fig. 6). Due to this fact, the highest air temperature under clear sky conditions on July 6, 2009 was observed at 18 local time. Short-term variability of daily mean air temperature was found in winter and spring, when it often exceeded 15°C. Therefore, the highest standard deviation of air temperature occurred in January 2009 (10.7°C) and January 2010 (7.6°C). Conversely, the lowest deviation was found in August 2008 (1.5°C) and August 2009 (2.0°C).

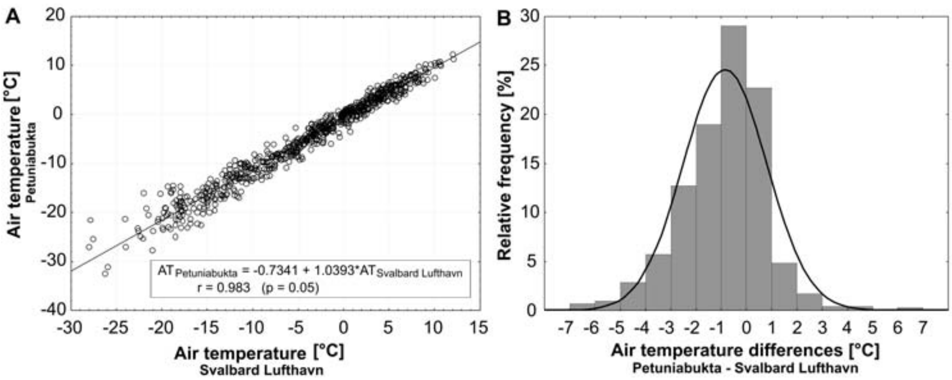

Fig. 7. **A**. Scatter plot of daily mean 2-m air temperature at Petuniabukta *versus* Svalbard Lufthavn in the period 2008–2010. Abbreviations on the graph: AT – air temperature, r – correlation coefficient, p – significance level. **B**. Relative frequency of differences of daily mean 2-m air temperatures between Petuniabukta and Svalbard Lufthavn, with the fitting of normal distribution function. Positive differences correspond to higher temperatures at Petuniabukta than in Svalbard Lufthavn and *vice versa*.

The positive surface energy balance due to the force of the solar radiation reaching the tundra vegetation strongly affected the diurnal amplitude of both ground surface and 2-m air temperatures (Fig. 6). However, the dependence of daily mean surface temperature on daily mean solar radiation was apparently weaker than between ground surface and 2-m air temperatures. The correlation coefficient varied between 0.433 (surface temperature as a function of radiation) and 0.983 (2-m air temperature as a function of surface temperature) at the significance level of 0.05. The above results were calculated for the snow-free period, from June to August in particular. Moreover, both relationships varied over time, with the highest correlations of 0.543 and 0.931 in July 2009. The seasonal variation of the correlation coefficient, therefore, clearly confirmed the essential roles of large-scale thermal advection and snow cover occurrence on air temperature variation in Petuniabukta. These results are in agreement with the previous studies of Winther *et al.* (2002), and Leszkiewicz and Caputa (2004), who carried out research in the regions of Ny-Ålesund and Hornsund, respectively.

The role of local wind at 6 m above the ground surface on the 2-m air temperature was studied in the period from July 2009 to June 2010 (Fig. 4). The highest air temperatures were primarily found in the air flow from the southeast sector. In these cases, mean air temperature varied between 0.2°C (south), -1.1°C (east), and -1.6°C (southeast). Furthermore, relatively warm air flow exceeding -1.9°C was documented from the northeast. This feature suggests a significant influence of large-scale circulation, through which mild maritime air masses come along the longitudinal axis of the Billefjorden, Ragnardalen, and Ebbadalen valleys. These conditions frequently occurred during cyclonic circulation linked to types Ec, SEc and NEc. Considerably cold air flow was recorded from the southwest to northwest sectors. The lowest mean temperature (-8.4°C) was found during a north-

Table 3

Seasonal variation of monthly means and extremes of 2-m air temperature differences between Petuniabukta and Svalbard Lufthavn in the period 2008–2010.

Month-Year	Air temperature difference			Standard deviation	Monthly correlation coefficient
	Mean	Min	Max		
	[°C]	[°C]	[°C]	[°C]	
Aug-2008	-0.3	-3.0	1.5	1.2	0.67
Sep-2008	-0.8	-2.7	0.7	0.8	0.97
Oct-2008	-0.7	-3.5	2.0	1.3	0.94
Nov-2008	-1.0	-3.2	1.3	1.2	0.97
Dec-2008	-1.5	-5.0	2.3	1.7	0.95
Jan-2009	-1.9	-7.0	5.8	3.0	0.96
Feb-2009	-1.6	-4.7	1.1	1.5	0.97
Mar-2009	-0.7	-4.8	6.2	2.2	0.94
Apr-2009	-1.2	-4.0	2.9	1.6	0.94
May-2009	-0.3	-2.6	1.7	0.8	0.96
Jun-2009	-0.3	-2.6	1.9	1.1	0.88
Jul-2009	-0.5	-2.4	1.7	1.2	0.90
Aug-2009	-0.1	-2.8	2.6	1.0	0.86
Sep-2009	0.2	-2.0	1.7	0.8	0.94
Oct-2009	-0.7	-4.0	2.7	1.6	0.84
Nov-2009	-1.1	-4.7	1.2	1.3	0.95
Dec-2009	-1.2	-3.8	1.1	1.0	0.98
Jan-2010	-2.5	-6.7	0.3	1.7	0.98
Feb-2010	-1.8	-6.5	1.8	1.9	0.97
Mar-2010	-0.1	-4.6	4.9	2.6	0.77
Apr-2010	-1.8	-4.5	0.6	1.3	0.94
May-2010	-0.1	-2.0	1.1	0.8	0.94
Jun-2010	-0.3	-2.2	2.2	0.9	0.93

westerly wind, while winds from the southwest to west caused the temperature to drop to -4.7°C and -7.6°C, respectively. This is also consistent with a gradual increase in geostrophic winds from the northern and western sectors and high frequency of the circulation types Nc (9.7% – January 2009), NWc (9.7% – January 2009), and SWc (22.6% – January 2010) during winter.

Comparison of air temperature between Petuniabukta and Svalbard Lufthavn. — In order to evaluate the differences in weather conditions between Petuniabukta and the nearest all-year round operating AWS (Svalbard Lufthavn), 2-m air temperature differences were calculated for the study period. Hereafter, positive differences correspond to higher temperatures at Petuniabukta, while negative differences indicate a higher temperature at the Svalbard Lufthavn station. As seen in Fig. 7 and Table 3, thermal differences confirmed the similar features of the local weather conditions between both sites. The mean temperature difference was -0.9°C from August 1, 2008 to June 30, 2010. The monthly mean differences ranged from -2.5 (January 2010) to 0.4°C (July 2010). The occurrence of positive daily mean differences was significantly smaller than negative ones (Fig. 7). Due to this fact, daily mean temperature at Svalbard Lufthavn was higher than that in Petuniabukta (negative thermal differences) in 69.2% of the period. Conversely, positive thermal differences, ranging from 0–1°C, occurred in 22.1% of the period. The highest negative daily mean difference was observed in January, while the highest positive ones in March. Seasonal variation of the thermal differences was expressed by standard deviation and the correlation coefficient between 2-m air temperatures at Petuniabukta and Svalbard Lufthavn. From Table 3, it is apparent that the closest relationship between both time series occurred in winter and spring (November–May), with correlation coefficients of 0.96 (2009) and 0.93 (2010) at the significance level of 0.05. On the other hand, the highest negative differences and standard deviations were found in the same period. The highest standard deviations were reported in January 2009 (3.0°C) and March 2010 (2.6°C). A slightly weaker connection was found in summer, with a correlation coefficient of 0.88 (June–August 2009). In spite of this fact, small standard deviations (interval of 1.0–1.2°C) and thermal differences, ranging from -0.3 to -0.1°C, were observed in the same period. Similar findings were previously reported by Rachlewicz and Styszyńska (2007) who compared air temperatures between Petuniabukta and Svalbard Lufthavn in the period from July 7, 2001 to August 13, 2003.

Seasonal variation of the thermal differences could be partly explained by both the effects of large-scale advection and the effects of local topography (*e.g.* blocking effect of the mountains, drainage effect of the fjords), character of the ground surface and their consequences on cloudiness variation and surface energy fluxes. This suggests that the local wind pattern, which is controlled by thermodynamical processes during advection of different air masses (large-scale weather systems), may also lead to thermal differences at the ground surface. Therefore, the highest negative thermal differences occurred during light winds from the western quadrant and strong radiative cooling of the snow/ice surface. Less often, the highest negative differences were observed for the northern and eastern sectors. Hence, the highest negative differences (less than -5.0°C) occurred only in January and February, when 2-m air temperatures at Petuniabukta dropped below -22°C. In these cases, local weather conditions were affected by the northerly and northwesterly geostrophic flows linked to circulation types NWa, with a thermal difference of -6.8°C (January 12, 2010), Nc and NWc, with differences of -6.3 and -6.5°C, respectively (January 12–14, 2009). Conversely, positive differences were observed during northeasterly drainage flow from the Ragnarbreen and Ebbabreen glaciers and southerly flow along the longitudinal axis of Billefjorden and Petuniabukta in particular. In these situations, the local weather conditions at both sites were affected by circulation type Ec, with a positive thermal difference of 6.3°C (March 24, 2009) and type NEa with the difference reaching up to 6.0°C (January 2, 2009). During these events, 2-m air temperatures at Svalbard Lufthavn dropped below -20°C, probably due to the different orientation of the fjord axis and gradual deceleration of the movement of the cold air mass into the inner parts of the fjords and the coastal zones.

Apart from the above-mentioned results, we found that in many cases the temperature differences between both sites can be affected by the sea ice conditions in Isfjorden and Petuniabukta in particular. High resolution sea ice charts of the Svalbard area were used for the comparison and evaluation of these effects. Data on sea ice extent indicate that Petuniabukta was mainly covered with fast ice or open drift ice (ice concentration between 1/10 and 4/10), which usually begin to form from October to December, but due to strong winds and high waves was broken up and often disappeared. The inner parts of Billefjorden and Petuniabukta were completely covered by sea ice mostly from January to June. In the study period, sea ice formation (open drift ice) started in Petuniabukta on November 3, 2008 (October 2, 2009), while the middle part of Isfjorden (near the Svalbard Lufthavn station) was covered by sea ice from December 12, 2008 (November, 24, 2009). Petuniabukta was completely covered with fast ice or closed drift ice (ice concentration more than 7/10) from January 2, 2009 (January 10, 2010) to June 11, 2009 (June 22, 2010). In the same period, open drift ice mostly occurred in the middle part of Isfjorden with a high variable of ice concentration between 1/10 and 7/10. In addition, ice-free situations appeared in this area, *e.g.* on January 19–22, 2009, January 12, 2010 and from March 12 to April 6, 2010. Hence, the negative thermal differences (higher temperature at Svalbard Lufthavn station) from -1.5°C to -6.8°C frequently occurred when the sea ice conditions significantly differed between both sites. This was also the situation on January 12–14, 2009 and January 12, 2010, with fast ice in Petuniabukta and open water (or open drift ice) in the middle part of Isfjorden. On the other hand, thermal differences higher than -1.4°C were affected by both the particular sea ice extent and the effects of large-scale circulations.

Conclusions

In this paper, we have provided the first analysis and results of the fundamental meteorological parameters measured at Petuniabukta in the period from August 2008 to June 2010. It has been shown that weather conditions in the central part of Spitsbergen were significantly influenced by atmospheric circulation, cloudiness, local topography, and sea ice extent. The results must be treated with caution due to the fact that several factors, such as air pressure variation and precipitation, were not considered. In general, our results confirm that synoptic-scale weather systems, character of the ground surface and air-sea temperature differences play major roles in forming local weather patterns at Petuniabukta. The influence of atmospheric circulation and local wind conditions were clearly pronounced in the variations of air temperature and surface wind speed. The highest air temperatures, ranging from 0.2°C to -1.9°C, were primarily found when winds were from the eastern and southern quadrants, associated with predominantly cyclonic circulations (Ec, SEc and NEc types). These large-scale flows were often modified by channelling and drainage effects accompanied by an increase in local wind speed. Therefore, strong katabatic winds in Petuniabukta were documented from the northeast and east towards the Ragnarbreen and Ebbabreen glaciers. Such a wind mainly occurred in autumn and winter, associated with circulation types Nc, NEc, Ec and Ea. In spite of this fact, the lowest air temperature was observed during a flow from the western quadrant with a mean wind speed of less than 3 ms^{-1}. The occurrence of relatively cold air in Petuniabukta can be explained by a combination of several factors: (1) a blocking effect of the mountains along the north-western coast of Petuniabukta, (2) strong transformation and a long fetch of the flow over these mountains, and (3) strong radiative cooling of the airflow from the snow and sea ice surface. A considerable close relationship between the ground surface and 2-m air temperatures was primarily reported during summer than winter. Furthermore, thermal differences between Petuniabukta and Svalbard Lufthavn confirmed that local weather conditions differ significantly between these sites, with sea ice cover in the fjords, advection of air masses from different directions, and the area of origin playing essential roles. The highest thermal differences between the sites were mainly affected by differences in sea ice concentrations and ice types in Petuniabukta in contrast to the middle part of Isfjorden close to the Svalbard Lufthavn station.

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References

BARANOWSKI S. and GŁOWICKI B. 1975. Meteorological and hydrological investigations in the Hornsund region made in 1970. *Acta Universitatis Wratislaviensis* 251: 35–39.

BARRY R.B. 2008. *Mountain Weather and Climate*. Cambridge University Press, Cambridge: 506 pp.

BEDNORZ E. and KOLENDOWICZ L. 2010. Summer 2009 thermal and bioclimatic conditions in Ebba Valley, central Spitsbergen. *Polish Polar Research* 31 (4): 327–348.

BRÁZDIL R. 1988. Variation of air temperature and atmospheric precipitation in the region of Svalbard. *In*: R. Brázdil (eds) *Results of Investigations of the Geographical Research Expedition Spitsbergen 1985*. J.E. Purkyne University, Brno: 187–210.

BRÁZDIL R., PROŠEK P., PACZOS S. and SIWEK K. 1991. Comparison of meteorological conditions in Calypsobyen and Reindalen in summer 1990. *Wyprawy Geograficzne na Spitsbergen*. UMCS, Lublin: 57–76.

ESAU I. and REPINA I. 2012. Wind climate in Kongsfjorden, Svalbard, and attribution of leading wind driving mechanisms through turbulence-resolving simulations. *Advances in Meteorology* 2012, Article ID 568454: 1–16.

FØRLAND E.J. and HANSSEN-BAUER I. 2003. Past and future climate variations in the Norwegian Arctic: overview and novel analyses. *Polar Research* 22: 113–124.

HANSSEN-BAUER I., SOLÚS M.K. and STEFFENSEN E.L. 1990. The Climate of Spitsbergen. *DNMI Rep. 39/90 Klima*: 40 pp.

KEJNA M. and DZIENISZEWSKI M. 1993. Meteorological conditions on the Kaffiöyra Plain (NW Spitsbergen) from 26th June to 31st August 1985. *Acta Universitatis Nicolai Copernici. Geografia* 24: 43–54 (in Polish).

KILPELÄINEN T., VIHMA T. and ÓLAFSSON H. 2011. Modelling of spatial variability and topographic effects over Arctic fjords in Svalbard. *Tellus A* 63 (2): 223–237.

KNUTSON T.R., DELWORTH T.L., DIXON K.W., HELD I.M., LU J., RAMASWAMY V., SCHWARZKOPF M.D., STENCHIKOV G. and STOUFFER R.J. 2006. Assessment of twentieth-century regional surface temperature trends using the GFDL CM2 coupled models. *Journal of Climate* 19 (9): 1624–1651.

KOSIBA A. 1960. Some of results of glaciological investigations in SW-Spitsbergen carried out during the Polish I.G.Y. Spitsbergen expeditions in 1957, 1958 and 1959. *Zeszyty Naukowe, Nauki Przyrodnicze, Uniwersytet Wrocławski im. Bolesława Bieruta, Ser. B* 4: 29 pp.

KOSTRZEWSKI A., KANIECKI A., KAPUŚCIŃSKI J., KLIMCZAK R., STACH A. and ZWOLIŃSKI Z. 1989. The dynamics and rate of denudation of glaciated and non-glaciated catchments, central Spitsbergen. *Polish Polar Research* 10 (3): 317–367.

KRUSZEWSKI G. 2006. The changes of zonal wind speed component (U-wind) at the West Spitsbergen area (1981–2005). *Problemy Klimatologii Polarnej* 16: 107–114 (in Polish).

LÁSKA K., WITOSZOVÁ D. and PROŠEK P. 2010. Climate Conditions of the Permafrost Active Layer Development in Petuniabukta, Billefjorden, Spitsbergen. *In*: J.R. Mertes, H.H. Christiansen and B. Etzelmüller (eds.) *Thermal State of Frozen Ground in a Changing Climate During the IPY*, Longyearbyen: 128–128.

LESZKIEWICZ J. and CAPUTA Z. 2004. The thermal condition of the active layer in the permafrost at Hornsund, Spitsbergen. *Polish Polar Research* 25 (3–4): 223–239.

MARSZ A. 2007. Air temperature. *In:* A. Marsz, A. Styszyńska (eds) *Klimat rejonu Polskiej Stacji Polarnej w Hornsundzie*. Wydawnictwo Akademii Morskiej w Gdyni: 131–174 (in Polish).

MÄKIRANTA E., VIHMA T., SJÖBLOM A. and TASTULA E.M. 2011. Observations and modelling of the atmospheric boundary layer over sea-ice in a Svalbard fjord. *Boundary-Layer Meteorology* 140 (1): 105–123.

MIGAŁA K., NASIÓŁKOWSKI T. and PEREYMA J. 2008. Topoclimatic conditions in the Hornsund area (SW Spitsbergen) during the ablation season 2005. *Polish Polar Research* 29 (1): 73–91.

MILLER G.H., BRIGHAM-GRETTE J., ALLEY R.B., ANDERSON L., BAUCH H.A., DOUGLAS M.S.V., EDWARDS M.E., ELIAS S.A., FINNEY B.P., FITZPATRICK J.J., FUNDER S.V., HERBERT T.D., HINZMAN L.D., KAUFMAN D.S., MACDONALD G.M., POLYAK L., ROBOCK A., SERREZE M.C., SMOL J.P., SPIELHAGEN R., WHITE J.W.C., WOLFE A.P. and WOLFF E.W. 2010. Temperature and precipitation history of the Arctic. *Quaternary Science Reviews* 29 (15–16): 1679–1715.

MOREAU M., LAFFLY D. and BROSSARD T. 2009. Recent spatial development of Svalbard strandflat vegetation over a period of 31 year. *Polar Research* 28: 364–375.

NIEDŹWIEDŹ T. 2007. Atmospheric circulation. *In:* A. Marsz and A. Styszyńska (eds) *Klimat rejonu Polskiej Stacji Polarnej w Hornsundzie*. Wydawnictwo Akademii Morskiej w Gdyni: 45–64 (in Polish).

NIEDŹWIEDŹ T. 2012. The calendar of atmospheric circulation types for Spitsbergen, a computer file, University of Silesia, Department of Climatology, Sosnowiec, Poland. http://klimat.wnoz.us.edu.pl/osoby/tn/Spitsbergen.zip

NILSEN F., COTTIER F.R., SKOGSETH R. and MATTSSON S. 2008. Fjord-shelf exchanges controlled by ice and brine production: The interannual variation of Atlantic Water in Isfjorden, Svalbard. *Continental Shelf Research* 28 (14): 1838–1853.

ØRBÆK J.B., HISDAL V. and SVAASAND L.E. 1999. Radiation climate variability in Svalbard: surface and satellite observations. *Polar Research* 18 (2): 127–134.

PEREYMA J. and PIASECKI J. 1988. Topoclimatic and hydrological conditions in the Werenskiold Glacier region Spitsbergen in the summer-autumn season of 1983. *In:* Wyprawy Polarne Uniwersytetu Śląskiego 1980–1984. *Prace Naukowe Uniwersytetu Śląskiego* 910: 107–122 (in Polish).

PRACH K., KLIMEŠOVÁ J., KOŠNAR J., REDCHENKO O. and HAIS M. 2012. Variability of contemporary vegetation around Petuniabukta, central Spitsbergen. *Polish Polar Research* 33 (4): 383–394.

PRZYBYLAK R. 1992. Spatial differentiation of air temperature and relative humidity on the western coast of Spitsbergen in 1979–1983. *Polish Polar Research* 13 (2): 113–130.

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: 587–614.

PRZYBYLAK R. and ARAŹNY A. 2006. Climatic conditions of the north-western part of Oscar II Land (Spitsbergen) in the period between 1975 and 2000. *Polish Polar Research* 27 (2): 133–152.

PRZYBYLAK R. and DZIERŻAWSKI J. 2004. Thermal and humidity relations in Treurenberg Bay and Massif Olimp (NE Spitsbergen) From 1st August 1899 to 15th August 1900. *Problemy Klimatologii Polarnej* 14: 133–147 (in Polish).

RACHLEWICZ G. 2003. Meteorological conditions in the Petunia Bay (central Spitsbergen) in summer seasons 2000–2001. *Problemy Klimatologii Polarnej* 13: 127–138 (in Polish).

RACHLEWICZ G. and STYSZYŃSKA A. 2007. Comparison of the air temperature course in Petunia Bukta and Svalbard-Lufthavn (Isfjord, West Spitsbergen). *Problemy Klimatologii Polarnej* 17: 121–134 (in Polish).

RACHLEWICZ G. and SZCZUCIŃSKI W. 2008. Changes in thermal structure of permafrost active layer in a dry polar climate, Petuniabukta, Svalbard. *Polish Polar Research* 29 (3): 261–278.

SERREZE M.C., BOX R.G., BARRY R.G. and WALSH J.E. 1993. Characteristics of Arctic synoptic activity. *Meteorology and Atmospheric Physics* 51 (3): 147–164.

STATISTICA 2011. STATISTICA software. Available online at: http://www.statsoft.com/products/statistica-product-catalog/ and http://www.statsoft.com/textbook/ (accessed 25 August 2011).

STORCH H. and ZWIERS F. 1999. *Statistical Analysis in Climate Research.* Cambridge University Press: 496 pp.

SVENDSEN H., BESZCZYNSKA-MØLLER A, HAGEN J.O., LEFAUCONNIER B., TVERBERG V., GERLAND S., ORBÆK J.B., BISCHOF K., PAPUCCI C., ZAJĄCZKOWSKI M., AZZOLINI R., BRULAND O., WIENCKE CH., WINTHER J.G. and DALLMANN W. 2002. The physical environment of Kongsfjorden–Krossfjorden, an Arctic fjord system in Svalbard. *Polar Research* 21 (1): 133–166.

WINTHER J.G., GODTLIEBSEN F., GERLAND S. and ISACHSEN P.E. 2002. Surface albedo in Ny-Ålesund, Svalbard: variability and trends during 1981–1997. *Global and Planety Change* 32 (2): 127–139.

ZIAJA W. 2005. Response of the Nordenskiöld Land (Spitsbergen) glaciers Grumantbreen, Håbergbreen and Dryadbreen to the climate warming after the Little Ice Age. *Annals of Glaciology* 42 (1): 189–195.

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