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GROUND TEMPERATURE AT THE HENRYK ARCTOWSKI STATION (KING GEORGE ISLAND, ANTARCTIC) – CASE STUDY FROM THE PERIOD JANUARY 2012 TO FEBRUARY 2013

Abstract: The article presents the results of measurements of ground temperature in the context of general meteorological conditions at the Henryk Arctowski Station (King George Island, South Shetland Islands, Antarctic) from the period of 20 January 2013 to 22 February 2013. The measurements were taken using a Vantage Pro+ automatic weather station and the thermal conditions of the ground were measured by means of a HOBO automatic data logger. The variability of ground temperature was analysed in an annual and diurnal cycle. A clear recurrent diurnal pattern was observed in the summer season, resulting from more favourable insolation conditions in that part of the year. In the winter, on the other hand, no major differences in the diurnal cycle of ground temperature were found, particularly with a dense snow cover.

Key words: ground temperature, climate, H. Arctowski Station, King George Island, the Antarctic.

Introduction

The temperature of the ground is affected by the amount of incoming solar energy, which alters as the Sun changes its height over the horizon. The amount of solar energy the ground receives also depends on advections of air masses, changes in the cloud cover, atmospheric precipitation, evaporation, albedo, and the extent of vegetation and snow cover (Washborn 1979), as well as on thermal and humidity conditions of the ground and its exposure in relation to the directions of the world. In polar regions, thermal conditions of the ground are also influenced by the depth of permafrost (Baranowski 1968).

There is little background literature concerning ground temperatures at the H. Arctowski Station. Full year data series have been presented in a few articles only. A detailed analysis was presented by Kruszewski (1998) for the year 1995 and Kejna and Láska (1997) for 1996. Besides, there are brief mentions of ground temperature in works dealing with general weather conditions in the area of the H. Arctowski Station or in descriptions of these for summer seasons (Kratke, Wielbińska 1981; Cygan 1981; Prošek et al. 1996; Kejna, Láska 1999; Kejna 2008a; Kejna et al. 2012). A comprehensive overview for 13 selected years from the period 1978–1998 was made by Zwolska and Rakusa-Suszczewski (2002), and by Kruszewski (2000) for the years 1990–1997.

The purpose of this article is to analyse the variability of thermal conditions of the ground at the H. Arctowski Station and to compare them with previously obtained data series. The study is important in the context of substantial climatic changes that have been occurring in recent decades on King George Island (Marsz, Rakusa-Suszczewski 1987; Kejna 1999a, b, 2003; Ferron et al. 2004; Angiel et al. 2010; Kejna et al. 2013) and in the entire west coast of the Antarctic Peninsula (Domack et al. 2003; King et al. 2003; Vaughan et al. 2003; Kejna 2008b; Šťastná 2010).

Location and methodology of measurements

The Henryk Arctowski Polish Antarctic Station is situated on the west coast of Admiralty Bay, on King George Island (South Shetland Islands, Antarctic) (Photo. 1). Observations were carried out in the north of the Site of Special Scientific Interest No. 8 (currently the Antarctic Specially Managed Area

No. 128). The SSSI No. 8 was established in 1979, at the request of Poland, due to the unique diversity of the fauna and flora, characteristic of the maritime ecosystem (Rakusa-Suszczewski 2003).

Meteorological measurements were conducted on the meteorological site of the H. Arctowski Station. The geographic coordinates of the site are as follows: latitude 62°09’33.0”S, longitude 58°28’05.9”S, and elevation 3 m a.s.l. The measurements were taken by means of a Davis Vantage Pro+ automatic weather station (Photo. 2), while thermal conditions of the ground were recorded by means of HOBO automatic loggers at a depth of 5, 20, 50 and 70 cm. Values of basic meteorological elements and ground temperature were recorded at one hour intervals. The site for measuring thermal conditions of the ground down to 90 cm b.g.l. is composed of sand and gravel formations with pebbles and clay soils underneath (Kruszewski 2000). The ground is heavily saturated with water throughout the year and frequently inundated or flooded by melt water, or even sea water during heavy storms. The surface is covered with sparse tundra vegetation, plants, lichens and mosses (Olech 2002; 2010).

Photo. 1. The Henryk Arctowski Polish Antarctic Station (photo by A. Araźny, February 2013)

In the area of the South Shetlands, western atmospheric circulation prevails, from which the station is sheltered by the dome of the Arctowski Glacier, over 650 m high (Marsz, Rakusa-Suszczewski 1987). An undisturbed flow of air is possible there only from the SE direction, along Admiralty Bay. The non-glaciated oasis of Point Thomas, where the station is located, forms a peculiar, specific, milder topoclimate (Kejna 2000).

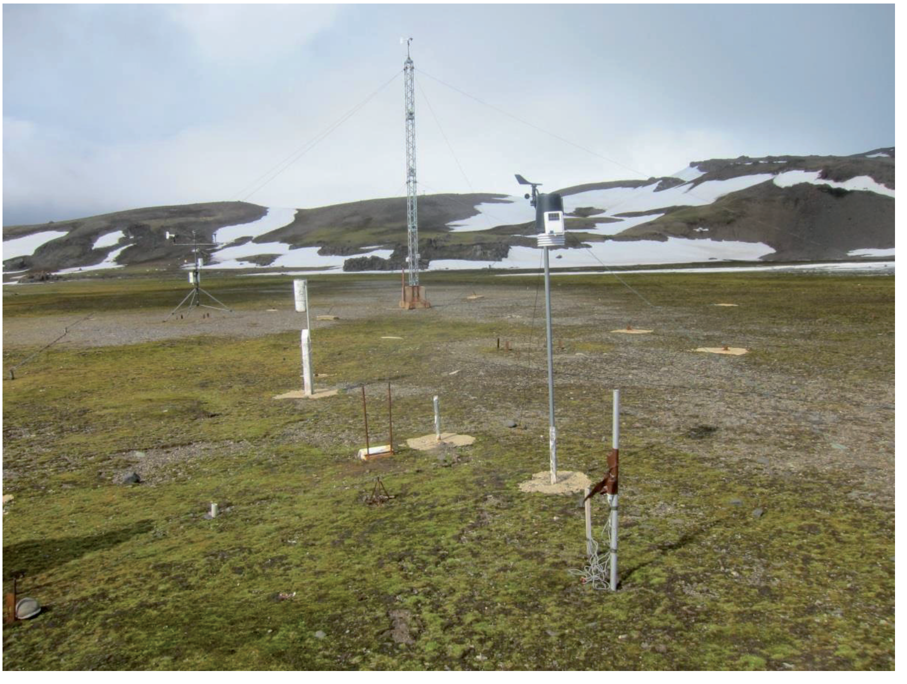

Photo. 2. The meteorological site at the H. Arctowski Station (photo by A. Araźny, January 2013)

Meteorological conditions

Thermal conditions of the ground depend on the thermal balance of its surface. The most important component of the balance is the solar radiation balance. The amount of incoming solar radiation at the H. Arctowski Station is astronomically determined (by the position of the Sun over the horizon and the length of day) and modified by atmospheric factors that restrict the irradiance (i.e. cloudiness, atmospheric phenomena increasing the optical mass of the atmosphere, and atmospheric extinction of solar radiation). At the

H. Arctowski Station the length of day (at 62°10'S) ranges from 4 hours and 57 minutes on 22 June to 19 hours and 42 minutes on 22 December. The solar altitude at the time of its culmination changes from 4 degrees on the day of the winter solstice (22 June) to 51 degrees during the summer solstice (22 December) (Marsz, Styszyńska 2000).

In 2012 (from 19 January to 31 December) 2,985.3 MJ·m^2 (8.60 MJ·m^2·day) reached the surface of the ground in the area of Admiralty Bay (Table 1). The greatest monthly sums were recorded in December 2012, reaching 567.8 MJ·m^2 (18.3 MJ·m^2·day), and the lowest – 10.4 MJ·m^2 (0.4 MJ·m^2·day) – in June. The greatest daily sums of solar radiation in November, December and January exceeded 25–30 MJ·m^2, e.g. on 15 December 2012 reaching 33.4 MJ·m^2. In June and July, on the other hand, these values did not exceed 1 MJ·m^2 per day.

The area of the South Shetland Islands is characterised by the mildest thermal conditions in the Antarctic (Kejna 2008), which results from a considerable oceanity of the climate there (Styszyńska 1995). The course of air temperature is distinguished by a substantial day-to-day and year-over-year variability, which depends on the atmospheric circulation and the type of inflowing air masses. In 2012, the air temperature at the H. Arctowski Station averaged at -1.5°C (Table 1), with the highest monthly mean occurring in January (2.4°C), and the lowest in June (-5.6°C). In the Antarctic summer the weather was more stable, whereas in the winter season dramatic rises and drops in temperature occurred, exceeding 10°C/day. The highest daily mean temperature was recorded on 2 March (6.2°C), and the lowest on 10 June (-15.2°C). On the same dates the highest (9.6°C) and the lowest (-17.2°C) air temperatures of the whole analysed period were measured (Fig. 1).

The relative humidity of the air in the area of the H. Arctowski Station is high due to the prevalence of maritime air masses. In 2012, the mean relative humidity was 83% (Table 1). In the annual course, the relative humidity was lower in the summer months (January 78.0%, February 78.7%, December 78.9%) than in the cold half of the year (July 87.4%, May 86.9%, August 86.7%).

Table 1. Monthly values of meteorological elements at the H. Arctowski Station in the period from 1 January 2012 to 22 February 2013

Month	SR($MJ \cdot m^{-2}$)	Ti(°C)	Tmax abs(°C)	Tmin abs(°C)	f (%)	$V^{\#}$ ($m \cdot s^{-1}$)	Smax [cm]
Jan 2012	476.7**	2.4	6.4	-1.0	78.0	3.9**	
Feb 2012	415.2	2.0	7.1	-5.0	78.7	4.5	2
Mar 2012	257.7	2.1	9.6	-3.9	82.6	4.5	2
Apr 2012	89.0	-2.9	5.7	-12.6	86.4	5.5	5
May 2012	25.1	-1.6	5.3	-13.1	86.9	4.2	21
Jun 2012	10.4	-5.6	2.6	-17.2	84.8	6.1	18
Jul 2012	22.2	-4.9	3.9	-17.0	87.4	4.1	50
Aug 2012	75.3	-3.2	6.3	-14.9	86.7	5.7	58
Sep 2012	234.1	-4.1	7.3	-15.6	85.4	5.9	37
Oct 2012	343.5	-2.2	7.7	-12.1	82.5	5.6	54
Nov 2012	468.4	-0.3	6.3	-6.2	82.1	4.6	22
Dec 2012	567.8	0.2	3.8	-4.3	78.9	3.1	3
2012	2985.3***	-1.5	9.6	-17.2	83.4	4.8	58
Jan 2013	401.0	1.9	8.0	-1.3	85.9	4.5	7
Feb 2013****	278.4	2.3	6.9	-4.1	85.3	4.2	2

Explanations: SR – totals of the global radiation, T – air temperature, f – relative humidity; V – wind speed; S max – maximum depth of snow cover [cm]; #at 2 m a.s.l.; ** – 19-31 January, *** – in the period from 19 January to 31 December; **** – 1–22 February

The direction and speed of wind at the H. Arctowski Station are shaped by macrosynoptic factors (the location of baric Highs and Lows, and a horizontal pressure gradient) and local constituents, connected with the passage of the air modified by the orography of King George Island. In 2012, the most frequent directions of winds at the H. Arctowski Station were SW (19.7%), WSW (13.0%) and E (9.5%). These directions stem from the prevailing western flow of air masses and the local orography of the

Admiralty Bay area. The average wind speed at the H. Arctowski Station, measured at a height of 2 m a.g.l., reached 4.8 $m \cdot s^{-1}$ in 2012. The highest speed of wind occurred in June (6.1 $m \cdot s^{-1}$) and September (5.9 $m \cdot s^{-1}$), and the lightest winds were observed in December (3.1 $m \cdot s^{-1}$) and January (3.9 $m \cdot s^{-1}$) – Table 1. Mean diurnal values of the wind speed reached 13.1 $m \cdot s^{-1}$ (17 August), and the highest wind speeds exceeded 40 $m \cdot s^{-1}$ in September and November 2012 (Fig. 1).

The snow cover (Table 1, Fig. 1) is an important factor insulating the ground surface in the winter season. Snowfalls or sleet occurred in every month. A constant snow cover did not form until mid-May. Most of the snow was penetrated and redeployed by high winds. The maximum thickness of the snow cover (58 cm) was measured on 12 and 13 August, and a snow layer of ≥ 25 cm was lying for 93 days (from 25 July until 25 October). The modest thickness of the snow cover and high winds inducing an intensively turbulent heat exchange with the surface result in a decrease in the insulating properties of snow in the process of winter chilling of the ground in tundra areas (Migała 1994).

Results of the ground temperature measurements

The annual course of ground temperature

In the analysed period (20 January 2012–22 February 2013), the ground temperature across the whole layer (5–70 cm) was uniform and remained at approx. 0.4°C (Table 2) while the mean temperature of the air was -1.2°C. The annual course of the mean ground temperature at a depth of 5 cm reveals considerable conformity with the diurnal course of air temperature (Figs 1 and 2). It is noteworthy that the ground temperature on the surface is always higher than the air temperature. The greatest differences were observed in September and October (4.0°C and 2.2°C, respectively). The near-surface ground temperature and the air temperature were the least diverse in November and March (0.3°C and 0.4°C, respectively).

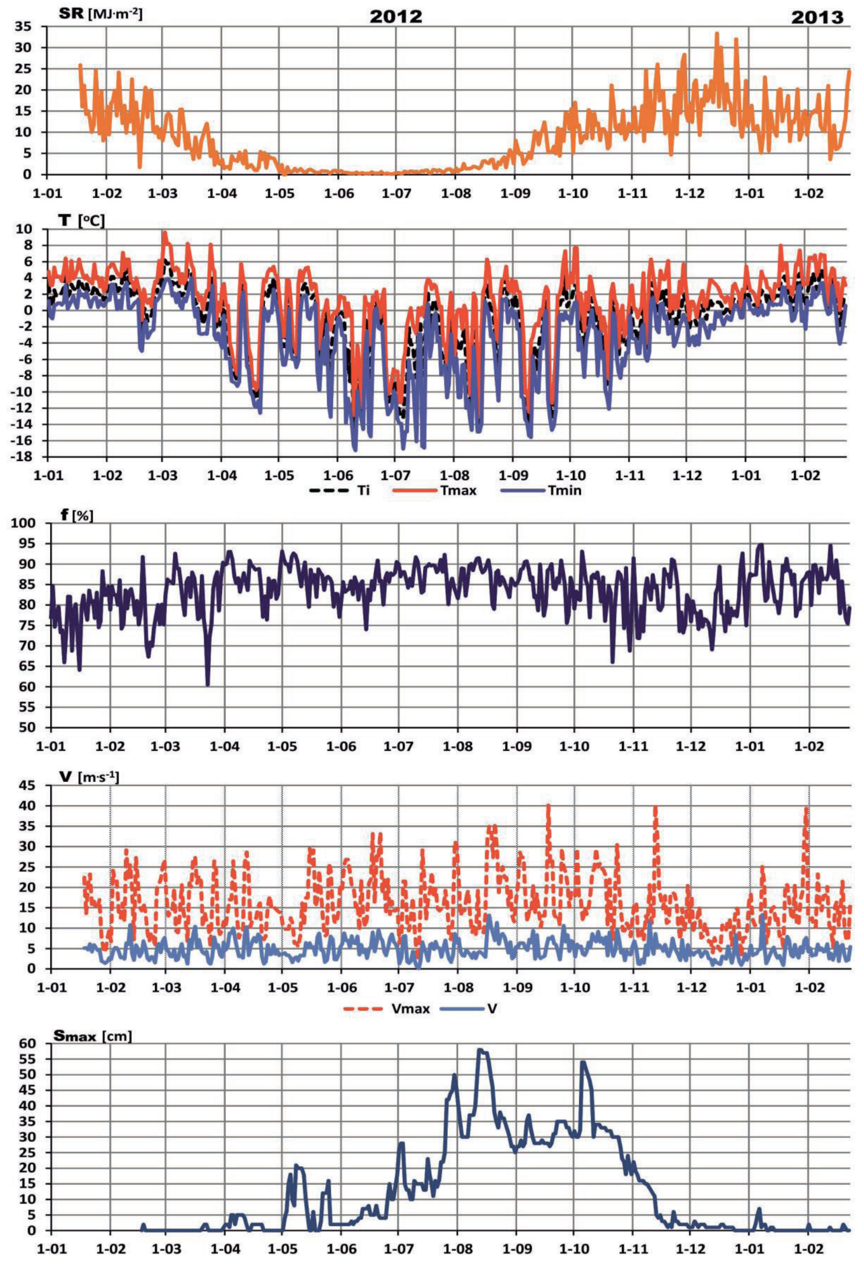

Fig. 1. Courses of selected meteorological elements at the H. Arctowski Station in the period from 1 January 2012 to 22 February 2013. For the legend see Table 1.

In the near-surface layer of the ground (5 cm) the highest mean monthly temperatures occurred in January and February (above 3°C) – Table 2. Long-term observation data (1990–1997) indicate that the highest (7.0°C) mean temperature of the ground at this depth in the summer season was recorded in January (Kruszewski 2000). Positive temperatures across the whole profile occurred from January until March 2012 and in February 2013. (Table 2, Fig. 2). In the summer, the deeper layers reach relatively high temperatures, which may reflect a good thermal conductivity of the ground, connected with its rich saturation with water. The ground began to freeze at the depth of 5 cm on 22 March 2012.

Table 2. Mean monthly values of ground temperature (°C) at the H. Arctowski Station in the period from 20 January 2012 to 22 February 2013

Year	Month	Depth of ground temperature			
		5 cm	20 cm	50 cm	70 cm
2012	Jan*	4.8	4.6	3.6	2.8
	Feb	3.8	3.6	3.3	3.0
	Mar	2.5	2.6	2.7	2.6
	Apr	-1.4	-0.6	0.3	0.5
	May	-0.7	-0.6	0.0	0.1
	Jun	-4.5	-3.7	-1.6	-0.5
	Jul	-3.3	-3.2	-2.4	-1.9
	Aug	-1.4	-1.5	-1.4	-1.3
	Sep	-0.1	-0.3	-0.3	-0.3
	Oct	0.0	-0.2	-0.2	-0.2
	Nov	0.0	-0.2	-0.1	-0.2
	Dec	1.0	0.2	-0.1	-0.2
2013	Jan	3.2	2.3	0.3	-0.1
	Feb**	3.8	3.0	1.6	0.5
20 Jan 2012-22 Feb 2013		0.5	0.4	0.4	0.3

Explanations: * 20–31; ** 1–22

The lowest ground temperatures at the depth of 5 cm were recorded in June and July (-4.5°C and -3.3°C, respectively). This was caused by very low temperatures of the air and a rather thin snow cover of a few centimetres (Table 1, Fig. 1). According to the long-term monthly means, the lowest mean temperature of the ground at 5 cm b.g.l. (-2.2°C) in the winter occurred in June (Kruszewski 2000). In the analysed period, during the four months from June to September the ground was frozen over across the whole profile. The thaw began in the summer, on 28 November 2012.

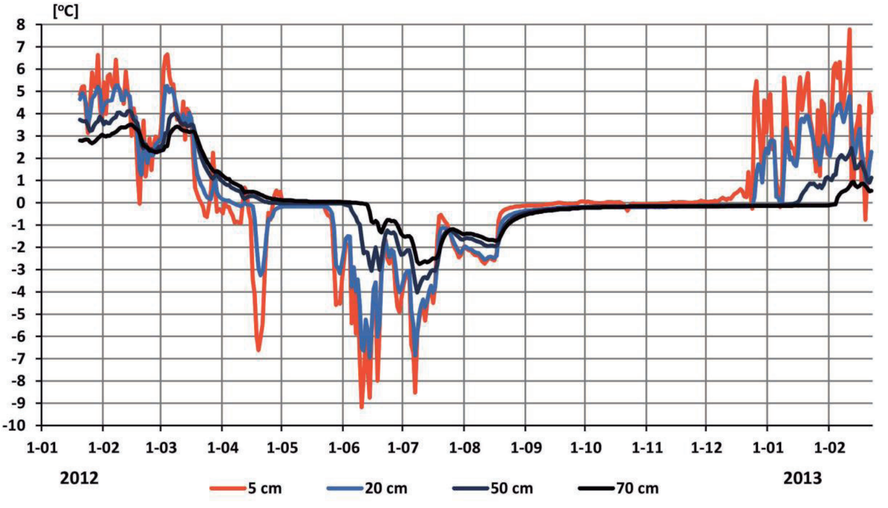

Fig. 2. Courses of mean diurnal values of ground temperature at 5, 20, 50 and 70 cm at the H. Arctowski Station in the period from 20 January 2012 to 22 February 2013

In the near-surface layer of the ground both the highest and the lowest temperatures were observed. At the depth of 5 cm, mean diurnal values of the temperature ranged from -9.2°C (10.06.2012) to 7.8°C (11.02.2013.).

The annual course of heat distribution in the ground is presented in the form of thermo isopleths (Fig. 3). From December until February the temperatures were decreasing with depth, i.e. the distribution of heat in the ground followed an insolation-dependent vertical pattern. From April until July, the situation reversed and the deepest layers of the ground remained the warmest, while the vertical pattern of heat distribution became radiation-dependent. In the remaining months the temperatures at all depths were uniform, i.e. the isothermal type of heat distribution occurred.

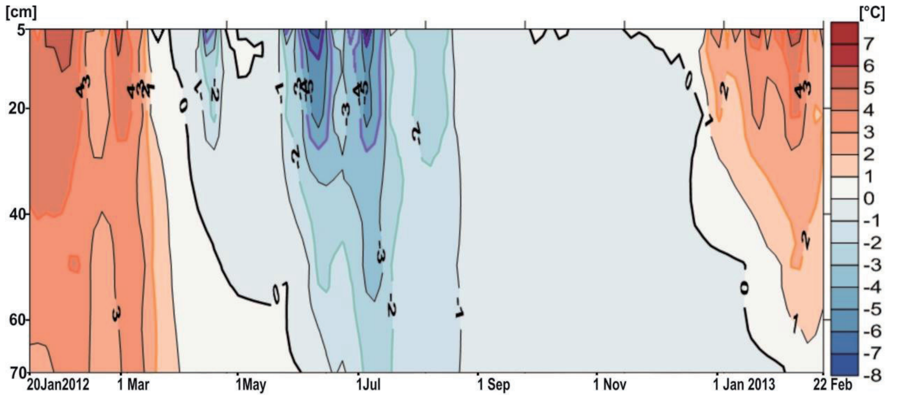

Fig. 3. Thermo-isopleths of the ground (°C) at the H. Arctowski Station in the period from 20 January 2012 to 22 February 2013.

The greatest variability can be observed in the mean diurnal ground temperature at a depth of 5 cm (standard deviation 3.0°C). As the depth of the analysed profile increases, the values fall to 2.5, 1.7 and 1.4°C at 20, 50 and 70 cm, respectively. In the annual course, the greatest variability of the mean diurnal temperature was observed at 5 cm in February 2013 (3.8°C) and March 2012 (2.4°C). Fluctuations of the mean diurnal temperature of the ground in the summer are mainly influenced by the radiation weather (extensive heating of the ground surface during the day and its cooling at night). The lowest values of standard deviation at the depth of 5 cm were observed from September until November (approx. 0.1°C) and are related to the retention of snow, which insulates the ground from external factors.

The diurnal course of ground temperature

In this article, the ground temperature data from the H. Arctowski Station are provided for the first time with an hourly resolution. This allows precise monitoring of changes over a diurnal course in individual months of the analysed period. Figure 4 presents diurnal courses of ground temperature for selected months with complete data series.

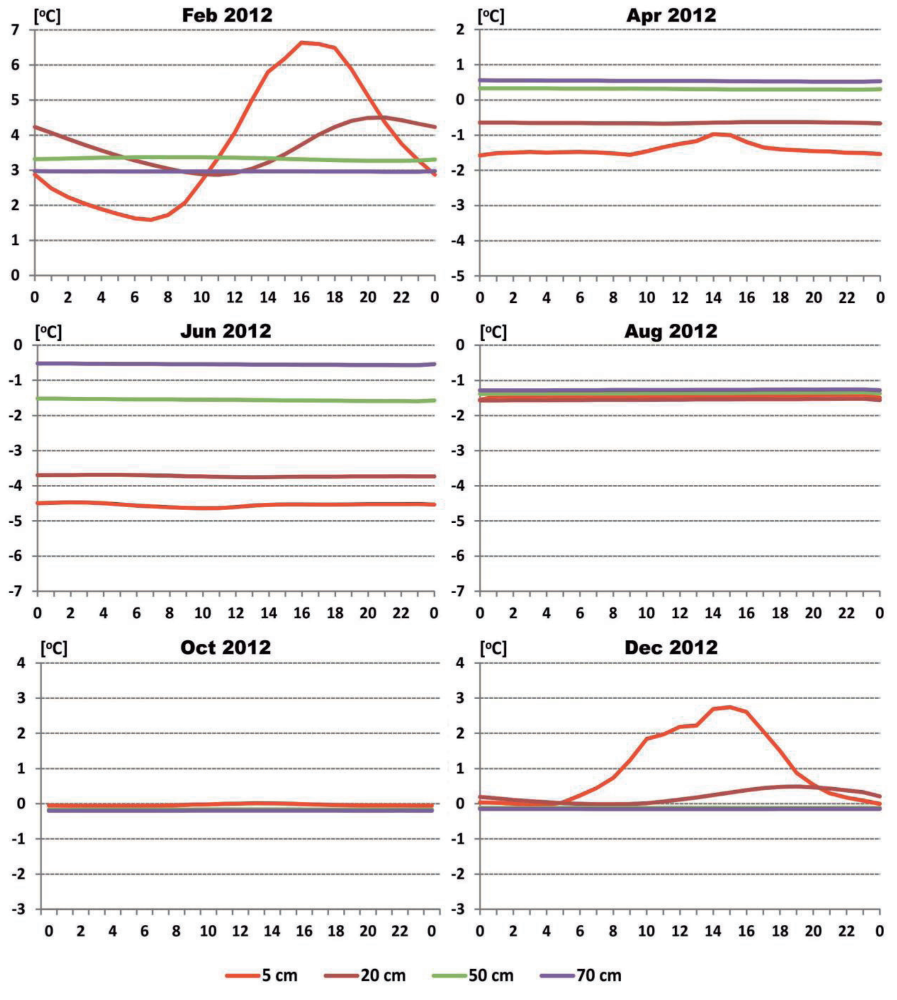

Fig. 4. Diurnal course of ground temperature (°C) at the H. Arctowski Station in selected months (February, April, June, August, October and December) of 2012.

The diurnal course of ground temperature at the H. Arctowski Station varies during the year. Of all the external factors mentioned at the beginning, the influx of solar energy and the presence and thickness of snow cover are the key elements affecting these variations in the diurnal cycle in that area.

In the Antarctic summer months, e.g. February and December 2012, mean diurnal courses of ground temperature are the most distinct, indicating clear increases in the near-surface layer in afternoon hours and decreases in night hours. In the summer, mean diurnal amplitudes do not exceed 3–5°C at a depth of 5 cm. As the depth increases, the heat distribution in the ground is evidently delayed and the diurnal amplitudes fall (Fig. 4).

In the autumn and early spring, small diurnal amplitudes (approx. 0.5°C) were observed at a depth of 5 cm. At greater depths, diurnal courses were balanced with a temperature inversion throughout the analysed profile.

From mid-winter until springtime (e.g. in August or October 2012) no differences in the temperature values were observed at any of the depths or in the diurnal cycle (Table 2, Figs 3 and 4).

Vertical gradients of ground temperature

The vertical distribution of ground temperature depends on the amount of heat that reaches its surface, whereas the measured values depend on the structural and humidity characteristics of the studied ecotope. The upper layer of the ground, down to a depth of 20 cm, reveals strong responses to atmospheric influences and is subject to the greatest changes both in the diurnal cycle and day after day. Deeper layers of the ground, between 20 and 70 cm, are less affected by weather elements, and the variability of temperature is either marginal or non-existent. The values of vertical gradients of ground temperature change in the annual course.

Summer months reveal the greatest drops in temperature with the depth of the ground. This is when the insolation type of vertical distribution of thermal conditions of the ground occurs (Table 3). On average, the greatest positive gradient was observed in January and February 2013 (0.51°C/10 cm). In the summer, the thermal conditions are the most diversified at individual depths (Fig. 5).

From April until July, the situation is reversed: the warmest layers of the ground are the deepest ones and the vertical distribution of temperature is typical of radiation weather. On average, the greatest negative vertical gradient of ground temperature occurs in June (-0.61°C/10 cm).

Table 3. Vertical gradients of ground temperature (°C/10 cm) at the H. Arctowski Station in the period from 20 January 2012 to 22 February 2013

Year	Month	5cm–20cm	20cm–50cm	50cm–70cm	5–70cm
2012	Jan*	0.16	0.33	0.38	0.31
	Feb	0.08	0.11	0.18	0.12
	Mar	-0.05	-0.03	0.05	-0.01
	Apr	-0.50	-0.32	-0.11	-0.30
	May	-0.11	-0.18	-0.05	-0.12
	Jun	-0.53	-0.72	-0.51	-0.61
	Jul	-0.10	-0.26	-0.24	-0.22
	Aug	0.07	-0.06	-0.05	-0.03
	Sep	0.14	0.01	0.03	0.04
	Oct	0.10	-0.01	0.02	0.03
	Nov	0.12	-0.01	0.02	0.03
	Dec	0.54	0.11	0.02	0.18
2013	Jan	0.57	0.68	0.22	0.51
	Feb	0.54	0.46	0.56	0.51

Explanations: * 20-31; ** 1–22.

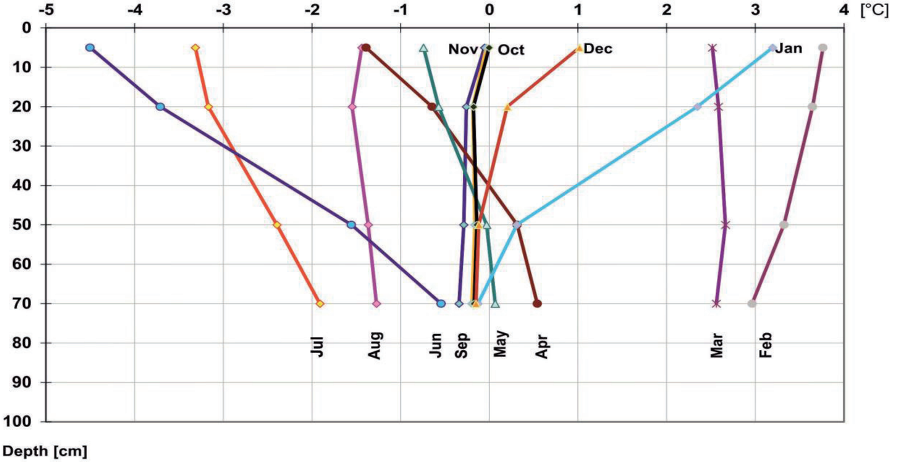

Fig. 5. Vertical gradients of ground temperature (°C/10 cm) at the H. Arctowski Station in the period from February 2012 to January 2013

From August until November, the temperature at all analysed depths was similar, i.e. remained in the state of homothermy (Table 3, Fig. 3).

Using a database of hourly measurements it is also possible to track changes in vertical gradients of ground temperature in the diurnal course. As mentioned earlier, for the whole profile (i.e. the depths from 5 to 70 cm) the greatest negative temperature gradient occurred in June 2012, and positive in January 2013 (Table 3, Fig. 5). The diurnal course of the vertical gradients of ground temperature in these two months is shown in Figure 6.

In June 2012, which is a winter month, the values of the gradient reveal little diurnal variability (between -0.61 and -0.63°C/10 cm), considering the 24 individual times of observation. On the other hand, in January 2013, being a summer month, the distribution of the ground temperature followed an insolation pattern throughout the day. The greatest gradient of ground temperature (1.04÷1.05°C/10 cm) across the whole profile was observed in early afternoon hours (13^{00}–14^{00} LMT), whereas at night (02^{00}–04^{00} LMT) it clearly decreased (0.09÷0.10°C/10 cm) (Fig. 6).

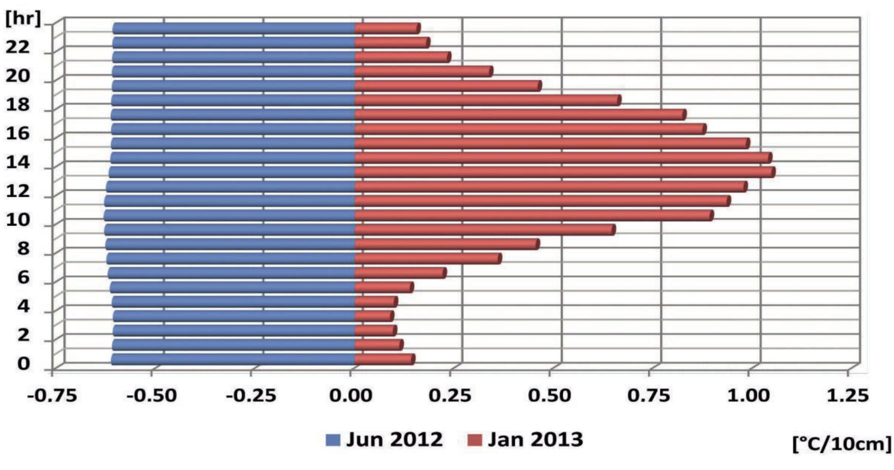

Fig. 6. Diurnal course of vertical gradients of ground temperature (°C/10 cm) at the H. Arctowski Station in June 2012 and in January 2013.

Selected weather situations

On individual days, diurnal courses of ground temperature are often considerably different from the mean course, which is generally caused by the occurrence of various external factors (types of synoptic situations, values of solar radiation, thickness of snow cover, etc.). For the purpose of a detailed analysis two days were selected, 21 October 2012 and 11 February 2013. The first of the two days represents a weather type with a thick snow cover, whereas in the case of the second one the ground was not covered by snow (Fig. 7).

On 21 October 2012, the values of ground temperature across the whole profile did not change throughout the day. Diurnal amplitudes of air temperature at all measurement levels remained at approx. ±0.1°C. There was a thick layer of snow on that day (30 cm), which insulated the ground from external factors (essentially, from the low temperature of the air). At 00^{00} – 04^{00} LMT, the air temperature was approx. -10÷-12°C. During the day, the air temperature started to increase quickly, mainly because of increased solar radiation reaching the surface. At 10^{00}–14^{00} LMT, the rate of solar radiation reached approx. 600–700 Wm^{-2}. In the afternoon hours, as the solar radiation decreased, the air temperature was also observed to fall. On that day, the solar radiation did not affect the values of ground temperature (Fig. 7).

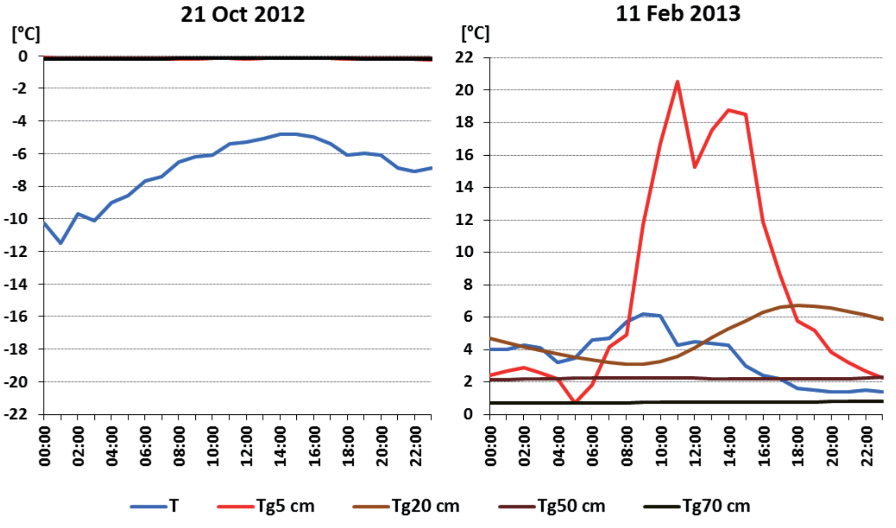

Fig. 7. Diurnal courses of ground temperature (Tg) and air temperature (T) on the selected days (21.10. 2012 – with a thick snow cover, and 11.02.2013 – without a snow cover) at the H. Arctowski Station

On the other day (11 February 2013), without a snow cover but with a lot of sunshine, the ground temperature revealed a striking variability throughout the day. The temperature measured at a depth of 5 cm in the ground reached 20.6°C, which was the highest value recorded during the observations. The direct factor that caused the record warming of the surface layer of the ground on that day was the amount of solar radiation that reached the ground on 11 February 2013. At 11^{00}–12^{00} LMT, its value reached 900 Wm^{-2}. On that day, the diurnal amplitude of the ground temperature at 5 cm b.g.l. was 19.8°C. According to Fourier's law, diurnal amplitudes were observed to decrease with depth (they amounted to 3.6, 0.2 and 0.1°C at the subsequent depths of 20, 50 and 70 cm, respectively).

Correlation between ground temperature and external factors

The ground temperature revealed the greatest connection with the temperature of the air (Table 4), and the strongest relationship observed was its link with the minimum and mean diurnal temperature of the air. The correlation coefficients for the parameters of air temperature (Ti, Tmax and Tmin) ranged from 0.73 to 0.58 for the series of ground temperature measurements taken down to 20 cm b.g.l. The lowest correlations ($r = 0.37$ to 0.47) were found, as expected, between air temperature and ground temperature at the lowest depth, i.e. 70 cm. All the correlations have the statistical significance level $p < 0.05$.

Very high values of the correlation coefficients were observed between ground temperature and solar radiation. Thermal characteristics of the ground are largely dependent on the amount of incoming solar radiation, which was evidenced by high values of correlation at different depth levels: from 0.62 at 5 cm to 0.35 at 70 cm. All the correlations have the statistical relevance level $p < 0.05$.

The other analysed meteorological elements (humidity of the air, atmospheric pressure and the speed of wind) do not have a significant influence on the values of ground temperature. However, all correlations between the relative humidity and the ground temperature are statistically significant for $p < 0.05$ (Table 4). Their correlation coefficients are, though, rather low and range from -0.13 to -0.29 for the whole profile of 5–70 cm. It is also noteworthy that the wind speed has a small, but still significant, cooling effect on the ground temperature in the near-surface layer (5 cm b.g.l.). The correlation coefficient here is -0.12 and its statistical relevance level is $p < 0.05$.

Table 4. Correlation coefficients between the values of mean diurnal ground temperature (at different depths: 5, 20, 50 and 70 cm) and mean diurnal values of selected meteorological elements at the H. Arctowski Station in the period from 20 January 2012 to 22 February 2013

Parameter	Ti	Tmax	Tmin	f	V	P	SR	5cm	20cm	50cm	70cm
Ti		**0.94**	**0.96**	**-0.12**	0.00	-0.02	**0.45**	**0.70**	**0.65**	**0.53**	**0.43**
Tmax			**0.84**	-0.08	-0.01	-0.02	**0.40**	**0.63**	**0.58**	**0.46**	**0.37**
Tmin				**-0.14**	0.05	-0.04	**0.46**	**0.73**	**0.69**	**0.57**	**0.47**
f					**0.27**	**-0.17**	**-0.51**	**-0.13**	**-0.14**	**-0.25**	**-0.29**
V						**-0.27**	**-0.24**	**-0.12**	-0.09	-0.07	-0.06
P							0.07	-0.06	-0.09	-0.09	-0.06
SR								**0.62**	**0.56**	**0.44**	**0.35**
5cm									**0.96**	**0.77**	**0.63**
20cm										**0.89**	**0.76**
50cm											**0.96**
70cm											

Explanations: Ti – means daily air temperature; Tmax – daily maximum temperature; Tmin – daily minimum temperature; f – relative humidity; V – wind speed; SR – totals of the global radiation; P – air pressure; 5, 20, 50 and 70 cm - levels in the ground; correlation coefficients statistically significant at the level of 0.05 are shown in bold.

Conclusions

In the area of the H. Arctowski Station, the ground temperature is essentially affected by the amount of incoming solar radiation, the temperature of air and the retention of snow.

When compared with the long-term data, the year 2012 at the H. Arctowski Station proves to be average as far as the temperature of air is concerned, and the difference between the temperature in 2012 and in the years 1977–

1998 (Marsz, Styszyńska 2000) falls within 0.1°C. At the same time, in 2012 notable anomalies occurred and some months were warmer than average, e.g. August by 2.4°C, May and July by 1.7°C, and March by 0.9°C.

The long-term series of measurement data (1990-1997) indicate that the highest mean ground temperature (at 5 cm b.g.l.) during the year was recorded in January, while the lowest in June (Kruszewski 2000). A similar pattern was observed in the analysed period, however with considerable anomalies in individual months (Fig. 8). The greatest negative differences in comparison with the long-term mean were found in the summer months and in the middle of winter (approx. 2–4.5°C at 5 cm).

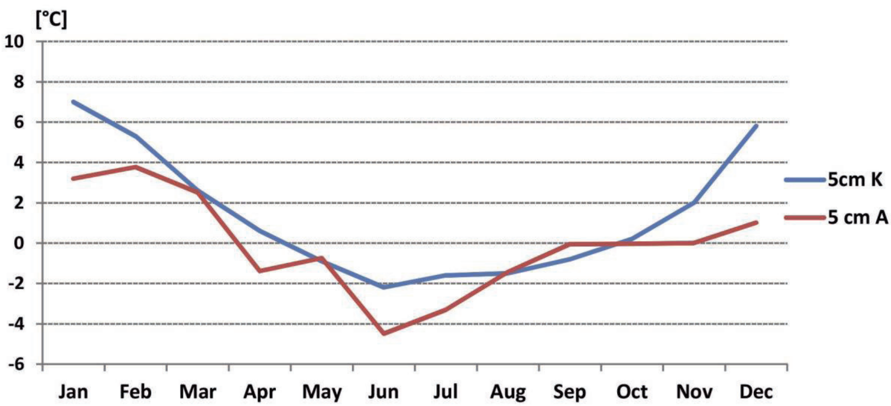

Fig. 8. Annual course of mean monthly values of ground temperature at 5 cm (°C) at the H. Arctowski Station. Explanations: A – according to the data presented in this article; K – according to the data provided by Kruszewski (2000) for the years 1990–1997

The values of ground temperature on the surface are consistently higher than the values of air temperature. The ground temperature in the near-surface layer and the air temperature demonstrate the strongest correlation in November and March, and the weakest in September and October.

In summer months, mean diurnal courses of ground temperature have a high amplitude. In the winter and spring no changes of temperature were identified in the ground at all depths or in the diurnal course, which resulted from insulating properties of the snow cover.

Across the whole profile, the greatest negative vertical temperature gradient (-0.61°C/10 cm) occurred in June 2012, whereas the greatest positive gradient (0.51°C/10 cm) occurred in January and February 2013.

Year over year, diurnal courses of ground temperature often considerably deviated from the annual course on individual days, which was generally caused by various external factors (different synoptic situations, cloudiness, solar radiation, snow cover etc.).

Some very strong and statistically significant correlations were found between series of diurnal values of ground temperature at all depths of measurement**.** Furthermore, some statistically significant correlations were found between the ground temperature and the temperature of air, or solar radiation. The correlation coefficients for air temperature parameters (Ti, Tmax and Tmin) and for solar radiation (the series of ground temperature down to 20 cm b.g.l.) range from 0.73 to 0.56.

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References

ANGIEL P.J., POTOCKI M. and BISZCZUK-JAKUBOWSKA J., 2010, Weather condition characteristics at the H. Arctowski Station (South Shetlands, Antarctica) for 2006, in comparison with multi-year research result, Misc. Geogr., 14, 5–11.

BARANOWSKI S., 1968, Termika tundry peryglacjalnej SW Spitsbergen, Acta Univ. Wratisl., 68, Wrocław, 74 pp.

CYGAN B., 1981, Characteristics of meteorological conditions at Arctowski Station during the summer season of 1979-1980, Polish Polar Res., 2(3–4), 35–48.

DOMACK E., LEVENTER A., BURNETT A., BINDSCHADLER R., CONVEY P. and KIRBY M., (red.), 2003, Antarctic Peninsula Climate Variability, Antarctic Research Series, 79, American Geophys. Union, Washington, 260 pp.

FERRON F.A., SIMÕES J.C., AQUINO F.E. and SETZER A.W., 2004, Air temperature time series for King George Island, Antarctica, Pesq. Antart. Bras., 4, 155–169.

KEJNA M., 1999a, Air temperature in the Admiralty Bay region (King George Island, Antarctica), in the period 1977-1996 according to meteorological data from the Arctowski Station, Wyd. Uni. M. Kopernika, Toruń, 128 pp.

KEJNA M., 1999b, Air temperature on King George Island (South Shetland Islands, Antarctica), Polish Polar Res., 20(3), 183–201.

KEJNA M., 2000, Warunki meteorologiczne na obszarze SSSI nr 8 (Wyspa Króla Jerzego, Antarktyka) w 1996 r., Acta Univ. Nic. Copernici, Geografia 31, 157–181.

KEJNA M., 2003, Trends of air temperature of the Antarctic during the period 1958–2000, Polish Polar Res., 24(2), 99–126.

KEJNA M., 2008a, Temperatura gruntu na Stacji Arctowskiego (Antarktyka) w sezonie letnim 2006/2007, (eds) Kowalska A., Latocha A., Marszałek H., Pereyma J., [in:] Środowisko przyrodnicze obszarów polarnych, Wrocław, 125–133.

KEJNA M., 2008b, Rozkład przestrzenny i zmiany temperatury powietrza na Antarktydzie w drugiej połowie XX wieku, Wyd. Uni. M. Kopernika, Toruń, 272 pp.

KEJNA M. and LÁSKA K., 1997, Temperatura gruntu na Stacji H.Arctowskiego (Szetlandy Pd., Antarktyka) w 1996 roku, Probl. Klimatol. Pol. 7, Gdynia, 109–124.

KEJNA M. and LÁSKA K., 1999, Spatial differentiation of ground temperature in the region of Arctowski Station (King George Island, Antarctica) in 1996, Polish Polar Res., 20(3), 221-241.

KEJNA M., ARAŹNY A. and SOBOTA I., 2013, The climatic change on King George Island (South Shetland Islands, Antarctica) in the years of 1948–2011, Polish Polar Res., 34(2): 213–235, DOI: 10.2478/popore-2013-0004.

KEJNA M., SOBOTA I. and ARAŹNY A., 2012, Warunki meteorologiczne w rejonie Stacji Arctowskiego (Wyspa Króla Jerzego, Antarktyka) w okresie 19.01-19.02.2012 roku, Probl. Klimatol. Pol., 22: 103–116.

KING J.C., TURNER J., MARSHALL G.J., CONNOLLEY W.M. and LACHAN-COPE T.A., 2003, Antarctic Peninsula climate variability ant its causes as revealed by analysis of instrumental records. [in:] Antarctic Peninsula Climate Variability, Antarctic Res. Ser., 79, 17–30.

KRATKE J. and WIELBIŃSKA D., 1981, Co-occurrence of particular meteorological elements in the region of Arctowski Station (King George Island, South Shetland Islands, in 1978, Polish Polar Res., 2 (3–4), 7–21.

KRUSZEWSKI G., 1998, Temperatura gruntu na Stacji Arctowskiego w roku 1995. [in:] Wyprawy geogr. na Spitsbergen, UMCS Lublin, 79–87.

KRUSZEWSKI G., 2000, Temperatura gruntu na Stacji Arctowskiego. [in:] Główne cechy klimatu rejonu Polskiej Stacji Antarktycznej im. H. Arctowskiego (Antarktyka Zachodnia, Szetlandy Południowe, Wyspa Króla Jerzego), (eds) Marsz A.A., Styszyńska A., WSM Gdynia, 215–221.

MARSZ A.A. and RAKUSA-SUSZCZEWSKI S., 1987, Charakterystyka ekologiczna rejonu Zatoki Admiralicji (King George Island, South Shetland Islands), Klimat i obszary wolne od lodu, Kosmos, 36(1), 103–127.

MARSZ A.A. and STYSZYŃSKA A., 2000, Główne cechy klimatu rejonu Polskiej Stacji Antarktycznej im. H. Arctowskiego (Antarktyka Zachodnia, Szetlandy Południowe, Wyspa Króla Jerzego), WSM, Gdynia, 264 pp.

MIGAŁA K., 1994, Cechy warstwy aktywnej zmarzliny w warunkach klimatycznych Spitsbergenu, Acta Univ. Wratisl., No 1590, 79–111.

OLECH M., 2002, Plant Communities on King George Island, [in:] Beyer L., Bolter M. (eds), Geoecology of Antarctic Ice-Free Coastal Landscapes, Ecological Studies, Vol. 154, Springer -Verlag Berlin, Heidelberg, 215–231.

OLECH M., 2010, Responses of Antarctic Tundra Ecosystem to Climate Change and Human Activity, Papers on Global Change, 17, 43–52.

PROŠEK P., JANOUCH M. and KRUSZEWSKI G., 1996, Składniki bilansu promieniowania i ich przebieg latem 1994/95 na Stacji im. H. Arctowskiego (Szetlandy Południowe), Probl. Klimatol. Pol., 6, Gdynia, 107–138.

RAKUSA-SUSZCZEWSKI S., 2003, Functioning of the geoecosystem for the west side of Admiralty Bay (King George Island, Antarctica): Outline of research at Arctowski Station, Ocean and Polar Research, 25 (4): 653–662.

ŠT'ASTNÁ V., 2010, Spatio-temporal changes in surface air temperature in the region of the northern Antarctic Peninsula and South Shetland Islands during 1950–2003, Polar Science, 4, 18–33.

STYSZYŃSKA A., 1995, Kształtowanie się wskaźnika oceanizmu w rejonie Półwyspu Antarktycznego i Morza Weddella, XXII Sympozjum Polarne, Zamek Książ, 85–98.

VAUGHAN D. G., MARSHALL G.J., W.M., PARKINSON C., MULVANEY R., HODGSON D. A., KING J. C., PUDSEY C.J. and TURNER J., 2003, Recent rapid regional climate warming on the Antarctic Peninsula, Clim. Change, 60, 243–274.

WASHBURN A.L., 1979, Geocryology: a survey of periglacial processes and environments, London, Edward Arnold, 406 pp.

ZWOLSKA I. and RAKUSA-SUSZCZEWSKI S., 2002, Temperature as an environmental factor in the Arctowski station area (King George Island, South Shetland Islands), Geographia Polonica, Special Series, Global Change 9, 51–65.