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WEATHER CONDITION CHARACTERISTICS AT THE H. ARCTOWSKI STATION (SOUTH SHETLANDS, ANTARCTICA) FOR 2006, IN COMPARISON WITH MULTI-YEAR RESEARCH RESULTS

Abstract. The maritime Antarctic is characterised by highly variable weather conditions throughout the year, as well as over multi-year periods. The annual variability of weather conditions constitutes an important basis for biological and geographical studies, allowing for the monitoring of the functioning and changes of the geographical environment of the west coast of Admiralty Bay (King George Island, South Shetlands, Antarctica). Year-round meteorological observations (1.2006-12.2006) measured: atmospheric pressure, wind speed and direction, cloud cover, air temperature, relative humidity, total precipitation, snow cover, and Admiralty Bay ice cover.

Key words: Antarctica, Arctowski Station, Meteorological condition, Climate.

INTRODUCTION

Meteorological measurements and observations were carried out at H. Arctowski Station (62°09'41"56 S, 58°31'49"99 W) from 1977 until 2001. After a hiatus, meteorological observations resumed there in late November 2005. The present article discusses weather conditions in the period 1.2006 – 12.2006 (Annex 1. includes data for December 2005).

The Polish Antarctic Station is situated on King George Island, in the South Shetland Archipelago (South Shetland Islands), approximately 100 km northwest of the Antarctic Peninsula (Trinity Peninsula). To the north, the islands are bounded by Drake's Passage while to their south is the Bransfield Strait. This location has a substantial influence on climactic conditions and results in the predominance of maritime characteristics in the climate, which is shaped by air masses moving mainly from west to east. The atmospheric circulation exchange system is highly dynamic, and results in the high variability of weather conditions throughout the year.

The King George Island has a surface area of 1310 km^2, 95% of which is covered by glaciers. Ice-free areas are located mainly on the island's southern coast. This is a function of more favourable weather conditions (compared with the northern coast), a complex coastline and variegated terrain relief. Many research stations are located in this part of the island, among which is the Polish Antarctic Station, situated on the western shore of the Admiralty Bay fjord.

Average air temperature values in the Admiralty Bay are approximately +0.7ºC higher than those measured at the Bellinghausen Station, in the northwestern part of the King George Island (Rakusa-Suszczewski 2002). Admiralty Bay conditions evolve under the influence of the Foehn effect, which occurs in the presence of air mass circulation from the north and northwest. (Martianov and Rakusa-Suszczewski 1989). The effect is produced by air masses moving over the 650m asl ice dome. Additionally, the configuration and steep slopes of the Admiralty Bay fjord influence wind strength and direction. These factors result in high climate variability within the bay.

STUDY METHODS AND METHODOLOGY

Data were collected using measuring equipment (LAB-EL recording equipment), such as: electronic air temperature and humidity sensors (thermohygrometer LB-710) as well as an anemometer produced by R. M. Young (LB-746). In November 2006 a barometer was installed (LB-716) as were additional temperature sensors (ten-channel LB-711), which allowed for ground temperature monitoring at depths of 0, 5, 10, 20, 50 cm, as well as 5 cm above the surface.

Data registered at the automatic station included air temperature, relative air humidity, wind speed and direction. Data were collected at 2-minute intervals until 17.4.2006, and at 2-second intervals thereafter. Monthly averages were calculated using automatic station data, as well as 8 daily measurements taken at: 00, 03, 06, 09, 12, 15, 18, 21 GTM (LTM = GMT – 4 h). When calculating maximum and minimal temperature values, the whole data set was taken into consideration. Observations of the degree and variety of cloud cover and meteorological phenomena were carried out at 00, 06, 12, 18 GTM, while total atmospheric precipitation and snow cover thickness measurements were taken at 06 GTM.

RESULTS

Atmospheric pressure

On King George Island, yearlong atmospheric depression centres play an important role in air mass circulation. Average annual atmospheric pressure values are low. Due to the dynamic movement of low-pressure centres between South America and the Antarctic Peninsula, changes in pressure are frequently sudden. The pressure tendency maximum (pressure variation within a 3-hour period) equalled -9 hPa. The highly dynamic atmospheric circulation over the South Shetlands is reflected in the variability of pressure changes over 24-hour periods, but it is not expressed in either monthly or annual averages (Marsz and Styszyńska 2000).

The average atmospheric pressure value in 2006 was 996.6 hPa. Maximum and minimum atmospheric pressure measurements were noted in September: 1031 hPa (23.09.2006) and 962 hPa (13.09.2006, daily average 964 hPa). In 2006, high-pressure systems were more frequent than over the multi-year period. August exhibited particularly high-pressure values and had the highest monthly average for the year at 1006.7 hPa. This value was linked to the development of high-pressure centres above the Antarctic Peninsula at that time. Other monthly average values were lowered due to this circulation: wind speed (4.7 m/s monthly average), cloud cover (lowest annual value at 5.8). Furthermore, there was a marked drop in air temperature with -22.9ºC recorded as the lowest temperature of the year. The winter of 2006 can thus be classified as a so-called "cold-core winter".

Wind direction and speed

Important pressure gradients in the South Shetland region result in the occurrence of strong winds. Average annual wind speed at the H. Arctowski Station equalled 6.1 m/s and was 0.5 m/s lower than the multi-year average. During 2006, based on 8 daily wind-speed measurements, wind speed was $\leq$ 10 m/s on 208 days, while values exceeding 15 m/s were noted on 75 days.

Winds of storm (above 17 m/s) and hurricane (above 30 m/s) strengths were observed during each month. They are a typical climate element in the region. Storm and hurricane winds were concurrent with wind directions from the north and west. They were generally accompanied by a sudden drop in pressure, linked to the movement of low pressure centres to wards the east. Longitudinal extent of the Admiralty Bay fjord, which branches out into the smaller bays of Ezcurra and Martel to the SW and NE, has a strong influence on air mass flow, and results in intensifying winds from those directions. Air masses flow over the island's elevations and suddenly descend along several hundred meters of the steep fjord slopes. When circulating from these sectors, they are subject to turbulent disturbances. In the presence

of these occurrences extremely strong wind gusts were noted, lasting several seconds, substantially exceeding average wind speed, and re-occurring at regular intervals of several minutes. Due to the high sensitivity of measurements registered by the anemometer, which took measurements at 2-second intervals, it was possible to carry out a series of detailed observations related to the dynamics of changes in wind speed. The results confirm a strong gustiness and very high turbulence intensity. The value of gustiness coefficient x, was calculated using the model:

$$x = V_{\max} / V_{śr},$$

where: $V_{\max}$ – maximum wind speed, $V_{śr}$ – average wind speed, reached as high as 7.4 (07/08.11.2006). Maximum turbulence intensity values (at 2-second intervals) I_x:

$$I_x = d_y / V_{śr} ,$$

where: d_y – actual wind speed standard deviation, equalled 2.47 (12.11.2006).

Wind speed measurements taken at 2-second intervals made it possible to observe the highest recorded wind speed of the station's 30-year existence at 68.8 m/s (12.11.2006). This value was registered during a hurricane wind blowing from the north-west that reached an average speed of 35.6 m/s during the six hours of its occurrence.

At the H. Arctowski Station location, winds from the western sector (SW, W and NW) predominate with a 50.5% proportion in multi-year observations. Among the western sector winds, the most frequent is the SW, accounting for 21.5% of overall multi-year observations (Marsz and Styszyńska 2000). In this respect, data from 2006 do not diverge from multi-year averages, which show that the western sector accounts for 48.7% of observations, while the SW wind represents 21.1%.

Cloud cover

The characteristic trait of the Admiralty Bay region climate is its high degree of cloud cover and its small degree of variation over the course of the year. The persistent cloud cover is linked to the dynamic circulation of air masses over the South Shetlands and, in particular, with numerous atmospheric fronts

Cloud cover was measured using 0-8 octa cloud cover (0-8). The average monthly cloud cover varies between 5.8 (July and August) to 6.9 (December). The annual average for 2006 equalled 6.3, corresponding to the multi-year average. The high degree of cloud cover is exemplified by observations of 166 days with a cloud cover above 7, but only 11 days with a cloud cover of less than 2, and 0 cloudless days in 2006.

Low-level Stratocumulus and Stratus clouds dominated the cloud cover structure in 2006. Next in frequency were mid-level clouds: *Altocumulus*, with a smaller proportion of *Altostratus*. High-level clouds (*Cirrus, Cirrocumulus*, *Cirrostratus*) were rarely observed, largely because of the high proportion of low and mid-level clouds in overall cloud cover. The formation of *Altocumulus lenticularis* and *Cumulus lenticularis* clouds occurred in relatively constant orographic positions and was concurrent with *rapid flow of the* over King George Island. These clouds were often characterised by strong vertical development and consisted of several *overlapping lenticular* clouds. Similar cloud cover structures and the stationary position of orographic lenticular clouds had been observed in previous years (Marsz and Styszyńska 2000).

Air temperature

The annual average air temperatures within the research area range between –3.6ºC (1980) and +0.1ºC (1989); for the period 1977-1998, the average was –1.6ºC (Kejna 1999). During the period 1978-1998, a trend towards higher annual averages was observed. The rise in temperature noted at the H. Arctowski Station is not a local phenomenon, but is characteristic of the Antarctic Peninsula overall. Analyses of long measurement series (1958-2000) from the Peninsula revealed rises in temperature as substantial as 0.67ºC/10 years (Kejna 2006).

The average air temperature at H. Arctowski Station in 2006 was –0.7ºC. An important characteristic of the local climate is the occurrence of above-zero air temperatures in each month. In 2005/2006, relatively high temperatures characterized the Antarctic summer. In January 2006, the temperature remained above zero during the whole month. The maximum value equalled 11.9ºC (22.01.2006). In such conditions, the dark bedrock undergoes intense warming. On the same day, ground temperature at the depth of 5 cm reached 20.1ºC. During the first three months of 2006 the monthly average temperature remained above 3ºC (January-March; the maximum value of 3.7ºC was recorded in January). Above-zero temperatures also characterised the last three months of the year (October-December). In August, the coldest month of 2006, the average temperature was –8.6ºC (multi-year average: -5.6ºC). The minimum air temperature for 2006 was also recorded that month: –22.4ºC (25.08.2006). Notably, after the occurrence of this minimum, the temperature rose by 24.4ºC to a value of +2ºC within 30 hours. These data confirm that weather conditions in Admiralty Bay are subject to highly dynamic changes.

Air humidity

Due to the ocean's significant effects on air masses, the South Shetlands region is characterised by high air humidity. The multi-year average for the period 1977-1998 equals 82.3 %. The average for 2006 was markedly lower at 75.7%. It is the lowest value observed at H. Arctowski Station since the began collecting data. During 2006, air humidity ranged between 71.2% (September) and 80.3 % (April). As well, significant drops in humidity were observed, reaching as low as 37.1 %. Such occurrences were observed simultaneously with circulation from directions producing the Foehn effect (Kejna and Láska 1997).

Atmospheric precipitation

Areas characterised by a rise in air temperature, were observed also to be marked by increased atmospheric precipitation (Fourtuin and Oerlemans 1990). This phenomenon was not, however, observed at the H. Arctowski Station. In the years 1978-1998, the trend for annual total precipitation within the research area was marked by decreased precipitation. This results from the localisation of the H. Arctowski Station in the precipitation shadow of King George Island (Marsz 2002).

Despite a descending trend during the 1978-1998 period, 2006 was a year of high total precipitation, reaching 610.4 mm, compared to the multi-year (1977-1998) average of 499.8 mm. During the most humid months (March, April, May), very high atmospheric precipitation totals were noted (particularly high for The Polish Antarctic Station). For those months, precipitation totals equalled, respectively: 115.9 mm, 125.2 mm, and 84 mm. The sum total was 325 mm, which constitutes more than half of the annual precipitation total. Precipitation for the three months mentioned above was characterised by values that were, on average, two times higher than multi-year averages. Precipitation totals for the three-month period were highly conditioned by values linked to sudden occurrences of precipitation (Table 1.) Precipitation occurrences totalling more than 5 mm represented more than 73% of precipitation totals for March-May. April precipitations were particularly sudden in character: 70% of the total precipitation for the month was noted on 4 days during which precipitation exceeded 15 mm (15.3 mm; 21.1 mm; 18 mm, as well as the highest one-day total recorded in 2006, 33.8 mm on 8.4.2006).

Table 1

Structure of precipitation for the period March-May 2006.

Month 2006	The number of appearance – number of days with precipitation:		*Monthly sum precipitation* values:		*Monthly sum of precipitation* values (mm)	Part of precipitation values in monthly sum:	
	> 5mm	> 10mm	> 5mm	> 10mm		% > 5mm	% > 10mm
March	11	3	91.7	36.7	115.9	79.1	31.7
April	6	4	99.4	88.2	125.2	79.4	70.4
May	6	3	61.6	39.1	84	73.3	46.5

An important characteristic of weather conditions in the vicinity of the H. Arctowski Station is the large number of days with precipitation. In 2006 there were 220 days with precipitation: 90 days with rainfall, 139 days with snowfall, and 2 days with hail. The precipitation structure was dominated by light precipitation: 101 days with precipitation totals of 0-0.1 mm, 71 days with totals of 0.1 mm-1.0 mm, 17 days with totals of 0.1-5 mm and 18 days with totals above 5 mm. Precipitation totals above 5 mm represent more than 70% of annual precipitation totals.

During precipitation linked with northwesterly circulation (12.4% of wind directions), accompanied by strong winds, water vortices carrying water mist towards land were observed in the Admiralty Bay. In 2006 the phenomenon was observed on 51 days. This is noteworthy because, together with precipitation, the phenomenon transports ocean water onto land, thus increasing precipitation totals. Chemical analyses confirmed the presence of chlorides in atmospheric precipitation at the Polish Antarctic Station (I. Zwolska 1999).

A significant factor reducing precipitation totals is the strong wind that frequently accompanies occurrences of precipitation. This is particularly the case during air mass circulation from the northwest sector, which is often accompanied by precipitation. In the presence of wind precipitation reaches the ground at an acute angle, which lowers the measurements collected using the Hellmann pluviometer. In extreme conditions, such as hurricane winds, which are often accompanied by precipitation, precipitation measurement totals may be greatly diminished.

Precipitation in the form of rain plays an important role in the melting-away of the surface layer of permafrost. Observations carried out in the active soil layer clearly point to a link between the accelerated melting of permafrost and rainfall. In late April 2006, in the vicinity of the station soil thawing reached depths of 85-184 cm. During sudden rises in air temperature, rainfall accelerates the melting of the snow cover, leading to its reduction, and even disappearance.

Snow cover

The snow cover at the H. Arctowski Station is subject to dynamic changes that are linked to climate characteristics. It frequently recedes and its depth is highly variable. The beginning of 2006 was characterised by a lack of snow cover (until 2.2.2006). Later in the year, significant variations in temperature, coupled with precipitation and wind, repeatedly resulted in the disappearance of the snow cover. Its maximum height in 2006 equalled 38 cm (01.09.2006). Over a four-month period, the vicinity of the station was permanently covered in snow (8.06-21.10.2006). However, snow-cover depth in this period underwent a significant degree of change. A sudden rise in air temperature during 7 – 11.07.2006 reduced the snow-cover to no more than 0.5 cm. In previous years, during the winter months, comparable reductions also were observed, as was the periodic disappearance of the snow cover (Rachlewicz 1997).

The snow cover in the vicinity of the H. Arctowski Station is also characterized by the high spatial variability in depth, as a result of snow displacement during periods of strong wind. A fresh snow cover does not remain in its place of accumulation when wind reaches speeds higher than 5 m/s (Gonera and Rachlewicz, 1997). In effect, snow banks that reach heights of several metres form on the leeward slopes of elevations and on the sides of buildings. Snow can frequently persist in these locations; even during periods of snow cover disappearance.

Admiralty Bay ice cover

In the formation of an ice-cover over large fjord, such as Admiralty Bay (122 km^2), a factor more important than thermal conditions is the freezing of the pack ice that has moved into the bay (Kruszewski 2002). Such was the situation in late August 2006. Circulation from the east and south-east sectors predominated causing pack ice accumulation in the bay. Intensely cold masses of continental air moved in during a high-pressure, low-wind weather caused the pack ice to freeze into an ice cover over the bay in the period 24.8–03.09.2006. The pack ice cover receded from the Admiralty Bay in early September 2006, when strong hurricane winds caused the ice to loosen within two days (with the exception of the western part of Ezcurra Bay).

Table 2

Monthly and annual averages for 2006 and multi-year averages for the period 1977 – 1998 of air temperature, atmospheric pressure, wind speed, relative air humidity, and monthly and annual atmospheric precipitation totals.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Air temperature [°C]													
2006	3.7	3.2	3.3	-0.3	-0.2	-3.7	-3.8	-8.6	-4.2	0.2	0.5	1.9	-0.7
1977 – 1998	2.5	2.3	1.2	-1.1	-3.3	-5.0	-6.6	-5.6	-3.7	-2.0	-0.2	1.5	-1.6
Atmospheric pressure [hPa]													
2006	997.4	1000.7	988.4	998.6	995.6	1004.7	1000.1	1006.7	998.0	998.6	985.7	985.2	996.6
1977 – 1998	991.5	990.5	990.6	992.2	995.7	994.1	993.7	991.6	991.8	988.5	986.7	990.9	991.5
Wind speed [m/s]													
2006	4.6	5.9	6.4	5.4	8.0	6.4	7.2	4.7	6.7	7.3	5.6	5.0	6.1
1977 – 1998	5.7	6.2	6.9	6.8	6.5	6.6	6.7	6.8	7.4	7.3	6.7	5.5	6.6
Relative air humidity [%]													
2006	74.2	78.0	80.3	79.6	76.1	73.0	74.4	73.1	71.2	76.2	74.1	78.5	75.7
1977 – 1998	82.9	82.8	82.3	83.1	82.8	82.6	83.0	81.9	82.4	81.8	82.6	83.3	82.3
Atmospheric precipitation totals [mm]													
2006	22.5	55.0	115.9	125.2	84.0	14.8	22.1	10.4	35.6	44.1	23.9	56.9	610.4
1977 – 1998	34.9	51.3	58.3	49.3	36.9	36.8	40.5	28.2	47.4	41.5	41.3	34.7	499.8

SUMMARY

During 2006 there was a higher frequency of high-pressure systems compared to the multi-year average; the average atmospheric pressure value for 2006 was 996.6 hPa. Wind speed averages did not diverge from the multi-year averages, equalling 6.1 m/s. As a result of the high sensitivity of anemometer measurements (taken at 2-second intervals) record wind gusts were recorded for the H. Arctowski Station – in November, they reached values of 68.8 m/s. The wind was characterised by a high gustiness and intense turbulence. During hurricane winds, maximum values of the gustiness coefficient x reached values of 7.4; turbulence intensity I_x reached maximum values equalling 2.47.

In 2006, the westerly circulation typical for the region predominated; wind directions from the western sector constituted 48.7 % of annual observations. Due to the many atmospheric fronts moving through the region, a persistent cloud cover was observed: 6.3 (on a scale of 0-8), corresponding to the multi-year average. The annual air temperature average at the station in 2006 equalled –0.7ºC, that is, 1.1ºC higher than the multi-year average. The winter of 2006 had the characteristics of a "cold-core winter": the monthly average air-temperature for August was –8.6ºC, 3ºC below the multi-year average for that month.

In, 2006 observations recorded precipitation totals equalling 610.4 mm, that is, 100 mm higher than the multi-year average. Particularly abundant in precipitation were the months: March, April, and May, with a total of 325 mm, constituting more than half of the annual precipitation total. An uninterrupted snow cover was observed during four months, from early June until late October. The maximum snow cover height was recorded in September at 38 cm. In late August – the coldest month of 2006 – the pack ice solidified and froze the Admiralty Bay for a period of 11 days.

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