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# Trends of air temperature of the Antarctic during the period 1958–2000

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ABSTRACT: The paper presents the trends of air temperature of the Antarctic. In its elaboration 21 stations were taken into consideration carrying out temperature measurements in the years 1958–2000, and 34 stations in the years 1981–2000. After checking the homogeneity of the series by the Alexandersson's (1986) test we found that at 16 stations the homogeneity has been broken. On the basis of the corrected measurement series we have determined the trends in air temperature. In the period 1958–2000 statistically significant (on 0.95 significance level) temperature increases occurred on the western coast of the Antarctic Peninsula (for example *Faraday* 0.67°C/10 years) and at the *Belgrano* and *McMurdo* stations. The greatest temperature rise was noted on the Antarctic Peninsula during the autumn-winter period. On the South Pole a negative trend in air temperature (–0.21°C) occurred, especially in the summer season. During recent years (1981–2000) significant changes took place in the air temperature tendencies in the Antarctic. In many regions of the Antarctic cooling began and on the cost of East Antarctica the temperature decreased by –0.82°C/10 years (*Casey*). In the interior of the continent also lower and lower temperatures occurred (*Amundsen-Scott* –0.42°C/10 years, *Dome C* –0.71°C/10 years). The coast of the Weddell Sea is getting colder (*Halley* –1.13°C/10 years, *Larsen Ice* –0.89°C/10 years). An increase in temperature was observed in the interior of West Antarctica (*Byrd* 0.37°C/10 years). The warming rate of the climate became weaker on the Antarctic Peninsula (*Faraday* 0.56°C/10 years). The largest temperature changes occurred in the autumn-winter season when in the Antarctic Peninsula region the temperature increased, while in the interior and at the coast of East Antarctica temperatures fell considerably.

Key words: Antarctica, trends in air temperature.

## Introduction

The progressive increase in the concentration of greenhouse gases in the atmosphere leads in consequence to the rise of global air temperatures. According to the III Report of IPCC (2001), from 1880 the mean temperature on the Earth has grown by 0.6°C ±0.2°C. Warming does not appear with the same intensity on the entire globe, however, and some areas have cooled down during recent years. The reaction of polar regions to the greenhouse effect is unknown. The first IPCC report (1990) gave for the Antarctic for the winter months even 10°C warming up (Budd 1991). According to the scenarios of the global greenhouse effect the temperature at the polar regions should grow by 3°C in summer and 4–5°C in winter (III Report of IPCC 2001). However, these model researches are not confirmed in reality. This shows that our knowledge concerning the functioning of climate system of the polar regions is insufficient.

The Antarctic, zone together with the Antarctic continent, is a huge reservoir of fresh water. About 30 million km$^3$ is bound in the Antarctic continental ice sheets (Fortuin and Oerlemans 1990) which could cause a significant rise in the world's ocean level due to the possible warming up and melting. The regime of sea ice also changes. The sea ice surface around Antarctica is functioning in an annual cycle, from 2 million km$^2$ at the end of summer to 18 million km$^3$ at the end of winter (Jacka 1990). These changes might lead to an immense disturbance in the functioning of the Antarctic ecosystem.

Over the Antarctic, in conditions of solar energy deficiency (Marshunova 1980) in connection with the polar situation of this continent, a specific climate system is functioning. From the central part of the East Antarctic ice dome (maximal heights >4000 m above sea level) air masses flow to coastal directions in the form of katabatic winds (Radok *et al.* 1996). Above the warmer water of the Southern Ocean this air gets warm, then ascends to the higher troposphere levels and around the Antarctic a very deep circumpolar trough appears. Air masses returning over the continent settle in the central regions of the Antarctic Anticyclone over East Antarctica (Voskresenskij and Chukanin 1980). The strong cool-down of the snowy surface of the Antarctic continent and the subsidence of air masses create good conditions for the appearance of a temperature inversion (Phillpot and Zillmann 1970, Connoley 1996).

The Antarctic climate shows a considerably greater variability in comparison with the lower latitudes of the Southern Hemisphere. This is conditioned by interactions between the atmospheric circulation, the ocean, and the cryosphere (King and Turner 1997). The higher atmospheric level also has an influence on the temperature at the surface. In the stratosphere a significant cooling appears due to ozone depletion (Farman *et al.* 1985).

The Antarctic continent is the least known among the continents on the Earth. The first meteorological observations were carried out during the expeditions at the end of the 19$^{th}$ century, for example during the expedition of the Belgian ship *Belgica* when H. Arctowski and A.B. Dobrowolski conducted geophysical research work. In 1903 the station *Orcadas* was established on the South Orkney Islands, but the conditions at this subantarctic station do not reflect the climate changes on the whole continent (Raper *et al.* 1984). The results of the first Antarctic expeditions showed that the beginning of the 20$^{th}$ century was considerably

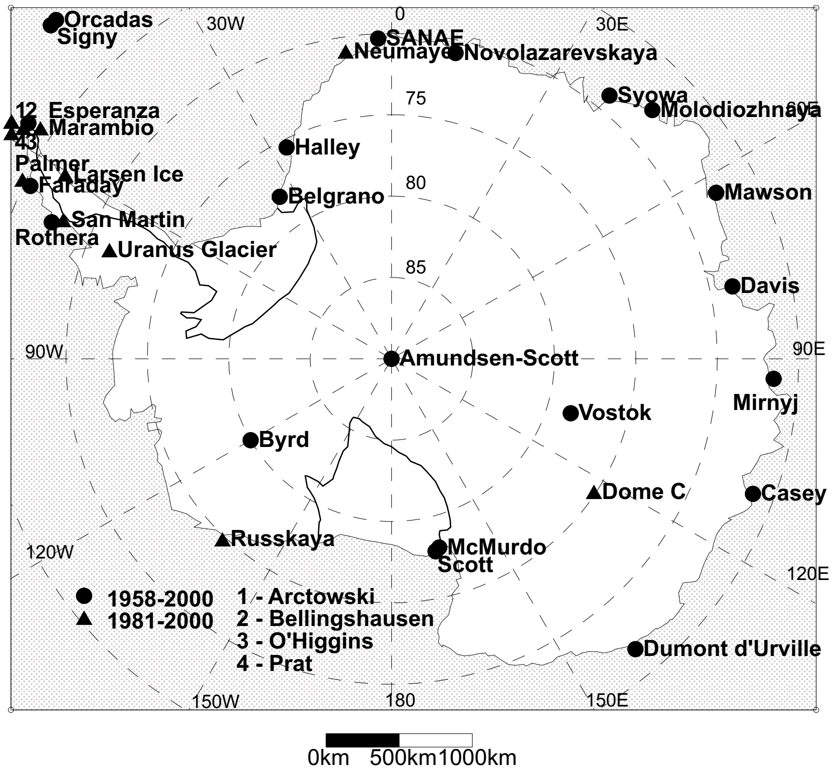


Fig 1. Location of Antarctic stations used in the analysis.

colder than the second part of the century (Jones 1990). Already during the International Geophysical Year (1957–1959) it was noticed that the temperatures were by 2–3°C higher in comparison to the pioneer expeditions (Averjanov 1960). It became possible to learn about the climate conditions and determine the tendency of temperature changes in this most inaccessible region of the world only after the foundation of the *Amundsen-Scott* and *Byrd* (1957), and *Vostok* (1958) stations in the interior of the continent (Fifield 1987).

Any changes in the Antarctic environment – changes in water temperature, sea currents, situation of sea ice, and the range of the continental ice sheet brought about by numerous interactions and feedbacks may lead to disturbances in the functioning of the Antarctic climate system (Stonehouse 1997). The problem of climate changes in the Antarctic has been analysed in many papers, for example Limbert (1974), Budd (1975, 1982, 1991), van Loon and Williams (1977), Carleton (1981), Mayes (1981), Raper *et. al.* (1984), Jones *et al*. (1986), Jones and Wigley (1988), Sansom (1989), Jones (1990), Koshelkov (1990), Martianov and Rakusa-Suszczewski (1990), Jacka and Budd (1991), Weatherly *et al.* (1991), King (1994), Stark (1994), Jones (1995), Ackley *et al*. (1996), Smith *et al*. (1996), Kejna (1999), van den Broeke (2000), Marshall *et al*. (2002).

## Source material

In this paper we have used monthly mean air temperature values for the 21 stations in operation on the Antarctic during the years 1958–2000, and for 34 stations recording observations in the years 1981–2000 (Fig. 1). Data come from different sources, for example Spravochnik po klimatu Antarktidy 1974 and 1977, Monthly Climatic Data (Jones and Limbert 1987) and from data bases available through the Internet from the following institutions: National Climatic Data Center, British Antarctic Survey, University of East Anglia, Australian Antarctic Division, Antarkticheskij Issledovatelnyj Institut, NOAA-Environmental Research Laboratories, and from automatic weather stations (AWS) from the University of Wisconsin. Some of the data have been obtained directly at the national institutes of countries conducting research in the Antarctic.

The density of the station network in the Antarctic is unsatisfactory, especially in the interior of the continent, where at present only two permanent stations are in operation: *Amundsen-Scott* and *Vostok*, complemented by a network of automatic stations, of which some have measurement series only a few years long, for example *Dome C* and *Byrd*. Nevertheless, the homogeneity of the snowy-glacial surface of the Antarctic interior allows us to extrapolate the results obtained to a considerable larger area (King and Turner 1997).

## Quality and homogeneity of the data

In order to analyse the climate conditions on a given area we should use homogeneous data not burdened with methodical errors or changing conditions in the environment of observations. The lack of homogeneity of measurement series on the Antarctic is the result of extreme weather conditions, which cause frequent failures and require exchanges of measurement instruments. Frequently mercurial and alcohol thermometers are replaced by electric ones, and automatic measurements are made instead of standard observations (King and Turner 1997). Methods, terms, and frequency of observations change. The mean daily values are counted in different ways. Some Antarctic stations move together with glacier streams or shelf glaciers, and in case of danger they are relocated to a safe place. The continuous exchange of observers may also result in a lack of homogeneity (Jones and Reid 2001).

In comparison to other regions the Antarctic series are free of direct anthropological influences, and this considerably increases their value in temperature change research.

To eliminate incorrect values we have counted the temperature anomalies for monthly and annual values. Observation series, especially during months with low or high temperature anomalies, were compared to neighbouring stations. In the analysed data sets there were erroneous values as well as missing data, mainly due to discontinuity in a station's activity. Missing data have been completed using the linear regression method with strongly correlated stations (Marsz 2000). Because of the significant annual cycle of the temperature difference between the particular stations, computations were made separately for each month.

The completed series were subjected to homogeneity control process. Temporary homogeneous climate data sets in comparison to the neighbouring stations results in a series of values accompanied by a constantly temporary synchronic homogeneous reference series (Miętus 1998). The homogeneity of data can be determined only by comparing it to data from neighbouring stations (Vizi *et al.* 2001 ).

For our homogeneity test of the Antarctic stations, we used the Alexandersson (1986) test:

$$Q_i = y_i = \frac{\sum_{j=1}^{k} w_j (x_{ji} - \bar{x}_j + \bar{y})}{\sum_{j=1}^{k} w_j}$$

where:
$x_{ji}$ – temperature at station $j$ at time $i$,
$y_i$ – temperature at the candidate station at time $i$,
$w_j$ – weight.

To verify the zero hypothesis that the data set for the tested station is homogeneous, a standardised series was created:

$$z_i = (Q_i - \overline{Q}) / \sigma_Q$$

where:
$\overline{Q}$ – mean value of the $Q_i$ series,
$\sigma_Q$ – standard deviation.

Then the $T$ test value is counted:

$$T = \mu \bar{z}_1^2 + (n - \mu) \bar{z}_2^2$$

where:
$\mu$ – time (year) of the break in homogeneity, $0<\mu<n$.
$\bar{z}_1$ – mean value of $z_i$ before the break
$\bar{z}_2$ – mean value of $z_i$ after the break

To verify the zero hypothesis the maximal value of $T$ was checked in the year $\mu$. The critical values of $T$ on 90 and 95% significance level are given by Alexandersson (1986).

When the value of $T$ was higher than the critical one we rejected the hypothesis about the homogeneity of the analysed series and made a correction to the part of the series before the break taking into account the mean values of $Q$ before and after the break. After this correction we conducted the homogeneity test again until the value of $T$ became lower than the critical value.

Table 1

Homogeneity of measurements series of selected Antarctic stations.

| Station | φ (°S) | λ | Height m a.s.l. | Years | Tmax | Year | T95% | Correcti on in °C |
|---|---|---|---|---|---|---|---|---|
| *Amundsen-Scott* | 90 | | 2800 | 1957–2000 | 5.86 | 1982 | 8.5 | |
| *Arctowski* | 62.1 | 58.5°W | 2 | 1977–2000 | 3.61 | 1990 | 7.7 | |
| *Belgrano* | 77.9 | 34.6°W | 32 | 1957–2000 | 35.88 | 1977 | 8.5 | +7.79 |
| *Bellingshausen* | 62.2 | 58.9°W | 16 | 1968–2000 | 5.64 | 1968 | 8.2 | |
| *Byrd* | 80.0 | 120.0°W | 1530 | 1957–2000 | 2.6 | 1980 | 8.5 | |
| *Casey* | 66.3 | 110.5°E | 41 | 1957–2000 | 9.12 | 1970 | 8.5 | +0.55 |
| *Davis* | 68.6 | 78.0°E | 13 | 1957–2000 | 4.95 | 1987 | 8.5 | |
| *Dome C* | 74.5 | 123.0°E | 3280 | 1980–2000 | 2.70 | 1980 | 7.4 | |
| *Dumont d'Urville* | 66.7 | 140.0°E | 43 | 1957–2000 | 4.08 | 1957 | 8.5 | |
| *Esperanza* | 63.4 | 57°W | 13 | 1945–2000 | 11.93 | 1975 | 8.8 | +0.66 |
| *Faraday* | 65.4 | 64.4°W | 11 | 1945–2000 | 14.96 | 1966 | 8.8 | +1.35 |
| *Frei* | 62.4 | 58.9°W | 10 | 1969–2000 | 13.53 | 1994 | 8.2 | –0.48 |
| *Halley* | 75.5 | 26.4°W | 39 | 1958–2000 | 9.28 | 1991 | 8.5 | –0.33 |
| *Larsen Ice* | 67.0 | 60.6°W | 17 | 1987–2000 | 6.67 | 1994 | 6.9 | –1.62 |
| *Marambio* | 64.2 | 56.7°W | 198 | 1970–2000 | 11.67 | 1975 | 8.1 | +0.96 |
| *Mawson* | 67.6 | 62.9°E | 16 | 1957–2000 | 8.17 | 1978 | 8.5 | –0.35 |
| *McMurdo* | 77.9 | 166.7°E | 24 | 1957–2000 | 1.92 | 1989 | 8.5 | |
| *Mirnyj* | 66.5 | 93°E | 30 | 1957–2000 | 7.95 | 1986 | 8.5 | –0.30 |
| *Molodiozhnaya* | 67.7 | 45.9°E | 40 | 1963–2000 | 7.00 | 1979 | 8.4 | –0.33 |
| *Neumayer* | 70.7 | 8.4°W | 50 | 1981–2000 | 1.17 | 1981 | 6.4 | |
| *Novolazarievskaya* | 70.8 | 11.8°E | 99 | 1961–2000 | 9.79 | 1974 | 8.4 | –0.24 |
| *O'Higgins* | 63.3 | 57.9°W | 10 | 1966–2000 | 5.29 | 1985 | 8.3 | +0.23 |
| *Orcadas* | 60.7 | 44.7°W | 6 | 1945–2000 | 6.05 | 1969 | 8.8 | –0.30 |
| *Palmer* | 64.8 | 64.1°W | 8 | 1974–2000 | 1.60 | 1977 | 7.8 | |
| *Prat* | 62.5 | 59.7°W | 5 | 1966–2000 | 2.09 | 1997 | 8.1 | |
| *Rothera* | 67.5 | 68.1°W | 16 | 1976–2000 | 11.25 | 1991 | 7.8 | +0.86 |
| *Russkaya* | 74.8 | 136.9°W | 100 | 1980–1990 | 2.84 | 1983 | 6.2 | |
| *SANAE* | 70.3 | 2.4°W | 52 | 1958–2000 | 1.61 | 1975 | 8.5 | |
| *San Martin* | 68.1 | 67.1°W | 4 | 1976–2000 | 5.33 | 1994 | 7.8 | |
| *Scott* | 77.9 | 166.7°E | 14 | 1957–2000 | 5.73 | 1980 | 8.5 | +0.31 |
| *Signy* | 60.7 | 45.6°W | 6 | 1947–2000 | 5.58 | 1966 | 8.8 | |
| *Syowa* | 69.0 | 39.6°E | 21 | 1957–2000 | 2.17 | 1991 | 8.5 | |
| *Uranus Glacier* | 71.4 | 68.9°W | 780 | 1986–2000 | 2.93 | 1998 | 7.0 | |
| *Vostok* | 78.5 | 106.9°E | 3488 | 1958–2000 | 4.20 | 1979 | 8.5 | |

The basis problem in homogeneity analysis of the Antarctic series is the insufficient number of reference stations, especially in the interior of the continent. Because of the great distances the correlation coefficients between the stations are not high enough, so we should be very careful with their interpretation. An additional problem is the lack of metadata, i.e. information about the history of meteorological observation. This is invaluable for the interpretation of the results. In this paper

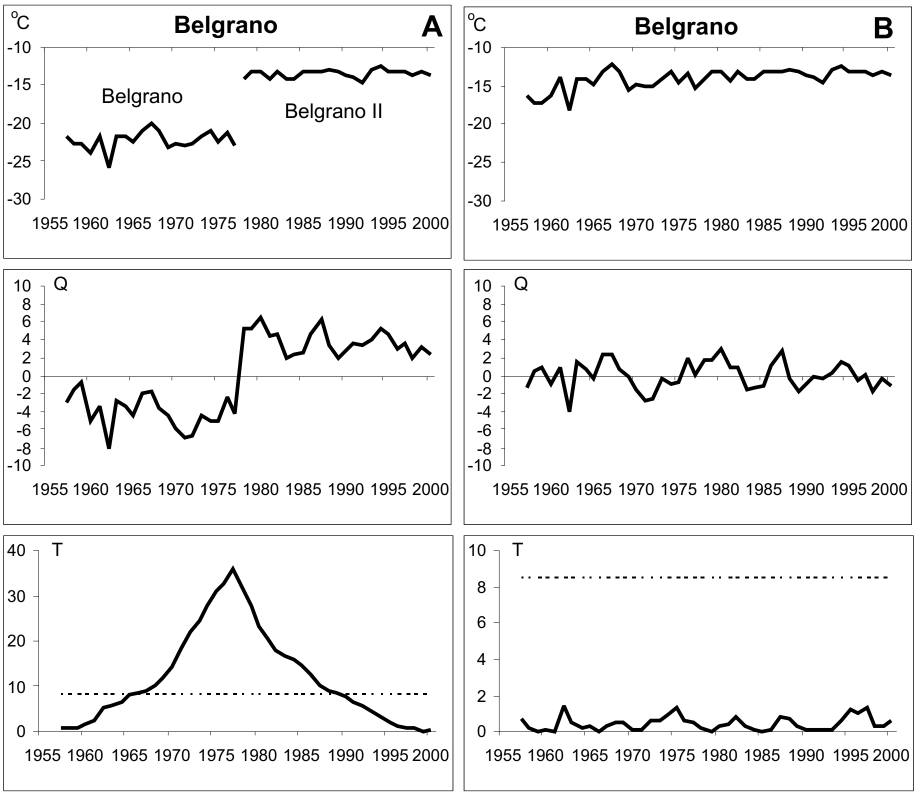


Fig 2. Courses of annual mean air temperature, differences between the candidate series and reference series (Q-series), and of the values (T-series with 90% critical level) for *Belgrano* station before (A) and after (B) homogenisation for the period 1958–2000.

we use information about meteorological observations published in Spravochnik po klimatu Antarktidy (1974), Pepper (1954), Stark (1994), King and Turner (1997), Turner and Pendlebury (2000) and from web pages by: Harangozo and Colwell (1995), Equipment history for climate data, B.A.S. Meteorological Database User Guide, Lagun (2002) main parameters measured at permanently operating stations, Arktichesko-Antarkticheskij Issledovatelnyj Institut, and Brief history of Australian involvement in Antarctica.

The most distinct break in the measurement series occurred at the Argentine station *General Belgrano*, situated on the Coats Land on the Filchner Shelf Glacier. This station was established in 1955 (77,58°S, 38,44°W). Due to the movement of the shelf glacier it was in danger, so in 1979 the station *Belgrano II* was built at 77,52°S, 34,37°W (King and Turner 1997). The relocation of the station by about 90 km caused a break in the homogeneity of its data.

For the *Belgrano* station we choose the nearest stations, *Halley* and *Faraday* as reference stations. After the calculation of the *Q* reference series a significant change was observed in the course of temperature at the *Belgrano* station in comparison to the neighbouring ones. The maximal T value occurred in 1979 and equalled 35.9, while the critical value for the 44 year-long series is 8.5. The temperature change resulting from the station relocation was as high as 7.8°C (Table 1). After the correction and applying the homogeneity test, a significantly higher T value was found in 1959 (–2.5°C correction was made), and so we obtained a homogeneous series (Fig. 2).

Even a small relocation of a station may cause a break in the measurement series. At the *Frei* station on the King George Island observations at the beginning were made at 8 m above sea level, and then in 1994 the measurement point was moved to the tower of the airport. At the same time an automatic observational system was introduced. On the basis of the nearby stations *Belligshausen*, *Esperanza*, *O'Higgins* and *Prat*, we checked the homogeneity of the series. It showed a break in 1994. The T value was 11.4, with the critical value being 8.1 for a 33 year-long measurement series. The relocation of the station caused a –0.3°C temperature decrease (Fig. 3).

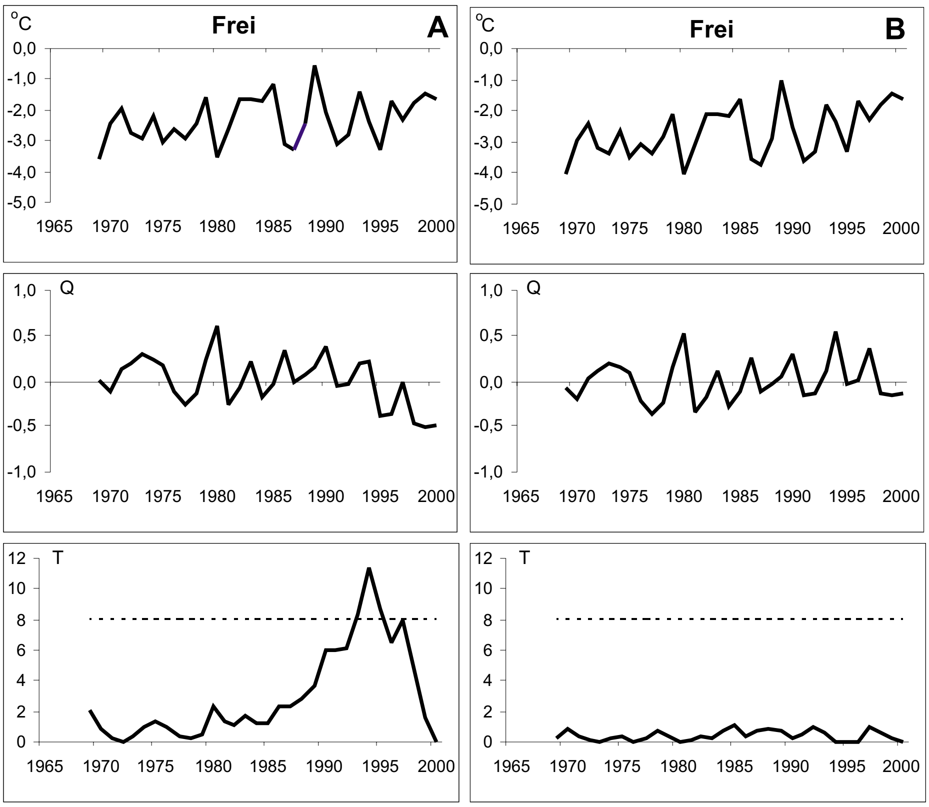


Fig 3. Courses of annual mean air temperature, differences between the candidate series and reference series (Q-series), and of the values (T-series with 90% critical level) for *Frei* station before (A) and after (B) homogenisation for the period 1969–2000.

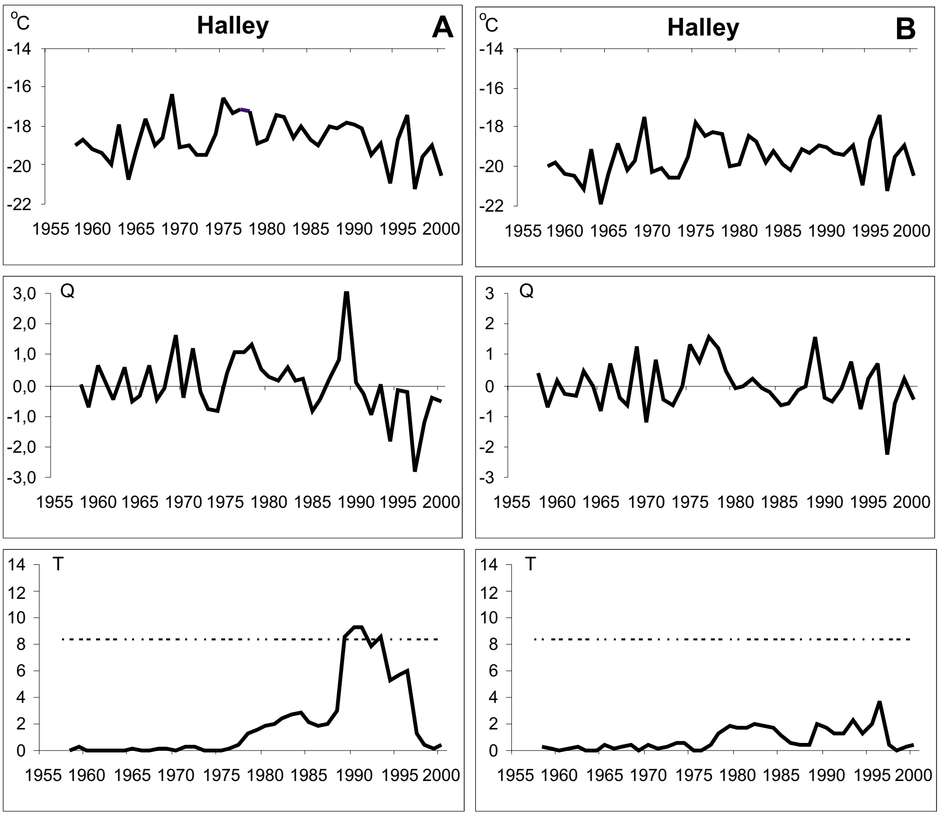


Fig 4. Courses of annual mean air temperature, differences between the candidate series and reference series (Q-series), and of the values (T-series with 90% critical level) for *Halley* station before (A) and after (B) homogenisation for the period 1958–2000.

Changes in the measurement instrumentation and methods of observations may also lead to a break in the homogeneity of the data. At the British *Halley* station observations were initially made manually every 3 hours. In 1986 the automatic station SCAWS was introduced, which obtained data every 3 hours. In February 1992 the station MAWS (Modular Automatic Weather Station) was introduced with a ventilated temperature and humidity sensor (Harangozo and Colwell 1995).

In the construction of the reference series we used the nearest stations *Belgrano* (after homogenisation) and SANAE. Our analyses showed that there was a homogeneity break in 1992. The value of T in this year reached 9.3 and was higher than the critical value (8.5). The change in the measurement system caused a –1.2°C decrease in the annual mean temperature (Fig. 4, Table 2). The continuous movement of the *Halley* station together with the glacier and its relocation from time to time also caused some problems. However, these relocations are not large, mainly less then 10 km (Harangozo and Colwell 1995).

Table 2

Mean air temperature and 5 year anomalies in air temperature during to the period 1958–2000 at the selected Antarctic stations

| Station | Mean 1961–90 | Anomalies | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 58–60 | 61–65 | 66–70 | 71–75 | 76–80 | 81–85 | 86–90 | 91–95 | 96–00 |
| *Amundsen-Scott* | –49.5 | 0.1 | 0.2 | 0.1 | 0.5 | 0.1 | –0.1 | –0.1 | –0.3 | –0.6 |
| *Belgrano II* | –14.0 | –0.7 | –1.1 | 0.4 | –0.9 | –0.4 | 0.4 | 0.7 | 0.3 | 0.9 |
| *Byrd* | –27.5 | –0.7 | –0.6 | 0.1 | 0.9 | –0.3 | –0.3 | 0.1 | 0.2 | 0.3 |
| *Casey* | –9.3 | –0.8 | –0.7 | –0.6 | 0.4 | 0.7 | 0.5 | 0.5 | 0.0 | –0.4 |
| *Davis* | –10.3 | –0.6 | –0.2 | 0.0 | 0.6 | –0.2 | –0.5 | 0.6 | –0.1 | 0.1 |
| *Dumont d'Urville* | –10.7 | –0.7 | –0.2 | 0.0 | 0.2 | 0.3 | 0.4 | 0.1 | 0.0 | –0.4 |
| *Esperanza* | –5.3 | –1.1 | –0.1 | –0.5 | –0.9 | 0.0 | 1.0 | 0.0 | –0.2 | 1.3 |
| *Faraday* | –3.8 | –3.1 | –0.6 | –0.4 | 1.2 | –1.4 | 0.7 | 0.7 | 0.2 | 1.5 |
| *Halley* | –18.6 | –0.3 | –0.8 | 0.5 | 0.1 | 0.8 | 0.6 | 0.5 | –0.6 | –0.9 |
| *Mawson* | –11.3 | –0.3 | 0.1 | 0.0 | 0.5 | 0.1 | –0.6 | 0.3 | 0.0 | –0.2 |
| *McMurdo* | –17.0 | –1.3 | –0.6 | 0.2 | 0.5 | –0.7 | 0.1 | 0.3 | 0.2 | 0.7 |
| *Mirnyj* | –11.4 | –0.6 | –0.4 | 0.1 | 0.6 | 0.2 | 0.0 | 0.3 | –0.2 | –0.2 |
| *Molodiozhnaya* | –11.0 | | 0.0 | 0.2 | 0.0 | 0.3 | –0.5 | 0.0 | 0.1 | –0.1 |
| *Nowolazarievskaya* | –10.0 | | –0.3 | 0.1 | 0.3 | –0.2 | –0.2 | 0.0 | 0.3 | 0.1 |
| *Orcadas* | –3.5 | –0.9 | 0.1 | –0.3 | –0.8 | –0.3 | 0.5 | 0.5 | 0.1 | 0.7 |
| *Rothera* | –5.0 | –3.0 | –0.5 | –0.4 | 1.3 | –1.7 | 0.9 | 0.9 | 0.0 | 1.4 |
| *SANAE* | –17.2 | 0.0 | –0.5 | 0.2 | 0.8 | 0.2 | 0.6 | –1.0 | –0.1 | –0.3 |
| *Scott* | –19.7 | –1.2 | –0.4 | 0.1 | 1.0 | –0.7 | 0.1 | 0.5 | –0.2 | 0.4 |
| *Signy* | –3.4 | –1.0 | 0.3 | –0.1 | –0.8 | –0.1 | 0.6 | 0.5 | –0.4 | 0.6 |
| *Syowa* | –10.5 | –0.5 | –0.1 | 0.2 | –0.3 | 0.1 | 0.2 | 0.2 | –0.2 | 0.1 |
| *Vostok* | –55.4 | –0.6 | –0.1 | –0.2 | 0.3 | 0.1 | 0.1 | 0.1 | 0.5 | –0.4 |

For the *Orcadas* station, which has the longest measurement series in this region (from 1903), the homogeneity test was applied in two steps. First we studied the period from 1905 to 1945, for which we had only data from the station in Grytviken on South Georgia for comparison. The analysis showed that the data set is homogeneous in this period. For the years 1945–2000 the *Esperanza*, *Signy*, and *Faraday* stations were used for the reference series. For a 56 year-long series the critical value is 8.8, while the maximal value of T equalled 6.05 in 1969. This means that the whole series is homogeneous.

At the Polish *Arctowski* station observations have been made at the same place from the moment of its establishment in 1977. However, there were changes in the terms of observations. Until 1989 measurements were made every 3 hours, in 1990 the measurements were made automatically, while in the years 1991–1994 measurements were made by thermographs. From December 1994 observations have been made every 4 hours. The changes in the measurement methods influenced to the quality of the results and their comparability to neighbouring stations, but did not cause a lack of homogeneity in the data set, as was shown by our analysis. The deviation from the reference series increased in the years 1990–1994 when the measurements were made in a non-standard way (Fig. 5).

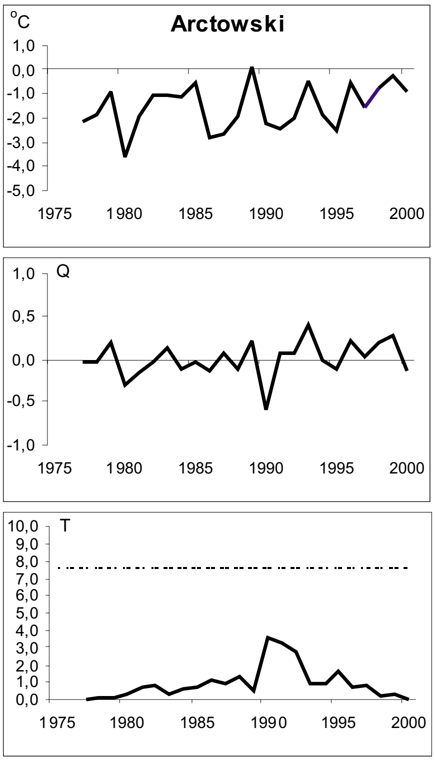


Fig 5. Courses of annual mean air temperature, differences between the candidate series and reference series (Q-series), and of the values (T-series with 90% critical level) for *Arctowski* station for the period 1977–2000.

After analysing the mean annual values of air temperature we can state that among the 34 studied stations as many as 16 contain a break in the homogeneity of the observations. Therefore any interpretations of climate changes based on raw data are burdened with errors which could lead to conclusions that do not reflect reality. A similar homogeneity analysis has been carried out for the mean seasonal values.

## Trends in air temperature in the Antarctic

An analysis of air temperature trends has been carried out for the period from the International Geophysical Year in 1958 to 2000. Mean annual values of air temperature were taken into account, as well as mean values for standard climatic seasons. The average trend values expressed by temperature change per decade are shown in Table 3, and their spatial distribution in Fig. 6. We should mention here, that the above maps present the distribution of temperature changes in the Antarctic resulting only from interpolation on the basis of rare station network. Some of

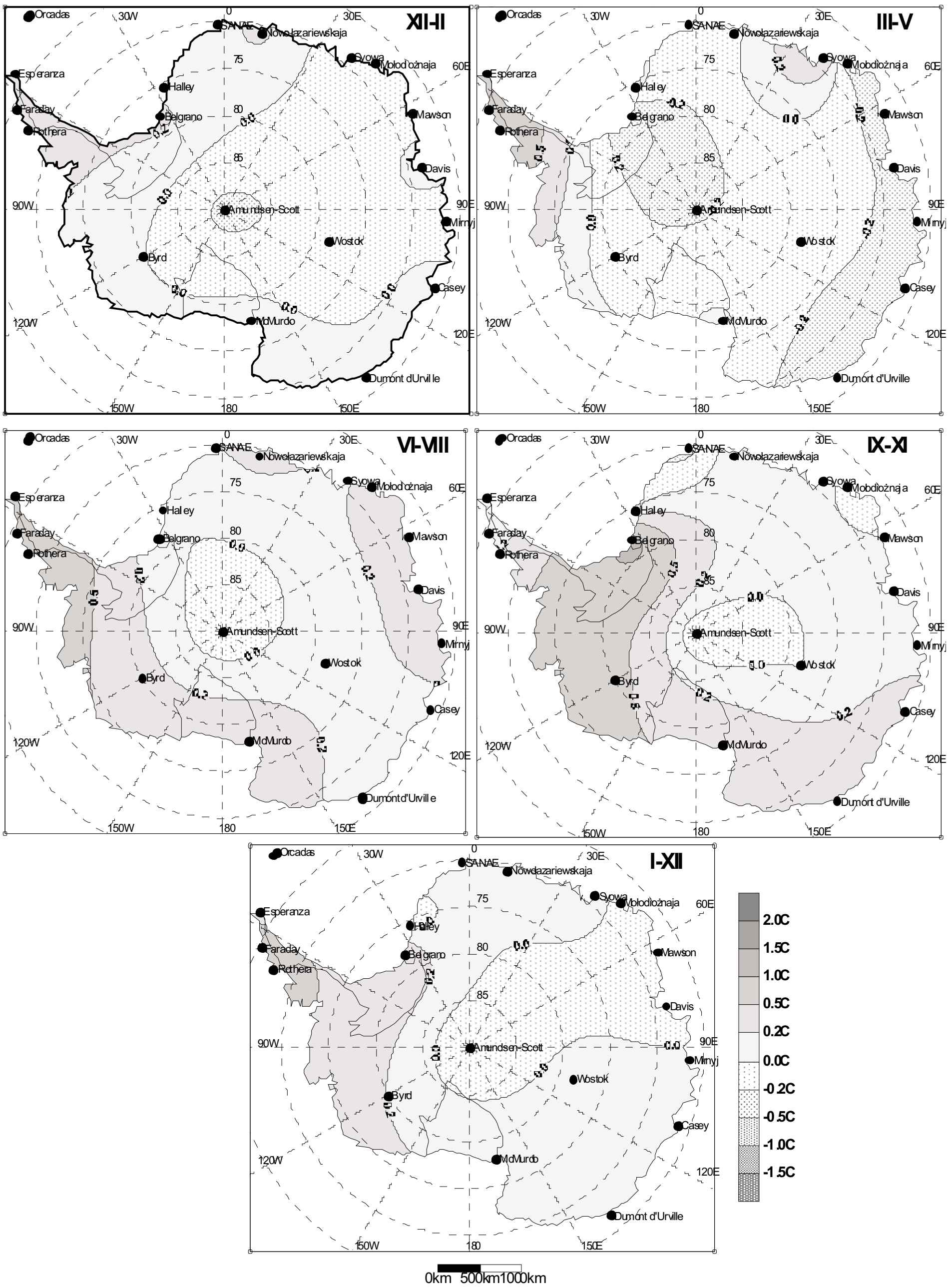


Fig. 6. Seasonal and yearly trends if air temperature (°C/10 years) in the Antarctic during the period 1958–2000.

the calculated coefficients are not significant statistically. Therefore these maps should be treated as an approximation to the climate changes on the continent.

Table 3

Trends of air temperature (°C/10 years) in the Antarctic durig the periods 1958–2000 and 1981–2000.

| Station | 1958–2000 | | | | | 1981–2000 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | XII–I | III–V | VI–VIII | IX–XI | I–XII | XII–I | III–V | VI–VIII | IX–XI | I–XII |
| *Amundsen-Scott* | –0.26 | –0.23 | –0.16 | –0.18 | –0.21* | –0.49 | –1.14* | –0.23 | 0.12 | –0.42 |
| *Arctowski* | | | | | | 0.37 | 0.95* | 0.09 | –0.14 | 0.32 |
| *Belgrano II* | 0.26* | –0.47 | 0.06 | 1.23* | 0.42* | –0.01 | –0.70* | –1.43 | 1.54* | 0.16 |
| *Bellingshausen* | | | | | | 0.26 | 0.81* | 0.07 | –0.02 | 0.23 |
| *Byrd* | 0.00 | –0.12 | 0.30* | 0.59* | 0.19 | 0.38 | –0.70 | 1.31* | 0.45 | 0.37 |
| *Casey* | 0.07 | –0.24 | 0.15* | 0.28* | 0.14 | –0.92* | –1.93* | –0.22 | –0.19 | –0.82* |
| *Davis* | 0.06 | –0.22 | 0.26* | 0.19* | –0.08 | –0.19 | –0.56 | 1.06 | 0.64 | 0.02 |
| *Dome C* | | | | | | –0.02 | –1.82* | –0.70 | –0.28 | –0.71* |
| *Dumont d'Urville* | 0.02 | –0.40 | 0.10* | 0.35* | 0.09 | –0.78 | –1.18* | –0.73 | 0.15 | –0.64* |
| *Esperanza* | 0.35* | 0.80* | 0.56* | –0.04 | 0.42* | 0.48 | 1.62* | –0.63 | –0.36 | 0.28 |
| *Faraday* | 0.26* | 0.69* | 0.86* | 0.06 | 0.67* | 0.05 | 0.30 | 1.13* | 0.73* | 0.56 |
| *Frei* | | | | | | 0.25 | 0.60 | 0.18 | –0.36 | 0.06 |
| *Halley* | 0.13* | 0.05 | 0.05 | 0.03 | –0.07 | –0.57 | –1.71* | –1.91* | –0.32 | –1.13* |
| *Larsen Ice#* | | | | | | –0.05 | 0.15 | –0.45 | –3.22* | –0.89 |
| *Marambio* | | | | | | 0.05 | 2.09* | –1.00 | –0.32 | 0.40 |
| *Mawson* | –0.05 | –0.27 | 0.31* | 0.00 | –0.04 | –0.57 | –0.21 | 1.27* | 0.16 | 0.16 |
| *McMurdo* | 0.09 | 0.03 | 0.47* | 0.60* | 0.30* | 0.77 | –1.36* | –0.47* | 0.92* | 0.20 |
| *Mirnyj* | –0.08 | –0.24 | 0.29* | 0.15* | 0.03 | –0.66 | –1.09* | 0.47 | 0.04 | –0.31 |
| *Molodiozhnaya* | –0.19 | –0.25 | 0.32* | –0.06 | –0.04 | –0.11 | –0.20 | 0.66* | 0.39 | 0.18 |
| *Neumayer* | | | | | | –0.23 | –1.28* | 0.31 | 0.00 | –0.03 |
| *Nowolazarievskaya* | 0.24* | –0.05 | 0.26* | 0.13* | 0.05 | –0.57 | –0.87 | 0.27 | 0.01 | 0.12 |
| *O'Higgins* | | | | | | 0.26 | 0.71* | 0.09 | –0.27 | 0.26 |
| *Orcadas* | 0.26* | 0.45* | 0.61* | –0.12 | 0.30 | 0.17 | 0.53 | 0.56 | –0.30 | 0.24 |
| *Palmer* | | | | | | 0.27 | 0.98* | 0.92* | 0.33 | 0.63 |
| *Part* | | | | | | 0.39 | 0.83* | 0.29 | 0.01 | 0.38 |
| *Rothera* | 0.31* | 0.97* | 1.01* | 0.24* | 0.63* | 0.13 | 0.68* | 0.24 | 0.45 | 0.38 |
| *Risky* | | | | | | 1.64 | 0.40 | 0.87 | –0.33 | 0.64 |
| *SANAE* | 0.15* | –0.16 | 0.19 | –0.28* | 0.11 | –0.59 | –0.73 | –0.30 | –0.61 | –0.56 |
| *San Martin* | | | | | | 0.35 | 0.75* | 0.53 | 0.64* | 0.66 |
| *Scott* | 0.12* | 0.19 | 0.40* | 0.44* | 0.18 | –0.12 | –1.36 | 0.34 | 1.14* | 0.00 |
| *Signy* | 0.19* | –0.10 | 0.72* | –0.02 | 0.19 | –0.11 | 0.17 | 0.17 | –0.41 | –0.04 |
| *Syowa* | –0.18 | 0.51 | 0.18* | 0.07 | 0.07 | –0.12 | –1.21* | –0.03 | 0.09 | –0.25 |
| *Uranus Glacier#* | | | | | | 1.67* | 3.61* | 2.10* | 1.76* | 2.29* |
| *Vista* | –0.15 | –0.15 | 0.13* | 0.00 | 0.07 | –0.40 | –0.75 | 0.21* | –0.56 | -0.26 |

* – trend statistically significant at the level of 0.05, # – in the period 1986–2000.

The counted temperature anomalies in relation to the mean values from the period 1961–1990 show considerable variability in temperature over separate 5-year periods (Table 2). On the Antarctic Peninsula (*Faraday*, *Rothera*) the last 20 years of the 20$^{th}$ century were decidedly the warmest. At the *Halley* and *SANAE* stations

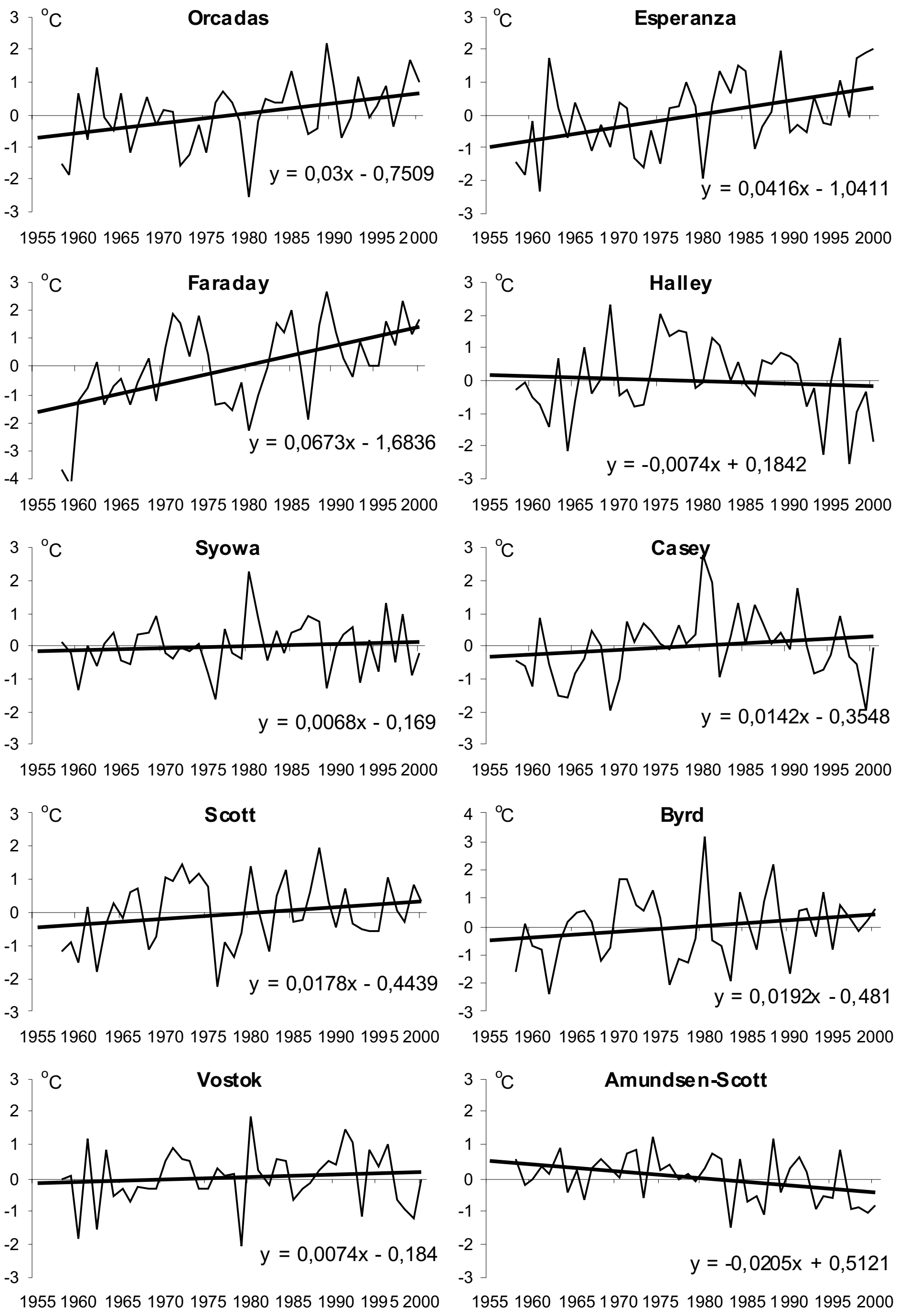


Fig. 7. Courses of air temperature anomalies and their linear trends at selected Antarctic stations during the period 1958–2000.

the 1970's years were the warmest, which is connected with the extensive polynya on the Weddell Sea (Enmoto and Ohmura 1990, Anderson 1993).

At the coast of East Antarctica (*Casey*), a considerably cooling appeared following the highest temperatures recorded at the turn of the 1970's and 1980's. Raper *et al*. (1984) consider the years 1971–75 as the warmest in the Antarctic. At the South Pole we can observe a successive decrease of the air temperature during recent years. On the highest parts of the glacial plateau (*Vostok*) the temperature oscillates insignificantly, without a distinct trend.

In the years 1958–2000 in the Antarctic the trend of the mean annual values of the air temperature shows great spatial differentiation (Table 3, Fig. 6). These differences are connected with the radiation balance depending on the variability of cloudiness and the albedo of the surface, and on the transformation of pressure fields and changes of the atmospheric circulation (King and Turner 1997).

Statistically significant (at the level 0.05) increases in air temperature were noted only in the region of the Antarctic Peninsula. The vast mountain massif, stretching along the Peninsula, is a climatic border in the region. The western coast is about 6°C warmer than the eastern part of the Antarctic Peninsula (Reynolds 1981). Climatic differences between the eastern and western coasts are connected with the extension of sea ice on the Bellingshausen and Weddell Seas (Jacobs and Comiso 1997, Styszyńska 1999) and with the specifics of the atmospheric circulation, disturbed by orographic factors in the region (Schwerdtfeger 1984). Disturbances in circulation lead to considerable variability in the air temperature on the Antarctic Peninsula (King 1994, Harangozo *et al*. 1994). Variations in the air temperature are influenced by the states of thermal field of the Bellingshausen Sea water (Styszyńska 2002).

Nevertheless, we can state that during the years 1958–2000 warming on the western coast of the Antarctic Peninsula reached 0.63°C/10 years at the *Rothera* station and 0.67°C/10 years at the *Faraday* station (Fig. 6 and 7). A slightly smaller temperature increase was noted at the northern part of the Antarctic Peninsula (*Esperanza* 0.42°C/10 years). The temperature rise in this region is connected with the intensification of western circulation and advection of warm air (Schwerdtfeger 1976). The change in the circulation causes an increase in cloudiness in the region (King 1994). Moreover, a significant temperature rise was noted at the *Belgrano* station on the coast of Weddell Sea (0.42°C/10 years) and at the *McMurdo* station by the Ross Sea (0.30°C/10 years).

A slight cooling occurred only at the coast of Antarctic in the Indian sector (*Davis* –0.08°C/10 years) and in the interior of the continent at the South Pole (*Amundsen-Scott*), where the temperature decreased by –0.21°C/10 years (Figs. 6 and 7).

In the climatic seasons we observe a different tendency of changes in air temperature. During the Antarctic summer (December–February) the temperature at the coastal part of the continent increases a little (*Esperanza* 0.35°C/10 years, *Rothera* 0.31°C/10 years, *Belgrano* 0.26°C/10 years and *Novolazarevskaya* 0.24°C/10 years), while in the interior of the continent cooling takes place, strongest at the South Pole (–0.26°C/10 years).

The autumn period is characterised by a significant decrease in temperature during the most recent decades, except for the Antarctic Peninsula and some coastal stations. The temperature decreased at the coast of East Antarctica, for example *Belgrano* (–0.47°C/10 years), *Dumont d'Urville* (–0.40°C/10 years), *Mawson* (–0.27°C/10 years), as well as in the centre of the Antarctic (*Amundsen-Scott* –0.23°C/10 years). At the same time on the Antarctic Peninsula and South Orkneys the temperature considerably increased (*Rothera* 0.97°C/10 years, *Esperanza* 0.80°C/10 years, *Orcadas* 0.45°C/10 years).

The temperature increased significantly almost over the whole continent, except the South Pole, during the winter season. On the Antarctic Peninsula at the *Rothera* station the temperature trend was 1.01°C/10 years, which means a 4.3°C temperature growth from 1958. In June at the *Faraday* station the temperature trend during the years 1944–1991 was 1.14°C (Smith *et al*. 1996). Significant warming occurred also at the other stations. In comparison to the years 1956–73 the temperature trend changed on the Dronning Maud Land, where considerable cooling was noted in winter, –0.25°C/10 years (van Loon and Williams 1977).

In spring a considerable temperature rise occurred on coast of the continent (*Belgrano* 1.23°C/10 years, *McMurdo* 0.60°C/10 years, *Scott* 0.44°C/10 years) and in the central regions of West Antarctica (*Byrd* 0.59°C/10 years). On the Antarctic Peninsula spring is characterised by lack of temperature change, and at some stations even by a small decrease (*Esperanza* –0.04°C/10 years).

In the Antarctic the air temperature in different seasons shows different trends. Only in the Antarctic Peninsula region is there an air temperature increase in every season, with a special intensification of this feature in the autumn-winter period. The winter trend in the Antarctic Peninsula is 2.5 times larger than in the summer (Stark 1994). In the central Antarctica a trend towards cooling of the climate dominates, at the coast a temperature growth is noted in winter and spring, while during summer and autumn at many of the stations there is colder and colder.

Different temperature changes in climatic seasons also have an influence on the annual amplitude of air temperature (Fig. 8). At the stations where a temperature increase has been noted during recent decades, at the same time decreases in the annual amplitude of the air temperature have occurred. For example at the western coast of the Antarctic Peninsula the annual amplitude became smaller by –1.28°C/10 years at the *Faraday* station and –1.03°C/10 years at the *Rothera* station, which means a decrease of the amplitude by about –5°C from 1958. The reason for the decreasing annual amplitudes is the growth of winter temperatures in this region (King 1994). At the northern edge of the Antarctic Peninsula (*Esperanza* station) the amplitude shows a large year-to-year variability. Decreases in the annual amplitude occur over the whole West Antarctica and at the coast of East Antarctica. The lessening annual amplitude indicates the growing oceanism of the climate.

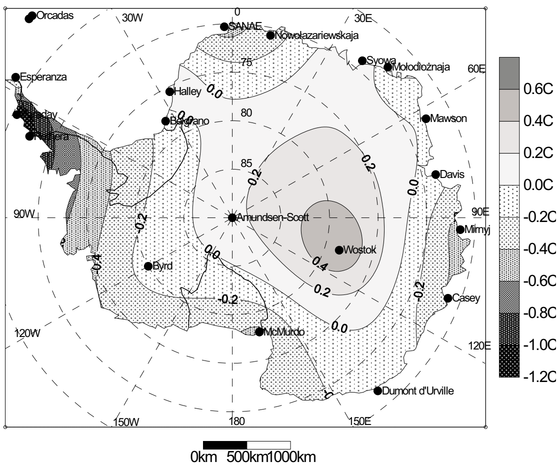


Fig. 8. Trends in annual amplitude of the air temperature (°C/10 years) in the Antarctic during the periods 1958–2000.

In the interior of the continent the annual amplitudes of the air temperature grow. At the *Vostok* station from 1958 the amplitude increased by 2.6°C (0.61°C/10 years). The growing continentalism of the climate can also be observed at the South Pole and at the *Halley* station, where a significant cooling is observed.

## Changes in temperature trends in the years 1981–2000

A clear turning point in the course of air temperature in the Antarctic was the beginning of the 1980's. In the region of the Antarctic Peninsula a violent increase in temperature began, while on the coast of East Antarctica a distinct cooling could be observed. We can look for the reason for these changes in the appearance of stratospheric ozone anomalies above the Antarctic (Farman *et al*. 1985). Together with the ozone depletion the temperatures in the stratosphere began to decrease (Aleksandrov and Majstrova 1998). From the end of the 1970's the temperature in the stratosphere decreased by 1–2°C/10year, mainly in the spring (Koshelkov 1992), but these changes can also be observed in summer (Trenberth and Olson 1989). The disturbances in the stratosphere and troposphere caused a change in the height of geopotential surfaces (Marshall 2002) and a rebuilding of the air circulation system in the Antarctic region. The vortex in the polar regions exhibits a general pattern of expansion from 1958 through the early 1980s (Burnett and McNicoll 2000).

From the second half of the 1970's the Semiannual Oscillation (SAO) of air pressure considerably weakened (van Loon 1993, Hurrel and van Loon 1994), and as a consequence the meridional exchange of air masses between the Antarctic and lower latitudes of the Southern Hemisphere lessened. In effect in some regions

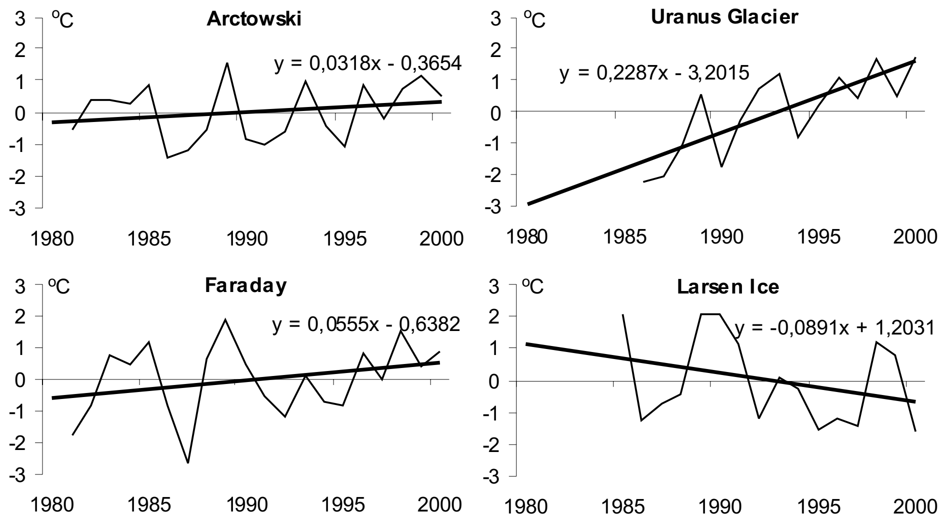


Fig. 9. Courses of air temperature anomalies and their linear trends at selected stations in the Antarctic Peninsula area in the period 1981–2000.

considerable temperature falls were noted. The growing surface of sea ice in the years 1979–1996 confirms this cooling (Cavalieri *et al*. 1997).

The violent growth in air temperature on the western coast of the Antarctic Peninsula somewhat weakened (Timofeyev *et al*. 2002) – *Esperanza* 0.28°C/10 years, *Rothera* 0.38°C/10 years, *Faraday* 0.56°C/10 years, *Palmer* 0.63°C/10 years (Table 3, Fig. 10). This is confirmed in the studies by Jones (1995). In the South Shetland Islands (*Arctowski* and *Bellingshausen* stations) the increasing temperature trend was slowed down in winter and spring. This is connected with the cold winters in 1991, 1992 and 1995 and with the cool springs in 1994, 1995, 1997, and 1998. The considerable cooling in this region is connected to the advection of frosty air masses inflowing from the south and southeast (Kejna 1999) along the Antarctic Peninsula in the form of barrier winds (Schwerdtfeger 1984).

West Antarctica is still warming (*Byrd* 0.45°C10 years). In some regions the changes are dramatic. For example the *Uranus Glacier* station shows warming 2.29°C/10 year (Fig. 9). However this increase might be conditioned by local factors.

In the East Antarctica, with the exception of Enderby Land, a considerable climatic cooling can be noticed (Fig. 10). The biggest temperature decrease was noted on the Wilkes Land (*Casey* –0.82°C/10 years, *Dumont d'Urville* –0.64°C/10 years) and in the basin of the Weddell Sea (*Halley* –1.13°C/10 years), as well as the eastern coast of the Antarctic Peninsula (Larsen Ice –0.89°C/10 years). This is caused by the changes that took place in the circulation system in this region of the Antarctic. The around-Antarctic trough does not move as far to the south (weaken-

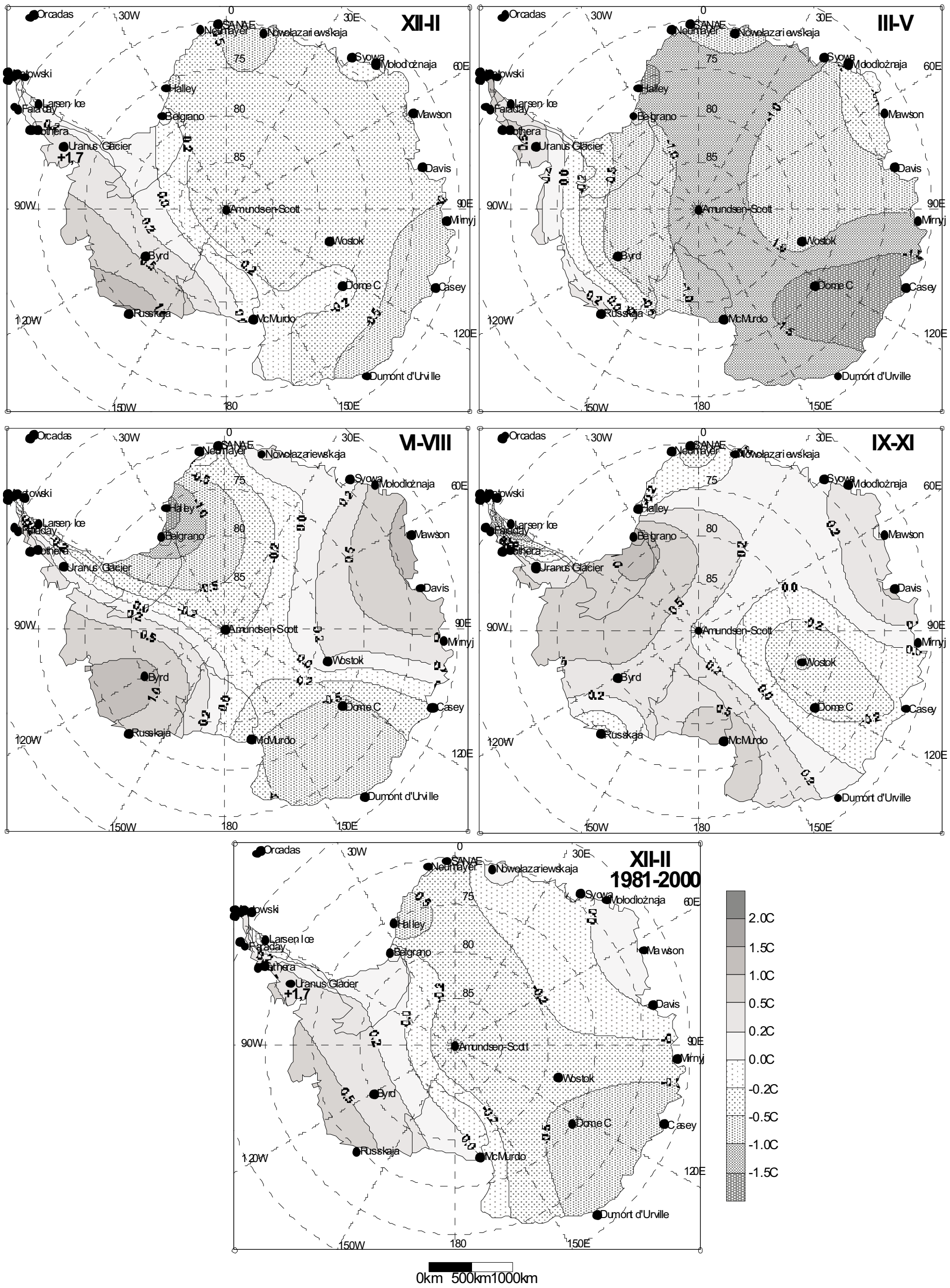


Fig. 10. Seasonal and yearly trends of air temperature (°C/10 years) in the Antarctic during the period 1981–2000.

ing SAO), and therefore the coast of the continent is under the influence of frosty air masses from inside of the continent (van den Broeke 2000).

The trends towards cooling is also strengthened in the centre of the continent in recent years (*Dome C* –0.71°C/10 years, *Amundsen-Scott* –0.42°C/10 years, *Vostok* –0.26°C/10 years). This is confirmed by satellite data, which show decreases in temperature by –0,34°C per decade over the East Antarctica for the period 1979–98 (Cosimo 1999).

In summer tendencies toward cooling have intensified over almost the whole East Antarctica coast (for example. *Casey* –0.92°C/10 years, *Mirnyj* –0.66°C/10 years, SANAE –0.59°C/10 years), as well as in the interior of the continent (*Amundsen-Scott* –0.49°C/10 years, *Vostok* –0.40°C/10 years). Rising temperatures were noted only on the NW coast of the Antarctic Peninsula (*Esperanza* 0.48°C/10 years, *Arctowski* 0.37°C/10 years). In the central part of the Peninsula the warming was slight (*Faraday* 0.05°C). A considerable temperature rise occurred in the West Antarctica (*Byrd* 0.38°C/10 years and *Russkaya* (growth by o 1.6°C in the years 1980–1990), and especially at the *Uranus Glacier* station (1.67°C/10 years).

In autumn the cooling tendency becomes even stronger. Very large temperature falls were noted along the whole coast from the *Belgrano* (–0.70°C/10 years) and *Halley* (–1.71°C/10 years) stations through *Casey* (–1.93°C/10 years), *Dumont d'Urville* (–1.82°C/10 years), and as far as the *Scott* station (–1.36°C/10 years). In the interior of the continent the temperature decrease in autumn is also large (*Dome C* –1.82°C/10 years, *Amundsen-Scott* –1.14°C/10 years and *Vostok* –0.75°C/10 years). On the other hand, on the Antarctic Peninsula a considerable temperature rise was noted in autumn, for example at *Esperanza* (1.62°C/10 years), *Marambio* (2.09°C/10 years), *Palmer* (0.98°C/10 years) and the biggest growth at the *Uranus Glacier* station (3.61°C/10 years).

During the winter period, which was characterised by a temperature increase in the years 1958–2000, the last 20 years have shown considerable cooling in many regions, for example in the basin of the Weddell Sea (*Belgrano* II –1.43°C/10 years, *Halley* –1.91°C/10 years) and on the eastern coast of the Antarctic Peninsula (*Marambio* –1.0°C/10 years, *Larsen Ice* –0.45°C/10 years) and in Wilkes Land (*Dumont d'Urville* –0.73°C/10 years). The temperature increased in the Maria Byrd Land (*Byrd* 1.31°C/10 years) in the West Antarctica, together with the western coast of the Antarctic Peninsula (*Faraday* 1.13°C/10 years) and in the Enderby Land (*Mawson* 1.27°C/10 years). There were no significant temperature changes in the centre of the continent.

In spring the positive temperature trend changed to negative. Large temperature falls were noted in the highest parts of the glacial plateau of the Antarctic (*Dome C* –0.28°C/10 years, *Vostok* –0.56°C/10 years) and on the eastern coast of the Antarctic Peninsula (*Larsen Ice* –3.22°C/10 years) and at the SANAE station (–0.41°C/10 years). In the remaining regions of the Antarctica temperature rise was noted (*Belgrano* II by 1.54°C/10 years, *Faraday* by 0.73°C/10 years, and *Scott* by 1.14°C/10 years.

## Summary and discussion

Data from Antarctic stations have been accepted by many authors uncritically, without checking the homogeneity of the measurement series. The applied Alexandersson (1986) test showed that at half of the analysed stations there were breaks in the homogeneity of the data sets. In some cases these breaks can be confirmed by information about the relocation of the station and by changes in the observational methods (metadata). The exchange of standard observations to automatic ones during the last years is also a great problem. In some cases we could not find the reason for the break in homogeneity. For example for the *Faraday* station we found that in 1966 the temperature, in comparison to the reference stations, grew by 1.34°C. In spite of the analysis of our observational registers from the station we could only state that the relocation of the station in 1954 by 700 m to the north did not cause a homogeneity break in the measurement series.

In analysing temperature trends the temperatures at the beginning and end of the period are significant. The years 1958–1962 in the Antarctica were especially cold (Raper *et al*. 1984), while the end of the 20th century was characterised by considerable regional differentiation.

The problem of climate changes in the Antarctic has been analysed in many papers, for example: Limbert (1974), Mayes (1981), Raper *et al*. (1984), Ackley *et al*. (1996), van den Broeke (2000), and Marshall *et al*. (2002). The results obtained confirm the air temperature rise in the West Antarctic signalised in earlier papers, especially on the western coast of the Antarctic Peninsula (Carleton 1981, Jones *et al*. 1986, Jones and Wigley 1988, Sansom 1989, Jones 1990, Martianov and Rakusa-Suszczewski 1990, Jacobs and Comiso 1997, King 1994, Stark 1994, Smith *et al*. 1996, Kejna 1999). This rise mainly comes from the temperature increase in the autumn-winter period. Summer temperatures have less influence, while in spring there is no significant trend. The temperature changes in the region of the Antarctic Peninsula are correlated with the extension and surface of sea ice, especially in winter (Weatherly *et al*. 1991). Sea ice, due to its high albedo, restricts the solar energy absorbed by the ocean and reduces the heat exchange between the ocean and the atmosphere (King 1984). In spite of the great variability of the sea ice extension, its surface area gets smaller on the Bellingshausen Sea (Jacobs and Comiso 1997) and just therefore the biggest air temperature increase is noted in winter. Winter ice influences the spring, and even the summer temperatures (Weatherly 1991). The warmer and warmer winters lead to a considerable decrease of the annual air temperature amplitude (King 1994). This indicates the growing influence of circulation factors in forming the climate on the western coast of the Antarctic Peninsula. In this region the decrease of atmospheric pressure (Jones and Wigley 1988), increasing cyclonic activity, intensification of western winds (Raper *et al*. 1984), and higher frequency of maritime air masses can be observed. The cloudiness also grows (King 1994) and in effect leads to a warming up of the climate and decreasing the annual amplitude of the air temperature.

For the South Orkneys region, for which we have an almost 100 year-long series, it can be stated that the first part of the 20th century was characterised by low air temperatures. Especially cold was the decade of the 1920's years with temperatures 1.1°C lower than the mean value for the whole measurement period (Petrov and Ljubarskij 1980). From this moment the temperature in the South Orkneys grows systematically. Only in the 1970's years did there appear a slight cooling. The highest temperatures (–3.1°C) occurred in the last two decades of the 20th century. For the whole observational period the mean trend of air temperature was 0.21°C/10 years, and taking into account the period 1958–2000 it grew to 0.30°C/10 years, while in the last 20 years it decreased to 0.24°C/10 years. In the region of South Orkneys an inverse relation was found between the temperature and atmospheric pressure. Besides, there is a clear periodicity in the temperature course in connection with the half year pressure oscillation (SAO), which shows a 12 and 35 years periodicity (van den Broeke 1998). The temperature also shows a strong negative relationship with the sea ice extension (Petrov and Ljubarskij 1980, Schwerdtfeger 1984). Changes in the ice extension especially influence the winter and spring temperatures. Unfortunately the almost 100 year-long observational series from *Orcadas* can not be representative for the rest of the Antarctica (Raper *et al*. 1984).

Progressive warming occurs over almost the whole West Antarctica, with the exception of the Weddell Sea basin. In the Maria Byrd Land a distinct temperature rise occurred, especially during the winter and spring months. This tendency especially intensified after 1980, when the temperature began to increase in the summer as well. The annual amplitude became less and a greater oceanic influence can be seen in this region. A very large temperature rise was noted in Alexander Island (*Uranus Glacier* station).

The Weddell Sea, permanently covered with ice, causes the eastern coast of the Antarctic Peninsula as well as stations located on the southern coast of this sea to be characterised by specific climate conditions. On the eastern coast of the Antarctic Peninsula the advection of cold air masses from south is frequent and in effect the temperature there is considerably lower then on the western coast, in winter even by 10°C (Schwerdtfeger 1984). The weather conditions show large year-to-year variability in connection with the sea-ice surface (Smith *et al*. 1996). On the basis of data from automatic stations (*Larsen Ice*) we can state that the climate there cools considerably. The colder and colder winters and springs influence this. The summer and autumn periods do not show significant trends.

Stations situated near the shelf glaciers Ronne/Filchner (*Belgrano II*) and the Ross glacier (*McMurdo* and *Scott*) show a rise in temperature by 0.3–0.4°C/10 years. The studies of snow/ice temperatures at 10 m depths confirm this trend. On the Ross Ice-Shelf glacier the temperature increased by 2°C during 16 years (Schwerdtfeger 1984).

The East Antarctica is covered by vast ice sheets with heights to 4000 m above sea level. The influence of the surrounding seas on the compact surface of East Antarctica is limited by the extent belt of sea ice. Therefore the influence of the Southern Ocean is limited to a narrow coastal belt (King and Turner 1997). On the coast the temperature trends are statistically insignificant. Significant temperature changes were noted only after 1981. On the coasts of the Wilkes Land and the Weddell Sea the temperature clearly decreased, especially in the autumn-winter period: for example in May the temperature at the *McMurdo* station decreased by 6.3°C in the years 1984–1993 (Aleksandrov and Majstrova 1998). On the Enderby Land the temperature increased.

The interior of the continent is characterised by considerable stability in weather conditions. Year-to-year temperature changes are smaller than on the coast. In spite of this, the temperature at the South Pole fell distinctly in the years 1968–2000 (–0.21°C/10 years). At the *Amundsen-Scott* station cooling can be observed in all seasons, but it is greater in the summer and autumn, when a decrease in solar radiation was observed in connection with the growing cloudiness after 1976 (Dutton *et al*. 1991). Rogers and van Loon (1982) stated that the intensification of western winds around the Antarctic leads to temperature falls in the interior of the continent. Together with the cooling the amplitude of annual temperature grows, which confirms the increasing influences of continentalism. *Vostok*, situated at the highest parts of ice dome, does not show a statistically significant trend. Considerable cooling, especially in autumn, occurred there only during the last 20 years.

Climate changes during the last 20 years of the 20$^{th}$ century have shown a weakening of the warming rate on the Antarctic Peninsula and a distinct cooling in the East Antarctica. Due to the great regional differentiation we can not state unequivocally in which direction the air temperature changes will proceed in the Antarctic. Counting the mean trends for the whole continent seems to be unauthorised. For example Jacka and Budd (1998) estimated the warming being 1.2°C/100 years for the period 1959–98, van den Broeke (2000) estimates this trend 1.3°C/100 years, while the mean trend on the Southern Hemisphere is 0.57°C/100 years (Jones *et al*. 1999).

An additional factor complicating the unequivocal characterisation of air temperature changes on the Antarctic is the influence of long scale oceanic-atmospheric phenomena. On the Pacific Ocean ENSO (El Nino-Southern Oscillation) functions for a period of a few years. Changes in the pressure field in the southern Pacific do not remain without influence around the Antarctic furrow of low pressure, and further will influence the atmospheric circulation, especially on the coast of the continent. The relocation of the circumpolar trough and subtropical wedges of high pressure appears in the Antarctic in the form of half-year pressure oscillation (SAO). Savage *et al*. (1988) even confirmed a statistical relation between the phases of SOI and the temperature at the South Pole. The influence of ENSO can also be found in ocean water temperature, frequency of meridional winds, and extension of sea ice (Simmonds and Jacka 1995). A 3–4 months delay was confirmed between the extension of sea ice and SOI, and in the case of temperature the dependence is equivocal (Smith *et al*. 1996).

Moreover various circulation indices have been designed and related to the climate variation in the Antarctic. Zonally-symmetric "see-saws" in air pressure between high and middle latitudes exist in the Southern Hemisphere. The zonal circulation index AAO (Antarctic Oscillation) has the potential to clarify climate regimes in Southern Hemisphere (Gong and Wang 1998). Antarctic Circumpolar Wave (ACW) moves around the continent (White and Peterson 1996), causing periodical changes in the temperature of sea water and air.

The increasing air temperature in the West Antarctic, especially in the Antarctic Peninsula, has brought about many natural consequences. The ablation of glaciers has clearly intensified, deglaciation takes place and glaciers are in retreat (Doake and Vaugham 1991, Kejna *et al*. 1998, Battke *et al*. 2001, Birkenmajer 2002). Some areas are becoming free of ice and a decay of shelf glaciers occurs, for example at *Larsen-A* (Vaughan and Doake 1996). The temperature of the oceans is rising. On the basis of satellite images from the years 1979–98 Cosimo (1998) found that, the ocean surface temperature in this region is growing at a rate of 0.54°C/decade. The extension and thickness of the sea ice is becoming smaller. In the region of the Antarctic Peninsula during the last 40 years the border of sea ice moved by 1°S (Gloersen and Campbell 1988), while isotherms at every 1°C by 1.5°S (Jacka and Budd 1991). There are changes in the circulation of air masses, the intensity of western winds are growing and the frequency of cyclones moving more and more frequently deep into the interior of the continent is increasing (Schwerdtfeger 1984).

The environmental changes lead to disturbances in the functioning of the Antarctic ecosystem (Rakusa-Suszczewski 1999, 2002). The uncovered areas under glaciers produce vegetation (Olech 1998, Lewis-Smith 2002), and new species of plants and animals appear. The population of species strictly connected with the border of sea ice – penguins (Ciaputa 1998) and seals – changes together with the changes of the sea ice extension (Fraser *et al.* 1992). On the Bellingshausen sea the period of ice-free water elongated in the years 1973–93 by one month (Jacobs and Comiso 1997).

The lack of warming, or even cooling, on the East Antarctica is favourable to maintain the present climate system in this region.

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