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VARIABILITY OF AIR TEMPERATURES OF THE TEMPERATE CLIMATIC BELT OF THE BESKID SĄ DECKI MOUNTAINS IN THE PERIOD 1971-2000 AS EXEMPLIFIED BY THE CLIMATOLOGICAL STATION IN KOPCIOWA

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ABSTRACT

The analysis of air temperatures from the period 1971-2000, recorded at the Kopciowa station near Krynica in the Beskid Sądecki Mountains (φ = 49° 27' N and λ = 20° 58' E) demonstrated that the highest temperature variability was characteristic of mean temperatures of cold months, particularly those of January and February. The coldest month of the 30-year research period was January (with the average temperature of -4.8 °C), while the warmest was July (with the average temperature of 14.9 °C). The highest increase of mean monthly temperature occurred in April (2.1 °C / 30 years), whereas the biggest drop was in December (-1.6 °C / 30 years). Mean annual amplitude, understood as the difference between mean monthly temperatures of the

warmest and coldest months of the year, increased during the period under research by 2.5 °C. Temperatures of spring, summer, autumn and mean annual temperatures were characterized by positive trends (0.6 °C / 30 years). Average winter temperatures were characterized by negative trends (-0.7 °C / 30 years). Results of research indicate a warming of the climate during the investigated 30 years and continentalization of the climate's thermal features.

Key words: Beskid Sądecki, air temperature, trend

INTRODUCTION AND AIM OF RESEARCH

Analysis of various climatic parameters in time function and together with their variability within space allows researchers to describe the dynamics of atmospheric processes. The long- and short-term fluctuations of air temperature determine the characteristic feature of the climate showing its instability.

Research on temperature tendencies has become very important in the context of the global warming of the troposphere. The over 100-year data sequences are particularly helpful in providing valuable information as they allow the researchers to assess the long-term fluctuations and directions of temperature changes [16, 18]. Equally important are the analyses of short-term series of measurements involving several decades. On such basis we obtain information about short-term fluctuations and tendencies in the changes of local thermal conditions. Analyses of several decade sequences are especially significant for the characterization of mountain climate [11, 15]. In the mountainous regions, the dynamics of the process of energy exchange between the atmosphere and its substratum becomes complicated by the diversified surface features.

The aim of this research was to obtain a characterization of thermal conditions and their variability in the cool temperate climatic belt of the eastern part of the Beskid Sądecki Mountains in the period 1971-2000. The period included the 1991-2000 decade, which was one of the warmest of the last century.

METHODS

The introductory material consisted of the results of temperature measurements conducted in the meteorological station located in an open space, in the area of the Krynica Forest Research Station, forest district of Kopciowa. The station is located in the cool temperate climatic belt [5] at the altitude of 720 meters, on a mountain ridge inclined slightly eastward (5°). The geographical locations of the station is as follows: φ = 49° 27' N and λ = 20° 58' E. The station represents a convex form of terrain.

The station has a full record of measurements from the investigated period. Uniformity of measurement series of mean annual temperatures was checked against data from the Meteorological and Hydrological Institute meteorological station in Nowy Sącz.

The researchers analyzed the values of mean temperatures, the measure of their variability and determined the directions and values of trends for the 30-year period under research. They used mean monthly, seasonal and annual temperatures. The winter season included December, January and February. Spring included March, April and May, summer - June, July and August and autumn - September, October and November. Average values from the 30 -year period were accepted as standards.

RESULTS

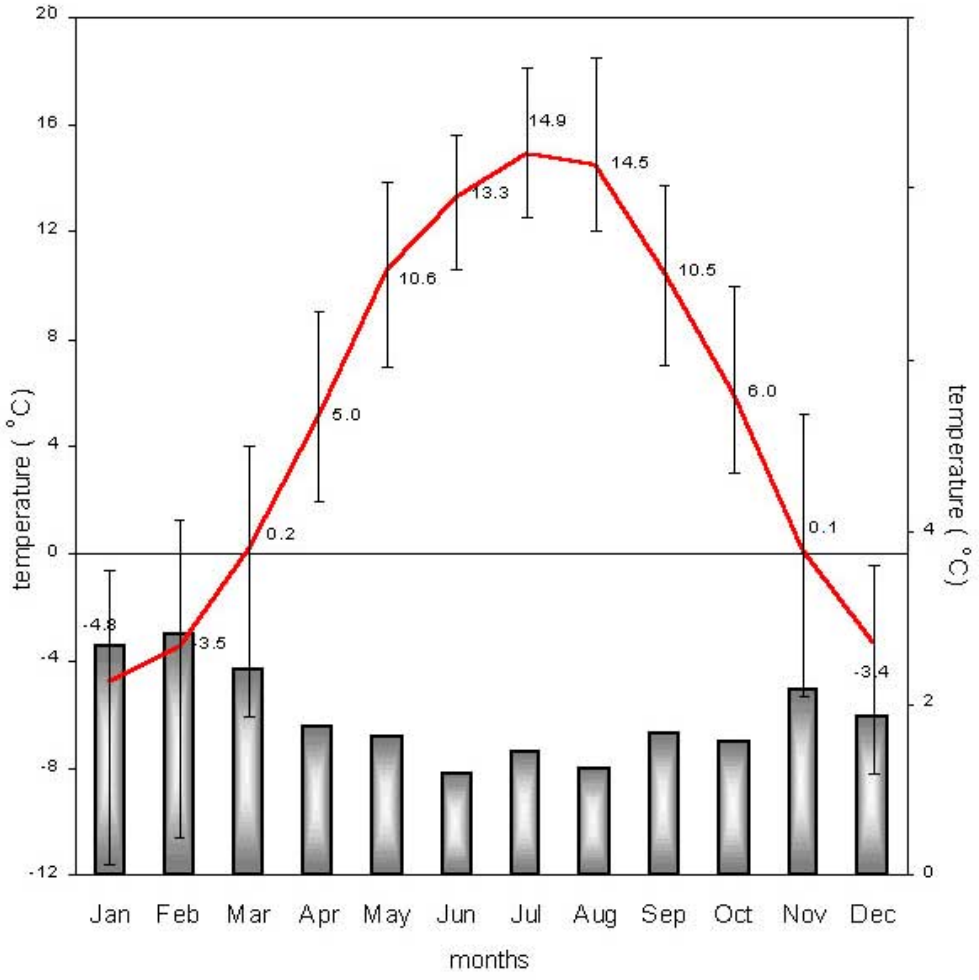
Mean temperatures of the cold months (November through March), particularly those of January and February were characterized by the highest variability. The smallest fluctuations of mean temperatures, was found for the warm months (June through August). In the case of these months, the scale of variability was almost twice as small as in the case of winter months (Table 1). Mean temperatures of March and November were characterized by a relatively high variability (Fig. 1).

Table. 1. Values of climatic elements in the years 1971–2000

Year	Mean of air temperature (°C)							Mean of year amplitude (°C)
	Season				Year	Most cool month	Warmest month	
	Winter	Spring	Summer	Autumn				
1971	–	5.0	14.2	4.5	5.4	–3.1(Feb)	15.7(Aug)	18.8
1972	–2.1	6.3	14.6	4.2	5.6	–5.6(Jan)	16.3(Jul)	21.9
1973	–2.4	4.8	13.9	4.5	5.0	– 4.1(Dec)	14.6(Aug)	18.7
1974	–2.4	5.2	13.3	4.7	5.4	–3.2(Jan)	15.7(Aug)	18.9
1975	–2.5	5.9	14.3	6.1	5.9	–4.7(Feb)	15.5(Jul)	20.2
1976	–4.7	3.8	13.3	6.5	4.7	–6.2(Jan)	15.3(Jul)	21.5
1977	–2.9	5.4	13.5	5.6	5.3	– 4.8(Dec)	13.7(Jul)	18.5
1978	–4.9	4.2	12.5	4.7	4.2	–5.4(Feb)	13.0(Jul)	18.4
1979	–5.1	5.4	13.9	5.2	5.2	–7.0(Jan)	15.6(Jun)	22.6
1980	–3.8	2.5	13.2	4.5	3.8	–8.3(Jan)	13.7(Jul)	22.0
1981	–5.2	5.7	14.3	5.9	5.2	–7.1(Jan)	14.7(Jul)	21.8
1982	–6.0	4.7	14.9	7.5	5.5	–7.5(Jan)	15.5(Aug)	23.0
1983	–2.6	7.3	14.9	5.2	6.1	–5.0(Feb)	16.3(Jul)	21.3
1984	–3.6	4.5	13.0	6.8	5.1	–4.4(Feb)	14.4(Aug)	18.8
1985	–8.0	5.8	13.5	4.6	4.2	– 10.6(Feb)	14.8(Jul)	25.4
1986	–5.0	6.7	14.1	6.0	5.1	–9.3(Feb)	15.0(Aug)	24.3
1987	–6.8	2.5	14.3	6.7	4.4	– 11.6(Jan)	16.4(Jul)	28.0
1988	–1.9	4.6	14.5	3.8	5.3	– 5.3(Nov)	16.4(Jul)	21.7
1989	–2.3	6.9	14.1	6.2	6.3	–3.6(Jan)	15.2(Jul)	18.8
1990	–1.4	6.6	14.1	5.7	6.1	– 3.8(Dec)	14.6(Aug)	18.4
1991	–4.8	4.4	14.7	6.2	5.0	–6.7(Feb)	16.3(Jul)	23.0
1992	–3.9	5.1	16.4	5.1	5.8	–4.1(Jan)	18.5(Aug)	22.6
1993	–4.3	5.6	13.7	5.0	5.2	–5.1(Feb)	14.3(Aug)	19.4

1994	–2.0	5.9	15.7	6.1	6.3	–4.3(Feb)	18.1(Jul)	22.4
1995	–2.5	4.5	15.0	4.7	5.2	–5.2(Dec)	17.0(Jul)	22.2
1996	–6.5	4.6	14.0	5.5	4.1	–8.2(Dec)	14.4(Aug)	22.6
1997	–6.2	4.4	13.9	4.5	4.6	–8.4(Jan)	14.4(Aug)	22.8
1998	–1.7	5.6	15.0	4.8	5.6	–6.8(Dec)	15.3(Jul)	22.1
1999	–4.9	6.5	15.5	6.4	6.2	–4.3(Feb)	17.2(Jul)	21.5
2000	–3.8	7.1	14.9	8.2	6.8	–5.8(Jan)	16.0(Aug)	21.8

Fig. 1. Thermal diagram for Kopciowa station (1971-2000). Mean monthly temperatures (dash line); highest and lowest values of mean monthly temperatures (vertical sections); standard deviation of mean monthly temperatures (bars)



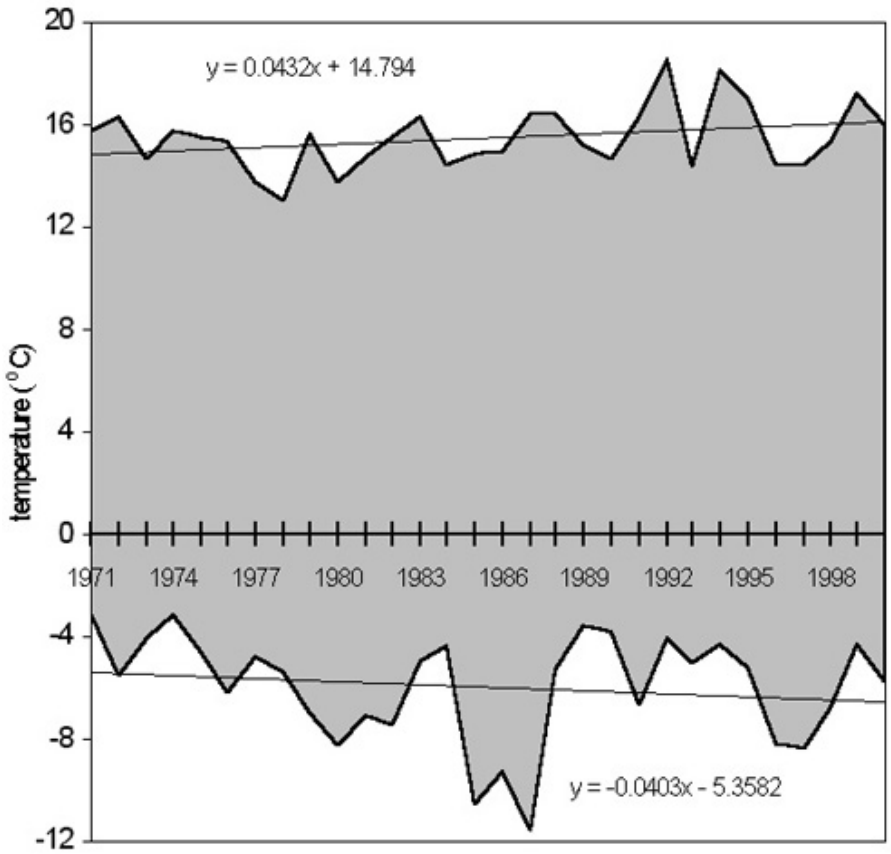
January was most often the coldest month of the year. It happened 12 times (Table 1) within the research period. The average multiyear temperature of January was -4.8 °C. The lowest value was reached in 1987 (-11.6 °C). The warmest January, with the average temperature of -0.6 °C (Fig. 1) occurred in 1994. The second coldest month was February, with the average multiyear temperature of -3.5 °C (Fig. 1). February was actually the coldest month 11 times during the 30-year period. In six cases, December had the lowest mean monthly temperature

of the year. It happened as many as four times within the last decade. Only once, in 1988, November was the coldest month.

Most frequently (as many as 17 times) the warmest month of the year was July. August was the warmest 12 times, whereas June had the highest mean monthly temperature only once, in 1979 (Table 1). The coldest July, with mean temperature of 12.5 °C was in 1979 (Fig. 1) while the warmest one (18.1 °C) happened in 1994 (Table 1). During the 30-year period, the highest mean temperature occurred in August of 1992 (18.5 °C). The average multiyear temperature of July was 14.9 °C, whereas the average multiyear temperature of August was lower: 14.4 °C (Table 1).

The variability of mean temperatures of the warmest and particularly the coldest month was the cause of relatively high fluctuations of mean annual amplitudes. The highest value was reached in 1987 (28.0 °C). It was caused by a very cold January. The smallest values of annual amplitude (18.4 °C) occurred in 1978, when the temperature of the warmest month was the lowest in 30 years (Table 1, Fig. 2). Mean annual amplitude for the 30-year period under research was 19.7 °C (Table 1).

Fig. 2. Course of mean monthly temperatures of warmest and coldest months and trend lines (dash lines). Mean annual amplitudes (gray area)



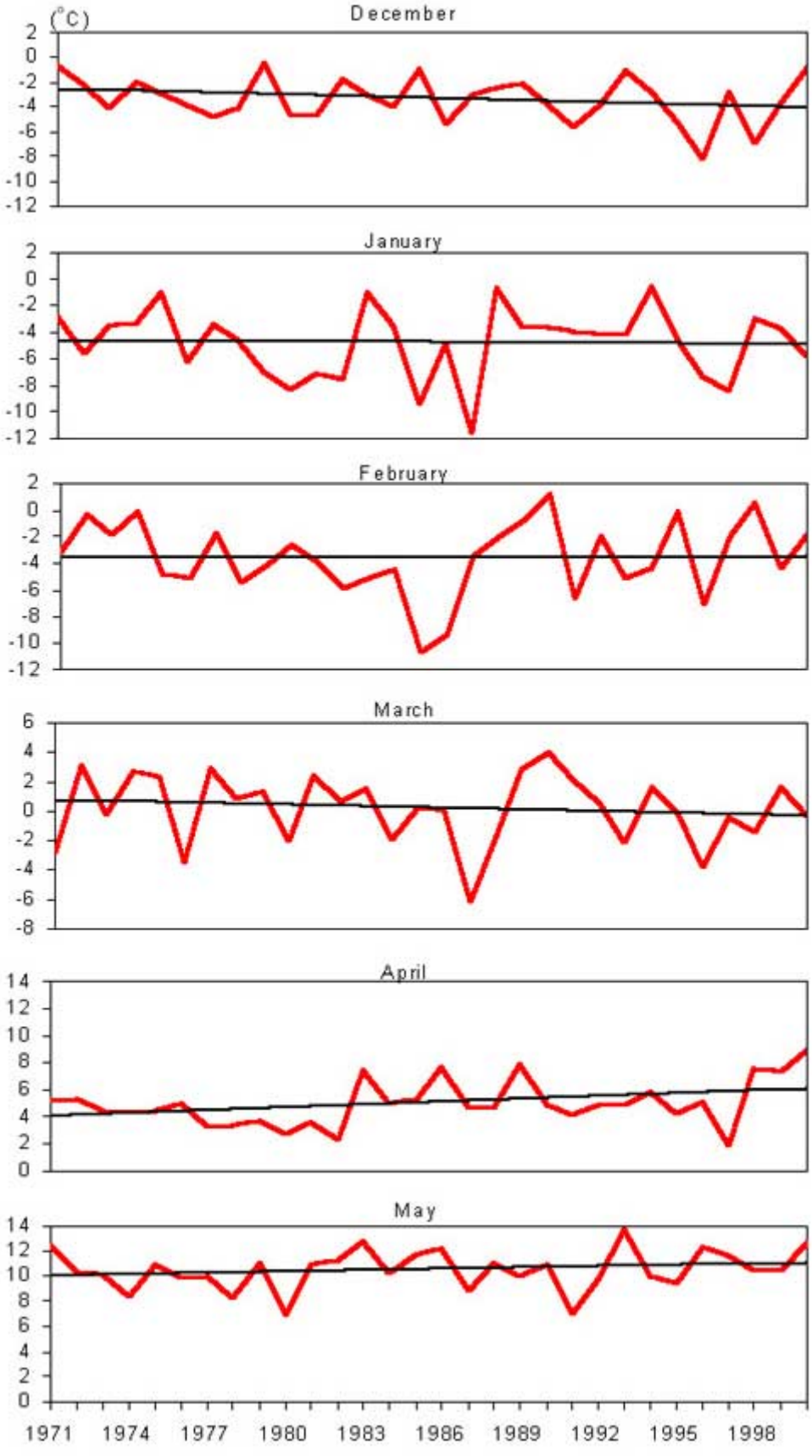
Two distinct patterns can be observed in the course of mean temperatures of the warmest and coldest months. The tendency in temperature changes of the warmest months is positive, while that of the coldest ones - negative. This was the reason why the annual amplitudes rose within last 30 years by as much as 2.5 °C.

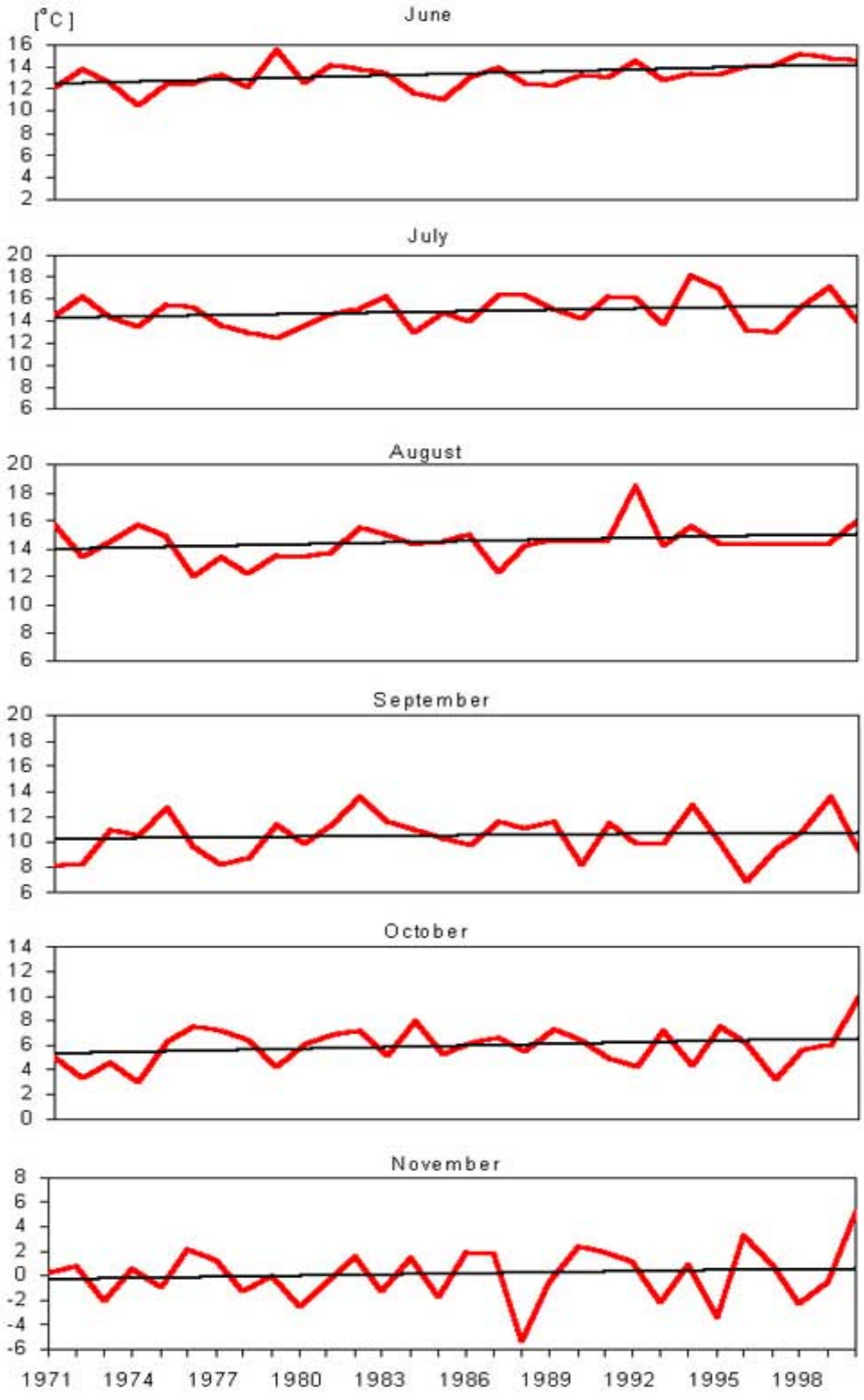
The above mentioned facts make the researchers suspect that on convex forms of terrain of the Beskid Sądecki Mountains we can talk about a rising trend for summer temperatures and a declining one for winter temperatures. In order to examine this phenomenon more closely, the researchers calculated the 30-year mean temperature trends for each month. It was thus determined that the temperatures of December, January and March had a negative tendency, the strongest one occurring in December (-1.6 °C / 30 years). In the remaining months of the cold 6-month period the tendency had a positive character (Table 2, Fig. 3). Mean monthly temperatures of the warm 6-month period indicate rising tendencies. In the 30-year period, the highest increase of mean temperature occurred in April (2.1 °C) and June (1.9 °C) (Table 2, Fig. 3).

Table. 2. Trends for mean monthly, seasonal and annual temperatures in Kopciowa in the period 1971-2000

Period	Equation of trend line	Value of trend
January	y = –0.0145x – 4.5559	–0.3
February	y = 0.0059x – 3.6021	0.3
March	y = –0.0366x + 0.7239	1.1
April	y = 0.0723x + 3.9186	2.1
May	y = 0.0344x + 10.024	1.0
June	y = 0.0656x + 12.28	1.9
Jule	y = 0.0388x + 14.299	1.1
August	y = 0.0385x + 13.9	1.1
September	y = 0.0177x + 10.182	0.5
October	y = 0.0432x + 5.2837	1.3
November	y = 0.0304x – 0.3407	0.9
December	y = –0.053x – 2.5416	–1.6
Winter	y = –0.0231x – 3.5943	–0.7
Spring	y = 0.0234x + 4.8888	0.7
Summer	y = 0.0476x + 13.493	1.4
Autumn	y = 0.0304x + 5.0416	0.9
Year	y = 0.0202x + 4.9643	0.6

Fig. 3. Course of mean monthly temperatures with trend lines

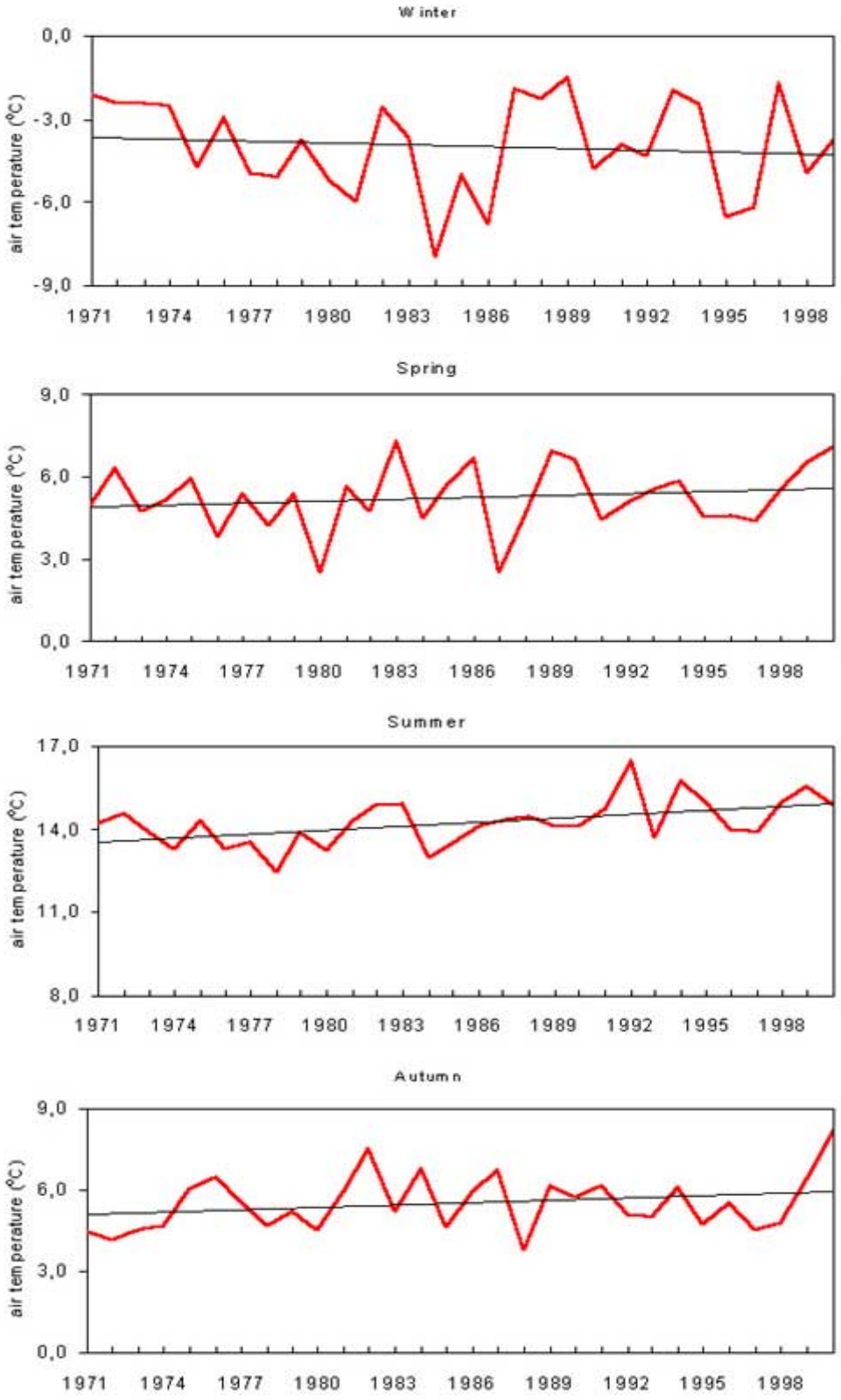




The course of mean seasonal temperatures is determined by the tendencies of particular months. Only mean temperatures of winters (December through February) indicate a negative tendency (Table 2, Fig. 4), whereas the trends of mean temperatures of other seasons have positive values. The biggest increase was recorded for summer (June through August) and a slightly smaller one for autumn and spring (Table 2, Fig. 4).

Seasonal temperatures varied in a relatively large range. Mean temperatures fluctuated from -8.0 °C (1985) to -1.4 °C (1990) for winter, from 2.5 °C (1980 and 1987) to 7.3 °C (1983) for spring, from 12.5 °C (1978) to 16.4 °C (1992) for summer, and 3.8 °C (1988) to 8.2 °C (2000) for autumn (Table 1).

Fig. 4. Course of mean temperature of winter, spring, summer and autumn with trend lines



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Mean annual temperature in the 30-year period was 5.3 °C and its standard error: 0.13 °C. Temperatures fluctuated from 3.8 °C (1980) to 6.8°C (2000) (Table 1). In 37% of cases they were within the range 5.1 °C - 5.5 °C. The frequency of occurrence of values higher or lower than the average was almost the same (Fig. 5).

The following years were considered as cold years: 1976, 1978, 1980, 1985, 1987, 1996 and 1997. In these years the mean annual temperatures were significantly lower than the multiyear average (Fig. 6). The dominance of warm years in the last decade (1983, 1989, 1990, 1992, 1994, 1999, 2000) was the cause of the positive tendency of annual temperatures (0.6 °C / 30 years) (Table 2, Fig. 6). This tendency is also confirmed by the increasing values of mean temperatures of subsequent decades. The average for the period of 1971-1980 was 5.1 °C, for the decade of 1981-1990: 5.3 °C and for the period of 1991-2000: 5.5 °C.

Fig. 5. Classes of frequency of occurrence of mean monthly temperatures in the years 1971-2000

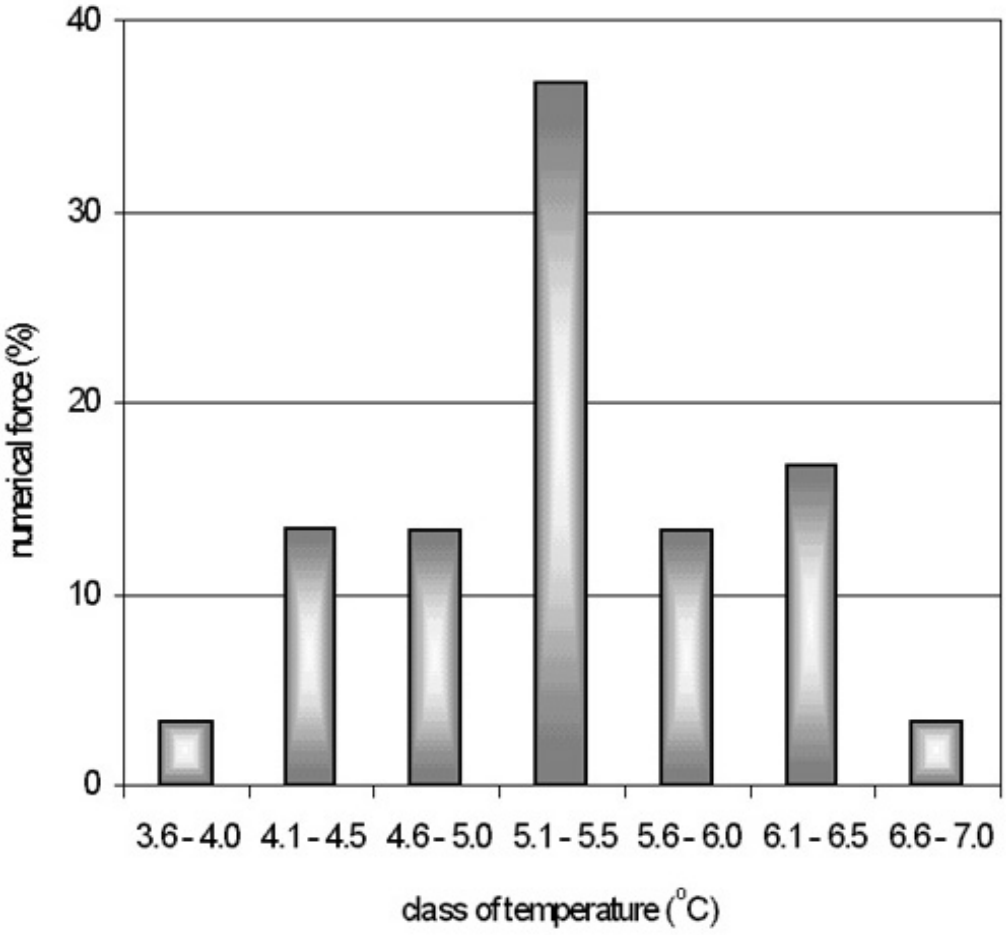
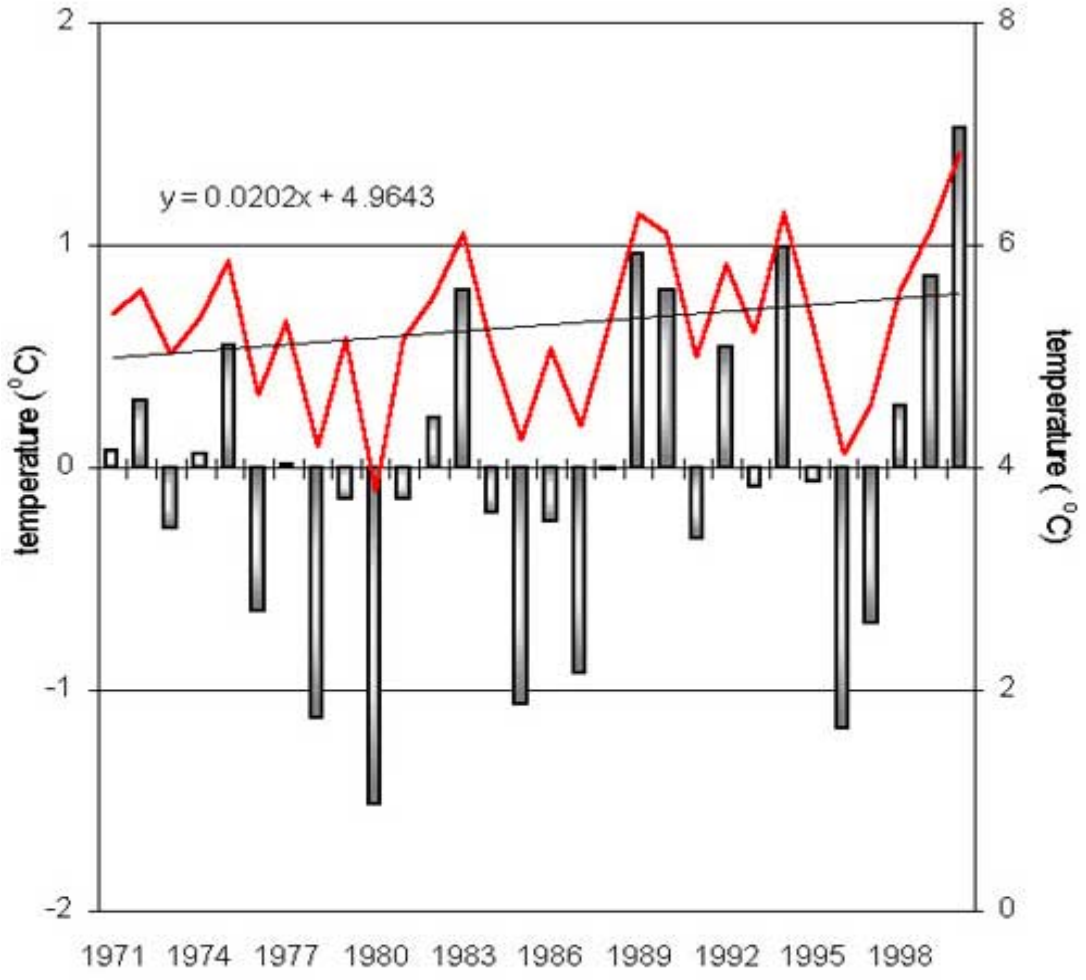


Fig. 6. Course of mean annual temperature (dash line) and trend line and deviation from standard (bars)



DISCUSSION

On the basis of the analysis of the selected thermal indicators the researchers determined that the Kopciowa station has a record of data allowing for an assessment of thermal conditions of convex terrain forms located in the vicinity of the station within the temperate climatic belt. Similarities in relations between the temperature values from Kopciowa and Nowy Sącz testify to this fact, as do similarities between thermal indicators of climate presented in the works of Hess [5, 6, 7], Hess et al. [8] and Obrebska-Starklowa [13].

The described thermal conditions are characterized by a high annual and multiyear variability. In the annual profile, temperatures of the cold months, particularly those of January and February, were most variable, whereas temperatures of the warm months were significantly stable. These characteristics of the thermal regime are typical of mountain and sub-mountain regions [1, 4, 8].

The positive temperature trend discovered by the research was determined by the positive tendencies of the temperatures of the warm 6-month period. Thus, also the positive trends of mean spring, summer and autumn temperatures were determined. Only winter indicates a negative trend of mean temperatures, which was caused by a significant drop in the mean temperatures of December. These facts were reflected in the rising annual amplitudes. This

points to the warming of the climate in the area under research with a direction towards continentalization. The annual amplitudes have been increasing, summers have been warmer and warmer and winters colder and colder.

In the case of European stations, which have at their disposal very long sequences of data [16, 17, 18], the mean annual temperature trend is clearly rising. Similar tendencies are shown by the 100-year series of mean annual temperatures from Zakopane [14] and from the alpine station in Hohenpeissenberg (located at the altitude of 983 meters) [17]. However, the analyses of long-term variability of mean temperatures of individual months and seasons indicate some diversity in the directions of these tendencies. The over 100-year-old series from the Jagiellonian University Observatory indicate a clear positive trend in the temperatures of winter months, particularly those of January, and a negative trend in the changes of summer temperatures [17]. The same directions of temperature changes of individual months was recorded in Zakopane [14]. Yet, in the Alps, temperature tendencies in the 20th century indicate the biggest warming in September and November and the biggest cooling in winter-months [17].

Publications regarding analyses of short observation series come from several stations located in the area of the Carpathians [4, 11, 14]. The Carpathians are characterized by a relatively diversified climate due to rich topography and surface features. Despite this diversity, however, temperature trends of months and seasons in the periods 1950-1990 and 1961-1990 are very similar [4, 11, 14]. The assessment of multiyear temperature variability in Zakopane, which includes the decade of 1991-2000, indicates that the shape of spring and autumn temperature trends [12] is similar to that from the Kopciowa station.

In the area of the Beskid Sądecki Mountains, the trends of winter temperatures recorded in the stations located in the river catchment valleys of the Poprad have a rising direction. On the other hand, temperature trends of summer months are declining [4]. These tendencies are different from those determined in Kopciowa. The cause of these differences seem to lie in the different locations of the measuring stations. The differences are even more conditioned by the non-uniformity of the time periods of the analyzed sequences. In the case of Kopciowa, the researchers were concerned with the tendencies of temperature changes in the years 1971-2000, thus including the 1991-2000 decade, which, according to climatologists, was a period of intensification of the warming effect and one of the warmest decades in the last 100 years [2, 3, 9].

SUMMARY AND CONCLUSIONS

The investigations conducted in southern Poland showed that:

1. The analyzed series of air temperatures involved the period from 1971 to 2000. Thus, it included the last, very warm decade. Mean monthly temperatures of the cold months, especially those of January and February were characterized by the highest temperature variability.
2. The coldest month of the 30-year period was January, while the warmest one was July.
3. Positive temperature trends were typical of mean temperatures of the warm part of the year: from April through November, resulting in a positive trend of mean annual temperature. The biggest increase of mean monthly temperatures occurred in April and June.

4. Negative monthly temperature tendency was characteristic of the winter season. The main cause of this was a strong negative trend in mean monthly temperatures of December. Spring, summer and autumn were characterized by positive trends.
5. Annual amplitudes had, in the last 30 years, a clear rising tendency, which was caused by the increasing mean monthly temperatures of the warmest months and by the declining mean monthly temperatures of the coldest months.
6. The results obtained by the researchers indicate, on the one hand, a warming of the climate (especially during the warm part of the year), and a clear continentalization of the thermal features of the climate on the other.

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