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Krzysztof Kożuchowski, Elwira Żmudzka

THE WARMING IN POLAND: THE RANGE AND THE SEASONALITY OF CHANGES IN AIR TEMPERATURE DURING THE SECOND HALF OF THE 20TH CENTURY

The year 2000, ending the 20th century, turned out to be the warmest one in Poland during the last half-century. The annual average calculated on the basis of the data from 51 weather stations across the country attained 9.5°C and was the highest in the series for the period 1951–2000. It was most probably also the highest annual average air temperature in the entire history of continuous temperature measurement in Poland, which started in Warsaw in 1779, and whose unified series was recently published by H. Lorenc (2000). The air temperatures in Poland averaged over the area are closely correlated with the local temperature series. The fact that in the year 2000 the values were attained and exceeded that have never been recorded before in Warsaw and some other weather stations allows for drawing of the conclusion that, despite the lack of complete data from the entire territory of Poland, the value of the annual average, quoted before, is the highest for the area of Poland over the period of more than 200 years.

The appearance of this kind of thermal all-time high motivates to undertaking of the attempts of determining the circumstances of this appearance. In particular, we can ask for the seasonal profile of the warming observed in 2000, and its relation to the systematic changes of temperature during the half-century analysed, i.e. 1951–2000. The question arises, as well, of the origins of the air temperature increase observed: can we associate it with the persistent, global climate warming ? The analysis of the time series of the average air temperature values from the area of Poland does not provide the basis for the definitive settlement of this problem. The statistical characterisation of the time series analysed might, however, constitute a synthetic assessment of the direction and scale of the contemporary evolution of the thermal conditions in Poland. Thus, it is possible to indicate to what extent the standard climatological data, cited within different contexts, reflect the thermal conditions, which prevail in the recent years.

Returning to the record-breaking year 2000 let us indicate that the very high average temperature was attained first of all due to the exceptionally warm transitory seasons of the year — Spring and Fall. The averages for April and October, similarly as for the entire year, were the highest over the entire half-century analysed. High averages were also observed in May and November. On the other hand, though, relatively low values occurred in July and September. This is well illustrated by the ranks of the monthly averages of air temperature in the year 2000, taken in the decreasing sequence put together for the entire half-century (Table 1). The highest annual average was, therefore, an expression of a very unevenly distributed air temperature surge in 2000. The monthly averages of July and September were in the year 2000 even lower than the respective 50-year averages. The coincidence of the highest annual average with the Spring and Fall maxima constitutes a definite singularity of the year 2000, because it has been usually so that the divergences in the annual averages was mostly influenced by the temperatures of the winter season.

Table 1.

Monthly and annual average air temperatures in Poland in the year 2000 compared to the respective mean values from the period 1951 – 2000*

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I–XII
Average	-1.2	2.4	3.5	11.6	14.7	16.8	16.1	17.7	12.1	11.7	6.6	1.5	9.5
Rank**	21	6	20	1	2	13	41	17	39	1	2	9	1
Deviation from mean 1951–2000	1.1	4.0	1.4	4.2	2.1	0.7	-1.5	0.7	-0.9	3.3	3.4	2.0	1.7

* Data from 51 weather stations located at the altitude below 1000 m a.s.l.

** Rank in the decreasing sequence of (50) respective months in terms of average temperatures.

Table 2.

The ten highest mean annual temperature values in Poland in the period 1951 – 2000, and the mean annual temperatures in the years 1991 – 2000, along with their ranks in the decreasing sequence of the mean annual temperatures in 1951 – 2000

No.	Year	Mean	Year	Mean	Rank
1	2000	9.5	1991	7.8	25
2	1989	9.2	1992	8.7	7
3	1990	9.1	1993	8.0	21
4	1999	8.9	1994	8.8	5
5	1994	8.8	1995	8.1	19
6	1983	8.8	1996	6.5	47
7	1992	8.7	1997	7.8	26
8	1975	8.7	1998	8.2	13
9	1967	8.6	1999	8.9	4
10	1951	8.5	2000	9.5	1

The monthly and annual averages of air temperature, shown in Tables 1 and 2, witness to the distinct concentration of the warmest years at the end of the century. During the last decade of the century (1991 – 2000) only the years 1996 and 1997 were characterised by the averages ranked in the second half of the decreasing sequence of values for the period 1951 – 2000, while as many as four years belonged to the respective groups of the 10 highest values from the half-century analysed. This observation is confirmed by the results from the analysis of the series of monthly and annual averages of air temperature in the period 1951 – 2000, meant to establish whether the sequence of the distribution in time of the smaller and bigger values is random or not. For this purpose the Mann-Kendall rank method of trend assessment was used (Michell, 1966).

The results obtained (see Table 3) indicate that the time series of the annual air temperature averages displays in the half-century considered a significant upward trend. The most pronounced increasing sequence is observed for the mean air temperature in March, though the trend of mean temperature in May is similarly significant. The average air temperatures in January, February, April, July, August, and October display non-significant increasing tendencies, while the ones of June, September, November, and December — the non-significant decreasing tendencies. Thus, one can simplify and say that during the period analysed a non-random appearance of the increasing values of annual means of the air temperature have been observed, associated with the increasing air temperatures in the spring season. It is worth emphasising again that it was not Winter, but Spring, that displayed a significant warming.

Table 3.

Rank evaluation of the trend of the mean monthly and annual air temperature values in Poland (1951 – 2000). The observed values of the Man-Kendall's τ statistics (* — values differing significantly from zero at $\alpha = 0.05$).

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I–XII
τ	0.14	0.15	0.20*	0.11	0.19*	-0.10	0.01	0.11	-0.05	0.02	-0.08	-0.03	0.19*

Similar conclusions can be reached on the basis of the analysis of temperature changes in the period 1951 – 2000, carried out with linear regression. The directional coefficient of the trend of the annual averages takes the value of 0.017, meaning an increasing tendency of temperature with the rate of almost 0.2°C per decade. This increase fulfils the condition of statistical significance at the 5% level. A similar significance is displayed by the mean temperatures in March and May, while the increase of temperature in February turned out to be significant at the 10% level. Downward trends have also been observed: the negative, but non-significant, coefficients appeared in the temperature change regressions in June, September, November, and December (Table 4).

It is interesting to see the estimates of the changes in mean temperature during the entire half-century. Thus, the average temperatures of February and March rose in Poland by approximately 3°C, of May — by 1.5°C, and of the annual mean — by 0.9°C, that is — from 7.3°C to 8.2°C. Hence, the maximum of the warming concentrated at the end of Winter and the beginning of Spring (Table 4). Here also the known phenomenon of thermal inertia of the winter season is expressed (see Kożuchowski et al., 1994). It is possible to formulate, as well, the opinion that despite the statistically indecisive symptoms of temperature increase in January or February, which are lost against the background of the very important variability of temperatures during the Winter, the winters got actually milder over the period in question, entailing, due to the thermal inertia already mentioned, an increase of temperature in the spring months, especially in March, this increase appearing as significant in the statistical estimations.

Table 4.

Directional coefficients of the linear trend equation for the changes of the mean monthly and annual air temperatures in Poland in the period 1951–2000: a — °C/year, b — °C/50 years (* — trend significant at the 5% level).

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I–XII
a	0.04	0.06	0.06*	0.02	0.03*	-0.01	0.00	0.01	-0.00	0.01	-0.02	-0.00	0.02*
b	2.1	3.2	2.8*	1.2	1.5*	-0.6	0.2	0.7	-0.0	0.3	-0.9	-0.1	0.9*

Due to the concentration of the highest means in the last dozen or so years and to the increasing temperature trend over the entire half-century the long-term averages significantly increased in the two last decades of the century. Both the annual mean temperature of the decade 1991 – 2000, and the mean for the 20-year period 1981 – 2000 differ essentially from the "norm" determined for the period 1951 – 2000. In terms of individual months May and August proved to be significantly warmer during the last 20 years. Likewise, temperature in March increased by 2.8°C and differed significantly from the 50-year mean for the significance level of 10%. Attention ought also to be paid to a definite decrease of temperatures in June and November (Table 5).

Table 5.

Mean monthly and annual temperature values on the area of Poland in the periods 1951 – 2000; 1981 – 2000; and 1991 – 2000 (* — the difference between the 10- and 20-year averages and the average for the period 1951 – 2000 significant at the level of $\alpha = 0.05$).

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I-XII
1951-2000	-2.3	-1.6	2.1	7.4	12.6	16.1	17.5	16.9	13.0	8.4	3.2	-0.5	7.7
1981-2000	-1.5	-0.9	2.8	7.9	13.3*	15.9	17.8	17.4*	13.1	8.6	2.9	-0.4	8.1*
1991-2000	-0.9	-0.2	3.0*	8.3*	13.0	16.2	18.1*	17.8*	13.2	8.3	2.7	-0.7	8.3*

Now, Table 6 presents the highest and the lowest 20-year averages for particular months within the 50-year period analysed. It is easily seen that such highest values usually occur for the 20-year periods close to the end of the half-century considered. Exceptions are, indeed, constituted by those monthly averages, which correspond to the downward trends: the highest average for June corresponds to the period from the beginning of the half-century, while the highest averages for September and October — to the periods from its first part. It is also worth emphasising that among the lowest 20-year averages for particular months the majority occurred in the first part of the period analysed. Even the monthly averages displaying a decreasing tendency have their 20-year minima well before the end of the 20^{th} century, and it is only the case of November that features the lowest mean in the years 1980–1999 (Table 6). Hence, it can be concluded from this comparison that the June and Autumn cooling has undergone a slowdown, if not stopping, in the final years of the century.

Table 6.

The highest and the lowest 20-year averages of the monthly and annual air temperatures in Poland in the period 1951–2000 (* — averages significantly differing from the respective 50-year average values at the level of $\alpha = 0.05$).

Month	Highest average		Lowest average	
	value	20-year period(s)	value	20-year period(s)
I	-1.4	1981-2000	-3.5*	1953-1972
II	-0.9	1981-2000	-2.7	1951-1970
III	2.8	1974-1993 1981-2000	1.0*	1952-1971
IV	7.9	1981-2000	6.8*	1963-1982
V	13.3*	1981-2000	12.2	1951-1970
VI	16.5*	1951-1970	15.6*	1972-1991
VII	17.8	1980-1999 1981-2000	17.1	1961-1980
VIII	17.4*	1981-2000	16.7*	1961-1980
IX	13.2	1951-1970	12.7	1977-1996
X	8.7	1952-1971	8.1	1969-1988
XI	3.7	1960-1979	2.6	1980-1999
XII	0.2	1970-1989	-1.1	1961-1980
I-XII	8.1*	1981-2000	7.5*	1954-1973

The seasonal differentiation of the trends in temperature change during the period considered caused characteristic shifts in the thermal relations between the seasons of the year. The uneven trends in the temperatures of the warmest and coldest months of the year resulted in the decrease of the annual temperature amplitude (at the monthly level of resolution). It decreased, namely, from 21.2°C (1953–1972) to 19.3°C (1981–2000). The relations of the average temperatures of the Spring and the Autumn reversed. Thus, in the last decade of the period analysed the Spring became somewhat warmer than the Autumn, while, initially, Autumn was warmer than Spring by almost 2°C. It is therefore worth emphasising that side by side with the distinct general warming there appeared in Poland during the half-century considered certain symptoms of a shift in the thermal regime. And so, the decrease of the annual thermal amplitude, the "reversal" of the relation Spring-Autumn, and the appearance of an earlier, but altogether milder Winter, were the characteristics of the thermal conditions of the recent years.

The observations concerning the behaviour of the average air temperature values on the area of Poland between 1951 and 2000 motivate to distinguish within this period the last 20 years, which featured a significant warming. The monthly averages in these 20 years — except for the ones for June and November — were higher than the 50-year "norms", and the averages for May and August differed from the respective "norms" in a significant manner. In the period 1981 – 2000 the warmest year of the second half of the 20th century, and perhaps even of the last two centuries, occurred. The downward trends of some of the monthly averages levelled out. During these 20 years there were only five years with temperature lower than the "norm". The majority of the monthly averages reached within these two decades their respective maximum values. Thus, January of 1983, February of 1998, March of 1990, April of 2000, May of 1993, July of 1994, August of 1992, October of 2000, and November of 2000 featured the highest respective monthly averages for the entire half century 1951 – 2000. The warming having taken place in the years 1981 – 2000 is insofar more pronounced as it follows immediately after the year 1980, the coldest one in the half-century considered, in which the average temperature on the area of Poland was at mere 6.5°C.

Fig. 1 presents the diagram reflecting the characteristic features of the course of the mean annual air temperature between 1951 and 2000. The warming of the last twenty years has been emphasised on the diagram by calculation of the deviations of the mean annual air temperatures from the average for the period 1951 – 1980, their course having been smoothed with the 5-leg binomial filter. One can see clearly the oscillations of temperature around this average value until the 1980s, and the two successive fluctuations at the end of the period analysed, albeit with respect to a significantly higher level (the increment amounted to approximately 0.5°C). Even without application of the advanced methods of analysis one can see from the diagram the persisting tendency of displaying a 7– 8-year periodicity in the fluctuations of air temperature (see also Żmudzka, 1995). The doubtless warming of the 1980s and 1990s is added onto these oscillations. The logistic curve, which was used to mark the temperature trend between 1951 and 2000, constitutes an attempt at synthetic illustration of changes in thermal conditions in this half-century. This curve cannot be extrapolated, but the symptoms of the warming, which took place at the end of the century, should not be ignored, neither. This warming has tangible ecological and economic consequences.

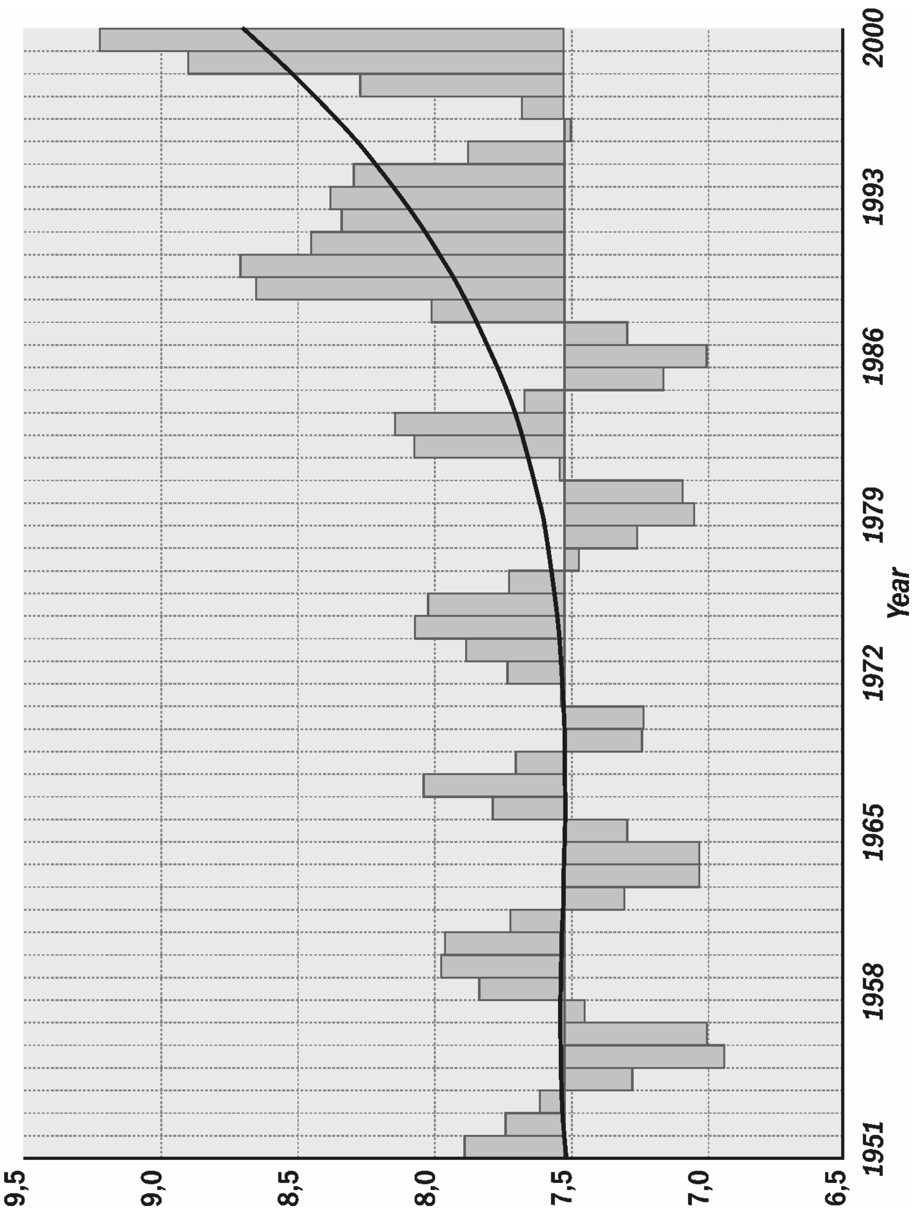

Fig. 1. Annual means of air temperature in Poland in the period 1951 – 2000. Deviations from the 1951 – 2000 mean smoothed with the 5-leg binomial filter. The trend curve is marked by the solid line.

The warming documented here can be partly explained by the influence exerted by the solar and circulation factors, conducive to the temperature increase. Thus, bigger insolation and the increased sums of solar radiation have been observed in Poland during the 1980s and 1990s (Bogdańska, Podogrocki, 2000). This phenomenon presumably contributed to the increase of temperature, especially in the warmer part of the year. Mild winters, and at the same time a distinct downward trend of temperature in June, are beyond any doubt associated with the development of the zonal circulation and the high values of the North Atlantic Oscillation indicator (NAO), reflecting the growing intensity of the inflow of oceanic air masses towards continental Europe. They bring the warming in winter, and at the beginning of Summer cause the "European monsoon" effect, whose symptoms have recently become more visible (Kossowska-Cezak, 1994; Fortuniak et al., 1998). Given the general intensification of the zonal circulation, the frequency increased of the types of circulation that have until quite recently been rather rare in Poland (Lorenc, 1994). As the result of these changes, a perceptible increase took place, in particular, of the frequency of the inflow of air from the SW, S, and SE directions (Kożuchowski, 2000). A new circulation epoch started in 1987, marked by the all-year intensity of the zonal movement of air masses over the Atlantic Ocean and Europe (Degirmendžić et al., 2000).

One cannot overlook the coincidence of the warming observed in Poland with the increase of global temperature in the 1990s. The decade of 1990–1999 turned out to be the warmest period in the entire series of the global means, starting with 1960 (*WMO*..., 1999). The warming having occurred at the end of the 20^{th} century might be interpreted as the consequence of the development of the greenhouse effect, predicted for quite some time already, although there are scholars who would rather see in this phenomenon the dominating role of the natural factors — the influence of the increased activity of the Sun or/and the progressing warming of climate after a Little Ice Age (of the 16^{th}–19^{th} centuries).

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