VARIABILITY OF CLIMATE IN CENTRAL EUROPE THE EXAMPLE OF POLAND 1951 – 2000

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Abstract: The paper presents results of researches concerning variability of air temperature, atmospheric precipitation and cloudiness over Poland in the second half of 20th century. The spatially averaged series of climate elements from Polish lowlands (below 300 m a.s.l.) were used in the analysis. It can form the basis for synthetic evaluation of the direction and the scale of the climatic conditions contemporary evolution in Central Europe.
Tendencies of changes and fluctuation of separate climate elements were determined. It was demonstrated that changes of climatic conditions correspond to changes of global solar radiation sums which constitute a significant element of the climate as well as an 'active' climatic control. Moreover it is concluded that significant part of the climate elements variability can be explained by a direct influence of the atmospheric circulation and its changes in the study long-term period.

Key words: variability of climate, global warming, atmospferic circulation

1. INTRODUCTION

One of the most important problems in climatology is the definition of variability and the assessment of climatic changes on various scales of time and space. An additional incentive for the undertaking of studies concerning this problem is the currently noted "signal" of global warming. The main directions of research include the definition of the "share" of natural and anthropogenic conditions in climate variability, the past evolution and the prognosis of climatic conditions, and the assessment of the possible consequences of climate change in the natural environment, as well as in various domains of human economic and social activities.

The aim of paper is to define of chosen climatic element variability. The determination of the rate and the direction of changes of temperature, sums of precipitation and magnitude of cloudiness in Poland in years 1951 – 2000 were also in the scope of presented research. The relation between climate elements and large-scale circulation conditions was also determined.

2. DATA AND METHODS

The data used for the analysis of climatic variability in Poland were the average monthly air temperature values, precipitation sums and magnitude cloudiness, collected at 45, 50 and 48 meteorological stations of the IMGW (Institute of Meteorology and Water Management), respectively; located less than 300 m above sea level, for each year from 1951 to 2000 (Figure 1). The series of climate elements were spatially averaged. The average monthly values of global solar radiation from Warszawa and Gdynia (1961 – 2000) were used.

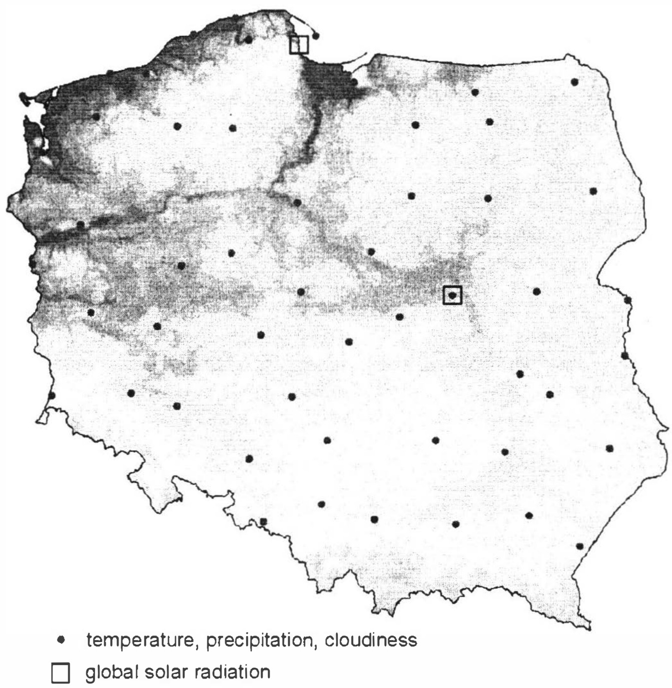


Figure 1 Distribution of meteorological stations

The homogeneity of the measurement series at individual stations was tested by means of the Alexandersson (1986) test. The choice of referential series and the decision on correction of source data was made upon analysis of history of stations and observation methods.

The series of spatially averaged climatic elements used in the analysis can give base for synthetic evaluation of direction and scale of present evolution of climatic conditions in Central Europe. This can be achieved thanks to close linkage between mean series mentioned above and observed values of climatic elements in stations situated in his part of Europe (Table 1).

Atmospheric circulation over central Europe was described using the average values of atmospheric pressure at the sea level in nodes of geographical grid for area of: φ 30° – 70° N and λ 40° W – 60° E (Figure 2A). Grid step is: 2.5 latitude and 5 longitude. Data source is NCEP/NCAR Reanalysis (1951 – 2000) database. Moreover geostrophic wind speed over Central Europe was used (Figure 2B) (Degirmendžić et al., 2004) and the frequency (number of days) of types and macro-types of atmospheric circulation after Lityński classification (Lityński, 1969). In the above mentioned classification for basis of qualification of direction of advection the values of zonal and meridional indices were accepted. They were calculated refer to the area $\varphi = 40 - 65°$ N, $\lambda = 0 - 35°$ E. For the index illustrating character of circulation the values of pressure in Warsaw were assumed.

Table 1 Correlation coefficients of spatially averaged values of air temperature, precipitation sums in Poland and values of this climate elements in chosen stations in Central Europe

Station	Temperature		Precipitation		Station	Temperature		Precipitation	
	January	July	January	July		January	July	January	July
Stockholm	0.80	0.77	0.36	0.43	Ostrava	0.94	0.89	0.42	0.71
Rostock	0.95	0.89	0.67	0.63	Debrecen	0.74	0.82	0.43	0.27
Berlin	0.97	0.90	0.83	0.70	Kijev	0.83	0.67		
Praha	0.92	0.86	0.60	0.49	Brest	0.96	0.94		
Wien	0.89	0.76	0.58	0.63	Turku	0.75	0.66	0.16	0.34

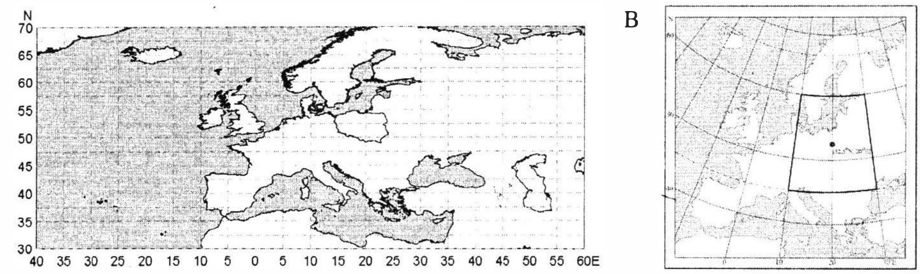
A B


Figure 2 Study area

For description the variability of climate elements were determined: the direction and rate of changes – using linear regression and Mann-Kendall rank test (Mitchell 1966); the fluctuations – on the basis of the cumulative deviations from the long-term average (1951 – 2000). Thermal, rains and nephological calendar for second half of 20th century was composed. The division of series was applied based on percentile intervals. It was assumed that the anomalous seasons were the ones. in which the values of climate elements exceeded the 90 % percentile or was below the value defined by the 10 % percentile.

Relations between climate elements and atmospheric circulation were described using coefficients of correlation as well as coefficients of linear and multiple regression. Long-term tendencies of changes of climate elements, global solar radiation, indices and the chosen types of atmospheric circulation were compared.

3. VARIABILITY IN CLIMATIC ELEMENT

In the years 1951 – 2000 over Poland a warm-up was noted. In whole year it was about 0.9 °C (Table 2). Significant increase of temperature appears in spring. Winters became milder; the mean winter temperature in the last decade of the 20th century was approaching 0 °C.

The strongest temperature growth-trend occurred on the turn of winter and spring (in February and March (Fortuniak et al., 2001). Some cooling was also characteristic of June and the period from September to December. However, only the temperature growth-trends in March and May were statistically significant (Kożuchowski, Żmudzka, 2002).

In the second half of the 20th century no significant trend can be observed in mean precipitation and cloudiness over Poland (Żmudzka, 2002, 2003a,b). Directional regression coefficients show small increase in precipitation in spring and autumn and a decrease in summer and winter (Table 2). Seasons differed in direction and change rate. During most parts of the year, there is insignificant decrease in cloudiness (in winter statistically almost significant), only in autumn an increase was observed. May and whole winter significantly differ in cloudiness change (significant negative tendency) and in September (significant increasing trend).

Better understanding of climate variability can be achieved through curves of cumulative deviations from the mean values of years 1951 – 2000 (Figure 3). Fluctuations observed in time series of seasonal and annual values of climate elements were not significantly different from random fluctuations with exception of temperature fluctuations in spring, and annual mean temperature fluctuations (Żmudzka, 2004a, b).

Increasing trend in temperature change in Poland is clearly shown after a minimum in the early 60. (Figure 3) (Żmudzka, 2004d). The last two decades of the 20th century deserve particular attention. This was when the rate of climate warming increased, what was noticeable not only during the winter/spring season (Jan. – May), but also during the warm part of the year (Fortuniak et al., 2001). High temperature values in summer period in last 20 years of 20th century linked with insufficient precipitation mainly in 1981 – 1994 resulted in dry seasons and droughts. In the late 90' of 20th century there was an increase in precipitation. Notice that after 1981 no year with anomalous cloudiness was observed (Figure 4).

Different seasonal and spatial tendencies in climate elements change can be observed in some signs of climate regime change (Kożuchowski, Żmudzka, 2001; Fortuniak et al., 2001) and somewhat in their spatial distribution over Poland determined using 1951 – 2000 data (Żmudzka, 2004d) (Figure 5). Yearly amplitude of temperature and precipitation decreased, spring is a little warmer than autumn, the ratio of winter precipitation to summer precipitation increased – mainly due to decrease in summer precipitation.

Due to temperature increase, which was greater in warmer (western) parts of Poland than in cooler (north-eastern) parts, thermal contrasts increased a little (Fortuniak et al., 2001). Spatial distribution of yearly sums of precipitation no significant change is observed compared to those from earlier years. Region of the greatest cloudiness was middle part of Pojezierze Pomorskie, not like before – north-eastern parts of Poland. Significant increase in cloudiness was observed in south-western Poland.

Tendencies in climate changes correspond with changes in global solar radiation sums which are significant element of climate as well as 'active' climatic controls (Table 3). Positive trend in yearly sums of global radiation is observed in Poland mainly due to increase in radiation in May (significant increase in temperature and less cloudiness). Particularly large surplus in radiation inflow is observed since mid-80. (cumulation of bright, warm, dry years).

Table 2 Linear trend coefficients a and rank evaluation (τ – the values of the Mann-Kendall's statistics) of the trend of changes of spatially averaged monthly, seasonal and annual values of chosen climate elements in Poland in years 1951 – 2000. Coefficients significant at the 0.05 level are bolded

	J	F	M	A	M	J	J	A	S	O	N	D	DJF	MAM	JJA	SON	Year
Temperature																	
a [oC/year]	0.04	0.07	**0.06**	0.03	**0.03**	-0.01	0.00	0.01	0.00	0.01	-0.02	0.00	0.04	**0.04**	0.00	0.00	0.02
τ	0.15	0.14	**0.22**	0.12	**0.20**	-0.10	0.00	0.12	-0.05	0.01	-0.07	0.01	0.18	**0.30**	-0.03	-0.09	0.17
Precipitation																	
a [mm/year]	-0.06	-0.03	0.27	0.07	-0.02	0.09	-0.18	-0.16	0.21	0.05	-0.03	0.05	-0.03	0.33	-0.24	0.24	0.29
τ	-0.06	-0.03	0.14	0.01	-0.04	0.05	-0.08	-0.09	0.10	0.02	-0.01	0.02	-0.01	0.12	-0.02	0.09	0.05
Cloudiness																	
a [%/year]	-0.10	-0.06	0.07	-0.01	**-0.21**	0.07	-0.06	-0.11	0.18	-0.05	-0.10	-0.04	-0.07	-0.05	-0.03	0.01	-0.04
τ	-0.16	-0.14	0.06	-0.05	**-0.29**	0.09	-0.06	-0.17	**0.19**	-0.06	-0.16	-0.09	-0.19	-0.12	-0.07	0.01	-0.14

Table 3 Linear trend coefficients *a* [MJm^{-2}/year] and rank evaluation (τ – the values of the Mann-Kendall's statistics) of the trend of changes of monthly, seasonal and annual values of global solar radiation in Gdynia and Warszawa in years 1961 – 2000. Coefficients significant at the 0.05 level are bolded

Station		J	F	M	A	M	J	J	A	S	O	N	D	DJF	MAM	JJA	SON	Year
Gdynia	*a*	0.04	0.23	-0.43	-0.06	1.49	-1.99	0.94	0.80	-0.57	0.20	0.08	-0.02	0.29	1.00	-0.25	-0.30	0.69
	τ	0.04	0.11	-0.07	-0.01	0.15	-0.24	0.06	0.05	-0.16	0.06	0.05	-0.03	0.09	0.08	-0.04	-0.05	0.05
Warszawa	*a*	0.38	0.70	0.85	1.28	**3.82**	0.03	1.26	1.92	0.01	0.87	**0.78**	**0.36**	**1.49**	**5.95**	3.21	1.66	**12.26**
	τ	0.21	0.19	0.22	0.18	**0.47**	-0.02	0.10	0.29	-0.03	0.17	**0.43**	**0.30**	**0.38**	**0.49**	0.14	0.23	**0.39**

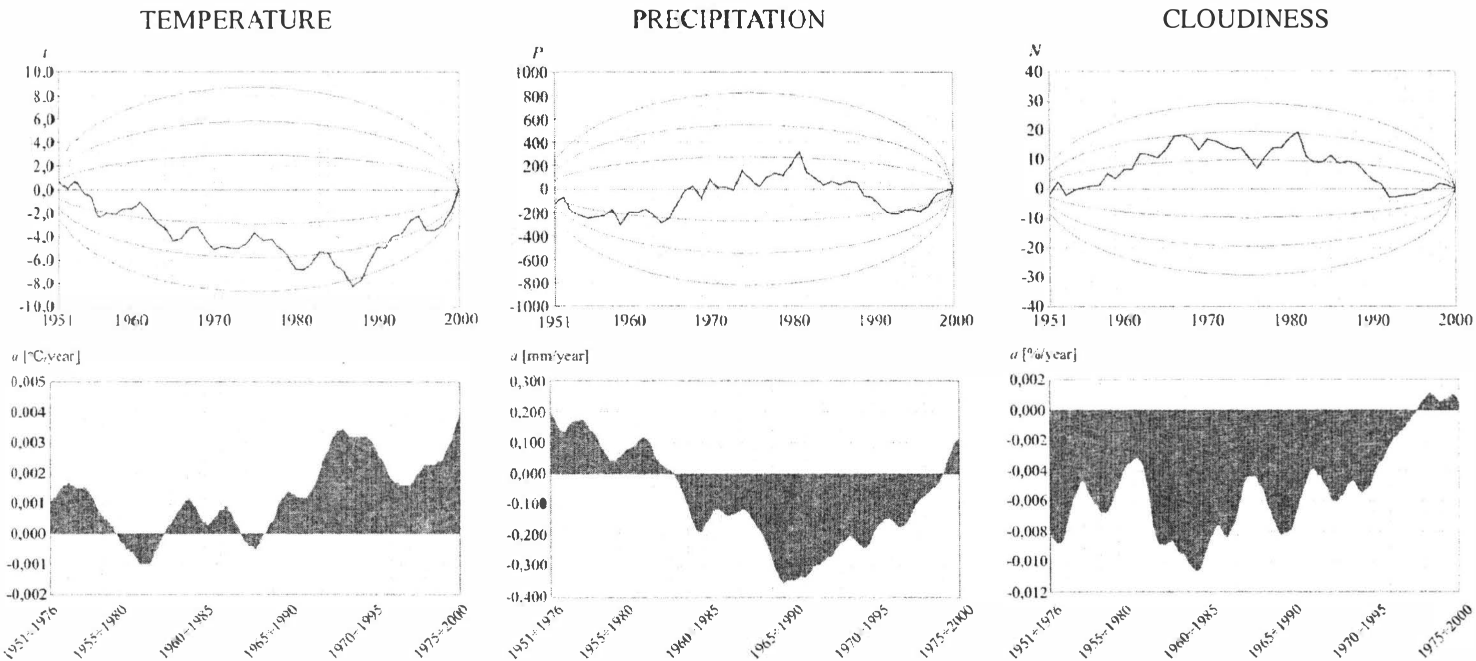
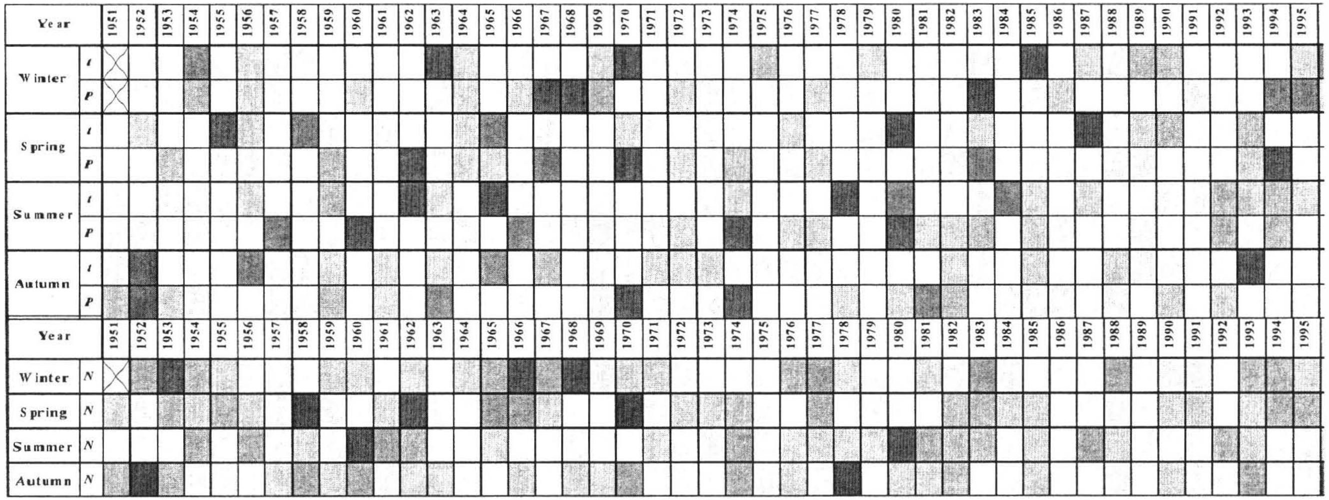


Figure 3 Cumulative deviations of annual mean values of temperature, precipitation sums and cloudiness from the 50-years means 1951 – 2000 in Poland (the ranges of 1,2 and 3 standard deviations are marked) and linear trend coefficients of changes a in moving 25-years (Żmudzka, 2004d)



Percentile (%) 1951-2000	Seasonal Specification		
	temperature *t*	precipitation *P*	cloudiness *N*
>95.00	extremely warm	extremely wet	extremely cloudy
90.01-95.00	anomalously warm	anomalously wet	anomalously cloudy
80.01-90.00	very warm (positive anomalous tendency)	very wet (positive anomalous tendency)	very cloudy (positive anomalous tendency)
60.01-80.00	warm	wet	cloudy
40.01-60.00	NORMAL	NORMAL	NORMAL
20.01-40.00	cold	dry	clear
10.01-20.00	very cold (negative anomalous tendency)	very dry (negative anomalous tendency)	very clear (negative anomalous tendency)
5.01-10.00	anomalously cold	anomalously dry	anomalously clear
?5.00	extremely cold	extremely dry	extremely clear

Figure 4 The thermal t, precipitation P and nephological N classification (according to quantile values for the period 1951 – 2000) and the seasonal calendar for Poland

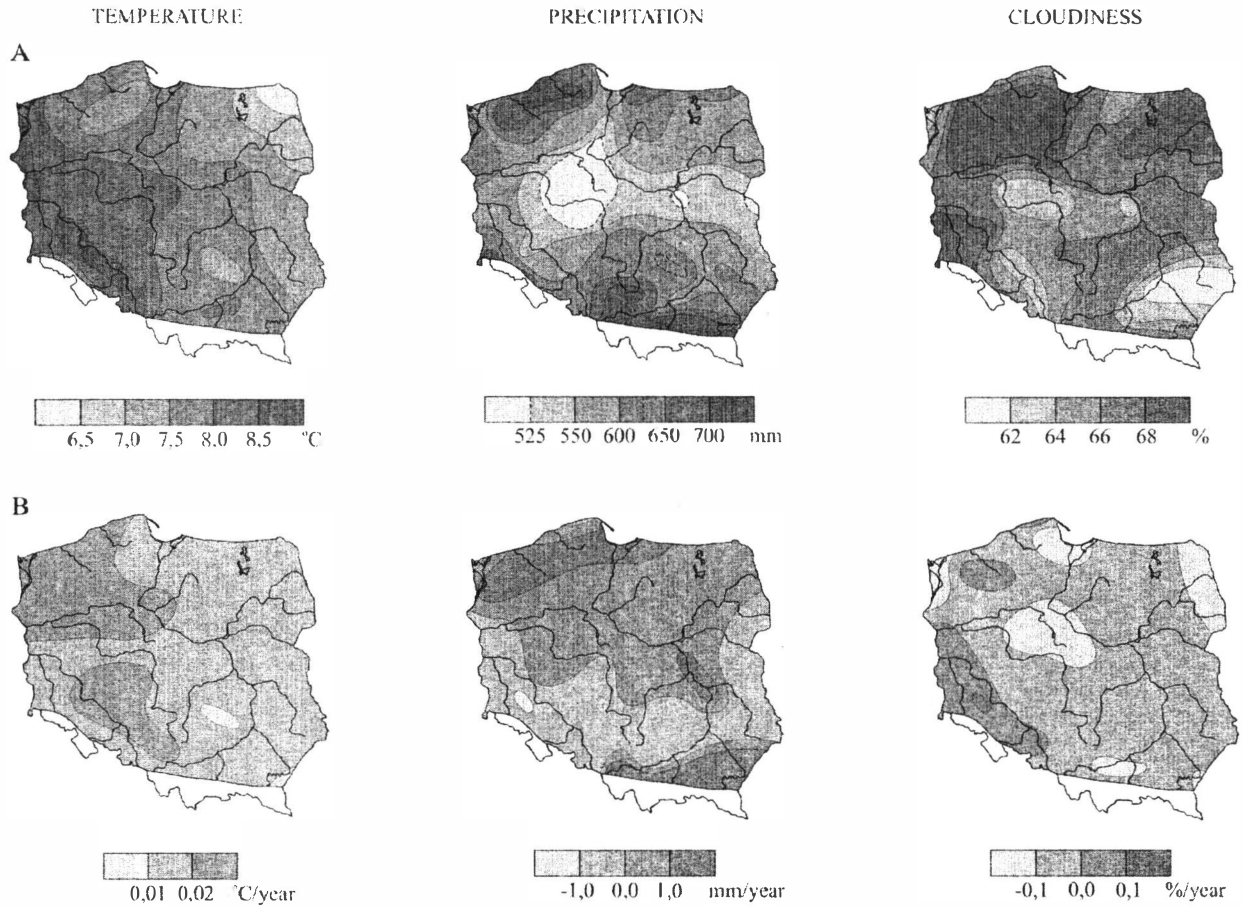


Figure 5 Mean annual values of climate elements in Poland (A) and their tendencies of changes (B) in years 1951 – 2000

Conducted research shows that large part of variability of climatic elements can be explained by direct influence of atmospheric circulation. Western and meridional component of atmospheric circulation over Central Europe and pressure in the centre of this area explain from 15 % (in August) up to 77 % (in June) mean monthly temperature variance, from 10 % (in August) up to 46 % (in July) monthly precipitation sums and from 28 % (in April) up to 71 % (in July) mean monthly cloudiness variance. (Degirmendžić et al., 2004; Żmudzka, 2004c).

From December to March main role forming temperature changes is western component of circulation which result in temperature rise (Table 4). In summer, intensification of west advection results in temperature drop. However from April to November (mainly in April and in September) main cause of temperature drop is advection from the north. During the year change can be observed in role and direction of western component interaction on precipitation. From April to November it results in drop in monthly precipitation sums and in the rest part of the year it results in rise in monthly precipitation sums. From April to August increase in precipitation is a result mainly of southern advection, and in the rest part of the year of northern advection (Degirmendžić et al., 2004). Increase in cloudiness in summer is depend mainly by intensification of western circulation coefficient and in transitional parts of the year – mainly in April and May and in September and October – by northern circulation component. In winter western component results in decrease in cloudiness.

Pressure in the centre of Central Europe influences strongly climatic elements in summer months – pressure rise results in temperature rise and drop in cloudiness and precipitation. In case of cloudiness and precipitation this direction of interaction is observed during whole year; in some months pressure plays dominant role shaping these elements. From October to February and in April pressure rise results in decrease of mean monthly temperature.

Characteristic trait of analysed long-term period, particularly last 20 – 30 years of 20th century is intensification of west circulation in moderate latitudes of northern hemisphere (ie. Makrogiannis et al., 1991; Kożuchowski, 1993, 1995; Ustrnul, 1997; Marsz, 1999; Degirmendžić et al., 2000, 2002; Niedźwiedź, 2000, 2003; Wibig, 2001; Kożuchowski, Żmudzka, 2002). This conclusion – drawn from various researches, conducted using different methods and with different circulation characteristics – can be also confirmed by pressure change tendencies distribution in Euro-Atlantic sector in 1951 – 2000 (Figure 6), which indicates rise in longitudinal gradient of pressure over the area – particularly in winter. Moreover in Central Europe, mainly its southern part, significant pressure rise was observed. This corresponds with significant positive trends in frequency of circulation types of western direction of advection in anticyclonal situations (Table 5).

Changes in circulation conditions explain well climatic conditions changes in Poland. In example observed temperature rise in winter and spring corresponds with intensification in western circulation, and temperature drop in turn of an autumn and winter correspond with significant increase of northern component of geostrophic wind (Kożuchowski, Żmudzka, 2002). However warming observed in last decade of the 20th century has exceeded circulation-induced increase of temperature. Increase in number of days with anticyclones (in all season except autumn), irrespective of inflow direction, can well explain observed tendencies in cloudiness changes (Żmudzka, 2004b, c). The same can explain precipitation tendencies (except spring). Decrease in cloudiness over Central Europe is a consequence of intensification in anticyclones activity which was indicated by Henderson–Sellers (1986) and Matuszko (1998).

Table 4 Coefficients of the regression equations (*a*, *b*, *c*) and multiple correlation (*R*) between mean temperature, precipitation sums and mean cloudiness in Poland area and components of the geostrophic wind (V_W, V_N) and pressure (*pL*) in point [52.5°N, 20°E]. Correlation coefficients significant at the 0.05 are bolded (Degirmendžić, et al., 2004; Żmudzka, 2004c)

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Temperature													
a (VW)	0.98	0.92	0.70	0.11	0.04	-0.28	-0.61	-0.14	0.07	0.32	0.47	0.73	0.89
b (VN)	-0.58	-0.39	-0.42	-0.86	-1.04	-0.76	-0.64	-0.53	-0.99	-0.38	-0.54	-0.44	-0.58
c (pL)	-0.02	-0.01	0.14	-0.03	0.11	0.23	0.27	0.11	0.14	-0.01	-0.09	-0.03	0.10
R	**0.88**	**0.84**	**0.72**	**0.57**	**0.56**	**0.62**	**0.71**	**0.39**	**0.70**	**0.58**	**0.66**	**0.73**	**0.69**
Precipitation													
a (VW)	0.58	1.72	0.87	0.88	7.36	-1.26	-6.65	-0.16	-1.08	-1.70	-0.84	1.92	0.96
b (VN)	2.23	0.89	2.34	-2.85	-1.62	-16.06	-10.56	-9.81	5.00	3.79	0.85	2.21	-0.23
c (pL)	-1.71	-1.22	-2.03	-2.26	-5.08	-4.52	-17.21	-3.20	-6.26	-4.55	-1.96	-1.81	-3.74
R	**0.63**	**0.66**	**0.57**	**0.45**	**0.56**	**0.46**	**0.68**	**0.32**	**0.57**	**0.67**	**0.37**	**0.57**	**0.57**
Cloudiness													
a (VW)	-0.19	-0.21	0.26	-0.43	0.92	1.89	1.90	1.11	0.26	0.37	-1.49	-0.29	-1.36
b (VN)	0.48	1.84	0.43	1.72	3.08	0.35	0.41	0.95	4.33	1.88	0.63	0.03	1.69
c (pL)	-0.81	-0.76	-1.55	-1.56	-2.10	-1.70	-3.07	-2.02	-2.73	-1.44	-0.59	-0.66	-1.57
R	**0.59**	**0.60**	**0.69**	**0.53**	**0.66**	**0.61**	**0.84**	**0.61**	**0.78**	**0.70**	**0.54**	**0.54**	**0.72**

Table 5 Linear trends of changes of the frequency of selected macro-types of circulation after Lityński classification [number of days per year] in the period 1951 – 2000. Significant coefficients are in bold

Macro-type	J	F	M	A	M	J	J	A	S	O	N	D	DJF	MAM	JJA	SON	Year
W + SW	0.10	**0.14**	0.12	-0.04	0.03	0.01	-0.03	-0.04	-0.03	0.03	0.06	0.05	**0.29**	0.11	-0.06	0.06	**0.40**
$W_A + SW_A$	**0.07**	0.06	0.05	-0.02	0.02	0.02	0.00	0.02	0.00	0.01	0.04	0.02	**0.14**	0.04	0.03	0.05	**0.27**
E + NE	-0.05	-0.08	-0.06	-0.01	-0.05	-0.02	0.03	0.01	0.01	-0.07	-0.01	-0.01	-0.17	-0.12	0.02	-0.07	-0.30
$E_C + NE_C$	-0.01	-0.02	-0.02	-0.01	-0.02	-0.01	-0.03	-0.02	0.01	-0.02	0.01	-0.01	-0.04	-0.05	-0.05	0.01	-0.13
S	-0.07	-0.05	0.01	0.01	0.02	-0.02	0.02	-0.02	0.01	0.06	-0.01	-0.05	-0.07	0.03	-0.06	0.07	-0.70
SC	-0.03	**-0.05**	-0.02	0.02	0.00	-0.01	0.00	-0.03	-0.01	0.02	-0.01	-0.04	**-0.10**	0.01	-0.04	0.01	-0.14
A	0.09	0.08	0.00	-0.06	0.07	-0.03	0.07	**0.13**	-0.04	-0.04	0.00	0.04	0.19	0.02	0.16	-0.08	0.30

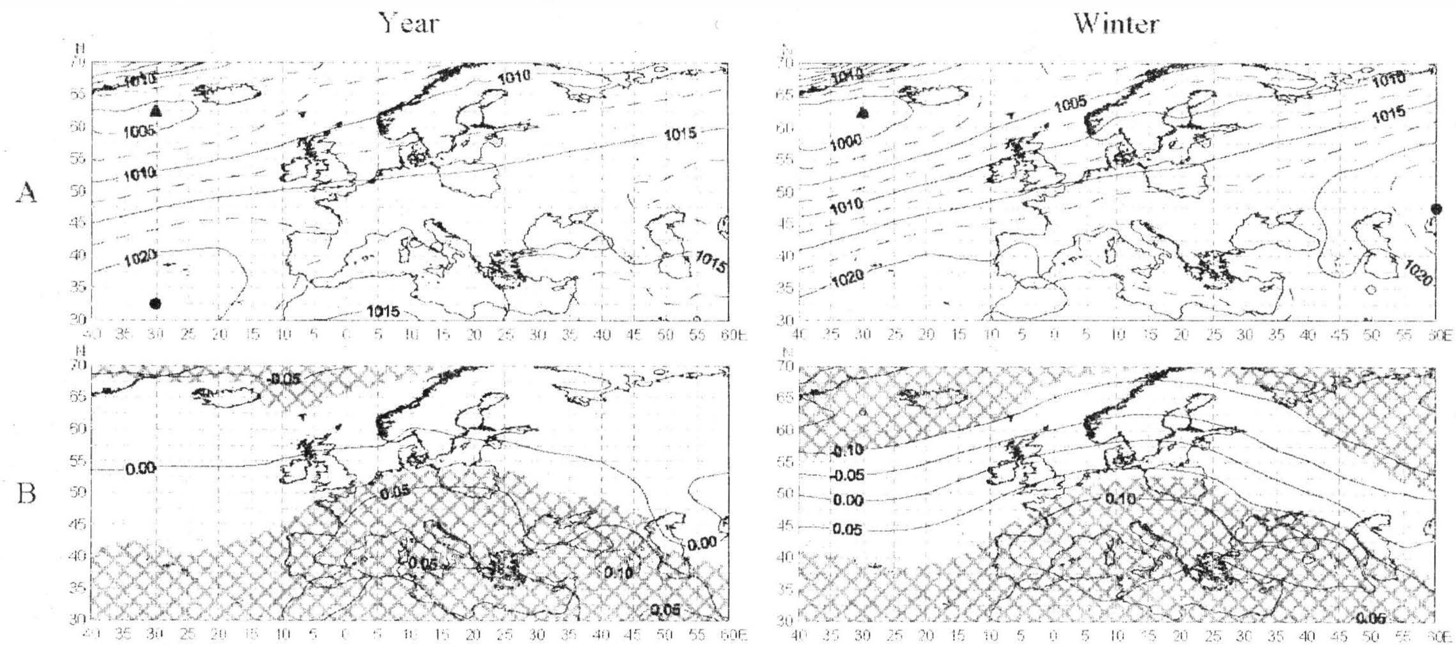


Figure 6 Mean pressure pattern (A) and tendencies of pressure change (B) in years 1951 – 2000

4. SUMMARY

- Linear trends explain little percentage of variability of climatic elements over Central Europe in second half of 20th century. Significant tendencies of changes and fluctuations are observed only in temperature in spring and during whole year,
- Diverse both seasonally and spatially tendencies of changes of climatic elements are slightly revealed in spatial distribution over Poland and in some symptoms of climatic regime change,
- Western circulation has significant role in shaping climatic conditions over Poland; in transitional parts of the year role of longitudinal component is greater,
- Evolution of climatic conditions in Central Europe in second half of 20th century is very well explained by changes in circulation conditions.

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Zmienność klimatu w Europie Środkowej: przykład Polski 1951 – 2000

Resume

W artykule przedstawiono wyniki badań dotyczących zmienności warunków termicznych, opadowych i nefologicznych w Polsce w drugiej połowie XX wieku. W analizie wykorzystano obszarowo uśrednione serie elementów klimatu z terenu Polski nizinnej (poniżej 300 m n.p.m.), które mogą stanowić podstawę syntetycznej oceny kierunku i skali współczesnej ewolucji warunków klimatycznych w Europie Środkowej.

Stwierdzono istotny wzrost temperatury wiosną; złagodzeniu uległy także zimy. Charakterystyczne było również pewne oziębienie w czerwcu oraz jesienią. W ciągu przeważającej części roku stwierdzono nieistotne zmniejszenie wielkości zachmurzenia, tylko jesienią wystąpił nieznaczny jej wzrost. Wyróżniły się znacząco zmiany zachmurzenia w maju i zimą (ujemna tendencja zmian) oraz we wrześniu (tendencja wzrostowa). Wysokość opadów nie wykazała istotnego trendu zmian.

Fluktuacje występujące w szeregach czasowych sezonowych i rocznych wielkości elementów klimatu nie różniły się istotnie od fluktuacji o charakterze losowym, z wyjątkiem fluktuacji temperatury powietrza wiosną i średniej rocznej.

W ostatnim 20-leciu XX wieku stwierdzono przyrost tempa ocieplenia; zaznaczyło się ono nie tylko w sezonie zimowo-wiosennym (I – V), ale także w ciepłej porze roku. Wysokie wartości temperatury w okresie letnim w połączeniu z niedostatkiem opadów,

przede wszystkim w latach 1981 – 1994 (kumulacja lat o wyjątkowo małym zachmurzeniu), przyczyniły się do wystąpienia okresów posuchy, a nawet suszy. Pod koniec lat 90. XX wieku nastąpił wzrost ilości opadów.

Tendencje zmian warunków klimatycznych korespondują ze zmianami sum promieniowania całkowitego, będącego zarówno ważnym elementem klimatu, jak i „aktywnym" czynnikiem klimatotwórczym. Wykazano ponadto, że znaczną część zmienności elementów klimatu można wyjaśnić bezpośrednim oddziaływaniem cyrkulacji atmosferycznej.