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SOME ASPECTS OF PRECIPITATION VARIABILITY IN POLAND IN THE PERIOD OF 1881 – 1980

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SUMMARY

The contribution deals with the study of atmospheric precipitation variation in Poland in the period of 1881—1980 on the basis of the series of the so-called spatial annual precipitation sums. Fundamental statistical characteristics are given and the driest years evaluated also with respect to further parts of Europe. The analysis of the series has been carried out by means of autocorrelation, power spectrum and coherency analyses, for selected periods also band-pass filtering has been performed. Precipitation variation is studied in connection with different indices of atmospheric circulation and solar activity.

1. INTRODUCTION

The annual sums of precipitation in most of Poland are lower by 20—40 % than the mean total in the zone of 50—55 °N which, according to Jaeger (1976), amounts to 794 mm. Precipitation in Poland is highly varied; in some parts of the country, standard deviations of the annual precipitation sums amount to ca. 20 % of the long-period mean values (Fig. 1).

In years and periods of low precipitation, the lack of water affects agriculture and economy. The lower limit of annual precipitation, necessary for the normal cultivation of plants in Poland, has been established as 500 mm (Schmuck, 1965). Smaller precipitation occurred in the last hundred years with a frequency of 46 % (Poznań), 42 % (Bydgoszcz), 26 % (Warsaw) and 24 % (Szczecin).

Relatively small amounts of precipitation in the fourth, fifth and sixth decades of the present century in the driest central parts of Poland were marked by the gradual lowering of ground water levels, and drying up of the soil. Changes occurred in flora and fauna with an increase in steppe features in the environment (Lambor, 1954). Investigations of the tendency to changes in precipitation in that period have shown a decrease in precipitation in a vast belt stretching from Berlin to Odessa (Okołowicz, 1947).

Precipitation in Poland displays a great spatial variety and dependence on land forms. The mean annual sums for the period of 1931—1960 oscillated from 459 mm (Pakość on the Noteć River) to 1629 mm (Kasprowy Wierch in the Tatra Mts.). Even small elevations receive markedly greater precipitation than lower lying terrains. For example, precipitation in the small Łódź Upland exceeds

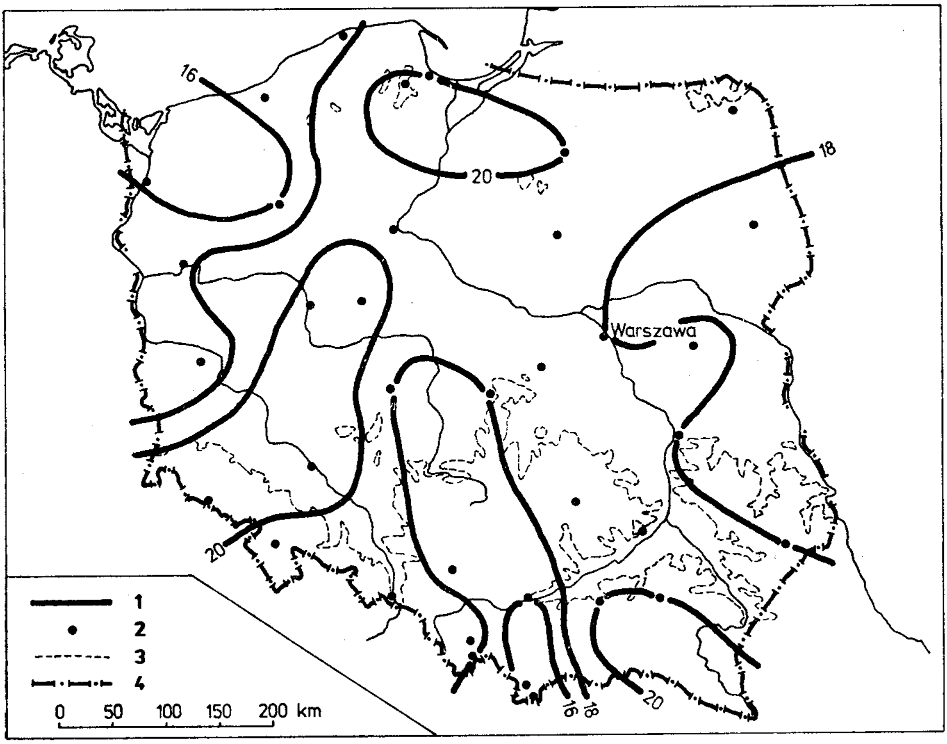

Fig. 1. Geographical distribution of variability coefficient of annual precipitation sums in Poland on the basis of data from 1931 to 1980. Marking: 1 — isolines of variability coefficient (%), 2 — meteorological stations, 3 — areas above 200 m a.s.l., 4 — country borders

by 20% that in the Mazowiecka Lowland; in some cases its twenty-four hour precipitation is five times higher (Dubaniewicz, 1974). A close correlation between the amount of precipitation and the height above sea level has been demonstrated by many authors on the basis of material obtained from different periods and areas of the country (Chełchowski, 1955; Dubaniewicz, 1974; Michna, 1971; Stopa-Boryczka and Boryczka, 1974—1976). Annual precipitation sums increase on the average by about 60 mm per 100 m in height.

The mean value as well as a pattern of the long-period course of precipitation depend on the geographical situation. A comparison of the results of investigations carried out for many years on the course of precipitation (Hohendorf, 1970; Kaczorowska, 1962; Kożuchowski, 1981; Ostromecki, 1948; Suryjak, 1974; Trepińska, 1977) permit one to draw the conclusion that parameters characterizing trends and cyclic oscillations of precipitation undergo remarkable spatial changes. Permanent spatial order of this differentiation has not yet been precisely defined. Preliminary investigations of the problem indicate the existence of a common pattern of oscillations of precipitation in greater part of western and central Poland. The position of the highest isocorrelates (Fig. 2) may be considered as a limit of this region.

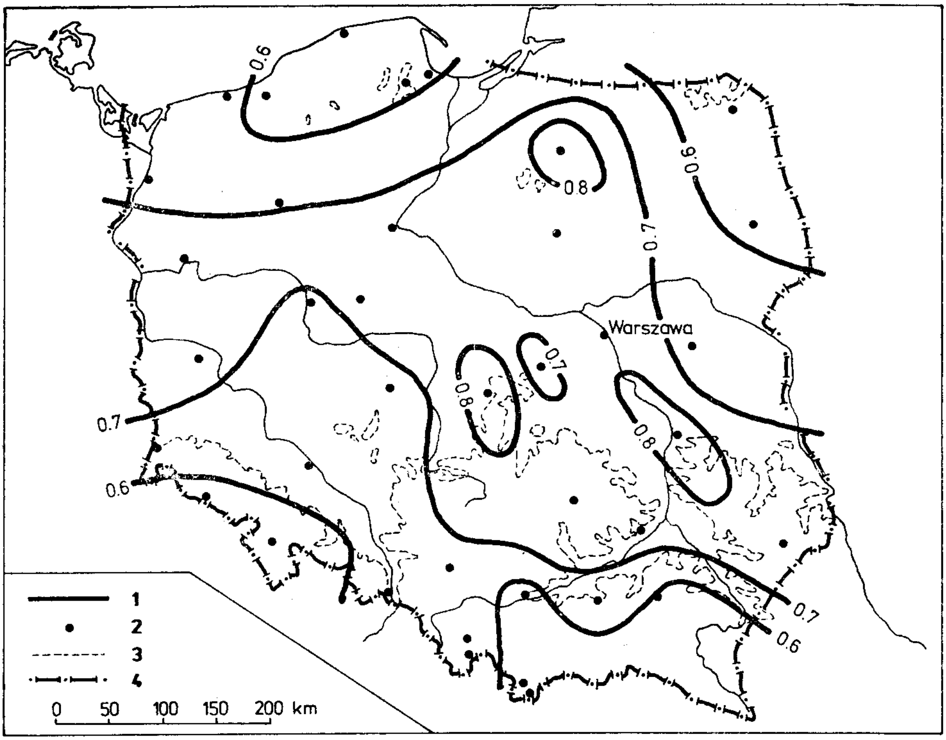

Fig. 2. Coefficient of correlation between the mean precipitation throughout Poland and precipitation in the particular stations. Marking: 1 — isocorrelates, 2—4 — as in Fig. 1

Precipitation on the territory of Poland is dependent on the transport of water vapour in the atmosphere. As stated by Lenart (1983), this transport reaches high values. The summary flux of water vapour in the year exceeds 70 kg . m^{-1} . s^{-1}, the mean vector of this flux exhibiting the westward direction. From this it can be judged that the western transport of air has a principal importance for precipitation in Poland. It is known that the diminution of precipitation in the 1930's, 1940's and 1950's agreed with the reduction of cyclonal circulation bringing air masses from the region of the Atlantic Ocean (Kudryan and Melnik, 1977).

2. SPATIAL ANNUAL PRECIPITATION SUMS FOR POLAND AND THEIR FUNDAMENTAL STATISTICAL CHARACTERISTICS

To express the overall character of precipitation variation on the territory of Poland and to eliminate local and regional differences, Kożuchowski (1985) calculated the so-called spatial annual precipitation sums (means) for the period of 1881—1980. For the calculation the formula for the weighted arithmetic mean $\bar{x}_v$ was used:

$$\bar{x}_v = \frac{\bar{x}_1 v_1 + x_2 v_2 + \ldots + x_n v_n}{v_1 + v_2 + \ldots + v_n} = \sum_{i=1}^{n} x_i v_i \Big/ \sum_{i=1}^{n} v_i,$$

where x_i are arithmetic means of annual precipitation sums of stations in the height intervals 0—150, 150—300, 300—500, 500—1000 and more than 1000 m above sea level and the weights v_i are represented by the area shares of the above intervals throughout the territory of Poland (the corresponding percentual shares are 54.4, 36.9, 5.7, 2.9 and 0.1 %, respectively). For calculating the mean annual precipitations sums in those intervals altogether 38 rain gauge stations more or less evenly distributed on the territory of Poland were used. The values thus obtained are given in Tab. 1. They present a value characteristic of the area of the country

Tab. 1. Annual spatial precipitation sums in Poland in the period of 1881—1980 (sums marked by the sign — are lower than $\bar{x} - s$, those marked with + are higher than $\bar{x} + s$)

Year	1	2	3	4	5	6	7	8	9	10
1880	511−	686	628	556	597	545−	565	690	674	651
1890	662	547−	606	601	562	618	641	651	705+	595
1900	634	616	727+	509−	669	611	632	592	647	683
1910	509−	739+	678	590	685	695	582	614	710+	573
1920	511−	684	648	618	677	783+	710+	564	560	729+
1930	676	531−	555−	617	622	631	612	626	715+	611
1940	725+	512−	512−	644	734+	611	594	641	621	600
1950	485−	678	496−	577	595	623	617	674	488−	729+
1960	621	661	570	565	664	761+	735+	657	495−	794+
1970	555−	626	598	785+	558	559	694	650	589	705+

and are correlated with precipitation sums in the particular meteorological stations. This is significant for every case studied. The correlation coefficients differ from 0.5 to 0.9 (Fig. 2).

The mean annual precipitation sum $\bar{x}$ in the period of 1881—1980 reached the value of 627 mm on the territory of Poland, the highest annual sums, 794 mm, being calculated for the year 1970 (i.e. 126.6 % of the annual mean for 100 years), the lowest, 485 mm, for the year 1951 (i.e. 77.4 %). The standard deviation s of the calculated series is 71.2 mm, the variation coefficient $v = 11.4$ %. In the intervals of $(\bar{x} \pm 1s)$ and $(\bar{x} \pm 2s)$ there are 69 and 97 %, respectively, of all annual sums, none of them exceeding the limit of $(\bar{x} \pm 2.5\,s)$. The distribution of the series approaches the normal one with a slight left hand side (positive) skewness (the skewness coefficient $c_a = 0.09$) and negative kurtosis (the kurtosis coefficient $c_\varepsilon = -0.50$).

The idea about the course of precipitation in the period studied is given in Fig. 3, in which the course of precipitation is smoothed by means of five-year and eleven-year gliding means. From the course of the five-year means it is evident that the maximum of precipitation fell to the mid 1920's and to the latter half of the 1960's, the lowest five-year means being registered in the first half of the 1950's. This corresponds to the distribution of precipitation in decades as well, when the annual mean of precipitation in the decades of 1921—1930 and 1961—1970 reached 103.5 and 104.1 %, respectively, of the value of the mean for 100 years,

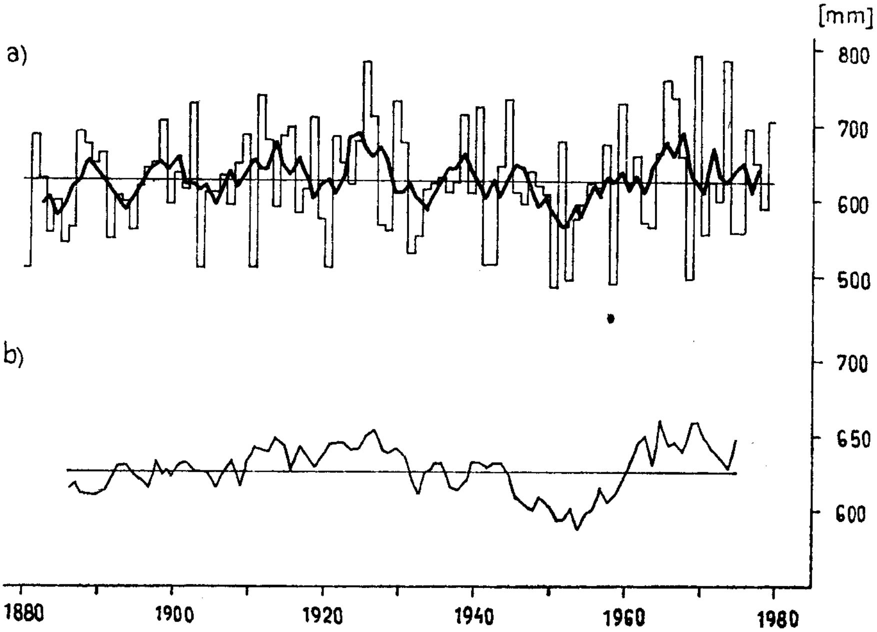

Fig. 3. The course of spatial annual precipitation sums on the territory of Poland (column diagram) in the period of 1881—1980, smoothed by five-year (a) and eleven-year (b) gliding means; horizontal line — annual mean for 100 years (1881—1980)

while in the years 1951—1960 it was only 95.1 % of the above value. The described facts are also reflected in the trends of the studied precipitation series, when the rising trend appears more or less with the beginning of the period processed and continues up to the latter half of the 1920's, and after a subsequent drop annual sums rise from the beginning of the 1950's up to 1970. If we follow the variability of annual precipitation sums expressed by means of variation coefficients for ten-year gliding time periods, a step-like increase in variability is apparent in the

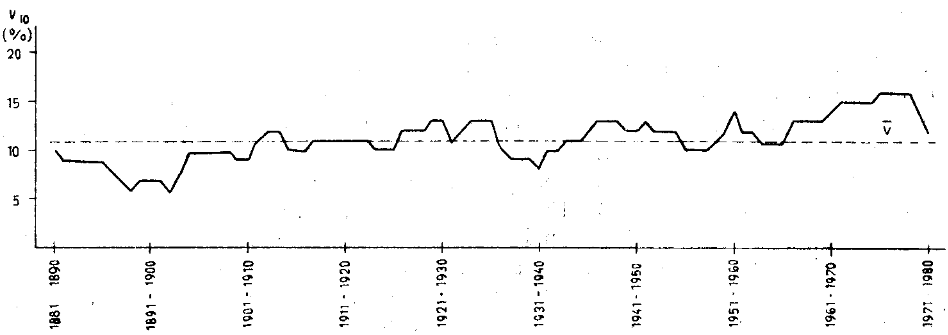

Fig. 4. The variation of variance coefficient $\bar{v}_{10}$ calculated for ten-year gliding time intervals ($\bar{v}$ — hundred-year average variation coefficient)

course of the period studied. The most variable were the annual precipitation sums in the last two decades (Fig. 4).

The calculated precipitation series for the territory of Poland exhibits statistically significant correlation coefficients with corresponding precipitation series of the neighbouring territories of central Europe (a list of those series and the kind of their calculation is given in the paper by Brázdil, 1986), varying between 0.65—0.70 (with the G.D.R. 0.70, with Bohemia 0.68, with Moravia 0.69, and with Slovakia 0.65). Westwards this correlation drops more slowly than southwards, since e.g. with the Baur series the correlation coefficient $r_{xy} = 0.67$, with the series of the F.R.G. 0.65 (period 1891—1970), but with Hungary only 0.27. These facts point to the importance of Atlantic precipitation effects in the direction of the parallels, and a dropping trend of Mediterranean precipitation effects from the south to the north (e.g., the correlation coefficient between Slovakia and Hungary is 0.74).

3. ANOMALIES OF ANNUAL PRECIPITATION SUMS ON THE TERRITORY OF POLAND IN RELATION TO A BROADER EUROPEAN REGION

From a practical point of view the subject of interest is the occurrence of extremely dry and/or humid years. A certain criterion for their delimitation can be e.g. the value of the standard deviation s, when the annual sums less than the value $(\bar{x} - s)$ are considered to be dry and greater than $(\bar{x} + s)$ humid. From this view there were altogether 15 years registered as dry and 16 as humid in Poland in the period of 1881—1980, i.e. their empirical probability of occurrence is practically the same (0.15 and 0.16, respectively). Often extreme years occur in the sequence of 2 to 3 years, such as in the years 1941—1943 or 1969—1971. Extremely dry years were not missing in any decade of the studied period of time (they occurred mostly 3 times in the years 1951—1960); extremely humid years did not occur in the decade of 1881—1890; in the years 1921—1930 and 1961—1970 they were, however, registered always three times.

From Tab. 2 it can be judged to the time correspondence of the occurrence of extremely dry years in Poland in comparison with other regions of Europe. An agreement in the occurrence of dry years was most frequent with the series of Bohemia (73.3 % of all dry years in Poland), the G.D.R. (66.7 %), Moravia, Slovakia and the Baur series (60 %), the series for the F.R.G. (58.3 %) and the Netherlands (46.7 %). In comparison with the precipitation series of England and Wales an agreement was found in one-fifth of all dry years in Poland. It is evident that with the growing distance the probability of a concurrent occurrence of dry years drops, which is in agreement with the information by Rauner (1979) about the local and regional occurrence of such years. In all the studied series listed in Tab. 2 there is not a single year in the period of 1881—1980 that may be described as dry. Thus, in 1921 the precipitation was higher than the limit $(\bar{x} - s)$ in Denmark and in the F.R.G., in 1933 in Slovakia and Hungary, in 1953 in Denmark and Hungary, in 1971 in England and Wales and in Denmark. This witnesses the fact that different parts of Europe get in a certain part of the years under the influence of situations limited differently by their extent in space, which can cause considerable differences in the geographical distribution of precipitation in the course of the given year.

Tab. 2. Occurrence of dry years (according to the criterion $\bar{x} - s$) in the European region, period 1881—1980. Explanation: symbols × denote the occurrence of a dry year for the given region; F. R. G. only 1891—1970; Netherlands 1881—1978; EW — England and Wales, Ne — Netherlands, De — Denmark, Ba — Baur series, Po — Poland, Bo — Bohemia, Mo — Moravia, Sl — Slovakia, Hu — Hungary

Year	Area										
	EW	Ne	De	F. R. G.	Ba	G. D. R.	Po	Bo	Mo	Sl	Hu
1881							×				
1884	×								×		
1885								×			
1886			×			×	×				
1887	×	×	×		×	×		×	×		
1892				×	×	×	×				
1893	×			×	×			×	×		
1894											×
1898	×										
1899			×								
1901			×								
1902	×		×								
1904		×	×	×	×	×	×	×		×	
1905	×										
1907		×		×							×
1908		×			×			×	×	×	
1911		×		×	×	×	×	×		×	×
1913			×								
1917								×		×	×
1920		×		×							
1921	×	×		×	×		×	×	×	×	×
1928										×	×
1929		×	×	×	×	×		×			
1932							×		×	×	×
1933	×	×	×	×	×	×	×	×	×		
1934				×	×	×		×	×		×
1941			×								
1942						×	×	×	×	×	
1943				×	×	×	×	×	×	×	
1946										×	×
1947			×					×	×	×	×
1949	×			×							
1951							×	×			
1953	×	×		×	×	×	×	×	×	×	
1955	×										
1956			×							×	
1959		×	×		×	×	×	×	×		
1961											×
1962						×		×			×
1963						×					
1964	×			×	×	×					
1967											×
1968											×
1969							×	×	×	×	
1971		×			×	×	×	×	×	×	×
1972						×		×			
1973	×							×	×	×	×
1975	×		×			×					
1976	×	×	×		×	×		×			
1978									×	×	

Note: The Bauer series — calculated as an arithmetic mean on the basis of data from 14 stations situated west of the Odra river (of these, 11 stations are on the territory of the F.R.G., Berlin-Dahlem in West- Berlin and 2 stations on the territory of the G.D.R.) (Baur, F.: Abweichungen der Monatsmengen des Niederschlags in Deutschland westlich der Oder in Ltr/m², Mittel aus 14 Stationen, vom 120jährigen Mittelwert 1851—1970. Beilage zur Berliner Wetterkarte d. Inst. f. Meteorol. d. FU Berlin, vom 24. 6. 1975)

4. VARIATION OF ANNUAL PRECIPITATION SUMS IN POLAND IN THE PERIOD OF 1881—1980

Several papers have been devoted to the study of periodical and cyclical components of precipitation series on the territory of Poland. By the application of the method of harmonic analysis on the precipitation series of Warsaw and Cracow (1842—1936) Kaczorowska (1962) found, besides periods in the length of 16a (a = year) for Warsaw and 14a for Cracow a long-term oscillation in the length of about 70 years for both stations (for Wroclaw in the same period about 90 years), but there is a problem of the importance of those long-term changes. Mikulski and Mikulska (1972), using Fuhrich's autocorrelation method, found for precipitation and water levels in the region of the Great Masurian Lakes (1866—1965) periods of 21.8 and/or 23.2a. Suryjak (1974) found a five-year and a two-year cycles in the case of the precipitation of northern and central Poland. Kożuchowski (1982) analyzed the annual precipitation from 38 polish stations in the period of 1931—1980, again using Fuhrich's autocorrelation method, finding for the most part periods in the length of 2—4a. In altogether 14 stations he found periods in the length of 2—3 years and for only 4 stations periods of 3.6—3.7a. The most important period found by the same method for the above series of spatial annual precipitation sums of Poland is 3.6a. A near value (3.7a) was determined by the power spectrum analysis in the paper by Šamaj et al. (1984).

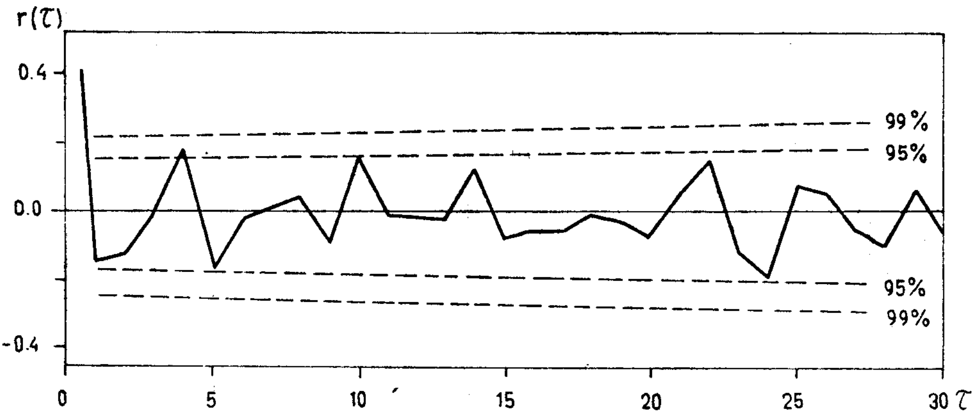

Fig. 5. The course of autocorrelation coefficients $r(\tau)$ of the series of spatial annual precipitation sums of Poland in the period of 1881—1980 (τ — time lag); dashed lines mark the respective 95 and 99 % confidence limits according to Andersson (in Nacházel and Patera, 1975)

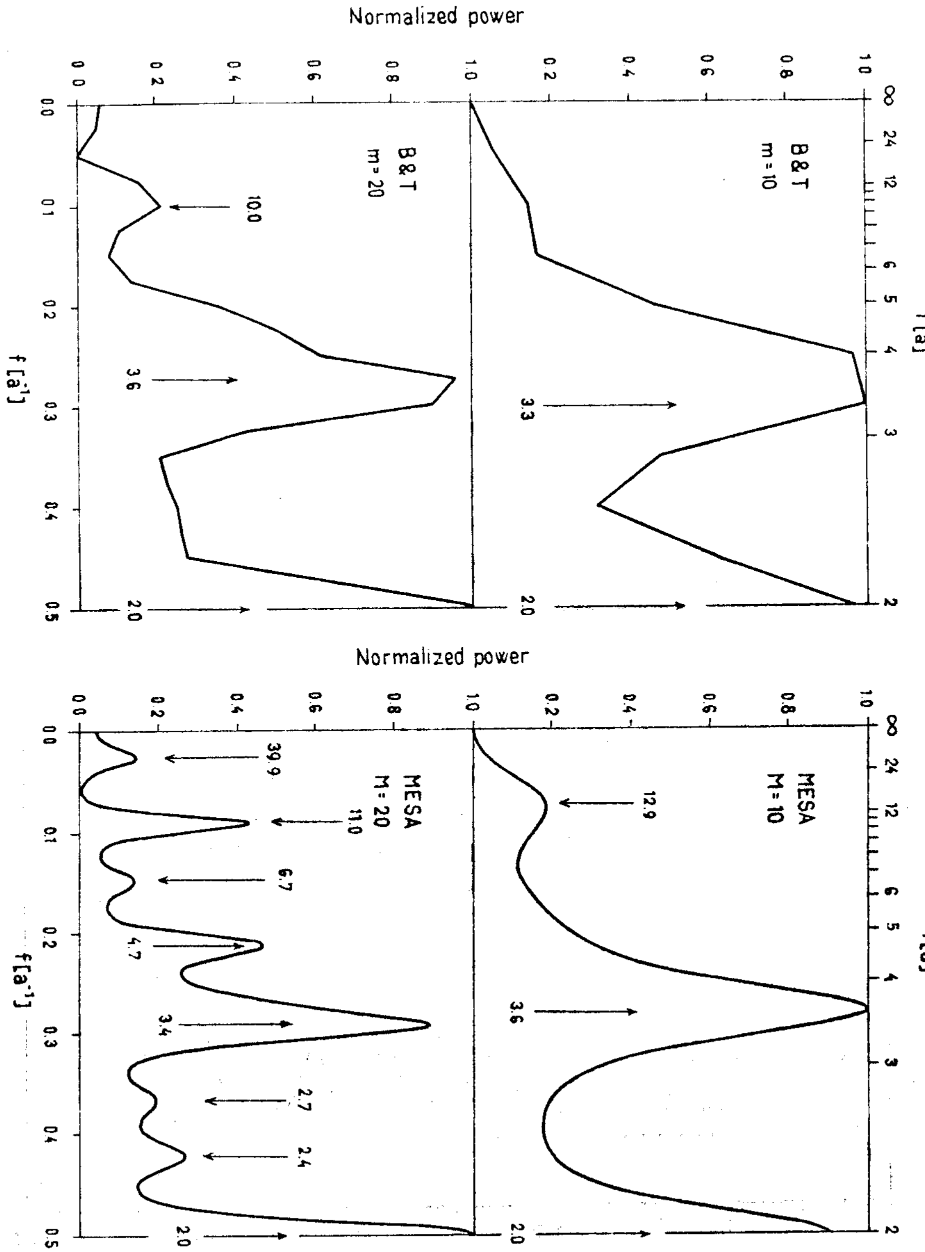

Fig. 6. Power spectrum analysis of the series of spatial annual precipitation sums of Poland in the period of 1881—1980 (m — maximum lag for B&T, M — filter length in MESA, T — period, f — frequency). The power spectrum is standardized in such a way as to attribute value 1 to the maximum value of the spectrum and zero to the lowest one. Significant on the level of significance $\alpha = 0.10$ is the period of 3.6a

For the analysis proper of precipitation variation methods of autocorrelation analysis, power spectrum analysis according to Blackman and Tukey (further B&T — Mitchell, 1966), maximum entropy spectral analysis (abbreviation MESA — Olberg, 1982; Junk, 1982), coherency analysis (Doberitz, 1968; Fleer, 1981) and numerical band-pass filtering (Schönwiese, 1974, 1975) have been used. In the literature quoted the description of the above methods can be found (in a summary form in application to precipitation series in the paper by Brázdil, 1986).

The maxima of the autocorrelation function of the series of spatial annual precipitation sums of Poland appear in the range of 2—4 years, statistically significant at the level of significance $\alpha = 0.05$ they are, however, only for $\tau = 4$ and 10a (τ is the time lag). Autocorrelation coefficients $r(\tau)$ do not leave the interval (—0,20; 0.20) — Fig. 5.

In the power spectrum of the series studied the most conspicuous period appears to be the one in the length of 3.3—3.6a, which in the power spectrum analysis according to B&T is significant for $\alpha = 0.10$ (the calculation with maximum lag $\tau = m = 20$) — Fig. 6. Very conspicuous is also the two-year oscillation and in the power spectrum also oscillations in the length of 10—13 years can be seen. The highest share in the overall variance of the series falls to the variations in the length of 2—3 years (33.8 %) which, together with oscillations of 3—4 years express altogether 62.3 % of the value of the variance of the series studied. Much

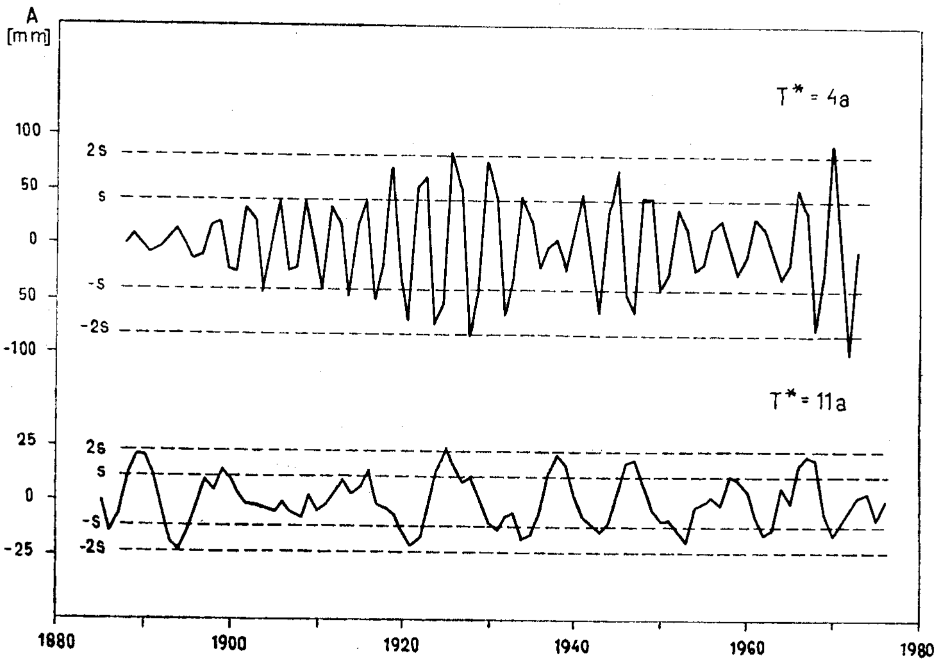

Fig. 7. The course of a band-pass filtered series of spatial annual precipitation sums of Poland for $T^* = 4a$ and $T^* = 11a$ $\left(\text{filter characteristic is } \left(\frac{3}{4}T^* \leftarrow T^* \rightarrow \frac{4}{3}T^*\right)\right)$; dashed lines mark limits corresponding to $\pm s$ and $\pm 2s$, where s is the standard deviation from the filtered series

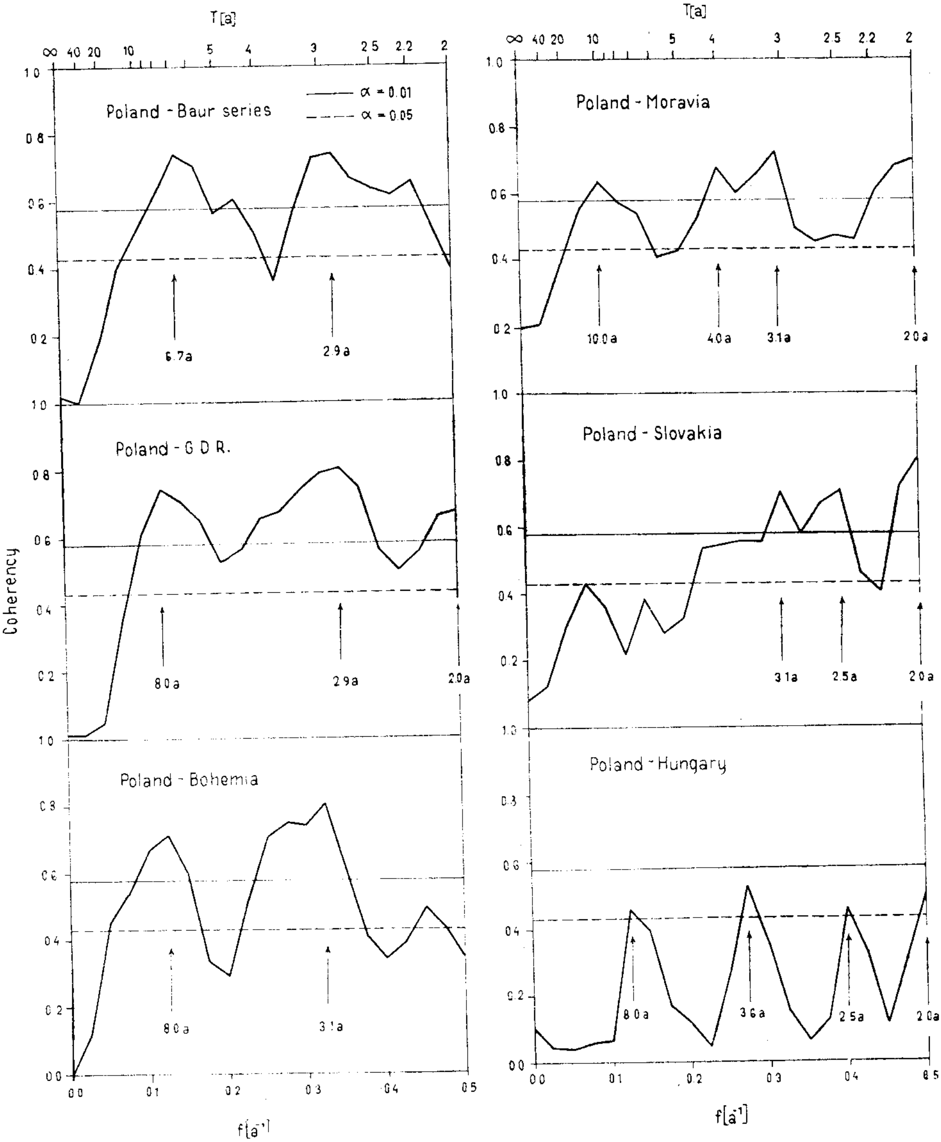

Fig. 8. Coherency analysis of the series of spatial annual precipitation sums of Poland with analogical series of selected neighbouring territories in the period of 1881—1980 (α — level of significance)

suppressed are variations longer than 20 years (5.4 %) and in the length of 10—20a (7.5 %), approximately balanced is the share of oscillations in the intervals of 5—10 and 4—5 years (12.2 and 12.6 %, respectively).

The time-connected of the most conspicuous oscillation is partly indicated by the course of the band-pass filtered series of annual precipitation sums with the filter characteristic $\left(\frac{3}{4} T^* \leftarrow T^* \rightarrow \frac{4}{3} T^*\right)$ (Schönwiese, 1974, 1975) for $T^* = 4a$ (T^* is a period not subject to amplitude variation; symmetric filtering weights are counted up to $k = 8$, the width of filter permeability is $d = 3.0$—5.3a). From Fig. 7 it is possible to see the inconstancy of the above period both in phase and in amplitude. The amplitude of the above period grows essentially from the beginning of the period studied up to about the 1920's, then there is more or less a drop up to the fifties, the maximum amplitude being reached about 1970 (15.4 % of the value of the mean for one hundred years). The variance of the thus filtered series represents 32.9 % of the variance value of the original series of annual sums. The band-pass filtering of the above precipitation series for $T^* = 11a$ ($k = 5$, $d = 8.2$—14.7a) points, on the other hand, to a small significance of long periods as well as to their minor phase stability, reflected in a number of secondary peaks in the course of the filtered series. The maximum amplitude reached in this case only 3.9 % of the mean of the series and the share in the overall variance of the original series is only 2.6 %.

The variation of precipitation on the territory of Poland can also be evaluated with respect to precipitation changes in the neighbouring regions by means of the method of coherency analysis (Fig. 8). Whereas in some cases the coherency with further European precipitation series can be significant for a considerable part of the frequency interval (see e.g. the coherency with the series of the G.D.R.), in other cases the coherency is significant for only some frequencies and/or periods (see e.g. the coherency with the series of Hungary). The highest coherency values concentrate about the periods of the length of 8.0a (in the case of Moravia and Slovakia as much as 10.0 and 13.3a, respectively, for the Baur series 6.7a), 3.1 and 2.9a (with Hungary 3.6a and with Slovakia 2.0a).

5. PRECIPITATION AND ATMOSPHERIC CIRCULATION AND SOLAR ACTIVITY

Searching for the general reasons of precipitation fluctuations occurring we can indicate that the revealed precipitation cycle corresponds also to the period of changes in circumpolar circulation which shows the 3—4-year periodicity (Girs, 1971). Girs also informs that dependence exists between the cyclic changes in circulation and the changes in the velocity of the Earth rotation. A close-fitting relation between the long-term curve of anomalies of the meridional circulation processes and the changes in diurnal of Earth rotation speed is found by Sidorenkov and Svirenko (1983). A conspicuous connection of the anomalies of circulation pattern and solar activity has appeared in the Girs (1977) paper.

Considering the well-known geographical character and variety of precipitation,

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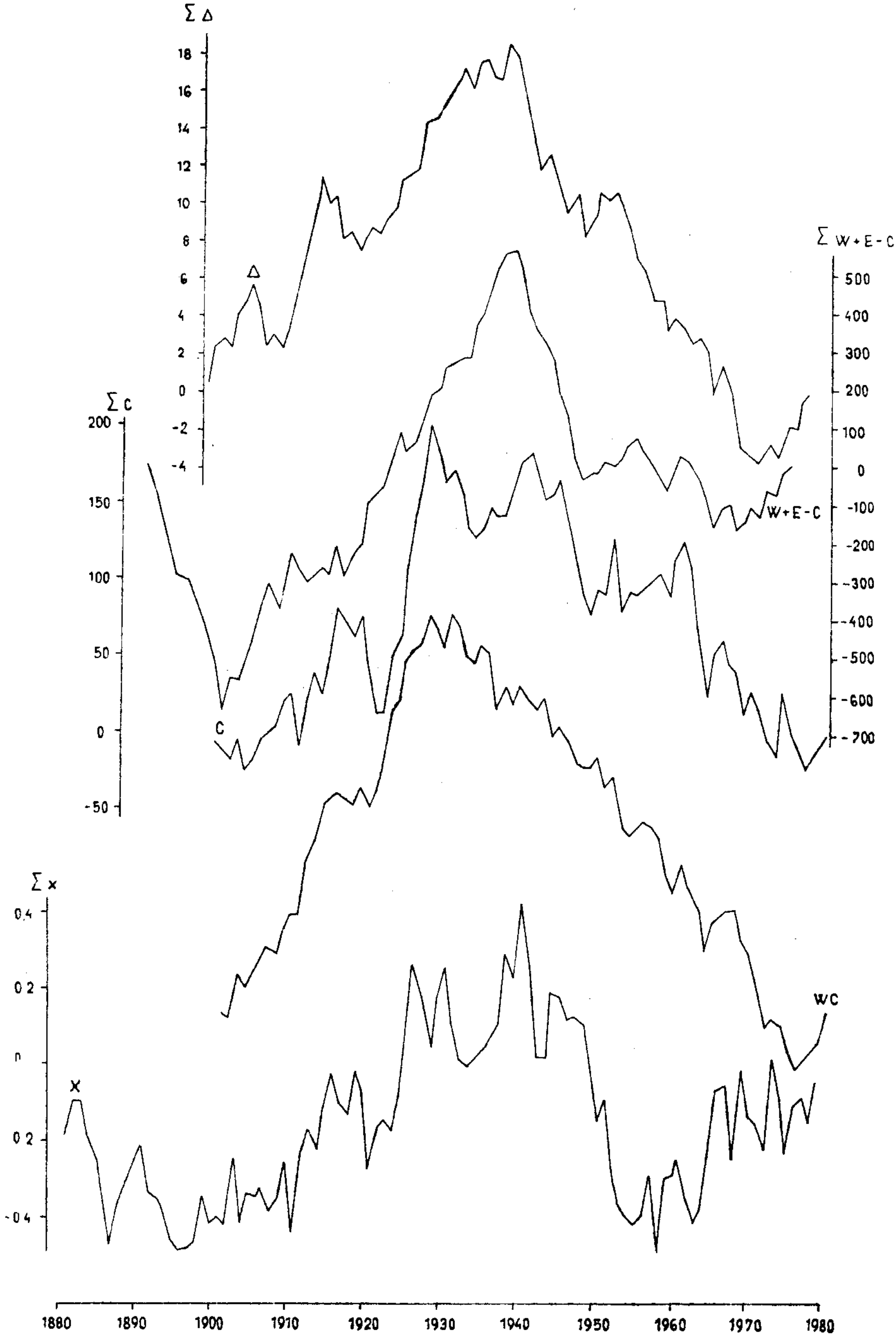
Fig. 9. A long-term course of cumulated anomalies of selected indices of atmospheric circulation and precipitation. Marking: △ — annual means of the Zonalindex (hPa), $W + E — C$ — annual frequencies of macrocirculation types according to the classification by Vangengejm and Girs (days), C — annual frequencies of cyclonal types (WC — western cyclonal types) for Poland according to the Osuchowska—Klein classification (days), x — annual precipitation anomalies calculated as $(x_i/\bar{x} - 1)$, where $\bar{x}$ is the average for 100 years and x_i the precipitation of the i-th year



Σ Δ
18
16
14
12
10
8
6
4
2
0
-2
-4
Δ
Σ W + E - C
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
W + E - C
Σ C
200
150
100
50
0
-50
C
Σ WC
250
200
150
100
50
0
-50
WC
Σ x
0.4
0 2
0
0 2
-0.4
X
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980

the problem may be examined whether that aspect of climate is determined by the processes of global scale. The following data show that some dependence exists.

The connection of precipitation in Poland with circulation patterns is well reflected in the graph presenting the long-term course of cumulative precipitation anomalies and the cumulative deviations of strength and occurrence of zonal circulation forms (Fig. 9). The indicator of zonality of circulation is the difference in pressure between the 35th and the 65th parallels of latitude over the whole Northern Hemisphere (Zonalindex). The other one, here, is the difference between the frequency of western and eastern forms and meridional forms of circulation in the Atlantic-European sector of the Northern Hemisphere (W + E — C).

The values of „Zonalindex" vere taken from the data published in „Grosswetterlagen Europas" (1968—1980) and in „Berichte des Deutschen Wetterdienstes" (1899—1967). The frequencies of W, E and C forms were estimated on the basis of the Girs calendar of circulation forms, included in the papers by Girs (1971) and Dydina (1982).

Fig. 9 also illustrate changes in frequencies of cyclonic and western cyclonic patterns of circulation in Poland. The frequencies were estimated on the basis of the Osuchowska—Klein (1978) cataloque of atmospheric circulation.

The correlation coefficient between the values of the Zonalindex and the precipitation sums in Poland amounts to 0.06, between the W+E—C index and precipitation 0.20. The last one is statistically significant for the level $\alpha = 0.10$. Considerably closer is the correlation between precipitation and the frequency of cyclonic types of circulation. The correlation coefficient amounts to 0.64 and is significant at the level $\alpha = 0.01$. The coefficient of correlation between precipitation and western cyclonic types of circulation amounts to 0.37. Then the correlation coefficient between the $W+E—C$ index and the frequency of cyclonic types amounts to 0.48.

The described correlation dependencies indicate that in spite of spatial variation and local connections the precipitation in Poland is also affected by circulation processes at the global scale. The zonal pattern of circumpolar circulation favours the occurrence of cyclonic patterns over Poland which in turn generate the increase in annual precipitation. The precipitation-circulation dependencies are expressed better in a long-term scale then in year to year changes. This is shown by the cumulative curves and the accounted correlation ceofficients.

Particular forms of circulation macroprocesses (W, E, C) dominate during periods of several years making so-called circulation epochs. During the epochs

Tab. 3. Mean annual precipitation sums ($\bar{x}$) and variation coefficients (v) for the territory of Poland in different circulation epochs

Epoch	Period	$\bar{x}$ (mm)	v (%)
W + C	1891—1899	621	8
W	1900—1928	637	11
E	1929—1939	625	10
C	1940—1948	620	14
E + C	1949—1967	619	12
E	1968—1976	625	13

of zonal forms the precipitation is somewhat higher then during the epochs of meridional forms (C) and during the epochs W+C and E+C (Tab. 3). The differences in the average precipitation do not exceed, however, 3 % and are not statistically significant.

A significant phenomenon, however, is the increase in the coefficient of variability of precipitation which has been recorded since the end of the nineteenth century (Tab. 3). The occurrence of maximum variability in the epoch of the meridional circulation (C) is not undoubtedly accidental.

A general growing tendency of precipitation variability can be observed throughout the whole analysed period. Other climatic indices show a similar tendency to the growing variability. It has been noted, among other things, that the variability of Zonalindex has increased twice since the beginning of the present century. Standard deviations of January Zonalindex increased from 3—4 hPa in the first two decades of the century to over 6 hPa during the sixties and seventies.

There are also data that point to the connection between the sums of precipitation in Poland and stratospheric circulation. Suryjak (1974) has demonstrated that in the years with an anomalously early spring reversal of stratospheric winds, precipitation is smaller than usual in northern and central Poland. The same dependence is characteristic of mean precipitation in the entire area of Poland. In the years enumerated by Suryjak, with an early reversal of stratospheric winds, the amount of precipitation in Poland was by about 10 % lower than the long-term average (Tab. 4).

Tab. 4. Years with early spring reversal of stratospheric winds (Suryjak, 1974) and annual precipitation sums throughout Poland

Year	Annual sum (in mm)	Annual sum (in % of the mean)
1955	595	95.0
1957	617	98.5
1959	488	77.9
1961	621	99.1
1964	565	90.2
1969	495	79.0
1971	555	88.6

If the solar activity is the factor correlated with the Earth atmospheric circulation then there should be a relation between changes in solar activity and precipitation fluctuations. A conspicuous relation between the smoothed course of precipitation in Poland and solar activity has been established by Šamaj et al. (1984). In the secular course the maximum of Wolf's numbers occurs simultaneously with the minimum of precipitation (Fig. 10).

In 11-year cycles of solar activity annual precipitation series in Poland exhibit 2 maxima and 2 minima (Tab. 5), which is in accordance with the information by Baur (1959). The most conspicuous increase in precipitation with respect to the mean can be registered in the second year following the year of the minimum, and/or two years before the year of the maximum of solar activity (about 7 %), the most marked drop (about 4 %) before the year of the minimum and a year after the maximum of solar activity.

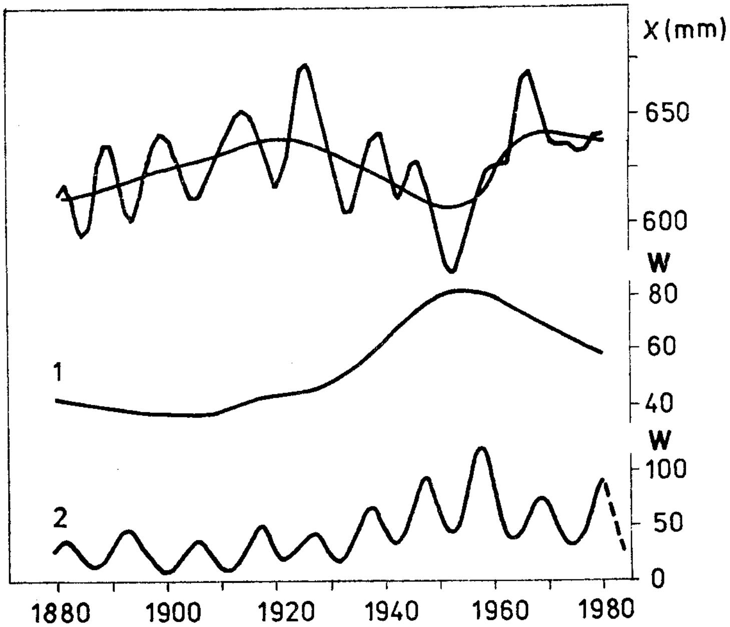


Fig. 10. A comparison of the course of spatial annual precipitation sums x in Poland (upper part of the graph) with the course of Wolf's relative numbers W (a two-fold or a twenty-fold smoothing of series by means of binomic coefficients was used — for W marked as 2 and 1, respectively) (Šamaj et al., 1984)

Tab. 5. Average percentage anomalies of annual precipitation sums throughout Poland at different stages of the sunspot cycle

Year of sunspot cycle	—3	—2	—1	Min.	+1	+2 ... —2	—1	Max.	+1	+2	+3
Anomalies (%)	—2.2	—4.0	—3.8	—0.9	+1.7	+7.4 ... +7.0	+1.9	—1.8	—4.3	+3.7	—2.3

6. CONCLUSIONS

On the basis of the analysis of the hundred-year series of spatial annual precipitation sums in Poland the chief conclusions can be summed up as follows:

1. The empirical distribution of the analyzed precipitation sums approaches the normal one, which corresponds to the regime of precipitation in the humid climate (Panofsky and Brier, 1958). Dry and humid years, given by the criterion ($\bar{x} \pm s$), appear with approximately the same probability, but their occurrence in the course of the period of one hundred years is highly irregular: dry years were concentrated mostly to the 1950's, humid years to the 1920's and 1960's.

2. In comparison with the neighbouring parts of central and western Europe the occurrence of dry or humid years in Poland is characterized by relatively great differences. The agreement in the occurrence of dry years with the areas west of Poland is higher than that with the regions situated to the south.

3. In the course of annual precipitation sums it is possible to more or less register a rising trend up to about the 1920's, alternated by a drop with the minimum in the 1950's. Practically throughout the period studied the variability of annual precipitation sums was growing.

4. From amoung numerous periods appearing in the power spectrum analysis of the studied precipitation series only the period in the length of 3.6a is statistically significant, almost 2/3 of the overall variance of the series (62.3 %) falling to oscillations in the interval of periods of 2—4 years. Less conspicuous are variations longer than 10 years (12.9 % of the variance value). Filtering of the given series by the band-pass filter points to the inconstancy of periods in phase and in amplitude. The Polish series exhibits significant coherencies for different frequency domains with precipitation series of neighbouring territories.

5. Besides the regional character of precipitation fluctuation in Poland also effects of changes in general circulation of atmosphere can be seen in the hundred-year series, particularly of changes in zonal circulation. Indices of zonal circulation (Zonalindex, W+E—C) exhibit, according to summation curves, a more or less identical course with annual precipitation sums. The correlation of annual values of these indices and precipitation is, however, relatively weak. The highest correlation appears between precipitation and the frequency of cyclonal circulation types in Poland.

6. In the years with early spring reversal of stratospheric winds precipitation in Poland is lower than normal. There also appears a connection between precipitation and solar activity — in a long-term course the maximum of activity corresponds to low precipitation, in the 11-year cycle there appear 2 maxima and 2 minima of precipitation.

The established information can have some prognostic value. It is, however, necessary to bear in mind the fact that there is a different character of dependence for changes in precipitation from year to year and a different one from the point of view of long-term trends.

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