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# ANOMALOUS MONTHS AND SEASONS IN TERMS OF TEMPERATURE AND PRECIPITATION IN THE SECOND HALF OF THE 20<sup>TH</sup> CENTURY IN WARSAW

Numerous scholars studying nowadays the changes of climate pay attention to the increased frequency of appearance of the extreme weather phenomena, such as high temperatures, strong frosts, draughts, floods, and other ones. In order to verify the respective opinions an attempt was undertaken of determining the frequency of the months and seasons, which have been anomalous in terms of average temperature and precipitation, in the second half of the 20<sup>th</sup> century in Warsaw. The study was based upon the values of monthly and seasonal temperature averages, as well as the monthly and seasonal precipitation values, for the period of 1951–2000, measured at the weather station of Warsaw-Okęcie, located at the periphery of Warsaw.

In any kind of study from the domain of climatology, in which the frequency of appearance of months, seasons, or any other anomalous periods, is considered, it is of primary importance to establish the boundaries of the “norm”, and therefore also — of the “anomaly”. It is commonly accepted that in the time series spanning many years the normal values are the ones that are contained in the interval determined by the average for the entire series  $\pm$  standard deviation, and so these observations, which are outside of this interval — are considered anomalous. When applying this yardstick for the determination of the norm and the anomaly, one assumes a priori that approximately 2/3 of all observations of a given weather element would be classified as normal, and that the anomalous values neighbour directly upon the normal ones.

A different criterion was adopted in the study here reported. Thus, the normal months and seasons in terms of temperature are assumed to be the ones, in which the average temperature value is contained in the interval defined as the average for the entire time series  $\pm$  half of the standard deviation (average  $\pm 0.5\sigma$ ). This narrowing down of the boundaries of the norm significantly decreases the number of the months and seasons classified as normal. Then, the months and seasons featuring the deviation from the average contained between 0.5 and 1.5 $\sigma$  are classified as “weakly anomalous” (cold and warm), and those with deviation from the long-term average temperature exceeding 1.5 $\sigma$  were considered to be truly anomalous (very cold

and very warm). The few cases with deviation from the average exceeding  $2.5\sigma$  were referred to as extremely cold and extremely warm.

Months and seasons were classified in a similar manner with respect to precipitation. Here, two values of the standard deviation were used, calculated separately for the negative deviations ( $\sigma_-$ ) and the positive ones ( $\sigma_+$ ). Thus, the normal months and seasons were distinguished, the weakly anomalous — wet and dry, the anomalous — very wet and very dry, as well as the extremely wet ones.

With this classification it was stated that in the period 1951–2000 in Warsaw there were only 17% of the normal months with respect to both meteorological elements considered (Table 1); 61% were weakly anomalous, of which — 38.5% with respect to either temperature of precipitation alone and 22.5% with respect to both these elements together. There were 22% of anomalous months, of which 8% — with respect to only one element, and 14% — with respect to both elements.

Similarly, the share of the normal seasons was also the lowest (see Table 2) — only 22.5%. There were 50% of the weakly anomalous seasons (31.5% with respect to one of the weather elements, 18.5% — with respect to both of them), and 27.5% of the properly anomalous ones (12% and 15.5%, respectively).

Thus, it turned out that in the climate of Poland, characterised by high variability and variety of weather situations in particular years, the weakly anomalous months and seasons appear more frequently than the “fully normal” ones.

In view of the low frequency of the normal months there was no year in the 50-year period considered, in which all months would be “normal”. There were just two years (1966 and 1997), in which six months were normal, and also two years (1957 and 1973), in which five months were normal, but there were as many as four years (1952, 1954, 1970 and 1988), in which none of the months was normal, and 16 years with only one normal month.

On the other hand, in three years (1957, 1961 and 1978) there were no anomalous months (only weakly anomalous ones), and there were seven years, in which only one month was “properly” anomalous. The highest number of the properly anomalous months was observed in the year 1984 (six anomalous months). Then, there were three years (1954, 1967 and 1994), in which five thermally and/or precipitation-wise anomalous months were observed (see Table 3).

Similarly, with respect to the seasons of the year — there was no single year in the 50-year period, in which all of the four seasons would be normal (Table 4). There were only four years with three normal seasons, while there were as many as 20 years with all of the seasons more or less anomalous (i.e. — without normal seasons), either with regard to temperature, or precipitation, or both.

The anomalies of temperature or precipitation occur most often in single months or seasons, although longer sequences of the anomalies of the same element, with the same sign of deviation, do also occur (see Tables 3 and 4). The longest sequences of anomalies observed were: six consecutive cool months, between April and September of 1978, and between March and

Table 2.  
Frequencies of seasons of different thermic and precipitation categories (in %). Warsaw-Okęcie, 1951–2000

p \ t	ec	vc	c	n	w	vw	ew
	vd	d	n	w	vw	ew	
vd	0.5	–	2.5	2.5	1.0	0.5	0.5
d	0.5	2.5	4.5	10.0	5.5	2.0	–
n	–	4.5	4.0	22.5	12.0	2.0	–
w	–	1.0	4.0	5.5	4.5	0.5	–
vw	–	–	1.5	3.0	1.5	–	–
ew	–	–	1.0	–	–	–	–

Grey area indicates the properly anomalous months or seasons

Table 1.  
Frequencies of months of different thermic and precipitation categories (in %). Warsaw-Okęcie, 1951–2000

p \ t	ec	vc	c	n	w	vw	ew
	vd	d	n	w	vw	ew	
vd	0.2	0.3	1.0	2.2	1.7	0.2	–
d	0.5	2.7	5.5	12.7	7.8	2.2	0.3
n	0.2	2.2	9.2	17.2	10.5	1.8	–
w	–	1.0	4.8	6.0	4.2	0.5	–
vw	–	–	0.5	1.2	2.3	–	–
ew	–	–	0.7	0.5	0.2	–	–

t — temperature  
ec — extremely cold  
vc — very cold  
c — cold  
n — normal  
w — warm  
vw — very warm  
ew — extremely warm

p — precipitation  
vd — very dry  
d — dry  
n — normal  
w — wet  
vw — very wet  
ew — extremely wet

August of 1980, six consecutive warm months between December 1988 and May 1989, seven consecutive dry and very dry months between June and December 1951, and seven consecutive wet and very wet months between October 1966 and April 1967. The dry months form more often the three-month and longer sequences (22 such sequences altogether) than the wet months (six such sequences). On the other hand, the warm months more often form only three-month long sequences (14 such sequences and only three longer ones), while the cool months form more often the four-month and longer sequences (nine such sequences were observed, while surprisingly, only seven having the three-month length).

The seasons of the year form the sequences of similar anomalies quite rarely. Thus, during the entire 50-year period (1951–2000) only two sequences of five similarly anomalous seasons were observed: the warm seasons between the Summer of 1982 and the Summer of 1983, dry seasons between Spring of 1953 and Spring of 1954. Further, three four-season sequences were observed: of the cool and very cool seasons, between Winter and Fall of 1954, of the warm seasons, between Fall 1958 and Summer 1959, as well as of the dry and very dry seasons, between Fall 1975 and Summer 1976.

The calendars of the months, and even more so of the seasons (Tables 3 and 4) make it possible to state that some periods were characterised by the increased frequency of the particular kinds of anomalies — both the weak, and the “proper” ones. Attention is first of all attracted by the high frequency of warm winters starting with the year 1988. From among 14 such winters having occurred during the last half-century as many as six occurred in the last 13 years of the period. In these years, besides, both of the very warm winters occurred, including the warmest winter of 1998/9, with the average temperature of 2.5°C and total precipitation of 69 mm. During the same period there were no cool winters, on the other hand (although there was one very cold winter). The coldest winter of the half-century considered was at the same time dry. It was the winter of 1962/3, with the average temperature of -8.4°C and precipitation of 29 mm.

The situation was similar regarding the springs: the last very cool one took place in 1987, but since 1983 as many as five out of all ten warm springs noted in the half-century occurred, and all of the four very warm ones, including the warmest spring of 2000, not only very warm, but also dry: 10.4°C and 93 mm. The particularly cool springs characterised the first 20 years of the half-century. The coldest was the spring of 1955 — a very cold one, with normal precipitation (5.1°C and 102 mm).

The cool summers were definitely more frequent during the 1970s. The summer of 1978 was one of the two coldest ones — very cool and wet: 15.9°C and 257 mm, the second one having occurred in 1962, similarly cool, but dry: 15.9°C and 156 mm. Warm summers would occur more often in the 1950s and 1990s. In 1951 the sole warm and simultaneously very dry summer occurred: 19.0°C and 109 mm, while in 1992 — the sole extremely warm and simultaneously very dry: 20.0°C and 90 mm.

Table 3.

Calendar of anomalous months. Warsaw-Okęcie, 1951–2000

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1951			-	+	+	+	-	-	+	-	+	-
1952	+	+	-	+	-	-	+	+	-	+	+	+
1953	+			+	-	+	+		-	+		
1954	-	-	-	-	+	+	-	+	+	-	-	+
1955		-	-	-	-		+	+	+	-		+
1956		-	-	-		+		-	-	+	-	
1957		+	+		-	+	-	-	+	+	-	
1958		+	+	-	+	-			-	+	-	+
1959	+	-	+		-	+	+	+	-	-	-	+
1960	+			-	-	+	-	+	-	+	+	+
1961		+	+	+	-	+	-	-	+	+	-	+
1962	+		+	+	-	+	+	-	-	+		+
1963	-	-	-	-	+	+	+	+	+		+	+
1964	-	-	-	-	-	+		-	+	-		+
1965		-	-	-	+	+	-	+	+	-	-	+
1966	-				-	+				+	+	+
1967	-	+	+	+	+	-	+	-	+	+	-	+
1968	-	+		+	-	+	-	-	+	-		+
1969	-	-	-	-	+	-		-	+	-	+	+
1970	-	-	-	+	+	-	+	-	-	+	+	+
1971		+	-		+		+	+	-		-	+
1972	-	-	+		+		+	+	+	+	+	-
1973	-	+	+				+		-	+	+	
1974	+	+	+	+	-	-	-	+	-	-	+	+
1975	+		+		+	-	+	+	+	-	-	+
1976	+	-	-	-	-	-	-	-	-	-	+	
1977	-	+	+	-		+	-	-	+	+	+	-
1978	+	-	+	-	+	-	-	-	+	+	+	-
1979	-	+		-	+	+	+	+	-	-	-	+
1980	-	-	-	-	+	-	+	-		+	-	
1981	+	-	+	+	-		+	-	+		+	-
1982		-	+	-	+	-	+	+	+	-	+	+
1983	+	+	+	+	+	+	-	+	+	-	-	-

Table 3 continued

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1984	+	-	-	+	-	+	-	+	-	+	+	-
1985	-	-	+	+	+	-	-	-	-	-	-	+
1986	+	-	-	+	+	+	-	-	-	-	+	-
1987	-	-	-	-	-	-	+	-	-	-	-	+
1988	+	+	+	+	+	-	+	+	+	-	-	+
1989	+	+	+	+	+	-	+	-	+	+	-	+
1990	+	+	+	+	+	-	-	-	-	+	+	-
1991	+	-	+	-	-	-	+	+	+	-	+	+
1992	-	+	+	+	-	+	+	+	-	+	+	+
1993	+	+	-	+	+	-	-	-	-	-	-	+
1994	+	+	+	+	+	+	+	+	+	-	+	+
1995	-	+	+	-	-	+	+	+	+	+	-	-
1996	-	-	-	-	+	-	-	+	+	+	+	-
1997	-	+	-	-	-	-	+	+	-	-	-	-
1998	+	+	+	+	+	+	+	-	+	-	-	-
1999	+	-	+	+	+	+	+	-	+	-	-	-
2000	+	+	+	+	+	+	+	+	-	+	+	+

An opposite tendency is observed with respect to the autumns: warm autumns occurred mainly in the first two decades of the half-century, including the warmest autumn of the entire period, very warm and dry, which took place in 1967: 10.6°C and 72 mm. Since 1985 cool autumns are more frequent, and during this part of the half-century one of two very cool falls took place (in 1998), as well as the coolest one in the half-century — the extremely cool and dry autumn of 1993: 5.7°C and 79 mm.

The appearance of the dry and wet seasons of the year displays a lesser regularity, although an increase of the frequency of wet winters can be noticed since 1966 (including the winter of 1966/7, very wet, with normal temperature: -1.6°C, 139 mm). In the recent years, on the other hand, the alternating appearance of the dry and very dry winters (like the driest winter of 1996/7: -2.7°C and 28 mm) and of the wet and very wet ones (like the ones of 1993 and 1995, with precipitation exceeding 120 mm) has been observed.

Dry springs were more frequent at the beginning of the period, until the middle of the 1960s. Precipitation was the lowest in the spring of 1953 (very dry, with normal temperature: 8.3°C and 49 mm). Yet, the wettest spring occurred also in the same part of the period, in 1962 (cool and extremely rainy: 6.7°C and 274 mm). The springs of the turn of the 1990s were also dry.

Table 4.

Calendar of anomalous seasons. Warsaw-Okęcie, 1951–2000

Year	Winter	Spring	Summer	Autumn	Year	Winter	Spring	Summer	Autumn
1951			+ -	+ -	1985	- -	- +	-	- -
1952	+ +	-	-	- +!	1986	-	+ +	-	-
1953		-	+	-	1987	-	-	-	-
1954	-	-	- +	-	1988	+	-	-	+ -
1955		+	+	+	1989	+	+	-	+
1956	-	+	-	-	1990	+	+	-	-
1957	+	+			1991		-	-	+
1958		+		- +	1992	+		+!	- +
1959	+	+	- +	-	1993		+	-	-!
1960		+	-	+	1994	+	+	+	-
1961	+	+	-	+	1995	+	+	+	+
1962		-	+!	-	1996	-	-		
1963	-!	-	+	- +	1997		-	-	+
1964	-	-	- +		1998	+	+	+	-
1965		-	-	+	1999		+	+	-
1966		+		+	2000	+	+	-	+
1967		+	+	- +					
1968		+		-					
1969	-	-	-	+					
1970	-	-	+	+					
1971			+	-					
1972		+	+	+					
1973	+	-		-					
1974	+	+	-	+					
1975	+	+	+	-					
1976		-	-	-					
1977		+	-	+					
1978			-	+					
1979	-	+	-	-					
1980		-	-	+					
1981			-	+					
1982	-	-	- +	+					
1983	+	+	+	-					
1984			-						

Month/Season:

-!	extremely cold	} anomalous
-	very cold	
-	cold	
	normal	weakly anomalous
+	warm	weakly anomalous
+	very warm	} anomalous
+!	extremely warm	

  

-	very dry	anomalous
-	dry	weakly anomalous
	normal	
+	wet	weakly anomalous
+	very wet	} anomalous
+!	extremely wet	

The dry summers, similarly as springs, were more frequent in the first part of the half-century, while the rainy ones — in the 1970s and 1980s. The rainiest summer occurred in 1972 (a warm, very wet summer: 18.3°C, 338 mm). The last decade of the 20<sup>th</sup> century was characterised by the intermittent appearance of the dry and wet summer seasons. In this decade the driest Summer of 1992 occurred (20.2°C and 90 mm).

Dry autumns appeared at the beginning of the period considered in an even more pronounced manner than springs and summers. Thus, all of the three very dry falls took place during the 1950s, including the fall of 1951 — warm and very dry (9.3°C and 20 mm). During the same part of the half-century, though, the fall with the most intensive precipitation occurred — the cold, extremely rainy fall of 1952 (6.9°C and 265 mm). Dry falls would also occur during the 1980s. The falls of the 1990s were, similarly as summers, alternately dry and wet.

The results presented clearly show that the climate of Poland is characterised by the more frequent appearance of the months and seasons anomalous with respect to temperature and/or precipitation than of the normal ones, that is — than those with the values of temperature and precipitation very close to the respective long-term averages.

Equally distinct is the warming of the last years of the 20<sup>th</sup> century. The appearance of the winters, springs and summers, which are very warm (anomalous) and warm (weakly anomalous), is quite pronounced, while the opposite tendency is observed as far as falls are concerned. In the sequences of the warm seasons, though, the very cold ones sporadically occur (winter of 1995/6), while in the sequences of the cold seasons — the very warm ones (autumn of 2000).

The warming is also visible in the frequencies of the extremely cold, very cold, and cold, as well as extremely warm, very warm, and warm months. During the first 30 years of the half-century (1951–1980) the joint share of the former group was 32%, of the latter — 27%, and of the normal months — 41%, while during the last two decades of the half-century these shares were, respectively, equal 22%, 39% and 39%. Thus, in the period 1951–1980 the months featuring the different intensities of the negative anomaly of temperature were by 5 percentage points more frequent than those with positive anomalies, while in the years 1981–2000 they were by 17 percentage points less frequent. The tendency towards the increase of frequency of the months in a variety of degrees warm became particularly pronounced in the decade of 1991–2000, when the share of such months amounted to as much as 42%, the share of the weakly anomalous warm months was even bigger than of the normal ones (36% and 35%, respectively), and the only two extremely warm months of the entire half-century occurred in this decade.

The warming of the recent years is accompanied by the “destabilisation” of the levels of precipitation — the alternating appearance of the months and seasons with the excess and shortage of precipitation. This is clearly seen through the frequency of seasons featuring both the respective proper and the weak anomaly.