THE VARIABILITY OF DAILY PRECIPITATION TOTALS IN POLAND (1951-2000)

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Abstract: The analysis concerned the variability of daily precipitation totals observed during the second half of the 20th century at five stations in Poland. The elements examined were number of days with precipitation exceeding given thresholds, lengths of wet and dry spells and precipitation amounts in a single spell. There is an upward trend for the number of spells and days with precipitation, and a downward trend for mean precipitation during a given spell. Changes in peak precipitation are not uniform, there being negative trends at some stations and positive ones at others. However the lack of a trend for precipitation totals combines with the climatic warming now to be observed to imply risk of a water deficit.

key words: wet spell, dry spell, precipitation extremes, linear trend, Poland

INTRODUCTION

Many studies have reported increased precipitation in the mid to high latitudes of the Northern Hemisphere over the last century. An increase of 10–50% has been observed over Northern and Western Europe (Watson *et al*., 1998). In Poland, a slight increase in precipitation totals can also be observed, but one that does not exceed the level of significance (Kożuchowski 2004). As the Third Assessment IPCC Report (Houghton *et al.* 2001) warns against a higher risk of floods and droughts occurring more often in a warmer world. This study focuses on variations in daily precipitation totals and the way they are related to atmospheric circulation indices.

DATA AND METHODS

Use was made of daily precipitation totals for the period 1951-2000 at five stations in Poland: Szczecin in the north-west, Suwałki in the north-east, Przemyśl in the south-east, Wrocław in the south-west and Łódź in the centre (Fig. 1). Daily gridded geopotential heights at the 700 hPa level from NCEP/

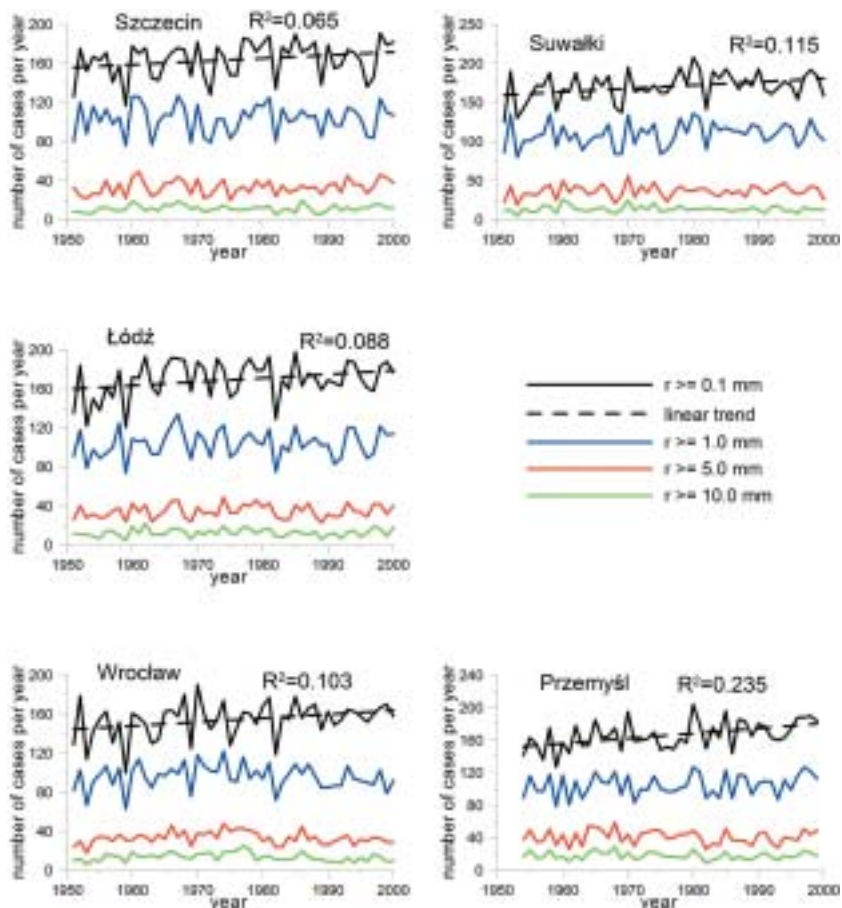Figure 1. Location of analysed stations.

Figure 2. Annual number of days with precipitation exceeding selected thresholds: $\geq 0.1, \geq 1.0, \geq 5.0, \geq 10.0$ mm with linear trend and determination coefficient (R^2) of number of rainy days, during the period 1951-2000.

NCAR reanalysis (Kalnay *et al.*, 1996) were used to analyze the influence of circulation on the occurrence of heavy precipitation events.

Two large European projects analyzing daily precipitation totals in the context of extreme events are: the European Climate Assessment (Klein Tank, A.M.G. Können, 2003) and EMULATE (Moberg *et al.*, 2006). Among the indices suggested by these groups are the highest daily total in the year, the numbers of days with precipitation exceeding thresholds defined by percentiles (75, 90, 95, 99) during a selected reference period, or by given values, and the fraction of precipitation totals noted on days with precipitation exceeding these thresholds. From

among these indices, this study applied: the highest daily total and annual frequencies of days exceeding selected thresholds. Because the area of interest is not large, the thresholds common to all stations used were: 0.1 mm – measureable precipitation, 1.0 mm – slight precipitation, 5.0 mm - moderate precipitation and 10.0 mm – high precipitation.

On that basis, the annual frequencies of wet days (r>0.0), and the 1, 5, 10, 25, 50, 75, 90, 95 and 99 percentiles for all wet days (r>0.0) were determined for each year separately, and trends therefore analysed (section 3).

The wet spells (section 4) and dry spells (section 5) were analysed in relation to changes in their length and intensity.
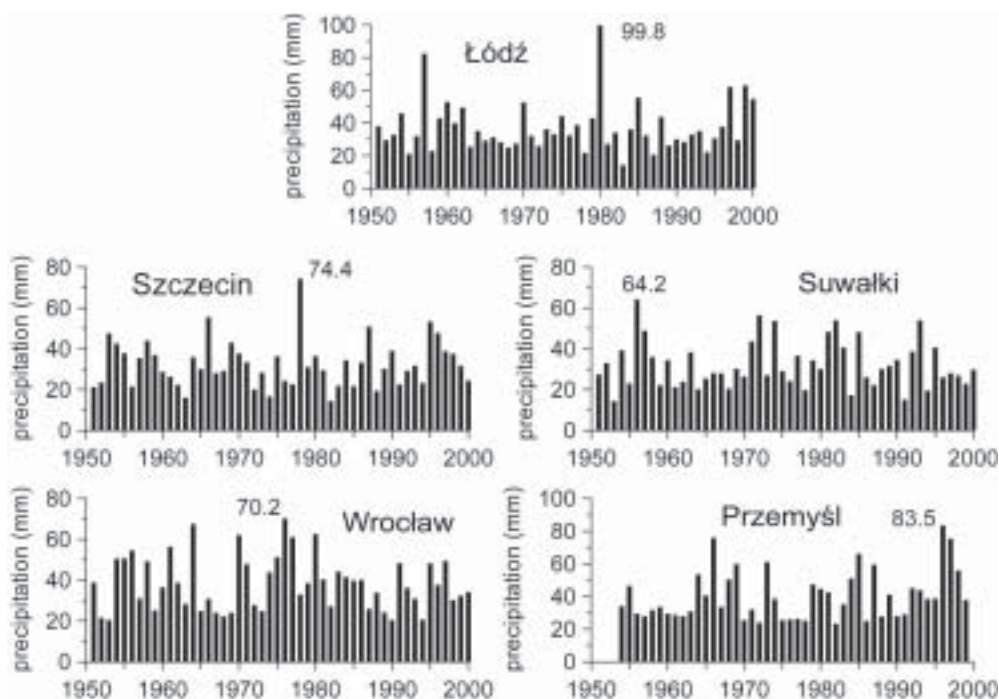
Figure 3. The highest daily total in a year, 1951-2000.

The synoptic situations favorable to high precipitation events were also analysed. To do this the sample of days with precipitation ≥20 mm at at least one station was chosen and the Lund method of field classification (Lund, 1963) used to distinguish the synoptic situations favorable to high precipitation events (section 6). In this classification, geopotential heights at the 700 hPa level on each selected day are correlated with those on all other days. The map with the highest number of correlation coefficients exceeding the given threshold (here 0.7) is selected and designated as type A. All days of this type (correlating with type A above the threshold) are removed from the sample and a next map with the highest number of correlation coefficients exceeding the given threshold is selected and designated as type B. The procedure is repeated until there are maps which correlate on the level exceeding the threshold.

Two methods were used to estimate linear trends and their statistical significances: the least squares method with Student t-test (which assumes that the data distribution is close to normal) and the Sen's slope method with Kendall *tau* test (Sen 1968), which does not make any assumption as regards data distribution.

DAILY PRECIPITATION TOTALS

The annual frequencies of days with precipitation exceeding selected thresholds were analysed (Fig.2). The four thresholds selected were: 0.1 mm – measureable precipitation, 1.0 mm – slight precipitation, 5.0 mm - moderate precipitation and 10.0 mm – high precipitation. Only the frequency of wet days has increased significantly at all analysed stations. This increase varied from 3.2 days per decade in Szczecin to 6.2 days per decade in Przemyśl.

In each year the percentiles 1, 5, 10, 25, 50, 75, 90, 95 and 99 of all wet days (r>0.0) were calculated and tested against the trend. The results are as presented in Table 1. The

Table 1. The trend coefficients in mm per decade of mean annual values of selected percentiles. Values significant at 5% (10%) level are **bolded** (in *italic*)

percentiles	1	5	10	25	50	75	90	95	99
Wrocław	0.00	**-0.01**	**-0.02**	**-0.04**	*-0.06*	*-0.15*	**-0.33**	-0.10	-0.23
Przemyśl	0.00	**-0.01**	**-0.02**	**-0.04**	*-0.07*	**-0.27**	**-0.40**	*-0.54*	0.63
Suwałki	0.00	**-0.01**	**-0.01**	**-0.03**	-0.03	-0.02	-0.19	*-0.39*	-0.51
Szczecin	0.00	**-0.01**	**-0.02**	**-0.04**	*-0.05*	0.01	0.12	0.07	0.60
Łódź	0.00	0.00	0.00	0.00	-0.02	0.03	-0.05	0.05	-0.18
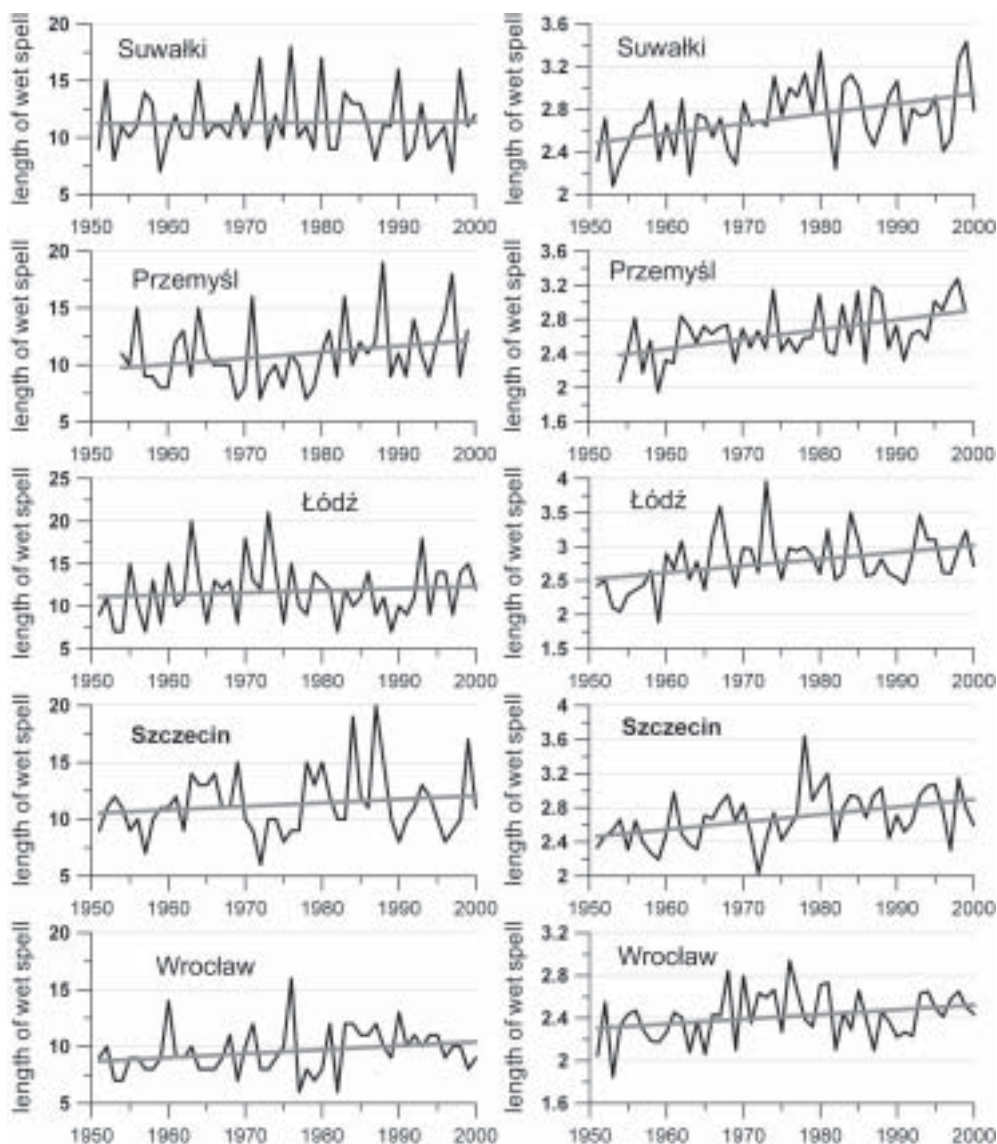
Figure 4. The longest wet spell in a year (left column) and the mean annual length of wet spell (right column) with linear trend estimated by the least square method and determination coefficient R^2, during the period 1951-2000.
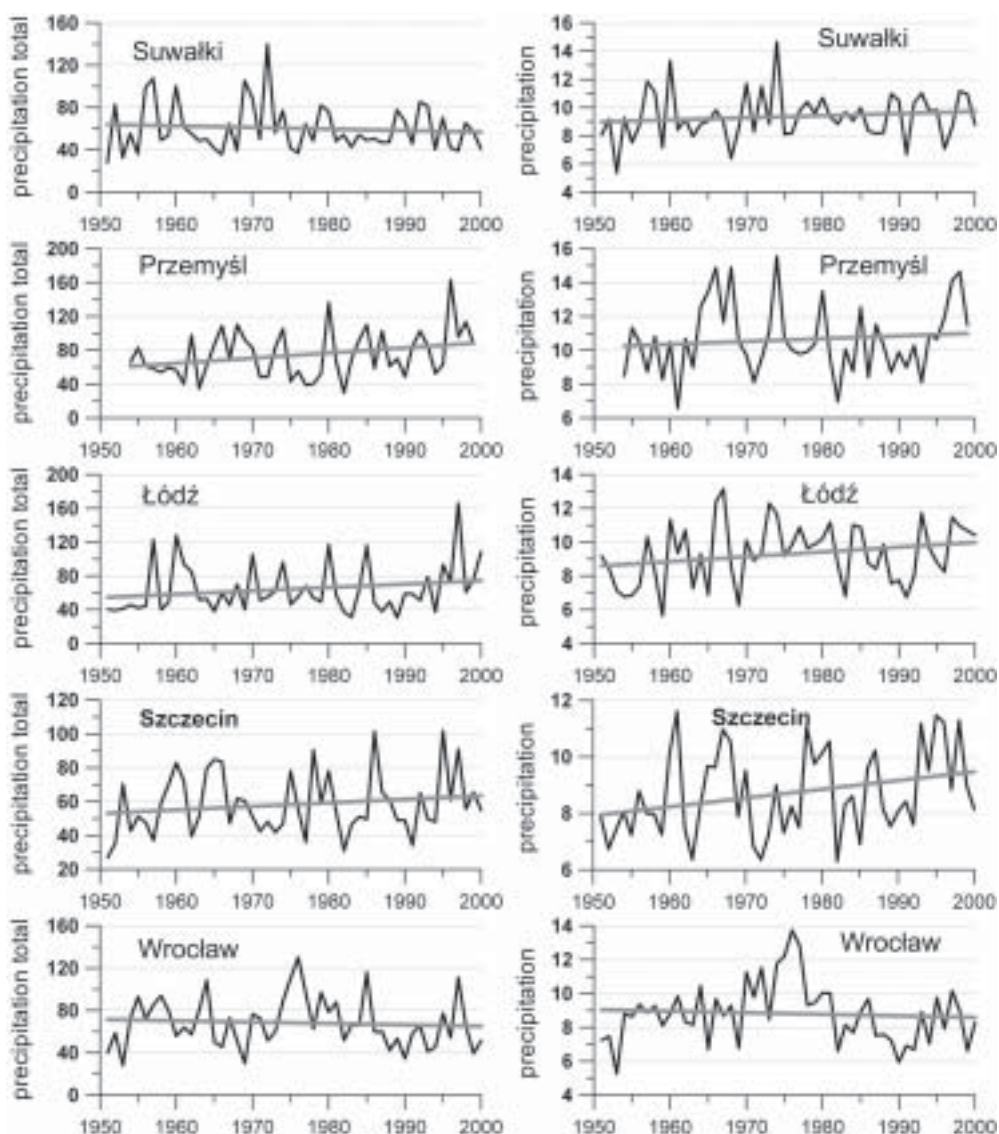
Figure 5. The highest precipitation total during one wet spell in a year (left column) and the mean annual precipitation total during one wet spell (right column) with linear trend estimated by the least square method and determination coefficient R^2, during the period 1951-2000.

low percentiles (5,10 and 25) have decreased significantly at the 95% level at four of the five stations. This means that lower daily totals have become more frequent. For higher percentiles negative trends still prevailed. A few positive trends were found, but these were not statistically significant.

The long-term course for highest daily precipitation totals at selected stations is as presented in Fig. 3. Only the record from Przemyśl reveals a slight upward trend (3.15 mm/decade). Changes were not observed at other stations. The highest daily totals varied from 64.2 mm in Suwalki to 99.8 mm in
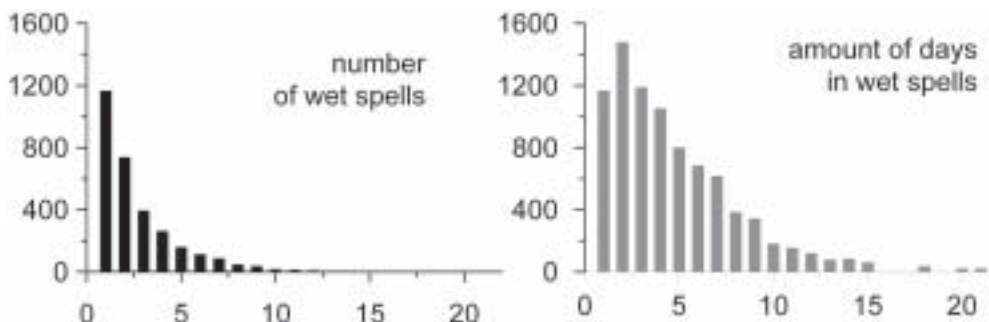
Figure 6. Number of wet spells in function of their length (left graph) and the amount of days in wet spell in function of their length (right graph) at Łódź in the period 1951-2000.

Table 2. Mean, standard deviation, maximum and minimum of mean annual length of wet spell and the longest wet spell in the year, the highest annual precipitation total during one spell and mean annual precipitation total during one spell in the period 1951-2000

		Wrocław	Szczecin	Łódź	Przemyśl	Suwałki
length of a wet spell	mean	2.4	2.7	2.8	2.7	2.7
	st. deviation	0.23	0.31	0.40	0.32	0.30
	maximum	2.9	3.6	4.0	3.3	3.4
	minimum	1.8	2.0	1.9	2.0	2.1
length of the longest spell in the year	mean	9.6	11.3	11.7	11.0	11.3
	st. deviation	2.00	2.81	3.34	2.83	2.62
	maximum	16	20	21	19	18
	minimum	6	6	7	7	7
precipitation total in a spell	mean	8.8	8.7	9.3	10.7	9.4
	st. deviation	1.8	1.5	1.8	2.1	1.7
	maximum	13.7	11.6	13.1	15.5	14.6
	minimum	5.3	6.3	5.6	6.6	5.4
the highest precipitation total in a spell	mean	68.3	58.4	64.5	75.1	60.4
	st. deviation	23.4	18.0	29.4	28.1	23.0
	maximum	130.1	101.9	166.0	163.2	139.9
	minimum	28.2	27.1	30.6	29.7	28.1

Łódź. Only in Przemyśl did the highest observed value occur in the last decade. These results are consistent with findings obtained by Moberg *et al.* (2006) and Klein Tank and Können (2003), who analysed indices for precipitation extremes in Europe, and did not note significant changes in Poland.

WET SPELLS

Wet spells were defined as uninterrupted sequences of days with daily precipitation >0. The mean annual number of such spells was slightly greater than 60. The lowest annual numbers of spells varied from 31 at Przemyśl to 54 at Suwałki. The highest number of spells in turn varied from 73 at Suwałki and Szczecin to 81 at Wrocław. The mean annual length of a wet spell was between 2.4 days in Wrocław and 2.8 in Łódź, but it could even reach 4 in particular years (Table 2). The longest annual wet spells were of 6 to 21 days, with mean values varying from 9.6 in Wrocław to 11.7 in Łódź. There is a downward trend for annual frequencies of wet spells, at four of the five analyzed stations. Together with trends for an increase in the number of wet days, this has resulted in longer mean lengths of wet spells (Tables 3 and 4). The slope estimators calculated by two methods give similar results. The magnitude of this increase is of about 0.09 days per decade. An upward trend can also be noted for in the length of the longest wet spell of the year. In this case the distribution of data is
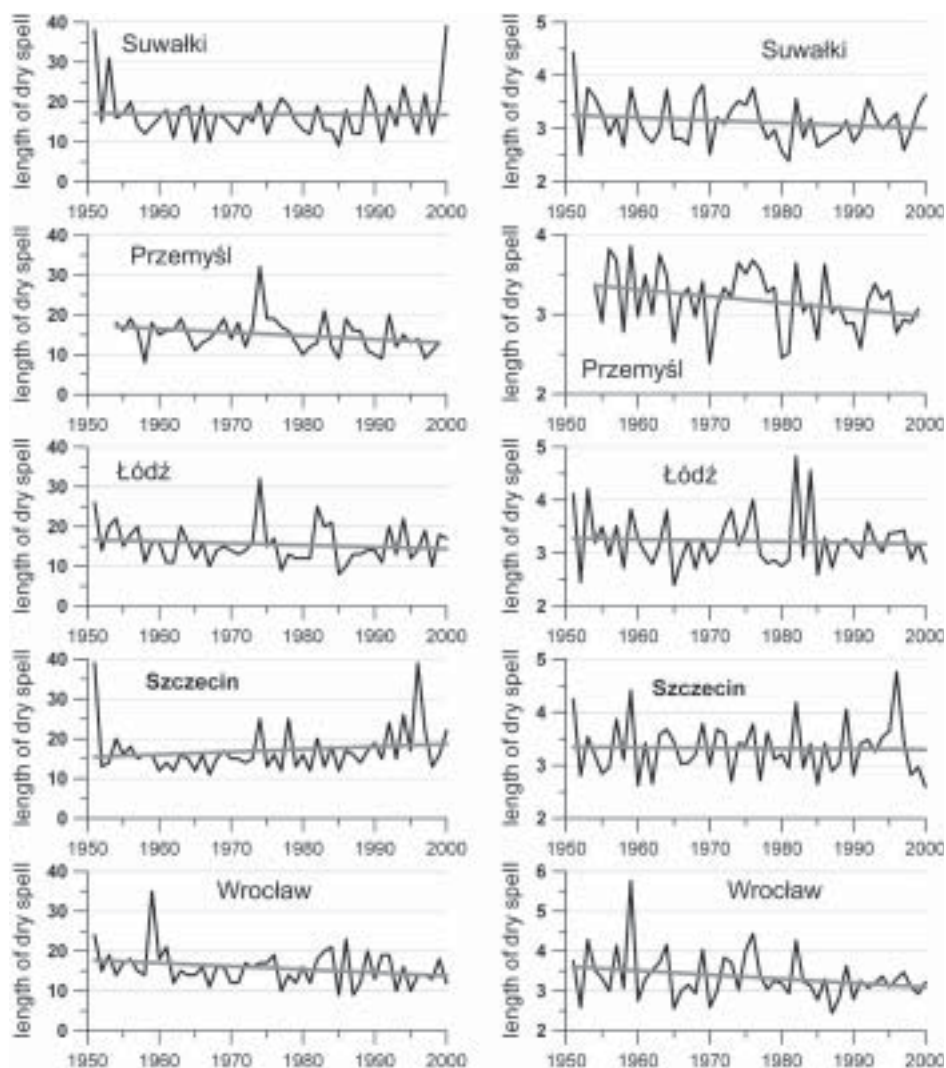
Figure 7. The longest dry spell in a year (left column) and the mean annual length of dry spell (right column) with linear trend estimated by the least square method and determination coefficient R^2, during the period 1951-2000.

far from normal and the slopes estimated by the two methods differ significantly, the Sen's slope estimates seeming to be more robust (Fig. 4).

The distribution of wet spells in relation to their length shows that one-day wet spells are most common. However, the greatest number of days are included among wet spells lasting two days. An example of the distribution of wet spells in relation to their length and of the distribution of numbers of days in wet spells in relation to wet spell length is presented in Fig. 6.

Precipitation totals during particular wet spells can have a major impact on flooding. Mean precipitation totals in a spell varied from 5.3 to 15.5 mm (Table 2, Fig. 5), but from the point of view of flood risk
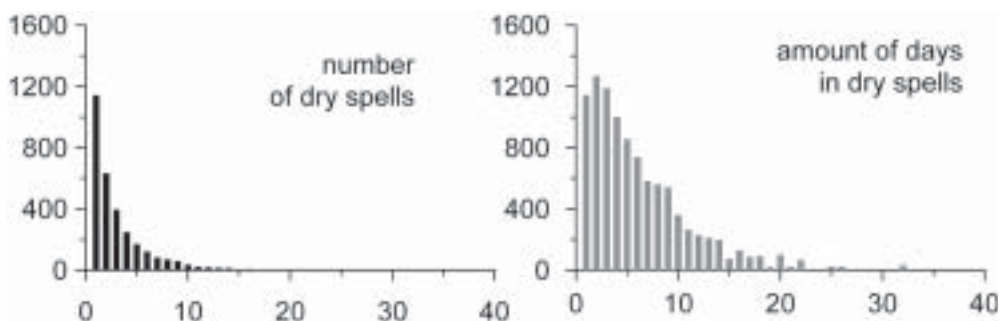
Figure 8. Number of dry spells in function of their length (left graph) and the amount of days in wet spell in function of their length (right graph) at Łódź in the period 1951-2000.

Table 3. Sen's estimate of slope in linear regression of selected features of wet spells
* - significant at 90% level, ** - significant at 95% level

element	unit	Wrocław	Szczecin	Łódź	Przemyśl	Suwałki
number of spells	cases/decade	0.31*	-0.89*	-0.96*	-0.63**	-0.63*
the longest spell	days/decade	0.31*	0.00	0.00	0.59*	0.00
mean length of a spell		0.03*	0.09**	0.09**	0.10**	0.09**
the highest precipitation in a spell	mm/decade	-3.25*	1.38*	3.4*	5.8**	-1.73*
mean precipitation in a spell		-0.15*	0.32**	0.32*	0.17*	0.20

Table 4. The least square estimate of slope in linear regression of selected features of wet spells
* - significant at 90% level, ** - significant at 95% level

element	unit	Wrocław	Szczecin	Łódź	Przemyśl	Suwałki
the longest spell	days/decade	0.35*	0.31	0.24	0.53*	0.03
mean spell length		0.04**	0.09**	0.10**	0.11**	0.09**
the highest precipitation in a spell	mm/decade	-1.29	2.11	4.0	6.11**	-1.45*
mean precipitation in a spell		-0.09	0.31**	0.28*	0.16	0.15

Table 5. Annual mean, standard deviation, maximum and minimum of number of dry spells, mean annual length of dry spell and the longest dry spell in the period 1951-2000

|		Wrocław	Szczecin	Łódź	Przemyśl	Suwałki
number of spells	mean	64.0	61.3	61.5	62.4	62.8
	st. deviation	5.98	5.40	5.98	6.41	4.56
	maximum	81	73	76	74	73
	minimum	46	49	45	31	54
length of dry spell	mean	3.4	3.3	3.2	3.2	3.1
	st. deviation	0.59	0.49	0.51	0.38	0.43
	maximum	5.8	4.8	4.8	3.9	4.4
	minimum	2.4	2.6	2.4	2.4	2.4
length of the longest spell in a year	mean	15.8	17.1	15.5	15.0	16.9
	st. deviation	4.52	5.79	4.7	4.20	6.16
	maximum	35	39	32	32	39
	minimum	9	11	8	8	9
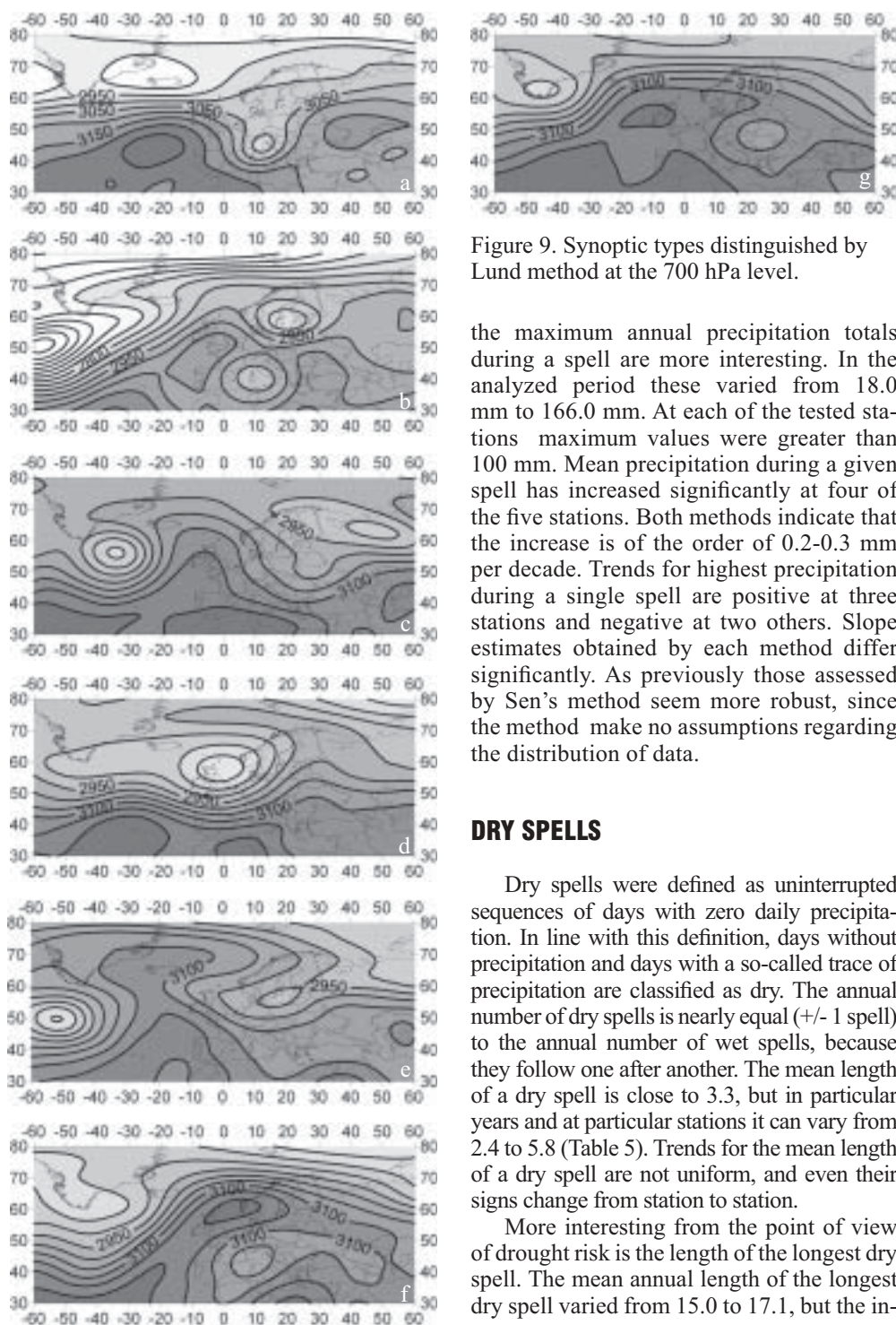
Figure 9. Synoptic types distinguished by Lund method at the 700 hPa level.

the maximum annual precipitation totals during a spell are more interesting. In the analyzed period these varied from 18.0 mm to 166.0 mm. At each of the tested stations maximum values were greater than 100 mm. Mean precipitation during a given spell has increased significantly at four of the five stations. Both methods indicate that the increase is of the order of 0.2-0.3 mm per decade. Trends for highest precipitation during a single spell are positive at three stations and negative at two others. Slope estimates obtained by each method differ significantly. As previously those assessed by Sen's method seem more robust, since the method make no assumptions regarding the distribution of data.

DRY SPELLS

Dry spells were defined as uninterrupted sequences of days with zero daily precipitation. In line with this definition, days without precipitation and days with a so-called trace of precipitation are classified as dry. The annual number of dry spells is nearly equal (+/- 1 spell) to the annual number of wet spells, because they follow one after another. The mean length of a dry spell is close to 3.3, but in particular years and at particular stations it can vary from 2.4 to 5.8 (Table 5). Trends for the mean length of a dry spell are not uniform, and even their signs change from station to station.

More interesting from the point of view of drought risk is the length of the longest dry spell. The mean annual length of the longest dry spell varied from 15.0 to 17.1, but the in-

Table 6. Sen's estimate of slope in linear regression of selected features of dry spells
* - significant at 90% level, ** - significant at 95% level

element	unit	Wrocław	Szczecin	Łódź	Przemyśl	Suwałki
number of spells	cases/decade	0.39*	-0.89*	-1.00*	-0.67**	-0.67*
the longest spell	days/decade	-0.38*	0.67	-0.28*	-1.05*	0.00
mean length of a spell		-0.05*	0.003*	0.003*	-0.10**	-0.01*

Table 7. The least square estimate of slope in linear regression of selected features of dry spells
* - significant at 90% level, ** - significant at 95% level

element	unit	Wrocław	Szczecin	Łódź	Przemyśl	Suwałki
the longest spell	days/decade	-0.08*	0.66	-0.47	-0.89**	-0.07
mean length of a spell		-0.10*	-0.01	-0.02	-0.108**	-0.05

dividual values ranged from 8 to even 39. At each station the longest dry spell during the second half of the 20th century was higher than 30. The trends for the longest dry spell during the year were not uniform. Downward trends were observed at three stations, upward ones at one, while at one there was no change (Tables 6 and 7, Fig. 7).

The distribution of dry spells in relation to length shows that one-day dry spells are commonest, though the greatest number of days are in dry spells lasting two days. An example of the distribution of dry spells in relation to their length and the distribution of the number of days in dry spells in relation to dry spell length is presented in Fig. 8.

ON THE DEPENDENCE OF EXTREME PRECIPITATION EVENTS ON ATMOSPHERIC CIRCULATION.

Many authors have pointed to the strong influence of atmospheric circulation on precipitation in Europe (i.e. Hurrell and van Loon, 1997, Wibig 1999, 2001, Haylock and Goodess, 2004), and in Poland (Wibig, 2004, Paszyński and Niedźwiedź, 1999). But only some of these papers have concentrated on precipitation extremes (Paszyński and Niedźwiedź, 1999, Haylock and Goodess, 2004). In this section an attempt was made to distinguish the synoptic types occurring on days with heavy rainfall. The set of 648 days with daily precipitation totals exceeding 20 mm at at least one of the analyzed stations in

the period 1958-2005 (the range of geopotential height data) was established, together with the appropriate set of geopotential high at the 700 hPa level over the area ranging from 30°N to 80°N in latitude and from 60°W to 60°E in longitude with a step of 2.5° in both directions. The synoptic types accompanying heavy rainfall situations in Poland were then classified using the Lund method. Seven types were distinguished, and more than 86% of selected days found to belong to one of these types. The model fields are as presented in Fig. 9, and the details summarized in Table 8.

The first type included more than 25% of all days with heavy precipitation. It presents intense zonal circulation with a wedge of low pressure over Central Europe. The second type, occurring on 11% of days with heavy rainfall, has two low-pressure centers over Europe: one over the southern Baltic and the second over the central part of the Mediterranean Sea. Neither of these are very intense, but there is an advection of humid air from the north-west to Poland.

In the third type, representative of almost 8% of selected days, there are two low-pressure systems. One in the climatological position of the Iceland Low and the second over the north-eastern part of European Russia. a high-pressure ridge is between them. Such a configuration causes the advection of humid air from the north-west to Poland. The fourth type has a zonal structure, whereby a centre of low pressure is located over the North Sea and humid air from the North Atlantic comes into Poland from the north west. This type occurs on 5.9% of days with heavy rainfall.

Table 8. Characteristics of synoptic types distinguished by Lund method at the 700 hPa level.

	date	number of cases	% of cases
1	20th July 1981	168	25.9%
2	6th March 1978	71	11.0%
3	4th July 1984	51	7.9%
4	16th September 1983	38	5.9%
5	17th May 1968	24	3.7%
6	12th June 1968	20	3.1%
7	28th July 1968	13	2.0%

The next three types are characterized by a low-pressure system with a centre located over the southern Baltic, northern Italy and south-eastern Poland respectively. Such situations are less common and occur together in less than 10% of days.

The heavy rainfall situations in days with north-easterly or north-westerly advections are generally in agreement with the results of Niedźwiedź (Paszyński and Niedźwiedź 1999). However heavy rainfall does not occur over the whole of Poland at the same time, so interregional differences can be quite large. A denser dataset would seem to be necessary if the influence of circulation on the occurrence of extreme precipitation events is to be determined in full.

SUMMARY AND DISCUSSION

The above analysis makes it clear that precipitation in Poland did not change greatly in the second half of the 20th century. Only the frequency of wet days has increased, though the fact that this is not connected with an increase in annual totals ensures that the mean precipitation on a wet day is decreasing. These findings are consistent with the results of Kożuchowski (2004), who has demonstrated reduced rainfall intensity (mean precipitation per wet day), as well as with those of Niedźwiedź (2000) and Kożuchowski and Żmudzka (2003), indicating a rise in the number of wet days in Poland.

Unfortunately, this does not mean there is no risk of water deficit in Poland. Indeed, just the opposite results can be anticipated, since the warming entails an increase in evaporation. The analyses of temperature trends for Poland shows that air temperature is rising

and will rise in future, whereas the amount of precipitation will not change significantly (Houghton *et al.* 2001). Such a situation will result in an increase in evaporation, ensuring that less water remains in the soil and available for runoff.

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