VARIABILITY OF WEATHER EXTREMES IN POLANDIN THE PERIOD 1951-2006

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RESUMEN

Series de indices de temperatura y precipitación extremas en el periodo 1951-2006 se calcularon a partir de datos de precipitación diaria y temperatura máxima y mínima en 21 estaciones en Polonia. dado que la distribución de indices de extremos es en general bastante distinta de la normal, en particular para indices que expresan ocurrencias diarias, los estimadores de tendencias mas usuales no son robustos en este caso. Se utilizaron el test *tau* de Kendall y el estimador de tendencias de Sen y sus resultados fueron comparados con los obtenidos con métodos mas tradicionales. Se observa un incremento estadísticamente significativo de la frecuencia de días cálidos en verano y una disminución de la frecuencia de heladas y de la duración de la estación fría en Polonia. Todos los percentiles de temperatura diaria máxima y mínima también se han incrementado, pero para los percentiles extremos (1, 5, 95 y 99) no resulto ser estadísticamente significantes de acuerdo al test *tau* de Kendall. Se analizaron también las tendencias de mas medias mensuales de la temperatura máxima y mínima diaria. Estas se han incrementado en invierno, primavera y al final del verano, pero en Junio y en otoño se observan tendencias decrecientes, aunque estadísticamente no significativas. En el caso de la precipitación no se observaron ningún cambio estadísticamente significativo. El incremento en la frecuencia de días con precipitación detectable fue la única tendencia estadísticamente significativa.

Palabras clave: Extremos meteorológicos, Precipitación, Temperatura, Estimadores de tendencias, Polonia

ABSTRACT

Daily precipitation totals and daily minimum and maximum temperatures from 21 Polish stations were used to calculate records of indices of temperature and precipitation extremes in the period 1951-2006. Because the distributions of extreme indices are generally far from normal, especially for indices defined as day counts, the popular trend estimators like linear trend calculated by the least mean squares method are not robust. The Kendall *tau* test and Sen's trend estimators were used and their results were compared with those obtained by more traditional methods. A statistically significant increase of annual frequencies of summer and hot days and the decrease in the frequencies of ice and frost days and in the length of the frost season has occurred in Poland. All percentiles of daily minimum and maximum temperature have increased also, but the increases of extreme percentiles (1, 5, 95 and 99) were not significant especially according to the Kendall *tau* test. Trends of monthly averages of daily minimum and maximum temperatures were also analyzed. They have increased in winter, spring and late summer, but in June and autumn months decreasing tendencies, although statistically insignificant, were observed. In the case of precipitation no significant changes in extremes were observed. The increase in frequency of days with measurable precipitation was the only significant tendency observed.

Key words: weather extremes, precipitation, temperature, estimates of trend, Poland

1. INTRODUCTION

Instrumental observations of European temperature records have revealed a warming since the end of the nineteenth century. According to KATZ and BROWN (1992) relatively small changes in the mean of climate variables can induce a strong change in the extreme events. Extreme events frequency and severity exert a considerable impact on society, much stronger than the change in mean (WATSON *et al.*, 1996).

The third Report the IPCC 2001 states: "An extreme weather event is an event that is rare within its statistical reference distribution at a particular place. Definitions of ‘rare’ vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile. By definition, the characteristics of what is called extreme weather may vary from place to place." An extreme climate event can be defined on the basis of rareness, intensity or the impact it exerts on society (BENINSTON and STEPHENSON, 2004). The indices used in this paper are based mainly on rareness and intensity.

It has been shown that warming in central and eastern Europe, also in Poland manifests in the stronger increase of minimum temperature than the maximum (HEINO *et al.*, 1999, WIBIG and GŁOWICKI, 2002). But the increase in mean minimum and maximum temperatures does not necessarily affect the frequency of extreme cold weather (WALSH *et al.*, 2001). In the case when the temperature distribution is shifted towards the higher temperatures, the frequency of very cold days should drop considerably. However the increase of temperature can be expressed by different changes in temperature distribution, so the influence of warming on cold day frequency does not need to drop so much.

In European literature a long series of extreme thermal indices has been presented KLEIN TANK and KÖNNEN (2003) and MOBERG and JONES (2005). Winter severity in Kraków since the 19th century was described by TREPIŃSKA (1976) and DOMONOKOS and PIOTROWICZ (2002). They all indicate that winters became more mild and less severe. Trends in indices describing a mean severity or intensity of winters are statistically significant. But even in warmer climate the series of days with very low temperatures can occur and they can exert dramatic impact on society and environment, like in winter 2005/2006 in Eastern Europe.

The fourth IPCC Report (2007) warns against higher risk of floods and droughts, which can occur more often in a warmer world. According to HAYLOCK and GOODESS (2004) the number of days with strong precipitation (exceeding the 90th percentile) has increased in the winter season over Scandinavia and Germany, but has also decreased in the southern and eastern parts of Europe. Mixed trends were observed over Poland.

Climate models indicate that we should expect more frequent weather extremes in the future. During the last decade a lot of assessments of weather extremes have been made (MOBERG *et al*., 2006; ALEXANDER *et al.*, 2006, GROISMANN *et al.*, 2005, KLEIN TANK and KÖNNEN, 2003). Unfortunately the Polish area seems to create a blank in almost all these assessments. The aim of this paper is to fill out this empty space and give on overview of observed variability in temperature and precipitation extremes in the period 1951-2006.

Station	latitude	longitude	height a.s.l. (in m)	Station	latitude	longitude	height a.s.l. (in m)
Bielsko	49°48'	19°00'	398	Slubice	52°21'	14°36'	20
Chojnice	53°42'	17°33'	173	Suwalki	54°06'	22°57'	165
Hel	54°42'	18°49'	1	Szczecin	53°24'	14°37'	1
Jelenia Gora	50°54'	20°54'	342	Sniezka	50°44'	15°44'	1603
Kalisz	51°44'	18°05'	140	Swinoujscie	53°55'	14°16'	2
Kasprowy W.	49°14'	19°59'	1991	Torun	53°03'	18°35'	69
Katowice	50°14'	19°02'	285	Warszawa	52°13'	21°02'	110
Legnica	51°13'	16°10'	121	Wlodawa	51°33'	23°33'	174
Lodz	51°44'	19°24'	184	Wroclaw	51°08'	16°59'	116
Poznan	52°25'	16°50'	86	Zakopane	49°18'	19°57'	844
Rzeszow	50°06'	22°03'	198				

Table 1. LOCATION OF ANALYZED STATIONS

2. DATA AND METHODS

The daily mean, maximum and minimum temperature and daily precipitation amounts from 21 stations in Poland were used. The data covered the period 1951-2006. The location of stations are summarized in Table 1 and presented on Figure 1.

Two different methods were used to assess the trend and to test for statistical significance. The linear regression estimated by the least square method and Student t-test demand the assumption of Gaussian distribution of variables and residuals so may not be robust in the case of some of indices. So the results obtained by these methods were compared with results of Sen's slope (SEN, 1968) and the Kendall *tau* test (KENDALL, 1970). They are non-parametric methods so should be more robust in the case of variables with non-Gaussian distributions.

Extreme temperatures were analysed on the basis of daily minimum (TN) and maximum (TX) temperatures. Two groups of extreme temperature indices can be distinguished. In the first group are those defined by constant thresholds, like frost day index (FD defined as a annual number of days with minimum temperature below 0°C). The ice day index (ID), the consecutive frost day number (CFD), the frost season length (FSL), the summer day index (SD) and the hot day index (HD) also belong to this group

Fig. 1: Location of analyzed stations

Name	Explanation	Unit
ID	annual number of days with TX ≤ 0°C	number of days
FD	annual number of days with TN ≤ 0°C	number of days
CFD	the greatest number of consecutive days with TN ≤ 0°C	number of days
FSL	length of the frost season calculated as a number of days between the first and the last frost day in the season starting on the 1st July and ending on the 30th June of the next year.	number of days
SD	annual number of days with TX ≥ 25°C	number of days
HD	annual number of days with TX ≥ 30°C	number of days
MEANTN	mean of daily TN	°C
MEANTX	mean of daily TX	°C
TNxP , TXxP	xth percentile of daily TN and TX (x = 1, 5, 10, 25, 50, 75, 90, 95, 99)	°C

Table 2. LIST OF TEMPERATURE INDICES USED IN THIS STUDY

In the second group are indices based on mean or percentiles of daily TN and TX values calculated for selected months or seasons. They all are expressed in degrees Celsius.

In this paper 13 precipitation indices have been defined. Most of them describe different aspects of precipitation extremes. Similar indices were used also in EMULATE (MOBERG *et al.*, 2006), by Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI) and in the ECA project (KLEIN TANK and KÖNNEN, 2003). Unfortunately their definitions differ slightly in spite of similar names. Indices used in this study can also be divided into three groups. In the first are two indices describing the intensity of the strongest 1 day and 5-day events expressed in mm. In the second group are indices showing the number of days with daily total (DT) exceeding selected thresholds. In the last group are indices based on site specific percentiles calculated for reference period 1961-1990. They describe the frequency (in number of days) and intensity (in percent of annual total) of heavy precipitation events.

Name	Explanation	Unit
MX1	the highest DT in each year	mm
MX5	the total precipitation in the wettest consecutive five day period in the year	mm
PD	the number of days in the year with DT ≥ 0.1 mm.	number of days
WD	the number of days in the year with DT ≥ 1 mm.	number of days
MWD	the number of days in the year with DT ≥ 5 mm.	number of days
VWD	the number of days in the year with DT ≥ 10 mm.	number of days
EWD	the number of days in the year with DT ≥ 20 mm.	number of days
PRExN	the number of days in the year with DT ≥ xth percentile defined for the reference period 1961-1990 on the basis of all WD (x= 75, 90, 95)	number of days
TOTx	percent of annual total falling on days with DT ≥ xth percentile defined for the reference period 1961-1990 on the basis of all WD (x= 75, 90, 95)	percent

Table 3. LIST OF PRECIPITATION INDICES USED IN THIS STUDY

3. TEMPORAL VARIABILITY OF INDICES OF TEMPERATURE EXTREMES

As was said previously, the linear trend in all records of analyzed indices was estimated using two methods: linear regression by LSM with standard t-test for significance and Sen's slope method with Kendall *tau* test. All results are presented in Tables 4-6, showing the number of stations with increase (decrease) of each particular index in comparison with the number of statistically significant increase (decrease) at 10 per cent level. This result is compared with numbers of stations with significant increases (decreases) according to Sen's method and Kendall t*au* test. Indices obtained on the basis of 20 stations were analyzed (without Rzeszow). When at least half of the stations show an increase (decrease) is statistically significant we can state that the statistically significant change is observed in Poland as a whole.

It is clear from Table 4 that all indices indicate warming. There is generally a decrease of all indices related to ice or frost days, but only the trend in number of frost days is significant in the light of both methods. The number of ice days has a significant trend according to a t-test at 10 stations but according to Kendall *tau* test only at 4 stations. The decrease in the length of the longest frost spell in the year is insignificant in the light of both tests. The frost season has shortened generally over the area of Poland, but these is one station in the north-eastern part (Suwalki) where the statistically significant extension was observed in spite of a fall in frequency of frost days at this point. It is be in agreement with cooling observed during late autumn in Poland. In eastern Poland it can cause an earlier appearance of first frost than it was before. This problem will be discussed latter (section 3.2) in more details.

Index	linear regression by LSM		Sen's method	
	number of increases all/sign.	number of decreases all/sign.	number of significant increases	number of significant decreases
ID	0/0	**20/10**	0	4
FD	0/0	**20/17**	0	**15**
CFD	1/0	19/5	0	3
FSL	3/1	**17/11**	1	8
SD	**18/14**	0/0	**14**	0
HD	**18/11**	0/0	2	0

TABLE 4. NUMBER OF STATIONS WITH AN INCREASE (DECREASE) OF INDICES BASES ON CONSTANT THRESHOLDS IN COMPARISON WITH NUMBER OF STATISTICALLY SIGNIFICANT INCREASE (DECREASE) AT 10 PER CENT LEVEL ACCORDING TO LSM AND SEN'S METHODS

Both indices describing the frequencies of warm days have shown a significant increase in the light of the t-test. But in the case of t*au* test only the increase in frequencies of summer days is significant. These indices were calculated only for 18 stations, because at two mountainous stations (Sniezka, Kasprowy) summer and hot days do not occur at all (Fig. 2).

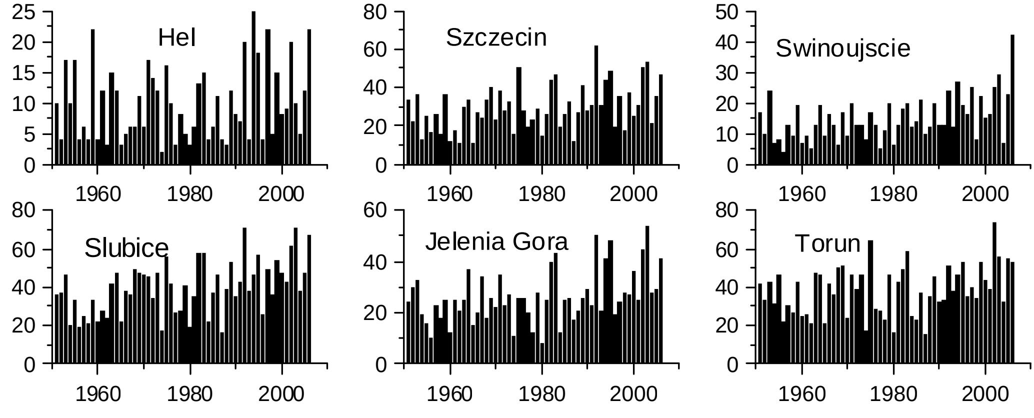

Fig.2: Annual number of summer days for selected stations

At all or almost all stations an increase in mean monthly minimum and maximum temperature is observed. In the case of minimum temperature this increase is statistically significant according to both tests from February to May and in July and August (Table 5). Trends in mean monthly maximum temperature are significant in the light of both tests in April, May and August. In June and November the strongest decrease in both extreme temperatures is observed although it is not significant in general. This means that spring is longer, summer begins slightly later than before, but winter can start as early as in November. Since the 1990s we can observe in Poland that winter has two colder phases separated by the warmer period between with above zero temperatures at least in lowland areas. The first part of winter is beginning earlier than before, even in first half of November, but ends in December. The second winter appears in January and can last for one or two months. This break in winter can be dangerous for trees and other plants, specially if the warmer period is relatively long and the dehardening of trees begins before the second attack of winter weather. It is also harmful for water balance, because snow cover melts during the warmer phase and there is less water in soil in spring after the main melting period. Positive trends in all months contribute to the strong, statistically significant increase in annual mean mimimum (Fig. 3) and maximum (not shown) temperatures.

There is a general tendency of an increase of all percentile values, but the trend is not significant for some of extreme percentiles: 1st of TN and TX, 10th of Tx and 99th of TX according to both tests and 5th of TN and 95 of TX basing on Kendall *tau* test (Table 6). Records of extreme percentiles have much stronger variability than those closer to the median, so much bigger increase (slope coefficient) is necessary for them to exceed the level of statistical significance.

Index	LSM	Sen	Index	LSM	Sen
	all/sign.	significant increases		all/sign.	significant increases
MEANTNJan	20/5	5	MEANTXJan	20/4	2
MEANTNFeb	**20/16**	**11**	**MEANTXFeb**	**20/16**	3
MEANTNMar	**20/18**	**16**	**MEANTXMar**	**20/11**	2
MEANTNApr	**20/14**	**13**	**MEANTXApr**	**20/16**	**12**
MEANTNMay	**20/20**	**19**	**MEANTXMay**	**20/20**	**20**
MEANTNJun	16/6	4	MEANTXJun	8/1	1
MEANTNJul	**20/16**	**15**	**MEANTXJul**	**20/15**	6
MEANTNAug	**19/18**	**16**	**MEANTXAug**	**20/17**	**15**
MEANTNSep	18/7	**16**	MEANTXSep	8/0	0
MEANTNOct	20/8	7	MEANTXOct	16/0	0
MEANTNNov	10/0	0	MEANTXNov	12/1	0
MEANTNDec	18/0	0	MEANTXDec	16/1	0

TABLE 5. NUMBER OF STATIONS WITH INCREASE OF MEAN MONTHLY MINIMUM AND MAXIMUM TEMPERATURE IN COMPARISON WITH NUMBER OF STATISTICALLY SIGNIFICANT INCREASE ACCORDING TO LSM AND SEN'S METHODS

4. TEMPORAL VARIABILITY OF INDICES OF PRECIPITATION EXTREMES

The only index showing a significant and almost uniform change in Poland is the number of days with measurable precipitation. It is increasing at 20 out of 21 stations according to linear regression and the increase is significant at 11 stations (Table 7). According to Sen's trend estimation the increasing trend is significant at all 21 analysed stations in Poland. All other indices have different tendencies at different stations and the number of stations with increases is usually similar to the number of stations with decreasing values of the same index. The spatial distribution of decreases and increases is rather chaotic, so it is rather impossible to find clusters of neighbouring stations with similar tendencies.

Index	linear regression by LSM		Sen's method	
	number of increases all/sign.	number of decreases all/sign.	number of significant increases	number of significant decreases
TN1P	20/6	0/0	1	0
TN5P	**20/18**	0/0	9	0
TN10P	**20/15**	0/0	**12**	0
TN25P	**20/16**	0/0	**17**	0
TN50P	**20/20**	0/0	**20**	0
TN75P	**19/19**	1/0	**18**	0
TN90P	**19/17**	1/0	**16**	0
TN95P	**20/16**	0/0	**16**	0
TN99P	**20/18**	0/0	**16**	0

TABLE 6. AS IN TABLE 4 BUT FOR PERCENTILES OF MINIMUM TEMPERATURE

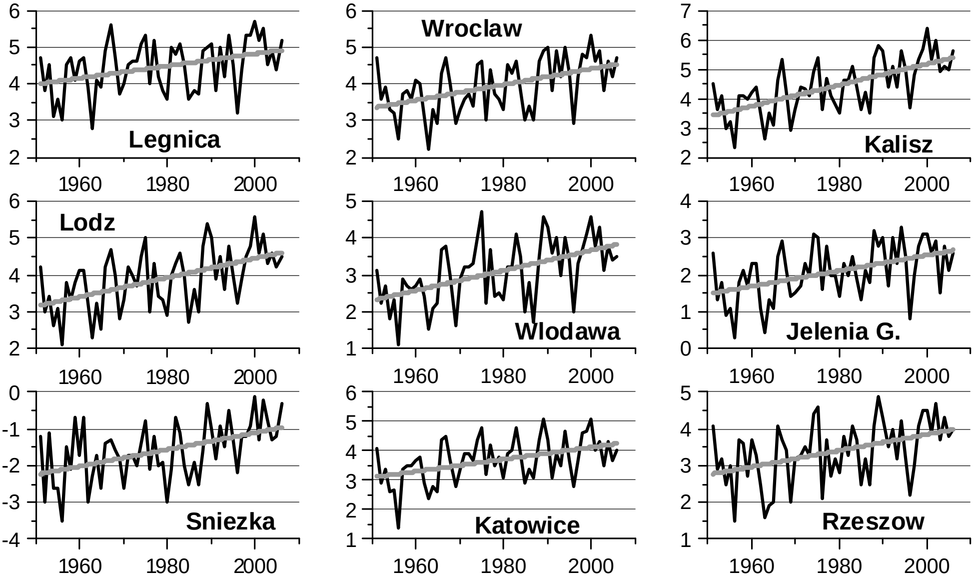

Fig.3: Mean annual values of daily minimum temperature (black line) together with trend (grey line) estimated by LSM method for selected stations

5. CONCLUSIONS

Warming trends dominate in Poland over the second half of the 20th century and the beginning of the 21st century both for the warm and cold tails of the temperature distribution. There are less ice days, with their number decreased about 2 day per decade. The decrease in the frequency of frost days is even stronger, reaching more than 3 days per decade on average. At the same time the length of the frost season has became shorter in Poland except for the north-eastern part. The length of the longest frost spell in the year is slightly lower but the change is not statistically significant. Frost spells are usually related to high pressure systems occurrence and there is a tendency to a lenghtening of the periods with highs presures.

Index	linear regression by LSM		Sen's method	
	number of increases all/sign.	number of decreases all/sign.	number of increases all/sign.	number of decreases all/sign.
MAX1	10/0	11/1	10/10	11/11
MAX5	13/0	8/1	11/10	10/10
PD	**20/11**	**1/0**	**21/21**	**0/0**
WD	12/0	9/2	9/9	9/9
MWD	13/1	8/3	15/12	6/6
VWD	8/0	13/2	4/4	6/6
EWD	11/0	10/1	1/1	1/1
PRE75N	11/2	10/2	9/9	6/6
PRE90N	10/1	11/1	2/2	2/2
PRE95N	9/0	12/1	1/1	1/1
TOT75	8/4	13/2	7/6	12/12
TOT90	8/0	13/2	7/6	14/13
TOT95	10/0	11/0	8/7	12/12

TABLE 7. NUMBER OF STATIONS WITH INCREASE (DECREASE) OF PRECIPITATION INDICES IN COMPARISON WITH NUMBER OF STATISTICALLY SIGNIFICANT INCREASE (DECREASE) AT 10 PER CENT LEVEL ACCORDING TO LSM AND SEN'S METHODS

Warming is not uniform within the year. The strongest increase in temperature is observed in late winter and spring. It has been warmer also in the middle and late summer, which manifests in higher frequencies of summer and hot days. But in early summer (June) and autumn, particularly in November, some tendency to cooling is observed. This cooling is statistically insignificant, but widespread and there are some signs of autumnal cooling from Lituania (BACC, 2008), and for western Germany (HUNDECHA and BARDOSSY, 2005)

In the case of daily maximum temperatures the increase in low percentiles (1, 5) is weaker than in high percentiles (95, 99) resulting in narrowing of the distribution. The opposite is true for the daily minimum temperatures. The increase in low percentiles (1, 5) is stronger than in high percentiles (95, 99) resulting in widening of the distribution.

The index of measurable precipitation is rather a measure of mean conditions, so it can be stated that precipitation extremes did not change significantly in Poland in the second half of the 20th century. It confirms previous results obtained on the basis of only five stations (WIBIG, 2008), that the extremes of precipitation have not changed, and the overall increase of days with precipitation shown by NIEDŹWIEDŹ (2000) an the basis of 14 stations. The papers by MOBERG and JONES (2005) and MOBERG *et al.* (2006) presenting the long-term trends of precipitation extremes over Europe do not analyse data from Poland, but the trends in the eastern part of Europe are opposite to this from the west indicating that in Poland the trend close to zero should occur, which is in agreement with Table 7.

Some authors (MOBERG and JONES, 2005; HUNDECHA and BARDOSSY, 2005) mention that the increase in heave precipitation events occurs mainly in winter, and that there are some signs of decreases in summer. It is necessary to analyse seasonal values of precipitation indices to find if it is true also for Poland. The precipitation amounts during heavy rainfall in winter are evidently lower than even moderate rainfall in summer so the results of this analysis do not allow an answer the question on the heavy precipitation in winter season.

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