Predisposition of drought occurrence in selected arid areas of the Czech Republic

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Abstract: Predisposition of drought occurrence is based on combined evaluation of above-normal temperatures and below-normal precipitation. According to the weight of the individual categories of extremity, the five degrees of predisposition to drought were determined (degree 1 is the lowest risk, degree 5 is the highest risk). Evaluation of temperature extremity is based on the determination of abnormality in comparison with average value and standard deviation. Individual categories of extremity of precipitation are determined by comparing the individual monthly data with percentile values. Monthly data of homogenized technical series of the Czech Hydrometeorological Institute were evaluated for the years 1961–2010 in two climatologically dry areas (Břeclav and Kladno county in the Czech Republic). Fourty-two months were rated risky in Břeclav county and fourty-four in Kladno county. The evaluation shows an increase of predisposition to drought, especially after 1990. The highest incidence of degree 5 was recorded in 2001 to 2010 in vegetation season. Subsequently the drought variability as a mean variance of years/season and drought severity as a sum of degree of predisposition to drought of years/season were assessed. A gradual increase of variability and severity from 1961–1970 to 2001–2010 is visible. The lowest values of variability (maximum 2) and severity (maximum 3) in both counties were recorded in winter.

Key words: drought, extremity, aridity, precipitation, air temperature, climatological index

1. Introduction

Drought means an environmental disaster and attracts the attention of environmentalists, ecologists, hydrologists, meteorologists, geologists and agricultural scientists. Aridity or dryness of the climate in the Czech Republic

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(CR) is a typical property mainly for Southern Moravia and Central Bohemia. Definition of dry regions of the CR can be, from the climatological perspective, expressed by describing the course of isohyet of the average annual precipitation of 500 mm. Expression of thus defined aridity, i.e. aridity in the climatological perspective, varies depending on soil conditions. With regard to the characteristics of the soil, we are talking about soil drought.

Drought definitions can be classified into different categories depending on the variable used to describe the drought. The first kind is meteorological drought defined as a period with subnormal precipitation alternatively in connection to other meteorological elements as temperature, evaporation, wind speed etc. The second kind is hydrological drought, i.e. subnormal flows. *Gumbel (1963)* defined a drought as the smallest annual value of daily streamflow. The third kind is agricultural drought. The Food and Agriculture Organization (FAO) of the United Nations defines a drought hazard as the percentage of years when crops fail from the lack of moisture (*FAO, 1983*). The *World Meteorological Organization (1975)* defines drought as a sustained, extended deficiency in precipitation. *Linsley et al. (1958)* defined drought as a sustained period of time without significant rainfall. The encyclopedia of climate and weather (*Schneider, 1996*) defines a drought as an extended period of deficient rainfall relative to the statistical multi-year mean for a region.

The most widespread approach to drought evaluation is based on drought indexes, but subjectivity in the drought definition has made it very difficult to establish a unique and universal one. Standardized Precipitation Index (*McKee et al., 1993*) is based just on the precipitations total.

Palmer (1965) described a drought as a significant deviation from the normal hydrologic conditions of an area. The Palmer Drought Severity Index (PDSI) enables measurement of both wetness and dryness based on the supply and demand concept of the water balance equation, and thus incorporates prior precipitation, moisture supply, runoff and evaporation demand at the surface level.

Briffa et al. (2009) in their analysis showed that a major influence on the trend toward drier summer conditions is the observed increase in temperatures. This effect is particularly strong in Central Europe (Pokladníková et al., 2008). Based on the 22 scPDSI (self-calibrating Palmer Drought Severity Index) records, a gridded scPDSI dataset covering a large part of Europe has been constructed and compared to a recent high-resolution scPDSI dataset spanning the twentieth century only. The scPDSI automatically calibrates the behavior of the index at any location by replacing empirical constants in the index computation with dynamically calculated values (*Wells et al., 2004*). A major cause for the large areal extent of summer drought in the last two decades is high temperatures has been observed. Temperatures in the 12 months preceding and including the summer of 2003 explain an increase in the areas experiencing slightly dry (or worse) conditions of 11.1%.

Precipitation-based drought indices rely on assumptions droughts are controlled by the temporal variability in precipitation. However the temperature rise markedly affects the severity of droughts. Therefore, the use of drought indices which include temperature data in their formulation is preferable.

Standardised Precipitation-Evapotranspiration Index (SPEI) has been formulated based on precipitation and potential evapotranspiration (*Vicente-Serrano et al., 2010*). It can be used for determining the onset, duration and magnitude of drought conditions with respect to normal conditions. *Potop et al. (2013)* divided the frequency distribution of the SPEI values for seven drought category classes (in percentage) indicates that normal moisture conditions represent approximately 65% of the total SPEI values, whereas moderate drought and moderate wet conditions are almost equally distributed around 10.5%. Differences in extremely dry conditions (5%) compared with extremely wet conditions (1.5%) were observed with increasing SPEI time scales.

2. Materials and methods

2.1. Area selection

This work deals with detailed assessment of extremity of monthly precipitation and monthly air temperature and their combinations in two districts of interest, both belonging to the climatologically defined dry areas of CR. Břeclav county represents the Southern Moravia, Kladno represents the Central Bohemia. Despite the fact that these areas are located in different regions, there are many similarities when it comes to demonstration of climate. Under climate classification the Czech Hydrometeorological Institute (CHMI) Břeclav county falls into warm areas A2 (dry, warm area with mild winters and shorter periods of sunshine) and A3 (slightly dry, warm areas with mild winters). According to agroclimatological division, Břeclav county belongs to a warm macroareas, very warm, mostly warm, sufficiently warm and quite warm areas, predominantly dry and slightly dry subareas and a district of mild and moderately cold winters (*Kurpelová et al., 1975*). Under the above mentioned climatological classification, Kladno county belongs to slightly warm areas B1 (dry, slightly warm with mild winters) and B2 (slightly dry, slightly warm with mostly mild winters). According to agro-climatic zoning it belongs to the warm and moderately warm macroarea, relatively warm and relatively mildly warm areas and a region of mild or moderately cold winters.

2.2. Database

Meteorological observations are usually carried out in accordance with regulations for observations and measurements in the network of climatological stations of the CHMI. The network of climatological stations is not dense enough to fully capture the varying conditions in the country through the use of representative measurements. As a result, data generated by a technical series of climatic elements were used for the analysis of climatic conditions of the areas of interest. The technical series of climatic elements was created on the basis of measured data of a station network of CHMI. It is a homogeneous and fully completed station series which was used as a basis of calculation of series of climatic elements in daily intervals for grid points placed 10 km apart (*Štěpánek et al., 2011; Štěpánek et al., 2013*). Consequently, one grid point was chosen from the database to represent each area. Data for the period of 1961–2010 were taken into consideration and evaluated.

2.3. Air temperature extremity

Evaluation of extremity of air temperature is based on the determination of abnormality. For the period 1961–1990, normal (average) monthly temperatures were estimated for the months from January to December ($\bar{x}_{61-90m}$)

as well as standard deviation ($s_{x61-90m}$). Subsequently, the difference of the average monthly temperatures for a particular month (e.g. January 1970, $\bar{x}_m$) and the normal monthly temperature for the month (January) were determined: $\Delta = \bar{x}_m - \bar{x}_{61-90m}$. According to the multiple of the standard deviation in this difference, the categories below (Table 1) have been earmarked.

Table 1. Categories of monthly temperature extremity

temperature-normal	TN	$\Delta \langle -1 * s_{x61-90m}; 1 * s_{x61-90m} \rangle$
temperature-above normal	TAN	$\Delta (1 * s_{x61-90m}; 1.5 * s_{x61-90m} \rangle$
temperature-very above normal	TVAN	$\Delta (1.5 * s_{x61-90m}; 2 * s_{x61-90m} \rangle$
temperature-extraordinary above normal	TEAN	$\Delta > 2 * s_{x61-90m}$
temperature-below normal	TBN	$\Delta \langle -1.5 * s_{x61-90m}; -1 * s_{x61-90m})$
temperature-very below normal	TVBN	$\Delta \langle -2 * s_{x61-90m}; -1.5 * s_{x61-90m})$
temperature-extraordinary below normal	TEBN	$\Delta > -2 * s_{x61-90m}$

2.4. Precipitation extremity

For the normal period of 1961–1990, i.e. months January to December, the values of chosen percentiles (boundaries of intervals) were defined. The method assumes that the precipitation data fall within gamma distribution. Individual values of monthly totals were compared with the obtained 2nd, 10th, 25th, 75th, 90th and 98th percentile. Precipitation amounts lower than 2nd percentile were classified as precipitation-extraordinary below normal (PEBN), lower than 10th percentile as very below normal (PVBN) and lower than 25th percentile as below normal (PBN). Similarly, the categories of the 75th, 90th and 98th percentile are defined as above normal (PAN), very above normal (PVAN) and extraordinary above normal (PEAN).

2.5. Determination of the degree of predisposition to drought occurrence

Predisposition to drought occurrence (PDO) and assessment of its degrees are based on the evaluation of the combination of the key factors, i.e. extraordinary/very/above normal temperatures and extraordinary/very/below normal precipitations. According to the weight of the individual categories of extremity, the following five degrees of PDO were determined (degree 1 is the lowest risk, degree 5 is the highest risk):

1st degree:	combination of TAN and PBN
2nd degree:	a) combination of TAN and PVBN
	b) combination of TVAN and PBN
3rd degree:	a) combination TVAN and PVBN
	b) combination of TAN and PEBN
	c) combination of TEAN and PBN
4th degree:	a) combination of TVAN and PEBN
	b) combination of TEAN and PVBN
5th degree:	combination of TEAN and PEBN

The analysis of temperature and precipitation extremity as well as PDO was prepared for whole year as well as for individual season and subsequently statistically and graphically expressed.

2.6. PDO variability and severity

PDO variability is defined as a mean variance of years/season within evaluated decade.

PDO severity is defined as a sum of degree of PDO (from 1 to 5) of years/season within evaluated decades (1961–1970, 1971–1980, 1981–1990, 1991–2000, 2001–2010).

3. Results and discussion

For the purposes of the analysis, characteristic points of the technical series of 10 km grid network for the district of interest were selected. Břeclav county was characterized by grid point of 188 m a.s.l. and Kladno county by grid point of 356 m a.s.l. The values of altitude, latitude and longitude of these grid points are closest to the average values of these districts (points are located roughly in the center of the districts). Basic climatological characteristics of the locations for the long-term period 1961–2010 are shown in

Table 2. Annual and seasonal maximum and minimum mean air temperatures and precipitation totals for the period 1961–2010 are shown in Table 3 and 4. Table 5 shows a PDO in Břeclav county (left) and in Kladno county (right).

The study revealed that there were nine months of 1st degree of PDO, ten months of 2nd degree, eighteen months of 3rd degree, two months of 4th degree and three months 5th degree in Břeclav county in period 1961–2010. The same period in Kladno county is characterized by the occurrence of thirteen months of 1st degree, thirteen months of 2nd degree, ten months of 3rd degree, five months of 4th degree and three months of 5th degree.

Seasonal PDO in Břeclav county (the period 1961–2010) is as follows: 1st and 3rd degrees occurred in DJF season. Degrees 1, 2, 3 and 5 occurred in MAM season. JJA season included all degrees. The highest incidence of 3rd degree was recorded in this season – eight times. SON season included 1st, 2nd and 3rd degrees. The highest incidence of 5th degree (the highest risk) was recorded in the last decade from 2001 to 2010 (two in MAM and one in JJA season – Břeclav and one in MAM, JJA and SON – Kladno).

Seasonal PDO in Kladno county (the period 1961–2010) is as follows: DJF season included 1st, 2nd, 3rd degree. All degrees of PDO occurred in all remaining seasons (MAM, JJA and SON). The highest incidence of 1st degree was recorded in MAM season – eight times. The highest incidence of most risk 5th degree was also recorded in the last decade 2001–2010 (one in the MAM, one in JJA and one in SON).

It is evident (see Table 5) that the highest risk (5th degree) occurred

Table 2. Basic climatological characteristics of the locations for the period 1961–2010

County	**mean annual air temperature 1961–2010 (°C)**												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	year
Kladno	-1.4	-0.1	3.5	8.4	13.3	16.3	18.1	17.7	13.5	8.4	3.3	-0.2	8.5
Břeclav	-1.4	0.5	4.6	10.1	14.9	18	19.6	19.1	14.9	9.6	4.4	-0.1	9.6

County	**mean annual precipitation total 1961–2010 (mm)**												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	year
Kladno	26	24	33	37	67	70	71	68	43	31	35	29	534
Břeclav	24	27	30	34	54	68	64	56	41	32	40	32	502

Table 3. Years and values of maximum and minimum mean air temperatures and precipitation totals for the period 1961–2010, Břeclav

mean air temperature						
		Annual	DJF (winter)	MAM (spring)	JJA (summer)	SON (autumn)
max	°C	11.1	3.8	12.1	21.6	11.9
	year	2000	2007	2000	2003	2006
min	°C	8.1	-5.5	7.4	16.9	8.1
	year	1985	1963	1987	1978	1965

mean precipitation total						
		Annual	DJF (winter)	MAM (spring)	JJA (summer)	SON (autumn)
max	mm	741.0	183.6	220.7	322.9	215.6
	year	2010	1977	2010	1997	1998
min	mm	364.9	30.0	61.3	103.9	41.6
	year	2003	1964	1974	1962	2006

Table 4. Years and values of maximum and minimum mean air temperatures and precipitation totals for the period 1961–2010, Kladno

mean air temperature						
		annual	DJF (winter)	MAM (spring)	JJA (summer)	SON (autumn)
max	°C	10.2	4.0	11.0	20.4	11.2
	year	2007	2007	2007	2003	2006
min	°C	7.1	-6.4	6.3	15.6	6.5
	year	1996	1963	1980	1978	1965
mean precipitation total						
		annual	DJF (winter)	MAM (spring)	JJA (summer)	SON (autumn)
max	mm	755.4	131.3	275.4	324.9	186.5
	year	1981	1987	1998	1977	1998
min	mm	343.5	34.1	72.5	106.5	44.3
	year	2003	1973	1965	1990	2003

Note (Table 3 and 4):
DJF (December, January, February)
MAM (March, April, may)
JJA (June, July, August)
SON (September, October, November)

Table 5. Degrees of PDO in Břeclav county (left) and Kladno county (right)

season	JF		MAM			JJA			SON			D
year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1961									2b			
1962												
1963							3b					
1964												
1965												
1966												
1967										1		
1968												
1969												
1970												
1971					2b							
1972												
1973												
1974			2a					2b				
1975									3c			
1976							2a					
1977												
1978												
1979												
1980												
1981												
1982									3c			
1983							3c	3a				
1984												
1985												
1986				1								
1987												
1988												
1989												
1990								2a				
1991												
1992	1					1	4a					
1993					3c							
1994						3b	3c		2b			
1995							3c					
1996												
1997												
1998		3b										
1999												
2000				3c	3c	4b						
2001										3a		
2002					3c							
2003						5						
2004												
2005												
2006						1	3c		3a	1	3a	1
2007				5	2b							
2008		1				3a		1			2b	
2009				5				2b				
2010												

season	JF		MAM			JJA			SON			D
year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1961			1									
1962												
1963												
1964						4b						
1965												
1966												
1967										2b		
1968												
1969												
1970												
1971												1
1972												
1973								1	2a			
1974			1									
1975								2b				
1976						1						
1977			1									
1978												
1979												
1980												
1981												
1982							1		4b			
1983							3c					
1984												
1985												
1986												
1987												
1988					2b							
1989												
1990			2b		2a			2b				
1991			1						2a			
1992					2b							
1993				3a								
1994											3c	
1995										3a		
1996												
1997												
1998		3a		3a	2a							
1999				1	1							
2000				4b				3c				
2001												
2002												
2003						3c		5			3b	
2004				1								
2005				2b						1		
2006									5		4b	
2007			1	5								
2008		2a										
2009				3c				4b	2b			
2010												

Legend

1	1st degree
2	2nd degree
3	3rd degree
4	4th degree
5	5th degree

within in decade 2001 to 2010 in both counties. Almost all occurrences of this degree passed into MAM and JJA season i.e. into vegetation period or growing season of the most agricultural crops.

PDO variability and severity (Fig. 1 to 10) in individual decades were assessed on the basis of Table 5.

The comparison of individual decades of year/seasons has shown differences of variability and severity of PDO. There is a statistically significant correlation between PDO variability and severity (r = 0.776 to 0.971**). The lowest value of correlation coefficient in Břeclav county was found out for SON period (r = 0.776**) and in Kladno county for MAM period (r =

Břeclav county

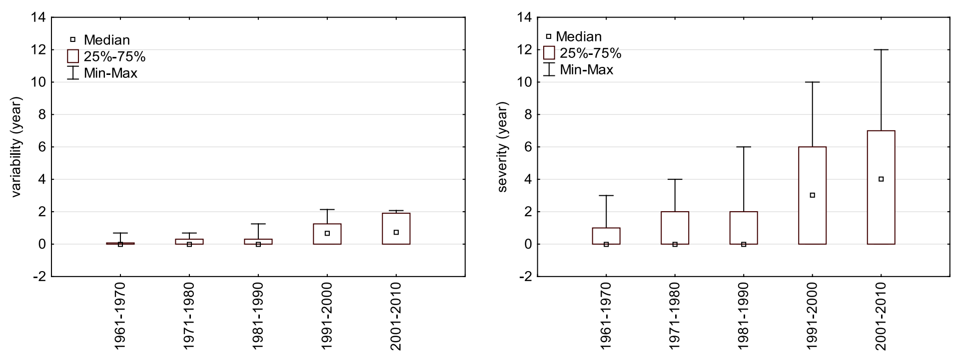

Fig. 1. PDO variability (left) and severity (right) of years within evaluated decades, Břeclav.

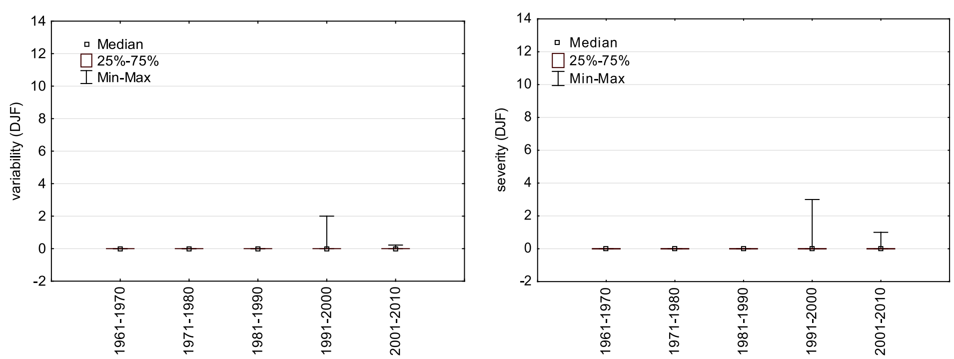

Fig. 2. PDO variability (left) and severity (right) of DJF season within evaluated decades, Břeclav.

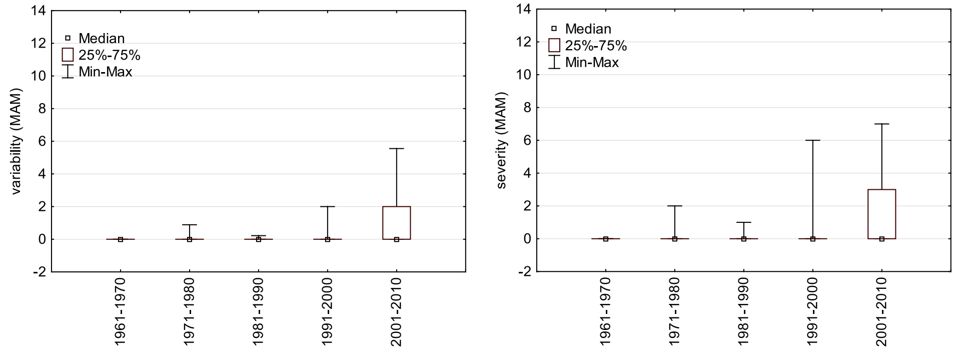

Fig. 3. PDO variability (left) and severity (right) of MAM season within evaluated decades, Břeclav.

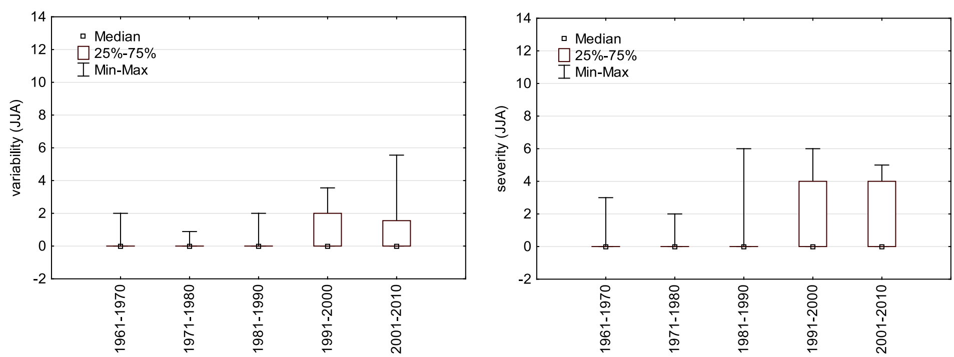

Fig. 4. PDO variability (left) and severity (right) of JJA season within evaluated decades, Břeclav.

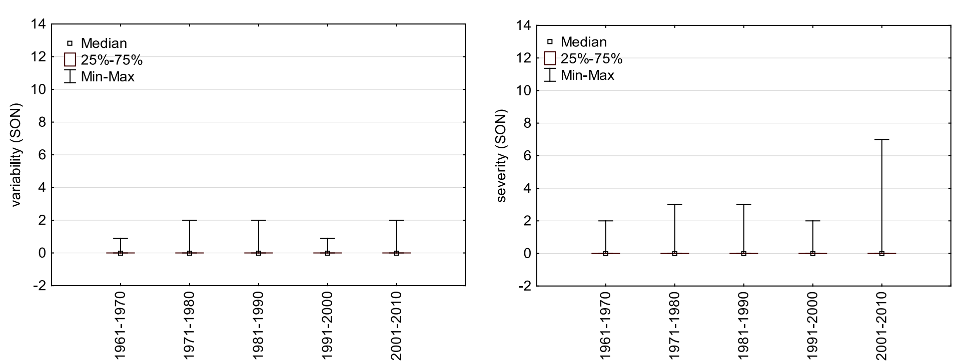

Fig. 5. PDO variability (left) and severity (right) of SON season within evaluated decades, Břeclav.

Kladno county

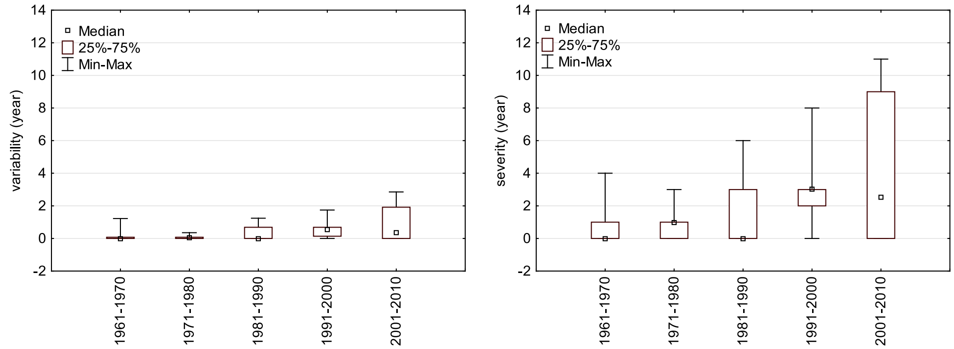

Fig. 6. PDO variability (left) and severity (right) of years within evaluated decades, Kladno.

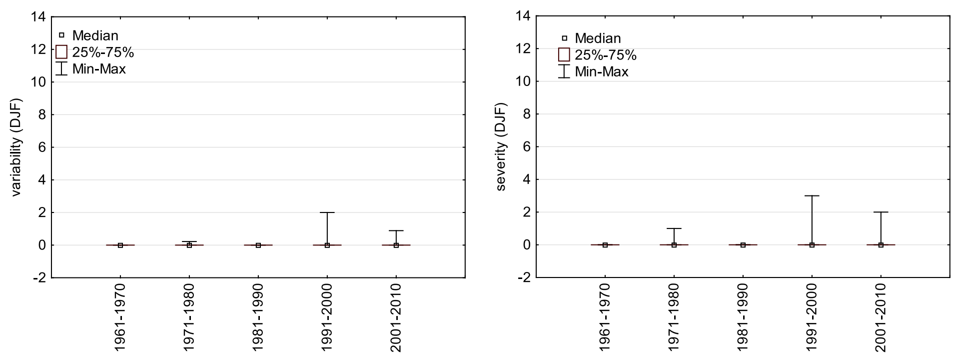

Fig. 7. PDO variability (left) and severity (right) of DJF season within evaluated decades, Kladno.

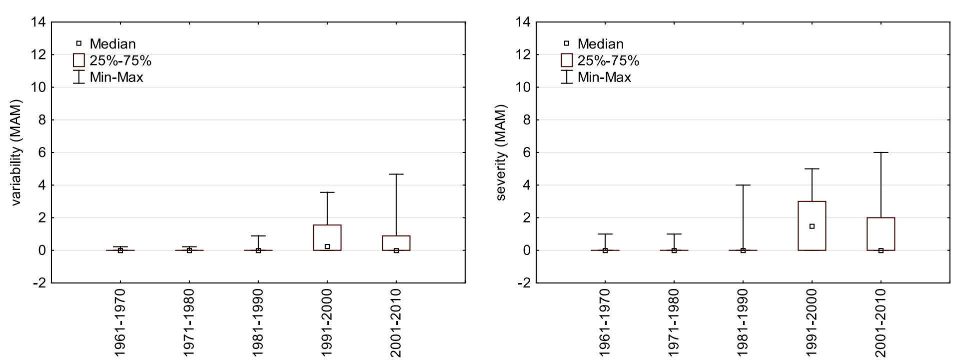

Fig. 8. PDO variability (left) and severity (right) of MAM season within evaluated decades, Kladno.

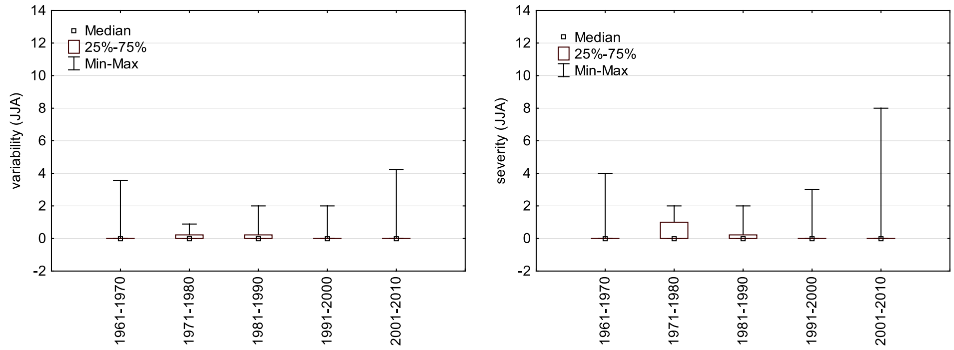

Fig. 9. PDO variability (left) and severity (right) of JJA season within evaluated decades, Kladno.

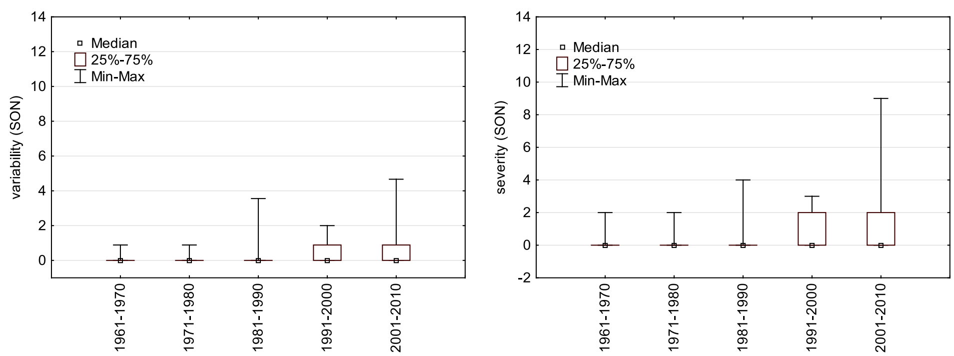

Fig. 10. PDO variability (left) and severity (right) of SON season within evaluated decades, Kladno.

0.892**). Level of statistical significance: one asterisk (*) if $p < 0.05$, two asterisks (**) if $p < 0.01$.

When evaluating the whole year, a gradual increase of variability and severity of PDO of single decade with maximum in the last one is visible. The similar trend could be observed in the case of most seasons as well. The lowest variability and severity of PDO has shown DJF season in both counties.

MAM season: Břeclav county: Variability is almost zero for the first and third decade, for the second decade is a little bit higher than for the fourth one and the highest is for the last one. The course of severity is similar.

Kladno county: Variability and severity of the first and second decade are equal. A gradual increase from the third decade is visible.

JJA season: Břeclav county: The lowest variability and severity is observed for the second decade. Variability of the first and third decades is the same and is growing from the third one. Severity reaches the maximum in the third and fourth decades. Kladno county: Maximum variability and severity is recorded in the last decade which is followed by the first one.

SON season: Břeclav county. There is not a significant difference of variability but severity of the last decade is much higher then previous. Kladno county: The last decade is characterized by a highest variability close followed by the third one. Course of severity is the same as in Břeclav.

4. Conclusion

Long-term results show that the existence of drought is typical for defined parts of our country and its incidence increases with climate variability and is more frequent and intense. The study deals with a detailed evaluation of extremity of monthly precipitation and monthly air temperatures for the period 1961–2010 in two districts of interest belonging to the climatologically defined dry areas.

Assessment of five PDO degrees is based on the evaluation of the combination extraordinary/very/above normal temperatures and extraordinary /very/below normal precipitations. Both annual and seasonal numbers of individual degrees were evaluated.

Nine months of 1st degree of PDO, ten months of 2nd degree, eighteen months of 3rd degree, two months of 4th degree and three months of 5th degree occurred in Břeclav county; thirteen months of 1st degree, thirteen months of 2nd degree, ten months of 3rd degree, five months of 4th degree and three months of 5th degree in Kladno county in period 1961–2010. The highest incidence of 5th degree was recorded in 2001 to 2010 in vegetation season. PDO in Břeclav county is higher than in Kladno county in long term perspective.

When evaluating annual and seasonal courses of variability and severity of PDO, a gradual increase from 1961–1970 to 2001–2010 is visible. The lowest variability and severity of PDO was in DJF season. Decade course of

PDO variability and severity in individual seasons are similar in both counties. Total PDO severity of the whole evaluated period is 106 in Břeclav county and 104 in Kladno county.

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