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## **Spatial and temporal evolution of drought conditions at various time scales in the Czech Republic during growing period**

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**Abstract**—This paper analyzes the characteristics of spatial evolution of the standardized precipitation evapotranspiration index (SPEI) at various time scales during the growing period (April–September) over the Czech Republic. The SPEI was calculated from monthly records of mean temperature and precipitation totals measured at a dense network of 184 climatological stations for the period 1961–2010. Using various lags, 1, 3, 6, 12, and 24 months. The drought at these time scales is relevant for agricultural, hydrological, and socio-economic impacts, respectively. The study refers to the warm season of the year (from April to September). The principal modes of variability of the SPEI calculated at these five time scales were identified by using the empirical orthogonal functions (EOF) analysis. The explained variance of the leading EOF ranges between 71 and 61% as the time scale for calculating the SPEI increases from 1 to 24 months. The explained variance of EOF2 and EOF3 ranges between 5 and 9%, and 4 and 6%, respectively, as the SPEI is calculated for 1–24 months. With a few exceptions at stations at the highest altitudes, the spatial coefficients of the EOF1 for all SPEI time scales have the same sign over the country's territory. Based on the spatial distribution of

the spatial coefficients of EOF2 and EOF3, at all SPEI time scales we have identified three climatically homogenous regions, corresponding to the altitudes below 400 m, between 401 and 700 m, and above 700 m. This regionalization corresponds to some extent to that which was previously used in other studies. These three regions reflect different land use types corresponding to: (i) mostly intensive agriculture, (ii) less intensive agriculture, and (iii) limited agricultural production and mostly forested, respectively. For these three regions, the frequency distribution of the SPEI values in 7 classes of drought category (%) were calculated based on station records for each region. The normal conditions represent around 65% out of the total values of SPEI for all time scales, in all three regions, while moderate drought and moderate wet conditions are almost equally distributed around 10.5%. As the SPEI time scale increases, the difference between the percentages of extremely dry and extremely wet conditions changes on average from 0.2% (SPEI 1-month) to 4% (SPEI 24-month).

*Key-words:* standardized precipitation evapotranspiration index, frequency distribution, empirical orthogonal function, Czech Republic.

## 1. Introduction

Drought indices associated with specific time-scales are useful tools for monitoring and management of drought. For quantifying the drought conditions, *Vicente-Serrano et al.* (2010) have developed a new drought index – the standardized precipitation evapotranspiration index (SPEI) based on precipitation and potential evapotranspiration (PET). The SPEI combines the sensitivity of the Palmer drought severity index (PDSI) to changes in evaporative demand (related to temperature fluctuations and trends) with the multi-temporal nature of the Standardized Precipitation Index (SPI). The various time scales provided by the SPEI can be related to different drought types in a region. Short time scales show a high relationship with variations of soil moisture, which determine water availability for vegetation and agriculture, while water resources in reservoirs are related to longer time scales (*Dai, 2011; Vicente-Serrano et al., 2011*).

In previous studies (*Potop et al., 2011, 2012*), drought was extensively analyzed by comparing results from the most advanced drought indices (e.g., SPI and SPEI), which take into account the role of antecedent conditions in quantifying drought severity in the lowland regions of the Czech Republic. Decadal trend in the drought extent detected by the SPEI are apparent, however, with higher values of drought incidences in the 1940s, early 1950s, and 1990s, and with fewer drought episodes in the 1910s, 1930s, and 1980s. These episodes coincide with the secular drought evolution recorded in the central part of Europe (*Brázdil et al., 2009; Dai, 2011*). Consequently, SPEI and SPI showed large differences in the evolution drought severity during decades with the lowest summer negative temperature anomalies combined with the lowest precipitation (cold and dry; the first two decades of the 20th century), the highest summer positive temperature anomalies (the end of the 20th century), both high spring positive temperature and precipitation anomalies (warm and

wet; the beginning of the 20th century), and the lowest deficit of water balance (1947, 2003, 1994, 1983, and 1933) (*Potop et al.*, 2012). On the other hand, similarities between two indices were reported during the decades with high fluctuations of positive spring temperature and lower precipitation (warm and dry; 1950s, 1990s, and 2000s); extremely long sunshine durations (155% of the normal amount in extremely dry June of 2006 and August 2003, up to twice the norm for April of 2007 and 2009, in the reference period of 1961–1990); and consecutive dry days. Therefore, the role of temperature was evident in summer drought episodes which depend on the intensity and duration of temperature anomalies, generating a higher water demand by potential evapotranspiration at the end of the last century.

New detailed results on the temporal evolution of the SPEI at various time-scales and the impact of drought on vegetable crops were discussed and presented in broader climatological and European contexts in, e.g., *Potop* and *Možný* (2011a, 2011b), *Potop* and *Soukup* (2011). However, more in-depth analysis is required to explore the vulnerability to drought in the context of climate change based on a denser station network to better representation of various climate conditions across the Czech Republic (*Potop et al.* 2012a; *Potop et al.* 2012b).

The present study aims at the analysis of the spatial evolution of the SPEI at various time scales during the warm period (April–September) over the Czech Republic. To this aim, the principal modes of variability of SPEI are examined based on data from a dense network of climatological stations in the Czech Republic during the period of 1961–2010 in order to reveal the regional characteristics of drought variability. Frequency distribution of SPEI values over the three regions in 7 classes of drought category (%) at time scales of 1, 3, 6, 12, and 24 months, and the spectral analysis of the series of the  $SPEI \leq -1$  were also analyzed.

## **2. Data and methods**

The SPEI was calculated from monthly records of mean temperature and precipitation totals using a dense network of 184 climatological stations from the Czech Republic for the period of 1961–2010. The selected stations as input dataset in calculation of the SPEI are uniformly covering the Czech Republic. Station elevations range between 158 and 1490 m above sea level (*Fig. 1*). The selected stations represent various climate conditions both in lowland and highland regions and reflect the differences between the maritime and continental weather regimes which manifest across the Czech Republic. Monthly series of temperature and precipitation were taken from the Czech Hydrometeorological Institute (CHMI) CLIDATA database. Measured data were subjected to quality control, gap filling, and homogenization by means of

ProClimDB and AnClim software (Štěpánek, 2010). The approach of quality control of daily and monthly temperature and precipitation series combines several methodologies such as differences of neighbor stations comparison, comparison with “expected” values calculated by means of geostatistical methods, etc. Interpolation, where needed, was carried out applying an approach adopted at CHMI. It is based on local linear regression (dependence of given meteorological element on altitude) and universal kriging interpolation, and inverse distance weighting methods (Šercl and Lett, 2002). The homogeneity of monthly precipitation and temperature series was tested using the Alexandersson’s SNHT, bivariate test, and Vincent methods (Štěpánek *et al.*, 2009; Štěpánek, 2010).

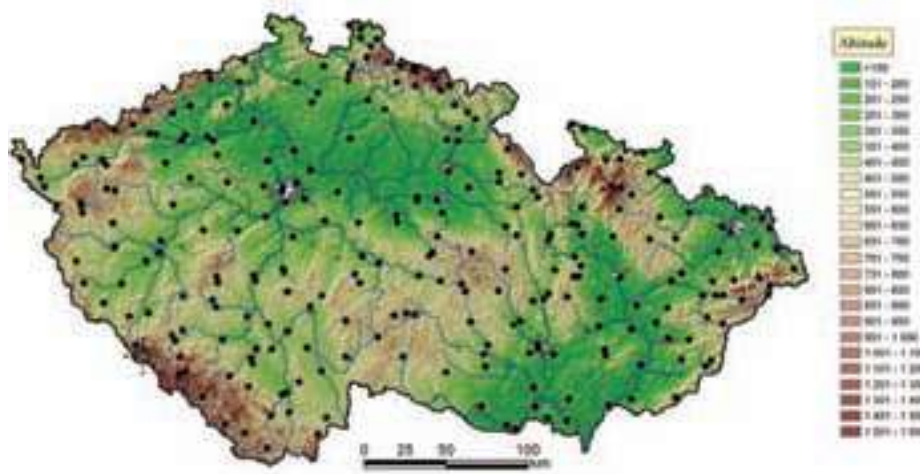


Fig. 1. Location of stations used for the calculation of the SPEI drought index in the Czech Republic.

For the SPEI calculations, the algorithm developed by *Vicente-Serrano et al.* (2010) was used. The SPEI is based on a monthly climatic water balance (precipitation ( $P$ ) minus potential evapotranspiration ( $PET$ )).  $PET$  is calculated using the method of *Thornthwaite* (1948). The documentation and executable files for SPEI calculation are freely available at <http://digital.csic.es/handle/10261/10002>. A batch script was created and used for optimizing the calculation of the SPEI for the 184 stations and five accumulated periods: 1, 3, 6, 12, and 24 months. The SPEI was calculated for each month of the year, but this study refers only to the warm season of the year (from April to September). The drought at these time scales is relevant for agricultural (1-, 3-, and 6-month), hydrological (12-month), and socio-economic

impacts (24-month), respectively. A drought episode was defined as a continuous period of months when the SPEI values were less than  $-1$ , while values between  $-0.99$  and  $0.99$  were considered as normal conditions. Drought categories according to the SPEI are presented in *Table 1*.

*Table 1.* Drought categories according to the SPEI

<b>SPEI</b>	<b>Drought category</b>	<b>Probability</b>
$\geq 2.00$	Extreme wet	0.02
1.50 – 1.99	Severe wet	0.06
1.49 – 1.00	Moderate wet	0.10
0.99 – (–0.99)	Normal	0.65
(–1.00) – (–1.49)	Moderate drought	0.10
(–1.50) – (–1.99)	Severe drought	0.05
$\leq (–2.00)$	Extreme drought	0.02

Taking into consideration the climatic characteristics in the Czech Republic such as the degree of continentality and the diversity of physico-geographic conditions (topography, soil type), the evaluation of drought was carried out in more details for the selected climatic regions. To identify the principal modes of variability of the SPEI at the various time scales, the empirical orthogonal functions (EOF) have been calculated over the territory of the Czech Republic. This approach has been widely used to explore regional patterns of the drought over Europe and various regions of the world (*Dai, 2011*). Based on the patterns of the spatial coefficients of the EOF2 and EOF3 of the SPEI at the considered time scales, we have identified three regions, corresponding to the altitudes below 400 m, between 401 and 700 m, and above 700 m. They correspond, to some extent, to a previous regionalization used in other studies (*Quitt, 1971; Tolasz et al. 2007; Trnka et al. 2009*). These regions correspond to different land use types with mostly intensive agriculture, less intensive agriculture, and mostly forested with limited agricultural production, respectively. Moreover, these regions also correspond to the climatic classification according to *Quitt (1971)*, where three main climatic regions (warm, moderate warm, and cold) were defined on the basis of 14 climatic characteristics [annual number of warm, frost, and ice days, number of overcast and clear days, number of days with snow cover, number of days with precipitation of 1 mm or more, mean air temperature in January, April, July, and October, sum of precipitation in warm (April-September) and cold (October-March) periods of year, as well as the number of days with mean temperature  $10\text{ }^{\circ}\text{C}$  and more]. For each station, the SPEI values were analyzed in order to assess the frequency distribution and the drought severity during the warm period of the year in the given regions.

The following analysis was carried out to assess the regional drought characteristics over the Czech Republic:

- (1) numerical values of the SPEI at five accumulated periods (1, 3, 6, 12 and 24 months) calculated for each station, which then allowed to evaluate the drought conditions both for entire territory of the Czech Republic and the selected climatic regions;
- (2) averaged number of drought episodes ( $SPEI \leq -1$ ) during the growing season at various time scales for three SPEI series: (1) at each station, (2) at each climatic region, and (3) at the entire country territory;
- (3) averaged number of drought episodes ( $SPEI \leq -1$ ) counted during the growing season at various SPEI time scales both for country level and each of the three climatic regions; and
- (4) frequency distribution of monthly SPEI values in 7 classes of drought category (%) at five accumulated periods for the above mentioned SPEI series.

### **3. Results and discussion**

#### *3.1. The principal modes of variability of the SPEI*

For each station, the monthly series of the SPEI were averaged over six months of the warm season (from April to September). These SPEI series at five accumulated periods (1, 3, 6, 12, and 24 months) were used for the empirical orthogonal functions (EOF) analysis in order to identify the characteristics of drought variability over the territory of the Czech Republic. The patterns of the three leading EOFs of the SPEI are very similar for all of the five accumulated periods. *Figs. 2 a,b, and c* show, as example, the spatial patterns of the three leading modes of variability of the SPEI calculated at 6-month lag and averaged over the warm season (from April to September). The spatial coefficients of the EOF1, with few exceptions, have the same sign over the country (*Fig. 2a*). The time series of the principal component (PC1) coefficients shows the temporal evolution of the EOF1 pattern, identifying the dry and wet years, and the intensity of its anomalies in terms of the standard deviation of the PC1 time series (*Fig. 3*). The periods with consecutive dry warm season were 1967–1969, 1981–1983, 1988–1994, and 1998–2000. The year 2003 was the driest during the period of 1961–2010 according to the PC1 of the SPEI at the 6-month accumulation period. The explained variance of the EOF1 ranges between 71 and 61% as the time scale of the accumulated period for calculation of the SPEI increases from 1 month to 24 months (*Table 2*). The pattern of the spatial coefficients of the EOF2 roughly separates the lowland and highland regions (*Fig. 2b*). The explained variance of the EOF2 and EOF3 ranges from 5 to 9% and 4 to 6%, respectively, as the SPEI is calculated for 1–24 months. The spatial

distribution of the EOF2 for all time scales of the SPEI corresponds, to some extent, to the regionalization previously used in other studies (Tolasz *et al.* 2007; Trnka *et al.*, 2009) which identified three climatically homogeneous regions, corresponding to the altitudes below 400 m, between 401 and 700 m, and above 700 m (Fig. 1 and Fig. 2). This station classification according to the altitude was further used in this study to assess the spatial and temporal drought characteristics over the Czech Republic.

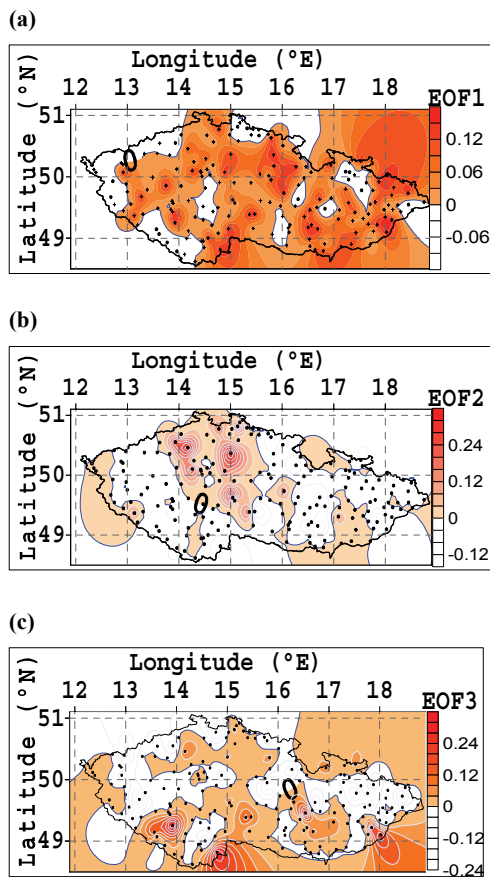


Fig. 2a, b, c. Spatial patterns of the three leading modes of variability from an EOF of average SPEI values during the warm season (Apr-Sept) over the Czech Republic (1961–2010) at time scale of 6-month.

Table 2. Explained variance of the leading EOFs of averaged SPEI (April-September) over the Czech Republic, 1961–2010

	Explained variance (%)				
	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SPEI-24
<b>EOF1</b>	71.68	70.03	69.14	64.46	61.49
<b>EOF2</b>	5.68	6.31	7.33	8.44	9.35
<b>EOF3</b>	4.36	4.12	4.65	5.32	6.05

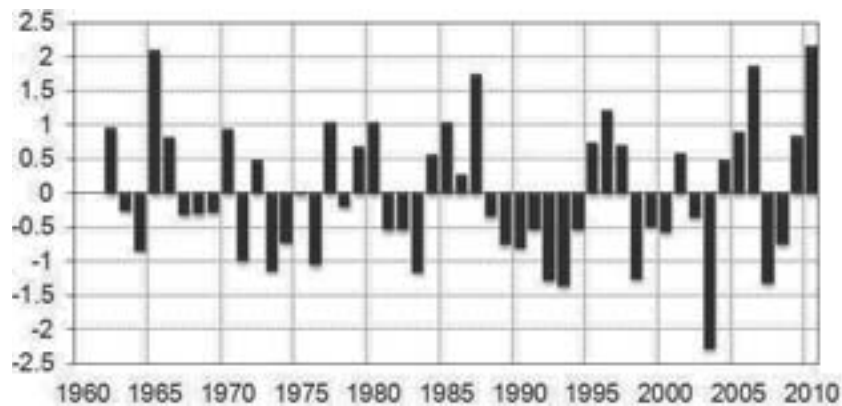


Fig. 3. Standard deviation of principal components (PC1) of SPEI series at 6 months during the warm season (Apr-Sept) over the Czech Republic (1961–2010).

### 3.2. Frequency distribution of the SPEI values

In this subsection, drought occurrences are analyzed on the basis of frequency distribution of the SPEI values in 7 classes (see Table 1). The frequency distribution was calculated as the ratio between the number of occurrences in each SPEI category and the total number of events counted for all stations in a given region for a given time scale (1, 3, 6, 12, and 24 months). The aim here is to identify the areas with high drought frequency detected by the SPEI during the growing season (i.e., April-September). The occurrences in varying drought categories at multiple scales are also analyzed on a regional basis inside the three main climatic regions: warm, moderate warm, and cold (Quitt, 1971). For these three regions, the frequency distribution of the SPEI values were calculated based on station records inside each region.

In the Table 3, percentage of drought occurrences is expressed in 7 classes of drought categories (%) at time scales of 1, 3, 6, 12, and 24 months for the period of 1961–2010. Normal conditions represent around 65% out of the total



values of SPEI for all times scales, in all three regions, while moderate drought and moderate wet conditions are almost equally distributed at around 10.5%. As the SPEI time scale increases, the difference between the percentages of extremely dry and extremely wet conditions changes on average from 0.2% (SPEI 1-month) to 4% (SPEI 24-month). As it is shown in *Table 3*, the frequency of extreme moisture conditions occurrence (the SPEI values outside  $\pm 2$ ) shows a slight tendency toward dry conditions, especially at long time-scales (12 and 24 months).

*Table 3.* Frequency distribution of monthly SPEI values in 7 classes of drought category (%) at time scales of 1, 3, 6, 12, and 24 months averaged per regions

Region	Extreme drought	Severe drought	Moderate drought	Normal	Moderate wet	Severe wet	Extreme wet
<b>SPEI-1</b>							
I	2.10	5.37	10.13	64.66	10.22	5.59	1.93
II	2.24	4.71	10.53	64.52	10.56	5.61	1.83
III	1.92	5.06	10.20	65.39	10.24	5.26	1.92
<b>SPEI-3</b>							
I	2.17	5.57	9.92	65.15	9.70	5.48	2.01
II	1.94	5.53	10.20	65.19	10.13	4.96	2.05
III	1.62	5.64	10.47	64.91	10.62	4.94	1.80
<b>SPEI-6</b>							
I	2.85	4.83	9.87	64.90	9.96	6.01	1.58
II	2.64	4.86	10.42	64.71	10.24	5.59	1.53
III	2.56	4.39	10.38	65.47	10.08	5.65	1.47
<b>SPEI-12</b>							
I	3.71	5.67	10.33	62.58	10.70	5.54	1.46
II	3.54	5.36	10.30	63.02	10.91	5.49	1.38
III	3.09	5.55	10.35	63.36	11.09	5.61	0.95
<b>SPEI-24</b>							
I	5.27	5.89	11.09	60.26	10.42	5.91	1.16
II	5.18	5.4	11.02	60.53	11.33	5.44	1.10
III	4.98	4.95	10.98	61.92	11.36	5.02	0.77

I : altitudes below 400 m,

II : altitudes between 401, and 700 m

III: altitudes above 700 m.

The results of the SPEI values for each station and the corresponding drought categories were mapped using a Surfer program. The Surfer program allows us to generate calculated data points (184 of station observations) on a regular spaced grid. We used the grid to generate the contour map (gridding by

Kriging interpolation technique) of the spatial frequency distribution of moderate, severe, and extreme drought at 1, 3, 6, 12, and 24 months time scales (Fig. 4). The spatial interpolation of SPEI values ranges from the longitude of 12.2°E to 18.8°E and the latitude of 48.6°N to 51.0°N. The lowest and highest grid points in the dataset have the elevation of 158 and 1490 m, respectively, with 1332 m elevation range (Table 4).

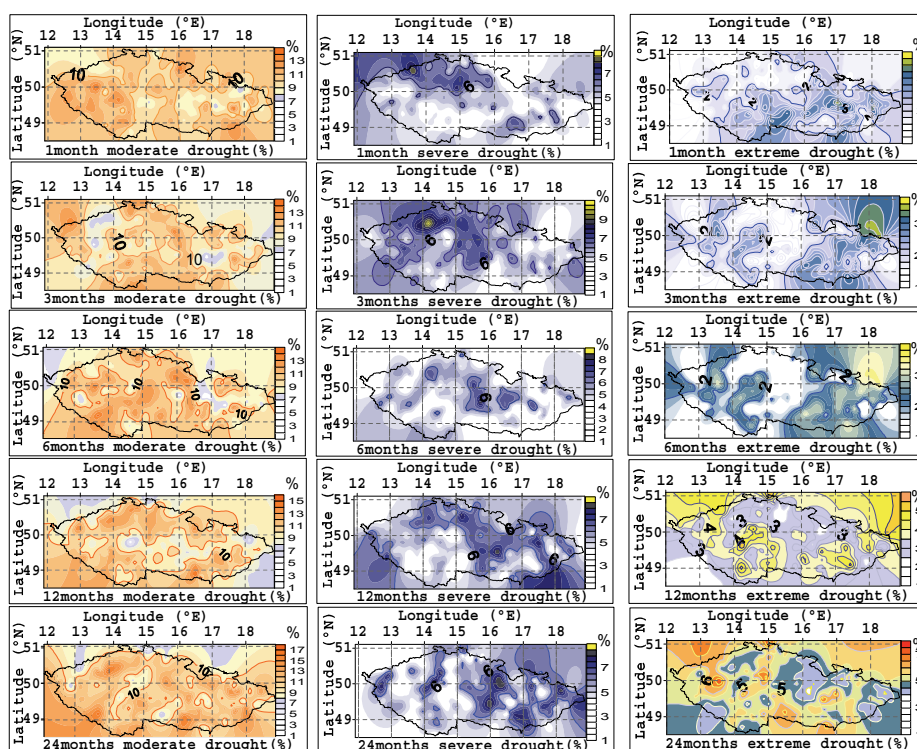
Table 4. Frequency distribution of moderate, severe, and extreme drought (%) occurrences during the warm period of the year at different time scales. It is spatially averaged over all stations ( $\lambda=12.2^{\circ}E - 18.8^{\circ}E$ ;  $\varphi=48.6^{\circ}N - 51.0^{\circ}N$ ,  $h=158 - 1490$  m a.s.l.)

	Coordinates			SPEI-1	SPEI-3	SPEI-6	SPEI-12	SPEI-24
	$\lambda^{\circ}E$	$\varphi^{\circ}N$	h, m					
<b>Moderate drought</b>								
Mean	15.5	49.7	450	10.3	10.1	10.2	10.3	11.1
Minimum	12.2	48.6	158	6.7	6.3	5.7	5.0	4.0
Maximum	18.8	51.0	1490	15.7	14.7	15.0	15.3	17.0
Range	6.6	2.4	1332	9.0	8.3	9.3	10.3	13.0
<b>Severe drought</b>								
Mean	15.5	49.7	450	5.1	5.6	4.8	5.5	5.6
Minimum	12.2	48.6	158	2.7	2.3	1.7	2.3	2.3
Maximum	18.8	51.0	1490	8.7	10.3	8.7	8.7	8.7
Range	6.6	2.4	1332	6.0	8.0	7.0	6.3	6.3
<b>Extreme drought</b>								
Mean	15.5	49.7	450	2.1	2.0	2.7	3.6	5.2
Minimum	12.2	48.6	158	0.7	0.3	1.0	2.0	4.0
Maximum	18.8	51.0	1490	3.7	3.7	5.0	5.7	8.0
Range	6.6	2.4	1332	3.0	3.3	4.0	3.7	4.0

These maps show that the shortest time scales (1 and 3 months) produce clear spatial patterns for the drought frequency. In other words, great percentage of frequency distribution of moderate, severe, and extreme drought occurrences at 1, 3, and 6 months (associated with meteorological and agricultural drought) were identified in regions with relatively low precipitation and high potential evapotranspiration (region I with mostly intensive agriculture, corresponding to the altitudes below 400 m).

The spatial analysis of the SPEI values with **moderate drought** occurrences during the growing period indicates that they tend to occur in the rain shadow of the Ore Mountains, in the south-eastern, south-western, and central parts of Elbe lowland at 1–3 months time-scales. Regions with elevations above 600 m are characterized by the lowest frequencies (lower than 9%) at the

same time scales (left panel of *Fig. 4*). The spatial distribution of frequencies of moderate drought ranges between 6.3% and 15.7% (*Table 4*). The maximum frequencies of moderate drought (15.7% occurrences) are shown in region I (stations situated in lowland region below 400 m a.s.l.). As the time-scale increases from 6 to 12 months, no major changes are observed for maximum frequencies (reached 15.3% at SPEI-12), rather a shift in the low drought occurrences toward the Bohemian Upland region is detected. At 24-month time scale, the moderate droughts occur more frequently and cover more than 60% of the country territory. Their spatial occurrence varies between 4% and 17%.



*Fig. 4.* Frequency distribution of SPEI values in moderate (left panel), severe (central panel), and extreme (right panel) drought categories (%) at time scales of 1, 3, 6, 12, and 24 months averaged for 50 years (1961–2010).

The occurrence of the **severe droughts** at shorter time-scales (1–3 months) was identified within the regions with the highest drought risk in the Czech Republic. According to the SPEI values, we found that high frequency of severe drought occurrences was detected in the following regions: lowlands of the Elbe river valley, central Bohemia, southern Moravia, and lowlands of southeastern

and southern Bohemia (central panel of *Fig. 4*). The same results obtained by different drought indices are highlighted in other studies (*Tolasz et al. 2007; Potop et al. 2008; Trnka et al. 2009; Potop et al. 2010; Možný et al. 2012; Potop et al. 2011*). These maps show the spatial distribution of severe drought which shifts from short-term (1 month, meteorological drought) and medium-term (3 and 6 months, agricultural drought) to long-term droughts (12 and 24 months, hydrological drought). Severe meteorological drought (SPEI at 1 month) identified first in the north-western Bohemia and southern Moravia have then extended at longer time scales in Elbe lowland and south-eastern areas. Not significant differences are shown in the spatial distribution of severe drought occurrences as the time scale for calculation of SPEI was increased (*Table 4*). The maximum frequency of severe drought occurrences ranges between 8.7% and 10%, while on average at country level it is 5.5%.

As for the **extreme droughts**, regional differences in its occurrence are observed when increasing the SPEI time-scales (right panel of *Fig. 4*). The areas affected by extreme drought evolve gradually, and the regions turn to be affected by higher frequency of extreme drought from shorter time-scales (meteorological drought) to longer time-scales (hydrological drought). The resulted maps show more spatial variability in frequency of drought at 12 and 24 months than for shorter time scales. In general, the SPEI at the 24 months time-scale indicates the more complex patterns of extreme drought frequency (right panel of *Fig. 4*). The highest percentage of extreme drought occurrences is 3.7% at short-term scale (SPEI-1), whereas at medium-term (SPEI-3 and SPEI-6 months) and long-term (SPEI-12, SPEI-24) the drought ranges from 5.7 to 8.0%. The frequency of extreme drought is the lowest or missing at stations with altitude more than 1000 m (0.3%).

### 3.3. Spectral analysis

The periodograms via fast fourier transform spectral techniques were also applied to search for significant periodicities in the time series of the  $SPEI \leq -1$  (moderate to extreme drought) averaged for the six months of the growing season (April-September). *Table 5* presents the results of the spectral analysis: the peak frequency and the length of cycles exceeding the 95% confidence level at various time-scales. The frequency is calculated as the number of cycles per time unit (where each observation is treated as one unit of time). The results of the peak frequency and the length of cycle in spectral analysis calculated for the three regions have been analyzed. Thus, at 1 month SPEI, the peak frequency of 0.41 (the number of units of time necessary to complete one full cycle) corresponds to a 2.5-year drought occurrence in the region I, while in the region II and region III the frequency of 0.34 corresponds to the occurrence of drought in every 3 years. This means that frequent meteorological drought events from moderate to severe in the SPEI-1 series are observed in every 2.5 years in the

region I that is considered the warmest and driest area in the country, while in the regions II and III the frequency of meteorological drought slightly decreased (*Table 5*). A clear peak frequency and cycle length of 3-month and 6-month (corresponding to agricultural drought) was 0.20 standing for the drought occurrence in every 5 years in all regions. The same result was reported in previous studies (*Potop et al., 2008; Potop et al., 2010*) which combine the three drought indices as a tool for the identification of the drought frequency in the Czech Republic. At the time-scale of 12-month (hydrological drought), the frequency peak was 0.11 corresponding to a drought occurrence period of 9.4 years. As the results in *Table 5* show, at time scale of 24-month (the largest socio-economic impact) there is a well-defined regional drought frequency pattern. In the region with the altitudes below 400 m, the frequency peak of drought was 0.13 corresponding to a period of drought occurrence of 7.6 years, while in the regions with altitudes between 401 and 700 m and above 700 m the frequency peaks were at 0.11 and 0.06, standing for the occurrence of drought in every 9.4 and 15.3 years, respectively (*Table 5*).

*Table 5.* Spectral analysis of SPEI<-1 series (at 95% confidence level) at time-scales 1, 3, 6, 12, and 24 months (1961–2010) per regions

	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SPEI-24
<b>I: the altitudes below 400 m</b>					
<b>Peak of frequency, %</b>	0.41	0.20	0.20	0.11	0.13
<b>Length of cycle, years</b>	2.50	5.00	5.00	9.40	7.60
<b>II: the altitudes between 401 and 700 m</b>					
<b>Peak of frequency, %</b>	0.34	0.20	0.20	0.11	0.11
<b>Length of cycle, years</b>	3.0	5.0	5.0	9.4	9.40
<b>III: the altitudes above 700 m</b>					
<b>Peak of frequency, %</b>	0.34	0.20	0.22	0.11	0.06
<b>Length of cycle, years</b>	3.0	5.0	5.00	9.40	15.30

#### 4. Conclusions

In this study, the characteristics of drought over the Czech Republic at various time-scales during the growing season (April-September) were analyzed. The drought was quantified with the standardized precipitation evapotranspiration index (SPEI) at 184 climatological stations during the period of 1961–2010. The main results can be summarized as follows:

- (a) In order to identify the drought variability over the territory of Czech Republic the empirical orthogonal functions (EOF) approach was used.

According to spatial distribution of coefficients of the EOF2, three drought homogeneous regions were distinguished, corresponding to the altitudes below 400 m, between 401 and 700 m, and above 700 m: the lowlands and the high altitude regions.

- (b) Regarding the drought time scales, most parts of lowlands and partially of highland regions are vulnerable to moderate agricultural drought during growing season. For the entire period of study, the vulnerability of extreme agricultural drought is low. However, the evolution of agricultural drought in the second half of the 20th century and the first decade of the 21st century showed increasing frequency that has been reinforced by long dry periods in the 1990s and 2000s. The drought during these periods was associated with high temperature anomalies (i.e., more than 2.5 °C). Consequently, the SPEI has the ability to detect the reinforcement of drought severity due to the temperature increasing during the 1990s and 2000s.
- (c) The occurrences of various drought time-scales and severity categories show distinct patterns. The maximum frequencies of **moderate and severe drought** were identified at stations situated in lowland regions below 400 m. High number of severe meteorological and agricultural drought events also occurred in the southern Moravia, the north-western Bohemian areas, the south-eastern areas, and in the Elbe lowland. In other words, the majority of the historical droughts occurred in the regions corresponding to the altitudes below 400 m and between 401 and 700 m. The highest percentage of **extreme drought** occurrences was 3.7% at short-term scale, whereas the highest percentage of medium-term and long-term droughts ranges from 5.7 to 8.0%. The frequency of extreme drought is the lowest in the region with stations with altitude higher than 1000 m (0.3%).
- (d) The short-term drought (meteorological drought) and mid-term drought (impacting agricultural production) occur at the whole territory of the country approximately in every three and five years, respectively. The long-term drought (impacting the water system) can occur in every nine years in all of the regions.

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