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Observed evolution of drought episodes assessed with the Standardized Precipitation Evapotranspiration Index (SPEI) over the Czech Republic

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Abstract. This paper investigates the spatial and temporal evolution of drought episodes assessed with the Standardized Precipitation Evapotranspiration Index (SPEI) over the Czech Republic. The SPEI were calculated from monthly records of mean temperature and precipitation totals using a dense network of 184 climatological stations for the period 1961-2010. The SPEI were calculated with various lags, 1, 3, 6, 12 and 24 months. The drought at these time scales is relevant for agricultural, hydrological and socio-economic impact, respectively. The study refers at the warm season of the year (April to September). The principal modes of variability of these five time scale SPEI were identified using the analysis of Empirical Orthogonal Functions (EOF). The explained variance of the leading EOF ranges between 71 and 61% as the time scale for calculating the SPEI increases from 1 month to 24 months. The explained variance of EOF2 and EOF3 ranges between 5 to 9% and 4 to 6%, respectively, as the SPEI is calculated for 1 to 24 months. Based on the spatial distribution of the EOF2 and EOF3 for all time scales of SPEI, which correspond to some extend to a regionalization previously used in other studies, we identified three climatically homogeneous regions, corresponding to the altitudes below 400 m, between 401 and 700 m and, above 700 m. These regions correspond to different land use types with mostly intensive agriculture, less intensive agriculture and 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 in each region. The 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 around 10.5 %. Differences in extremely dry conditions (5%) compared to extremely wet conditions (1.5 %) were observed when increasing the SPEI timescales.

Data description and methods

- The SPEI was calculated from monthly records of temperature means and precipitation totals for the period 1961-2010, using a dense network of 184 climatological stations uniformly covering the territory of Czech Republic. The station elevation ranges between 158 and 1490 m above sea level (Fig. 1).
- Monthly series of the SPEI were selected from the Czech Hydrometeorological Institute CLIDATA database based on spatial distribution and completeness of observation time series.
- The quality control of the data was carried out by combining several methods: (i) by analyzing difference series between candidate and neighboring stations – i.e. pairwise comparisons (ii) by applying limits derived from interquartile ranges and (iii) by comparing the series values tested with "expected" values – technical series created by means of statistical methods for spatial data (e.g. IDW, kriging).
- For calculation the SPEI, the algorithm developed by Vicente-Serrano et al. (2010) was used. The documentation and executable files 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 at the warm season (April to September). The drought at these time scales is relevant for agriculture (1, 3 and 6 months), hydrology (12 months) and socio-economic impacts (24 months), respectively. Drought categories according to the SPEI are presented in Table 1.
- Averaged number of drought episodes during growing season determined by SPEI≤-1 at various time scales for three SPEI series: (1) each station, (2) each climatic region and (3) the entire territories of country.
- To identify the principal modes of variability of the SPEI over the territory of the Czech Republic the Empirical Orthogonal Functions (EOF) analysis have been performed at various time scales (Table 2 and Fig. 2, 3).
- 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 and for a given time scale (1, 3, 6, 12 and 24 months) (Table 3).
- We used the grids to generate the contour map (gridding by Kriging interpolation technique) of spatial distribution of frequency occurrences of moderate, severe and extreme drought at time scales of 1, 3, 6, 12 and 24 months (Box 1).
- The spatial evolution of the SPEI could be associated to some extend with the three regions, corresponding to the altitudes below 400 m, between 401 and 700 m and, above 700 m (Box 2).

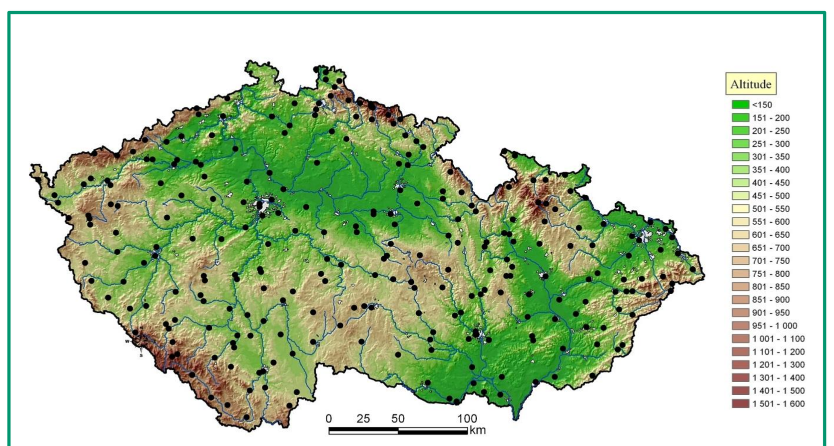


Fig. 1. Location of stations used for the calculation of the SPEI drought index in the Czech Republic.

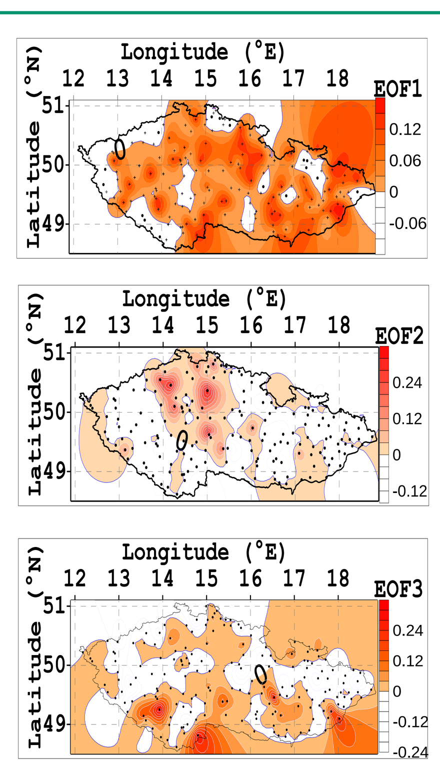


Fig. 2. Spatial patterns of the three leading modes of variability from an EOFs of averages SPEI during warm season over the Czech Republic (1961-2010) at time scale of 6-month.
The monthly series of the SPEI were averaged for the six months (i.e. from April to September) within the warm season of the year at each station. These the SPEI series of five accumulated periods were used for the Empirical Orthogonal Function (EOF) analysis in order to identify the characteristics of drought variability over the territory of the Czech Republic at 184 stations.

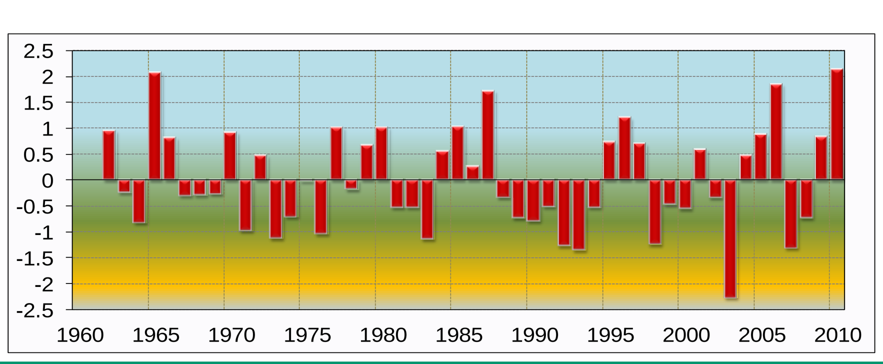


Fig. 3. The standardized of principal component (PC1) of the SPEI series at 6 months during warm season (Apr-Sept) over the Czech Republic (1961-2010).

Table 1. The 7 classes of SPEI category according to its value.

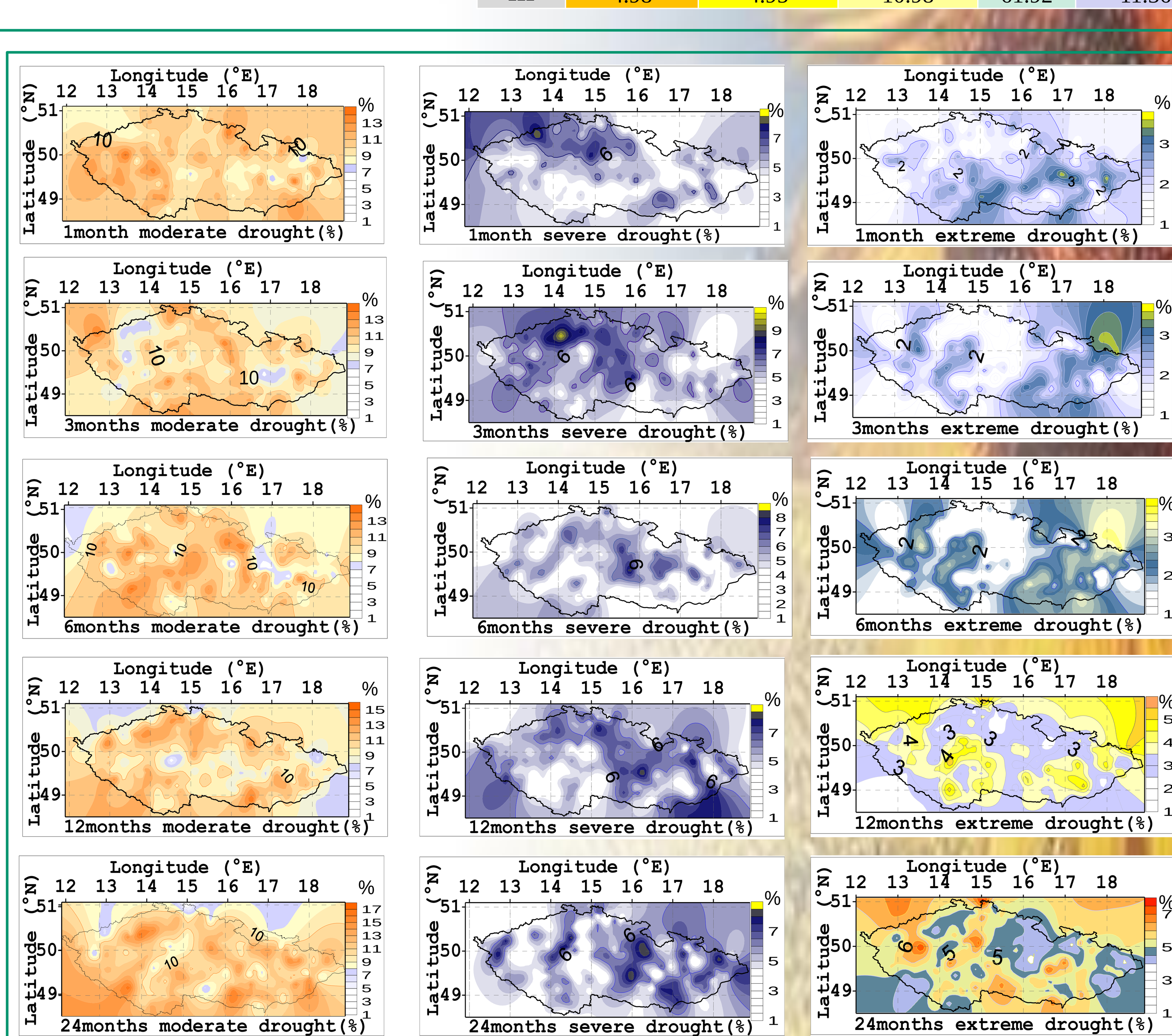
SPEI	Drought category	Probability
≥2.0	Extreme wet	0.02
1.50 – 1.99	Severe wet	0.06
1.49 - 1.00	Moderate wet	0.10
0.99 - -0.99	Normal	0.65
-1.00 – -1.49	Moderate drought	0.10
-1.50 - -1.99	Severe drought	0.05
≤-2.00	Extreme drought	0.02

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

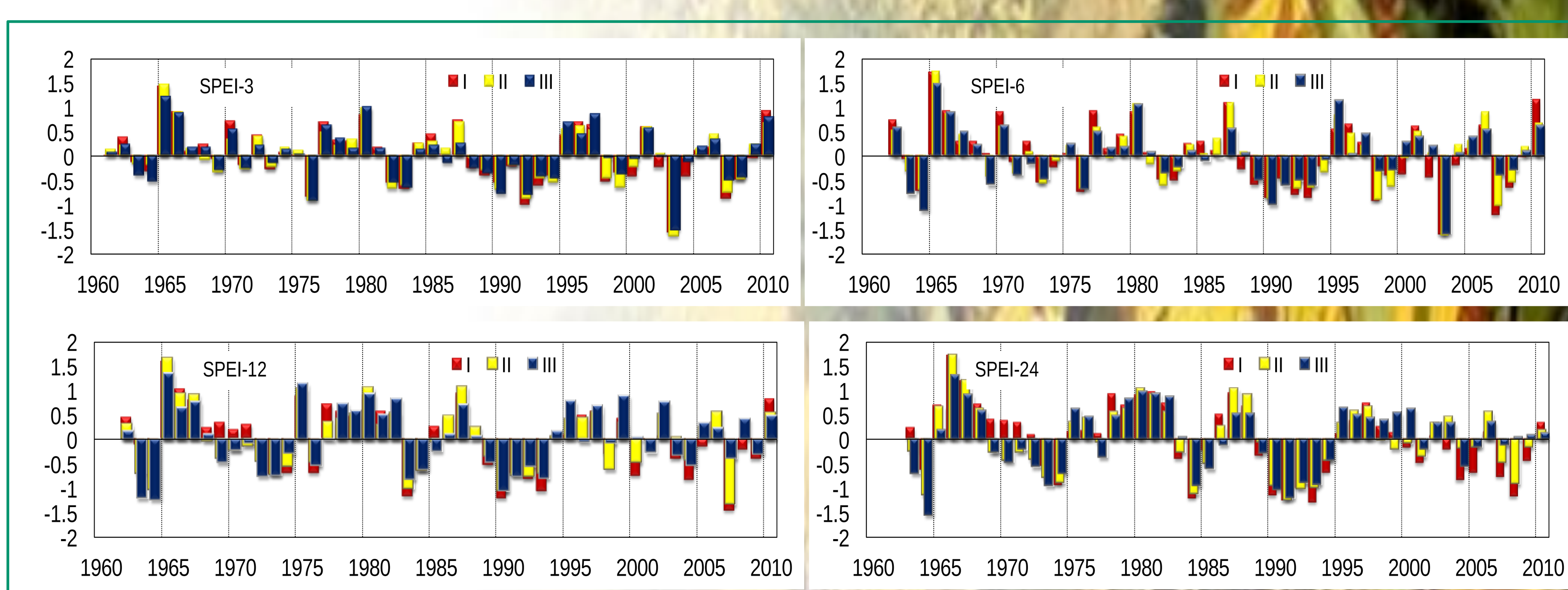
	Explained variance (%)				
	SPEI-1	SPEI-3	SPEI-6	SPEI-12	SPEI-24
EOF1	71.68	70.03	69.14	64.46	61.49
EOF2	5.68	6.31	7.33	8.44	9.35
EOF3	4.36	4.12	4.65	5.32	6.05

Table 3. Frequency distribution (%) of the SPEI values during the growing season in 7 classes of moisture category at time scales of 1, 3, 6, 12 and 24 months per regions.
Region I: the altitudes below 400 m, region II: between 401 and 700 m and region III: above 700 m.

region	Extreme drought	Severe drought	Moderate drought	Normal	Moderate wet	Severe wet	Extreme wet
	SPEI-1						
I	2.1	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	10.2	65.39	10.24	5.26	1.92
	SPEI-3						
I	2.17	5.57	9.92	65.15	9.7	5.48	2.01
II	1.94	5.53	10.2	65.19	10.13	4.96	2.05
III	1.62	5.64	10.47	64.91	10.62	4.94	1.8
	SPEI-6						
I	2.85	4.83	9.87	64.9	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
	SPEI-12						
I	3.71	5.67	10.33	62.58	10.7	5.54	1.46
II	3.54	5.36	10.3	63.02	10.91	5.49	1.38
III	3.09	5.55	10.35	63.36	11.09	5.61	0.95
	SPEI-24						
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	1.1
III	4.98	4.95	10.98	61.92	11.36	5.02	0.77



Box 1.
Frequency distribution of SPEI values in moderate (left panel), severe (central panel) and extreme (right panel) drought category (%) at time scales of 1, 3, 6, 12 and 24 months averaged for 50 year (1961-2010).



Box 2.
Temporal evolution of the SPEI at various lags: 3, 6, 12 and 24 months during the growing season (April-September) for three regions:
I - the altitude below 400 m, II - 400-700 m, and III – above 700 m.

Conclusions

It was found that the spatial distribution of drought frequency detected by the SPEI in the Czech Republic differs in relation to the time scales. In this study, drought was climatologically evaluated for the entire growing season (April–September) during the period 1961-2010. The main results can be summarized as follows:

- In order to identify the drought variability over the territory of the Czech Republic at the Empirical Orthogonal Functions (EOF) approaches was used. According to spatial distribution of coefficients of the EOF2 were distinguished three drought homogeneous regions, corresponding to the altitudes below 400 m, between 401 and 700 m, above 700 m the lowlands and the high altitude regions.
- In respect of time scales, most parts of the lowlands and partially of highland regions of the country are vulnerable to moderate agricultural drought during growing season. For entire period of study, the vulnerability of extreme agricultural drought is low. While evolution of agricultural drought in the second half of 20th century and the first decade of the 21st century showed its increasing frequency that was reinforced by long dry periods in the 1990s and 2000s. Drought during these periods corresponded to higher temperatures deviations (i.e., more than 2.5°C). Consequently, the SPEI possesses the ability to detect the intensification of drought severity due to increasing temperature conditions independent of the analysis time scale in the 1990s and 2000s.
- The occurrences of different drought time scales and severity categories show distinct spatial patterns. The maximum frequencies of **moderate and severe drought** are reached in stations situated in lowland regions below 400 m. The highest number of severe meteorological and agricultural drought events also occurs in the southern Moravia, the north-western Bohemian areas, the south-eastern areas and in Elbe lowland. In other words, the majority of the historical droughts that occurred in regions corresponds to the altitudes below 400 m and between 401 and 700 m. The highest percent of **extreme** drought occurrences reached 3.7% at short-term scale, whereas at medium-term and long-term droughts ranged from 5.7 to 8.0%. The frequency of extreme drought is the lowest in stations with altitude more than 1000 m (0.3%).

References:
Vicente-Serrano SM, Beguería S, López-Moreno JI (2010) A Multi-scalar drought index sensitive to global warming: The Standardized Precipitation Evapotranspiration Index – SPEI. Journal of Climate 23 (7): 1696-1718

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