LARGE SCALE CIRCULATION PATTERNS ASSOCIATED TO SEASONAL DRY AND WET CONDITIONS OVER THE CZECH REPUBLIC

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RESUMEN

Este trabajo analiza la relación entre las condiciones estaciónales extremadamente secas y húmedas en la República Checa y los patrones de circulación de gran escala. El índice estandarizado de precipitación y evapotranspiración (SPEI) se utiliza para cuantificar las condiciones de humedad. El SPEI fue calculado a partir de los registros mensuales de temperatura media y precipitación total de una densa red de 184 estaciones climatológicas para el período 1961-2010 en la escala temporal de un mes. Fueron identificados los principales modos de variabilidad estacional del SPEI utilizando el análisis de funciones empíricas ortogonales (EOF). El porcentaje de varianza explicada de los tres primeros EOF varía entre 58% y 66% dependiendo de la estación. Se hicieron mapas compuestos de la presión media al nivel del mar (MSLP), del contenido de vapor de agua (WPC) y de la temperatura superficial del mar (SST) sobre la base de la serie PC1 del SPEI estacional en la escala de un mes, para los años en que el valor fue mayor o menor que 0.75 desviaciones estándar de la serie. Los patrones de gran escala para el MSLP, WPC y SST ofrecen una visión sobre los principales factores que conducen a condiciones extremas, secas y húmedas, en la República Checa a escala estacional.

Palabras clave: Índice estandarizado de precipitación y evapotranspiración, condiciones secas y húmedas, funciones empíricas ortogonales, República Checa.

ABSTRACT

This paper analyzes the link between the extremely dry and wet conditions over the Czech Republic and the large scale circulation patterns, at seasonal scale. The Standardized Precipitation Evapotranspiration Index (SPEI) is used to quantify the moisture conditions. The SPEI for one month lag was calculated from monthly records of mean air temperature and precipitation totals using a dense network of 184 climatological stations for the period 1961-2010. The principal modes of variability of the seasonal SPEI were identified using the Empirical Orthogonal Functions (EOF) analysis. The explained variance of the leading EOF ranges between 58% and 66% depending on the season. Composite maps of the mean sea level pressure (MSLP), water vapor content (WPC) and global sea surface temperature (SST) anomalies were built based on the PC1 series of the seasonal

SPEI at one month lag for the years when its value was grater/lower than 0.75 standard deviation of the series. The large scale patterns in the fields MSLP, WPC and SST provide some hints on the driving factors for extreme seasonal moisture conditions over the Czech Republic.

Key words: Standardized precipitation evapotranspiration index, dry and wet moisture conditions, empirical orthogonal function, Czech Republic.

1. INTRODUCTION

The recent economic crisis has sent shock waves around the globe, reaching all parts of the economic system, even as the drought situation in many European regions has become more severe (e.g., 2003 and 2006 in Central Europe, 2007 in southern and Eastern Europe, and 2010 in Eastern Europe). This underscores just how significant can be the impact on European economies (Potop et al. 2010; Potop 2011). Droughts and floods may be considered as the most disastrous natural events in the Czech Republic (Brázdil et al. 2009). The highest frequency of "flash drought" occurrences were detected in lowland regions of the Czech Republic during the growing seasons of vegetable crops. The flash drought is the result of a synoptic meteorological pattern in which the reference level of evapotranspiration greatly exceeds the level of precipitation for a period no shorter than 3 weeks. The increasing frequency of flash drought episodes in the lowlands region in the Czech Republic has led to reduced yields and greater yield variability for vegetable crops, which has resulted in increases in the costs necessary to grow vegetables and increasing economic losses for farmers. According to studies of Trnka et al. (2009a) and Brázdil et al. (2009), in the Czech Republic prevails the number of stations with statistically significant trends towards drier conditions (in terms of available soil moisture) over those where either no trend at all or a tendency toward wetter conditions was noted. These shifts in intensity and frequency of drought in the region were shown to be driven by changes in near surfaces temperatures rather than changes in precipitation. Relatively few scientists have dealt with atmospheric processes that could help to explain the causes of these changes (Trnka et al. 2009b). The aforementioned studies serve as the main motivation to investigate the variability of seasonal moisture conditions over the Czech Republic in relation with the large scale circulation patterns.

2. DATA AND METHODS

2.1. Data description

A dense network of 184 climatological stations uniformly covering the territory of the Czech Republic was used for calculation the Standardized Precipitation Evapotranspiration Index (SPEI) to quantify the moisture conditions over the country. For this study the SPEI at 1 month lag was calculated from monthly records of mean air temperature and precipitation totals for the period 1961-2010.

Monthly series of temperature and precipitation were selected from the Czech Hydrometeorological Institute (CHMI) CLIDATA database based on spatial distribution and completeness of time series. The station elevations range between 158 m and 1490 m above sea level (Fig. 1). The selected stations represent different climate conditions in both lowland and highland regions and reflect differences between the maritime and continental weather regimes which manifest across the Czech Republic.

Prior to SPEI calculation, the climatological series were quality controlled and homogenized using ProClimDB and AnClim softwares (Štěpánek et al. 200; Štěpánek 2010).

To investigate the relationship of seasonal SPEI over the Czech Republic with the large scale fields of variable which might explain moisture conditions over the Czech Republic we used global data of Monthly Sea Level Pressure (MSLP) and Precipitable water content (PWC) from the Twentieth Century Reanalysis (V2) data sets available at http://www.esrl.noaa.gov/psd/data/gridded/data.20thC_ReanV2.html (Compo et al. 2006, 2011; Whitaker et al. 2004), and Sea Surface Temperature (SST) from NOAA Extended Reconstructed Sea Surface Temperature (SST) V3b available at http://www.esrl.noaa.gov/psd/data/gridded/data.noaa.ersst.html. The large scale gridded data at spatial coverage grid 2ºlat X 2ºlon cover the same period as station data, 1961-2010.

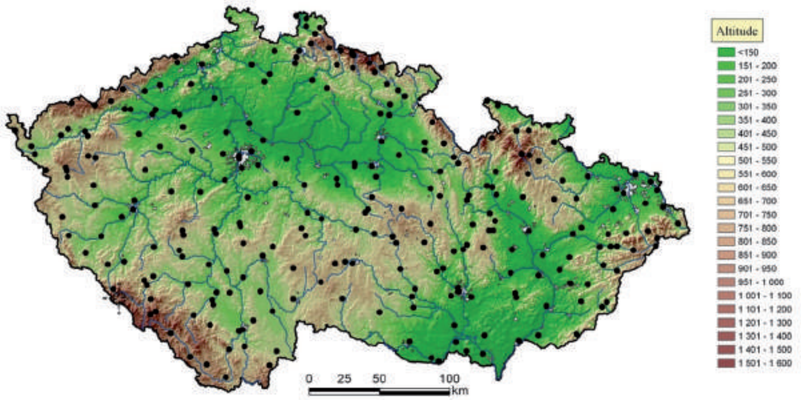

FIG. 1: *Location of stations used for the calculation of the SPEI in the Czech Republic.*

2.2. Methods

For calculation the SPEI, the algorithm developed by Vicente-Serrano et al. (2010) and the documentation and executable files freely available at http://digital.csic.es/handle/10261/10002 were used. A batch script was created and used for optimizing the calculation of the SPEI for the 184 stations at 1 month lag. The drought at this time scales is mostly relevant for agriculture. The SPEI was calculated for each month of the year and then averaged for the each season: winter (December, January, February), spring (March, April, May), summer (June, July, August), and autumn (September, October, November). Drought categories according to monthly SPEI values are presented in Table 1.

The principal patterns of variability of the seasonal SPEI over the territory of the Czech Republic were identified with the Empirical Orthogonal Functions (EOF) analysis (Preisendorfer 1988, von Storch 1995). EOF technique aims at finding a new set of variables that captures most of the observed variance from data through a linear combination of the original variables. This method splits the temporal variance of data into orthogonal patterns called empirical eigenvectors. This approach has been widely used to identify the patterns of drought at global (Dai, 2011) or European scales (Brázdil et al. 2009; Ionita et al. 2012). The EOFs were calculated on detrended and standardized anomalies of seasonal SPEI series.

In order to search for large scale patterns associated to seasonal wet and dry conditions over the Czech Republic, we constructed the composite maps between the standardized PC1 time series for each seasonal EOF1 of SPEI calculated for 1 month lag and the anomalies of the northern hemisphere mean sea level pressure (MSLP), precipitable water vapor content (PWC) over the Atlantic European region, and global sea surface temperature (SST). The precipitable water vapor content is the amount of water that can be obtained from the surface to the "top" of the atmosphere if all of the water and water vapor were condensed to a liquid phase. Concentrated areas of precipitable water vapor are usually indicative of clouds and precipitation, and therefore an indicator of potential moisture content in an area.

The composite maps were constructed for the years when the values of the PC1 series were higher than +0.75 standard deviation (wet years) and lower than -0.75 standard deviation (dry years), respectively. In the paper we will show and discuss the composites maps corresponding both to wet and dry seasons.

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 1: *The classes of spei category according to its value.*

3. RESULTS

3.1 Principal modes of SPEI variability

In order to identify the dominant patterns of seasonal variability of the SPEI, the EOF analysis at 184 stations was performed.

The spatial patterns of the three leading EOFs do not differ essentially from one season to another. Therefore, we decided only to exemplify in the Fig. 2 (upper panel) the loading patterns of the first three leading EOFs of summer SPEI at 1 month lag. The spatial coefficients of EOF1 have positive loadings at all stations. This fact points out on the large scale factors that might drive the SPEI variability. The distribution of the spatial coefficients of EOF2 delimitates two regions with opposite signs of loadings in the eastern and western halves of the country. The spatial distribution of EOF3 coefficients roughly delimitates the lowland in the north-western and south-eastern parts of the country and the highland in the southern half of the country where the loadings have opposite signs. These spatial distributions of EOF2 and EOF3 correspond to some extend to the regionalization previously used in other studies (Tolasz et al. 2007; Trnka et al. 2009; Potop et al. 2012) which identified three climatically homogeneous regions, corresponding to the altitudes below 400 m, between 401 and 700 m and, above 700 m (Fig. 1).

The PC expansion coefficient time series of summer SPEI at one month lag is presented in the lower panel of Fig. 2. The PC time series show the temporal evolution of EOFs identifying the dry and wet years and the intensity of their anomalies in terms of normalized values of PC time series. According to the magnitudes of the PC1 of summer SPEI at one month lag, the year 2003 was the driest during the period 1961-2010 at country level, this characteristic being induced by the large scale factors. The PC2 and PC3 time series show the temporal evolution of summer SPEI variability which mostly depend on regional and local factors.

The explained variances of the first three EOFs of seasonal SPEI are presented in Table 2. The EOF1 explained the highest variance (65.81%) in autumn and the lowest in winter (57.81%). The percentage of explained variance for EOF2 ranges between 14.36% (in winter) and 7.52% (in spring) while for the EOF3 it ranges between 6.08% (in winter) and 4.92% (in summer).

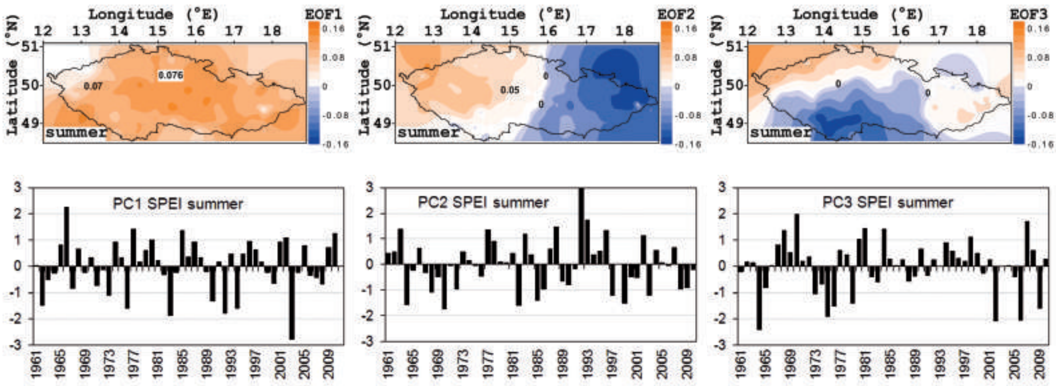

FIG. 2: *The spatial patterns of the first three EOFs of summer SPEI at 1 month lag over the Czech Republic (upper panel) and the corresponding temporal PC series normalized by its standard deviation (lower panel).*

	Explained variance (%)			
	wi	**sp**	**su**	**au**
	SPEI_01			
EOF1	57.81	61.30	58.83	65.81
EOF2	14.36	7.52	8.93	8.83
EOF3	6.08	5.69	4.92	5.61

TABLE 2: *The explained variance of the first three EOFs of seasonal spei for various lags.*

3.2 Relationship with the large scale factors

Because the leading mode of the SPEI variability (EOF1) shows similar patterns over the territory of the Czech Republic for each season we conclude that the variability of the SPEI as an indicator of wet and dry conditions depends on the large scale factors. In order to explain the variability of the SPEI in relation with the large scale fields of selected variables we have constructed the composite maps between the standardized time series of PC1 corresponding to each seasonal EOF1 patterns of the SPEI and the anomalies of the northern hemisphere mean sea level pressure (MSLP), Atlantic European water vapor content (WPC), and global sea surface temperature (SST). The composites were built with the maps of the years when the values of the time series were higher (lower) than +0.75 (- 0.75) standard deviation of the PC1. This threshold was arbitrary chosen as a compromise between the strength of the PC1 anomalies associated to large scale anomalies and the number of maps which satisfy these criteria. The years (wet and dry) based on which the seasonal composites were built are listed in Table 3. To show the temporal evolution of wet and dry conditions over the Czech Republic the SPEI was averaged over all 184 stations for each season. The averaged series of seasonal SPEI are represented in Fig. 3. All the seasonal series of SPEI have the mean zero. The standard deviation is 0.44 for winter and spring and 0.47 for summer and autumn, respectively. The overwhelming majority of the wettest/driest years identified in standardized series of PC1 have the values of averaged SPEI greater/lower than 0.4/-0.4, respectively. The wett/dry years with the value of averaged seasonal SPEI fulfilling these criteria that are not among the selection listed in Table 3 have been identified in the standardized series of PC2 and PC3, respectively (not shown). Notwithstanding this study was not focused on the influence of El Niño/La Niña events on moisture conditions in the Czech Republic, it is worth to note that the exceptionally strong El Niño/La Niña years are among the selected dry/wet years listed in Table 3. El Niño and La Niña events are classified by a number of different criteria like the strength and sign of the Southern Oscillation Index (SOI), the Sea Surface Temperature (SST) anomalies for a variety of Pacific regions or a combination of several criteria to gauge the type and strength of the event. We used a consensus list for the El Niño/La Niña years and a 3 month running mean series of the Oceanic Niño Index (ONI) http://ggweather.com/enso/years.htm to help interpreting our results in connection with these large scale events. According to this source the El Niño years were 1965-66, 1972-73 (strong), 1977-78, 1982-83 (strong), 1987-88, 1991-92 (strong), 1997-98 (strong), 2006-07, 2009-10, and La Niña years 1964-65, 1970-71, 1973-74 (strong), 1974-75, 1975-76 (strong), 1988-89 (strong), 1998-99, 2000-01 and 2010-11.

Fig. 4 presents the large scale seasonal composites associated to wet conditions over the Czech Republic. For winter (top panel), a pattern of higher than normal MSLP over the Arctic and adjacent areas is associated with lower than normal MSLP in the central Atlantic and all Europe. This pattern (negative phase of Arctic Oscillation AO) induces cold Arctic air advection over the Northern Europe and Asia and favors storms development with precipitation over the Mediterranean and Central Europe. As the composite of winter PWC shows the descending of cool and dry air over the northern Europe is associated with deficit of PWC over these areas while the excess of PWC producing wet winter conditions in Czech Republic comes from the Central North Atlantic and western Mediterranean. The composite of winter global SST associated with wet conditions in the Czech Republic shows a pattern that can be associated with a positive ENSO phase due mainly because of the El Niño years (1977, 1983, 1987-88) that might prevailed over the La Niña years (1988 and 2010). The patterns of MSLP and PWC composites for spring (the second top panel) look very much alike with the patterns for winter but with more intense MSLP anomalies both over the Arctic (positive) and central Atlantic and Europe (negative). The spring wetness conditions might be due to the positive PWC anomalies over the central Atlantic, western Mediterranean and Eastern Europe. The SST composite shows larger areas of positive anomalies (2.0-3.0 ºC) in the North Atlantic and Central and Eastern Pacific though the selection shows both El Niño (1987, 2006) and La Niña (1965, 1970, 2001) years. For summer (the third top panel), the area of higher than normal MSLP over the Arctic is narrower that during the previous season and the anomalies less intense. The PWC anomalies are consistent with the MSLP anomalies pointing out on higher than normal precipitable water content over the Central Atlantic and Central and Eastern Europe including the Czech Republic. Most probable, the wet conditions during summer might also arise from mesoscale convective precipitation. In autumn (the bottom panel), the MSLP anomaly pattern associated to wet conditions over the Czech Republic is similar to the negative AO identified for the previous seasons. The source or wetness conditions during autumn might be in the Eastern Mediterranean where the excess of PWC could produce higher precipitation in our study region.

Fig. 5 presents the large scale seasonal composites of MSLP, PWC and SST anomalies associated to dry conditions over the Czech Republic. For all seasons the MSLP composites present a dominant pattern of lower than normal atmospheric pressure over the Arctic that helps the middle latitude jet stream to blow strongly and consistently from west to east, thus keeping the cold Arctic air locked in the polar region. The positive MSLP anomalies over the Central North Atlantic and over Europe associated with deficit of PWC over the same areas represent concurrent driving factors for dry conditions over the Czech Republic. The signature of strong El Niño events (1972-73, 1997-98 in winter, 2002-03 in spring, 1992 and 2003 in summer and 1982-83, 2003, 2009 in autumn) is apparent in the SST composites.

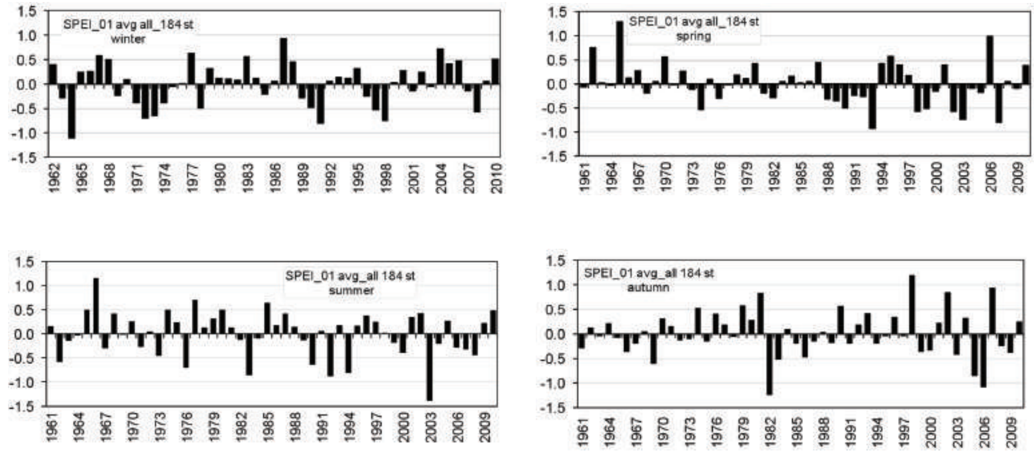

FIG. 3: *Temporal evolution of seasonal SPEI at 1 month lag averaged over all 184 stations.*

Season	Winter	Spring	Summer	Autumn
Wet years	1962, 1967, 1968, 1977, 1983, 1987, 1988, 2004, 2005, 2006, 2010	1962, 1965, 1970, 1980, 1987, 1994, 1995, 1996, 2001, 2006, 2010	1965, 1966, 1974, 1977, 1980, 1985, 1987, 1996, 2001, 2002, 2005, 2010	1974, 1976, 1979, 1981, 1990, 1993, 1998, 2002, 2007
Dry years	1964, 1971, 1972, 1973, 1974, 1978, 1990, 1991, 1997, 1998, 2008	1968, 1974, 1976, 1989, 1990, 1993, 1998, 1999, 2002, 2003, 2007	1962, 1967, 1973, 1976, 1983, 1990, 1992, 1994, 2003	1969, 1982, 1983, 1986, 1999, 2003, 2005, 2006, 2009

TABLE 3: *The wetest and driest years (standardized amplitude of pc1 > 0.75 and < - 0.75, respectively) used to build the composite maps*

4. CONCLUSIONS

This study has investigated the seasonal modes of variability of the SPEI calculated at one month lag at 184 stations of the Czech Republic and identified the sources of their variability in the associated large scale MSLP, PWC and SST patterns of anomalies. The explained variance of the EOF1 ranges between 58% (winter) and 66% (autumn) and the spatial coefficients have positive loadings at all stations. These facts point out on the large scale factors that may drive the SPEI variability and implicitly the moisture conditions over the Czech Republic. In line with other studies

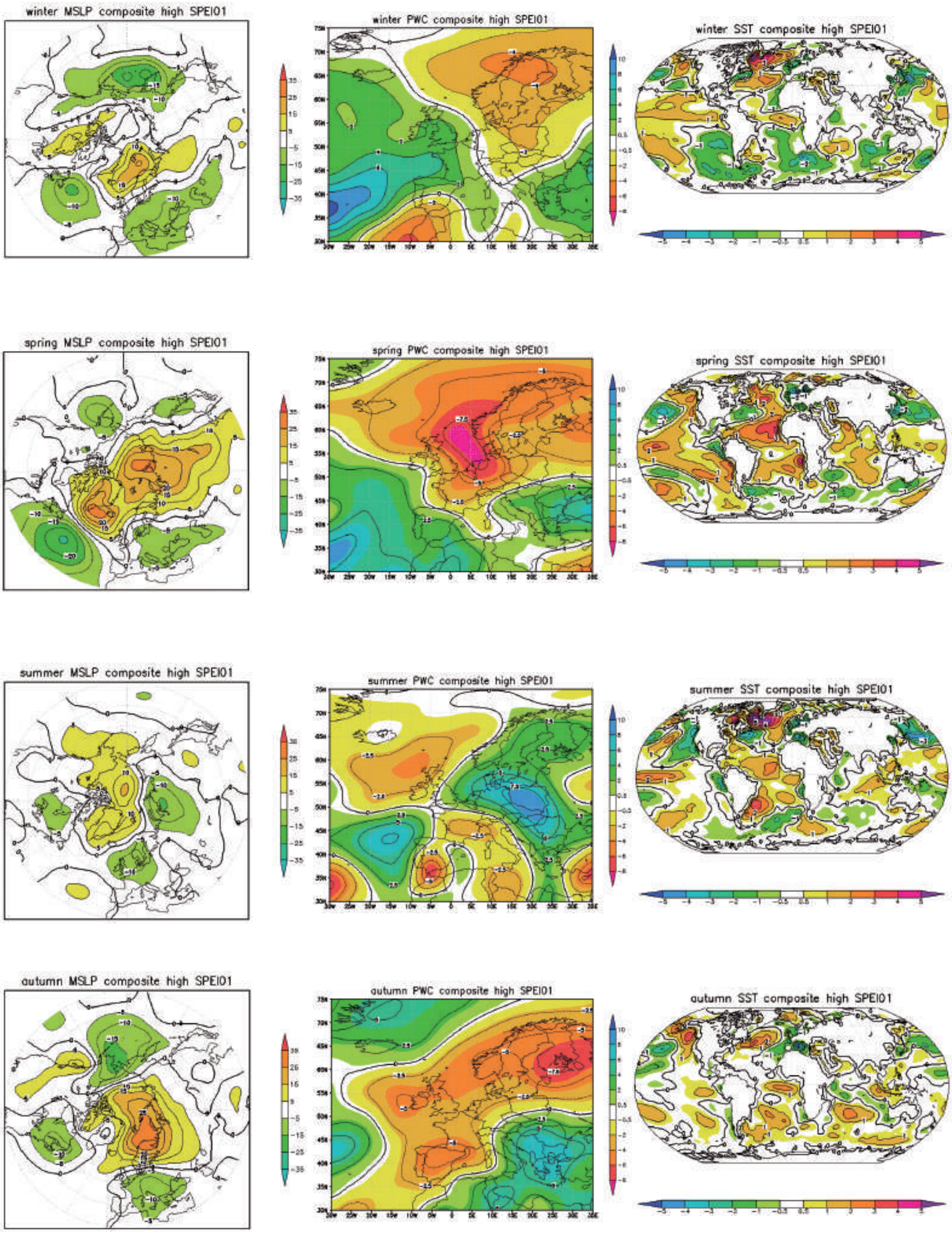

FIG. 4: *Composite maps of anomalies of mean sea level pressure (left panel), precipitable water vapor content (central panel) and sea surface temperature (right panel) based on standardized amplitudes of PC1 series of seasonal SPEI at 1 month lag > 0.75. Units of anomalies: MSLP (hPa), PWC (kg/m²) and SST (ºC).*

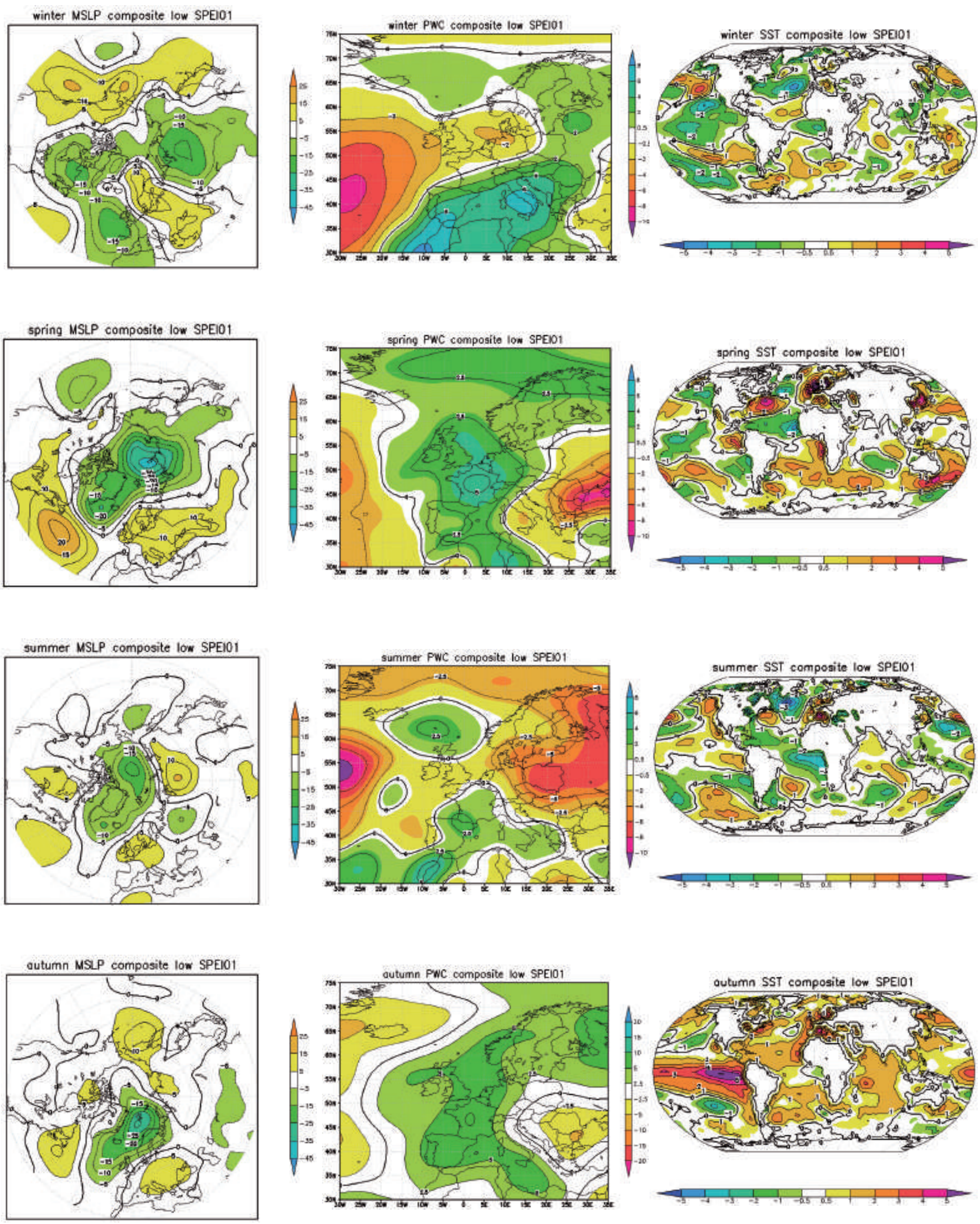

FIG. 5: *Composite maps of anomalies of mean sea level pressure (left panel), precipitable water vapor content (central panel) and sea surface temperature (right panel) based on standardized amplitudes of PC1 series of seasonal SPEI at 1 month lag < 0.75. Units of anomalies: MSLP (hPa), PWC (kg/m^2) and SST (ºC).*

(Ionita et al. 2012), the seasonal composite maps of MSLP, PWC and SST anomalies built on selected standardized values of PC1 (higher/lower than ± 0.75 standard deviation of the series) point out on large scale driving mechanisms (negative/positive AO phase associated with La Niña/El Niño years) which may induce wet /dry conditions over the Czech Republic.

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