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Abstract. El Niño – Southern Oscillation (ENSO) effects on the European circulation features and on the regional climate of Hungary are evaluated in this paper. European climate is represented by atmospheric macrocirculation patterns (MCPs). Local climate characteristics are linked to ENSO phases through regionally averaged temperature values and precipitation amounts. Significant statistical relationship was found between the European circulation and the ENSO phases. Furthermore, considerable differences were detected in the empirical frequency distribution of monthly climate anomalies in Hungary during El Niño and La Niña episodes.

1 Introduction

El Niño – Southern Oscillation (ENSO) phenomena are recognized as one of the most important interactions between the ocean and the atmosphere of the climate system (Philander, 1990). Effects of ENSO can be directly observed in the climate of the tropics since ENSO events are the most important sources of year to year variability in climate over the lower latitudes of the globe. Furthermore, several teleconnections were described in the extratropical regions (Glantz et al., 1991). The European continent is located far from the tropical Pacific Ocean, however, climatic teleconnections of ENSO can still be detected (e.g., Wilby, 1993; Fraedrich, 1994; van Oldenborgh et al., 2000). According to the results of Dong et al. (2000) and Mathieu et al. (2004), circulation features in winter are strongly connected to ENSO related SST anomalies in the tropical Pacific region. Merkel and Latif (2002) analyzed GCM outputs, and concluded that during El Niño winters the midlatitude cyclone centers move southward.

In this paper, ENSO related teleconnections on the Central/Eastern European region are analyzed using statistical methodologies. Data sets are described in Sect. 2, then our results are presented and discussed. Section 3 focuses on the effects of ENSO phases on the circulation features of the North Atlantic European region, while Sect. 4 presents the analysis of regional climate parameters (i.e., monthly temperature and precipitation observed in Hungary, located in Central/Eastern Europe) depending on ENSO episodes. Finally, the main conclusions are summarized in Sect. 5.

2 Data

Daily circulation and temperature fields were analyzed on the base of the NMC Grid Point Data Set (version III, 1996). This hemispherical database was composed in 1996 by the Department of Atmospheric Sciences at the University of Washington, and the Data Support Section in NCAR. Height and temperature fields of several geopotential levels are available in NMC octagonal grid form (Lenne, 1970). The total 47×51 gridpoints are equally spaced when viewed on a polar stereographic grid, centered on the North Pole. We used the following data sets: sea level pressure, 500 hPa, 700 hPa, 850 hPa geopotential heights, and temperature on 500 hPa, 700 hPa and 850 hPa geopotential levels. Time series consist of 33 years (1962–94) or 40 years (1955–94) daily data fields and were separated into seasonal subsets of data. In the present paper the original grid was converted into a latitude-longitude grid and the North Atlantic European region (30°–70° N latitude, 25° W–40° E longitude) were selected. It is represented by 63 gridpoints using $10°\times10°$ diamond grid resolution.

Other sources of circulation information include the macrocirculation pattern (MCP) classes. In the present paper, MCP defined by Hess and Brezowsky (1952, 1977) for the European continent was used. The dataset consists of daily HB codes from 1881 to 2001.

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Table 1. Years associated with different ENSO phases based on instrumental records (Kiladis and Diaz, 1989).

El Niño	La Niña
1902	1903
1904	1906
1911	1908
1913	1916
1918	1920
1923	1924
1925	1928
1930	1931
1932	1938
1939	1942
1941	1949
1943	1954
1946	1964
1948	1970
1951	1973
1953	1975
1957	1988
1963	1998
1965	
1969	
1972	
1976	
1977	
1982	
1986	
1991	
1993	
1994	
1997	

Regional climate is represented by monthly mean temperature values and precipitation amounts, observed at ten meteorological stations located in Hungary. Both the temperature, and the precipitation time series cover the entire 20th century.

3 ENSO related circulation variability in the North Atlantic European region

First, Empirical Orthogonal Function (EOF) analysis (von Storch, 1995) is applied to identify the action centers of the North Atlantic European region during El Niño and La Niña episodes. In the numerical procedure, the eigenvalue equations of correlation matrices of geopotential fields are solved. Dimension of a matrix equals to the number of gridpoints, that is 63 in the present case, representing the North Atlantic European region, defined between 30°–70° N latitude and between 25° W–40° E longitude. Eigenvectors provide EOF modes corresponding to the eigenvalues, which indicate percentages of contribution to total variance of the geopotential fields. Thus, the largest positive and negative values demonstrate action centers on the maps showing EOF modes. Daily geopotential height and temperature fields of selected

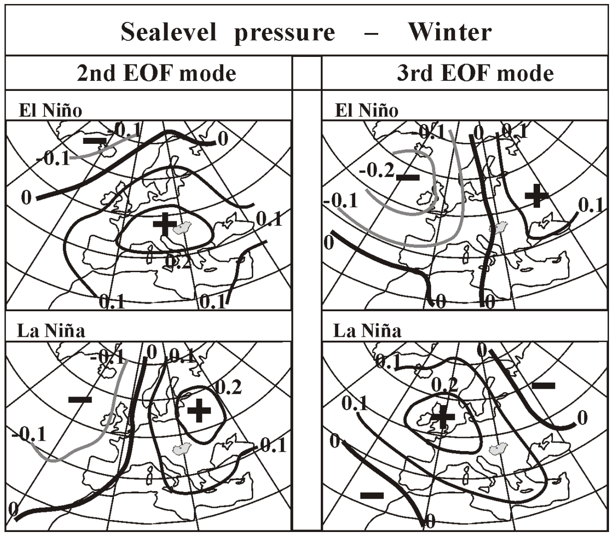

Fig. 1. 2nd and 3rd EOF modes of sea level pressure field during El Niño and La Niña phases (November–December–January, 1962–1994).

geopotential levels (AT500, AT700, AT850) were evaluated (Pongrácz and Bartholy, 2000), as well, as daily sea level pressure field.

EOF modes of circulation were calculated in the North Atlantic European region during El Niño and La Niña phases. The ENSO phases were determined according to Kiladis and Diaz (1989) on the base of instrumental records, and they are listed in Table 1. The twelve months periods of ENSO phases start from April of the given year and last until the following March. Contributions to total variance of the 1st, 2nd, and 3rd EOF modes are 21–26%, 16–23%, and 12–17%, respectively. The first six EOF modes usually explain the 80% of total variance, while the first nine EOF modes the 90%.

Our results suggest that the 1st EOF modes do not significantly differ during the ENSO phases since the largest portion of the total variance in the Northern midlatitudes is not associated with the ENSO phenomena. The 2nd and the 3rd EOF modes of sea level pressure are presented in Fig. 1 for the winter season (November-December-January) where considerable differences can be seen between El Niño and La Niña periods. Positive and negative action centers change their locations during different ENSO phases. The 2nd EOF modes can be characterized by zonal and meridional structure in El Niño and La Niña episodes, respectively. Significant differences can be detected in case of the 3rd EOF modes between El Niño and La Niña phases, in the right panel of Fig. 1. The spatial structure is meridional during El Niño events, while some zonality is superponed during La Niña events (resulting in a blocking pattern). EOF modes of temperature field were also determined at three geopotential levels (850 hPa, 700 hPa, 500 hPa). Their contributions to total variance of the fields are slightly smaller (by 3–4%) than in case of circulation (Pongrácz and Bartholy, 2000).

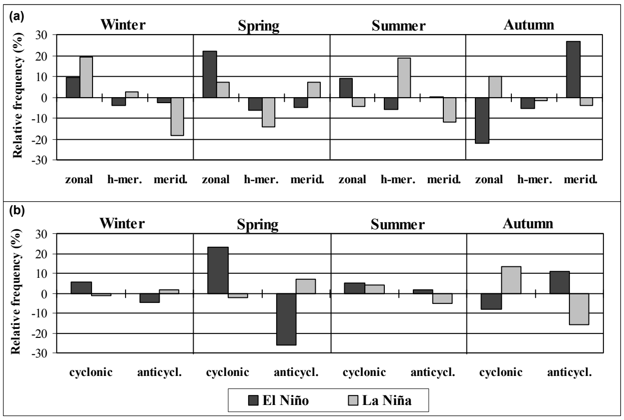

Fig. 2. Changes in MCP frequency during El Niño and La Niña phases, 1955–2001. **(a)** Zonality of the MCP types is considered. **(b)** Cyclone/anticyclone dominance is analyzed.

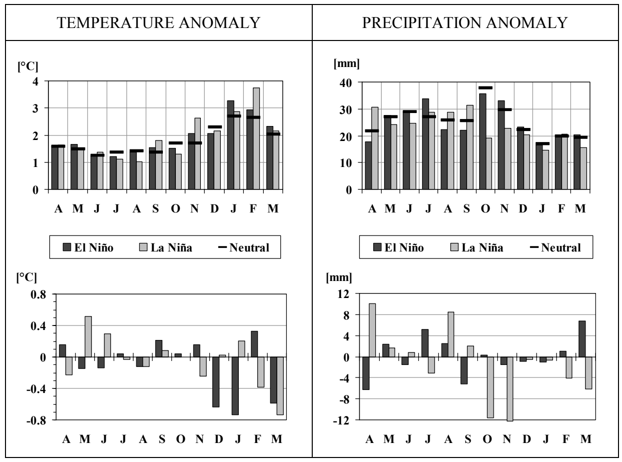

Fig. 3. Standard deviation (upper panels) and average (lower panels) of anomalies of regional climate parameters (temperature and precipitation, based on 10 Hungarian meteorological stations) during different ENSO phases.

Another methodology to analyze different circulation conditions during El Niño and La Niña, is to evaluate frequency distribution of MCP classes based on Hess–Brezowsky classification scheme. The available dataset consists of daily MCP codes from 1881 to 2001 for Western and Central Europe. In order to find the major components of ENSO phases on regional features of circulation, it is necessary to aggregate the original 29 HB types into groups (Pongrácz and Bartholy, 2000). Several aspects can be considered as the base of this aggregation, namely, (1) dominant direction of air mass movements, (2) circulation characteristics, and (3) cyclonic or anticyclonic dominance. According to the circulation characteristics, zonal, half-meridional and meridional MCP classes may be defined. Zonal MCP class includes 4 HB types, meridional MCP class consists of 18 different HB types, and the other 7 HB types compose the half-meridional MCP class. These MCP classes containing several HB types were statistically analyzed. The empirical relative frequencies of MCP classes are compared and evaluated during El Niño, La Niña and neutral periods.

The upper panel of Fig. 2 shows how the relative frequency of zonal, half-meridional and meridional MCP classes changed during El Niño and La Niña events in the four seasons in the second half of the 20th century. In general, frequency of zonal MCP classes increased during El Niño episodes, except in autumn when it decreased by 22%. The largest increase (by 22%) can be detected in spring. The largest change in the frequency of meridional MCPs occurred in autumn, it increased by 27% during El Niño compared to neutral phase. During La Niña winters the zonal and meridional MCPs show similar but opposite change in the occurrence. Zonal MCPs became more frequent by 20%, while the frequency of meridional MCP classes decreased by about 19–20%. Furthermore, considerable increase (by 20%) of half-meridional MCPs can be detected in summer during La Niña phases. The frequency distribution of El Niño, La Niña and neutral phases can be considered different using Chi-square test at 0.05 level of significance. These changes, often exceeding 15% in occurrence of MCP classes, suggest significant changes in regional temperature and precipitation patterns, too.

The lower panel of Fig. 2 presents the frequency change of cyclonic and anticyclonic MCP classes. The effect of ENSO phases is not significant at 0.05 level in the solstice seasons. The largest changes occurred during El Niño springs: cyclonic dominance increased by 23–24%, while anticyclonic dominance decreased by 26–27% in the second half of the 20th century. Also considerable but weaker and opposite changes can be detected in autumn. Cyclonic MCPs increased by about 14%, and anticyclonic MCPs decreased by about 16% during La Niña years. Frequency changes are opposite to this during El Niño autumns.

Both the EOF and the MCP analyses presented in this paper show that circulation conditions in the North Atlantic European region significantly differ during El Niño and La Niña periods.

4 ENSO related regional climate analysis

After analyzing the continental scale ENSO effects on circulation features of Europe, ENSO related climate conditions are evaluated on a finer spatial scale. In order to fulfil this task standard deviations of regional monthly temperature and precipitation values are calculated besides the average anomalies (Fig. 3). Based on the results, large negative temperature anomalies are present during El Niño winters (December, January, and March), while warmer conditions were more likely to occur in May and June during La Niña phase. La Niña springs (from February to April) are indicated by colder climate conditions. Furthermore, our analysis suggests that La Niña episodes affect the regional monthly precipitation more than the El Niño events do. Large negative

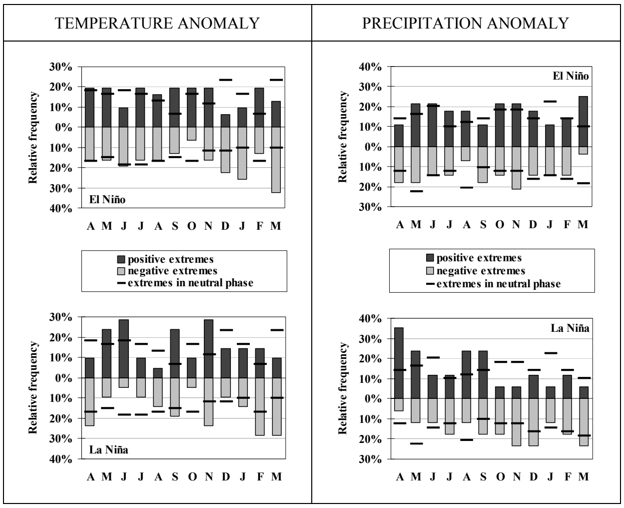

Fig. 4. Outlier frequencies of regional temperature and precipitation anomalies during different ENSO phases, 1901–2000.

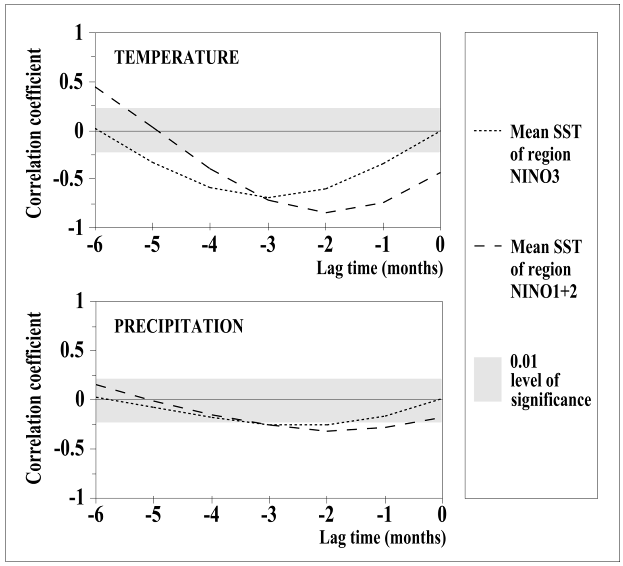

Fig. 5. Correlation coefficients between the regional temperature/precipitation time series and the mean sea surface temperature (SST) of different ENSO-regions using time lags of 0–6 months, 1950–2000.

precipitation anomalies occurred in October and November, and wetter conditions were likely to be observed in April and August. Standard deviation of winter months is about twice as much as that of summer months in case of temperature, while standard deviation of precipitation anomalies is the smallest in winter.

Relative frequencies of outliers of regional climate parameters are determined during different ENSO phases in each month. In this paper, a temperature or precipitation anomaly is considered as an outlier if it is out of the $[-\sigma;\ \sigma]$ interval where σ indicates standard deviation of time series in a given month. In general, positive and negative outliers altogether occurred in about 30–36% of the total time series. The left panels of Fig. 4 compare monthly outlier occurrences of regional temperature during different ENSO phases. In El Niño years, extreme warm conditions occurred more frequently in September and February than in neutral phases. Frequency of extreme cold conditions was higher in the winter half-year (especially, in December, January, and March) during El Niño episodes than in neutral years. Furthermore, less frequent extreme warm December and March, and less frequent extreme cold October were detected during El Niño. Larger differences can be seen in the lower panel of Fig. 4 where La Niña conditions are presented. The extreme warm conditions in September and November occurred considerably more frequent during La Niña episodes than in neutral years. Frequency of extreme cold conditions increased significantly in November, February and March during La Niña phases. Extreme cold conditions occurred considerably less frequent in June and October.

The right panels of Fig. 4 compare monthly outlier occurrences of regional precipitation during different ENSO phases. The upper panel presents outlier frequency during El Niño episodes. Extreme wet and dry conditions occurred more frequent in March, and in September/November, respectively. Less extreme wet conditions were detected in January, while less extreme dry conditions occurred in August and March during El Niño years than in neutral phases. Similarly to the temperature anomalies, La Niña conditions are compared to neutral phase in the lower panel. Extreme wet conditions were detected considerably more frequent in April, August, and September while they became less frequent in June, October, November, and January. Frequency of extreme dry conditions was higher in autumn months during La Niña episodes than in neutral years. Furthermore, less frequent extreme drought was detected in May and August.

In order to evaluate the possible time lag of ENSO climatic effects detected in Hungary, the correlation coefficients between the ENSO indices NINO1+2 and NINO3 (defined as the mean sea surface temperature in the corresponding NINO regions of the tropical Pacific Ocean, 0°–10° S, 80°–90° W, and 5° S–5° N, 90°–150° W, respectively) and the regional climate variables (i.e., temperature and precipitation observed in the Hungarian meteorological stations) were calculated. According to the results presented in Fig. 5, the teleconnection between the ENSO indices and the precipitation is very weak and mostly not significant (except using the time lag of 1–3 months). While in case of temperature, significant relationships with the NINO1+2 and NINO3 indices were detected using the time lag of 0–4 months, and 1–5 months, respectively. The largest correlation coefficients (0.71) between the regional temperature and the NINO1+2 index occurred with 2 month time lag. Stronger relationship (the correlation coefficient is 0.84) was found between the regional temperature and the NINO3 index using the time lag of 3 months.

5 Conclusions

ENSO effects on the North Atlantic European large-scale circulation and on the regional climate conditions of Hungary were analyzed. Based on the results presented in this paper, the following conclusions can be drawn.

(1) The spatial structures of the 2nd and the 3rd EOF modes of the European tropospheric circulation considerably differ during El Niño and La Niña episodes. Furthermore, the positive and negative action centers change their locations both in case of the 2nd and the 3rd modes.

(2) Considerable changes were detected in MCP empirical frequencies during El Niño and La Niña periods. The largest increase and decrease of zonal MCP classes were detected in El Niño springs and autumns, respectively. Meridional MCPs occurred significantly more frequent in autumn during El Niño phase than in neutral years. Changes in empirical frequencies of cyclonic and anticyclonic MCP classes are the most dominant in El Niño springs.

(3) Outlier and anomaly statistics of regional precipitation and temperature differ considerably during El Niño and La Niña episodes. Specifically, La Niña autumns were dominated by large negative anomalies in precipitation observed in Hungary, while wet conditions occurred in April and August during La Niña phase. Furthermore, cold conditions were detected in Hungary during El Niño winters, and warm conditions occurred considerably more frequent in May and June during La Niña episodes.

(4) Based on the teleconnection analysis using the correlation coefficients between the regional temperature/precipitation time series and the ENSO indices, the strongest relationships were found in case of the 2–3 months time lag.

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