THE RELATIONSHIPS BETWEEN ATMOSPHERIC CIRCULATION AND SURFACE CLIMATIC ELEMENTS IN EUROPE

Autoreport on Doctoral Thesis

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VLIV ATMOSFÉRICKÉ CIRKULACE NA PŘÍZEMNÍ KLIMATICKÉ PRVKY V EVROPĚ

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Introduction

The variability of atmospheric circulation is the most important factor determining the changes in spatial distribution of temperature, cloudiness, precipitation and other climatic elements. In the European sector, such variations are often related to the North Atlantic Oscilation (NAO). When the spatial patterns of low-frequency sea level pressure or geopotential field variability were identified, the NAO pattern was found to be one of the most pronounced, particularly during winter months (Barnston and Livezey, 1987). However, with the exception of the NAO, the other patterns can be distinguished over the Euro-Atlantic sector, for example the East Atlantic, Scandinavian and Eurasian patterns (Barnston and Livezey, 1987; Rogers, 1991; Clinet and Martin, 1992).

Recent studies (e.g., Werner and von Storch, 1993; Chen, 1999; Quian et al., 2000 a,b) investigated relations between spatial modes of atmospheric circulation and station temperatures and precipitation over Europe. There are many papers about the NAO and its influence on climate in Europe, mostly in winter season (Trigo et. al., 2002; Uvo, 2003). But only few authors pay attention to other circulation modes, other seasons and further climatic elements, such as relative humidity, wind speed and direction, cloudiness and sunshine duration.

Two approaches generally have been used for detection of low-frequency variability (i.e. time-scales of a week and longer). The first one, the teleconnection method (Walker and Bliss, 1932; van Loon and Rogers, 1978; Wallace and Gutzler, 1981) produces, for a given meteorological parameter, correlation fields (one-point correlation maps) called teleconnection patterns. The second method - statistical - uses a Principal Component Analysis (PCA). Compared with the teleconnection method, the major advantage of the PCA is its ability to summarize the variability of a given data set through a few orthogonal spatial patterns (also called loadings) and a set of corresponding temporally uncorrelated time components (time series or scores). For better meteorological interpretation, alternative solutions obtained through a linear orthogonal transformation (varimax rotation) of preliminary results, are usually used (Horel, 1981).

The occurrence of the large-scale circulation variability modes is not uniform during the year. Barnston and Livezey (1987) computed ten monthly spatial variability modes in a hemispheric 700-hPa dataset and were the first to examine seasonality of upper-air low-frequency variability patterns. The character of modes, the shape and the magnitude of action centres vary as a function of season.

The dissertation consists of two major parts. The first one examines the influence of the modes of variability on temperature and precipitation characteristics in Europe and on a variety of climate elements in the Czech Republic. The other part studies the sensitivity of the effects of the North Atlantic Oscillation (NAO) on surface climate to the way how the NAO is defined.

Data and Methods

The circulation data used in this study are large-scale gridded 500-hPa heights (Z500) and sea level pressure (SLP) retrieved from the National Center of Environmental Prediction/National Center for Atmospheric Research Reanalysis (NCEP/NCAR) for the period 1958-1998. They are defined on a 5° latitude by 5° longitude grid box and are expressed as anomalies from the corresponding monthly averages of the same period. The domain extends from 20° N to 85° N. I used a quasi equal area grid with a reduced number of points per latitude circle northwards of 60° N (it means 72 points per latitude circle from 20° to 55°, 36 points from 60° to 70°, 24 points at 75°, 18 at 80° and 8 at 85° with no point at the pole, entered to PCA).

Principal component analysis (Wilks, 1995) was applied on monthly mean 500 hPa heights for all seasons. Linear transformation called rotation was applied to solution of PCA with ambition to obtain modes with simple but well pronounced structure. Different numbers of components were rotated in individual seasons (9 components in winter, spring and summer, 11 in autumn). The same approach was employed to SLP data, for which 8 components were rotated in winter and autumn, 11 in spring and 12 in summer. Modes in both levels were assigned following the highest correlations and structure similarities of the modes in both levels.

Table 1 *List of 82 stations in Europe, their location, elevation and list of climatic characteristics. Tn, Tg, Tx refer in turn to minimum, average, and maximum temperature; R refers to precipitation.*

Number	State	Station	Elevation. [m]	Climatic elements
1	Austria	Kremsmün	383	Tn,Tx,R
2	Bosnia	Sarajevo	577	Tn,Tg,Tx,R
3	Croatia	Zagreb	157	Tn,Tg,Tx,R
4	Czech Rep.	Praha	191	Tn,Tg,Tx,R
5	Denmark	Kobenhaven	9	Tn,Tx,R
6	Denmark	Nordby	4	Tn,Tx,R
7	Denmark	Vestervig	18	Tn,Tx,R
8	Estonia	Tartu	59	Tn,Tg,Tx,R
9	Finland	Helsinki	4	Tn,Tg,Tx,R
10	Finland	Jyväskylä	137	Tn,Tg,Tx,R
11	Finland	Sodankylä	179	Tn,Tx,R
12	France	Bordeaux	49	Tn,Tx,R
13	France	Châteauroux	160	Tn,Tx,R
14	France	Lyon	172	Tn,Tx,R
15	France	Marseill	75	Tn,Tx,R
16	France	Paris	75	Tn,Tx,R
17	France	Perpignan	43	Tn,Tx,R
18	France	Toulouse	152	Tn,Tx,R
19	Germany	Bamberg	282	Tn,Tg,Tx,R
20	Germany	Berlin	55	Tn,Tg,Tx,R
21	Germany	Bremen	4	Tn,Tg,Tx,R
22	Germany	Jena	155	Tn,Tg,Tx,R
23	Germany	Schwerin	59	Tn,Tg,Tx,R
24	Germany	Stuttgart	401	Tn,Tg,Tx,R
25	Germany	Zugspitze	2960	Tn,Tg,Tx,R
26	Greece	Hellinikon	15	Tn,Tg,Tx,R
27	Ireland	Birr	70	Tn,Tg,Tx,R
28	Ireland	Valentia	9	Tn,Tg,Tx,R
29	Italy	Brindisi	10	Tn,Tg,Tx,R
30	Italy	Cagliari	2	Tn,Tg,Tx,R
31	Italy	Roma	105	Tn,Tx,R
32	Italy	Verona	68	Tn,Tx,R
33	Latvia	Riga	6	Tn,Tx,R
34	Lithuania	Kaunas	75	Tn,Tg,Tx,R
35	Lithuania	Klaipeda	6	Tn,Tg,Tx,R
36	Lithuania	Vilnius	189	Tn,Tg,Tx,R
37	Luxembourg	Luxembourg	376	Tn,Tg,Tx,R
38	Macedonia	Prilep	373	Tg,R
39	Netherlands	De Bilt	2	Tn,Tg,Tx
40	Netherlands	Eelde	4	Tn,Tg,Tx,R
41	Netherlands	Vlissingen	8	Tn,Tg,Tx,R

Table2 *continuation*

Number	State	Station	Elevation. [m]	Climatic elements
42	Norway	Glomfjord	39	Tn,Tg,Tx
43	Norway	Karasjok	129	Tn,Tg,Tx
44	Norway	Oksoy Fyr	9	Tn,Tg,Tx
45	Norway	Oslo	94	Tn,Tg,Tx
46	Norway	Utsira Fyr	55	Tn,Tg,Tx
47	Portugal	Beja	246	Tn,Tx,R
48	Portugal	Braganca	690	Tn,Tx,R
49	Portugal	Lisbon	77	Tn,Tx,R
50	Portugal	Porto	93	Tn,Tx,R
51	Romania	Arad	117	Tn,Tx,R
52	Romania	Calarasi	19	Tn,Tx,R
53	Romania	Tirgu Jiu	203	Tn,Tg,Tx,R
54	Russia	Kem	8	Tn,Tg,Tx,R
55	Russia	Kursk	247	Tn,Tg,Tx
56	Russia	St. Peter	6	Tn,Tg,Tx,R
57	Russia	Pskow	45	Tn,Tg,Tx,R
58	Russia	Smolensk	239	Tn,Tg,Tx,R
59	Russia	Sortavala	19	Tn,Tg,Tx,R
60	Serbia	Beograd	132	Tn,Tg,Tx,R
61	Slovakia	Hurbanovo	115	Tn,Tg,Tx
62	Spain	Badajoz	185	Tn,Tx,R
63	Spain	Navacerrada	1890	Tn,Tg,Tx,R
64	Spain	San Sebastian	259	Tn,Tx,R
65	Spain	Tortosa	48	Tn,Tx,R
66	Spain	Valencia	11	Tn,Tx,R
67	Sweden	Karlstad	18	Tn,Tx,R
68	Sweden	Linköping	93	Tn,Tx,R
69	Sweden	Östersun	376	Tn,Tx,R
70	Sweden	Stensele	325	Tn,Tx,R
71	Sweden	Växjö	166	Tn,Tx,R
72	Switzerland	Basel	316	Tn,Tg,Tx,R
73	Switzerland	Lugano	273	Tn,Tg,Tx,R
74	UK	Armagh	62	Tn,Tg,Tx,R
75	UK	Eskdalemuir	242	R
76	UK	Hull	2	R
77	UK	Oxford	63	Tn,Tg,Tx,R
78	UK	Wick	36	Tn,Tg,Tx,R
79	Ukraine	Kijiv	166	Tn,Tg,Tx,R
80	Ukraine	Lugansk	59	Tn,Tg,Tx
81	Ukraine	Polatava	160	Tn,Tg,Tx,R
82	Ukraine	Uzhgorod	115	Tn,Tx,R

Daily values of maximum, minimum and mean temperature and precipitation amounts over the period of 1958-1998 originate from „European Climate Assessment (ECA) project“ from webpage http://eca.knmi.nl/dailydata/index.php

(Klein Tank et al., 2002). Monthly means of all characteristics and additional characteristic of monthly precipitation occurrence (number of days with precipitation total >0 with respect to the number of days during the corresponding month) were computed at the 82 stations over the Europe (Tab. 1). Also the test of normal distribution (Wilks, 1995) was applied and it must be mentioned that we cannot reject non-normal distribution for the precipitation occurrence at more than half stations and also for the precipitations amounts at some stations in Europe. But deviations from the normal distribution express oneself by higher skewness or elongation of the distribution to higher values, which still allow employment of the Pearson correlation coefficient.

Number	Station	Elevation [m]
1	Cheb	474
2	Přimda	745
3	Doksany	158
4	Milešovka	833
5	Praha-Karlov	232
6	Praha-Ruzyně	364*
7	Churáňov	1118
8	Vyšši Brod	559
9	České Budějovice	388**
10	Liberec	398***
11	Hradec Králové	278
12	Přibyslav	530
13	Havlíčkův Brod	455
14	Svratouch	737
15	Kuchařovice	334
16	Kostelní Myslová	569
17	Holešov	224
18	Brno-Tuřany	241
19	Červená	750
20	Ostrava	251
21	Lysá Hora	1324

Table 2 *List of 21 stations in Czech Republic and their elevation above sea level.*

* *up to 31.12.1978 elevation 380 m*

** *up to 6.2.1976 elevation 387 m*

*** *up to 31.12.1989 elevation 400 m*

Monthly means of 11 climatic elements, daily maximum, minimum and mean temperature, precipitation occurrence and precipitation totals, cloudiness, sunshine duration, relative humidity, wind speed and zonal and meridional direction of the wind, at 21 stations (Tab. 2) (at 71 stations for precipitation characteristics) in the Czech Republic were used from the period of 1961-1998 as a representative region in central Europe. Here we cannot reject non-normal distribution for precipitation occurrence amounts at several stations either.

The Pearson correlation coefficient

$$r_{xy} = (N\sum x_i y_i - \sum x_i \sum y_i)/\{\sqrt{[N\sum x_i^2 - (\sum x_i)^2]} * \sqrt{[N\sum y_i^2 - (\sum y_i)^2]}\}$$

was used for quantification of relationship between circulation modes and climatic elements.

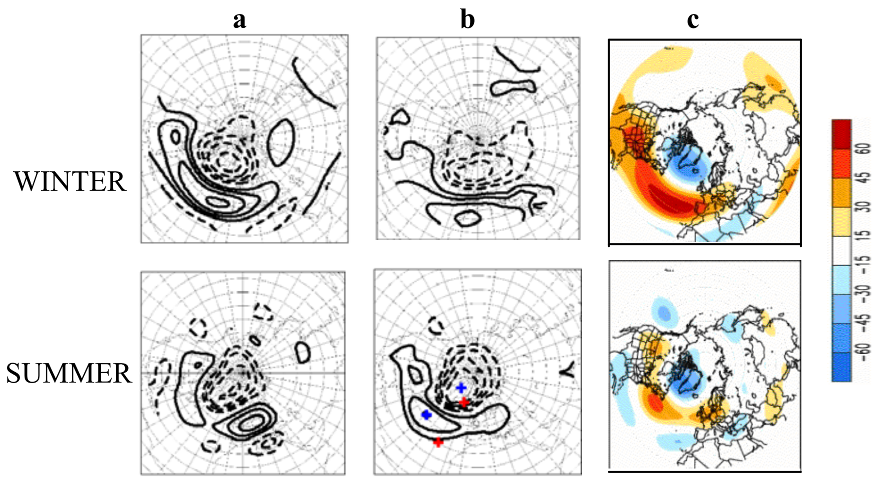
Regarding to the high autocorrelations in all time series, the effective numbers of degrees of freedom were used (Bretherton et al., 1999): $N^* = N(1+r_1r_2)/(1-r_1r_2)$.

In the part of the dissertation where climate effects of several different definitions of the NAO are compared, the NAO index time series for the period 1958-1998 originate from several sources (only winter and summer season is focused):

- Index based on normalized sea level pressure anomaly between Ponta Delgada, Azores, and Stykkisholmur, Iceland, (Hurrell, 1985), for the location of stations see Fig. 1b; www.cgd.ucar.edu/cas/jhurrell/indices.data.html#naostatmon (short NAO-A).
- Index based on SLP anomaly between the centres of the Azores High (AH) and Icelandic Low (IL) (Mächel et al., 1998), http://atmos.msrc.sunysb.edu/coa/naomonth.shtml (short NAO-C).
- The first principal component of 4 characteristics of the NAO centres: SLP anomalies in the centres of the AH and IL, and the latitude of centres (Paeth et al., 1999), (short NAO-P).
- Score of the NAO produced by the National Weather Service, NOAA (The rotated PCA was applied to monthly mean standardized 500-mb height anomalies in the analysis region 20°N-90°N between January 1950 and December 2000. For each of the twelve calendar months, the ten leading unrotated EOFs were first determined from the standardized monthly height anomaly fields in the three-month period centred on that month [i.e., the July patterns are calculated based on the June through August monthly standardized anomaly fields] and then a varimax rotation was applied to these ten leading un-rotated modes), www.cpc.noaa.gov/products/precip/CWlink/pna/nao_index.html (short NAO-NOAA). see Fig. 3c

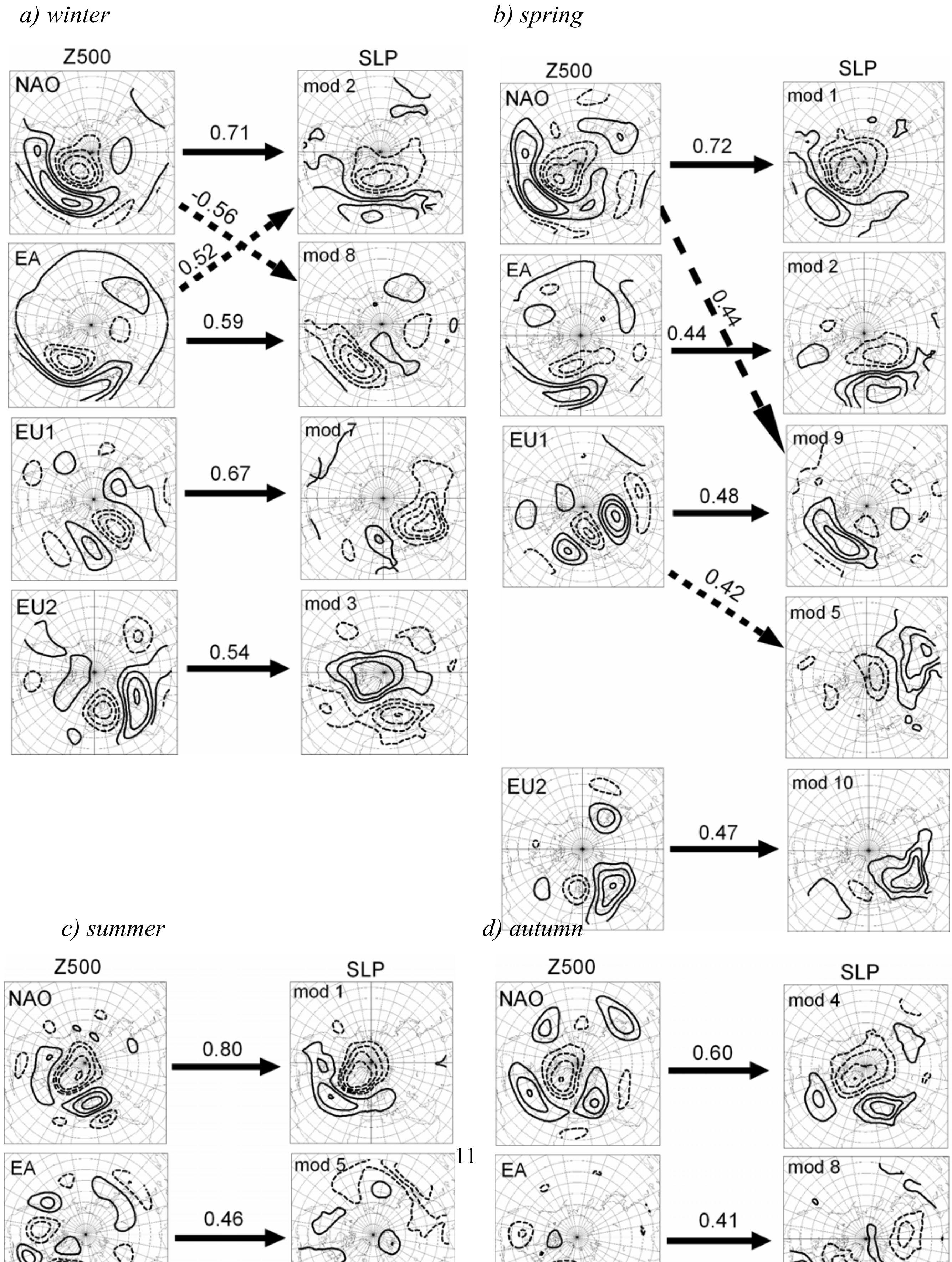
- Score of the NAO mode computed from the 500 hPa height field of the NCEP/NCAR reanalysis (short NAO-Z500). see Fig. 3a
- Score of the NAO mode computed from the SLP field of the NCEP/NCAR reanalysis (short NAO-SLP). see Fig. 3b

Fig. 3 *Loadings of NAO mode from NCEP/NCAR datasets at the 500 hPa level (Z500) (a) and at SLP (b) in winter and summer are displayed in terms of correlations of its intensity with the 500 hPa heights, SLP respectively. The contour interval is 0.2. Positive (negative) values are indicated by solid (dashed) lines; zero correlation line is not shown. Stations Ponta Delgada, Azores, and Stykkisholmur, Iceland are marked by red crosses, blue crosses symbolically denote centres of AH and on picture (summer b). Loadings of NAO mode from CDAS datasets (NOAA) for January and July (c) are displayed in terms of correlations of its intensity with the 500 hPa heights; the colour scale indicates values of correlations.*



Statistically significant difference between correlations of NAO indexes and climate elements over Europe was tested using the test for equality of correlation coefficients (Huth et al. 2006). Correlation coefficients r_1, r_2 were Fisher-transformed $z_i = 0.5\ln[(1+r_i)/(1-r_i)]$, the test characteristic $u = (z_1-z_2)/\sqrt{[1/(n_1-3)+1/(n_2-3)]}$ being normally distributed, n_i is the sample size. Statistically significant difference of the correlation coefficients has been checked by the two–tailed test of the Student distribution, significance level 95 % was discussed.

Fig. 4 *Correlations of modes in Z500 with modes in SLP. Modes are displayed in terms of correlations of its intensity (i.e., the corresponding PC score) with the 500 hPa heights or SLP for each season separately. The contour interval is 0.2. Positive (negative) values are indicated by solid (dashed) lines, the zero correlation line is not shown. The values of correlations are marked above arrows. Only the correlations higher in absolute value than 0.4 are shown.*



Results and Discussion

Modes of circulation variability were identified in monthly mean Z500 and SLP for all seasons by the rotated PCA. Four modes in Z500 significantly influence climatic elements in Europe. I named them, according to the nomenclature introduced by Barnston and Livezey (1987), the North Atlantic Oscillation (NAO) pattern, the East Atlantic (EA) pattern, and two Eurasian patterns (EU1, EU2). The modes in SLP were attributed to their counterparts in Z500 by the highest correlation between the modes at the two levels (Fig.4).

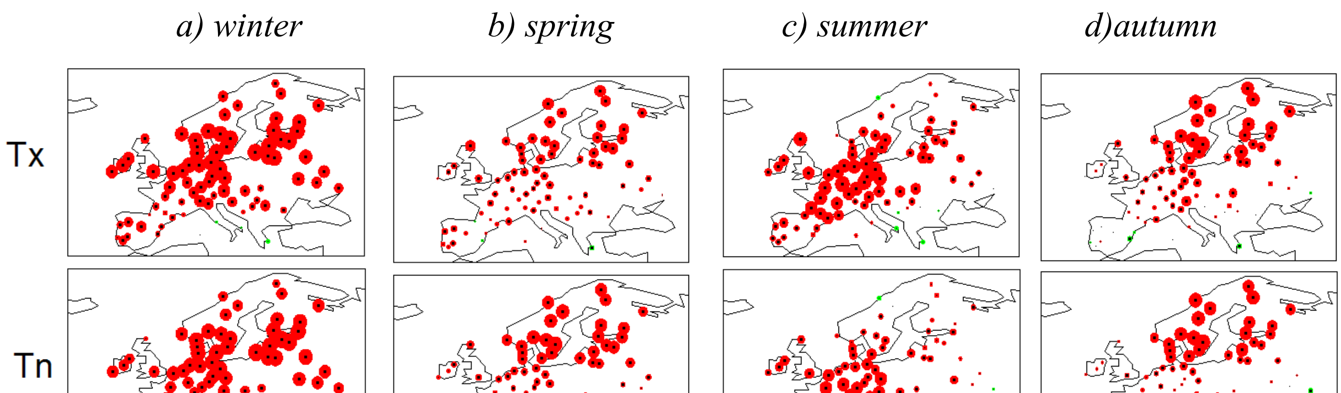
High and statistically significant correlations for all modes in each season demonstrate connection between both levels during whole year. Influence of modes of both levels on climate in Europe is documented by statistically significant correlations with temperatures, precipitation and other climatic variables in all seasons and is discussed in following text for each mode separately.

North Atlantic Oscillation mode

The NAO mode is characterized by the northern center of low pressure over Iceland and Greenland and the southern center of high pressure along 40° N from central North America to eastern Europe in winter and spring. The corresponding modes in SLP have similar character as modes NAO in Z500 in both seasons. During the positive phase, there is a westerly zonal flow (in winter more intensive), which brings wet and warm air to western and central Europe during both seasons. Daily maximum, minimum and mean temperatures at European stations are higher than normal (Jones et al., 2003; Bartzokas ans Metaxas, 1996), precipitation totals and occurrence are lower than average in southern European regions in winter and over almost whole Europe in spring (Wibig, 1999), see Fig. 5. Positive correlations with wind speed are registered in central Europe in both seasons.

In summer and autumn the NAO changes its zonal character, the band of high pressure divides into two cells in Z500, and the eastern one has the center over the central Europe. Also the mode in SLP changes the same way in autumn, whereas in summer it maintains its winter character with one northern and one southern center, which extends to eastern Europe indeed. The climate in Europe is affected by an anticyclone during the positive phase of modes. During the positive phase, the temperatures are higher than average at all European stations, precipitation are less frequent and precipitation totals are lower than normal at all stations except southern and western Europe. Lower cloudiness and longer sunshine duration are observed in central Europe.

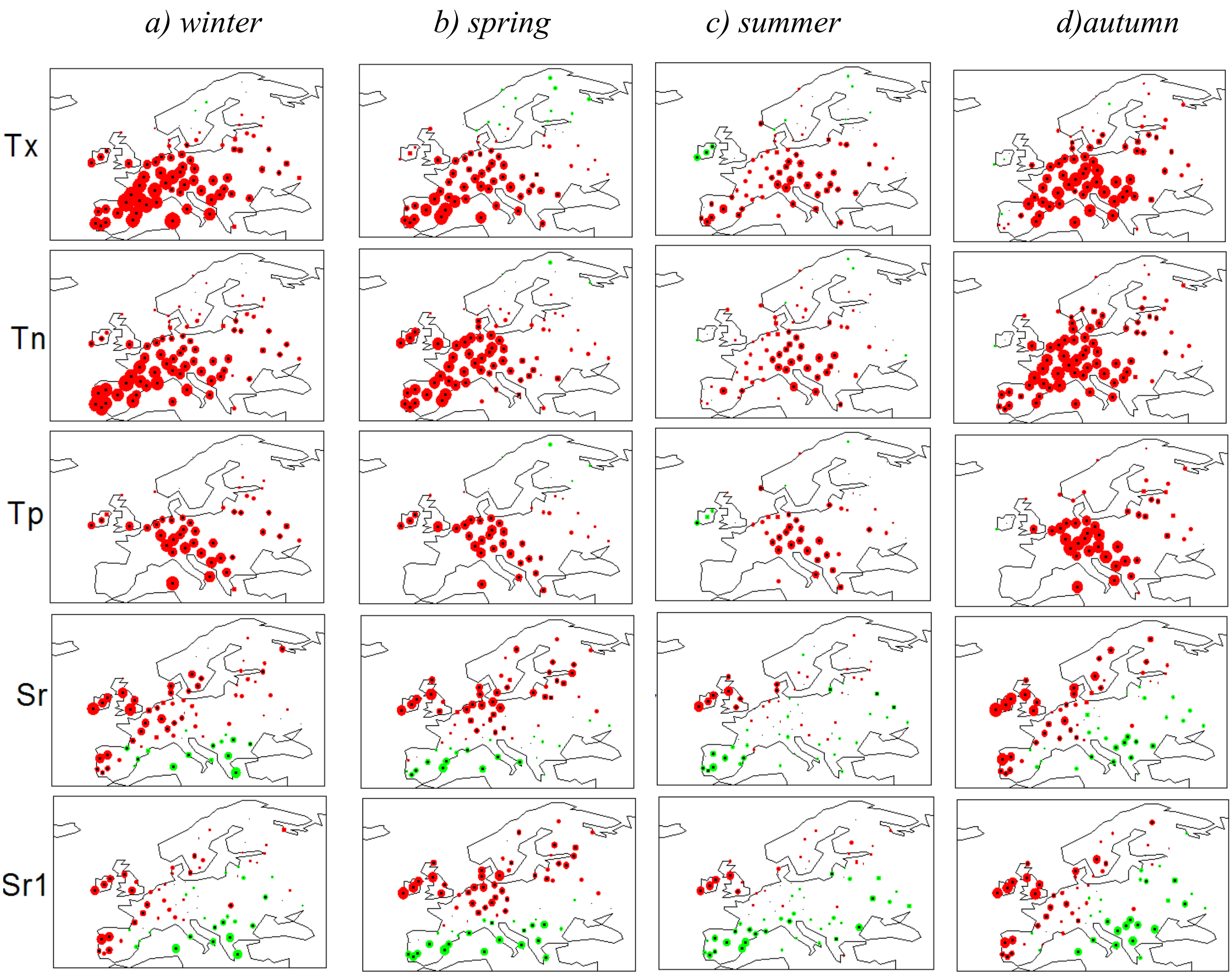
Fig. 5 *The correlations of the NAO mode in Z500 with climatic elements in all seasons. The positions of circles correspond to the geographical position of stations. The circle size corresponds to the value of correlation at the station, red / green indicating positive / negative correlations; the statistical significance is denoted by a black point.*



East Atlantic mode

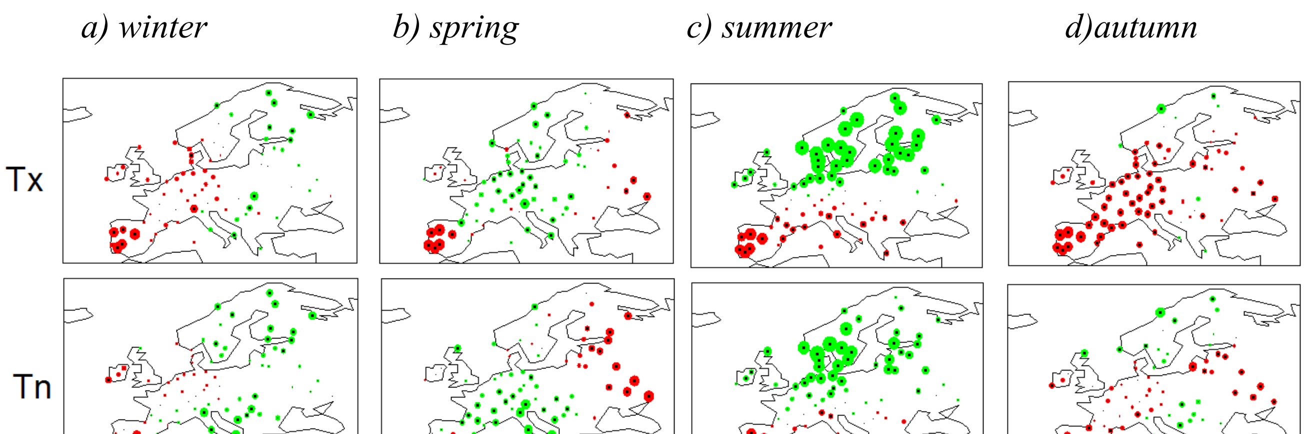
The EA mode has the similar structure as the winter NAO mode, its centres are located farther southward in comparison with winter NAO mode. The main cell is located westward from the British Islands and the band of high pressure extends in lower latitudes, over central Atlantic, northern Africa and southern Europe, in summer and autumn it extends to northeastern Europe. The character of mode remains similar throughout the whole year. The highly correlated modes in SLP have different character from that of the EA mode in individual seasons; actually the centers of mode 5 do not cover Europe in summer. During the positive phase of EA modes in Z500 the southern and eastern regions of Europe are affected by positive anomaly, western and northern regions are influenced by southwestern flow around the eastern flank of the negative centre. Daily maximum, minimum and mean temperatures at European stations were higher than average; the precipitation was higher over all Europe except the Mediterranean and eastern Europe (Trigo et al., 2004; Wibig, 1999) (see Fig. 6). Less cloudiness and longer sunshine duration were observed during the positive phase of EA mode in central Europe in summer and autumn. Similar effect as mode EA in Z500 has only mode 2 in SLP in spring and mode 8 in autumn except the eastern stations. Mode 5 in SLP in summer has negligible effect on climate in Europe. During the positive phase of mode 8 in SLP

Fig. 6 *As in Fig. 5, but for the Eastern Atlantic mode.*



in winter higher temperatures and more frequent precipitation were observed in the Mediterranean; lower temperatures were observed in northern Europe and dry conditions additionally in central and eastern Europe.

Fig. 7 *As in Fig. 5, but for the Eurasian mode 1.*



Eurasian mode 1

The EU1 (elsewhere named also Scandinavian pattern) has the dominant cell over the Scandinavia and eastern Europe. The cells of opposite sign are located on both sides of this cell. There is another cell of the same sign as the Scandinavian one, located over China in spring and over Far East in summer and autumn. The modes in SLP have quite different character in winter and spring in comparison with EU1 in Z500, the main cell of modes 12 and 2 in summer and autumn is situated over the Scandinavian peninsula, but the shape of modes is different from that of EA1. The character of EU1 mode in Z500 is similar in winter, spring and autumn, during the positive phase the north-west flow brings wet and cold air to central Europe, southern regions are forced by positive anomaly. Temperatures are lower and precipitation totals were higher than average at stations in northern and eastern Europe, on the contrary temperatures were higher and precipitations lower in southern and western regions (Popova, 2007; Bartzokas and Metaxas, 1996; Bueh and Nakamura, 2007), see Fig. 7. North and west wind directions and higher wind speed in central Europe were observed.

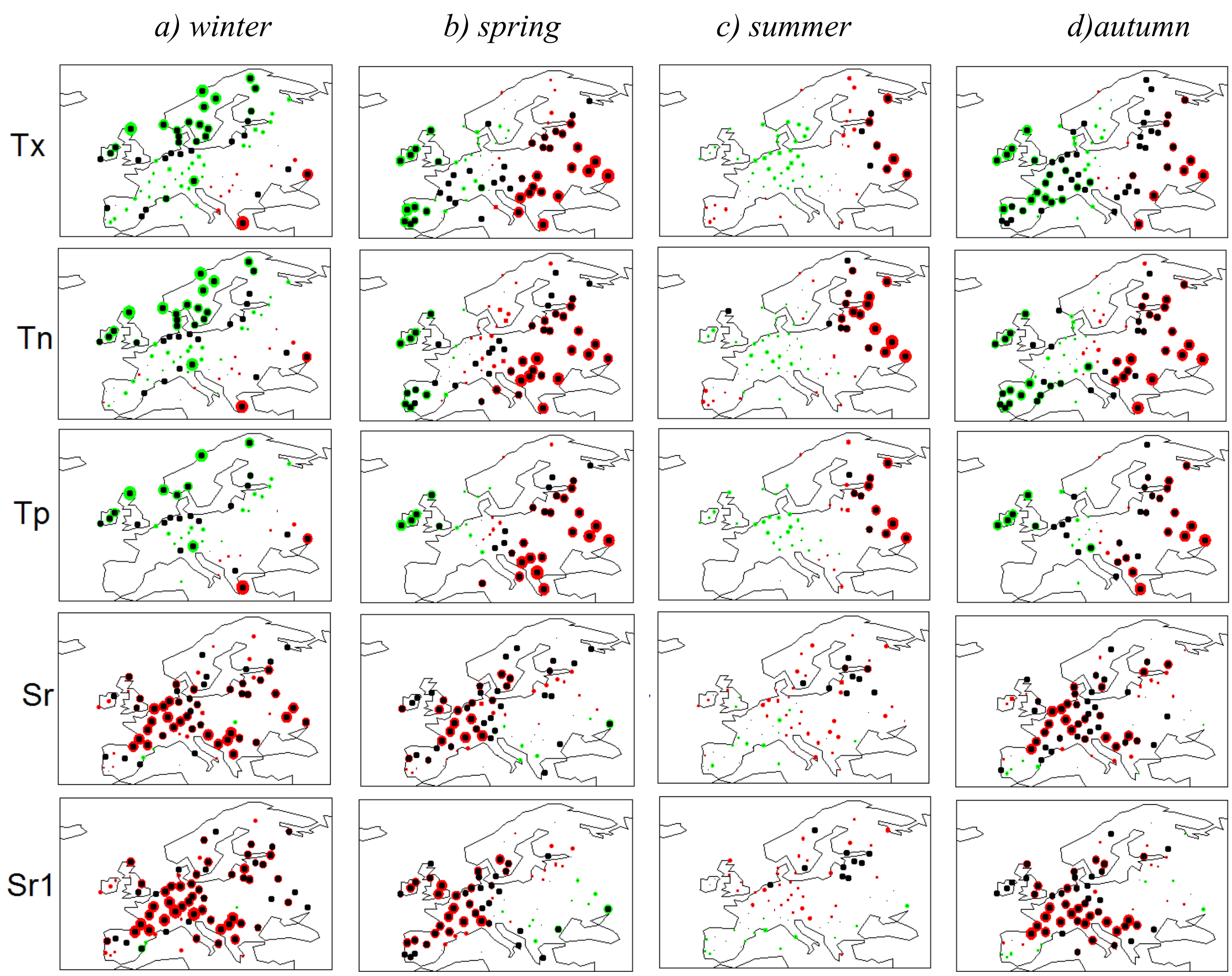
Different character of EU1 mode is the reason for western flow over the Europe continent during the positive phase in summer. Lower temperatures and higher precipitations were observed in northern regions of Europe, higher temperatures and lower precipitations in southern regions.

Although associated modes in SLP have different character in comparison with modes in Z500, their effect on European climate is similar in spring, summer and autumn too. Positive phase of mode 7 in winter was related to lower minimum temperatures almost over whole Europe except Ireland and Spain; correlations of this mode with maximum and mean temperatures were insignificant at most stations. Lower precipitation was observed in southwestern half of Europe and at several stations in Scandinavia, again higher precipitation was observed in central and western Europe.

Eurasian mode 2

The EU2 has the strong cell located over Siberia and Arabian Peninsula with the centre near the Caspian Sea. One cell of opposite sign is located over Europe with centre near Denmark, the other lays over the Far East with centre near Japan in winter and over Mongolia in summer and autumn. The character of EU2 mode conserves during winter, spring and autumn. During the positive phase is considerable part of Europe affected by cell of negative anomalies in winter, stronger control of the cell of positive anomalies is pronounced in spring and autumn. Lower daily maximum, minimum and mean temperatures were observed in western part of Europe continent and even in northern regions in winter (Fig. 8). Precipitation occurred more frequently and the totals were higher than average at almost all stations in winter and autumn and in western and southern parts of European continent in spring (Wibig, 1999; Quian et al., 2000a,b). The wind flew from south direction during the spring and autumn and there were observed shorter sunshine duration in winter and autumn in central Europe.

Fig. 8 *As in Fig. 5, but for the Eurasian mode 2.*



The character of the EU2 mode changes in summer; only the Siberian cell is well pronounced, other centres over the Euro-Atlantic region disappear. Northern and eastern Europe is affected by positive anomaly during the positive phase of this mode, higher temperatures and lower precipitations were observed at stations in these regions.

Corresponding modes in SLP have similar character as EU2 mode in spring, summer and autumn, the main cell of those modes has its centre near the Caspian Sea, too. Their correlations with temperature and precipitation are similar as correlations of EU2 mode, in summer they are even higher. The position of main cell of mode 3 in winter is shifted westward and there exists the centre of opposite sign over polar regions. Higher temperatures were observed in Mediterranean and lower elsewhere during the positive phase of mode 3 in winter, there were observed the same annomalies of the precipitation characteristics as for EU1 in winter.

The NAO in winter and spring and the EA during the year are zonal modes and influence temperatures more than other climatologic elements. The correlations are higher for the NAO than for the EA and they are higher in summer, when temperature amplitude is enhanced by longer sunshine duration and smaller cloudiness. EU1 and EU2 are meridional modes in spring and autumn, they influence especially precipitation. High correlations with wind directions occur for every strongly expressed (pronounced) pattern. The correlations are generally higher in winter when the circulation modes are better pronounced.

Comparison of different definitions of NAO

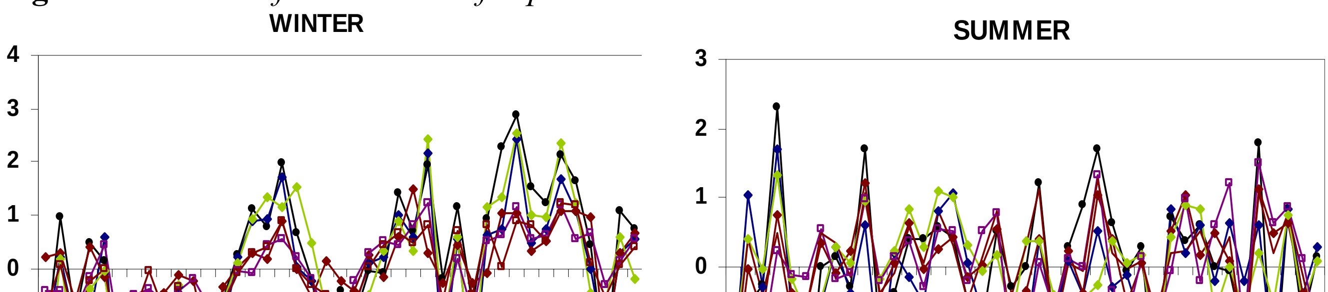
Correlations between NAO indexes and scores range from 0.64 to 0.86 in winter and from 0.50 to 0.87 in summer, correlations of all pairs of indexes and scores are statistically significant, Tab. 3. For comparison of NAO indices time series see Fig. 9.

During the winter season, there were found positive significant correlations of NAO indices with maximum and mean temperatures at almost all stations in Europe and except the Mediterranean also with minimum temperatures. Statistically significant positive correlations between NAO indices and precipitation characteristics were found at stations in northern and northwestern Europe, significant negative in southern part of Europe.

Table 3 *Correlations among the NAO indices in winter (black values) and summer (red values)*

	NAO-A	NAO-C	NAO-P	NAO-NOAA	NAO-Z500	NAO-SLP
NAO-A		0,83	0,82	0,8	0,73	0,79
NAO-C	0,72		0,89	0,88	0,86	0,72
NAO-P	0,71	0,72		0,84	0,81	0,64
NAO-NOAA	0,7	0,56	0,65		0,86	0,72
NAO-Z500	-0,5	-0,46	-0,44	-0,73		0,71
NAO-SLP	-0,72	-0,6	-0,67	-0,87	0,8	

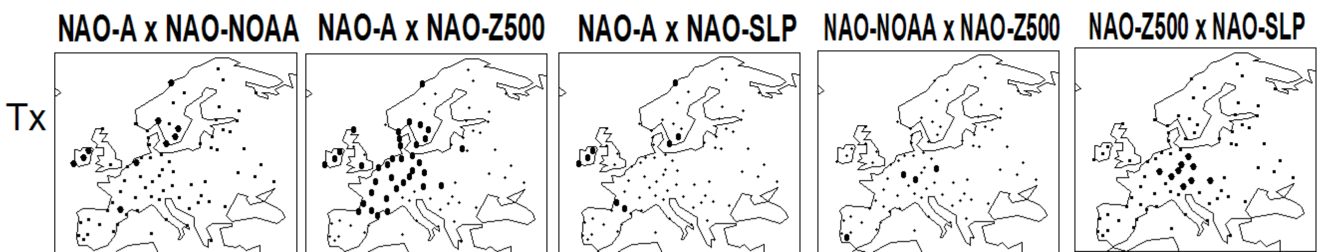
Fig. 9 *Time series of NAO indices for period 1958-1998 in winter and summer*



In winter, the correlations of NAO with temperature and precipitation characteristics were generally the highest for the NAO-SLP, except precipitation on Iberian Peninsula. Significant differences were found between correlations of the NAO-SLP and other NAO indices for maximum temperature at many stations in western and central Europe, and for correlations with other climatic characteristics at individual stations in southern and eastern Europe.

During the summer season, the correlations of NAO indices with temperature were positive for almost all European stations, except southeastern regions. The values reached the significance level for NAO-A and NAO-P indexes in northeastern Europe and for all scores at almost all stations. Correlations of the NAO indexes with precipitation were negative but weak at most stations; they were significant only at several stations in central and western Europe. There were positive and significant correlations for NAO-A index with precipitation in northwestern part of British islands. But significant correlations at almost all stations were found for all NAO scores, positive in southern and southeastern Europe and negative elsewhere. The highest correlations were obtained for NAO-Z500.

Fig. 10 *Statistically significant differences between correlations of selected NAO indices for all climatic elements in summer are denoted by black circles. Dots mark stations with no significant differences.*



In summer, no significant differences were found between correlations of NAO-A, NAO-C and NAO-P indexes with examined climatic elements and between correlations of NAO-NOAA and NAO-SLP indices with all elements. Very similar correlations of NAO-Z500 and other two scores with temperatures occur at many stations except central Europe and with precipitation at all stations, Fig. 10, the 4th to 5th column. There were found significantly higher correlations of all scores with precipitation characteristics in comparison with correlations of NAO-A, NAO-C, NAO-P and precipitation at many stations in the northern part of Europe; see Fig. 10, the 1st to 3rd column. The correlations of NAO-A, NAO-C, NAO-P and NAO-NOAA, NAO-SLP with temperatures are very similar at many stations except several stations in northern and western Europe. But correlations of NAO-Z500 with temperatures are significantly higher at many stations over central, western and northern Europe; Fig. 10, the 2nd column.

Conclusion

In this work, I focused on the relationship between atmospheric circulation and surface climatic elements like the temperature and the precipitation amounts and occurrence over the European region and some other climatic elements in central Europe. I chose the low-frequency modes of atmospheric circulation as the leading principal components from fields of the 500 hPa geopotential height level and of the sea level pressure for characterisation of atmospheric circulation in the particular seasons. Here applied Pearson correlation coefficient is widely used for the description of the relationships, mentioned above.

The principal component analysis (PCA) applied to seasonal data of the 500 hPa geopotential high level (Z500) computed four circulation patterns over Euro-Atlantic sector that influence climate in Europe all over the year. I named them, following the nomenclature introduced by Barnston and Livezey (1987), the North Atlantic Oscillation (NAO) pattern, the East Atlantic (EA) pattern, and two Eurasian patterns (EU1, EU2). They occur during all seasons of the year, although their character, the shape and the magnitude of cells vary as a function of season.

There exists at least one pattern in SLP with cells over Euro-Atlantic sector that has a strong correlation (from 0.4 to 0.8) with one mode of the Z500. This is valid for all modes in Z500 in all seasons except EA pattern in summer. Linkage of NAO and EA modes with modes in SLP in winter is not clear; there are high correlations between all pairs of modes.

All modes are the best pronounced generally in winter and are the weakest in summer. Statistically important correlations of modes in Z500 and SLP with maximum, minimum and mean temperature, precipitation amounts and occurrence of precipitation at European stations were identified in all seasons. In addition, several modes have strong influence on duration of sunshine, relative humidity, cloud cover, wind speed and direction in central Europe. The sign and magnitude of correlations can be explained through synoptic structures of modes, the shape and the magnitude of their cells. From this point of view we can divide the modes into three groups:

a) modes with zonal character. During one phase of modes the strong west flow brings to Europe wet and in winter warm air (Jones et al., 2003; Wibig, 1999; Trigo et al., 2004; Popova, 2007) (e.g. EA mode in all seasons, NAO mode in winter and spring, EU1 mode in summer),
b) modes with meridional transport of air masses. During one phase of modes the invasion of cold Arctic air was observed and currently more frequent and heavier precipitation appeared in north and east Europe regions (Wibig, 1999; Quian et al., 2000a,b) (EU1 and EU2 modes in winter and spring belong to this group),
c) modes with one centre situated over central Europe. During one phase, higher temperatures and dry conditions at almost all European stations were registered (Feidias, 2007; Bartzokas a Metaxas, 1996) (NAO mode in summer and autumn, EU2 in winter and autumn could be mentioned in this case).

Modes with well pronounced centres over the Europe have statistically significant correlations with climatic elements. Assigned modes in SLP have similar magnitude of correlations and almost the same number of statistically significant correlations with surface elements as modes in Z500.

It should be mentioned that NAO considerably changes its character in summer – it is not the leading factor for zonal transport and so its influence on climatic elements does not comply with general expectations (in fact, its positive phase brings higher then average temperatures and smaller precipitation in summer) (Feidias, 2006; Slonosky et al., 2001). So I have propounded a question whether NAO indexes widely used for expression of NAO can capture the real influence of NAO on surface climate in Europe.

The comparison of 6 different NAO index definitions including scores of modes from PCA is the aim of the second part of this study. The correlations with surface climate elements at European stations were used to illustrate the influence of individual NAO indices.

There are no differences between NAO indexes and scores at the first sight. The correlations of time series of all pairs of indices range from 0.64 to 0.89 in winter and from 0.44 to 0.87 in summer and are statistically significant in all cases. Also the differences between correlations of NAO indices with temperatures and precipitations at European stations are negligible in winter (Hurrel, 1995; Osborn et al., 1999; Río et al., 2007). But the statistically significant differences between NAO indices based at station values and scores, computed from NCEP/NCAR database, were found in summer for almost all stations in Europe, except the Iberian Peninsula and Mediterranean. The character of the subtropical centre is sensitive to the definition of the NAO in warm months. It shifts westward and northward for the definition based on SLP (Mächel et al., 1998). For the definition based on patterns in SLP or 500 hPa heights, the southern centre of the NAO extend to central and eastern Europe, all Europe except the Mediterranean being influenced by a strong positive anomaly (Slonosky et al., 2001; Portis et al. 2001). The correlations of the NAO indexes with surface temperatures and precipitation are weak and insignificant, except for the station-based NAO index, but they are strong for all the NAO scores at many stations.

Although all NAO indices mutually strongly correlate and seem to represent atmospheric circulation the similar way, it is clear, that in summer only indices based on scores of NAO modes can do that the right way (Ulbrich et al., 1999; Portis et al., 2001).

It was shown that low frequency circulation modes are applicable to describe the relationship between atmospheric circulation and surface climate in the scale of months or seasons.

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