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SNOW COVER OCCURRENCE IN CENTRAL EUROPEAN LOWLANDS UNDER NORTHERN HEMISPHERE CIRCULATION PATTERNS

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Summary – Four circulation patterns (North Atlantic Oscillation NAO, East Atlantic pattern EA, East Atlantic/Western Russia EATL/WRUS and Scandinavia SCAND) persistent in the Euroatlantic region are taken into consideration and their influence on snow cover occurrence in 35 Central European lowland stations is investigated. The correlation coefficient (r) between the monthly number of days with snow cover and monthly circulation indices is computed and mapped. Anomalies in the monthly number of days with snow cover at positive/negative extremes of each circulation pattern are calculated and tested. The most significant negative relationships are found between the NAO index and snow cover duration (r up to -0.7 or even -0.8 in northwest Poland and northeast Germany). The difference between the number of days with snow cower during positive and negative NAO extremes is statistically significant and reaches 18 days in January. Three remaining circulation patterns have much less impact on snow cover. Some significant positive snow signals are found for the negative phase of EA in January and February, and for negative phase of EATL/WRUS in December. The Scandinavian anticyclone in the SCAND positive phase is favourable for snow cover duration in February and March, but only in the north eastern edge of the studied area.

Key words: Central-Europe, correlation, snow cover, circulation patterns

1. INTRODUCTION

Snow cover is not a permanent winter phenomenon in Central European lowlands. It is considered to be ephemeral in the west and becomes more frequent towards the east. Its occurrence is conditioned by air temperature, precipitation and – indirectly – by atmospheric circulation. The aim of this study is to determine how large-scale circulation patterns, associated with air masses of specific temperature and humidity, influence winter snow conditions in Central European lowlands.

The North Atlantic Oscillation (NAO) is the best-known Northern Hemisphere circulation pattern determining the spatial distribution of climatological elements, such as temperature, precipitation and – consequently – snow cover in the Euroatlantic region. The relationships between the NAO index and the annual number of days with snow cover or snow depth are statistically significant in Poland but they fade away towards the east (Bednorz 2002, 2004, Falarz 2002, 2004). Gutzler and Rosen (1992) have found that the NAO-like teleconnection pattern is the only one exhibiting appreciable correlations with anomalies in snow cover extent over Europe. Clark et al. (1999) have investigated the Eurasian snow layout and its atmospheric controls on the basis of NOAA weekly snow extent charts of the whole Northern Hemisphere. They have found significant decreases in the snow cover extent over Central Europe in positive NAO extremes. Fluctuations of the European snow extent have also been observed during other circulation patterns, such as the Eurasian Type 1 and the Siberian (Clark et al. 1999).

In this study four circulation patterns persistent in the Euroatlantic region are taken into consideration and their influence on snow cover occurrence in 35 Central European lowland stations is investigated.

2. DATA AND METHODS

The study is based on snow cover data from 35 ground stations located in Central Europe. Analyses based on the data from ground stations encompassing a large part of Central Europe are rare, partly because of difficulties in access to the meteorological data, particularly from the former socialistic countries. The area of study spreads throughout Poland and neighbouring countries: Germany, Austria, Czech Republic, Lithuania, and Russia (Kaliningrad District), excluding mountainous regions. The elevation of the stations is generally lower than 300 m A.S.L., only five stations are located at 300-500 m A.S.L. and two stations have higher location (up to 900 m A.S.L.) (Fig. 1).

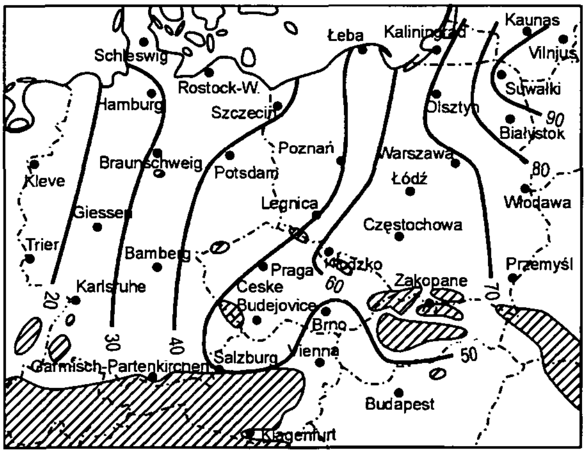

Fig. 1 Location of the meteorological stations used in this study and the annual number of days with snow cover

The data covers the period 1960-2000, winter months from December to March. Polish snow cover data was supplied by the Institute of Meteorology and Water Management (Warsaw). Data for the German stations were derived from 'Deutsches Meteorologisches Jahrbuch' published by the Deutscher Wetterdienst (Offenbach, Potsdam). The Russian and the former Soviet Union data were obtained from the Historical Soviet Daily Snow Depth (HSDSD) Version 2 (Armstrong 2001) and partly from the Lithuanian Hydrometeorological Service. Data for the Austrian stations were derived from 'Jahrbuch der Zentralstalt für Meteorologie und Geodynamik' published by the Zentralanstalt für Meteorologie und Geodynamik (Wien). Czech snow cover data was supplied by the Czech Hydrometeorological Institute and data from Budapest were supplied by the Hungarian Meteorological Service.

The monthly numbers of days with snow cover were calculated based on daily snow cover data. Days with snow cover were those days when the snow cover depth ≥1 cm at 6.00 UTC.

Circulation patterns are represented by monthly indices available at the NOAA Climate Prediction Centre (CPC) datasets. The procedure used to identify the Northern

Hemisphere teleconnection patterns and to calculate the indices available at CPC datasets is based on the Rotated Principal Component Analysis worked out by Barnston and Livezey (1987). Four patterns which are significant for the Euroatlantic region are chosen to the analysis (Fig. 2):

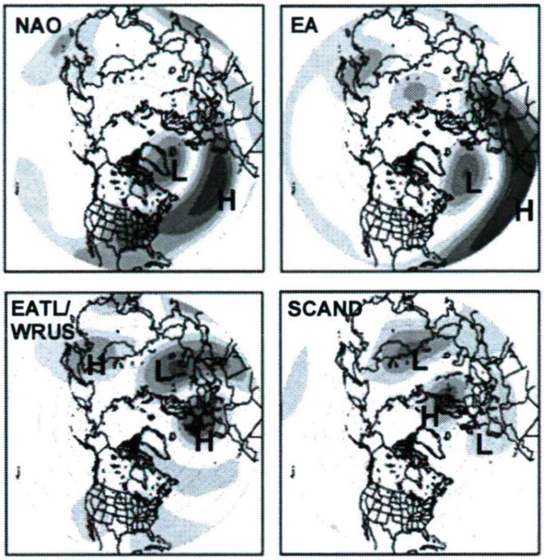

Fig. 2 Positive phases of macro-scale circulation patterns. L – centres of negative pressure anomalies (low pressure), H – centres of positive pressure anomalies (high pressure) (www.cpc.noaa.gov/data/teledoc/telecontents.shtml)

- NAO, being the most important for Europe, is represented by a structure of a north-south dipole of anomalies, with one centre located over Greenland and the other centre of opposite sign over the North Atlantic, between 35°N and 40°N. The positive phase of this circulation mode signifies a pronounced difference in the air pressure between the northern low and southern high centres. It causes a stronger-than-usual westerly air flow and intensifies cyclonic activity over Europe (Carleton 1988, Serreze et al. 1997).
- The East Atlantic pattern (EA) has a similar structure to the NAO. However, the anomaly centres are displaced to the southeast and the southern centre contains a strong subtropical link.
- The East Atlantic/Western Russia (EATL/WRUS) pattern has two main anomaly centres located over the Caspian Sea and Western Europe. Persistent negative phases of EATL/WRUS with low over Great Britain or France and high over the Caspian Sea tend to occur in winter.
- The Scandinavia pattern (SCAND) has one centre which spans the Scandinavian Peninsula and some parts of the Arctic Ocean and a weaker centre with opposite sign located over Western Europe. The positive phase of the SCAND pattern is associated with an anticyclone over Scandinavia.

The research considers four months from December to March. The monthly number of days with snow cover against monthly circulation indices is analysed. The correlation coefficient (r) is calculated and mapped for each month separately. As 40 years of observations are taken into consideration, $r > |+0.3, -0.3|$ is statistically significant at 0.05 and $r > |+0.4, -0.4|$ is statistically significant at 0.01. Then, the months of each circulation pattern extremes are separated. Months, when the index of a particular circulation pattern is >0.75/<-0.75, are recognized as positive/negative extremes. Values of 0.75 and -0.75 are close to the first and the third quartile of all considered indices. Monthly numbers of days at positive and negative extremes are compared using the two-sample t-test for independent groups. Anomalies in the number of days with snow cover at positive/negative extremes are shown in a table, indicating stations, where t-value is statistically significant.

3. RESULTS

Snowiness is both spatially and temporally variable in the studied area. The mean annual number of days with snow cover ranges from about 15 days in the west to over 90 days in the northeast, considering lowland territories only (Fig. 1). However, these numbers may vary from several days, or even zero, during mild winters in Germany to over 130 days during extremely snowy winters in Lithuania. The variability coefficient reaches 100% in the least snowy places and 30% in the snowiest regions. In the east, the snow cover usually starts to appear during the last third of November. The first single days with snow cover in western Germany are observed in the beginning of December. The snow season ends between the beginning of February (the 10th of February in the north western Germany) and April (eastern Poland, Lithuania and Kaliningrad District).

3.1. NAO

Statistically significant negative relationships between the NAO index and the number of days with snow cover are found for each winter month. Many more days with snow are observed in the negative NAO phase, than in positive. However, the relationships are not the same in each winter month.

In December, the value of r is negative over the entire area, statistically significant (<-0.3) only in its central part (Poland, western Germany, Czech Republic). In western Germany, where the mean number of days with snow cover in December is <5, the value of r is close to zero. Even the extremes of the NAO do not cause there any significant differences in the number of days with snow. In south eastern Poland, where the mean number of days with snow cover in December exceeds 10, the aforementioned difference amounts to 6 days and is statistically significant (Fig. 3, Table 1, 2).

January is the snowiest month in Central Europe. The monthly mean number of days with snow cover varies from 6 days in the Rhein valley to more than 25 in the northeast of the studied area. In January a strong influence of the NAO on snow cover is observed. The value of r is statistically significant over the entire area. The strongest negative relationships are observed in the central part of the studied area (western part of Poland and Czech Republic, northern Austria and eastern Germany).The value of r amounts to -0.83 in the town of Szczecin (Poland) and it decreases both towards the west and towards the east. The differences in the number of days with snow cower during the positive and negative NAO extremes are significant and they vary from 10 to 18 days.

In February, the number of days with snow in Central Europe is slightly lower than in January. The NAO influence on snow cover weakens but it is still significant over most of the analysed territory. In the west and in the south the value of r amounts to -0.3 or even -0.2. Differences in snowiness in February under the positive and negative NAO phases are not significant only in the south (<5 days). There is a low anomaly in the number of days with snow cover under the positive NAO phase.

In March, snow appears on the ground for 2 days in the west (Rhein valley) and for over 15 or even 20 days in the northeast. These numbers are influenced by the NAO. The value of r is statistically significant over the entire area, excluding Hungary and the southernmost parts of Germany and Austria. Most of the stations are sensitive to the NAO extremes and the differences in the number of days in the positive and negative phases are significant even in the least snowy regions.

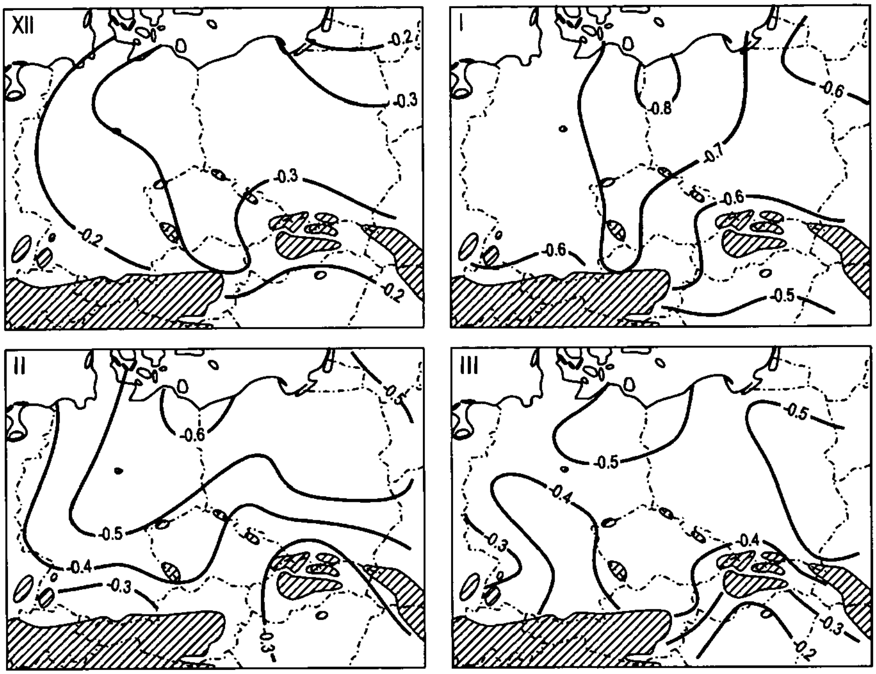

Fig. 3 Correlation coefficient (r) between the monthly number of days with snow cover and the North Atlantic Oscillation (NAO) index (December – March)

Table 1 Mean monthly number of days with snow cover. Data for years 1960/1961 – 1999/2000.

		XI	XII	I	II	III	IV
1.	Schleswig	1.9	6.3	10.7	8.9	4.2	0.6
2.	Rostock - Warnemuende	1.6	5.5	11.5	8.9	4.1	0.6
3.	Hamburg	1.3	5.6	9.4	7.4	3.2	0.4
4.	Potsdam	2.6	8.5	13.6	10.6	5.4	0.4
5.	Kleve	0.5	2.8	5.5	4.3	0.9	0.0
6.	Braunschweig	1.8	6.0	9.9	9.1	3.7	0.2
7.	Trier	1.4	3.5	6.1	4.4	1.3	0.2
8.	Giessen	1.4	5.5	9.3	7.8	1.7	0.2
9.	Bamberg	2.2	7.8	13.7	9.0	2.8	0.3
10.	Karlsruhe	1.4	3.9	7.5	5.2	1.7	0.1
11.	Garmisch Partenkirchen	9.1	24.5	26.8	23.4	17.3	5.1
12.	Salzburg	4.9	14.5	17.7	11.8	6.8	1.1
13.	Klagenfurt	5.2	17.4	25.1	19.9	8.6	1.1
14.	Vienna	2.6	10.1	15.5	10.1	4.9	0.4
15.	Praha	4.4	11.1	16.8	12.4	5.9	1.0
16.	Ceske Budejovice	4.2	11.5	15.6	11.1	5.7	1.2
17.	Brno	2.4	10.2	15.9	10.6	3.6	0.3
18.	Budapest	1.9	6.0	11.3	6.3	1.8	0.0
19.	Szczecin	2.3	7.0	12.0	10.2	4.2	0.4
20.	Łeba	2.8	9.9	15.6	14.1	7.3	0.8
21.	Poznań	2.6	11.0	15.9	12.2	5.8	0.5
22.	Legnica	3.4	9.0	13.1	10.5	5.0	0.5
23.	Kłodzko	5.4	14.5	18.2	15.1	8.5	1.5
24.	Częstochowa	5.8	15.0	21.4	16.4	8.8	1.3

Table 1 (continued)

		XI	XII	I	II	III	IV
25.	Łódź	4.6	13.1	18.7	14.9	8.1	0.9
26.	Warszawa	3.8	11.9	17.5	14.5	7.4	0.6
27.	Olsztyn	5.4	15.3	22.1	19.6	12.4	1.6
28.	Białystok	5.0	17.7	22.6	21.3	14.0	1.4
29.	Suwałki	6.9	19.6	23.1	22.5	16.3	2.0
30.	Włodawa	5.6	16.4	21.9	18.4	11.9	0.8
31.	Zakopane	13.4	25.9	28.0	26.1	22.7	7.8
32.	Przemyśl	6.8	17.8	21.6	18.6	10.4	1.2
33.	Kaliningrad	4.9	14.1	19.6	17.8	11.1	0.8
34.	Kaunas	5.0	16.4	21.2	20.6	14.7	1.6
35.	Vilnjus	6.3	20.3	25.4	23.8	20.3	2.3

Table 2 Anomalies in the number of days with snow cover in the North Atlantic Oscillation (NAO) extremes. Data for years 1960/1961-1999/2000.

		Negative (NAO index <-0.75) (cm)				Positive (NAO index >0.75) (cm)			
		XII	I	II	III	XII	I	II	III
1.	Schleswig	-0.1	**9.7**	**7.3**	**4.9**	-0.9	**-5.6**	**-4.0**	**-0.3**
2.	Rostock - Warnemuende	1.0	**10.7**	**8.9**	**5.2**	-1.5	**-5.3**	**-5.3**	**-1.9**
3.	Hamburg	0.6	**9.3**	**8.3**	**4.2**	-2.0	**-6.3**	**-3.8**	**-0.8**
4.	Potsdam	1.3	**11.3**	**7.5**	**6.6**	-2.2	**-6.6**	**-4.5**	**-2.4**
5.	Kleve	0.1	**5.7**	3.5	**1.0**	-0.3	**-3.4**	-1.8	**-0.6**
6.	Braunschweig	0.9	**8.0**	**8.2**	**4.7**	-2.2	**-6.3**	**-4.2**	**-2.1**
7.	Trier	0.5	**5.8**	**5.0**	**2.6**	0.4	**-4.6**	**-1.3**	**-1.0**
8.	Giessen	0.2	**8.2**	**7.2**	**1.2**	-1.3	**-5.4**	**-3.5**	**-0.6**
9.	Bamberg	0.1	**9.6**	**6.5**	**2.1**	-1.6	**-7.1**	**-3.8**	**-1.6**
10.	Karlsruhe	0.3	**8.2**	**6.2**	**2.8**	-0.8	**-6.3**	**-1.9**	**-1.4**
11.	Garmisch Partenkirchen	-1.1	**4.1**	1.3	**3.9**	-0.3	**-3.4**	-0.4	**-3.9**
12.	Salzburg	1.5	**9.7**	4.1	**3.5**	-2.3	**-10.0**	-3.8	**-2.9**
13.	Klagenfurt	0.5	**5.9**	**6.3**	2.8	3.9	**-3.6**	**-4.1**	-1.8
14.	Vienna	2.1	**11.0**	5.1	**5.1**	-2.8	**-10.1**	-3.5	**-3.1**
15.	Praha	1.8	**9.7**	**6.3**	**3.3**	-2.8	**-8.0**	**-5.4**	**-2.2**
16.	Ceske Budejovice	1.9	**9.3**	**4.9**	**4.7**	-3.0	**-9.4**	**-4.5**	**-3.6**
17.	Brno	1.7	**8.1**	**4.6**	**3.2**	-0.7	**-7.7**	**-4.1**	**-1.7**
18.	Budapest	2.7	**11.9**	**6.6**	**3.6**	0.6	**-6.0**	**-2.7**	**-0.4**
19.	Szczecin	1.2	**12.1**	**10.1**	**6.3**	-2.2	**-8.9**	**-5.5**	**-1.7**
20.	Łeba	2.0	**11.9**	**7.9**	**6.2**	-1.7	**-8.8**	**-6.2**	**-3.5**
21.	Poznań	2.1	**10.5**	**7.0**	**4.8**	-2.8	**-8.6**	**-5.4**	**-2.3**
22.	Legnica	1.6	**10.2**	**6.5**	**5.0**	-2.3	**-8.3**	**-4.6**	**-2.5**
23.	Kłodzko	**3.4**	**6.3**	3.0	**5.5**	**-3.2**	**-8.1**	-3.1	**-2.9**
24.	Częstochowa	1.8	**6.5**	**5.1**	**5.0**	-2.3	**-8.3**	**-3.7**	**-2.8**
25.	Łódź	**1.8**	**8.7**	**6.3**	**4.8**	**-3.3**	**-8.5**	**-6.2**	**-2.6**
26.	Warszawa	**2.5**	**9.3**	**8.3**	**6.7**	**-3.2**	**-8.3**	**-5.8**	**-3.0**
27.	Olsztyn	1.8	**7.9**	**5.3**	**8.2**	-2.5	**-6.7**	**-5.1**	**-4.1**
28.	Białystok	1.3	**7.9**	**6.0**	**7.8**	-1.7	**-8.0**	**-5.8**	**-5.6**
29.	Suwałki	2.1	**6.8**	**4.9**	**6.5**	-0.6	**-5.9**	**-5.0**	**-3.8**
30.	Włodawa	**3.1**	**7.0**	**6.1**	**7.8**	**-4.4**	**-9.0**	**-5.6**	**-4.6**
31.	Zakopane	**2.6**	**2.6**	0.6	3.3	**-1.9**	**-4.8**	-0.7	-0.6
32.	Przemyśl	**2.6**	**7.1**	**6.5**	**7.5**	**-4.7**	**-9.9**	**-2.5**	**-4.7**
33.	Kaliningrad	0.9	**9.1**	**7.6**	**6.6**	-1.8	**-6.4**	**-5.4**	**-3.2**
34.	Kaunas	0.2	**8.1**	**5.4**	**8.1**	-1.1	**-7.2**	**-5.5**	**-5.6**
35.	Vilnjus	3.3	**5.6**	**4.1**	**6.5**	-1.3	**-6.6**	**-5.2**	**-4.5**

Boldface – differences between positive and negative extremes are statistically significant

3.2. EA

The EA pattern influences snow cover occurrence mainly in the middle of winter. The value of r is negative and statistically significant (r < -0.3) in the central and north eastern part of the studied area (January). In south eastern Poland absolute values of r exceed 0.5. In February the greatest relationships are observed over Austria, Czech Republic and southern Poland (r < -0.4).

The same areas are most sensitive to the EA pattern extremes. The totals of anomalies in the number of days with snow cover in the positive and negative extremes amount to 17 days in south eastern Poland in January (Fig. 4, Table 3). In December and March the value of r is negative but not significant in most of the stations and even the extremes of the EA pattern do not cause any particular differences in the number of days with snow (Fig. 4, Table 3).

Table 3 Anomalies in the number of days with snow cover in the East Atlantic (EA) extremes. Data for years 1960/1961-1999/2000.

		Negative (EA index <-0.75) (cm)				Positive (EA index >0.75) (cm)			
		XII	I	II	III	XII	I	II	III
1.	Schleswig	2.5	1.6	2.1	0.3	0.2	-6.4	-1.6	-0.6
2.	Rostock - Warnemuende	2.5	3.1	-0.4	0.3	0.2	-4.0	0.0	-0.1
3.	Hamburg	3.0	3.1	0.5	0.2	-1.2	-5.8	-1.0	0.0
4.	Potsdam	1.7	**4.0**	4.2	1.0	0.0	**-6.5**	-2.0	-1.2
5.	Kleve	0.2	2.8	-0.6	1.0	0.4	-3.9	-0.6	-0.2
6.	Braunschweig	3.4	3.5	2.4	1.9	-1.5	-5.2	-0.4	-0.9
7.	Trier	0.5	1.6	1.2	1.3	0.5	-2.9	-1.9	-0.6
8.	Giessen	3.4	3.6	2.6	0.4	-1.3	-4.1	-1.1	0.5
9.	Bamberg	3.8	**4.6**	3.8	0.3	-1.3	**-8.0**	-1.8	0.2
10.	Karlsruhe	1.4	3.5	0.2	0.1	0.3	-3.5	-2.1	0.7
11.	Garmisch Partenkirchen	**3.7**	3.1	**4.6**	1.4	**-1.6**	-2.8	**-3.2**	-2.9
12.	Salzburg	3.7	**5.5**	**8.3**	0.5	-0.7	**-8.2**	**-4.8**	-1.2
13.	Klagenfurt	1.7	1.6	**5.2**	-0.1	-0.1	-5.5	**-3.3**	-1.2
14.	Vienna	2.2	**6.8**	**4.5**	0.4	-0.7	**-7.8**	**-3.8**	0.2
15.	Praha	2.3	**3.5**	5.2	1.5	0.6	**-7.4**	-2.3	-2.1
16.	Ceske Budejovice	4.5	**5.1**	**6.9**	0.6	-0.1	**-6.7**	**-3.3**	0.6
17.	Brno	0.2	**7.1**	**5.8**	0.7	-0.6	**-7.9**	**-2.4**	-1.4
18.	Budapest	1.7	**5.3**	2.1	1.1	2.1	**-4.8**	-0.5	0.9
19.	Szczecin	2.6	**6.0**	0.8	1.1	-0.6	**-6.5**	-0.8	-0.1
20.	Łeba	1.9	**5.2**	1.8	1.0	0.4	**-8.2**	-1.3	0.2
21.	Poznań	2.9	**6.5**	**5.0**	1.3	-0.3	**-7.6**	**-3.3**	-1.2
22.	Legnica	1.6	2.2	4.6	0.6	0.6	-5.8	-2.5	-1.0
23.	Kłodzko	1.3	**7.3**	**7.2**	0.7	1.2	**-8.2**	**-3.8**	-1.9
24.	Częstochowa	0.4	**5.9**	**6.2**	1.7	2.1	**-7.1**	**-2.7**	-1.3
25.	Łódź	1.8	**4.4**	**6.3**	0.6	2.4	**-7.2**	**-2.9**	-1.7
26.	Warszawa	2.3	**5.2**	**5.5**	-0.4	0.5	**-6.0**	**-3.2**	-0.4
27.	Olsztyn	1.9	**4.9**	2.2	0.2	1.6	**-6.2**	-1.9	-0.4
28.	Białystok	0.7	**6.4**	2.2	-0.4	1.4	**-6.3**	-3.2	0.5
29.	Suwałki	-0.6	**5.4**	1.9	0.4	1.4	**-5.9**	-2.7	-1.3
30.	Włodawa	3.3	**6.7**	3.8	0.1	2.4	**-5.9**	-2.9	-0.1
31.	Zakopane	1.0	**3.0**	**1.8**	1.0	0.9	**-4.0**	**-2.9**	-2.7
32.	Przemyśl	2.2	**8.2**	**4.4**	0.5	1.1	**-9.1**	**-4.8**	1.3
33.	Kaliningrad	1.9	**5.1**	0.6	-0.4	1.8	**-7.0**	-1.4	0.0
34.	Kaunas	1.5	**7.0**	3.5	1.8	-0.5	**-8.9**	-3.9	-0.4
35.	Vilnjus	-1.5	**5.1**	0.7	2.8	2.2	**-6.7**	-3.5	0.1

Boldface – differences between positive and negative extremes are statistically significant.

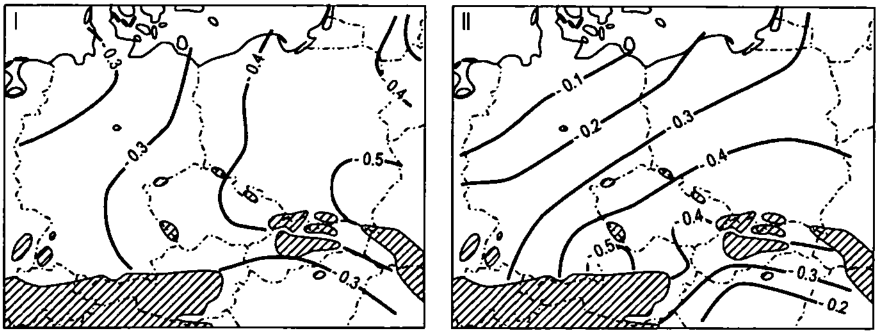

Fig. 4 Correlation coefficient (r) between the monthly number of days with snow cover and the East Atlantic (EA) index (January, February)

3.3. EATL/WRUS

EATL/WRUS pattern influences snow cover occurrence only in the beginning and in the end of winter. In December the value of r is negative over the most of territory. In the area of the strongest relationships (Germany and north western Poland) the absolute value of r exceeds 0.4. The differences in the number of days in the positive and negative phase of EATL/WRUS are most significant in central Germany (up to 13 days). In March the correlation between the EATL/WRUS index and the number of the days with snow cover is weaker, statistically significant only in northern Poland. The extremes of the pattern do not cause any significant changes in the number of days with snow cover (Fig. 5, Table 4).

Table 4 Anomalies in the number of days with snow cover in the East Atlantic/Western Russia (EATL/WRUS) extremes. Data for years 1960/1961-1999/2000.

		Negative (EATL/WRUS index <-0.75) (cm)				Positive (EATL/WRUS index >0.75) (cm)			
		XII	I	II	III	XII	I	II	III
1.	Schleswig	**5.9**	0.7	2.2	1.5	**-3.0**	-5.0	-4.5	0.4
2.	Rostock - Warnemuende	3.4	2.3	1.2	2.2	-2.3	-3.5	-5.0	0.3
3.	Hamburg	**4.7**	-0.2	2.6	1.2	**-3.5**	-4.7	-3.9	1.1
4.	Potsdam	4.9	0.7	1.5	2.3	-2.6	-4.1	-3.6	1.1
5.	Kleve	1.4	2.3	0.3	0.0	-1.6	-0.9	-2.9	0.0
6.	Braunschweig	**5.4**	1.0	0.7	0.6	**-3.1**	-1.8	-3.6	1.0
7.	Trier	**3.2**	1.9	0.0	0.5	**-2.1**	-0.7	-2.3	-0.9
8.	Giessen	**4.3**	2.0	-0.1	-0.1	**-2.9**	-3.0	-3.7	0.9
9.	Bamberg	**7.6**	1.8	-0.2	1.8	**-5.8**	-1.4	-2.6	-0.3
10.	Karlsruhe	3.0	0.1	0.0	0.2	-1.8	-1.2	-1.8	0.7
11.	Garmisch Partenkirchen	**5.1**	-0.6	2.9	2.2	**-1.3**	-0.1	0.0	0.9
12.	Salzburg	**4.1**	-1.2	0.4	1.5	**-3.3**	-3.5	-1.5	-0.4
13.	Klagenfurt	**5.7**	2.2	1.1	2.0	**-5.4**	-2.9	-5.7	1.3
14.	Vienna	1.8	-2.5	0.3	1.4	-0.5	-1.2	0.8	1.2
15.	Praha	4.8	0.5	1.8	2.7	-1.5	-4.8	-1.8	-1.0
16.	Ceske Budejovice	3.0	-1.6	1.0	1.9	0.9	-3.3	-1.6	0.8
17.	Brno	**5.7**	-0.2	1.4	2.6	**-3.1**	-4.8	-2.2	0.0
18.	Budapest	3.8	0.1	1.8	0.7	0.2	1.8	-1.2	2.4
19.	Szczecin	4.9	-1.8	-0.2	2.0	-2.7	-4.3	-3.8	0.6
20.	Łeba	**6.1**	0.0	0.7	6.0	**-4.2**	-8.0	-2.2	-0.5
21.	Poznań	**4.7**	-0.2	1.5	4.1	**-3.6**	-6.3	-1.3	-0.6

Table 4 (continued)

		Negative (EATL/WRUS index <-0.75) (cm)				Positive (EATL/WRUS index >0.75) (cm)			
		XII	I	II	III	XII	I	II	III
22.	Legnica	2.7	-1.2	0.1	2.3	-0.6	-3.8	-1.7	1.6
23.	Kłodzko	1.9	-1.0	-0.1	3.8	-1.5	-4.1	0.1	-0.2
24.	Częstochowa	2.8	-2.4	-0.8	3.9	-0.8	-4.1	-1.4	0.6
25.	Łódź	2.6	-1.6	1.0	3.6	-1.0	-6.5	-1.5	0.1
26.	Warszawa	3.2	-0.4	-0.1	3.0	-3.6	-5.9	-3.1	1.7
27.	Olsztyn	3.3	-1.8	1.8	7.1	-3.0	-5.2	-0.4	0.0
28.	Białystok	1.4	-0.6	2.2	6.6	-1.8	-5.5	-2.1	2.7
29.	Suwałki	1.4	0.9	3.4	8.5	-2.1	-8.5	-2.0	0.9
30.	Włodawa	0.8	-2.5	-0.6	5.4	-0.5	-4.5	-3.4	2.8
31.	Zakopane	-0.7	-1.8	0.8	5.7	1.1	-0.6	-0.1	0.3
32.	Przemyśl	0.1	-4.0	-0.6	4.7	1.2	-3.4	-0.6	1.8
33.	Kaliningrad	3.7	1.7	2.2	5.9	-1.6	-7.0	-0.6	1.0
34.	Kaunas	3.0	1.9	2.8	7.5	-1.6	-7.7	-2.2	2.2
35.	Vilnjus	0.7	0.2	2.6	5.7	-0.4	-3.3	-1.3	5.0

Boldface – differences between positive and negative extremes are statistically significant

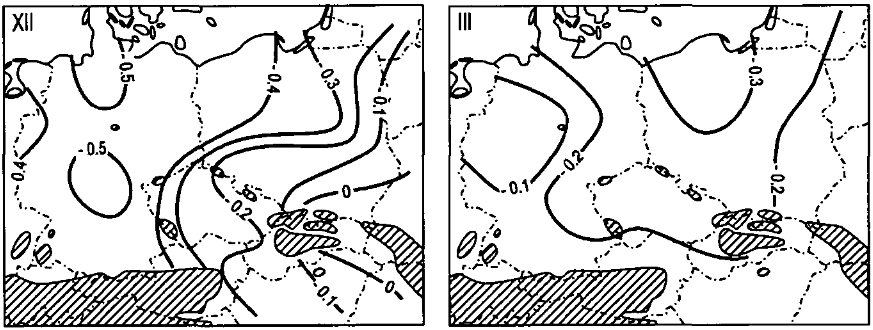

Fig. 5 Correlation coefficient (r) between the monthly number of days with snow cover and the East Atlantic/Western Russia (EATL/WRUS) index (December, March)

3.4. SCAND

Table 5 Anomalies in the number of days with snow cover in the Scandinavian type (SCAND) extremes. Data for years 1960/1961-1999/2000.

		Negative (SCAND index <-0.75) (cm)				Positive (SCAND index >0.75) (cm)			
		XII	I	II	III	XII	I	II	III
1.	Schleswig	0,8	0,8	-5,9	-1,8	3,2	-1,6	1,7	0,2
2.	Rostock - Warnemuende	0,7	-0,1	**-8,2**	-2,0	2,2	-0,4	**1,5**	2,3
3.	Hamburg	1,4	2,0	-5,3	-1,6	3,0	-2,1	1,0	-0,1
4.	Potsdam	2,5	0,5	-6,9	-2,4	2,1	1,3	-0,3	1,0
5.	Kleve	0,7	1,4	-2,8	-0,3	-1,8	-3,3	0,6	0,1
6.	Braunschweig	0,1	0,3	-5,9	-2,0	2,0	-0,9	0,5	1,3
7.	Trier	0,7	1,9	-2,6	-0,5	-1,1	-2,1	1,1	0,2
8.	Giessen	0,8	2,3	-5,6	-1,0	0,2	0,6	0,3	0,1
9.	Bamberg	0,5	-0,3	-5,5	-1,7	2,3	1,3	0,6	0,7

Table 5 (continued)

		Negative (SCAND index <-0.75) (cm)				Positive (SCAND index >0.75) (cm)			
		XII	I	II	III	XII	I	II	III
10.	Karlsruhe	-1,1	0,5	-4,2	-1,0	-0,1	-1,0	2,1	0,5
11.	Garmisch Partenkirchen	1,6	1,3	-3,8	-4,5	-0,1	2,1	1,8	0,6
12.	Salzburg	2,6	-1,2	-6,3	-3,4	2,3	3,1	-0,3	-0,1
13.	Klagenfurt	-3,1	-0,8	-7,7	**-6,1**	-1,0	3,8	**2,5**	**6,0**
14.	Vienna	0,5	-0,3	-5,8	**-3,1**	1,0	3,4	2,2	**2,3**
15.	Praha	1,6	-0,7	-5,2	-2,4	2,5	2,5	-0,9	0,7
16.	Ceske Budejovice	1,6	0,2	-4,9	**-3,1**	0,7	0,9	-1,6	**1,6**
17.	Brno	-0,9	1,2	-4,4	-1,1	0,0	0,1	0,0	2,2
18.	Budapest	4,2	2,0	-1,3	-0,2	1,0	1,3	2,9	2,5
19.	Szczecin	2,2	1,5	-7,0	-2,2	2,3	0,2	0,3	0,8
20.	Łeba	1,7	0,8	**-9,6**	**-3,3**	2,6	2,3	**3,1**	**4,0**
21.	Poznań	3,6	0,4	-7,3	-2,7	2,4	3,1	0,7	1,9
22.	Legnica	1,8	0,3	-6,1	-1,9	2,8	4,2	0,7	0,4
23.	Kłodzko	1,0	1,0	-5,1	-2,2	0,6	-0,6	-1,2	0,2
24.	Częstochowa	3,1	0,1	-5,8	-2,8	-1,1	2,2	-1,1	2,3
25.	Łódź	3,4	0,7	-8,4	-3,1	0,1	3,2	-0,7	2,1
26.	Warszawa	2,3	0,6	-9,0	-3,0	1,2	3,1	-0,6	1,9
27.	Olsztyn	2,4	0,5	**-9,7**	-2,7	1,6	3,2	**5,7**	4,1
28.	Białystok	3,0	0,3	**-11,6**	**-5,5**	1,2	1,7	**4,0**	**5,5**
29.	Suwałki	2,2	0,1	**-10,9**	**-5,4**	1,4	4,9	**3,9**	**6,6**
30.	Włodawa	3,1	-0,8	**-9,6**	**-5,1**	1,6	3,8	**1,8**	**5,5**
31.	Zakopane	1,7	1,1	-3,3	-3,2	0,1	0,9	1,0	1,5
32.	Przemyśl	1,9	1,4	-6,3	**-4,6**	2,5	1,8	0,9	**5,0**
33.	Kaliningrad	4,0	0,2	**-10,5**	-3,4	2,5	2,3	**5,7**	3,3
34.	Kaunas	2,7	0,0	**-11,3**	**-4,9**	1,6	2,6	**5,2**	**6,0**
35.	Vilnjus	0,2	-0,2	**-9,5**	**-6,3**	2,4	1,5	**4,1**	**5,0**

Boldface – differences between positive and negative extremes are statistically significant.

Very weak positive correlation between the SCAND circulation pattern and snow cover is observed in Central Europe. The SCAND pattern gains importance only in February and March in the north eastern edge of the studied area. The value of r amounts to 0.4 in Lithuania and north eastern Poland. In the same regions strong anomalies in the number of days with snow cover below/above average occurring in negative/positive SCAND extremes (Fig. 6, Table 5).

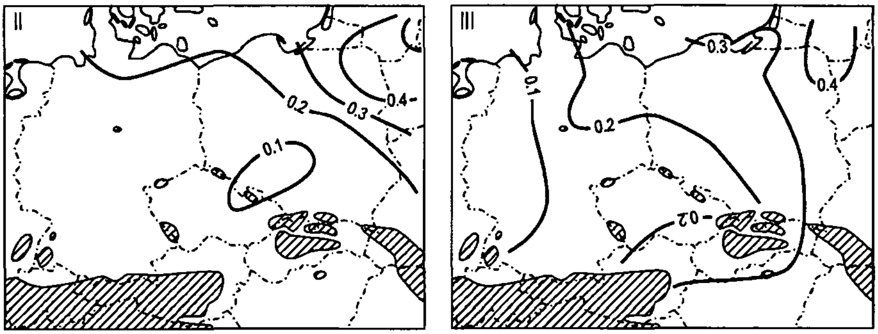

Fig. 6 Correlation coefficient (r) between the monthly number of days with snow cover and the Scandinavia (SCAND) index (February, March)

4. DISCUSSION AND CONCLUSIONS

The influence of the NAO on snow cover in Central Europe is obvious and it has been confirmed by several studies (Gutzler and Rosen 1992, Clark et al. 1999, Falarz 2002, Bednorz 2002, 2004). However, the impact of this circulation pattern on snowiness in our continent is both spatially and temporally variable. The NAO is well known to have a significant impact on the European air temperatures (Hurrell 1995, Wibig 2001). The predominant westerly air flow caused by the strong subtropical Azores High and the polar Icelandic Low at the positive phase of the NAO brings mild maritime air over Europe and causes an increase in the air temperature. In Central Europe, where average air temperatures in winter months are slightly below zero such increases usually mean going above the melting point and they result in thaws. These fluctuations of the air temperature over and below 0°C are the main factor determining the appearance and disappearance of snow cover (Jaagus 1997, Clark et al. 1999, Falarz 2002, Bednorz 2002, 2004). The strongest correlation between the monthly number of days with snow cover and the NAO index found in the north-central part of the studied area can be explained primarily by the fluctuations in the air temperature. This correlation weakens to the east and northeast, where the winter temperature is constantly well below zero. The NAO impact on snow cover is limited to about 30° λ E (Bednorz 2004). East to this area snow cover occurrence is controlled mainly by precipitation, which is slightly below-normal under the NAO negative phase. The snow cover – NAO relationships also diminish towards the west and to the south, where snow cover, appearing for a few days in a month, can be considered an ephemeral phenomenon. In addition, the southern area is isolated from westerly and northwesterly airflows by the Alpine and Carpathian range.

When investigating the Eurasian snow cover extent, Clark et al. (1999) have found strong negative snow cover signals over Central Europe in the positive NAO extremes. The opposing snow-extent increases in the negative NAO mode are not significant there. This study confirms that the NAO extremes cause significant anomalies in the number of days with snow cover in January, February and March. Weaker relationships are observed in the beginning of winter.

No other circulation pattern has as much impact for snow cover occurrence in Central Europe as the NAO. However, in some areas, during particular winter months some significant relationships are observed. The EA pattern influences snow cover occurrence in the middle of winter. The area of strongest relationships between snow cover and EA is shifted to the southeast, in comparison to the area of strongest relationships between snow cover and NAO.

The negative phase of the EATL/WRUS pattern with low over Great Britain or France and high over the Caspian Sea can cause stronger than usual cyclonic activity over north Western Europe. Lows moving over west Europe may bring north western air masses resulting in snowfalls, which may appear particularly in Germany in the beginning of winter.

Clark et al. (1999) have found some fluctuations of the European snow extent during the Eurasian Type 1 pattern which is similar to the SCAND pattern. Over Europe, small increases in snow extent are observed in both positive and negative Eurasian Type 1 extremes. In this study positive significant fluctuation in the number of days with snow cover are detected only in the positive extreme of SCAND and they are limited to Lithuania and the north western edge of Poland. In the positive phase of SCAND an anticyclone persists over Scandinavia. It brings dry but very cold air over Eastern Europe (Wibig 1999). It suppresses total precipitation, but may be favourable for snow persistence.

Analysis based on monthly characteristics gives the general idea of snow cover – circulation relationships. Closer analysis involving the daily data would allow determining precisely which kind of circulation patterns and synoptic situations are favourable for snow cover forming and persistence.

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