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SYNOPTIC STUDY OF THE HEAVIEST SNOWFALLS IN POZNAŃ SINCE 1960/61 TO 2009/2010

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Summary: Composite maps of the sea level pressure and 500 hPa geopotential heights means and anomalies were constructed for the days with the high snow accumulation in Poznań. Similar maps of the air temperature at the isobaric level 850 hPa and of precipitable water content were presented. Additionally, 48-hours back trajectories of air masses for chosen days with the most effective snowfalls were constructed, using the NOAA HYSPLIT model. Negative anomalies of sea level pressure and 500 hPa heights, which mean low pressure systems spreading over Europe, are the basic condition of abundant snowfalls in Poznań. Snowfalls may appear as a result of fronts in the colder parts of Mediterranean cyclones with the dynamic warm and humid air of distant southern origin climbing upwards on the cooler and more stabile polar air masses from the north or east. The alternative location of snow-bringing low pressure systems is the Baltic Sea region.

Key words: snowfalls in Poland, air circulation, synoptic conditions, back trajectories

1. INTRODUCTION

Winter in the European moderate zone is a very changeable season, with mild periods alternating with the cold ones, the latest being often accompanied with snowfalls or even heavy snowstorms. These severe weather events may have a strong economic impact. Abundant snowfalls, often simultaneous with low temperatures, may cause traffic hazards, communication problems, and power shortages; consequently, they can paralyze community life. The European community experienced such events for example in the end of November 2005 after short but strong snowstorms which took place in Germany and Western Europe. Dramatic events took place in Bavaria in January 2006 when a deep snow accumulation after heavy snowfalls crushed building structures, and caused the collapse of the roof of the ice rink, and also in Katowice (Poland), where the exhibition hall collapsed during the racing pigeon show. Both tragedies brought many deaths and injuries.

Serious social and economic effects justify research into the synoptic reasons for heavy snowstorms, as it may be helpful in forecasting such weather events. Snow occurrence is determined by the air temperature, precipitation and, indirectly, by the inflow of particular air masses. The atmospheric circulation is a driving factor for weather conditions in winter and it is responsible for the above mentioned intra-seasonal variability of the winter weather in the moderate zone. The aim of this study is to find the daily circulation patterns and daily synoptic conditions responsible for abundant snowfalls in Poznań, resulting in daily increase in snow cover depth by at least 10 cm. Closer analysis of synoptic conditions of heavy snowfalls may be helpful in recognizing circumstances of these phenomena, however rare, but having a strong economic impact.

The analysis of severe snowstorms formation in Europe has already been performed in a regional scale, for example for the Swedish east coast (Andersson and Nilsson 1990, Andersson and Gustafsson 1993). The synoptic classification of severe snowstorms in Austria has been worked out by Spreitzhofer (1999a, 1999b). Bednorz (2008) has found circulation patterns responsible for heavy snowfalls in the German-Polish lowlands. Babolcsai and Hirsch (2006) have worked out detailed characteristics and synoptic classification of heavy snowfall events in Budapest for the period 1953-2003, consisting of eight weather types. Most of them were connected with different kinds of Mediterranean cyclones and additionally with secondary lows in north-western Europe. In this study the detailed analysis was performed for Poznań, located in the central Europe.

The extent of the seasonal snow cover is going to decrease in central Europe, according to climate projections (EEA 2012, 2013). The increase in winter precipitation expected in most models will not mean more snow on the ground, as snow cover is sensitive to winter temperature as well as to snowfalls (Raisanen 2008, Raisanen and Eklund 2012). Number of days with snowfall above 10 cm will increase only in the north and they will probably decrease in other parts of Europe. Also the reduced number of snow cover days is expected in the analyzed region (Kjelstrom et al. 2011). In such context research on the synoptic conditions of high snow occurrence in a central European station seems to be justified.

2. MATERIAL AND METHODS

In this study, the intensity of snowfalls was evaluated by the increase in the snow cover depth accumulated on the ground. Snow depth observations at the meteorological stations are taken once a day at 6:00 UTC with 1 cm precision. The days when the snow has a depth of ≥ 1 cm are considered as the days with snow cover. For the purpose of the study, the days during which snow cover depth increased by ≥ 10 cm were selected. Changes in the snow cover depth were calculated by subtracting the snow cover depth of a given day from the snow cover depth of the following day. Daily data of snow cover depth in the station of Poznań Ławica, regarding 50 winter seasons from December to March 1960/1961-2009/2010, was derived from the Institute of Meteorology and Water Management dataset. Besides, the extreme 2-, 3-, 4- and 5-days lasting events of snow accumulation were identified.

In order to describe the circulation, daily sea level pressure (SLP) and 500 hPa geopotential heights (Z500) data were selected from the National Centers for Environmental Prediction (NCEP) – National Center for Atmospheric Research (NCAR) reanalysis data (Kalnay et al. 1996). From the same source, grid-based temperature values at isobaric level 850 hPa (T850) and the content of precipitable water (PW), were obtained and used in the study. The PW index designates the mass of water contained in the column of air above the unit surface area, irrespective of the state of aggregation, and is expressed in kg m^{-2} (Wibig and Siedlecki 2007).

Firstly, the correlation coefficients between the daily snow increases, reaching and exceeding the critical values of 5 cm and 10 cm and the daily values of SLP and Z500 in the grid points in the area 35-70°N latitude by 35°W-40°E longitude were calculated and mapped. Rikiishi and Sakakibara (2004), analyzing the intensity of snow accumulation in the territory of the former Soviet Union, have calculated the pentad differences in the depth of snow cover and referred these to atmospheric circulation.

Furthermore, composite maps of the SLP Z500 means and anomalies were constructed for the days with increase in the snow cover depth of ≥ 10 cm. Anomalies were computed as differences between composite values and multiannual means of the winter season. Similar anomaly maps of T850 and PW were constructed. The composite analysis has been used previously to identify the atmospheric circulation patterns associated with heavy snowfalls in the mountains (Birkeland and Mock 1996). Finally, 48-hours back trajectories of air masses for three chosen days with the most effective snowfalls (i.e. days with the highest snow accumulation), were constructed, using the NOAA HYSPLIT model (Rolph 2012, Draxler and Rolph 2012, http://ready.arl.noaa.gov/HYSPLIT.php). The model analyzed the movement of air masses for three altitudes above sea level: 300-500 meters (corresponding to the medium level of the mixing layer), 1500-2000 meters (corresponding to the mean altitude of isobaric surface 850 hPa) and 4000-5000 meters (corresponding to the altitude of isobaric surface 700-500 hPa). An analysis of air trajectories at the three altitudes provided significant input to the information obtained from synoptic maps and made it possible to identify the probable source area of air masses causing snowfalls. This method is often used to detect the source area of pollution deposit (Avila and Alarcon 1999, Salvador et al. 2010).

Additionally, the synoptic maps from 00:00 UTC for the days with extreme snow accumulation were collected from the Institute of Meteorology and Water Management database and used to identify the precise synoptic conditions of the selected cases of extreme snowfalls.

3. RESULTS

Poznań is situated in the least snowy region in Poland, where the mean annual number of days with snow cover does not reach 50 days (Bednorz 2011). The Poznań Ławica station experiences on the average 48 days with snow cover a year, however there are on the average 17 days with snow accumulation noted in the station.

16 cases of snowfalls resulting in a snow depth daily increase by at least 10 cm were identified in Poznań during 50 winter seasons 1960/61- 2009/10 (Table 1). Four of them were noted in the snowy period of the 1960s and three in the beginning of the 1970s. Seven cases were reported in the 1980s, four of them happened in the snowy season 1985/86. The further two decades, regarded as not snowy ones, experienced only two events of extreme snow accumulation in Poznań. The maximum daily snow accumulation, resulting in snow cover depth increase by 17 cm, was recorded in the beginning of March 1965. Snowfalls could persist for more than one day when the low pressure systems with the snow-bringing fronts moved over Central-Europe. Therefore the cases when a great amount of snow came in a short time period (from 2 to 5 days) were also identified (Table 2). The 2-days snowfall exceeding 10 cm may happen once a year on the average and the 3-days snowfall of the same effectiveness (i.e. causing the increase in snow cover depth by at least 10 cm) may happen twice a year. However, the annual number of cases of snowfalls lasting 1-5 days and resulting in snow cover increase by ≥ 10 cm, varies from year to year (Fig. 1). In the least snowy winters (i.e. 1972/1973, 1983/1984, 1988/1989, 1996/1997, 1997/1998, 2000/2001, 2002/2003, 2007/2008, 2008/2009) there were no such days at all, while in the most snowy

winters (i.e. 1968/1069, 1969/1970, 1978/1979, 1985/1986, 1987/1988) there were over a dozen of such cases. In the last two decades (1990-2010) the number of abundant snowfall events has been smaller than in the 1960s and 1980s, however there is no statistically significant trend of changes in the 50-years period. Events of snowfalls lasting several days and causing at least 20 cm snow accumulation are very rare and they happened in the seasons 1964/65, 1969/70 and in December 2001.

Table 1 Events of the daily snow cover increase by ≥ 10 cm in Poznań in winters 1960/61-2009/10

Data	**Daily snow cover increase in cm**
03-03-1965	17
08-03-1966	10
26-12-1968	10
26-11-1969	11
16-01-1970	14
02-03-1970	11
29-11-1973	10
29-12-1985	10
26-01-1986	11
19-02-1986	11
10-04-1986	13
12-01-1987	12
30-01-1988	13
08-03-1988	11
19-11-1993	10
20-02-1996	10

Table 2 Number of cases with the highest snow cover increase in Poznań in winters 1960/61-2009/10

Length of the period	**Snow cover increase by**		
	≥ 10 cm	**≥ 15 cm**	**≥ 20 cm**
1 day	16	1	0
2 days	50	4	1
3 days	98	10	2
4 days	165	19	9
5 days	246	22	9

The correlation coefficients between the daily snow increases by at least 5 cm and the daily values of SLP and Z500 in the grid points show distinctly the areas of negative relationships, which indicate instant pressure decreases, accompanying abundant snowfalls (Fig. 2, left). The centre of the negative correlation falls to the south of Europe, exactly to the Venice Bay on the Adriatic Sea. The same computing performed for 16 cases of the highest snow accumulation allowed to produce the second correlation map (Fig. 2, right), where two centers of negative correlation appear, one of them located south of Poland, and the other one west to the British Islands.

Abundant snowfalls in Poznań, resulting in a snow cover depth increase by at least 10 cm are coexistent with a deep and vast low pressure system extending over Central-Europe (Fig. 3, left). Negative SLP anomalies exceed -12 hPa over the cyclone centre, while Z500 lowers by over 200 gpm (Fig. 3, right). The negative center of the SLP correlation field is shifted towards the south-east, regarding the negative center of the Z500. At the same time, higher-than-normal pressure is observed over the northern Atlantic, with a centre of positive anomalies (> 9 hPa) right over Island, which may be associated with the negative phase of the North Atlantic Oscillation (NAO). Contours of Z500 constructed for the days with snow cover increase by at least 10 cm bend to the north over the Atlantic and to the south in central Europe, suggesting northerly and northwesterly flow in the middle troposphere over Western-Europe. At the same time, such pressure pattern indicates eastern and northeastern airflow in the lower troposphere. High pressure trough extending over Scandinavia may intensify the eastern and northeastern airflow over the Baltic Sea and northern Poland.

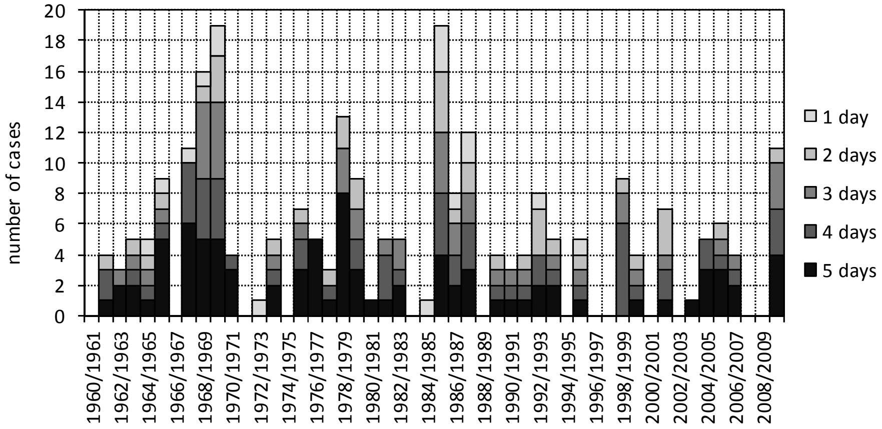

Fig. 1 Seasonal number of cases with snow cover increase by ≥ 10 cm during 1-, 2-, 3-, 4-, and 5-days periods

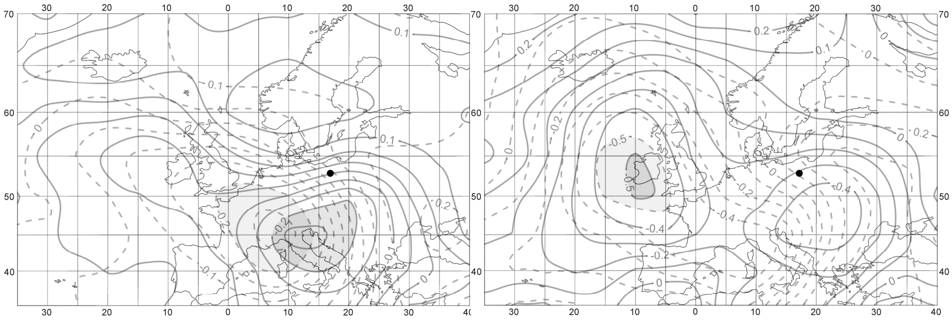

Fig. 2 Correlation coefficients between the daily values of SLP (solid lines) Z500 (dashed lines) and the daily snow increases of at least 5 cm (left) and 10 cm (right) in Poznań. Statistically significant values are shaded, location of Poznań marked with a dot

Contours of Z500, cutting the central European low meridionally, allow distinguishing a colder part of the SLP low in the north and a warmer part in the south. In the colder part, higher air density decreases the Z500, which is more than 300 gpm lower than in the southern part. Poznań is placed in the cold northeastern section of the low pressure system. Strong negative anomalies of T850 are observed over entire Europe, excluding the southeastern outskirts (Fig. 4). Temperature is lower than normal by 3-6 deg over central Europe and by 7-8 deg in the northern Europe. Negative PW anomalies are correlated to low temperatures over Europe and they are distributed similarly.

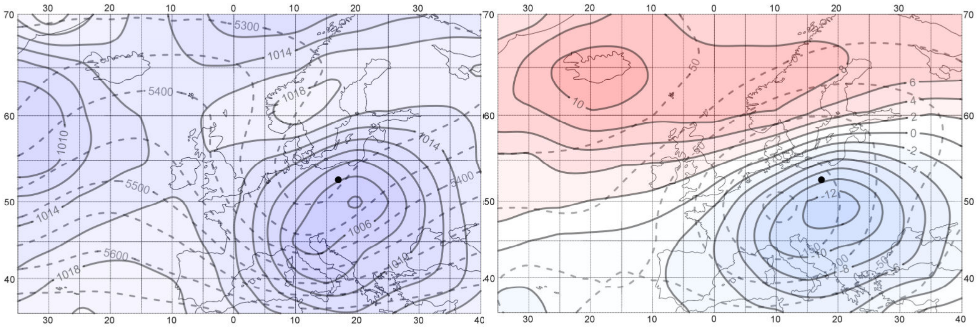

Fig. 3 Composite map (left) and anomaly map (right) of SLP (solid lines) and Z500 (dashed lines) for the days with snow cover increase by at least 10 cm in Poznań.
Location of Poznań is marked with a dot

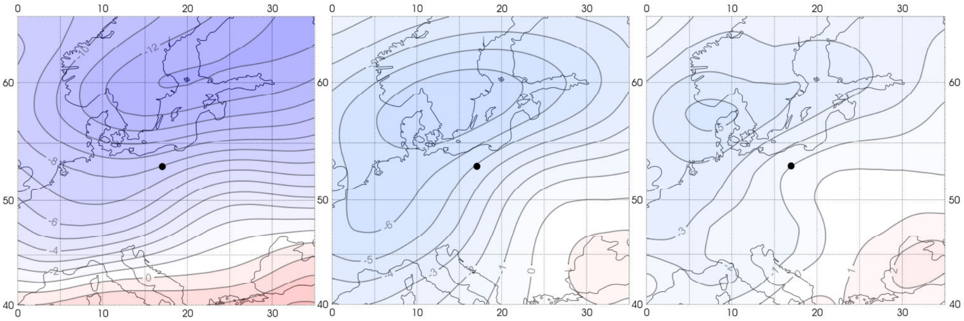

Fig. 4 Composite map (left) and anomaly map (middle) of T850 and anomaly map of PW (right) for the days with snow cover increase by at least 10 cm in Poznań.
Location of Poznań is marked with a dot

Obviously, the circulation patterns observed during the selected 16 days of snow depth increase by at least 10 cm in Poznań were not identical. The detailed analysis of several synoptic maps allowed finding differences in the position of cyclonic centers over Europe. The synoptic map of 12 January 1987 represents the typical location of a low-pressure system for most of analyzed cases. It spreads in the south of Europe, in the Mediterranean region, with one center located over the Balkan Peninsula and a secondary centre over Italy and the Adriatic Sea (Fig. 5). At the same time a strong anticyclonal ridge spreads latitudinally over Scandinavia and northeastern Europe. The air pressure in a local centre over central Scandinavia exceeds 1050 hPa. The high pressure system over Northern-Europe preserves very cold air, of the polar continental origin, coming from the eastern direction in the lower troposphere. On the other hand the south cyclone is a reservoir of warm air from the Mediterranean. The meeting of these two elements results in heavy snowfalls in Central-Europe. The described processes signify warm front structure, with the dynamic warm and humid air of distant southern origin climbing upwards on the cooler and more stable polar continental air masses from the east. The demonstration of such a situation is shown at back trajectories at Fig. 5 drawn for the snowstorms on 12-13 Jan 1987 (12 cm of the new fallen snow). A quite similar situation took place on the 19-20 Feb 1986 (11 cm of the new fallen snow), with the cyclonal systems in the south of Europe and anticyclonal centre over northeastern Europe (Fig. 6).

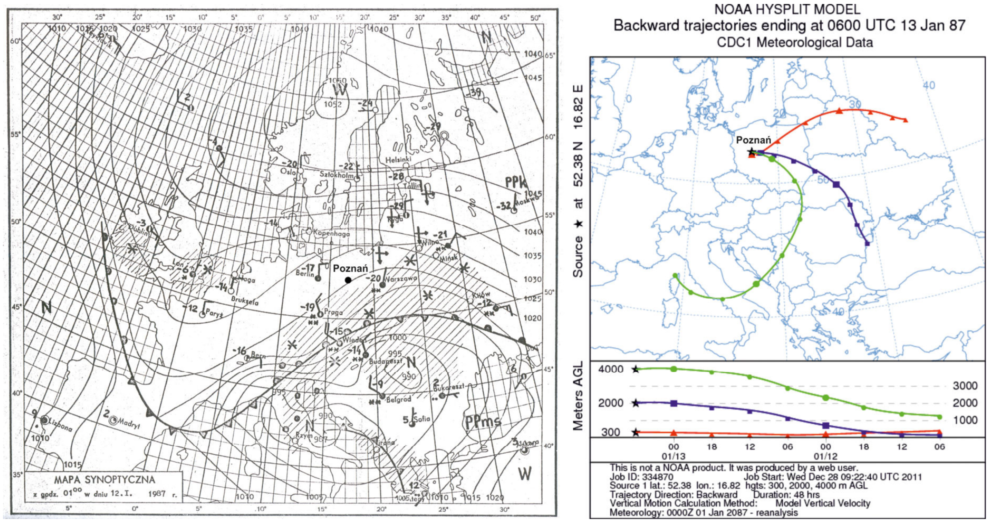

Fig. 5 Synoptic map and the 48-hours back trajectories of air particles at heights of 300 m (triangles), 2000 m (squares) and 4000 m (circles) above ground level for 12-13 January 1987

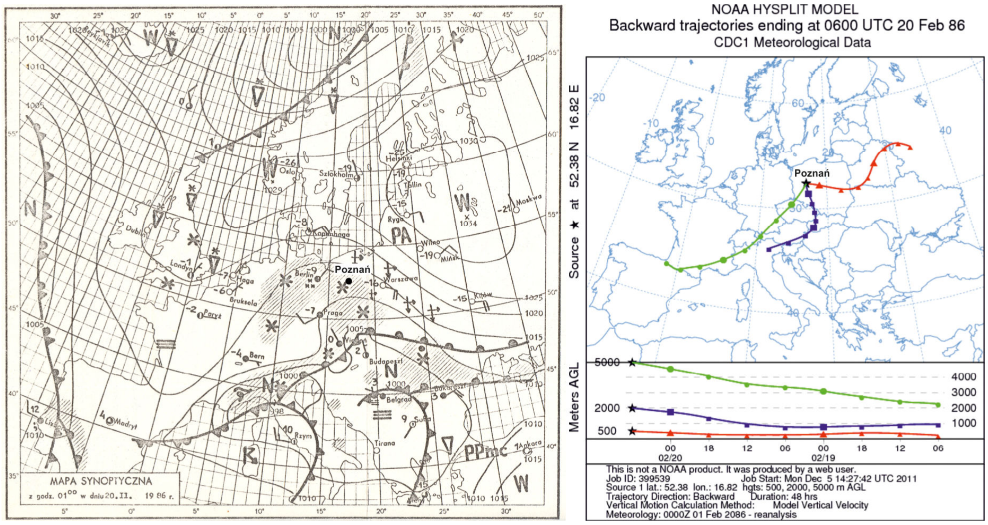

Fig. 6 Synoptic map and the 48-hours back trajectories of air particles at heights of 500 m (triangles), 2000 m (squares) and 5000 m (circles) above ground level for 20 February 1986

The situations, when the cyclones, bringing heavy snowfalls to Poznań spread over Central-Europe are distinctly rarer. Only 30% of all distinguished cases of abundant snowfalls are caused by low pressure systems with heir centers located right over Poland, over northern Germany or northeast of Poland, as shown at Fig. 7. The small, but rather deep centre formed over the Baltic Sea and east thereof causes the northern flow of the arctic air to entire Poland at all tropospheric levels (Fig. 7). This time the Baltic Sea is a source region for the abundant snowfalls (11 cm of the new snow), as may be concluded from the back trajectories of the air masses.

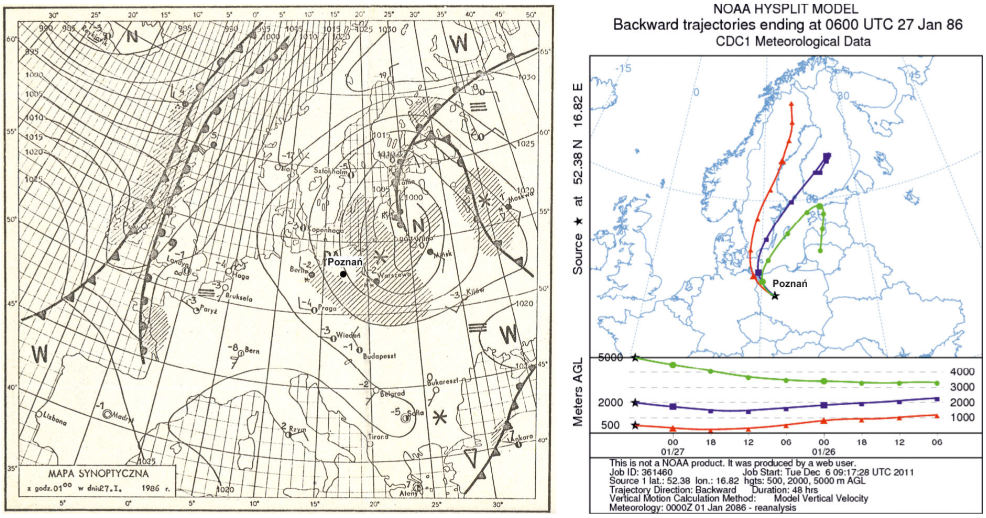

Fig. 7 Synoptic map and the 48-hours back trajectories of air particles at heights of 500 m (triangles), 2000 m (squares) and 5000 m (circles) above ground level for 27 January 1986

4. DISCUSSION AND CONCLUSIONS

Abundant snowfalls in Poznań, resulting in high snow accumulation and increase in snow cover depth, are associated with negative anomalies of both SLP and Z500 over the central and southern part of the continent, which means widespread low pressure systems over Southern-Europe. Snowfalls, which are directly determined by the air temperature and precipitation and indirectly by the inflow of particular air masses, appear as a result of fronts in the colder parts of Mediterranean cyclones. Low pressure centers are often situated over the Balkan Peninsula or over Italy and the Adriatic Sea. At the same time the high pressure system spreads over Scandinavia and northeastern Europe. Such pressure pattern causes the southeastern air inflow over Poland. The eastern sector of inflow dominates in the lower troposphere, bringing dry, but very cold polar continental air, while in the upper troposphere the southern inflow of warm and humid air of a Mediterranean origin is observed. The structure described in the study signifies the warm front, with the dynamic warm and humid air of distant southern origin climbing upwards on the cooler and more stable polar continental air masses from the east. The meeting of these two elements results in snowstorms in Central-Europe.

The alternative, although rarer location of low pressure systems causing abundant snowfalls in Poznań is northeastwards of Poland or right over Central-Europe, with the Baltic Sea or Atlantic Ocean being a source region of the humid and relatively cold air.

The described pressure patterns and anomalies causing abundant snowfalls in Poznań, namely the cyclonal activity over the continent and simultaneous weakening of Icelandic Low, correspond to the negative NAO phase, which has been proven to contribute to a large snow cover extent in Europe (Gutzler and Rosen 1992, Clark et al. 1999, Bednorz 2002, Falarz 2007, 2013). It has been also proved that during the negative phase of NAO the number of Mediterranean cyclones, which contribute to abundant snowfalls in central Europe, is larger compared to the positive NAO phase (increase by 20%) and the mean European cyclone path is shifted southwards (Pinto et al. 2009, Nissen et al. 2010, Lionello (ed.) 2012).

The positive phase of NAO results in less snowy winters in western Poland, whereas the negative phase increases the probability of snowy winters (Bednorz 2002). The key to explain such a relationship is the air temperature. NAO is well known to have a significant impact on European air temperatures (Hurrell 1995). The predominant westerly air flow caused by the strong subtropical Azores High and the deep polar Icelandic Low at the positive phase of NAO brings mild maritime air over Europe and causes an increase in the air temperature. In Poznań, where average air temperatures in winter months are slightly below zero (Jan -1.6°C, Feb -0.9°C) such increases usually mean going above the melting point and they result in thaws. During the negative phase of NAO, the northeast and east flow is predominant. They bring the north arctic air or the cold continental air from the winter Siberian High to western Poland.

Heavy snowfalls in Poznań may appear only at the condition of negative temperature anomalies, extending over most of the continent (Bednorz 2011). However, despite of high humidity of snow-bringing air masses, the content of PW in the atmosphere over Poland during the days of high snow accumulation is not higher than average. It is because PW and the air temperature are positively correlated and the highest degree of relationship is observed in winter in the middle and high latitudes (Smith 1966, Viswanadham 1981).

Similar low pressure systems (one with a centre over the Baltic Sea and the other the Mediterranean) were defined by Spreitzhofer (1999b, 2000) as typical weather patterns related to intense snowfalls in Austria. Also Scherrer and Appenzeller (2006) defined cyclonic activity over southeastern Europe being one of important factors causing snowfalls in the Swiss Alps.

Concluding, the atmospheric circulation and consequently the synoptic conditions are the main factors contributing to the occurrence of the extreme winter weather events i.e. heavy snowfalls in central Europe. Therefore, analyses of the circulation and synoptic conditions associated with heavy snowfalls, as undertaken in this study, may improve forecasts of snowstorms occurrence and may give a chance to protect the community from their economic impact.

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