SYNOPTIC CONDITIONS OF HEAVY SNOWSTORMS IN EUROPE

Ewa Bednorz

Adam Mickiewicz University in Poznań, Department of Climatology, Dzięgielowa 27 60-61-680 Poznań, Poland, ewabedno@amu.edu.pl

(Dated: 26 August 2011)

I. INTRODUCTION

Despite of the warming effect observed in the winter season in several regions in Europe, the frequency of heavy snowstorms in the central part of the continent does not decrease. These severe weather events may happen all over the cold season and they may have a strong economic impact. Snowstorms, often simultaneous with low temperatures, may cause traffic hazards, communication problems, power shortages and consequently, they can paralyze the community life. Serious social and economic effects of severe snowstorms 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 over mentioned intra-seasonal variability of the winter weather in the moderate zone.

Therefore, the aim of this study is to find the daily circulation patterns and daily synoptic conditions responsible for heavy snowstorms in different locations in Europe. Closer analysis of snowstorms conditions may be helpful in recognizing circumstances of these phenomena, however rare, but having a strong economic outcome.

The analysis of severe snowstorms formation in Europe has been performed in a regional scale, for example for the Swedish east coast (Andersson and Nielsson, 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 snowstorms in the German – Polish lowlands. In this study the analysis was performed for four locations within the central part of Europe.

II. MATERIAL AND METHODS

In this study, the days with snowstorms were selected using the criterion of daily sums of snowfalls (in cm). Daily snowfalls totals of at least 10 cm were qualified as snowstorms. The analysis was performed for four stations: Oslo (Norway) which represents northern part of Europe, Bremen (Germany) located in the western part, Smolensk (Russia) in the eastern Europe and Budapest (Hungary) located south to the Carpathian range. Stations are distant from each other and they represent regions of different winter climate conditions. Daily data of snow cover depth in each of the four stations, regarding 40 winter seasons 1960/1961-2009/2010, derived from the European Climate Assessment dataset, were used. For the purpose of the study, the days during which snow cover depth increased by ≥ 10 cm were selected.

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.

Firstly, the correlation coefficients between the daily snow increases 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, for each station separately. Furthermore, composite maps of the SLP and 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 contour maps of T850 and PW were constructed. Finally, 48-hours back trajectories of air masses for the chosen days with the most effective snowstorms, were constructed, using the using the NOAA HYSPLIT model (http://ready.arl.noaa.gov/HYSPLIT.php). The model analyzed air masses movement for three altitudes above sea level: 300-500 meters (corresponding to the central part of the mixing layer), 1500-2000 meters (corresponding to the mean altitude of isobaric surface 850 hPa) and 3000-5000 meters (corresponding to the altitude of isobaric surface 700-500 hPa). An analysis of air trajectory at the three altitudes provided significant input to the information obtained from synoptic maps and made it possible to identify probable source area of air masses causing snowfalls.

III. RESULTS

The correlation coefficients between the daily snow increases and the daily values of SLP and Z500 in the grid points, mapped for each station separately, showed distinctly the areas of negative relationships, which indicated low pressure systems accompanying snowfalls. The intensity and location of the lows varies, however, depending on the region receiving snow. Snowfalls in Oslo are coexistent with the weak SLP and Z500 depression over the area between the North Sea and the Norwegian Sea. The negative center of the SLP correlation field is shifted towards the south east, regarding the negative center of the Z500. This indicates the south eastern movement of the low pressure system. Snowfalls in Smolensk are conditioned by the pressure depressions located over the eastern and central part of the continent and also moving towards the south east. Lows of similar location bring snowfalls in Bremen, but this time low pressure systems are deeper and they extend towards the west, reaching the British Islands. Quite different location of the SLP and Z500 depressions cause snowfalls in the southern area, represented by Budapest located behind the Carpathian Range. This time the correlation field show deep and vast depression with a center located over the north Mediterranean.

During 50 winter seasons taken to the analysis there 88 cases of snowstorms (with snow accumulation ≥ 10 cm) were recorded in Oslo. Such events require deep low pressure system over the north Atlantic, with the anomalies of SLP in the centre exceeding -12 hPa, observed over the southern part of the Norwegian Sea (Fig. 1). Similar anomalies appear in the middle troposphere, where the Z500 is lowered by 100 gpm. Such pressure pattern remains the positive phase of the North Atlantic Oscillation, with the northern center shifted to the east. Snowstorms in Oslo are not much related either to the T850 anomalies, nor PW content in the atmosphere. The 48-hours back trajectories constructed for chosen days with extremely heavy snowstorms in Oslo show the transport of air particles from west and south west. These humid Atlantic air masses lift slowly, like in the typical warm front structure. At the same time in the low troposphere southern or south eastern flow of slightly colder air masses is observed.

The 33 days with snowstorms in Smolensk were selected to the further analysis. Composite map show a vast trough of low pressure over Scandinavia with a small, but rather deep centre formed over the Baltic Sea and east thereof. It is an area of strong SLP and Z500 anomalies. The position of the anomaly centers indicates eastward or southeastward movement of the low, which may origin from the north Atlantic or closer – from the Baltic Sea. The interpretation of the contoured composite anomalies is similar to the traditional weather anomaly maps, with clockwise (anticyclonic) flow around the positive centers and counterclockwise (cyclonic) flow around the negative centers (Birkeland and Mock, 1996). Therefore, the humid air masses bringing snowstorms come from the west or from the south. Back trajectory show the transport of air particles from west, the upper stream bringing the distant air masses from Atlantic. Humid air masses may also come from the Mediterranean, lifting from the ground level to the height of 5 km, which signifies warm front structure. The southern path of the air masses runs through an area of distinct positive PW anomalies.

The 49 cases of snowstorms were reported during the 50-year period in Budapest. A contour composite map, drawn for these cases, shows a low pressure system shifted to the south, with a centre over the Italian peninsula and Adriatic Sea, southwest of Budapest. Contours of Z500, cutting the 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 lowers the Z500, which is more than 300 gpm lower than in the southern part. Budapest is placed in the cold north eastern section of the low pressure system. At the same time a high pressure system grows up over east Europe (>1020 hPa). Such pressure pattern is anomalous in comparison with the mean winter pressure layout, and it strongly resembles the negative NAO phase. The high over east Europe preserves very cold air, of the polar continental origin, coming from the northern or eastern direction in the lower troposphere. On the other hand the low located southwest of Budapest is a reservoir of humidity from the Mediterranean. Meeting of these two elements may result in heavy snowstorms.

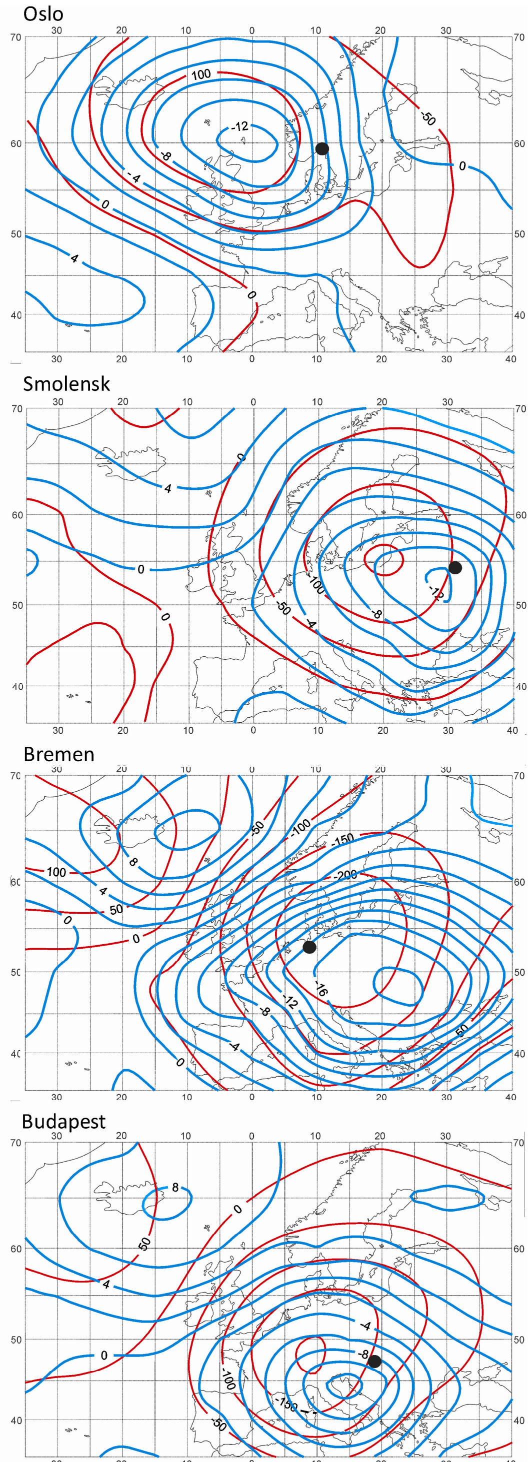

FIG. 1: Anomalies of sea level pressure (blue) in hPa and geopotential height of 500 hPa in gpm (red) for the days with snowstorms in four sites (marked with dots).

III. DISCUSSIONAND CONCLUSIONS

Snowstorms in Europe are associated with negative anomalies of sea level pressure and 500 hPa heights, which means low pressure systems spreading over the analyzed region. The lows differ in the intensity and localization, depending on the region receiving snow. In the Alpine and Carpathian foreland, represented by the southernmost station, namely Budapest, heavy snowstorms appear as a result of fronts in the colder parts of Mediterranean cyclones, the centers of which are often situated over the Italian Peninsula. Another typical location of cyclones or troughs of low pressure is the Baltic Sea region, where meteorological fronts appear quite frequently and may cause snowstorms in western part of East Europe (Smolensk). The cyclonic activity over the continent, which brings very snowy weather in Bremen, is simultaneous to the weakening of Icelandic Low and significant positive pressure anomalies over the north Atlantic. Such pattern of pressure anomalies corresponds 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, 2004; Falarz, 2007). Opposite situation i.e. positive NAO phase expressed by negative pressure anomalies over the North Atlantic, with a low pressure centre over the Norwegian Sea may cause snowstorms only in the north of the continent, namely in Scandinavia.

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. Scherrer and Appenzeller (2006) defined have defined low pressure over south eastern Europe, being responsible for snowfalls in the Swiss Alps.

The counterclockwise (cyclonic) flow around the negative centers indicates two, in general, sources of air masses bringing snowstorms, which are available in Europe: the Atlantic region and Mediterranean. Humid air masses are transported for the long distances and on the way they are shifted from the low troposphere in the source regions to the upper layers, according to the 48-hours back trajectories of air particles, constructed for the chosen days with snowstorms in all analyzed sites. The distant humid and warm air masses from the Atlantic or Mediterranean region transform on the long way and they meet the colder air coming by the lower stream usually from the closer distance from northern or eastern direction. Meeting of these two different elements may result in heavy snowstorms. The described processes signify warm fronts structure, with the dynamic warm and humid air of distant western or southern origin climbing upwards on the cooler and more stabile polar air masses from the north or east.

Heavy snowstorms in western, central and southern Europe, where the mean winter temperature is close to 0^{o}C, may appear only at the condition of negative temperature anomalies, extending over most of the continent. Only in northern Europe this condition does not have to be fulfilled. In most sites, positive anomalies of PW content in the atmosphere are observed only on the way of fronts forming in the low pressure systems, spreading over Europe, while in general, due to lower-than-normal temperatures, weak negative PW anomalies are observed.

V. REFERENCES

Andersson T., Gustafsson N., 1993: Coast of departure and coast of arrival. two important concepts for the formation and structure of convective snowbands over seas and lakes. *Mon. Weather Rev*. 122 1036-1049.

Andersson T., Nilsson S., 1990: Topographically induced snowbands over the Baltic Sea and their precipitation distribution. *Weather Forecast* 5 299-312.

Bednorz E., 2002: Snow cover in western Poland and macro-scale circulation conditions. *Int. J. Climatol.* 22 533-541.

Bednorz E., 2004: Snow cover in eastern Europe in relation to temperature, precipitation and circulation. *Int. J. Climatol.* 24 591-601.

Bednorz E., 2008: Synoptic conditions of snow occurrence in Budapest. *Meteorol. Z.* 17, 1 39-45.

Birkeland K.W., Mock C.J., 1996: Atmospheric circulation patterns associated with heavy snowfall events, Bridger Bowl, Montana, U.S.A. *Mt. Res. Dev.* 16 281-286.

Clark M.P., Serreze M.C., Robinson A.D., 1999: Atmospheric controls on Eurasian snow extent. *Int. J. Climatol.* 19 27-40.

Falarz M., 2007: Snow cover variability in Poland in relation to the macro and mesoscale atmospheric circulation in the twentieth century. *Int. J. Climatol*. 27 2069-2081.

Gutzler D.S., Rosen R.D., 1992: Interannual variability of wintertime snow-cover across the Northern Hemisphere. *J. Climatol.* 5 1441-1447.

Kalnay E., Kanamitsu M., Kistler R., Collins W., Deaven D., Gandin L., Iredell M,. Saha S., White G., Woollen J., Zhu Y., Leetmaa A., Reynolds R., Chelliah M., Ebisuzaki W., Higgins W., Janowiak J., Mo K.C., Ropelewski C., Wang J., Jenne R., Joseph D., 1996: The NMC/NCAR 40-Year Reanalysis Project. *Bulletin of American Meteorological Society* 77 437-471.

Scherrer S.C., Appenzeller C., 2006: Swiss Alpine snow pack variability: major patterns and links to local climate and large-scale flow. *Climate Res.* 32 187-199.

Spreitzhofer G., 1999a: Synoptic classification of severe snowstorms over Austria. *Meteorol. Z.* 8 3-15.

Spreitzhofer G., 1999b: Spatial, temporal and intensity characteristics of heavy snowfall events over Austria. *Theor. Appl. Climatol.* 62, 209-219.