CHANGES IN SNOW COVER OCCURRENCE IN FIVE CENTRAL EUROPEAN STATIONS DURING THE SECOND HALF OF THE 20TH CENTURY

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ABSTRACT
Changes in snow cover occurrence in central Europe during the second half of the 20th century were investigated. Five stations were taken into consideration. Most of the stations represent central European lowlands and one is placed in the Alpine foreland. Data concerning daily snow cover depth from winters 1950/51-1999/2000 was used. Linear trends show negative changes in the number of days with snow cover in all lowland stations. Trends are statistically significant at the 0.05 level only in two stations (Hamburg and Giessen), where absolute changes reach about -4 days per 10 years. Weak positive changes were found in the Alpine foreland. Changes in the maximum snow cover depth were analysed at the same way and again, negative tendencies were found in lowland stations, statistically significant only in Giessen and Vienna.

Key words: central Europe, multi-annual variability, snow cover

RESUMEN
El objetivo de este trabajo es analizar los cambios experimentados por la cobertura nivosa en Europa Central durante la segunda mitad del siglo XX. Se han utilizado series diarias de espesor de la cubierta nivosa de cinco estaciones, la mayoría en tierras bajas de esa región y una en la montaña Alpina. Las tendencias lineales indican cambios negativos en el numero de días con nieve en todas las estaciones de tierras bajas, con significación estadística el 95% solo en dos de ellas (Hamburg and Giessen), con una disminución en torno a 4 dias/decada. En la region Alpina se detecta ligeras tendencias positivas. Igualmente, la evolución del espesor máximo de nieve presenta tendencias negativas significativas únicamente en Huyesen y Viena.

1. INTRODUCTION

Winter snow cover is an important climatic variable in the midlatitude zone. Its occurrence is conditioned by air temperature, precipitation and - indirectly - by atmospheric circulation. Therefore, year-to-year changes in snow cover occurrence are considered as a good characteristic of the winter season climatic variability (FALARZ, 2004). At the same time snow is an important factor modifying weather conditions. Because of its high albedo snow cover influences the earth-atmosphere energy budget, having this way a strong impact on the climate system (ROBOCK, 1980, ROBINSON and KUKLA, 1985). It modifies the weather conditions

mainly by lowering the air temperature and by changing air circulation, cloudiness and precipitation.

There are a number of studies concerning snow cover temporal variability in different spatial scales. The ones concerning the global scale are based on weekly digitized maps of the Northern Hemisphere snow cover available since 1972 (GUTZLER and ROSEN, 1992, GROISMAN *et al*., 1994). Long-term study of the Northern Hemisphere snow cover variability and change based on historical and reconstructed data was given by BROWN (2000). Continental scale research of the recent variations of snow cover in relation to precipitation and temperature was carried out in North America by KARL *et al*. (1993). Long-term studies of snow cover variability were conducted in Canada and in the USA (BROWN and GOODISON, 1996, HUGES and ROBINSON, 1996).

There are also some papers by European authors describing snow cover temporal variability on a local scale. FALARZ (2004) performing an analysis of snow cover occurrence in the XXth century in Poland, found negative trends in the annual number of days with snow cover over the majority of the country (particularly in the second half of the XXth century). Positive trends appear only at the mountainous stations. The number of days with snow cover decreased in Estonia (JAAGUS, 1997, TOOMING and KADAJA, 1999), as well, as in some regions of the European Russia (YE *et al*., 1998; BEDNORZ and KOSSOWSKI, 2004). Snow cover persistence in Austria lowered by 10-30 % during the last 100 years (MOHNL, 1994, cited in: HANTEL *et al*., 2000), in the Swiss Alps snow season has shortened significantly since the 1980s (BENISTON, 1997).

In this study changes in snow cover occurrence in central Europe during the second half of the 20th century are investigated.

2. DATA AND METHODS

Five stations are taken into consideration, three of them located in Germany (Hamburg, Giessen, Garmisch-Partenkirchen – Ga-Pa), one in Poland (Poznań) and one in Austria (Vienna). Most of the stations represent central European lowlands (below 200 m a.s.l.) only Ga-Pa (719 m a.s.l.) is placed in the Alpine foreland. Data concerning daily snow cover depth from winters 1950/51-1999/2000 was used. Polish snow cover data from Poznań were 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). Data for Vienna were derived from 'JAHRBUCH DER ZENTRALSTALT FUR METEOROLOGIE UND GEODYNAMIK' published by the Zentralanstalt fur Meteorologie und Geodynamik (Wien).

The snow depth data are based on daily measurements made with a 1 cm precision at 6.00 UTC. A day is considered as a day with snow cover, when snow depth is $\geq$ 1 cm. Two characteristics of snow cover appearance are taken into consideration: annual number of days with snow cover and the maximum snow cover depth in every winter season. Standard deviation and variability coefficient have been computed in order to find out multi-annual variability of both these characteristics. Furthermore, their trends in the second half of the XX century have been investigated and plotted. Additionally, equations of trend and linear

regressions for each station have been computed. At the base of equations of trend changes in the annual number of days with snow cover and changes in the maximum depth of snow cover per 10 years have been calculated.

3. RESULTS

Central Europe is an area of rather poor snow conditions. The amount of snow diminishes from the east to the west of the region. The mean seasonal number of days with snow cover ranges from less than 30 in the west to nearly 45 in the east, excluding Ga-Pa, where it exceeds 100 days. However, these numbers vary from year to year. During extremely snowy winters, such as, 1962/1963 and 1969/1970 the number of days with snow cover exceeded 80 or even 100 days at the lowland stations. On the other hand, there are only a few days with snow cover (or even zero) during very mild winters. Variability in the annual number of days with snow cover is the greatest in the least snowy stations. The coefficient of variability exceeds 50% in Poland and Austria and it is over 70 % in northern Germany. The lowest variability in the annual number of days with snow cover is observed in Ga-Pa, where the variability coefficient amounts to 26.1 %. Ga-Pa is the most snowy station with over 100 days with snow cover on average (Tab. 1).

The multiannual course of the seasonal number of days with snow cover together with the 7-yr moving average has been drawn for each station. Linear trends with equations show negative changes in the number of days with snow cover at all lowland stations. However, trends are statistically significant at 0.05 level only at two stations (Hamburg and Giessen). Positive, but not statistically significant trends in the changes of the number of days with snow cover have been found in the mountainous station – Ga-Pa (Fig. 1). Absolute changes in the number of days with snow cover are given in Table 2. They reach about -4 days per 10 years in north German stations.

	Mean	Maximum	Minimum	Standard deviation	Coeff. of variability (%)
Hamburg	27.7	89	0	20.0	72.4
Giessen	26.0	86	2	20.1	77.1
Poznań	46.6	121	2	25.0	53.6
Vienna	42.8	101	3	22.5	52.6
Ga-Pa	103.2	153	39	27.0	26.1

Table 1: VARIABILITY IN THE NUMBER OF DAYS WITH SNOW COVER IN WINTERS 1950/1951-1999/2000.

The average maximum snow depth amounts to 10 cm in the west and it reaches 24 cm in Vienna. In the subalpine station Ga-Pa the average maximum snow depth amounts to almost 60 cm. The seasonal maximum snow depth, as well as the seasonal number of days with snow cover, are characterised by a large multiannual variability, mainly in the north western stations of poor snow conditions.

	Changes in the annual number of days with snow cover		Changes in the maximum depth of snow cover	
	days·10 years^{-1}	%·10 years^{-1}	cm·10 years^{-1}	%·10 years^{-1}
Hamburg	**-3.9**	**-14.1**	-0.9	-6.9
Giessen	**-4.0**	**-15.4**	**-1.5**	**-14.2**
Poznań	-2.0	-4.2	-1.0	-6.8
Vienna	-1.4	-3.4	**-1.5**	**-6.1**
Ga-Pa	2.0	1.9	0.6	0.1

Table 2: CHANGES IN SNOW COVER OCCURRENCE IN WINTERS 1950/1951-1999/2000. VALUES STATISTICALLY SIGNIFFICANT AT 0,05 IN BOLD

The coefficient of variability amounts to about 60-70 % in Poland and northern Germany and it is much lower in the southern stations (slightly over 40 % in Vienna and Ga-Pa). Snow depth may amount to as much as 67 cm in Hamburg after the unusually abundant snowfalls in winter 1978/1979. Lower records were noted in Vienna (50 cm in winter 1962/1963, 45 cm in winter 1969/70), Poznań (46 cm in winter 1969/70) and Giessen (29 cm in winter 1962/1963, 25 cm in winter 1969/70) (Tab. 3, Fig. 2).

The multiannual courses of the maximum snow depth together with the 7-yr moving averages and trend lines (Fig. 2) show great year-to-year variability and a negative tendency of changes in most stations. However, trends are statistically significant at the 0.05 level only in two lowland stations (Vienna and Giessen). Positive, but no statistically significant trend in the changes of the maximum seasonal snow depth have been found in Ga-Pa. Absolute changes are given in Table 2. They amount to about -1.5 cm by 10 years in Vienna and Giessen.

	Mean (cm)	Maximum (cm)	Minimum (cm)	Standard deviation (cm)	Coeff. of variability (%)
Hamburg	15.1	67	3	10.9	72.0
Giessen	10.6	29	1	7.0	66.0
Poznań	14.2	46	1	8.4	59.0
Vienna	24.1	50	3	10.5	43.6
Ga-Pa	59.3	110	22	24.8	41.7

Table 3. VARIABILITY IN THE MAXIMUM DEPTH OF SNOW COVER IN WINTERS 1950/1951-1999/2000.

4. DISCUSSION

Results indicate negative trends in snow cover occurrence (meaning the number of days with snow and its maximum depth) in most of Poland found by FALARZ (2004). However, the same author found some positive trends in snow cover characteristics in mountainous regions of Poland. Negative trends in the number of days with snow cover were observed in other parts of

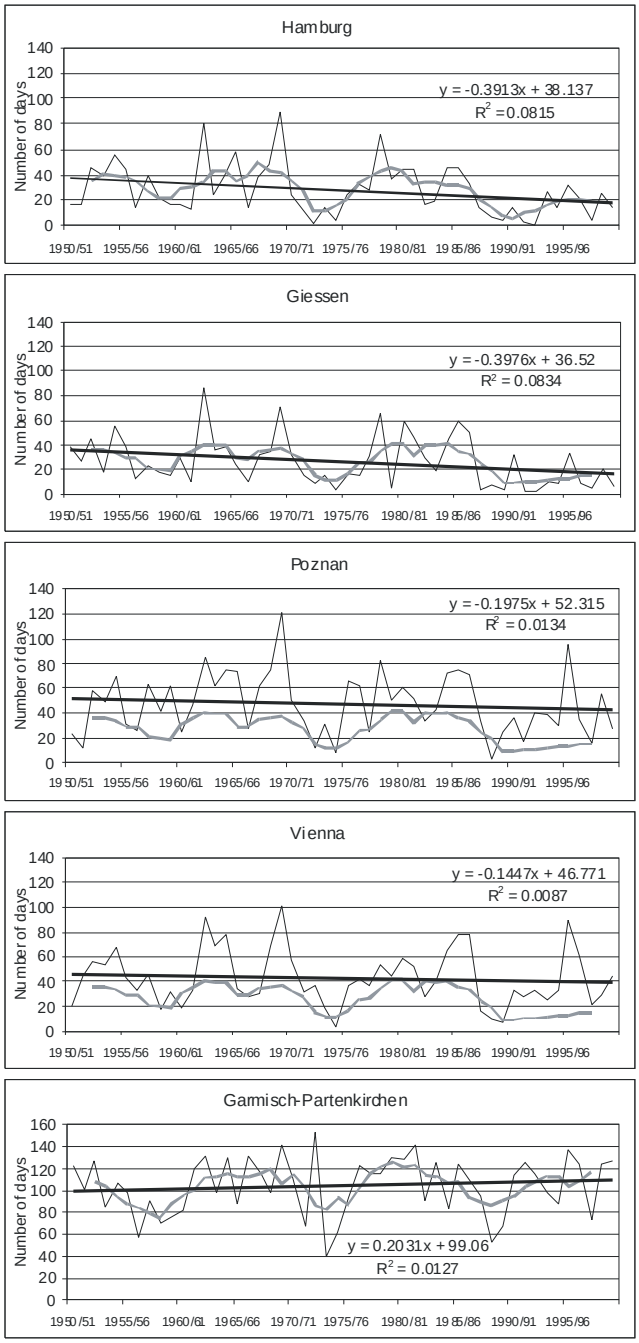

Fig. 1: Multi-annual course of the number of days with snow cover (real values and 7-yr moving averages) with the linear trend and its equation for winters 1950/1951-1999/2000.

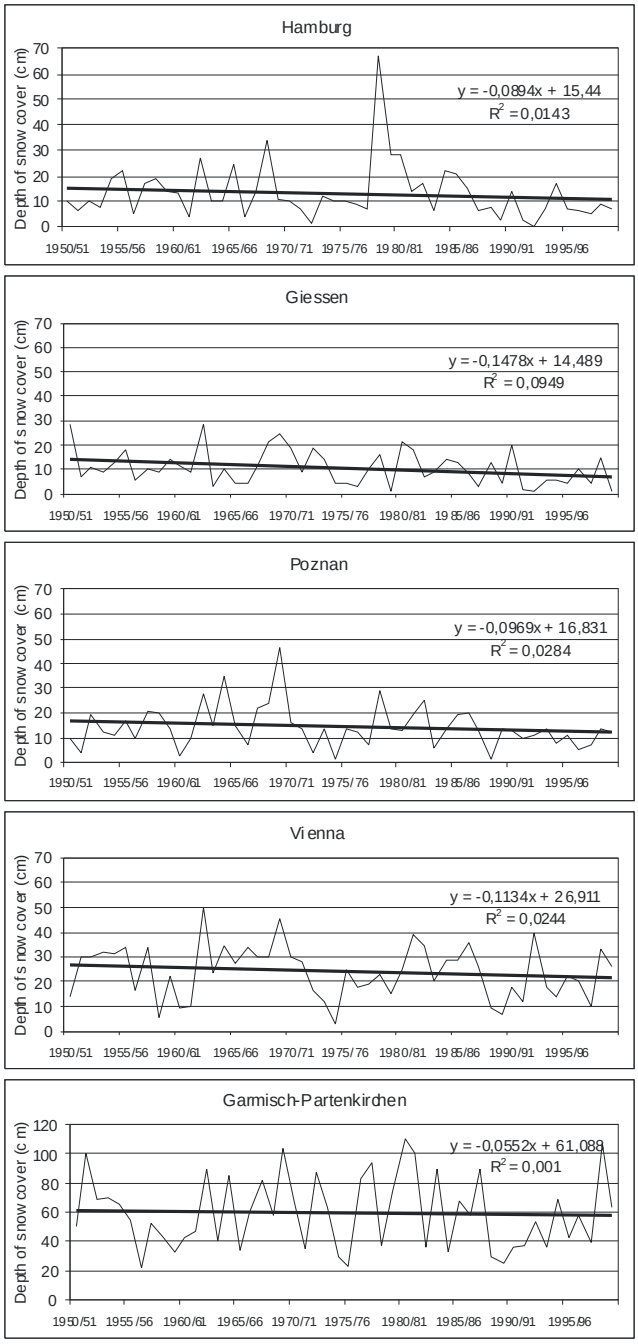

Fig. 2: The multi-annual course of the maximum snow cover depth with the linear trend and its equation for winters 1950/1951-1999/2000.

Europe: Estonia (JAAGUS, 1997, TOOMING and KADAJA, 1999) Austria (MOHNL, 1994, cited in: HANTEL *et al*., 2000) and Swiss Alps (BENISTON, 1997). Snow cover depth diminished in the European part of Russia during the 20th century (YE *et al*., 1998, BEDNORZ and KOSSOWSKI, 2004).

While analysing and interpreting the trends one has to remember that snow cover occurrence is characterised by high diversity and variability from year to year. The range of snow cover characteristics, such as maximum snow depth and the number of days with snow cover, is wide and the extreme values seem to have a strong impact on the detected trends. Therefore, the negative trends of both characteristics appeared to be statistically significant only at one station (Giessen).

Negative tendencies in snow cover occurrence in central European lowlands, during the second half of XXth century may be related to changes in winter temperature or precipitation. In this area mean winter temperature is slightly above 0 °C. Therefore, daily and seasonal oscillations of the air temperature (above and below zero) are considered as the main factor causing occurrence, persistence or disappearance of snow in this area (CLARK *et al*., 1999, BEDNORZ, 2002, 2004, FALARZ, 2004). Multi-annual negative trends in the occurrence of snow cover are caused probably by the increase in the air temperature observed in Europe (SCHÖNWIESE and RAPP, 1997, cited in: FALARZ, 2004). FALARZ (2004), however, points out, that the reasons for changes in snow cover occurrence in Poland are more complex and strongly connected with air circulation.

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