SNOW AS AN INDICATOR OF CLIMATIC CHANGE

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SUMMARY

The present paper deals with a long-term variation of snow pattern characteristics on the territory of Moravia and Silesia. Author tries to describe basic features of variation of areal-means time series for number of days with snowfall and those with the snow cover for 7 regions. Long-term changes are expressed by means of a Gauss filter and linear trend. Winters in the studied period can be characterized as rich in snow in the first half of 1940s and in the latter half 1960s. Decrease in values in the first half of the 1970s is evident. Relation between the snow pattern and the variation of temperature and precipitation is studied by correlation analysis. From it follows that with the increase in air temperature the values of the number of days with snowfall and with the snow cover should decrease. The dependence between the characteristics of the snow condition and those of atmospheric precipitation is looser. Since most climatic scenarios agree generally on the fact that the warming trend - will in the medium latitudes - in winter result in the increase in precipitation sums, the height above sea level will have a decisive effect for the snow conditions.

1. INTRODUCTION

The growing effect of man and his activities on the climatic system has acquired a global character recently. That is why efforts are increasing at estimating qualitative as well as quantitative changes in the climatic system linked up with the growth of concentrations of greenhouse gases with subsequent global warming. The above efforts are above all reflected in devising possible scenarios of climatic changes.

According to Brázdil (1991) climatic scenarios are qualified estimates of climatic conditions of the future period on the basis of which it is possible to estimate the impacts of the future climatic change on nature, man and different areas of his activity.

Devising climatic scenarios is nowadays approached from two points of view (Brázdil, 1991). The first approach is based on the method of analogy. Such scenarios start either from palaeoclimatic reconstructions or from the study of fluctuation of series of meteorological elements in the period of instrumental observations. This approach requires relatively long homogeneous series of observing meteorological elements. For that reason most of hitherto scenarios concern air temperature and atmospheric precipitation, the procession of other meteorological elements being neglected.

The second approach is based on climate modelling. The best known group of models is represented by the so-called General Circulation Models (GCMs). Their list is given e.g. by Kalvová (1991). The utilization of data from GCMs for making regional scenarios brings along a number of problems connected above all with their lower resolution ability (Brázdil, 1992).

For that reason the procession of time characteristics of snow conditions can bring new information for setting up an analog climatic scenario for the territory of the Czech Republic.

2. THE IMPORTANCE OF CHARACTERISTICS OF THE SNOW CONDITIONS FOR THE STUDY OF GLOBAL CLIMATIC CHANGES

In the last two decades a number of studies and hypotheses have appeared in which characteristics of the snow cover are considered to be an important indicator of the fluctuation of other climatic elements in time as well as of climatic changes as a whole. The dependence between the characteristics of the snow cover and the fluctuation of climate is studied in the papers by Wagner (1973), Foster et al. (1982), Bartholy (1990).

In the papers Lamb (1972, 1975) and Namias (1985) snow and snow cover are considered to be a sensitive indicator which affects directly the circulation conditions in the atmosphere. The authors demonstrated a relatively close relation between the character of the circulation in high layers of the atmosphere and the spatial and temporal changes in the characteristics of the snow cover. A simplified model of the above dependence is based on the fact that due to different radiation conditions conspicuous horizontal temperature gradients are formed between the surfaces covered with a snow cover and those without snow. The result of this imbalance is different warming of air masses above the mentioned regions, the rise of compensatory circulation processes in the upper troposphere and the intensification of cyclogenetic processes (Lamb, 1972). Namias (1985) analysed the relation between the deviations of mean monthly temperatures and the area with the snow cover.

Lamb (1975) suggests to use the snow cover as the so-called index of climatic fluctuations and he elaborated a method of how to utilise that index for forecasting the fluctuation and changes of climate and also how to quantify the fluctuation of the climate in the past by means of the above index. As a proof he states that up to the 1940s the increase in air temperatures and the intensive zonal circulations were accompanied by the reduction of the area of the continental snow cover as well as the area of polar glaciation. Then there followed a period with a more intense meridional character of circulation accompanied by the drop in air temperatures and a longer duration of the period with the snow cover.

3. THE MATERIAL USED

To express the fluctuation of the regime of solid precipitation in the cold half-year series of selected characteristics of snow conditions from the period of 1920/21 to 1984/85 were used from 49 stations from the territory of Moravia and Silesia. Due to a considerable spatial variability of the employed characteristics for further processing series of regional means were set up with the objective of filtering off insubstantial local influences.

To express regional means, first the territory studied was divided into 7 regions by the method of cluster analysis. A detailed method of regionalisation is described in Dobrovolný (1992). The division of the studied territory into regions is expressed in Fig. 1. By regional means a considerable spatial variability of the studied characteristics was eliminated. From the point of view of temporal variability the series

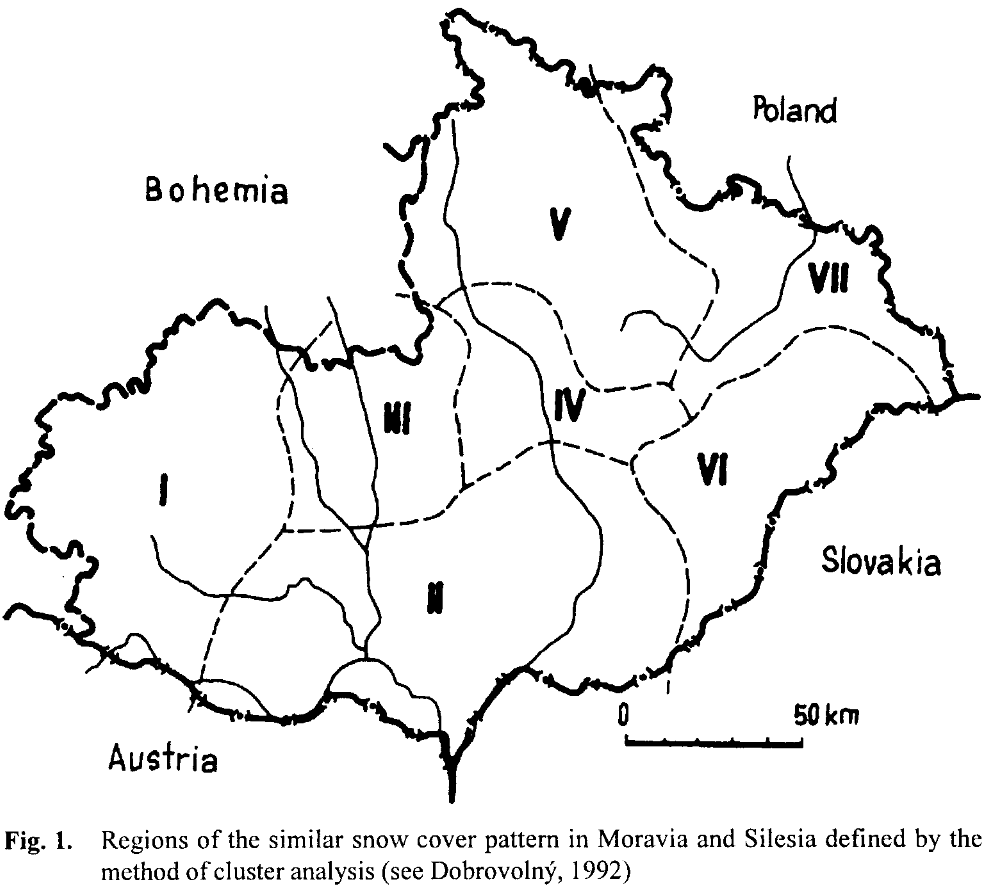

Fig. 1. Regions of the similar snow cover pattern in Moravia and Silesia defined by the method of cluster analysis (see Dobrovolný, 1992)

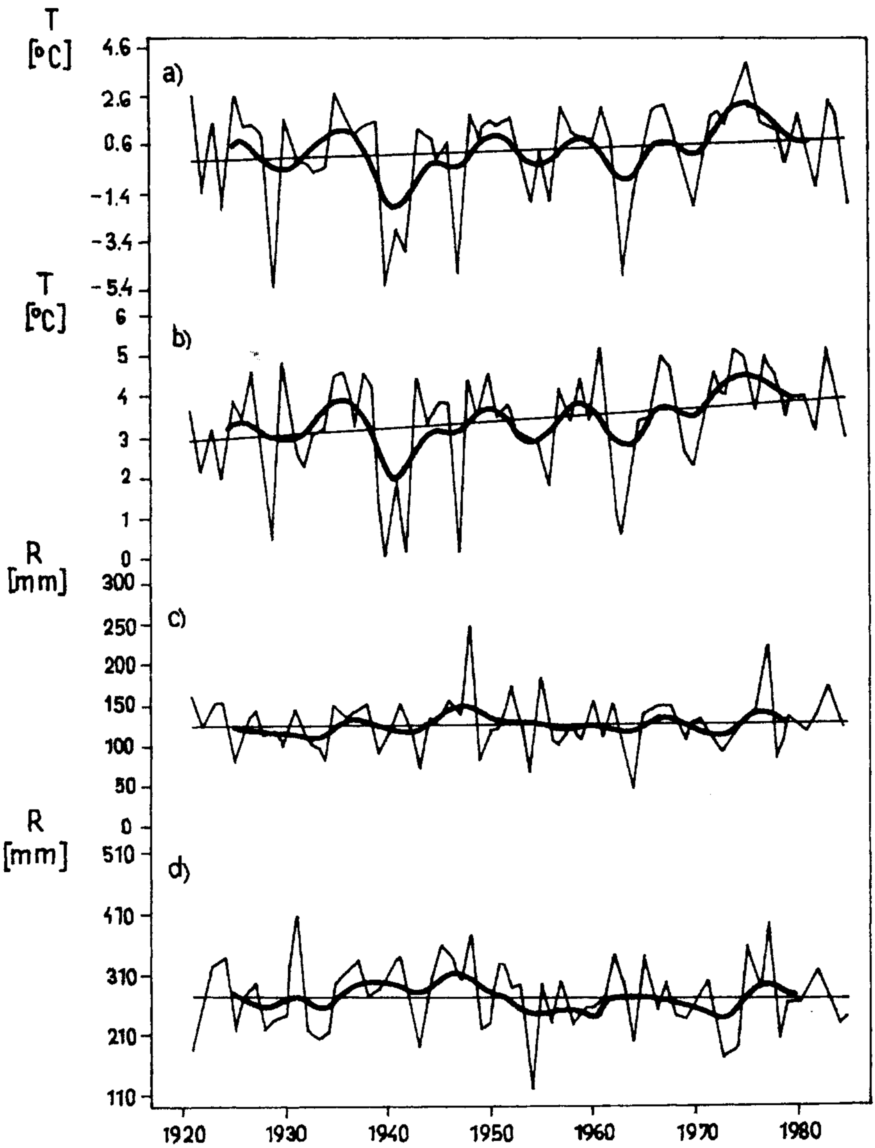

Fig. 2. Temperature in Prague - Klementinum for winter (a), cold half-year (b) and areal sums of precipitation in Moravia and Silesia for winter (c) and cold half-year (d) for the period 1920-1985. Annual values are smoothed by a Gauss filter and completed by linear trend

were further smoothed by a Gauss filter and completed by an analysis of first order trend.

4. MAIN TRENDS IN THE TEMPERATURE AND PRECIPITATION CHARACTERISTICS FOR WINTER AND THE COLD HALF-YEAR

For expressing the trend in air temperatures from the near surroundings only the series from Prague-Klementinum was available. Air temperature is an element much less spatially variable than is the case of atmospheric precipitation, and therefore it can be assumed that the main trend in air temperatures will be similar for the territory of Moravia and Silesia.

From the analysis of the linear trend it follows that at the station Prague-Klementinum air temperatures increased in the period of 1920-1985 both for winter and for the cold half-year (Fig. 2). In the two series two periods of air temperature increase can relatively easily be seen. They can be delimited by the years 1940-1952 and 1963-1975. But not even in those periods the increase in mean air temperatures was unambiguous (see e.g. the severe winter of 1946/47). But the overall warming trend is evident.

In the series of areal precipitation sums of Moravia and Silesia (Brázdil et al., 1985) in the period of 1920-1985, there appear different linear trends for winter (insignificant increase in precipitation sums) and for the cold half-year (drop). Also conspicuous periods of air temperature rise (1940-1952 and 1963-1975) are not reflected in precipitation sums unambiguously. From the values smoothed by a Gauss filter both a drop and a rise in precipitation sums of those periods is evident (Fig. 2). As a period with prevailing drop in precipitation sums can be denoted roughly the period from the latter half of the 1940s to the beginning of the 1960s. This drop is more conspicuous for the cold half-year. A more evident uninterrupted period of rise in the period studied, above all for the winter months, is missing, an exception being the first half of the 1940s.

5. LONG-TERM CHANGES IN SELECTED CHARACTERISTICS OF THE SNOW CONDITIONS IN MORAVIA AND SILESIA

5.1 Long-term variation

In all series of the number of days with snowfall (Fig. 3) a growing linear trend appears. The series point to an occurrence of two periods with prevailing high values - the first half of the 1940s and the latter half of the 1960s. Between these maxima a drop in values can be recorded. A relatively permanent increase in the number of days with snowfall can be noticed in the 1930s and after the year 1960.

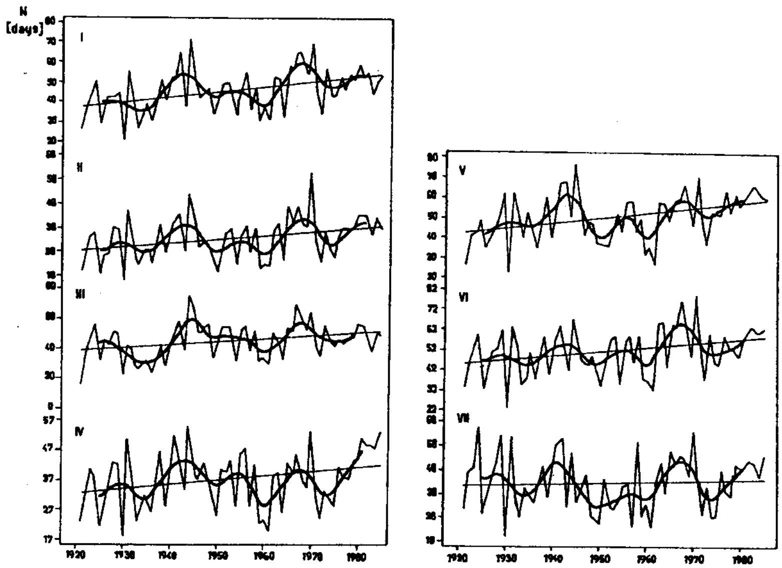

Fig. 3. Number of days with the snowfall for the regions on the territory of Moravia and Silesia in the period 1920-1985. Regions see Fig. 1. Annual values are smoothed by a Gauss filter and completed by linear trend

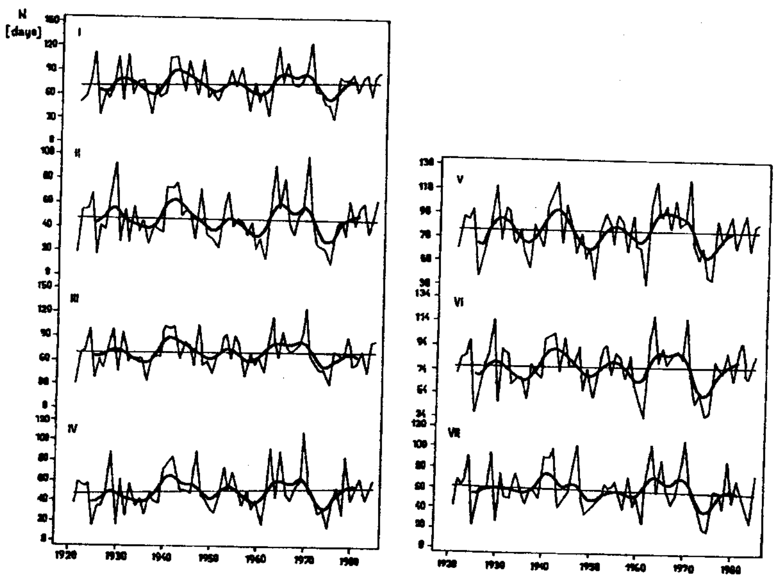

Fig. 4. See text to Fig. 3, number of days with the snow cover

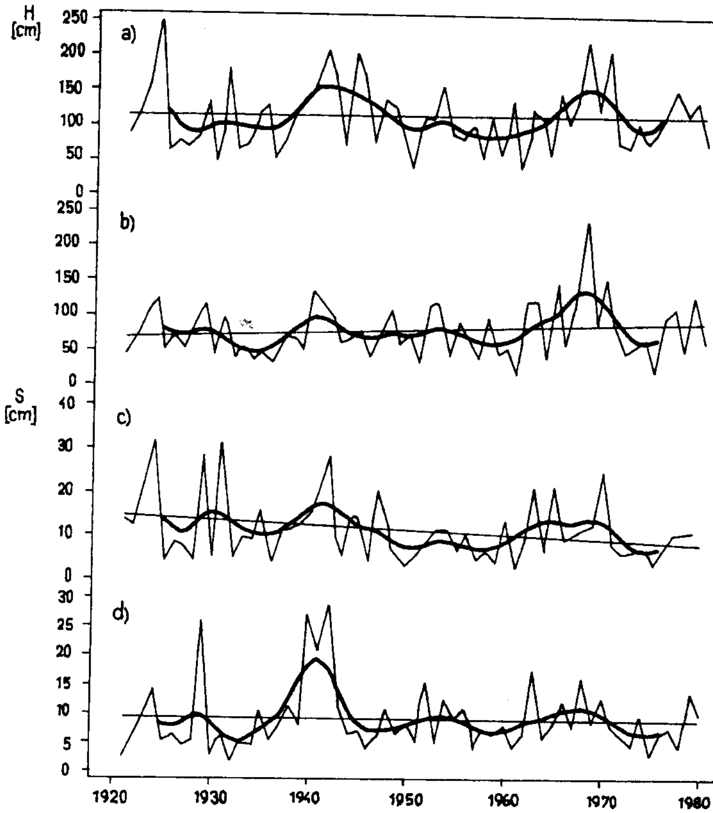

Fig. 5. Heights of the new snow cover H for the stations Bohdalov (a) and Luhačovice (c) and the sum of the average heights of the snow covers for the same stations (b, d) in the period 1920-1985. Annual values are smoothed by a Gauss filter and completed by linear trend

The course of the values of the number of days with snow cover (Fig. 4) is quite similar to the above series. Only three regions exhibit a rising trend, in the others the values have a decreasing trend, even though that decrease is insignificant. In all series the decrease in values in the first half of the 1970s is evident.

From the comparison of long-term variations of the occurrence of the first and the last days with snowfall and the snow cover a trend is evident to the shift of the possible occurrence of snowfall to a later date, conspicuous particularly at the end of the 1950s.

From the point of view of the amount of the fallen snow the winters in the studied period can again be characterised by a double wave (Fig. 5) with maxima (winters rich in snow) in the first half of the 1940s and in the latter half of the 1960s. The above two stations have a rising trend. Similar features are also those of the series of the mean height of the snow cover in which, however, an overall decreasing trend appears.

5.2 Correlation analysis

The results of the correlation analysis between the characteristics of the snow conditions, air temperature and atmospheric precipitation are summarised in Table 1.

Table 1. Correlation coefficients $R_{x,y}$ between the characteristics of the snow patterns, temperature (T) and precipitation (S) for winter and the cold half year (October-March) in the period 1920-1985. Regions see Fig. 1

	winter				cold half year			
	number of days with				number of days with			
	snowfall		snowcover		snowfall		snowcover	
Region	T	S	T	S	T	S	T	S
I	-0.715	0.339	-0.222	0.305	-0.688	0.247	-0.230	0.300
II	-0.760	0.447	-0.296	0.285	-0.716	0.212	-0.298	0.329
III	-0.728	0.270	-0.184	0.323	-0.724	0.268	-0.196	0.316
IV	-0.718	0.116	-0.318	0.379	-0.680	0.230	-0.323	0.354
V	-0.654	0.388	-0.298	0.203	-0.676	0.191	-0.267	0.212
VI	-0.700	0.197	-0.242	0.360	-0.702	0.242	-0.255	0.324
VII	-0.770	0.178	-0.496	0.253	-0.751	0.292	-0.508	0.280

In the period studied there exists a relatively close inverse linear dependence between the mean air temperature and the number of days with snowfall. In the case of series of the number of days with the snow cover all studied series also indicate an inverse dependence on air temperatures, even though statistically insignificant. This also holds in the case of comparison with the sums of atmospheric precipitation. The values of correlation coefficients are low, nevertheless showing direct dependence.

5.3 Main trends of development in the compared series

Maxima in the series of the numbers of days with snowfall and those with the snow cover in the first half of the 1940s correspond well with the occurrence of severe winters. In the case of the second maximum (the latter half of the 1960s) the connection with the occurrence of severe winters is missing. In the precipitation series for the former period the values of precipitation sums fluctuate considerably without any trend towards an increase or decrease. In the case of the latter half of the 1960s a transitory increase in the precipitation sums is recorded.

The prevailing increase in mean air temperatures from the early 1940s to the beginning of the 1950s corresponds relatively well with the increase in the number of days with snowfall and that with the snow cover. A marked increase in the number of days with snowfall and with the snow cover starting roughly with the mid-1950s is not reflected unambiguously in temperature and precipitation series. In the case of precipitation sums a rather decreasing trend prevailed.

6. CONCLUSION

The objective of the present contribution was to express the importance of characteristics of snow conditions for the study of climatic fluctuation and changes.

In the period studied, characterised by an overall increase in mean temperatures as well as precipitation sums also the mean values of the number of days with snowfall exhibited a rise; in the series of days with the snow cover the trend is not unambiguous. In the dates of the occurrence of the first and the last days with snowfall and with the snow cover a trend appeared towards the delay of their occurrence. That was conspicuous above all towards the end of the 1950s, when in the temperature series the increase in values culminated after the cold first half of the 1940s.

The employed series of the mean height of the snow cover indicate an overall slight drop, the series of the heights of new snow on the other hand a slight rise. In the two series again two maxima appeared (the first half of the 1940s and the 2nd half of the 1960s), the former maximum correlating well with the occurrence of severe winters.

From the correlation analysis it follows that with the increase in air temperature the values of the numbers of days with snowfall and with the snow cover should decrease. The dependence between the characteristics of the snow conditions and those of atmospheric precipitation is generally looser.

Since most climatic scenarios agree generally on the fact that the warming trend will - in the medium latitudes - in winter result in the increase in precipitation sums, the height above sea level will have a decisive effect for the characteristics of the snow conditions. Mean temperatures of the winter season fluctuate about 0°C in the period studied. Then the general increase in temperatures and precipitation in higher heights above sea level (with the temperature below 0°C) should result in the increase in the number of days with snowfall and with the snow cover as well as in a greater amount of fallen snow. On the other hand, in lower heights above sea level (with the temperature above 0°C) the warming will bring an increase in precipitation sums, the drop in the number of days with snowfall and with the snow cover, as well as a smaller amount of fallen snow. The outlined process can, however, be modified, e.g. by the effects of changes in circulation.

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