PRACE GEOGRAFICZNE, zeszyt 107

Instytut Geografii UJ
Kraków 2000

Małgorzata Falarz

AN ATTEMPT OF RECONSTRUCTION OF NIVAL CONDITIONS ON THE TURN OF THE 19TH CENTURY IN CRACOW AND ZAKOPANE

Abstract: The attempt of reconstruction of seasonal snow cover data in Cracow and Zakopane on the turn of the 19th century based on climatic data was made by using the multiple regression method. The results appear to be more successful for the station located at lower altitude (Cracow). The reconstructed data obtained for Zakopane appear to be overestimated for the number of snow cover days and sum of daily snow cover thickness. Thus, they have been excluded from further calculations. An analysis of long-term snow cover variability in Cracow (1895/96-1998/99) and Zakopane (1914/15-1998/99) has shown no statistically significant trends for characteristics under investigation.

Key words: snow cover, reconstruction, climate variability, time series analysis.

1. Introduction

The quite regular and documented results of snow cover observations in southern Poland appeared in meteorological reports only in the beginning of the 1920's or 1930's. Therefore, it is practically impossible to track the snow cover changes over a period longer than 70-80 years to compare them with changes of thermal and precipitation conditions observed in the last century. An analysis of long-term variability of snow cover can provide detailed information on climate changes in winter seasons. The state of snow cover resulting from interaction of thermal and precipitation conditions and indirectly from atmospheric circulation can be used as a good indicator for climatic conditions.

The availability of data related to climate elements that decide on snow cover formation, persistence and disappearance allow the reconstruction of nival conditions for the periods when no snow cover observations were made or for which relevant records are missing, unreliable or unavailable.

This study is focused on the following objectives:

1. methodological – an attempt to reconstruct nival data on the turn of the 19th century based on available information on circulation, thermal and precipitation conditions;
2. cognitive – an investigation of long-term variability of snow cover in southern Poland based on extended nival data.

The reconstruction of daily nival data was carried out by Brown and Goodison (1996) based on a model that included such parameters as solid precipitation, maximum temperature, water from melted snow and snow cover for the previous day. The nival data series for southern Poland taken from 50-76 winter seasons were analysed by Falarz (1998) and Falarz et al. (1998). A slight, not significant decreasing tendency of snow cover characteristics was observed in the majority of stations in southern Poland. The downward tendency has been more evident from the beginning of the 1960's.

2. Data and Method

The nival, thermal and precipitation data from two stations: Cracow (206 m a.s.l.), a city located in the Upper Vistula valley in the Carpathian Foothills, and Zakopane (857 m a.s.l.), a town situated in the Sub-Tatra fault trough were analysed. In addition, the atmospheric circulation indices obtained by Niedźwiedź (1998) for the Upper Vistula basin were used. Direct data related to snow cover in Cracow in the period 1921/22-1998/99 (78 winter seasons) were collected. An attempt at reconstruction for the years 1895/96-1920/21 (26 winter seasons) was carried out to extend an analysis of nival conditions over 104 winter seasons. The nival data series for Zakopane covers 85 winter seasons (1914/15-1998/99). A successful reconstruction for the years 1895/96-1913/14 (19 winter seasons) could result in data series of the same length as those of Cracow.

The reconstruction of nival conditions was made for seasonal snow cover values (number of days with snow cover, maximum thickness of snow cover and sum of daily snow cover thickness) by using the multiple regression method. The reconstruction was carried out as follows:

1. The climatic parameters strictly related to nival conditions and available for the period before snow cover observations were made, have been chosen. There are following characteristics: mean air temperature, number of snowfall days, zonal westerly circulation index for Cracow (for the period Dec.-Feb. (XII-II)) and mean air temperature, number of snowfall days (for the period Oct.-Apr. (X-IV) or Dec.-Feb. (XII-II)), zonal westerly index for the number of days with snow cover and southerly circulation index (for the period Dec.-Feb. (XII-II)) for sum of daily snow cover thickness for Zakopane (Tab. 1). It has been found that the correlation between snow cover and cyclonicity index is statistically insignificant.

2. The multiple regression equations were calculated for the basic period 1966/67-1995/96 (30 winter seasons) while taking into account the snow cover dependence on characteristics quoted above. Among many combinations, the equations of highest confidence level and lowest standard estimation error and of coefficient of

Tab. 1. Correlation coefficients of snow cover characteristics and the other climatic elements (base period: 1966/67-1995/96).
Only the coefficients significant on the level 0.05 are shown. (ND SC – number of days with snow cover; MAX TH – maximum thickness of snow cover; SUM SC – sum of daily snow cover thickness; "period" – the period of climatic elements, for which the correlation with a season snow cover characteristic is the highest.)

Station	snow cover characteristic (whole season)	mean temperature	number of days with snow precipitation	number of days with snow and mixed precipitation	zonal westerly circulation index	southerly circulation index	cyclonicity index
Cracow	ND SC period	-0.85 XII-II	0.84 XII-II	0.75 XII-II	-0.82 XII-II	x	x
	MAX TH period	-0.72 XII-II	0.74 XII-II	0.69 XII-II	-0.69 XII-II	x	x
	SUM SC period	-0.74 XII-II	0.82 XII-II	0.75 XII-II	-0.77 XII-II	x	x
Zakopane	ND SC period	-0.53 X-IV	0.68 X-IV	0.54 X-IV	-0.37 VIII-VII	x	x
	MAX TH period	-0.47 XII-II	0.52 X-IV	0.52 XII-II	x	x	x
	SUM SC period	-0.52 XII-II	0.70 X-II	0.55 XII-II	x	-0.46 XII-II	x

determination as high as possible. The models that produced improbable (e.g. negative) nival characteristics were rejected. The final equations are presented in Table 2.

3. The results obtained from snow cover reconstruction by using the regression equations were verified and compared with observations data gathered for the basic (1966/67-1995/96) and control (1951/52-1965/66 for Cracow and 1941/42-1965/66 for Zakopane) periods (Tab. 3, Fig. 1, 2).

4. The snow cover characteristics were determined for the period when no nival records were gathered.

The second objective was reached by investigating and comparing the long-term snow cover characteristics for both stations and by analysing the obtained time series. The percentage variability coefficient defined as the ratio of standard deviation to arithmetic mean.

3. Results

All the final regression equations used for nival data reconstruction contain, except for the sum of snow cover thickness for Zakopane, two components (Tab. 2).

Tab. 2. Final equations for the snow cover reconstruction.
(ND SC – number of days with snow cover, MAX TH – maximum thickness of sow cover, SUM SC – sum of daily snow cover thickness, TAVG – mean temperature, PSN – number of days with snow precipitation, WNDX – zonal westerly circulation index, SNDX – southerly circulation index, R – correlation coefficient, R^2 – determination coefficient, error – standard error of estimation.)

station	linear equation	R	R^2	error
Cracow	ND SC = 1.398 $PSN_{(XII-II)}$ – 0.396 $WNDX_{(XII-II)}$ + 43.931	0.92	0.85	± 11 days
	MAX TH = 0.470 $PSN_{(XII-II)}$ – 0.113 $WNDX_{(XII-II)}$ + 15.155	0.80	0.64	± 6 cm
	SUM SC = -69.119 $TAVG_{(XII-II)}$ + 34.998 $PSN_{(XII-II)}$ – 232.945	0.83	0.69	± 336 cm
Zakopane	ND SC = 0.997 $PSN_{(X-IV)}$ – 0.126 WNDX $_{(VIII-VII)}$ + 95.352	0.78	0.60	±11 days
	MAX TH = -3.006 $TAVG_{(XII-II)}$ + 0.622 $PSN_{(X-IV)}$ + 22.217	0.58	0.33	±16 cm
	SUM SC = -247.376 $TAVG_{(XII-II)}$ + 88.814 PSN $_{(X-II)}$ – 17.104 $SNDX_{(XII-II)}$ – 509.318	0.76	0.58	±1042 cm

Tab. 3. The comparison of the observed and reconstructed snow cover data in the basic (1966/67-1995/96) and control (1951/52-1965/66 for Cracow and 1941/42-1965/66 for Zakopane) period. (*ND SC – number of days with snow cover; MAX TH – maximum thickness of snow cover (cm); SUM SC – sum of daily snow cover thickness (cm); corr. – correlation coefficient; O – observed data; R – reconstructed data).*

station	characteristic	basic period						control period					
		ND SC		MAX TH		SUM SC		ND SC		MAX TH		SUM SC	
		O	R	O	R	O	R	O	R	O	R	O	R
Cracow	corr.	0.92		0.80		0.83		0.75		0.54		0.82	
	mean	57	57	21	21	582	582	70	66	25	23	758	823
	R-O	0		0		0		-4		-2		65	
	R/O	1.00		1.00		1.00		0.94		0.92		1.09	
Zakopane	corr.	0.78		0.58		0.76		0.63		0.57		0.71	
	mean	128	128	61	61	3123	3123	123	133	70	68	3150	3857
	R-O	0		0		0		10		-2		707	
	R/O	1.00		1.00		1.00		1.08		0.97		1.22	

The equations obtained for Cracow (R^2=0.64-0.85) described the snow cover variations much more better than those of Zakopane (R^2=0.33-0.60). For each station the best reconstruction results were obtained for number of days with snow cover (R^2=0.85 for Cracow, R^2=0.60 for Zakopane), while the worst for seasonal maximum snow cover thickness (R^2=0.64 and 0.33 respectively). This allows preliminary quality assessment for the results of reconstruction. The standard estimation error for most cases under investigation is higher for Zakopane, but due to higher snow cover mean value compared to Cracow, this parameter can not decide definitely on worse data fit for Zakopane.

The comparison of the observed snow cover characteristics with those calculated from the equations used for reconstruction indicates satisPublication financed by Institute of Geography, Jagiellonian University factory results for the basic period in both stations (Tab. 3, Fig. 1, 2). The smallest differences, as expected, are obtained for the number of snow cover days for which the fit of 10-year consecutive means is very good (R=0.92 for Cracow). Generally, the calculated snow cover thickness maximum and sum of snow cover thickness are smaller

---

Fig. 1. Observed and reconstructed snow cover characteristics in Cracow *(obs. - observed, rec. - reconstructed, c. & b. - control and basic period).*

than observed ones in the case of extremely high values, while are greater for extremely low observed values.

Similar comparison made for the control period lead to much worse results (Tab. 3, Fig. 1, 2). While there are no major objections to the results obtained for Cracow, the calculated number of snow cover days and sum of snow cover thickness for Zakopane is clearly too high. The snow cover maximum for this station does not reach its extreme values, thus resulting in considerable flattening of the consecutive mean line. The confidence level for all correlation coefficients is about 0.05. The highest correlation were calculated for sum of daily snow cover thickness (0.82 for Cracow and 0.7 for Zakopane). The average differences for the entire period does not exceed, except for the sum of daily snow cover thickness in Zakopane, a few percent. The considerably overestimated sum of daily snow cover thickness (by 22% in average) and the number of snow cover days in Zakopane (by 8%, i.e. 10 days) within the control period cause that the results of reconstruction for the turn of the 19th century become less reliable and can rise an objection. Thus, these cases were excluded from statistical analysis performed for

Fig. 2. Observed and reconstructed snow cover characteristics in Zakopane *(obs. - observed, rec. - reconstructed, c. & b. - control and basic period).*

many-year time series. It is difficult to explain such large discrepancies. An analysis of equation components has shown no data errors for the control period. Also, many attempts to use other equations and to eliminate individual components have failed.

The principal statistical parameters for snow cover time series containing both observed and reconstructed values for all three snow cover characteristics for Cracow and for maximum snow cover thickness for Zakopane (104 winter seasons) and for observed values only for the number of days with snow cover and sum of snow cover thickness for Zakopane (85 winter seasons) are presented in Table 4. No statistically significant tendency in snow cover variability was found for all six cases. The mean number of snow cover days in Zakopane is twice as large as that of Cracow. The lowest snow cover was recorded in the season 1924/25, when in Cracow snow cover persisted for 10 days only. The highest snow cover was recorded in Cracow in the season 1962/63 when relevant parameters in Zakopane were also above its typical values (Fig. 1, 2). The snow cover variability coefficient is much more higher in Cracow than in Zakopane. In both stations the sum of snow cover thickness shows the highest variability (50% in Zakopane, 91% in Cracow).

4. Conclusion

The snow cover reconstruction for the turn of the 19th century based on climatic data appears to be more successful for the station located at lower altitude (Cracow). In this case the results obtained can be considered as reliable but, obviously with some errors. The results obtained for Zakopane appear to be overestimated for the number of snow cover days and sum of daily snow cover thickness, as demonstrated for the control period. Such results could affect an analysis of long-term snow cover variability. Thus, they have been excluded from further calculations.

An analysis of long-term snow cover variability in Cracow and Zakopane has shown no statistically significant trends for characteristics under investigation.

References

Brown R.D., Goodison B. E., 1996, *Interannual Variability in Reconstructed Canadian Snow Cover, 1915-1992*, Journal of Climate, vol. 9, No. 6, June, 1299-1318.

Falarz M., 1998, *Wieloletnia zmienność pokrywy śnieżnej w Krakowie na tle zmian w obszarach podmiejskich*, Acta Universitatis Lodziensis, Folia Geographica Physica, nr 3, Materiały III Ogólnopolskiej Konferencji „Klimat i Bioklimat Miast", Łódź, 22-24 października 1997, 473-481.

Falarz M., Fasko P. Lapin M., 1998, *Long-Term Variability of the Snow Cover in the Western Carpathians*, [in:] *Proceedings of the 2nd European Conference on Applied Climatology*, ECAC 98, 19 to 23 October 1998, Vienna, Austria, „Oesterreichische Beitrage zu Meteorologie und Geophysik" Zentralanstalt fur Meteorologie und Geodynamik, Publ. Nr 384, Heft 19, Wien, p.19 and full text on „ECAC CD-ROM", session 1, 6.

Tab. 4. Characteristic of snow cover in Kraków and Zakopane.

station	average	the highest	in season	the lowest	in season	standard deviation	variation coefficient (%)	change/100 years	analysed period	length of series (seasons)
	number of days with snow cover ≥ 1 cm									
Kraków	60	133	1995/95	10	1924/25	22	36.7	3.5	1895/96-1998/99	104
Zakopane	126	170	1931/32	84	1924/25	19	15.0	0.2	1914/15-1998/99	85
maximum thickness of snow cover (cm)										
Kraków	21	65	1962/63	5	1924/25,1988/99	10	49.1	2.1	1895/96-1998/99	104
Zakopane	63	123	1944/45	25	1924/25,1960/61	20	31.9	-7.0	1895/96-1998/99	104
sum of daily snow cover thickness (cm)										
Kraków	599	3336	1962/63	19	1924/25	544	90.9	40.1	1895/96-1998/99	104
Zakopane	2977	6939	1951/52	761	1924/25	1489	50.0	206.7	1914/15-1998/99	85

Niedźwiedź T., 1998, *Variability of Atmospheric Circulation Indices above the Western Carpathians*, [in:] *Proceedings of the 2nd European Conference on Applied Climatology*, ECAC 98, 19 to 23 October 1998, Vienna, Austria, Österreichische Beiträge zur Meteorologie und Geophysik, Central Institute for Meteorology and Geodymamics, Nr 19, (CD-ROM), session 1, 6.

Małgorzata Falarz
Institute of Meteorology and Water Management, Branch Cracow
Cracow
Poland