Snow Cover Changes in Bulgarian Mountainous Regions, 1931–2000

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ABSTRACT

Principal component analysis (PCA) was carried out on annual snow cover series from 15 mountain climate stations in Bulgaria to characterize the spatial and temporal variability in snow cover over the 1931–2000 period. The PC analysis revealed three distinct snow cover response regions in Bulgarian mountains: (1) high elevation sites above 1500 mASL; (2) the eastern Rodope Mountains and (3) a mid-mountain zone covering 1000–1500 mASL. Over the 1931–2000 period snow cover exhibited evidence of decadal-scale variability but no evidence of any long-term trends linked to climate warming. Over the more recent 1971–2000 period stations in the 1000–1500 elevation band have exhibited more coherent temporal variability in maximum snow accumulation and a trend toward a later start to the snow cover season. No clear links were found between snow cover variability and NAO, and only spring snow cover at the higher elevation sites was found to be significantly correlated with regional air temperatures. The results reflect the complex climate of Bulgaria.

Key words: snow cover, Bulgarian mountainous regions, principal component analysis

INTRODUCTION

There is relatively little information on snow cover changes in many mountainous regions of the world because of a lack of available long-term datasets. The Bulgarian National Institute of Meteorology and Hydrology has assembled a meteorological and snow cover dataset extending back to the early 1930s for 15 sites in the Bulgarian mountains. An initial assessment of this dataset (Petkova *et al*., 2004) found no evidence for recent widespread significant reductions in mountain snow cover documented in other areas of Europe such as the Swiss Alps (Laternser and Schneebli, 2003; Beniston**,** 1997).

This paper applied PC analysis to fall and spring snow cover duration (SCD), annual snow cover duration and maximum annual snow depth to characterize the spatial and temporal variability in snow cover over the 1931–2000 period. In addition, the paper examined the correlation of the PC series with monthly regional temperature anomalies and leading modes of NH circulation such as NAO in an effort to explain the observed variability.

DATA AND METHOD

The snow cover duration and depth series used in this study were generated from daily snow depth measurements made over the 1931–2000 winter seasons at 15 mountain weather stations

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located above 800 mASL (Figure 1). Quality control was carried out by comparing data from neighboring stations, and replacing erroneous or missing values with interpolated values. Snow cover duration (SCD) was defined as a day with 1 cm or more of snow on the ground. The annual SCD series were additionally split into fall (August–January) and spring (Feb–July) halves to examine variability in snow cover onset and disappearance. This approximates the first and last dates of permanent snow cover. Annual time series for 4 snow cover variables were generated for subsequent PC analysis: annual SCD, fall and spring SCD, and annual maximum snow depth. PC analysis was carried out for the 1931–2000 period with 12 stations with more-or-less complete data in the period, and for the more recent 1971–2000 period with data from all 15 stations. The number of PCs was fixed at 6 in the calculations and a varimax rotation applied. Only PCs explaining more than 15% of the variance were retained for further analysis.

To examine linkages to broad-scale temperature and atmospheric circulation variability, the PC series were correlated with monthly regional temperature anomalies from the Jones and Moberg (2003) dataset for a 5º by 5º lat/long grid (40–45ºN, 20–25ºE) covering Macedonia, Western Bulgaria, and Yugoslavia, and with the winter North Atlantic Oscillation (NAO) index from the NOAA Clmate Prediciton Center.

Figure 1. Location of meteorological stations used in the study along with the major snow cover groupings identified by the PC analysis.

RESULTS AND DISCUSSION

The snow cover series exhibited considerable decadal and longer time scale variability, however few stations showed evidence of significant long-term trends in snow cover. Only 2 stations (Samokov and Undola) showed evidence of significant trends toward earlier snow cover disappearance over the 1931–2000 period. There was no evidence of any recent trend toward earlier spring melt that has been documented in many other regions of the NH (Brown, 2000). Also there was no evidence that lower elevation sites are showing any preferential response to recent (1971–2000) NH warming.

Maximum snow depth

PCA regional grouping results for maximum snow depth during 1931–2000 showed two main regional clusters: PC1 explaining 21% of the variance with two eastern Rodhope mountain stations (Mts) (Chepelare and Raikovo) and one Pirin Mts (Bansko); and PC2 explaining 19% of the variance including two high elevation Rila Mts (Sitnjakovo and Saragiol). The temporal variation in the two dominant PCs is shown in Figure.2. The two series are approximately in phase

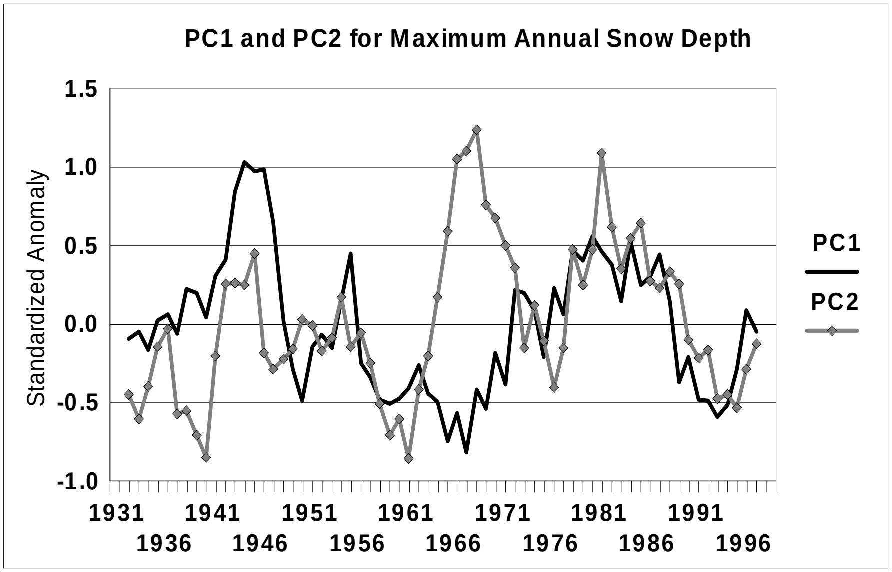

Figure 2. The two dominant PCs for maximum snow depth smoothed with a 5-year running average.

(with the exception of a period of increased snow accumulation in the Rila Mountains during the late 1960s and early 1970s) with periods of above-average snow accumulation in the 1940s and 1980s. Winter precipitation in Bulgaria has been found to be significantly correlated to the NAO pattern (Nikolova, 2004). The 5-yr smoothed values of PC2 are correlated with corresponding 5-yr smoothed values of the winter (DJF) NAO index up to the end of the 1980s (r = 0.59), however, the relationship between positive values of the NAO and above average winter snow accumulation appears to break down during the 1990s. PC results for the more recent 1971–2000 period provided evidence of a widening regional response for annual snow accumulation variations with six stations (Manastir, Chepelare, Raikovo, Krastetc, Samokov and Borovetc) in the 1000–1500 mASL elevation zone loading onto a pattern with a similar temporal response to PC1 in Figure 2.

Fall snow cover duration

The PC analysis revealed three dominant PCs for the fall SCD during the period 1931–2000: PC1 explaining 21% of the variance including one Eastern Rodope Mts. (Raikovo) and one Pirin Mts (Bansko); PC2 explaining 19% of the variance with three high elevation Rila/Vitosha Mts (Sitnjakovo, Saragiol, Mt. Chernyvrah); and PC3 explaining 19% of the variance with two Northern Rila Mts (Samokov and Borovetc) and one Sredna Gora Mts Koprivshtitca. The results (not shown) revealed considerable regional and temporal variability in fall snow cover apart from a period during the late-1950s and early-1960s with consistent below-average snow cover duration for PCs 1 and 2. This corresponds to a period with above-average October–December air temperatures over the Balkans caused by a southerly airflow. PC results for the more recent 1971–2000 period provide evidence of a widening regional response for fall snow cover duration with six stations (Manastir, Chepelare, Leeve, Undola, Koprivshtitca and Petrohan) loading onto PC1 which explained 30 % of the variance. These are most of the stations in the 1000–1500 elevation band and show a recent trend toward a later start to the snow cover season in response to warmer fall air temperatures.

Spring snow cover duration

The PC analysis results exhibited three dominant PCs for the spring SCD during the period 1931–2000; PC1 explaining 22% of the variance with one Eastern Rodope Mts (Raikovo) and one Pirin station (Bansko); PC2 explaining 24% of the variance including three high elevation

Rila/Vitosha Mts (Sitnjakovo, Saragiol and Mt. Cherny vrah); and PC4 explaining 15% of the variance with one Northern Rila Mts (Samokov) and one Sredna Gora Mts (Koprivshtitca). The results (not shown) revealed considerable regional and temporal variability in spring snow cover with a brief period of coherent low spring snow cover during the late-1950s and early-1960s (as noted above for fall snow cover) and a brief period of above-average spring snow cover during the early 1980s (a period of cooler spring temperature across the Balkans). For the more recent 1971–2000 period there was no evidence of any widening regional response for spring snow cover characteristic of snow cover response in many other regions of the NH (Brown, 2000).

Annual snow cover duration

The PC analysis results for annual snow cover duration over the 1931–2000 period generated the same station groupings as the spring snow cover duration results. This result indicates that spring period processes dominate annual snow cover duration variability over Bulgaria. Time series for the 3 dominant PCs are shown in Figure 3. Annual snow cover duration is characterized by a decrease from the 1940s to the 1960s, followed by a gradual increase in snow cover for PCs 1 and 2 in response to a cooling trend over the Balkans. PC results for the more recent 1971–2000 period provide evidence of a widening regional response for annual snow accumulation variations with six stations (Petrohan, Koprivshtitca, Samokov, Undola, Leeve, and Chepelare), loading onto PC1, which explained 29% of the variance. These are most of the stations in the 1000–1500 elevation band and they are showing a trend toward a shorter snow season over the 1971–2000 period most of which is being driven by a later start to the snow cover season.

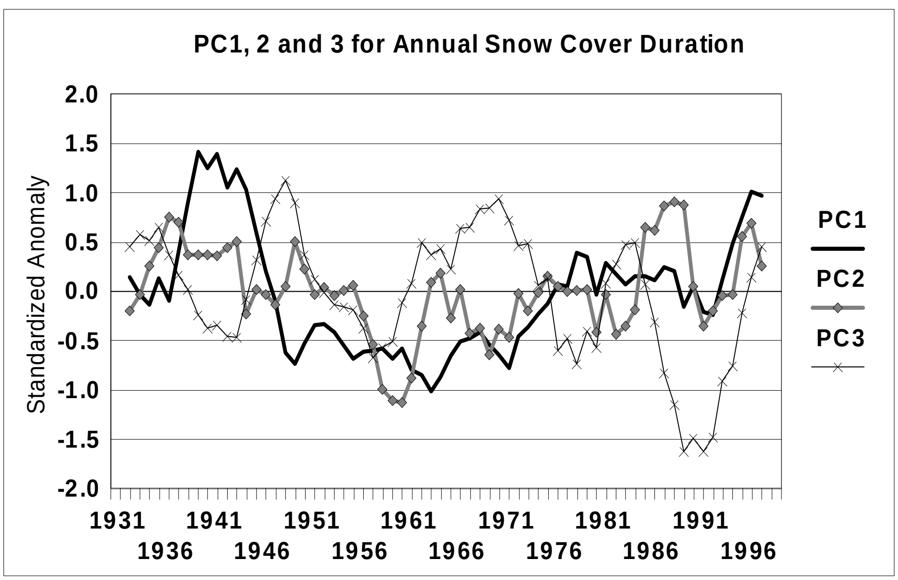

Figure 3. The three dominant PCs for annual snow cover duration smoothed with a 5-year running average.

Correlation analysis

Correlation of PCs series for the four snow cover variables with regionally averaged monthly temperature anomaly series over the 1941–2000 period generated few correlations exceeding 0.5. The exception was the high elevation sites Saragiol, Sitnjakovo and Mt. Chernyvrah where spring snow cover had a correlation of –0.65 with April regional temperatures. Further analysis is required to determine the reason for this result, as the expectation was that the lower elevation sites would be more highly correlated with regional temperatures; Beniston (1997) found that the sensitivity of the snow-pack to climatic fluctuations diminished above 1750 mASL. For the more recent 1970–2000 period, the dominant PC for fall snow cover variability was significantly correlated with November regional temperatures (r = –.52) which confirms that warmer fall temperatures are contributing to the trend toward a later start to the snow season at a number of locations.

Beniston (1997) found that snow depth and snow cover duration in Switzerland were correlated to the North Atlantic Oscillation. As mentioned previously, winter precipitation in Bulgaria is significantly correlated with NAO (Nikolova, 2004) and maximum snow depth and the NAO appear to be more or less in phase until the 1990s. However, none of snow cover series exhibit significant correlations with NAO over the 1931–2000 period. Further work is being carried out to assess possible large-scale controls on Bulgarian snow cover variability. For example, Latinov (2000) showed that Mediterranean cyclones are one of the main factors determining winter weather character in Bulgaria. Composite analysis of cyclone frequency and other meteorological fields during high and low snow years will be carried out to investigate potential controls on snow cover variability in more detail.

CONCLUSIONS

PC analysis of Bulgarian snow cover data revealed three distinct snow cover response regions in Bulgarian mountains (see fig.1); (1) high elevation sites above 1500 mASL; (2) the eastern Rodope Mountains and (3) a mid-mountain zone covering 1000–1500 mASL. The snow cover series exhibited considerable decadal and longer time scale variability and there was no evidence of widespread significant long-term trends over the 1931–2000 period. However, it was found that climate stations in the 1000–1500 m elevation range are exhibiting a more coherent response over the last 30 years, and show evidence of a recent trend toward a later start to the snow cover season. There was no evidence of any widespread trend toward earlier disappearance of snow in the spring as has been documented in many other regions of the NH over the last 20–30 years. Only the higher elevation sites above 1500 mALS exhibited a significant correlation with regional temperature in the spring period. No obvious links were found between snow cover variability and the NAO.

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