A QUANTIFIED CORRELATION BETWEEN SWISS ALPINE SNOW COVER DURATION AND ATMOSPHERIC THICKNESS FOR A RANGE OF TERRESTRIAL ALTITUDES AND SNOW DEPTHS

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Abstract: The natural interannual variation of mean atmospheric temperature has been used as an indicator of how snow cover duration in the Swiss Alps may decrease in response to global warming. Using atmospheric thickness as a measure of temperature, correlations between thickness and snow cover duration have been found at 27 locations within the Swiss Alps, at altitudes between 900 and 1800m. For each location, mean seasonal thickness was compared to the number of days between 1st October and 31st May with 5cm, 30cm and 50cm depth of snow, for the winter seasons from 1960 to 1999. Correlations were then validated through statistical analysis that tested the probability that no correlation exists. Strong correlations were found at all locations for all snow depth thresholds, with the highest and most reliable correlations at lower altitudes. Similar results were also found for a comparisson between snow cover duration and mean 500 hPa height, though results appear to show that correlations strengthen with increasing altitude.

Keywords: *Snow cover duration, atmospheric thickness, atmospheric temperature, global warming, ERA-40 re-analysis*

1. Introduction

Regional Climate Model predictions for the Swiss Alps have forecast a localised warming by 2100 of 4°C (Christensen *et al*., 2002). Anomalously warm winters during the past 40 years have evoked speculation concerning potential consequences for the skiing industry, and allowed an insight into the effect this degree of warming could impose on mean snow conditions. In order to maintain viability, resorts require a snow depth of 30cm for a duration that includes both the Christmas and Easter holiday periods, typically 130 days. The commercial and social importance of snow cover also extends more deeply into the viability of mountainous regions, influencing industries and services such as drinking water reservoirs and hydroelectricity, as well as inflicting hazards such as road closures and avalanches. The need to quantify the response of snow cover depth and duration in a warming climate is therefore of paramount importance, a need re-iterated by observations during the most recent winter. Official DJF figures from MeteoSchweiz show a positive deviation from the 1961-1990 mean of 3°C for the whole of Switzerland (MeteoSchweiz 2007).

Several authors, including Nakamura *et al*., (1996), Whetton *et al*., (1996), Beniston (1997), Martin *et al*., (1998) and Beniston *et al*., (2003) have identified that during an average winter, temperature exerts the most definitive and important control on snow cover duration at altitudes below 1700m. This research has therefore attempted to express snow cover duration as a function of temperature, using the natural interannual variation of mean atmospheric thickness and snow cover duration at 27 locations in the Southern Swiss Alps.

2. Methods

Mean atmospheric 1000-500 hPa thickness has been calculated using ECMWF ERA-40 re-analysis pressure data at the 47°N and 9°E grid point, for the winter seasons 1960 to 1999. Each season has been defined as 1st October to 31st May. Assuming temperature differences between the two pressure levels to be negligable, it can be approximated that a 1°C increase in mean temperature results in a 20.3m increase in atmospheric thickness. This method for representing temperature has been used in preference to surface observations in order for several reasons. Thickness serves as the most accurate form of reconstructing historical temperature measurements, as well as allowing the snow formation regions to be included in analyses. It also allows any local influences on surface temperature such as buildings, local topography, aspect, forestry, etc. to be discounted.

Snow data locations have been chosen from a vast snow monitoring network in Switzerland, given that the following conditions are met:

- Homogeneous location for the duration of the study
- Continuous observations for the duration of the study
- Location within the altitude range at which > 90% Swiss ski resorts lie; 900-1800m.

Twenty seven monitoring stations were identified, and snow cover duration was then calculated as the number of days with 5cm, 30cm and 50cm snow depth between 1st October and 31st May. These depth thresholds were selected because of the following;

- 5cm – Minimum depth for the aesthetic value of having snow present in a ski resort (Jaagus 1997)
- 30cm – Minimum depth required to facilitate skiing (Bultot *et al*., 1994 and Elsasser *et al*., 2001)
- 50cm – Prefered minimum depth on the slopes (Elsasser *et al*., 2001).

Snow data was provided by the Swiss Federal Institute for Snow and Avalanche Research (SLF).

Mean seasonal thickness and snow cover duration were then compared for each depth threshold at each of the 27 stations. Any correlation identified between the two variables was then subject to statistical analyses to ensure that the correlation was reliable. This was achieved by calculating the probability that no correlation exists.

Snow cover duration and the mean seasonal height of the 500 hPa pressure contour were also compared using the same method described above. This allowed the combined effects of temperature and precipitation on snow cover duration to be analysed.

3. Results

Figure 1 shows regression plots of mean atmospheric thickness against snow cover duration for 4 of the 27 stations analysed. Results for stations at 910m, 1190m, 1735m and 1800m are shown along with their correlation statistics. All stations researched display strong correlations, and those in figure 1 act as a representation of the altitude range. It can clearly be observed from figure 1, that the strongest and most reliable correlations occur at the lower altitudes. This trend continues for all 27 stations (statistics not shown).

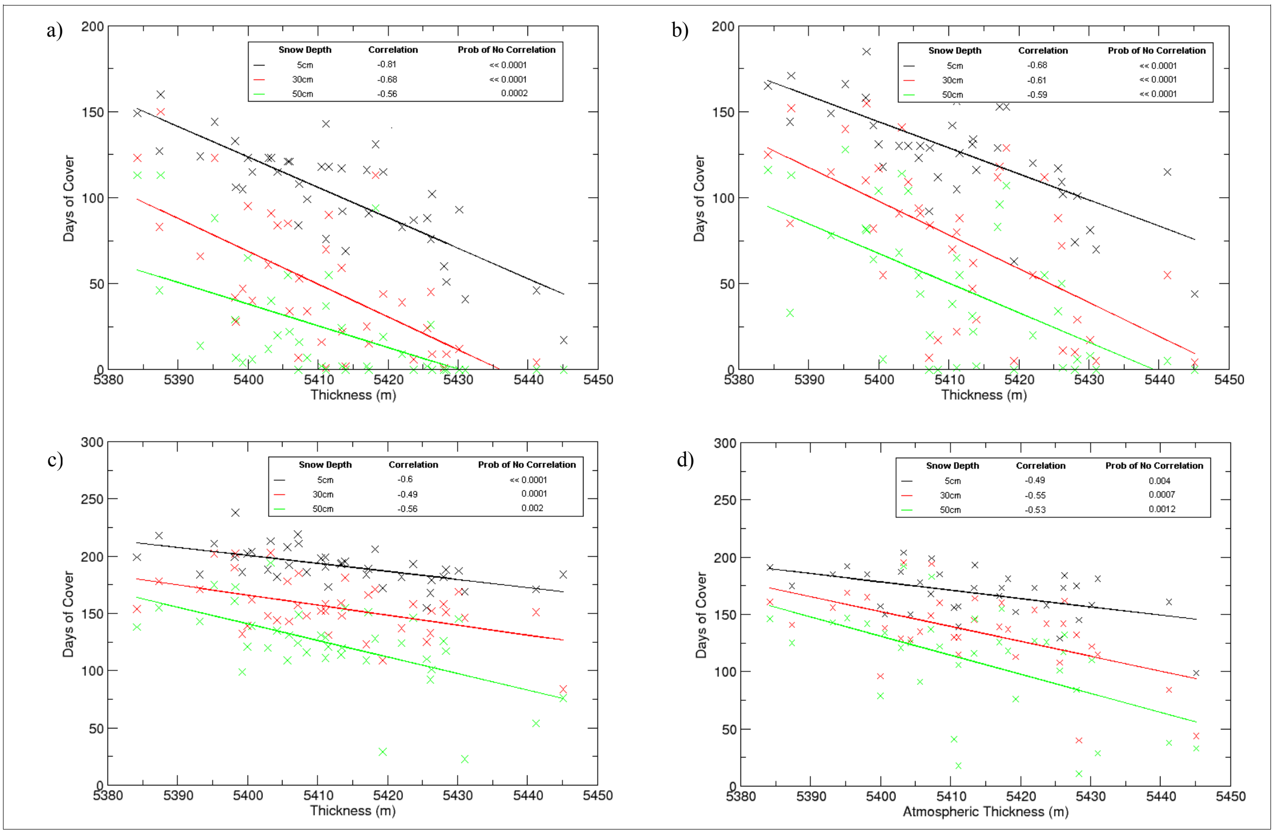

Figure 1: Regression plots and correlation statistics for mean atmospheric thickness and snow cover duration at a) 910m, b) 1390m, c) 1570m and d) 1800m altitude.

Figure 2 shows regression plots for mean 500 hPa height against snow cover duration for the same stations as those in figure 1. Again reliable correlations have been found to exist at all locations and snow depth thresholds, however, an weakly opposing trend of correlation strength and reliability appear to be evident. The statistics for all stations (again not shown) losely show a trend for correlations to strengthen with increasing altitude.

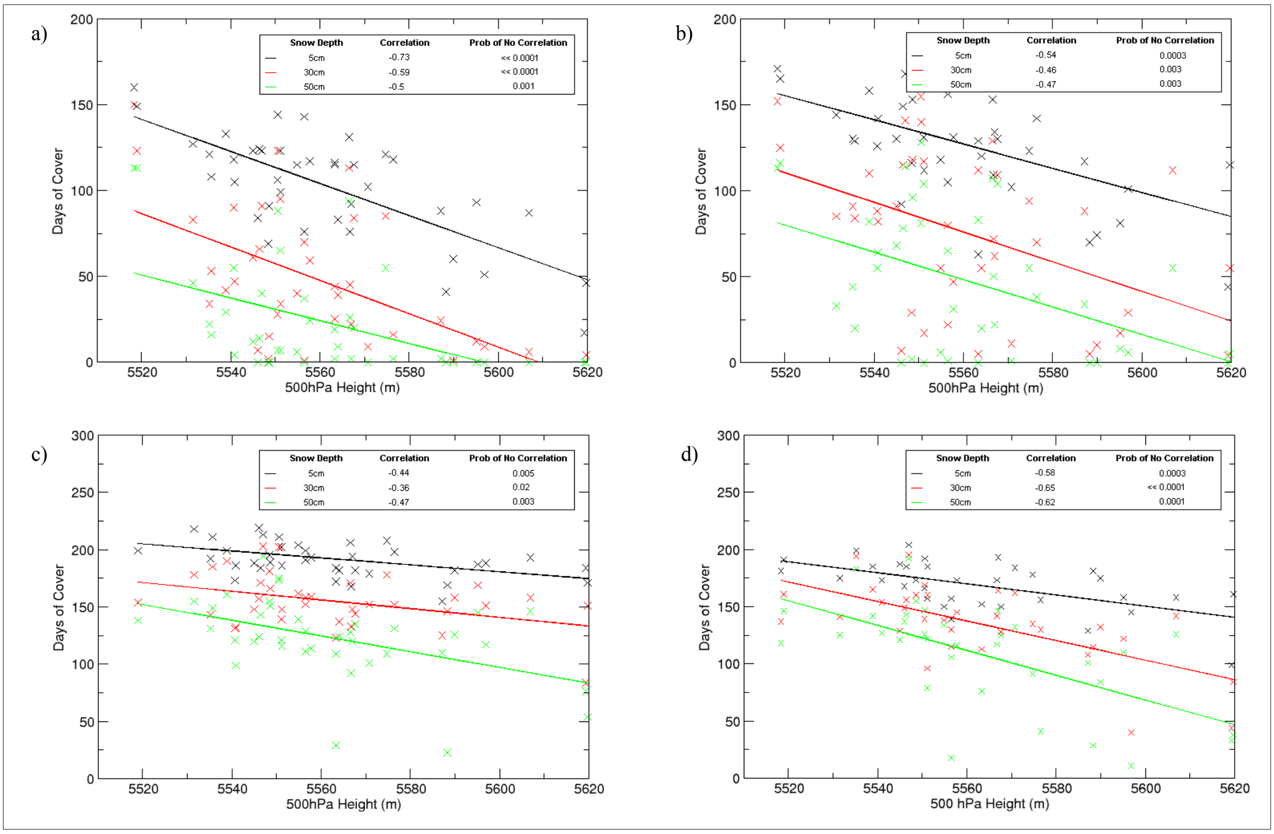

Figure 2: Regression plots and correlation statistics for mean 500 hPa height and snow cover duration at a) 910m, b) 1390m, c) 1570m and d) 1800m altitude.

4. Conclusions

The extremely high reliability of the thickness:duration correlations at all stations investigated, confirms the pivotal role of temperature on snow cover duration in the Swiss Alps. Results show the strongest and most significant correlations to occur at lower altitudes, which suggests that in response to global warming, a reduction in snow cover duration will most markedly be observed at these lower altitudes. Within the range of mean thickness observed during the study period, an approximate positive deviation of 2°C from mean conditions has been experienced, and has resulted in a decrease in snow cover duration below the viable number of days of 130, for all altitudes investigated. This suggets that the predicted warming of 4°C will be catastrophic for the skiing industry.

The closer correlation of snow cover duration at higher altitudes to 500 hPa height suggests that higher elevations are more dependant on variations of both temperature and precipitation. This is because 500 hPa height responds to both temperature and weather system changes. The effect of global warming on higher altitude ski resorts must therefore be considered in terms of both of these variables. If global warming leads to an increase in precipitation, it is possible that snow cover duration could increase due to increased snow fall, as discussed by Beniston (1997) and Beniston *et al*., (2003).

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