Climate change impacts on Austrian ski areas

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Abstract

Climate change is a threat to the snow-dependent winter tourism industry. In this paper, the impact of climate change on the snow reliability of 228 Austrian ski areas was investigated using a ski season and snowmaking simulation model (SkiSim 2.0). The results show that snowmaking can balance the negative impacts of climate change on snow up to a warming of 2 °C, but with high regional differences, i. e. higher and earlier impacts in the East. A multiplying of current snow production required in a warmer climate marks snowmaking as being no long-term adaptation measure for the Austrian winter tourism industry.

Keywords: climate change, winter tourism, snowmaking, Austria, vulnerability

1 Introduction

Climate change is a threat to the snow-dependent winter tourism industry. Decreasing snow trends on the one hand (e. g. Laternser & Schneebeli 2003 for Switzerland; Durand et al. 2009 for France; Pons et al. 2009 for Spain; Schöner et al. 2009 for Austria) and the economic relevance of winter tourism in many mountain regions on the other hand have led to a wide range of climate impact studies. While first generation impact studies considered natural snow only (e. g. McBoyle & Wall 1987, Canada; Galloway 1988, Australia; Abegg 1996, Switzerland), second generation studies also incorporated snowmaking and thus considered a potential climate change adaptation measure in their assessments (e. g. Scott et al. 2003, Canada; Hennessy et al. 2008, Australia; Steiger & Mayer 2008; Steiger 2010, Austria). The impact of climate change on the ski tourism industry was found to be lower in second generation studies, but current snowmaking technology is likely to reach both climatic limits (i. e. temperatures too high to produce enough snow) and economic limits (increasing snowmaking costs) in the next decades (Scott et al. 2008; Steiger 2010).

In terms of global skier days, Austria is ranked third behind the US and France with a share of 15% (Vanat 2010). The winter tourism sector is estimated to generate € 7.4 billion to € 11.4 billion (the latter including multiplier effects), representing 3.2 to 4.9% of the Austrian GDP (Arbesser et al. 2010). Due to comparatively low elevated ski areas, especially in the eastern part of the country, climate change is assumed to have severe impacts on Austrian ski areas (Abegg et al. 2007; Breiling et al. 1997). However, Abegg et al. (2007) and Breiling et al. (1997) did not consider snowmaking, and Steiger (2010) only investigated the impacts on three case studies in Tyrol/Austria. This represents a major limitation, as e. g. in Austria snow can be produced on about 66% of all ski slopes (Fachverband der Seilbahnen Österreichs 2011).

This paper aims to overcome this limitation by using established methods and indicators to assess the impacts of climate change on Austrian ski areas. A ski season and snowmaking simulation model "SkiSim 2.0" (Steiger 2010) was applied for 228 Austrian ski areas. SkiSim 2.0 is a further development of the Canadian SkiSim model with applications in Canada (Scott et al. 2003; Scott et al. 2007) and the US Northeast (Dawson & Scott 2010; Scott et al. 2008). By using the 100-days rule and ski area data (e.g. mean altitude and definition of ski areas) of Abegg et al. (2007), results can be directly compared to the so-far most comprehensive climate change impact study published by the OECD in 2007 covering 666 ski areas across the Alps (France, Switzerland, Germany, Austria and Italy) (Abegg et al. 2007).

2 Methodology

2.1 SkiSim 2.0 – a ski season and snowmaking simulation model

SkiSim 2.0 is a degree-day model simulating snow depth on a daily basis with temperature and precipitation as input data. Snow production is calculated on an hourly basis by linear interpolation of daily minimum and maximum temperature resulting in potential snowmaking hours with air temperature ≤ -5 °C. The production capacity is set to 10 cm/day and represents a current state-of-the-art snowmaking system (i.e. three days required to open the ski slope). Snow is produced if the day is within the snowmaking season dates (Nov 1–Mar 31) and if modelled snow depth is below a calibrated critical snow depth.

This calibrated critical snow depth represents the practitioners' experience on the amount of snow required. Thus this threshold is calibrated to maintain a ski season until April 1 in 90% of all winters in a 30-year period being based on interviews with ski area managers conducted between 2007 and 2010 in Tyrol (Austria). More details on the model procedures can be found in Steiger (2010).

Meteorological data was provided by the Central Institute of Meteorology and Geodynamics (ZAMG). Stations were excluded from the database, if data gaps of more than 10 days per season were detected, or if no data was available in the period 1981–1999. Snowfall temperature and the degree-day factor was calibrated for each station separately for the period 1981/82 to 1989/90 and validated for the period 1990/91 to 1998/99. The evaluation of model performance at the remaining 53 stations at altitudes between 295–2,304 m showed a maximum negative (positive) deviation of modelled to measured snow cover days of −8.5 % (5.0%) with −1.8% mean and 3.1% standard deviation in the validation period. It can thus be concluded that SkiSim 2.0 performs well for multi-year averages of snow cover duration at different altitudes and regions within Austria and is suitable for climate change impact assessments in the skiing tourism industry.

Each of the 228 ski areas was assigned to a climate station with the nearest neighbour principle. In some cases, e.g. when the nearest climate station was north of the main alpine divide and the ski area was south of the divide resulting in potential high climatic differences, an alternative station with longer distance to the ski area, but a similar climate was chosen. Temperature and precipitation were extrapolated to the mid-station of each ski area. The mid-station of a ski area is the mean altitude between the lowest and the highest point of a ski area. The lapse rate for precipitation was pre-set with 3%/100 m. For temperature the lapse rate was derived for each station using an additional station at higher altitude (up to 3,105 m). In order to adequately represent temperature inversions, which can be quite persistent in December and January, the lapse rate was derived on a monthly basis for dry and wet days separately (precipitation <1 mm and ≥ 1 mm, respectively). The mean lapse rate between November and April at the 53 stations on dry days was 0.3 °C/100 m, on wet days 0.5 °C/100 m. The overall mean in the winter half year was 0.39 °C/100 m which corresponds well with findings of Kunz et al. (2007) who derived a similar winterly lapse rate for Swiss stations.

2.2 Climate change scenarios

Due to uncertainties underlying climate model data, it is recommended to use a multi-model ensemble of climate models as well as greenhouse gas emission scenarios for climate change impact assessments (Semenov & Stratonovitch 2010). Though the use of multi-model ensembles for uncertainty analysis is out of question, hypothetical warming scenarios were used in this paper to be able to assess the sensitivity of ski areas to specific temperature increases. A positive side-effect is that results can be directly compared to Abegg et al. (2007).

In contrast to Abegg et al. (2007) who only used a +1 °C, +2 °C and +4 °C scenario, eight future scenarios from +0.5 °C to +4 °C in 0.5 °C steps were simulated in this study. The meteorological data was perturbed by the climate change signal using a stochastic weather generator ("LARS-WG5", Semenov & Barrow 1997) producing daily time series of future, "synthetic" weather. The reference period was set to the climatological normal period 1961–1990. For climate stations with a shorter time series, the warming signal was adjusted with a correction factor. This factor was derived from a reference station with a long time series covering both the reference period and the period of available data at the specific station.

2.3 Assessing the sensitivity of ski areas to climate change

In order to assess the ski areas' sensitivity to climate change, thresholds or indicators are required to describe potential changes. A ski area can be considered viable if snow conditions are sufficiently reliable for a profitable ski operation. A common indicator for profitable ski operation (often to referred as snow reliability), also confirmed by ski area managers, is the so-called 100-days rule (Abegg 1996; Abegg et al. 2007; Scott et al. 2008). It states that a ski area can be considered snow reliable, if a ski season with a length of at least 100 days (snow depth ≥ 30 cm) in 7 out of 10 winter seasons can be provided at the mid station of a ski area (Abegg 1996).

3 Results

The 100-days rule was applied to the mid-stations of all 228 ski areas in Austria. In the reference period 1961–1990, 80% of all ski areas can be defined as naturally snow reliable (Figure 1). The remaining 20% are not likely to be profitable. According to the former (1990–2010) chairman of the Austrian Cableway Association (Fachverband der Seilbahnen Österreichs 2011), about one third of ski lift companies achieve a good cash flow, another third has an acceptable cash flow and one third is virtually unprofitable (Karl 2007). Though additional factors such as variety of ski slopes, accessibility and weather determine the profitability of ski operation, the 100-days rule seems to be an adequate predictor for the most important location factor – the availability of snow (e.g. Fleischhacker et al. 2009).

The SkiSim 2.0 model results show a continuously declining share of naturally snow reliable ski areas (Figure 1). A 2 °C warming, which is projected for the middle of the 21st century by climate models, would halve the number of naturally snow reliable ski areas, and with a 4 °C warming, expected for the end of the 21st century, only a very small proportion of ski areas would remain.

With current snowmaking technology and capacity, almost all ski areas (97%) can provide at least a 100-days season. Thus at present, snowmaking is a suitable measure to improve snow conditions or to balance natural climate variability. With a warming higher than 2 °C, however, the number of snow reliable ski areas is decreasing rapidly as temperatures become too warm to produce the required amount of snow in the majority of ski areas (Figure 1).

Analysing the results on regional scale, considerable differences of snow reliability between Austrian provinces can be detected. Tyrol has the highest proportion (100%) of naturally snow reliable ski areas in the reference period not least to the fact that ski areas in this province are the highest elevated in Austria (Figure 2). The comparably low number of current naturally snow reliable ski areas in Carinthia is due to a higher temporal variability of snow conditions south of the alpine divide. In

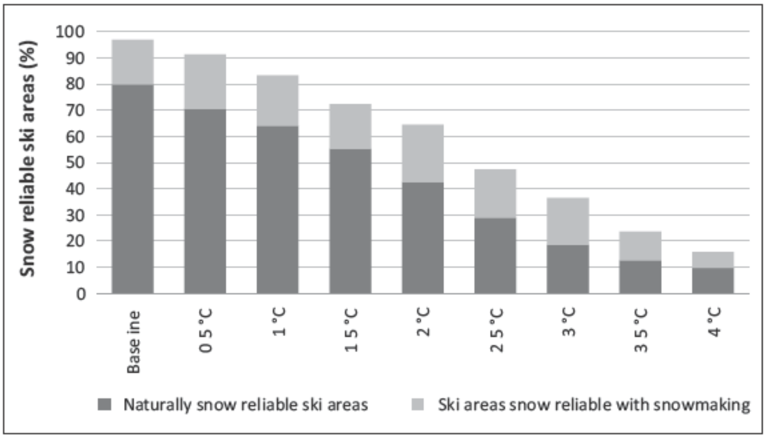

Figure 1: Share of snow reliable ski areas in Austria with and without snowmaking.

Table 1: Required snow production (temperature-independent) per province.

Province	Ref.	0.5 °C	1 °C	1.5 °C	2 °C	2.5 °C	3 °C	3.5 °C	4 °C
	(cm)	change of required snow production (%)							
V	24	26	59	103	158	228	315	419	541
T	16	15	35	62	98	150	220	312	423
S	21	16	36	63	101	157	236	331	452
C	26	19	43	72	108	151	200	257	324
UA	26	26	68	130	211	302	408	526	661
LA	43	24	56	94	136	180	227	278	333
ST	28	16	36	61	95	140	198	267	348
A	23	18	42	72	113	167	237	322	425

V (Vorarlberg); T (Tyrol); S (Salzburg); C (Carinthia); UA (Upper Austria); LA (Lower Austria); ST (Styria); A (Austria).

Upper, Lower Austria and Styria, the low mean altitudes of ski areas are responsible for a low share of naturally snow reliable ski areas.

The share of snow reliable ski areas including snowmaking in Tyrol, Vorarlberg and Salzburg decreases rather slowly up to a warming of 1.5–2 °C, whereas in the eastern provinces a warming of only 0.5–1.5 °C is sufficient to more than halve the number of snow reliable ski areas (Figure 2). Current snowmaking technology will be ineffective in almost all ski areas in all Austrian provinces in a 4 °C scenario.

Assuming a temperature-independent snowmaking technology in the model, the required amount of snow to guarantee a 100-days season can be calculated. On average, produced snow volumes must be at least doubled in a 2 °C scenario in all provinces (Table 1). In Upper, Lower Austria and Vorarlberg a doubling would already be needed in a 1.5 °C scenario. In a 4 °C scenario, at least the four-fold (Carinthia, Lower Austria and Styria) up to a seven-fold (Upper Austria) of current snow production would be required. Even if temperature limits of snowmaking technology can be raised to be technically able to produce snow in a warmer climate, a multiple of the current snow production would be required due to less natural snowfalls and higher melt-rates. Thus snowmaking is no long-term strategy due to economic and ecologic concerns of such an increase of resource use.

4 Discussion

This is the first study to investigate the impacts of climate change on skiing tourism in Austria also considering snowmaking. By simulating the impacts both on natural snow conditions and on snow conditions including snowmaking, the results can be compared to previous studies. The results from Abegg et al. (2007) only considering natural snow conditions are within the SkiSim results with and without snowmaking (Figure 3). Two reasons are basically responsible for the difference of results:

First, Abegg et al. (2007) used a statistical-empirical relationship for their assessments. They assumed that the 100-days rule is fulfilled at 1,200 m in the western

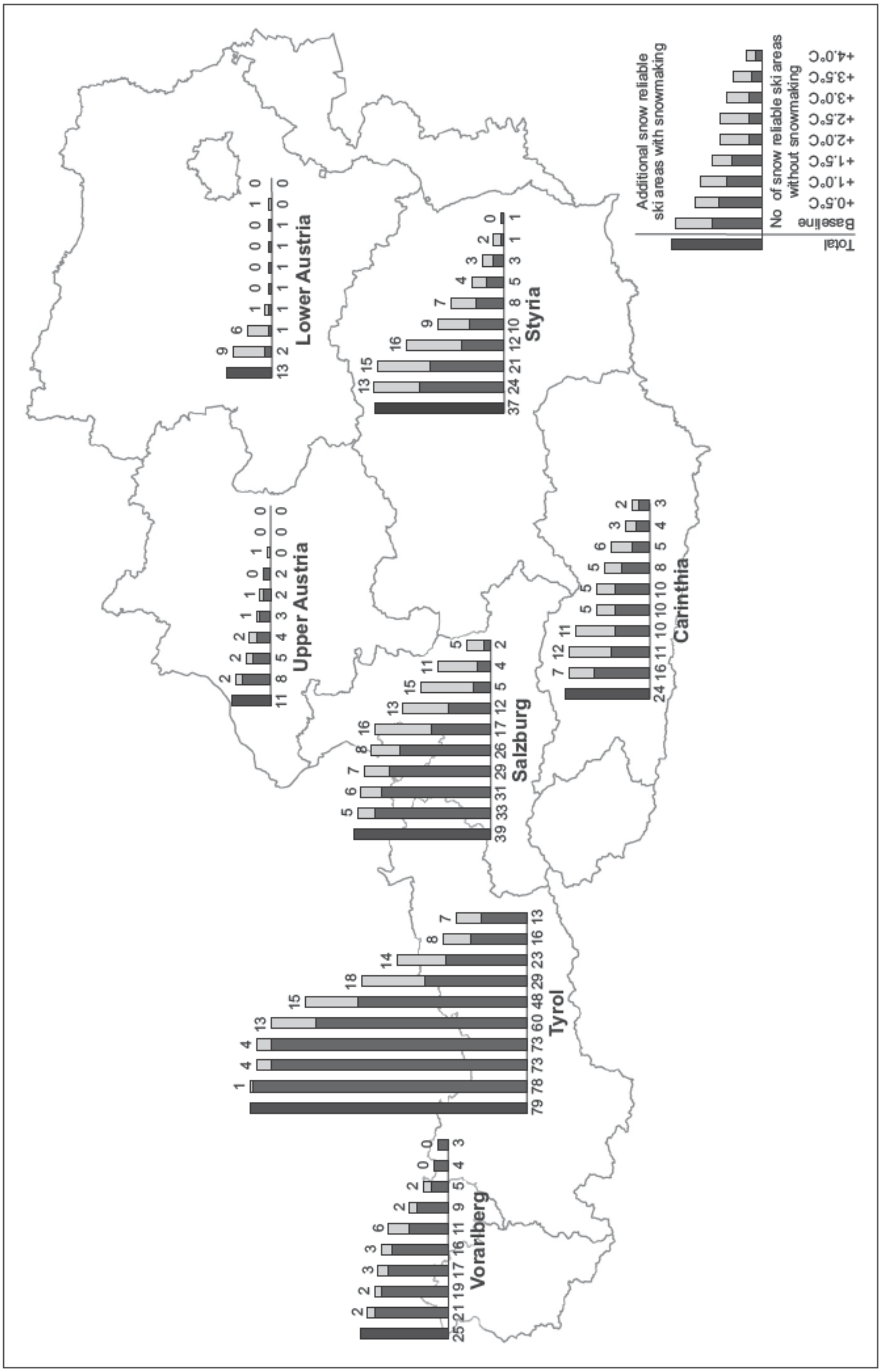

Figure 2: Share of snow reliable ski areas per province (the final figure will be the diagrams within a map of Austria).

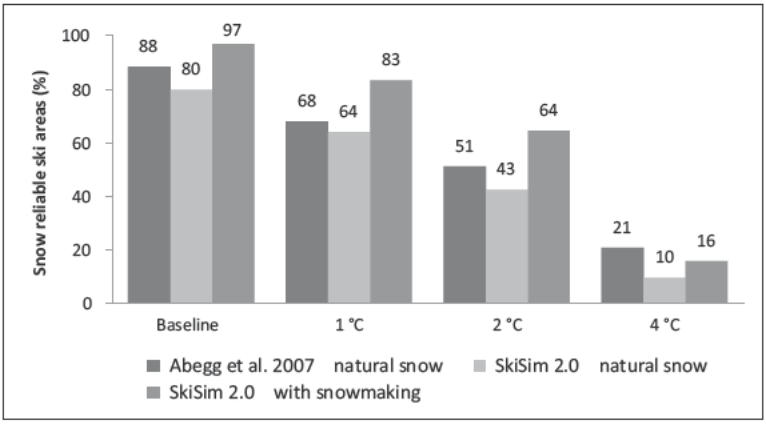

Figure 3: Comparison of Abegg et al. (2007) and SkiSim 2.0 results.

part and at 1,050 m in the eastern part of the Alps (and at 1,500 m in the southern Alps, not being applied to Austria). The 1,200 m altitude was proven for Switzerland (Abegg 1996; Bürki 2000), France (Martin et al. 1994) and parts of southern Germany (Steiger 2007), but has not been verified for the other countries so far. For Tyrol, Steiger (2010) showed that this rule cannot be applied, as the climatic differences within the province are too large. Analyzing the data available for this study, neither the 1,050 m nor the 1,200 m altitude can be verified. Three out of five stations in eastern Austria located above 1,050 m do not fulfill the 100-days rule and five out of ten stations in western Austria located above 1,200 m do not fulfill the rule likewise. Furthermore, the number of days with snow depth ≥ 30 cm can vary greatly between stations at the same altitude (e. g. Prutz at 870 m in southwestern Tyrol with 10 days and Schoppernau in Vorarlberg at 835 m with 92 days). Taking this into account leads to the conclusion that the number of naturally snow-reliable ski areas in Austria has been overestimated by Abegg et al. (2007).

Second, Abegg et al. (2007) assumed that the line of snow reliability will rise by 150 m per 1 °C warming. This corresponds to a temperature lapse rate of 0.66 °C/100 m. But the lapse rate is considerably lower in the winter months, 0.39 °C/100 m in the average at the stations used in this study. Applying this lapse rate, the upward shift of the line of snow reliability would be 250 m per 1 °C warming. This means that Abegg et al. (2007) underestimate the upward shift by 100 m per 1 °C warming, adding up to 400 m underestimation in the 4 °C scenario. This explains the growing differences in the number of naturally snow reliable ski areas between the two studies with an increasing temperature scenario.

5 Conclusion

The SkiSim model results including snowmaking confirm the findings of previous studies (Abegg et al. 2007; Breiling et al. 1997) that climate change is a serious challenge to the Austrian ski industry. It was shown that the impact of climate change can be balanced with snowmaking, but it was also shown that the sensitivity of ski areas including snowmaking to a warming differs greatly (i. e. the impacts are generally earlier in the eastern parts of Austria) and that snowmaking is no adaptation measure towards a warming of more than 2 °C.

Surveys and the investments of the past decade show that ski area managers are confident that snowmaking will be an adequate adaptation measure in the upcoming decades to deal with climate variability and change (Abegg et al. 2008; Wolfsegger et al. 2008). This confidence can be partly confirmed by the SkiSim 2.0 model results, but (i) the suitability of snowmaking to guarantee a 100-days season differs greatly between the provinces (see Figure 2) and (ii) although snowmaking will technically be possible even in a warmer climate, resource use (water, energy) would multiply for snow production (see Table 1). Currently, about 10–20% of the annual turnover is spent for snowmaking (Steiger 2010), marking it as an important cost factor. It is questionable, whether ski areas are able to cope with greatly increasing costs and/or if the customer is willing to pay for it. A further reduction of the ski area supply is very likely, where small to medium sized ski areas need to cease operation which in turn could negatively influence demand, if reasonably priced ski areas in vicinity to agglomerations (day-trips) vanish. Apart from the economic perspective, ecological concerns arise from the projected increase of snow production: Though water is not consumed but rather temporally stored on the ski slopes in the winter season and redistributed to the system in spring, water for snowmaking needs to be stored in ponds and lakes over the course of the summer season to be readily available for use in autumn. In rather dry regions in the Alps conflicts of water usage might arise, especially where high tourism intensity (higher per capita water consumption) accompanies intense irrigation agriculture (e. g. parts of South Tyrol/Italy). Last but not least, energy consumption is a major concern. As snowmaking is less energy efficient at higher temperatures (Teich et al. 2007), the increases of energy use are likely to be greater than the required growth rates for snowmaking as illustrated in Table 1. Such an increase of energy consumption contradicts climate change mitigation goals. Tourism as a sector being highly dependent on natural resources would be well-advised to be a forerunner in environmental issues and especially in climate change mitigation.

References

Abegg, B. 1996: *Klimaänderung und Tourismus. Klimafolgenforschung am Beispiel des Wintertourismus in den Schweizer Alpen*. Zurich.

Abegg, B., S. Agrawala, F. Crick & A. de Montfalcon 2007: Climate change impacts and adaptation in winter tourism. In: Agrawala, S. (ed.): *Climate Change in the European Alps. Adapting Winter Tourism and Natural Hazards Management*. Paris: 25–60.

Abegg, B., M. Kolb, D. Sprengel & V.H. Hoffmann 2008: Klimawandel aus der Sicht der Schweizer Seilbahnunternehmer. In: Bieger, T., C. Laesser & R. Maggi (eds.): *Jahrbuch der Schweizerischen Tourismuswirtschaft 2008*. St. Gallen: 73–83.

Arbesser, M., G. Grohall, C. Helmenstein & A. Kleissner 2010: *Die ökonomische Bedeutung des Wintersports in Österreich*. Vienna.

Breiling, M., P. Charamza & O.R. Skage 1997: *Klimasensibilität österreichischer Bezirke mit besonderer Berücksichtigung des Wintertourismus*. Rapport 1, 1997. Alnarp.

Bürki, R. 2000: *Klimaänderung und Anpassungsprozesse im Wintertourismus*. Publikation der Ostschweizerischen Geographischen Gesellschaft 6, St. Gallen.

Dawson, J. & D. Scott 2010: Systems Analysis of Climate Change Vulnerability for the US Northeast Ski Sector. *Tourism and Hospitality Planning & Devlopment* 7, 3: 219–235.

Durand, Y, G. Giraud, G.M. Laternser, P. Etchevers, L. Mérindol & B. Lesaffre 2009: Reanalysis of 47 Years of Climate in the French Alps (1958–2005): Climatology and Trends for Snow Cover. *Journal of Applied Meteorology & Climatology* 48: 2487–2512.

Fachverband der Seilbahnen Österreichs 2011: *Winter am Berg*. Available at: http://www.seilbahnen.at/winter (accessed 08/06/2011).

Fleischhacker, E., H. Formayer, O. Seisser, S. Wolf-Eberl & H. Kromp-Kolb 2009: *Auswirkungen des Klimawandels auf das künftige Reiseverhalten im österreichischen Tourismus. Am Beispiel einer repräsentativen Befragung der österreichischen Urlaubsreisenden*. Forschungsbericht im Auftrag des Bundesministeriums für Wirtschaft, Familie und Jugend. Vienna.

Galloway, R. 1988: The potential impact of climate changes on Australian ski fields. In: Pearman, G. (ed.): *Greenhouse Planning for Climate Change. Melbourne*. Collingwood: 428–437.

Hennessy, K., P. Whetton, K. Walsh, I.N. Smith, J. Bathols, M. Hutchinson & J. Sharples 2008: Climate change effects on snow conditions in mainland Australia and adaptation at ski resorts through snowmaking. *Climate Research* 35, 3: 255–270.

Karl, I. 2007: Personal communication with the former chairman of the Austrian Cableway Association (1990–2010).

Kunz, H., S. Scherrer, M.A. Liniger & C. Appenzeller 2007: The evolution of ERA-40 surface temperatures and total ozone compared to observed Swiss time series. *Meteorologische Zeitschrift* 16, 2: 171–181.

Laternser, M. & M. Schneebeli 2003: Long-term snow climate trends of the Swiss Alps (1931–99). *International Journal of Climatology* 23: 733–750.

Martin, E., E. Brun & Y. Durand 1994: Sensitivity of the French Alps snow cover to the variation of climatic variables. *Annales Geophysicae* 12: 469–477.

McBoyle, G. & G. Wall 1987: Impact of CO_2 induced warming on downhill skiing in the Laurentians. *Cahiers de Géographie du Québec* 31: 39–50.

Pons, M.R., D. San-Martín, S. Herrera & J.M. Gutiérrez 2009: Snow trends in Northern Spain: analysis and simulation with statistical downscaling methods. *International Journal of Climatology* 30, 12: 1795–1806.

Schöner, W., I. Auer & R. Böhm 2009: Long term trend of snow depth at Sonnblick (Austrian Alps) and its relation to climate change. *Hydrological Processes* 23: 1052–1063.

Scott, D., G. McBoyle & A. Minogue 2007: Climate Change and Quebec´s Ski Industry. *Global Environmental Change* 17: 181–190.

Scott, D., J. Dawson & B. Jones 2008: Climate change vulnerability of the US Northeast winter recreation– tourism sector. *Mitigation and Adaptation Strategies for Global Change* 13: 577–596

Scott, D., G. McBoyle & B. Mills 2003: Climate change and the skiing industry in southern Ontario (Canada): exploring the importance of snowmaking as a technical adaptation. *Climate Research* 23: 171–181.

Semenov, M. & P. Stratonovitch 2010: Use of multi-model ensembles from global climate models for assessment of climate change impacts. *Climate Research* 41: 1–14.

Semenov, Mi. & E. Barrow 1997: Use of a stochastic weather generator in the development of climate change scenarios. *Climatic Change* 35: 397–414.

Steiger, R. 2007: *Der Klimawandel und seine Auswirkungen auf die Skigebiete im bayerischen Alpenraum*. Bremen.

Steiger, R. & M. Mayer 2008: Snowmaking and Climate Change. Future Options for Snow Production in Tyrolean Ski Resorts. *Mountain Research and Development* 28, 3/4: 292–298.

Steiger, R. 2010: The impact of climate change on ski season length and snowmaking requirements. *Climate Research* 43, 3: 251–262.

Teich, M., C. Lardelli, P. Bebi, D. Gallati, S. Kytzia, M. Pohl, M. Pütz & C. Rixen 2007: *Klimawandel und Wintertourismus: Ökonomische und ökologische Auswirkungen von technischer Beschneiung*. Birmensdorf, Davos.

Vanat, L. 2010: 2010 International report on mountain tourism. Available at: http://www.vanat.ch/RM-world-report-2010-VLV.pdf (accessed 08/06/2011).

Wolfsegger, C., S. Gössling & D. Scott 2008: Climate Change Risk Appraisal in the Austrian Ski Industry. *Tourism Review International* 12, 1: 13–23.