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Source: Mountain Research and Development, 28(3) : 292-298

Published By: International Mountain Society

URL: https://doi.org/10.1659/mrd.0978

Mountain Research and Development Vol 28 No 3/4 Aug–Nov 2008: 292–298 doi:10.1659/mrd.0978

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Future Options for Snow Production in Tyrolean Ski Resorts

Winter tourism is highly sensitive to climate change. The sufficiently studied altitudinally dependent line of natural snow reliability is losing its relevance for skilift operators in Austria, where 59% of the ski area is covered by artificial snowmaking. But the diffusion of snowmaking facilities cannot be monocausally linked to climate change, as trends in tourism, prestige, and competitive advantage are important factors. Despite the fact that snowmaking is limited by climatological factors, skilift operators trust in technical improvements and believe the future will not be as menacing as assumed by recent climate change impact studies. The aim of the present study is to define reasons for the diffusion of snowmaking systems and to determine whether snowmaking can be a viable adaptation strategy despite ongoing warming, using a simple degree-day model. Results obtained with this method of assessing technical snow reliability show that current snowmaking intensity will not be sufficient to guarantee the desired 100-day season at elevations below 1500–1600 m. Snowmaking will still be possible climatically even at lower elevations, but the required intensification of capacity will lead to significantly higher operation costs.

Keywords: *Snowmaking; ski tourism; climate change; Alps; Austria.*

Peer-reviewed: *May 2008* ***Accepted:*** *August 2008*

Introduction

Since the 1990s the potential vulnerability of ski tourism to climate change has repeatedly received attention in the media, in the marketing activities of ski resorts, and not least in scientific discussions concerning the future of winter tourism (Abegg 1996; Hall and Higham 2005; Scott et al 2005). The latest OECD report on *Climate Change in the European Alps* (Agrawala 2007), published during the excessively warm winter of 2006–2007, with +3.2°C above mean for December 2006 to February 2007 in Tyrol (ZAMG 2007), suggests that due to global warming the line of natural snow reliability will rise by about 150 m per 1°C of warming. Consequently, the European Alps are expected to experience a loss of snow reliability, especially for low-elevation resorts, and a concentration of ski tourism at elevations higher than 1800–2000 m (Abegg et al 2007). Nevertheless, these projections may be of little consequence; in Austria, for example, 59% of the ski area is covered by snowmaking facilities (FSÖ 2007). Some resorts have already covered most of their slopes (>80%; Figure 1).

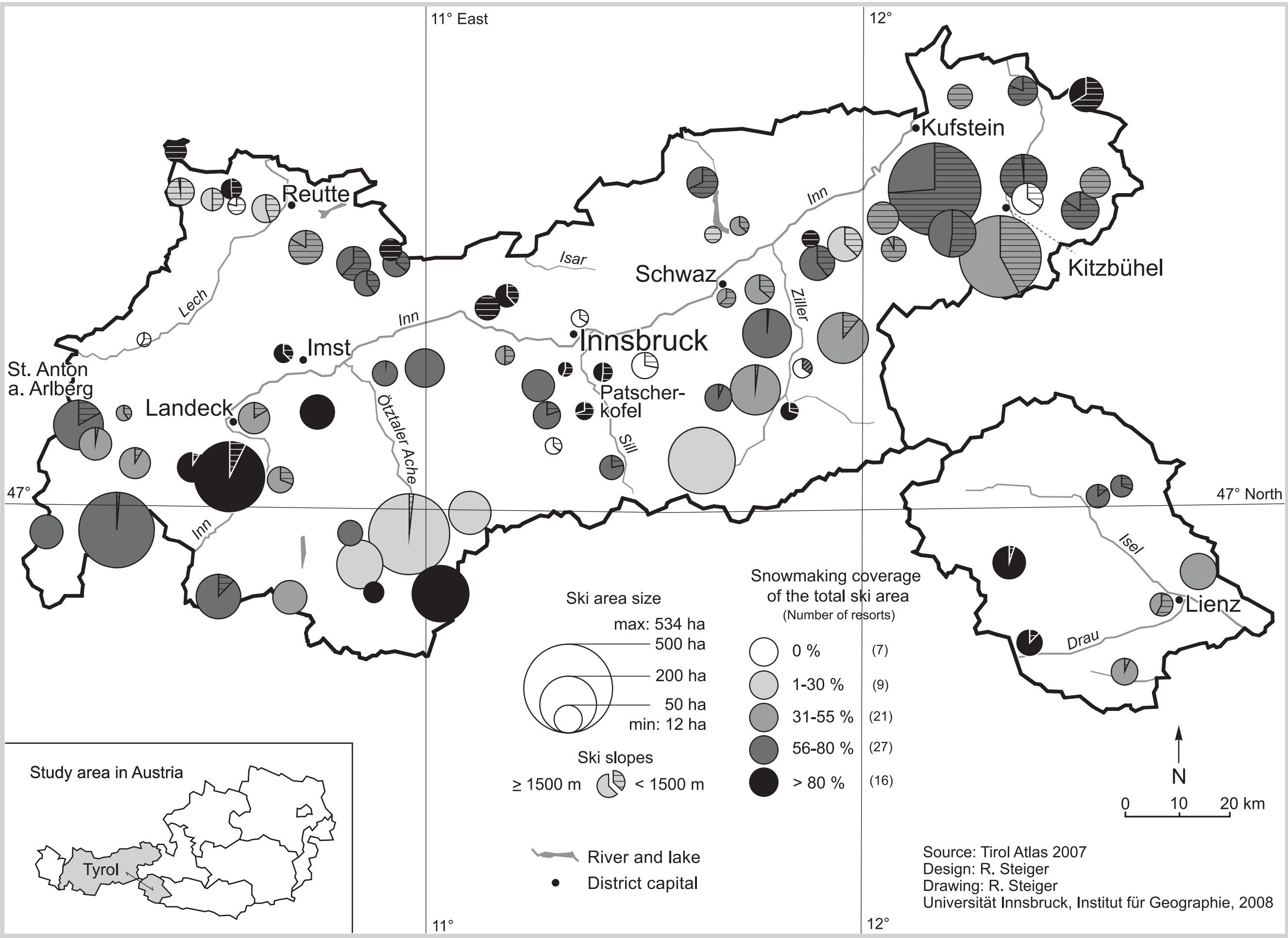
However, in the case of Tyrol, there does not appear to be any link between a ski area's elevation and the degree of snowmaking coverage (Figure 1). This is confirmed by the results of qualitative interviews with ski area operators as well as manufacturers of snowmaking and skilift technology, making clear that the continuing diffusion process of snowmaking is driven by different factors. There is a complex bundle of driving factors and background variables that influence the diffusion of snowmaking in Austria (see "Factors influencing the diffusion of snowmaking" below), which, due to the lack of adequate data, are only verifiable with the help of qualitative approaches. The one-dimensional perspective—climate change is responsible for the diffusion of snowmaking—would be too simple to capture the complexity of the phenomenon. However, Wolfsegger et al (2008) have shown that snowmaking is the dominant strategy of ski area managers for coping with projected climate change. This strategy proved useful even in the extraordinarily warm winter season of 2006–2007, also at low-altitude resorts with intensified snowmaking facilities (Figure 2). The most important question in the future will be whether it is possible to produce enough artificial snow at an acceptable cost level (Scott et al 2003).

In order to be able to differentiate between natural and man-made snow reliability, the latter should be designated as *technical snow reliability*. Studies including snowmaking and a complex snow model have been done in Canada (Scott et al 2003, 2006), Australia (Hennessy et al 2003), Scotland (Harrison et al 2005), and Switzerland (Teich et al 2007). These complex models require high resolution climate data that may not be available everywhere. Consequently, Steiger (2007) developed a method that closes the gap between a very simple approach (using monthly average temperatures; see Breiling et al 1997) and a very costly approach (using complex snow models), using a data set based on daily average temperatures (see "Snow reliability" below).

Factors influencing the diffusion of snowmaking

In preparation for the winter season of 2006–2007 the Tyrolean ski industry invested EUR 55 million (US$ 80 million) in snowmaking, with EUR 270 million (US$ 396 million) in overall investments (Tiroler Tageszeitung 2006), although the preceding winter seasons had delivered enough snowfall even at lower

FIGURE 1 Ski areas, snowmaking coverage, and altitudinal distribution of ski slopes in Tyrol. (Map by R. Steiger)



elevations. This indicates, first, that although the operators perceive climate scenarios as often too vague and unclear, they are well aware of climate change and are searching for adaptation strategies (Wolfsegger et al 2007). Second, medium-term investment strategies are not adapted, as there is much confidence in the mitigation capabilities of snowmaking technology as well as an obvious perceivable gap between climate trends and economic investment cycles (Mayer et al 2007). Third, while the bad winter seasons at the end of the 1980s sparked snowmaking in Tyrol, further diffusion was not linked to climate variability and climate change scenarios.

The recent trend of equipping even naturally snow-reliable ski runs in high Alpine regions above 2000 m, or in some cases 2500 m, with snowmaking facilities cannot be explained by deteriorating snow conditions; these altitudes can be considered as naturally snow-reliable even in pessimistic climate change scenarios (Abegg et al 2007; Mayer et al 2007). Thus, there must be other reasons for the diffusion of snowmaking: it can be explained by a widely diverse range of contexts of justification and general conditions (Figure 3). Pröbstl (2006) sums up 4 "dominant motivations for the phenomenal diffusion of snowmakers:" snowmaking should guarantee tourist capacity utilization (ie the tourism industry as a whole), cable car companies' incomes, and images of destinations in which international ski competitions take place. It should also assure general conditions for training and exercise of winter sports (eg World Cup). These points, however, cannot explain the current situation, as they do not take into account the consequences of global warming, general trends in tourism, and their resulting impacts.

Furthermore, modes of snowmaking must be differentiated according to time (season, duration), altitude, covered surface, and intensity:

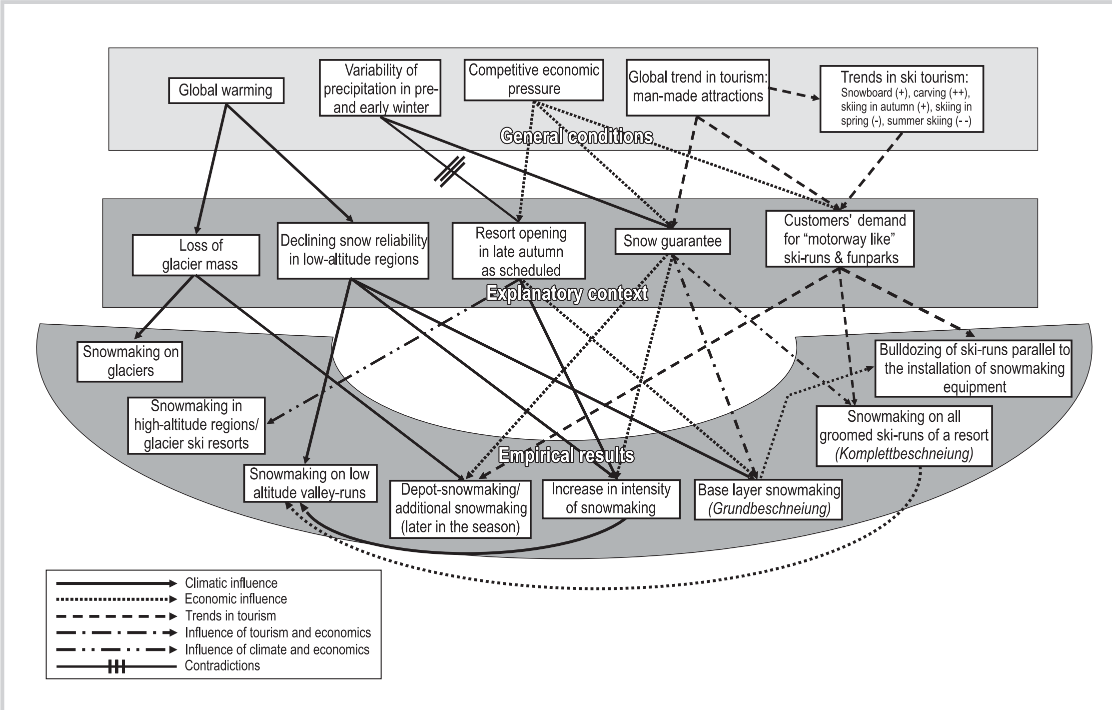
- **Base layer snowmaking (*Grundbeschneiung*):** can be defined as "the first area-wide snowmaking of a ski season, mostly started between mid-November and beginning of December" (Pröbstl 2006). The reasons

FIGURE 2 Intensive snowmaking enabled the destination of Schladming (745 m) to mitigate the impacts of abnormal warm temperatures in the winter of 2006–2007. (Photo by Marius Mayer, 17 February 2007)

for base layer snowmaking (Figure 4) are the following: seasonal opening of the operations has to be scheduled in economic terms (marketing plan, events, seasonal labor). But the variability of precipitation conflicts with such scheduled openings. Declining snow reliability at lower altitudes (Mayer et al 2007, pp 169–170) is another reason for the diffusion of basic snowmaking.

- **Snowmaking on all ski runs of a resort (*Komplett-beschneiung*):** means that all groomed slopes can be covered artificially, simultaneously or successively. In the case of large ski resorts, every skilift has at least one artificially covered ski run. The driving force is the operators' and guests' pursuit of snow guarantee on schedule, which is in turn determined by two background variables: the competition of ski resorts to outperform each other and the global tourist trend of man-made attractions, which demands a guarantee of variables such as snow or sun (Job 2005, pp 128 ff). Thus complete snowmaking coverage is indispensable for marketing and image creation at a winter sport destination.
- **Snowmaking in high-altitude regions:** the operators' goals are the following: an early opening of the winter season with the greatest possible reliability, use of costly skilift infrastructure, and improved quality of ski runs on stony high Alpine grounds. Relevant examples include Hochgurgl (Austria, up to 3080 m) and Val Thorens (France, up to 3000 m, Figure 4).
- **Snowmaking on glaciers:** this is done to assure summer skiing and early opening in September (unique selling propositions for glacier ski areas). The spectacular tongue retreats and increasing mass losses of Alpine glacier areas since the early 1980s (Zemp et al 2006) are caused by higher melt rates and fewer snowfall events during warming summers (Haeberli et al 1999; Weber and Braun 2004). Melting alimentation areas of the ice fields and a lack of snowfall in summer are supposed to be compensated by snowmaking. But snowmaking is not a realistic option to preserve entire glaciers from shrinking. Examples of snowmaking on glaciers in Austria are the Mölltaler Gletscher/Carinthia (up to 3120 m), the Rettenbachferner/Sölden/Tyrol (up to 3000 m) and the Stubaier Gletscher/Tyrol (up to 2900 m).
- **Expansion of snowmaking intensity:** to optimize the use of periods with low temperatures, the snow output per hour is enhanced, by increased density of snow guns, higher pump output, and water reserves.

FIGURE 3 Determining factors for the diffusion of snowmaking. (Source: Mayer et al 2007, p 163)



Thus the necessary time for base layer snowmaking is rapidly decreasing and is now about 50 hours at top-end resorts.

- **Snowmaking on low-altitude valley runs:** this is a new trend that started in the late 1990s. Since the low-altitude slopes in particular would be affected first by rising temperatures, it is surprising that extremely low-altitude valley runs can nowadays be reliably opened up for about 3 months—with the help of intensive snowmaking. An example is the Tyrolean Zillertal, where 3 destinations compete to offer the longest artificially covered valley run (lowest point at 561 m).
- **Depot snowmaking/additional snowmaking:** the reserve production serves to fulfill two goals: glacier ski resorts introduce them (in combination with snow farming) to enable guaranteed opening as early as possible in autumn. At normal ski resorts, depots are needed to assure skiable slopes during warmer periods, especially during *foehn* events and warm periods in spring on sun-exposed slopes, to guarantee skiing until the Easter holidays. Normally 120 to 150% of the amount of snow produced for base layer snowmaking is used for depots and additional snowmaking during the season (Pröbstl 2006).

Without a doubt, trends in ski tourism, like the snowboard and carving boom since the early 1990s and 2000s, respectively, supplement the general conditions mentioned. These new trends require totally different prerequisites for ski run quality, preparation, and consistency than, for instance, classical alpine skiing. These sports require a nearly perfect "ski run parquet" that is much more reliable and easier to create with the support of snowmaking (Veit 2002, p 219). Above all, the competitive economic pressure between ski resorts fosters the advance of snowmaking: first, the winter sport industry hopes to become more independent of meteorological conditions. Second, to optimize the utilization of high-tech skilifts with high fixed costs, the ski season needs to be assured and extended to late autumn and early winter. All this

FIGURE 4 Base layer snowmaking in Val Thorens, France, above 2300 m, in autumn. (Photo by François Balzeau, 3 November 2006)

EQUATION 1 Formula to calculate the required number of snowmaking days per month, if potential snowmelt is included.

Required number of snowmaking days =

[((Degree days / month) * F) * 1.91] * 0.025

F = degree-day factor (either 2 or 3 mm)

shows that the increased use of artificial snow is based on a complex bundle of economic, touristic, and climatologic considerations and should not be considered one-dimensionally.

Snow reliability

The scientific definition of snow reliability and the view of ski operators is quite different. Today when operators talk about snow reliability they think of their snow guns as being the most important factor. The *100-day rule,* formulated by Abegg (1996), stated that ski resorts can be considered as snow-reliable "if, in 7 out of 10 winters, a sufficient snow covering of at least 30–50 cm is available for ski sport on at least 100 days between December 1 and April 15." By analyzing climate data Abegg (1996) defined a line of snow reliability for Switzerland, lying at 1200 m today and rising by 150 m per 1°C warming. This methodology was adopted in a recent Organisation for Economic Co-operation and Development (OECD) study (Abegg et al 2007) of the Alps. Taking into account the different climate regions, actual snow reliability is considered to be above about 1050 m for the northern rim of the Alps, and 1500 m for the Southern Alps. Unfortunately, snowmaking was not considered. Being aware of this insufficiency, and motivated by several North American studies (Scott et al 2003, 2005, 2006), Steiger (2007) developed a method that incorporates the role of snowmaking as a possible and effective adaptation strategy for deteriorating snow reliability in Bavaria. Here the methodology is applied to Tyrol, using a +2°C climate scenario (timeline 2021–2050).

Methods

Snowmaking conditions are influenced by temperature and humidity—if the air is more humid, cooler temperatures are needed. The so-called *wet-bulb temperature* combines these two climatic factors. With current snowmaking technology snow can be produced starting at –5°C wet-bulb temperature without chemical additives (which are currently prohibited in most parts of the European Alps). In other words, snow can be produced at an air temperature of –3°C to –4°C and average humidity (60%). Good snow quality can be achieved with snow production starting below –6°C at average humidity (Breiling et al 1997; Steiger 2007). Fliri's (1974) climate tables show a strong correlation between –2°C daily average temperature and –6°C daily minimum temperature. Days reaching the threshold of –2°C daily average temperature are defined as *potential snowmaking days* with optimal snowmaking conditions. Furthermore, snowmaking is only considered reasonable if it can balance out the loss through snowmelt. In order to assess the effectiveness of snowmaking and the degree of possible independence from natural snowfall, the latter is not included in the model.

A simple degree-day model is used to calculate snowmelt. This model works as follows: the sum of all positive daily average temperatures (= degree days) is multiplied by a degree-day factor. This factor describes the runoff (in mm) per degree day. A value range of 2–3 mm water equivalent per degree day is realistic for the research area in winter months (Steiger 2007). The average density of groomed technical snow is 523 g/l (Rixen et al 2004, p 419), thus a 1 mm runoff water equivalent means 1.91 mm of melted snow depth. With these values and factors the necessary extent of snowmaking can be calculated for a given snow depth. The minimum snow depth for alpine skiing is 30 cm on grassland and 50 cm in stony areas with poor vegetation (Abegg 1996). As the density of artificially produced snow is higher than natural snow density, 20 cm of groomed artificial snow is required in order to get an adequate slope. Average snowmaking systems are able to produce this amount of snow in 5 days (Steiger 2007). Thus 0.025 days are required to produce 1 mm of artificial snow (Equation 1).

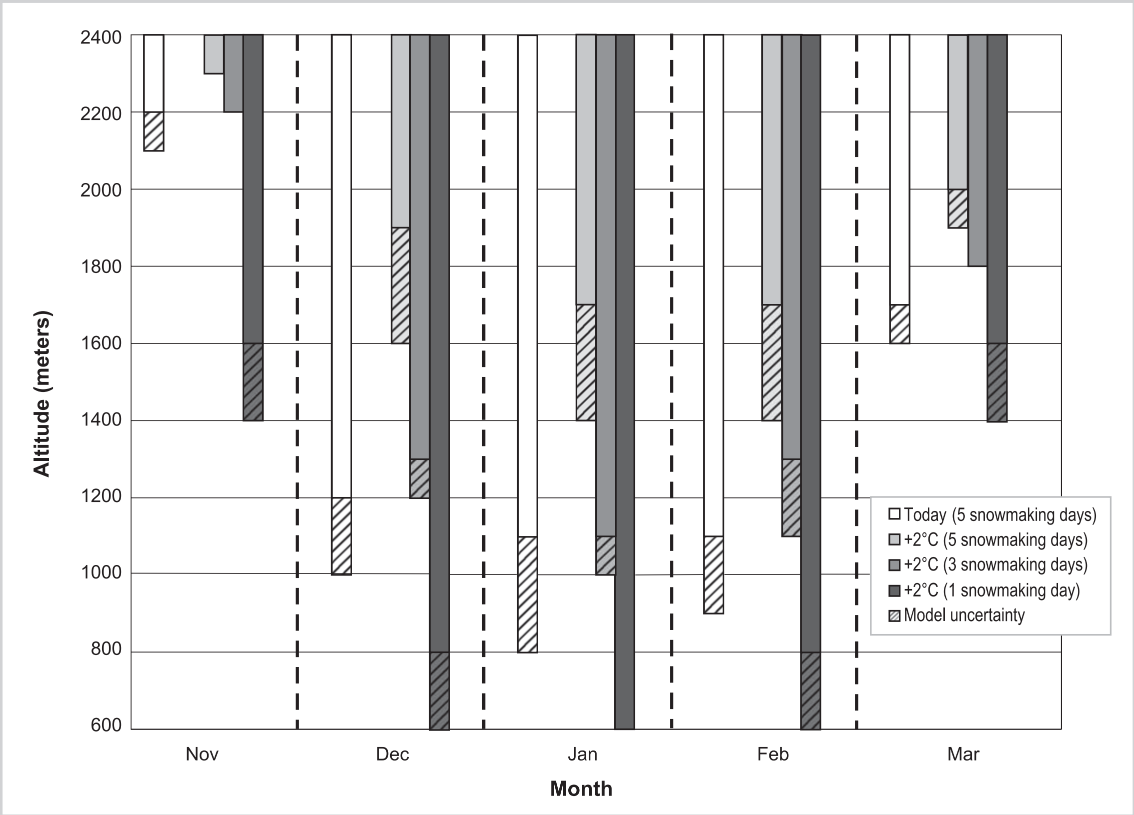
A month can be defined as *suitable* for snowmaking, if the number of *potential snowmaking days* is greater than the *required number of snowmaking days.* Finally, the line of artificial snow reliability can be calculated to compare these results with older studies that do not include snowmaking. In contrast to Abegg's (1996) 100 days in 7 out of 10 winters, a stricter threshold for snowmaking is used (9 out of 10 winters), as the snowmaking facilities should be operable (almost) every year.

Climatic potential for snowmaking in three Tyrolean climate stations

With these prerequisites, datasets (1971–2000) for 3 climate stations in Tyrol were analyzed: Kufstein, at 495 m, St. Anton, at 1275 m, and Patscherkofel, at 2247 m (see Figure 1). Monthly varying vertical temperature gradients were then calculated by inter- and extrapolating temperature from 500 m to 2400 m.

Today snowmaking can guarantee snow reliability at elevations above 1000 m (December to February) for 90% of all winters. In a +2°C climate scenario current snowmaking intensity will not be sufficient below 1500–1600 m (Figure 5). Small to medium-sized ski

FIGURE 5 Elevations suitable for snowmaking today and with a projected 2°C warming, with different snowmaking intensities (5, 3, 1 snowmaking days). The range of uncertainty depends on the degree-day factor (2 mm / 3 mm) chosen.



resorts, many of which are found at lower elevations (Figure 1), may face serious problems if climate change predictions prove to be correct. Especially base layer snowmaking will be made more difficult, as it needs to be done in the early winter months: the number of potential snowmaking days will be reduced by 1/3 in November at high altitudes (> 2000 m), and in December at lower altitudes (1000–1500 m).

Increasing snowmaking capacity is the current strategy of ski area operators when preparing for warmer winters with fewer cold days. The base layer snowmaking has to be completed within 48 hours (Mountain Manager 2007a, p 81). The line of technical snow reliability declines significantly with rising snowmaking intensity (Figure 5). The success of resorts like Schladming (Figure 2) and good skiing conditions—even in the 2006–2007 season—can be explained by this development.

In addition, it can be expected that snowmaking technology will be enhanced. Prototypes produce snow starting at –0.5°C wet-bulb temperature (+2°C at 60% humidity) without chemical additives (Mountain Manager 2007b, p 54). Climatic conditions will not be the primary limitation to snowmaking, at least not with a temperature rise of 2°C. The problem ski resorts will have to face over the next decades is the rising cost of snowmaking.

Conclusion

Although climate change is one reason, but surely not the main reason, for the diffusion of snowmaking facilities, technically produced snow is the most-used adaptation strategy for extraordinarily warm winter seasons. Snowmaking is a considerable short- to medium-term adaptation strategy, not only for high-altitude ski resorts but also for financially strong year-round destinations at lower elevations, such as Kitzbühel (762–1995 m). More frequent warm winters will force ski resorts to intensify snowmaking capacity with consequences for their financial vitality. Already about 27% of Swiss ski resorts have a poor cash flow (< 5%) and most do not seem to be independently viable (Seilbahnen Schweiz 2006).

Future studies on the impacts of climate change on winter tourism will have to go into more detail in order to assess the possible changes at a regional or even a local scale. Keeping in mind that there are different types of snowmaking over the winter season, the impact of rising temperatures on these types will vary. As the very intense base layer snowmaking being done at the very beginning of the season is most affected when snowmaking conditions are at the climatic limits anyway, it is very likely that the ski season will shorten despite intense snowmaking. This requires more complex snow models as well as regional climate scenario data.

As there is little knowledge about the cost-effectiveness of snowmaking investments, an economic analysis should be carried out to assess the suitability of this adaptation strategy for certain ski resorts. Finally, the most unpredictable field of research is change in demand and behavioral adaptation (Teich et al 2007). As rising costs will have to be paid by the consumers, their potential reactions have to be examined to understand the possible changes in the financial viability of ski resorts.

ACKNOWLEDGMENTS

We would like to thank Hubert Job, Dale Forbes, Martin Müller, Bernadette Schauß, and the two anonymous referees for critical reading and insightful comments.

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