SkiSim - A tool to assess the impact of climate change on ski season length and snowmaking

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ABSTRACT:
A semi-distributed ski season simulation model (“SkiSim”) was developed to analyze potential impacts of climate change on ski season length and snowmaking requirements. The validation process at three ski areas in different climatic regions and altitudes in the province of Tyrol/Austria showed a very good performance of the model with a maximum difference of one day comparing reported and modeled ski season length. Future climate change scenarios were produced for the 2020s, 2030s, 2050s and 2080s with a low (B1) and a high emission scenario (A1B) based on data of the regional climate model REMO. Changes in ski season length, which are very likely to make a profitable operation impossible, are projected for the 2050s to the 2080s depending on the altitude of a ski area and the emission scenario. Until the end of the century the required snow volumes are projected to increase by up to 123% with current snowmaking technology, and by up to 242% assuming a temperature-independent snowmaking technology.

KEYWORDS: climate change, snowmaking, ski tourism, Austria

1 INTRODUCTION

Most forms of tourism are linked to the natural environment and are therefore influenced by local climate conditions (Becken and Hay, 2007). Winter tourism is highly vulnerable to climate change due to its dependency on snow. The continuing warming trend is likely to derogate the natural snow reliability. Depending on the individual vulnerability of winter destinations, significant structural changes will be necessary to keep current competitiveness. These changes pose a great challenge for stakeholders in terms of a sustainable development.

Tourism is an important source of income in many alpine regions as for example in the Alps where it generates about 10-12% of the jobs (Abegg et al., 2007). Its development especially in peripheral areas did not only stop the depopulation of mountain villages but even led to immigration into formerly poor and disadvantaged communities (Bätzing, 2003).

As the winter snowline is expected to rise by 150 m per 1°C warming (Beniston et al., 2003), destinations are faced with shorter winter seasons resulting in less competitiveness with negative effects on the local economy. A significant decline of snow reliability is expected between 2030 and 2050 for different geographical regions of the world, e.g. Austria (Breiling and Charamza, 1999), Australia (König, 1999), Canada (McBoyle and Wall, 1992), Japan (Fukushima et al., 2003), Scotland (Harrison et al., 2005), Sweden (Moen and Fredman, 2007) and Switzerland (Abegg, 1996). A study commissioned by the OECD concludes that today 91% of 666 ski areas in the Alps can be considered as naturally snow-reliable. This group could be reduced by 25%-70% with a temperature rise of 1°C-4°C (Abegg et al., 2007). The validity of these results is limited by two major factors: (1) the spatial differentiation of the altitudinal line of snow reliability is rather coarse, climatic differences within the provinces are not accounted for and (2) snowmaking, meanwhile an indispensable technology for ski areas, is not considered. Scott et al. (2003) showed that the projected loss of skiable days for some Canadian ski resorts is significantly less including snowmaking than in preceding studies only regarding natural snow conditions (7-32% reduction including snowmaking vs. 40-100% reduction without snowmaking by 2050). In studies for the Bavarian Alps/Germany (Steiger, 2007) and Tyrol/Austria (Steiger and Mayer, 2008) the line of technical snow reliability was analyzed, currently being 700m lower than the line of natural snow reliability. But it was also revealed that a potential warming of 2°C would result in an upward shift of the line of technical snow reliability by 500-600m. The results clearly show that snowmaking can only serve as a short to medium term adaptation strategy, but not as a sustainable solution.

In the view of ski area managers, snowmaking is seen as the answer to the potential shortening of the ski season (Abegg et al., 2008; Wolfsegger et al., 2008). So far no sensitivity analysis or ski season model considers the vertical extend of the ski area at least not in the manner that an analysis can be made for any altitude of the ski area. Therefore a semi-

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distributed ski season simulation model "SkiSim" was developed. For this paper three ski areas and climate stations in the province of Tyrol/Austria were chosen to test the model performance in different climatic sub-regions and altitudes of the study area (Tab. 1). Meteorological data was provided by the Hydrological Service of Tyrol ("Hydrographischer Dienst Tirol").

2 METHODOLOGY

SkiSim calculates snow depth and technically produced snow on a daily basis for each 100 m altitudinal band of a ski area. Temperature and precipitation is used as input data. Additionally, snow depth or snowfall is required to calibrate the snowfall temperature for each climate station. The natural snow module is based on a snow model by Kleindienst (Kleindienst*,* 2000). The snowmaking module was originally developed by Scott (e.g. Scott et al*.,* 2003) but has been modified for reasons of the semi-distributed character of the model.

Monthly 30-year changes of temperature and precipitation taken from a regional climate model (REMO, 10*10km resolution) for the corresponding grid cell of each climate station are used as input data into a weather generator (LARS-WG, Semenov and Barrow*,* 1997). Together with the daily data set of the climate stations, it is possible to produce daily future time series of temperature and precipitation as input into SkiSim.

Snow melt is driven by a variable degree-day factor (2-5,5mm/°C/day), which is increasing during the snow season (due to snow metamorphosis and higher radiation in the proceeding snow season) and decreasing after snowfall events due to the higher albedo of fresh snow. Temperature is distributed with a standard lapse rate of 0,65°C/100m. For precipitation a lapse rate of 3%/100m was chosen, representing the average lapse rate in the study area.

The temperature threshold for snowmaking is set to -5°C air temperature. Snowmaking hours are calculated by a linear interpolation of temperature from the daily minimum to the maximum. At the start of the ski season 30 cm of technical snow are produced independently of natural snowfall (base layer snowmaking, see Steiger and Mayer*,* 2008). The amount of snow that is produced afterwards is calibrated for each altitudinal band separately in order to reach a ski season length of 100 days in the high season in 7 out of 10 winters (Abegg et al*.,* 2007). Snowmaking capacity is set to 10 cm/day representing an up to date snowmaking system.

In order to validate the results of SkiSim, the calculated number of operation days was compared to reported ski season lengths of the three ski areas. As all three ski areas can be separated into an upper and a lower part, a critical altitude had to be defined by the ski area managers, which drives the opening and closure of the ski area in the model. This was necessary as the ski areas are usually in operation, even if the run to the base has a lack of snow at the beginning or the end of the season.

Though significant differences may occur in single years, SkiSim produces good results for multi-year averages (at least 20 years, depending on the station's data availability) with a maximum difference of simulated to observed skiable days of one day (Tab. 1).

Ski area	(A) St.Johann i.T.	(B) Alpbach	(C) Axamer Lizum
Elevation range	668-1605 m	820-2025 m	1561-2340 m
median of ski area	1100 m	1600 m	2000 m
Ski lifts	13	8	8
Distance to climate station	1.1 km	0.5 km	5 km
Altitude of climate station	756 m	1040 m	1070 m
Winter precipitation (Nov-Apr)	662 mm	464 mm	295 mm
Reported/modeled ski season length (in days)	117/118	126/125	138/139

Table 1. Ski area statistics.

3 RESULTS

3.1 Climate change signal

The projected changes of temperature and precipitation in the winter half year (Nov-Apr) are illustrated in Tab. 2 and represent an average over the three grid cells of the different ski areas. While the temperature increase is higher in the high emission scenario especially from the 2050s onwards, precipitation increase is slightly higher in the low emission scenario with a maximum in the 2030s.

	2020s		2030s		2050s		2080s	
	B1	A1B	B1	A1B	B1	A1B	B1	A1B
Temperature (°C)	0,7	0,6	0,8	1,1	1,4	2,5	2,7	4,2
Precipitation (%)	12	7	14	9	10	9	8	12

Table 2. Changes in temperature and precipitation.

3.2 Ski season length

Skier frequency and revenues are not equally distributed over the ski season. Interviews with ski area managers in the provinces of Tyrol/Austria and South Tyrol/Italy revealed that about 80% of the revenues are generated in the high season from Christmas to Easter. Thus it can be assumed that a loss of operation days in the low season is less problematic than in the high season. Therefore the ski season in SkiSim was divided into a low season (Nov 1 – Dec 21 and Apr 1 – Apr 30) and a high season (Dec 22– Mar 31.). Furthermore the 100-days rule is also regarded, assuming that a ski area can only be profitable if it is able to offer at least 100 operation days per season in the average (Abegg et al., 2007).

As the altitudinal distribution of ski slopes can be significantly different between ski areas even if their base and peak altitudes are similar, the modeled season length has to reflect this distribution to be able to compare the results of the ski areas. Thus the calculated skiing days at each elevation are weighted based on the percentage of ski slopes in that altitudinal band. Thus the season lengths in Fig. 1 differ from the values of the model validation process (Chap. 2), where only the season length at the critical altitude was regarded.

In the low emission scenario, ski area A drops below 100 operation days in the 2080s. Although ski area B and C are projected to experience shortening seasons (loss of 27 days for ski area B and 16 days for ski area B in the 2080s), they stay well above the 100 operation days with hardly any change in the high season (Fig. 1a). In the high emission scenario a significant ski season loss can be expected in the 2050s for ski area A (Fig. 1b). Both a drop in the low as in the high season and less than 100 operation days are likely to hinder a profitable operation. Ski area B is also expected to experience a drop in the 2050s but only in the low season. In the 2080s the situation for ski area B is the same as for ski area A in the 2050s. Even the high altitude ski area C must cope with a significantly shortened ski season in the 2080s, but being still above the 100-days line.

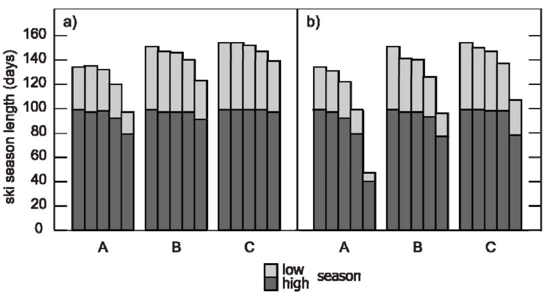

Figure 1. Projected ski season lengths for ski areas A-C in the low (Fig. 1a) and high (Fig. 1b) emission scenario.

3.3 Snowmaking requirements

Less snowfall and more melting energy due to rising temperatures require more technically produced snow. SkiSim calculates the amount of snow that is needed to be operable until the end of the high season (Mar 31) at each altitudinal band. Again, the values are weighted based on the distribution of ski slopes. Therefore the amount of snow produced represents the average of snow production over the whole ski area. Naturally the required snow volumes are more at lower altitudes and less in the higher regions of the ski area than this weighted average. At ski area A for example SkiSim produces 124 cm at the base and 33 cm at the peak.

The results for the baseline show a very good match with the real amount of snow produced given in the interviews (e.g. 60 cm at ski area A versus 62 cm produced by SkiSim). In the low emission scenario (Fig. 2a) the relative increase is highest at ski area C (+123%) until the end of the century, while ski area A has the highest amount of snow produced (92 cm). In the high emission scenario (Fig. 2b) the relative increase is - again - biggest at the high altitude ski area C (+187%) as well the amount of snow produced (119 cm). This is due to the sharply decreasing natural snowfall (more rain events) and more snow melt, but with still sufficient snowmaking hours.

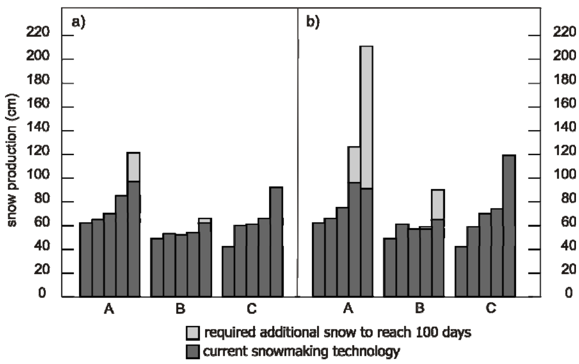

Figure 2. Projected snow production for ski areas A-C in the low (Fig.2a) and high (Fig. 2b) emission scenario.

Accounting for a further development of snowmaking technology, the required additional amount of snow in order to reach at least 100 operation days in the high season was calculated in those time series, where current snowmaking technology is not sufficient to reach that goal. The technology to produce snow independently of temperature already exists and has been introduced at two glacier ski areas in Austria and Switzerland (Pitztal and Zermatt). But due to significantly higher operation costs and the centralized production method, this technology is yet not ready for a wide spread use. To be still operational in the high season in the 2080s high emission scenario, ski area A would require an increase of 242% compared to current volumes of produced snow. It is questionable that a ski area can still be profitable considering that already today many ski areas operate with very low margins.

4 CONCLUSION AND DISCUSSION

A semi-distributed ski season simulation model "SkiSim" was developed and tested at three ski areas in the province of Tyrol/Austria in different climatic regions and altitudes. The validation process showed a very good performance comparing multi-year averages of modeled ski season length with reported ski season length of the ski areas. Thus the model seems appropriate for an assessment of climate change impacts on the ski tourism sector.

Changes in ski season length which are very likely to make a profitable operation impossible are projected for ski area A for the 2050s (high emission) and 2080s (low emission) and for ski area B for the 2080s (high emission). Although ski area C is within the group of the highest ski areas in the province, severe season losses are projected for the 2080s in the high emission scenario. Even with temperature-independent snowmaking technologies it seems unlikely that such technological development enables the potential losers to survive, as the required snow volumes are projected to be about 3,5 times higher than today.

These results may not be interpreted in such a manner that there won't be a problem before the 2050s or the 2080s. As shown, the snow volumes produced will be rising continuously. Taken into account that energy costs are likely to increase in the next decades, it can be assumed that snowmaking costs are likely to rise disproportionately to the rising volumes. The economic limits of snowmaking might be reached (much) earlier than the technological limits presented in this paper. As no official statistical data on snowmaking costs is available for the study area, it is not possible to make assumptions on the economic limits of snowmaking.

When clustering the ski areas in the province into low (median of ski area < 1500m), medium (< 2000m) and high altitude ski areas (2000m and above), each of the ski areas chosen for this paper represents about 1/3 of the ski areas in the research area. But it is not possible to make a statement that is valuable for all ski areas in a category based on the results of only one ski area. This is because of the climatic differences within the study area (see Tab. 1). The timing of the impact might be different at two ski areas at the same altitude but located in different climatic regions (dry/wet). Another reason is that within a category there is still a difference in medium elevation of the ski areas of several 100 meters. The results of these three ski areas should thus be noticed as a first estimation of when and how strong the impact might be. The model will be run for each ski area in the provinces of Tyrol/Austria and South Tyrol/Italy and based on these results further interpretations of regional vulnerabilities and a spatial market shift can be made. These results are expected for early 2010.

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