Final Report

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A) Project Data

Title:	CC-Snow II: Effects of Future Snow Conditions on Tourism and Economy in Tyrol and Styria
Program:	ACRP 2nd Call for Proposals
Applicant:	Department of Geography and Regional Science, University of Graz (Austria) – has changed to Institute of Geography, University of Innsbruck, Austria
Contact – Name:	Prof. Dr. Ulrich Strasser
Contact – Address:	Innrain 52f A-6020 Innsbruck
Contact – Phone:	+43 (0512) 507 - 5404
Contact – E-Mail:	Ulrich.Strasser@uibk.ac.at
Project partners:	(P1) Dr. Andreas Gobiet, ReLoClim, Wegener Center for Climate and Global Change and Institute for Geophysics, Astrophysics and Meteorology, University of Graz (Austria) (P2) Prof. Dr. Johann Stötter, Institute of Geography, University of Innsbruck (Austria) (P3) Dr. Hannes Kleindienst, GRID-IT, Innsbruck (Austria) (P4) Prof. Dr. Friedrich Zimmermann, Department of Geography and Regional Science, University of Graz (Austria) (P5) Prof. Dr. Karl Steininger, EconClim, Wegener Center for Climate and Global Change and Department of Economics, University of Graz (Austria) (P6) Dr. Franz Prettenthaler, Center for Economic and Innovation Research, Jo-anneum Research (Austria)
Website:	http://www.cc-snow.at
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B) Project Overview

1 Executive Summary

CC-Snow II builds upon the ACRP-funded project CC-Snow (1st ACRP call, duration 1.1.2010–31.12.2011). Whereas CC-Snow provided coupled modeling of future A1B climate and snow conditions, CC-Snow II aims at determining the potential economic and structural impacts of climate change on winter tourism in the provinces Tyrol and Styria (Austrian Alps). Even though both funded by ACRP (in the first and the second call for proposals), the two projects are organizationally, financially and formally completely independent from each other. In CC-Snow II, downscaled and bias corrected climate model output of historical and potential future (scenario) conditions is used to force two adapted and enhanced snow models at different spatial scales. At the local scale, the deterministic snow model AMUNDSEN is applied for the case study sites Kitzbühel and Schladming, including numerical simulation methods for the production of technical snow. At the regional scale the conceptual snow model SNOWREG is applied for the simulation of snow conditions in the two provinces Tyrol and Styria. Whereas AMUNDSEN is physically based and does not require site-specific calibration, SNOWREG builds upon on the temperature-index approach and therefore requires calibration, performed by means of assimilating remote sensing data and measured snow depths. Both snow models provide simulation results for snow reliability at the respective scales and regions, and a comprehensive set of indicators which have been jointly defined by the project partners in the initial phase of the project. These indicators are utilized for the interface of the natural sciences modeling approach and the socio-economic analysis. They allow a translation of huge amounts of quantitative model output into aggregated, integrated information which can be passed along the modeling path and across disciplines, and which can be understood, interpreted and utilized by all project partners.

In CC-Snow II, a prototype of a coupled modeling framework has been developed to construct mutual interaction of the different disciplinary model components, and thus to enable and visualize the path of the climate change signal through the different models and disciplines. This modeling framework represents the project's concept of integration across the disciplines and is a methodical innovation in itself; it technically enabled to produce the main scientific outcome of the project. The aim and additional value of this approach is to foster the generation of new results that stand for more than just the sum of all model results. The challenge consisted in developing appropriate interfaces to couple the models and methods in a holistic, interdisciplinary workflow. This concept of integration has been jointly constructed in several meetings by a task-force, installed by the project coordination, consisting of at least one member of each partner research group. This group met several times in the course of the project, and developed the across-disciplines interfaces during these inspiring workshops. Most of the methodically new and scientifically interesting aspects of CC-Snow II was initiated by the CC-Snow task force in these workshops.

Within the interdisciplinary workflow of the coupled CC-Snow II modeling scheme the concept of a two-scale analysis is continued in the economy and tourism sector subsequent to the snow simulations. Model results from AMUNDSEN and SNOWREG (e.g. season length or daily weather variables) are used in the cost-revenue analysis of snow production and are validated with real costs and skier visit data provided by the ski lift companies of the case study sites. Results from the tourism demand models, the cost-revenue analysis and simulated snow indicators are combined with high resolution tourism data on the local scale to identify different impacts and sensitivities for each destination. The transformation of the detailed case study results to the regional level is based on the cluster analysis of tourism destinations and model results from SNOWREG. In return, the results at the regional scale serve as input for a subsequent cluster analysis using future simulations (e.g. season length, tourism demand). The final product of this integration process is a coupled, specific scenario tool that is capable of simulating the impacts of climate change on the Austrian tourism industry at the local as well as on the regional scale.

Results of the regional snow model show that in general the impacts in Styria are greater than in Tyrol. In Tyrol, the share of snow reliable ski areas (including technical snowmaking) declines from 76-86 % in the reference period to 18-54 % in the future period (the uncertainty range is due to the different A1B climate scenario realizations). In

Styria, the share is considerably lower, with 22-63 % snow reliable ski areas in the reference period. According to the scenario applied, these values further decreases to 3-19 % in the future period.

The impact of snow depth on daily visitor numbers was found to be positive and highly significant. The demand models (with input from AMUNDSEN) produce a decline of season revenues for the three chosen ski areas between 0.7 to 3.9 million Euros (or -5% to -34%) when taking technical snowmaking into account - depending on the ski area and the climate scenario realization. When considering natural snow conditions only, the ski areas would lose between 0.7 to 6.3 million Euros (or -17% to -70%). The modeled increases of snowmaking costs are between +18% to +76%. Nevertheless, snowmaking is still profitable even at a discount rate of 5% if no real ticket price changes are assumed.

At the regional scale, the overall reduction of overnight stays of all municipalities with statistically significant results amounts to -59,100 (~€ 8 million revenue losses). In Tyrol overnight stays are projected to decline by 210,900 per winter season (~€22.5 million revenue losses).

The most important future challenge for owners of lodging establishments in the Schladming region is reducing and clearing of debts after the Alpine Ski World Championships in 2013. In Kitzbühel improving or extending parking facilities is the most mentioned challenge.

Though snow reliability and snowmaking was also mentioned as important for the future, it came out that potential climate change impacts do not have a high priority.

In CC-Snow II, we have made for the first time an attempt to couple models of future climate, snow and economy of skiing at two different scales to estimate future skiing conditions, and climate change related consequences for winter tourism. The integrative indicators that have jointly been developed serve as interface between the models for future climate and snow condition evolution, and the models for skiing economy and tourism implications.

In potential future applications, the developed coupled modeling scheme can be used for applying a variety of potential future climate and snow cover developments, together with meaningful management options for the skiing areas. It will be of both high practical and scientific interest – for both the natural sciences and socio-economy, as well as for practitioners, the community of stakeholders, the skiing industry and policy makers – to jointly develop feasible, realistic and coupled scenarios of future conditions for the skiing tourism sector in a highly participative process for the two regions and sites. An approprirate methodical tool for such an integrative investigation is provided by CC-Snow II.

2 Background and objective

Tourism is an important economic sector in Austria contributing about 7.5 % to the GDP (Statistics Austria 2012). In mountainous areas, the dependence on this economic sector can be considerably higher – up to more than 50 % of the gross regional product (Breiling et al. 1997). Tourism has been repeatedly identified as particularly vulnerable to climatic changes, especially the snow-dependent winter tourism industry (Scott et al. 2012). However, knowledge on consequences of climate change for Austria's winter tourism sector still remains comparably limited, and research in this field is, with its 20 years of history, still in its infancy.

The main intention of CC-Snow II is to assess the potential economic impacts of climate change on winter tourism, including snowmaking as an adaptation measure. CC-Snow II follows the general methodology of CC-Snow (ACRP project of the 1st call) combining assessments on the province level (Tyrol and Styria) with more detailed investigations at smaller scales (case study regions Schladming (Styria) and Kitzbühel (Tyrol)). The strength of this project is its interdisciplinary set of methods and the combination of models and techniques to reach the research objectives.

Climate change impact studies on winter tourism highlight the importance of economically oriented research questions. The adaptation strategy of snowmaking implies that ski season losses due to climate change will be not as severe as projected in earlier studies (Steiger & Abegg 2011). Nevertheless, Scott et al. (2006) argue that climate change will create winners and losers and in combination with other business factors, such as access to capital, demand trends, energy prices and water supply, it will likely result in a further contraction and consolidation in the ski industry. Two major needs for future research could be identified: 1) The economic limits of snowmaking might be reached earlier than the climatic limits (Steiger 2010) due to higher required volumes of produced snow. 2) Potential winners and losers of climate change will be determined by "the relative advantages of local climatic conditions and the adaptive capacity by individual ski areas" (Scott et al. 2008, p. 593).

The main objectives of this project are:

1. the analysis of the impact of changing snow conditions on demand
2. the investigation of microeconomic aspects (costs and benefits) of snowmaking and
3. the inquisition into tourism stakeholders' perception of climate change

From an economic point of view, our project contributes to overcome two major limitations in existing approaches to quantify climate change impacts on winter tourism:

(1) The current literature, which is heavily focused on studying climate change impacts on supply-side indicators, is expanded and supplemented by detailed analysis of their interaction with demand-side data and the resulting economic effects. The analysis was based on higher frequency demand data and examined the relationship on a daily basis for the case study regions (total visitor numbers) and on a monthly basis for all skiing areas in the two provinces (overnight stays). This also allowed adjusting supply-side indicators both for the extent (percentage of non-available slope capacities) and timing (level of demand during the course of the season) of poor snow conditions. Furthermore (and beyond the current literature), demand-side analyses were enhanced in that the estimated impact functions were combined with the modeled probabilities of (both current and future) natural and technically improved snow conditions.

(2) The current literature on snowmaking investment costs are supplemented by incorporating consideration of economic benefits of snowmaking as well as on potential effects on ski ticket prices.

Since energy and water use as well as current costs of snowmaking vary amongst others with the snowmaking system (e.g. utilization of stored water in ponds or flowing waters), the climatic conditions (less energy efficiency at higher temperatures) and the location (e.g. water prices), a broad range of figures is found in the literature (see e.g. Bark et al. 2010, Breiling et al. 2008, Gonseth 2008, Hahn 2004, Lang 2009, Pröbstl 2006). Being aware that figures on snowmaking costs heavily depend on technology, data source and local conditions and that it is challenging to point out snowmaking benefits, this project focuses on the following economic aspects:

- The underlying economic risks and uncertainties,
- the ranges, functional dependencies and variability in the costs and benefits of snow production
- costs and benefits of snowmaking in a dynamic investment model.

3 Contents and results

The initial situation for CC-Snow was that for climate modeling, snow modeling, economic analysis of skiing tourism and regional winter tourism effects sophisticated methods existed, but no integrative framework has yet been developed to integrate these methods into a holistic, coupled and quantitative approach to track future climate change signals all the way through the natural and technical snow conditions, economic effects in the skiing areas to touristic structural changes in winter tourism regions in Austria. This new and innovative scientific objective led to building a consortium of partners from the related disciplines, and develop the proposal for CC-Snow II. The project could intensively make use of the former, also ACRP-funded project CC-Snow, and extend the approach developed in the proVISION-funded project STRATEGE (Formayer et al. 2009).

In CC-Snow II an integrative, interdisciplinary and coupled modeling scheme has successfully been developed and applied for four A1B future climate realizations, and skiing areas in the test regions of Kitzbühel in Tyrol, and Schladming in Styria. Both the local and the regional scale have been investigated. Scientific advances have been achieved both sectorally in the scientific disciplines of the partners, as well as integratively in developing new interfaces between the different methodical approaches. The task force with representatives of each research partner group designed these interfaces, and the routing of data and knowledge across the disciplines; the work and outcome of this task force proved to be a scientific highlight of the project.

Difficulties were encountered in the work load (and costs) for the integrative part of the project. In this respect, many lessons were learned, and many experiences were made; they represent an investment in the scientific career of the PhD's and PostDoc's in the future, and are now very valuable for the development of new projects. These young researchers from the project consortium, especially those active in the task force, will mostly profit for their future careers from the experience and new interdisciplinary horizons gained in CC-Snow II.

Climate modeling

In CC-Snow II four selected climate models (pre-selected in CC-Snow) of the ENSEMBLES project (van der Linden et al. 2009) were downscaled and error corrected. This selection includes warm/cold and wet/dry conditions, representing the upper/lower end of the changes in temperature and precipitation for the winter half year. The selected models with little warming are ICTP (RCM: RegCM3, GCM: ECHAM5-r3) with drier conditions and SMHI (RCM: RCA, GCM: BCM) with humid conditions, METNO (RCM: HIRHAM, GCM: HadCM3Q0) projects average warming and C4I (RCM: RCA3, GCM: HadCM2Q16) projects strong warming and dry conditions.

Downscaling and bias correction

The downscaling and error correction techniques developed in CC-Snow (previous ACRP project finished end of 2011) were extended to meteorological variables with particular importance for snowmaking. The applied technique to mitigate errors in climate simulations is a quantile based error-correction method, quantile-quantile mapping (for details see the methods section). The annual (Figure 1) and monthly (not shown here) bias can be reduced for all variables to about zero in a technical evaluation approach (neglecting the effect of climate variability and change on the error characteristics of RCMs) and to close to zero in a split-sample evaluation in most cases. QM successfully corrects independently of the shape of density distribution and aligns the RCM with the observational distribution (Wilcke et al. submitted).

Determination of precipitation phase

For forecasting and modeling snowfall, the differentiation of solid and liquid precipitation is a major concern. An evaluation of available methods was done within this project. In the literature, either single temperature thresholds (e.g. Fontaine et al. 2002; Hofer 2007; Buttle 2009) or two temperature thresholds are used (e.g. Aiguo Dai 2008; Auer 1974; Chimani et al. 2011; Quick & Pipes 1977). It was found that the temperature thresholds vary with season and location (e.g. Vehviläinen 1992; L'Hôte et al. 2005), even though only a couple of studies take that into account. In this project we decided to evaluate the hyperbolic tangent approach (e.g. Aiguo Dai 2008; Chimani et al. 2011) on two stations in Austria, using air temperature and wet bulb temperature in comparison. The wet bulb temperature was achieved by two different approaches, iterative and empirical. The results show no differences in using air temperature or wet bulb temperature. This leads to the conclusion that additional uncertainty (iterative or empirical approaches for calculating wet bulb temperature) can be avoided by using the directly measured air temperature.

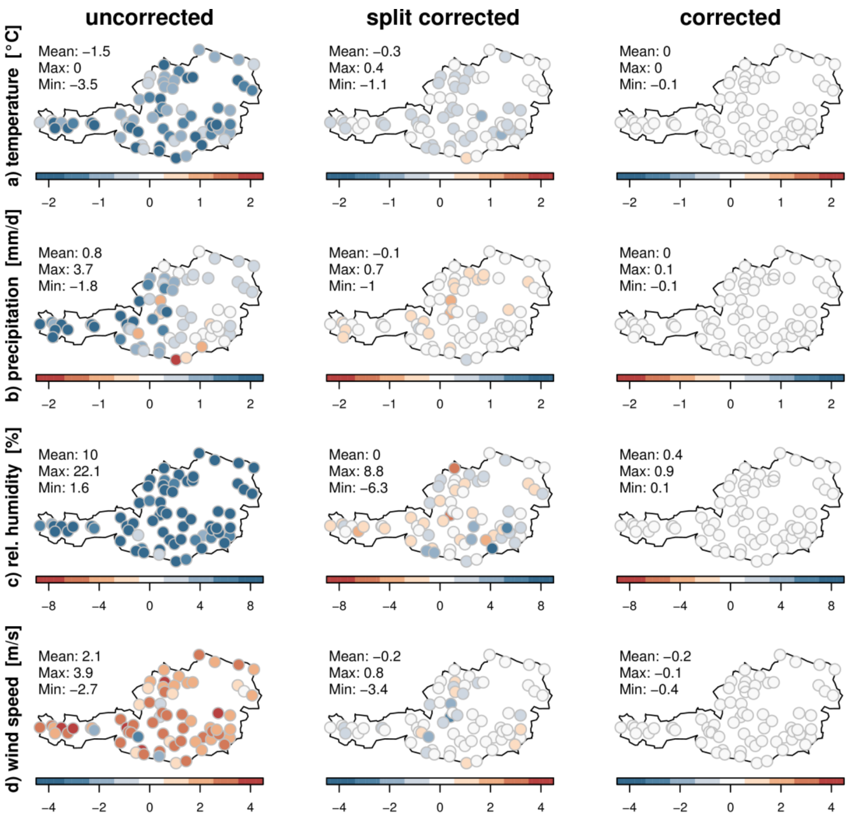

Figure 1: Annual mean RCM bias at observation stations (1991-2010) for a) temperature, b) precipitation, c) rel. humidity, and d) wind speed (top down) for the raw RCM (for temperature altitude corrected), the error-corrected RCM with split sample evaluation, and the error-corrected RCM in technical evaluation (same calibration and application period).

Altitude based precipitation correction

As primary analysis showed a significant underestimation of the snow depth at high altitude regions, an elevation based precipitation correction was established. The underestimation was caused by multiple factors, e.g. systematic errors during measurements and bad influence of wind-drift during snowfall events. Goodison et al. (1998), Habib et al. (1999) and Armstrong et al. (2008) mention errors up to 50% depending on the given gauge type. This massive variation is attributed to difficulties during the measurement process and varies between each station (type, elevation) and during time (weather influences). Multiyear snow depth measurements at 55 ZAMG snow gauges were used to correct the overall precipitation of the measured datasets (Figure 2).

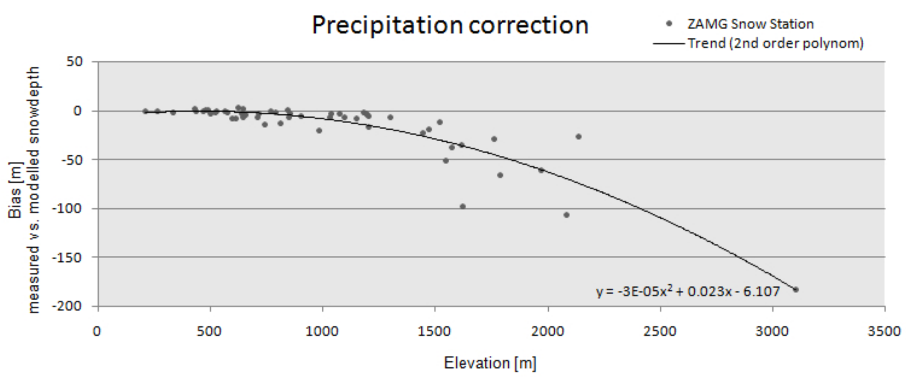

Figure 2: Measured and modeled snow depth at 55 ZAMG stations.

An increasing underestimation of the simulated snow depth can be observed and a second order polynomial trend curve fitted. This curve is used to correct the precipitation input amount of the regional and local snow models. Approximately an increase of 12% per 100m could be considered. Primary results show an overall good agreement, the results are more reliable regarding the snow cover-period and in context of the CC-Snow II project the results are a good basis to establish an artificial snow module to the snow models.

Snow modeling

Snow modeling at the local scale

The aim of the local snow simulations with AMUNDSEN in this project was to calculate technical snow production for all four ENSEMBLES realizations used in CC-Snow II. The simulated snowmaking hours as a function of potential snowmaking hours (as determined by the wet-bulb temperature) and snow demand is illustrated for a ski resort in the Schladming area for the seasons 1985/86–2010/11 in Figure 3.

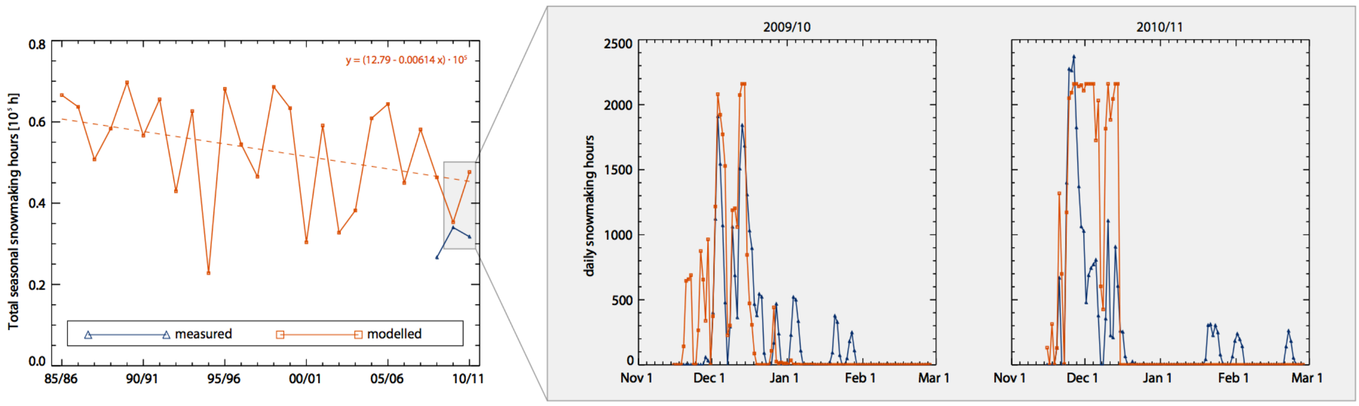

Figure 3: Simulated snowmaking hours for the winter seasons 1985/86–2010/11 (left) and selected seasons (right) as calculated for a ski resort in the Schladming area on the basis of meteorological station recordings.

The comparison of measured and simulated snowmaking hours is limited by the lack of validation data, which was only available for two seasons (see Figure 3). As illustrated, 2009/10 is better reproduced by the model than the season 2010/11. This can be explained by the fact that the early season 2010/11 (October-December) was colder than usual, which corresponds with better snowmaking conditions. The model utilizes the potential snowmaking time to the maximum, while in reality the actual snow production was reduced starting from the end of November (as soon as ideal snow conditions have been achieved). The related water and energy consumption is later used for the economic analysis. An example for the water consumption that is associated to the snow production in Figure 3 is shown in Figure 4. The overestimation of snowmaking hours observed for the season 2010/11 results in a severe overestimation of the total water consumption for this season, while the water consumption for the season 2009/2010 is again well reproduced by the model.

Figure 5 shows the course of simulated snowmaking hours and the associated water consumption for the entire ski area in the Schladming site as averaged over all considered realizations of the A1B scenario. The decrease in snowmaking hours is relatively small indicating that snowmaking is still possible in the future for the considered site. However, the decrease in water consumption indicates that the increase in temperatures does not allow to route the same amount of water through the production facilities – snow production is hence less effective.

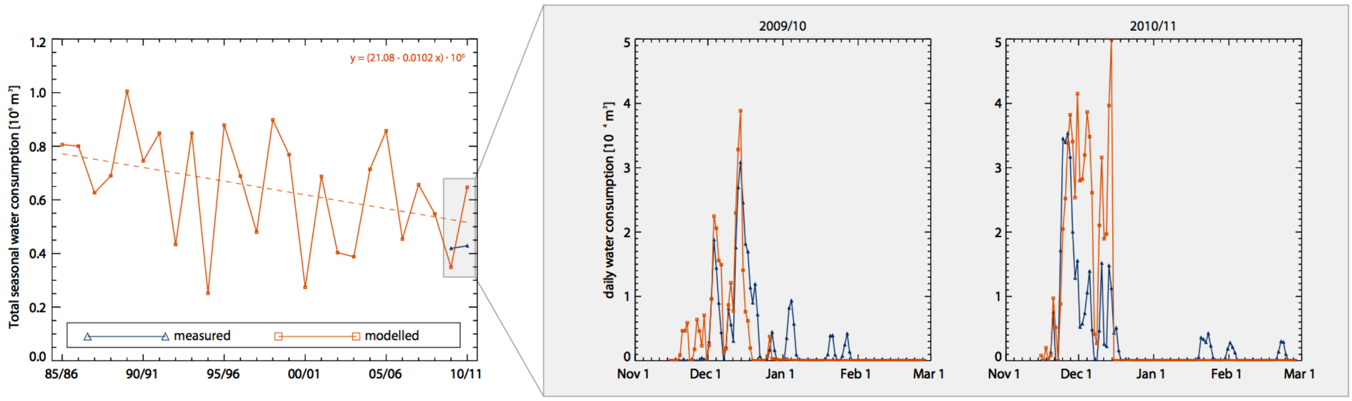

Figure 4: Simulated water consumption for the winter seasons 1985/86–2010/11 (left) and selected seasons (right) as calculated for a ski resort in the Schladming area on the basis of meteorological station recordings.

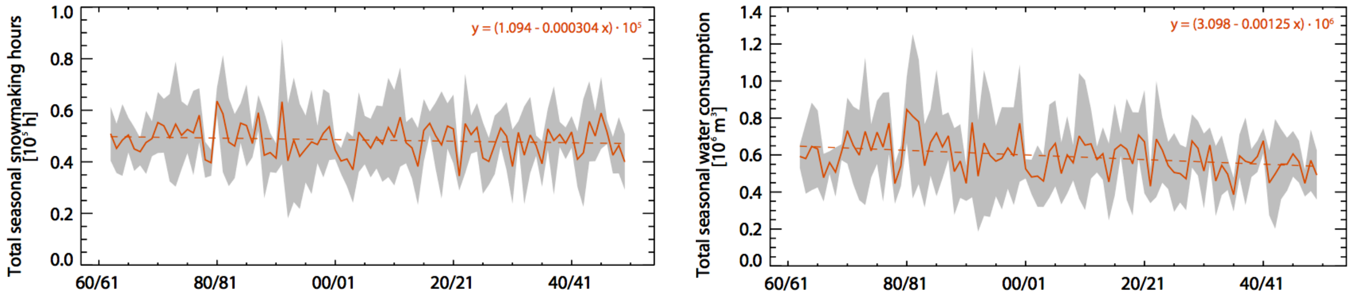

Figure 5: Seasonal number of snowmaking hours (left) and seasonal water consumption (right) for an exemplary ski area in the Schladming region as simulated for the period 1962–2050 (averaged over all scenario realizations). The gray shaded areas indicate the range of the results for all realizations. Linear trends are shown as dashed lines.

Figure 6 shows the natural and technical snow conditions for the minimum and maximum elevation of the skiing area. According to the displayed model results, the natural snow cover and the produced amount of technical snow decrease in lower as well as in higher elevations in the future. The decrease is, however, more severe in higher elevations. This can be explained by the fact that the change in temperature is most distinct in higher elevations (see results of CC-Snow published in the final report of the CC-Snow project).

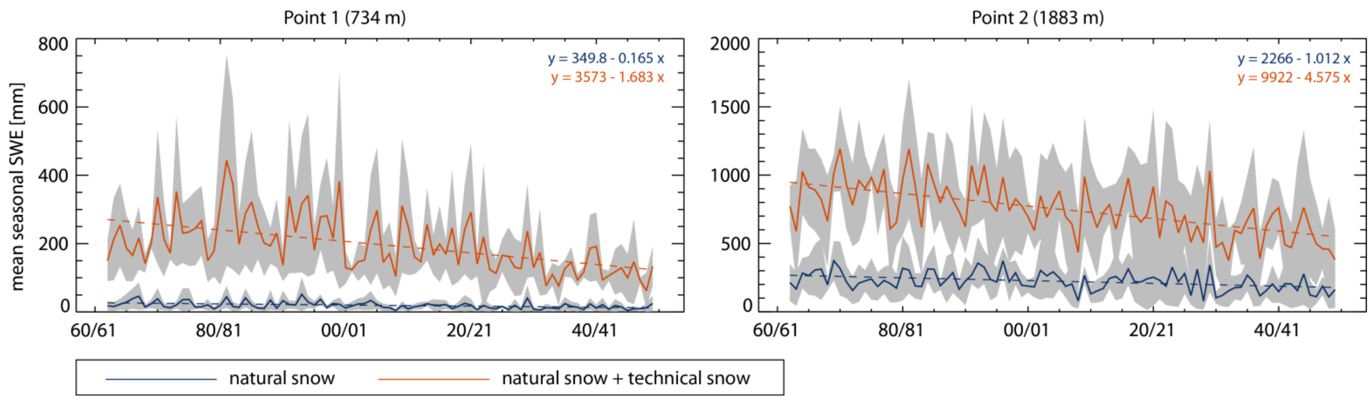

Figure 6: Mean seasonal snow water equivalent (SWE) for two elevations in an exemplary ski area in the Schladming region as simulated for the period 1962–2050 (averaged over all scenario realizations). The gray shaded areas indicate the range of the results for all realizations. Linear trends are shown as dashed lines.

Overall model performance was evaluated by comparing the season length reported by the ski area to the modeled season length at the one pixel in the model domain that is critical for opening/closing of the ski area (i.e. the base station of the upper part of the ski area). The model reproduces the real season length very well for most of the recent seasons (Figure 7), but shows a tendency to overestimate the season length for seasons further in the past. This is consistent with expectations, since the model runs were performed with the current state of the snowmaking infrastructure which most certainly not matches the historical conditions (less snow making facilities in the past). Season length, both with and without snowmaking, decreases in the future (see Figure 8), which is in accordance with the issues described in the previous paragraphs.

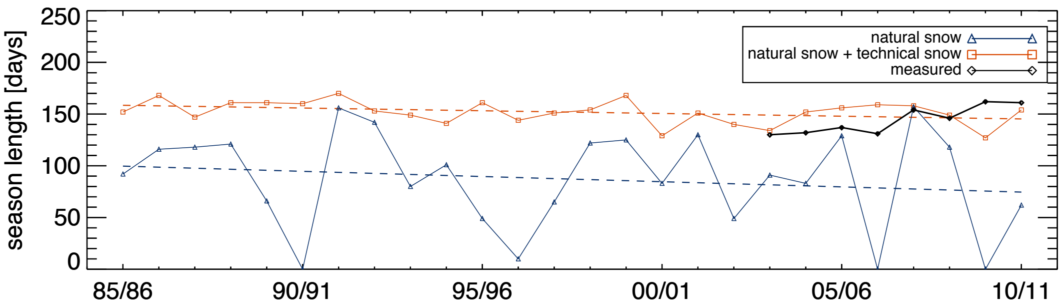

Figure 7: Modeled season length for an exemplary ski area in the Schladming region as simulated for the period 1985–2011 using historical station recordings. Linear trends are shown as dashed lines.

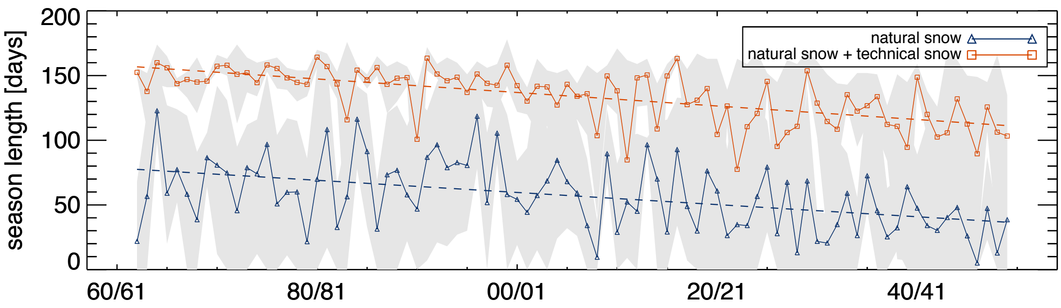

Figure 8: Modeled season length for an exemplary ski area in the Schladming region as simulated for the period 1962–2050 (averaged over all scenario realizations). The gray shaded areas indicate the range of the results for all realizations. Linear trends are shown as dashed lines.

Snow modeling at the regional scale

SNOWREG was applied to simulate snow depth including snowmaking for the whole provinces of Styria and Tyrol. Results for the average warming scenario METNO indicate that snowmaking can double the snow depth throughout most of the three decades. Still, the decreasing snow depth including technical snow production shows that snowmaking conditions deteriorate, i.e. that the required temperature is not reached as often as in the reference period (Figure 9).

Transferring the results to a ski area level, changes in the number of snow reliable ski areas can be assessed. Following the international literature, we used the 100-days rule for the term snow reliability. This rule states, that a ski area is snow reliable if ski operation can be maintained for at least 100 days in 7 out of 10 seasons (Abegg et al. 2007). In addition, we define a ski area as snow reliable, if at least 50% of the ski slopes fulfill this rule. As expected, the number of snow reliable ski areas is higher when including technical snow production (see Figure 10).

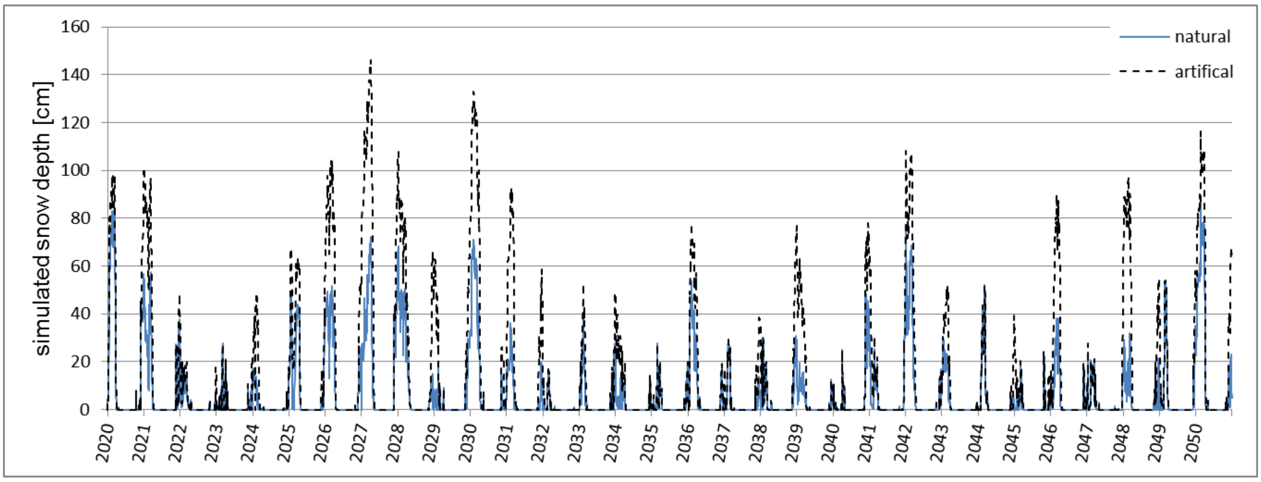

Figure 9: Simulated snow depth for the time period 2020-2050 in the METNO realization. South faced slopes for the altitude region 1000-1200m, "Steirische Kalkalpen West".

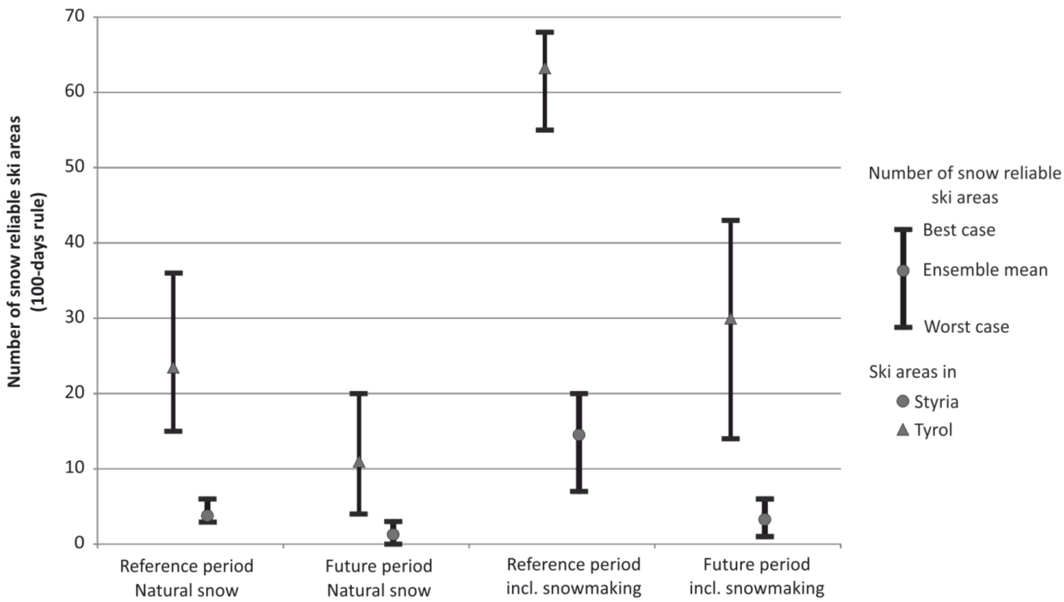

Figure 10: Number of snow reliable ski areas in Tyrol and Styria as simulated by SNOWREG.

The magnitude of uncertainty is considerable due to the different climatic characteristics of the future scenarios. In Tyrol, the share of snow reliable ski areas (including snowmaking) declines from 76-86 % in the reference period to 18-54 % in the future period. In Styria, the current share is considerably lower, with 22-63 % snow reliable ski areas. This values further decreases to 3-19 % in the future period. Without technical snow production, only few ski areas will remain snow reliable in the 2021-2050 period regardless of the climate scenario. Including technical snow production, it largely depends on the climate scenario wether snow production (as defined in the model, see methods section) can be considered as a viable adaptation measure for many ski areas or not.

The change in operation days (including technical snow production) where ski areas are able to open at least 50 % of their skiing terrain, is illustrated in Figure 10. In Styria 13 ski areas lose more than half of their current ski season despite snow production. In general the impacts in Styria are greater than in Tyrol, both in terms of the highest losses per ski areas as well as in the number of seriously affected ski areas. Only few ski areas in the north-western part of Styria (some of them within the case study region of Schladming) and in the northern center have moderate losses. In Tyrol almost all ski areas along the main Alpine divide suffer comparatively little losses, due to their high altitude. The most affected ski areas are located in the north-west (Außerfern), the center (Innsbruck region) and the north-east (case study region of Kitzbühel). While the Kitzbühel ski area is among the group with less than a 25 % shortening of the season, the 4-mountain link in the Schladming region is among the class with up to 50 % shortening of the ski season (see **Error! Reference source not found.**1).

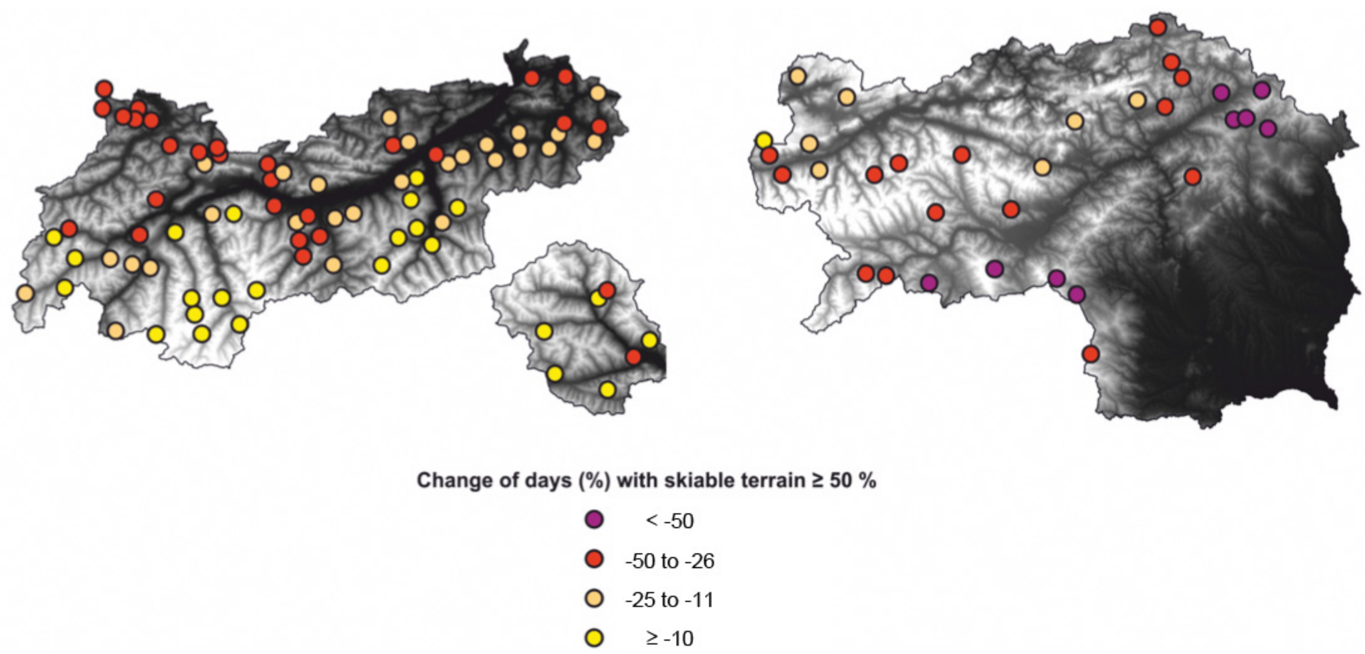

Figure 11: Change of operation days (%) including technical snow production according to SNWOREG simulations based on the METNO realization 2020-2050 compared to 1971-2000.

Economy and tourism

Impacts of climate change supply conditions on skier visits

To determine the potential impacts of climate change on skiing activities and on the future profitability of skiing operations the effects of weather variability on skiing have to be explored first. Following Hamilton et al. (2007) and Shih et al. (2009), we examined this relationship from the demand side and on a local and daily resolution, which “allows a detailed examination of the time and spatial structure of weather effects on skiing” (Hamilton et al. 2007). Hence, we developed models of daily visitor numbers (subsequently also referred to as skier days) for three different ski areas in the Schladming region with a special focus on the impacts that variations in weather and snow conditions do have on daily skiing demand.

Exemplarily, Figure 12 illustrates the comparison of observed daily visitor numbers to estimated daily visitor numbers based on the fitted regression model for Ski Area I. As shown by the graphs, seasonal and weekly cycles as well as other variations in visitor numbers are captured by the model most of the time. Each of the final regression models is able to explain at least 84% of the variations in daily visitor numbers. Moreover, the impact of snow depth on daily visitor numbers is indicated to be positive and highly significant.

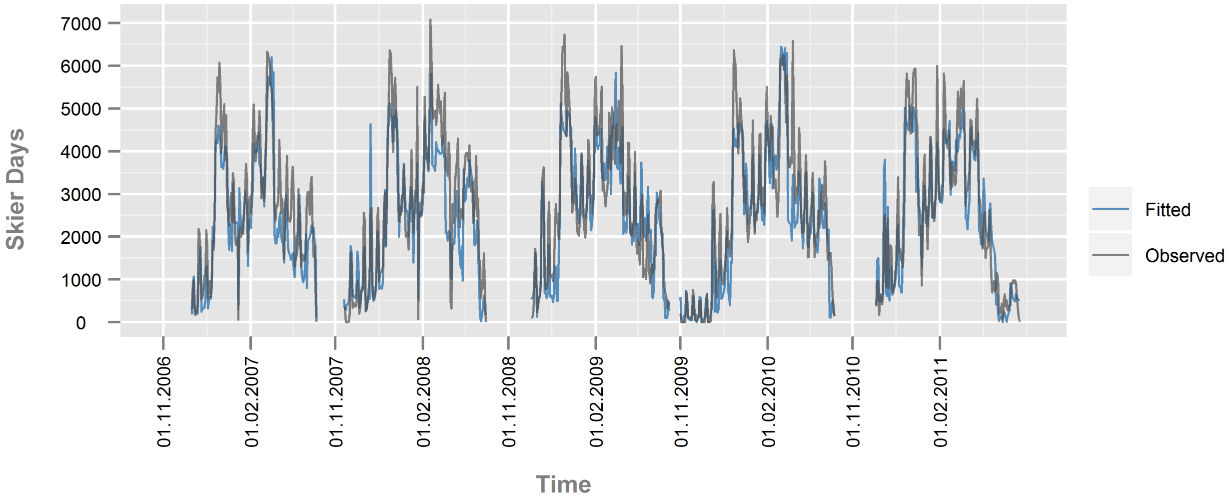

Figure 12: Observed vs. fitted daily visitor numbers (Ski Area I).

Running the calibrated models with meteorological scenario data resulting from four different regional climate models under the A1B scenario pursued two goals: (i) providing projections on visitor numbers until 2049/50 regarding only natural snow conditions as well as including snow production, for the cost-revenue analyses of snowmaking and skiing operations and (ii) analyzing the potential impacts of climate change on skiing demand in the three ski areas by comparing visitor numbers projected to the scenario period 2020/21–2049/50 to visitor numbers simulated for the reference period 1970/71–1999/00.

For each of the three examined ski areas, **Error! Reference source not found.**13 shows the difference between the average monthly revenues modeled under the climate of the reference period compared to the average monthly revenues modeled for the climate of the scenario period, both in absolute (upper bar charts) and relative (lower bar charts) terms. The bars themselves represent the means resulting from applying four different climate realizations, whereas the error bars indicate the range of these outcomes. Results suggest potential climate change impacts to be quite similar for all three ski areas. Measured in relative terms, i.e. in percent of the skier days or revenues simulated for the reference period, the highest impacts are expected for the month of April, typically followed by November or March, whereas the smallest impacts are indicated for January and February. A somewhat different picture arises when measuring the difference between reference and scenario period in absolute terms, i.e. in million Euros. Then, impacts are the highest for March and the lowest for November.

The presented results are of course sensitive to the assumptions made with reference to the snowmaking strategy applied, which gets particularly obvious when looking at the potential impacts of climate change that result under the assumption of producing no snow at all. The respective climate-induced changes in revenues are outlined in Figure 14. Assuming no snow production at all, potential climate change impacts measured in relative terms are distributed somewhat more evenly across the months and tend to be higher in most of the months compared to Figure 13. The difference is especially pronounced in case of January and February. In Figure 14 these two months also tend to show the highest potential climate change impacts measured in absolute terms (upper bar graphs). Compared to the analysis where snowmaking is taken into account, results under purely natural snow conditions suggest absolute climate change impacts to be lower in November and April. This can be traced to the circumstance that, when excluding snowmaking, revenues under the reference climate are already considerably lower than when including snowmaking. In contrast, climate change impacts for the months December, January and February are suggested to be higher in case of purely natural snow conditions.

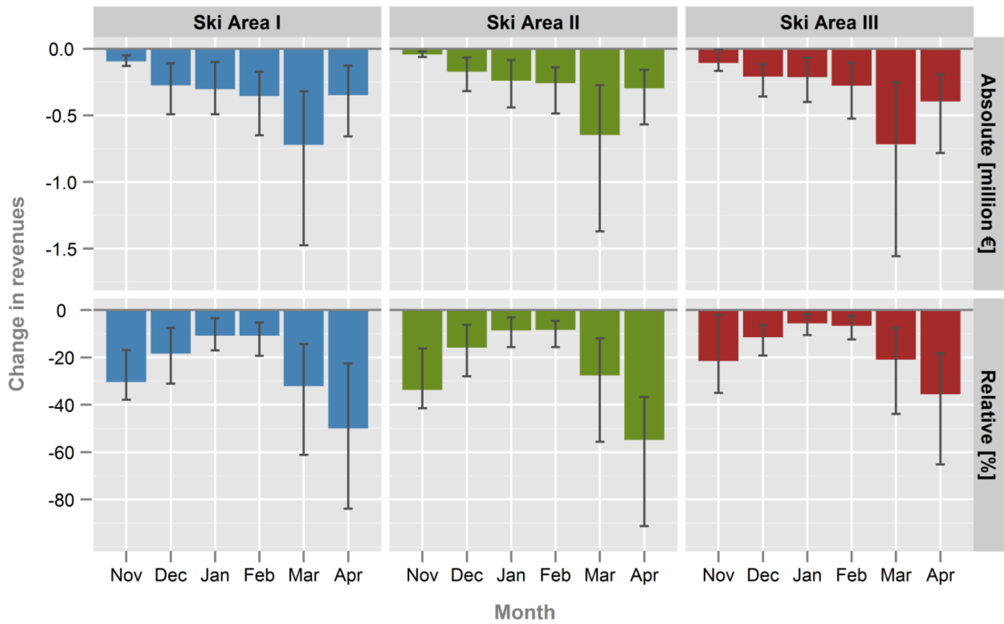

Figure 13: Potential climate change impacts on ski areas' revenues per month: absolute and relative difference in the average monthly revenue between the reference period 1970/71-1999/00 and the scenario period 2020/21-2049/50 taking snow production into account. The error bars indicate the range induced by the different climate realizations.

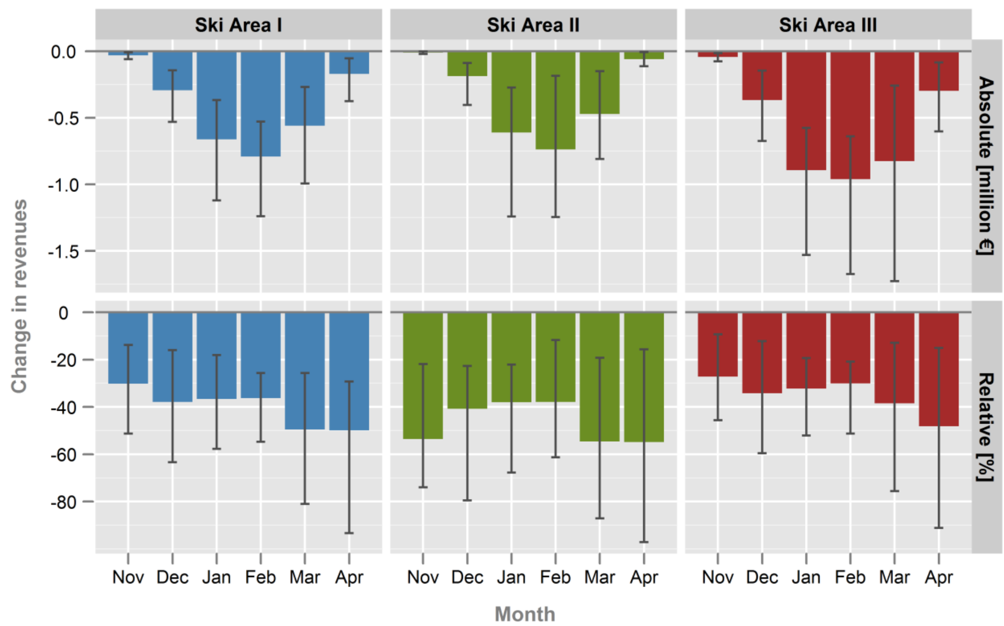

Figure 14: Potential climate change impacts on ski areas' revenues per month: difference in the average seasonal revenue between the climate reference period 1970/71–1999/00 and the climate scenario period 2020/21–2049/50 taking only natural snow conditions into account. The error bars indicate the range induced by the different climate realizations.

Regarding the whole winter season, the results suggest potential climate change impacts on ski area's seasonal revenues to range from -0.7 to -3.9 million Euros or -5% to -34% when taking snowmaking into account – depending on the ski area and the climate scenario realization – and from -0.7 to -6.3 million Euros or -17% to -70% when considering only natural snow conditions.

Economics of technical snow production

We carried out a detailed analysis of snowmaking costs and revenues for the Schladming case study region under projected future climate conditions. Therefore, we evaluated the profitability of snow production using dynamic investment models, whereby the annuity served as investment decision criterion. The annuity represents a calculated average profit of an investment project and in the case of a single investment decision an investment project should be realized if the expected net present value and hence the annuity is positive. Therefore, we first analysed if the future costs of snowmaking could be offset by the additional revenues attributable to artificial snow. A positive result is crucial to justify investments in snowmaking technologies. Additionally, an overall analysis of costs and revenues was done to answer the question if skiing operations as a whole would still be profitable in future.

The development of electricity costs in one ski area in the Schladming region is illustrated for the realizations in Figure 15. The average of the underlying electricity price scenarios was used, while the error bars show the range of all electricity price scenarios. The change in required hours of snowmaking due to changing climatic conditions is denoted as "quantity effect" whereas the changing energy costs due to an expected increase of electricity prices are denoted as "price effect". It can be seen that price increases are mainly responsible for projected increases in the electricity costs of snowmaking. In the period between 2021 and 2050 the energy costs of snowmaking increase by 18% to 76% compared to the - in earlier years theoretical[1] - snowmaking energy costs of the period 1971 to 2000.

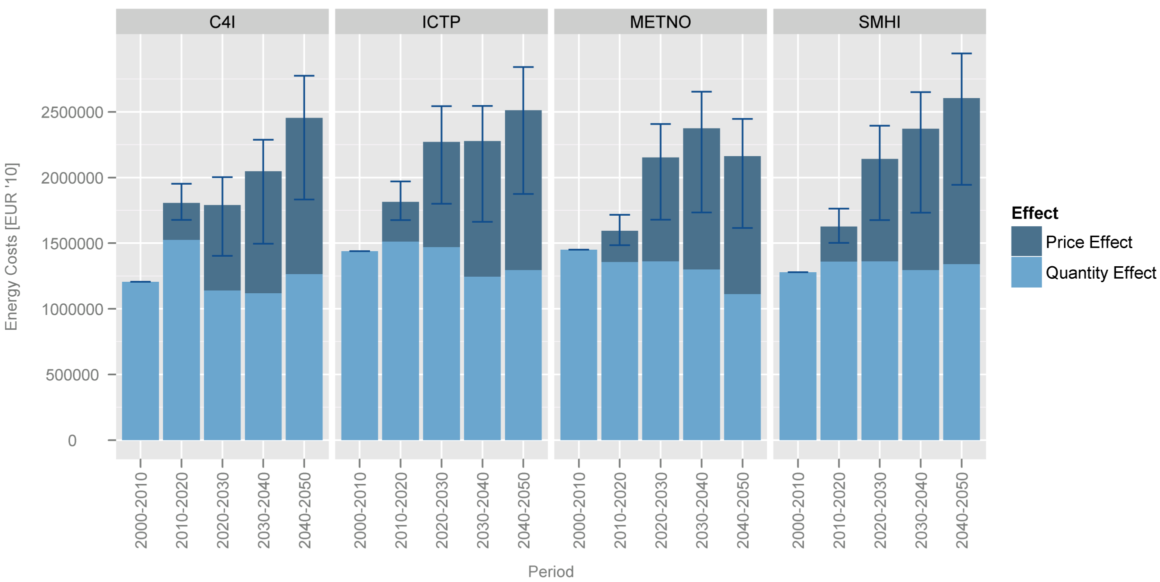

Figure 15: Energy costs of a ski area in the Schladming region for the different climate scenario realizations (in real terms, EUR 2010). The error bars show the range of the energy price scenarios.

In the present analysis the premise for a ski area operator for the utilization of snowmaking is that the snowmaking investment project - separately considered - is profitable. That means that all snowmaking investments and operating costs should be covered by additional ski ticket sales attributable to snowmaking within the operating life. **Error! Reference source not found.** 16 shows the results for the calculated annuity for the different realizations and discount rates (i) of the separately considered snowmaking investment analysis. The annuity is positive in every case ranging from 5.5 million € to 12.9 million €.

The analysis here considers only costs and revenues which were directly related to snow production. According to climate and snow model projections, both purely natural snow conditions as well as snow conditions including snow production show a negative trend. However, since this trend is more pronounced in the former case, the benefit

[1] Technical snow production started in the 1990s.

resulting from snowmaking in the form of additional skier days shows an increasing trend. Thus, it is not surprising that in the future snowmaking - considered separately - is still profitable. The highest annuity is yielded in the most severe climate realization C4I followed by the SMHI run.

A key variable of investment analyses is the discount rate, the rate used to discount future cash flows to the present value. The higher the imputed discount rate, the lower the present value of future cash flows and as a consequence the calculated annuity. As stated in Dayananda et al. (2002) the risk-free rate can be derived by considering government bond yields or insured banks' term deposit rates and represents the time value of money. In 2011 the average secondary market yield reached a value of 2.63% in Austria (OeNB 2012). To choose an appropriate discount rate especially in the present case of a very long time horizon is somewhat difficult. The risk-free discount rate can be adjusted for risk of future cash flows. Different scenarios of discount rates between 1% and 5% were therefore considered to show the implications of different levels of risk and uncertainty about future cash flows.

Thus, snowmaking considered separately is still profitable at a discount rate of 5%. In the illustrated case in Figure 16 no real ticket price changes were assumed, i.e. yearly nominal ticket price increases are in accordance with the assumed inflation rate of 2%. Ticket price increases in real terms as they were observed in the past years (1.5% above the inflation rate) would therefore increase the calculated annuity, given that ski tourism demand is rather price inelastic.

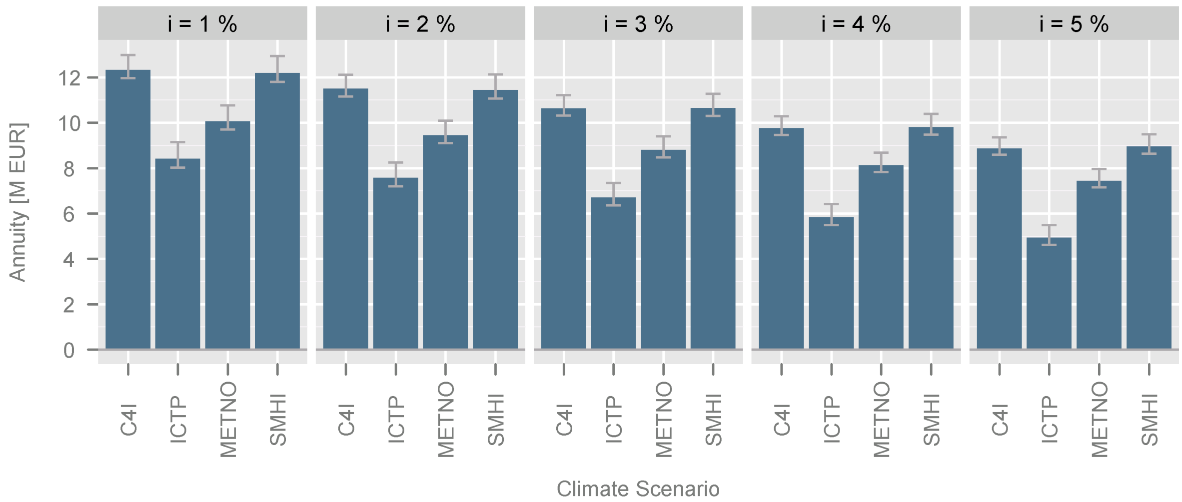

Figure 16: Calculated annuity for a ski area in the Schladming region for the different realizations discount rates (i) – snowmaking separately considered. Ski ticket prices are assumed to be constant over time in real terms (pISDchange = +0%). The error bars show the range of electricity price scenarios.

Figure 17 shows the results of annuity calculations of the overall profitability analysis by climate realization, discount rate (i), and real ski ticket price changes (actually, changes of average revenue per individual skier day). If no price increases are undertaken in real terms (pISDchange = 0%) skiing operations under future snowmaking requirements is not profitable anymore in almost every climate scenario and selected discount rate regarding a time horizon until 2050. The annuity gets positive if real price changes are undertaken and a low discount rate is given. Relating to ski ticket price increases it has to be stated that in the underlying ski visitor projections the price elasticity of demand was assumed to be zero implying perfectly inelastic demand. It means that price changes do not affect ski tourism demand. Of course, this assumption cannot fully hold. But tourism demand in general is relatively price inelastic with price elasticities of demand between 0 and -1 (Crouch 1996). In our case study regions ski visitor numbers have been increasing in the last years, although annual price changes above the rate of inflation were given. In the literature no reliable figure of price elasticity of the special case of ski tourism demand could be found. Unfortunately, it was not possible to include ski ticket prices in the present econometric analysis of ski tourism demand because of a too short time series of demand data. However, skiing operations will still be profitable in the future if ski tourists are willing to accept annual ski ticket price increases as observed in past years.

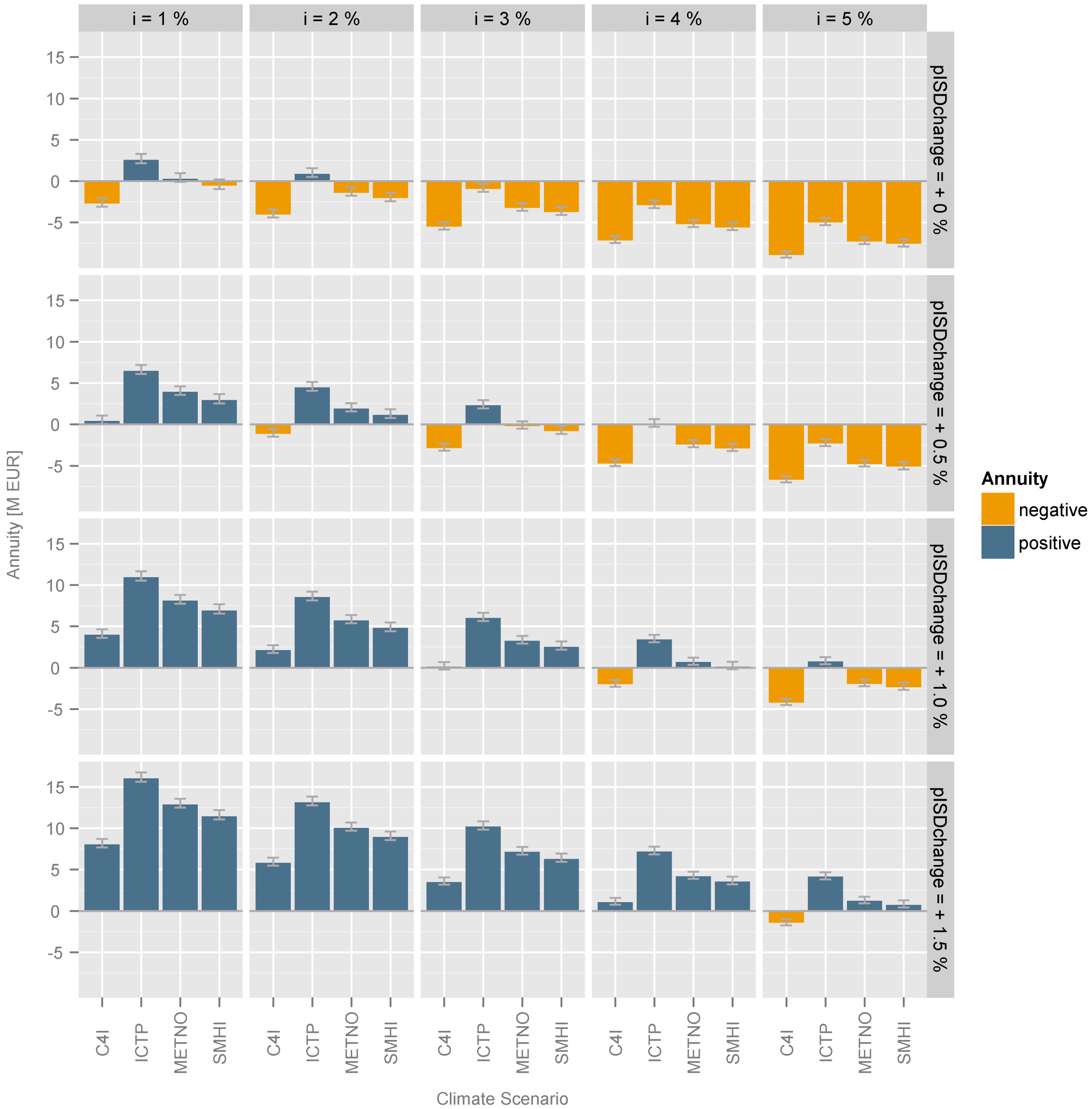

Figure 17: Calculated annuity for a ski area in the Schladming region by climate scenario, discount rate (i) and ski ticket prices (pISDchange) – overall analysis. The error bars show the range of electricity price scenarios.

Climate change impacts on overnight stays

Deteriorating snow conditions are likely to influence customer satisfaction and consequently result in a decline of overnight stays in the affected regions. We assessed potential impacts of changing snow conditions in Styrian and Tyrolean ski areas on municipal winter overnights stays by analyzing the sensitivity of overnight stays towards variations of snow conditions in ski areas associated to the municipality (i.e. municipalities hosting an access to one of the ski areas considered in the project). A snow index was incorporated into a multiple regression model explaining municipal winter overnight stays. Such models were developed for 32 Styrian and 90 Tyrolean municipalities using monthly calibration data of 20 winter seasons (Styria) and 10 winter seasons (Tyrol), respectively, and snow data from the SNOWREG model. Holding all input variables except snow conditions constant – i.e. fixing them at their 2008/09 values – the parameter estimates from the empirically calibrated models were used along with snow scenario data to simulate municipal winter overnight stays in the reference (1970/71-1999/00) and the scenario period (2020/21-2049/50).

Figure 18 gives an overview on the sensitivities of municipal winter overnight stays towards overall (natural and technical) snow conditions in the associated ski areas, which are derived from the calibrated “best” overnight-stays-demand models (for details on the demand models please refer to the methods section). In Styria, the municipalities where the models deliver statistically significant results, the sensitivity is positive, i.e. bad (good) snow conditions lead to a decrease (increase) of overnight stays. In Tyrol, municipalities with a significant positive sensitivity are located along the northern fringe of the alps (with lower average altitude). Municipalities with a negative sensitivity (Fulpmes, Serfaus, Finkenberg, Rohrberg and Tux) host an entrance or are closely located to a high elevated ski area, hence a potential explanation for the negative snow sensitivity of their winter overnight stays is that they strongly depend on these high elevated ski areas that show comparative advantages in situations with generally poor snow conditions. Municipalities being not statistically significant either have only small ski areas and therefore the dependency on snow conditions in these ski areas is lower (e.g. the Achensee region in the northern part of Tyrol or the Innsbruck region with a strong city tourism), or are characterized by large high altitude ski areas (e.g. Sölden, Ischgl, Neustift).

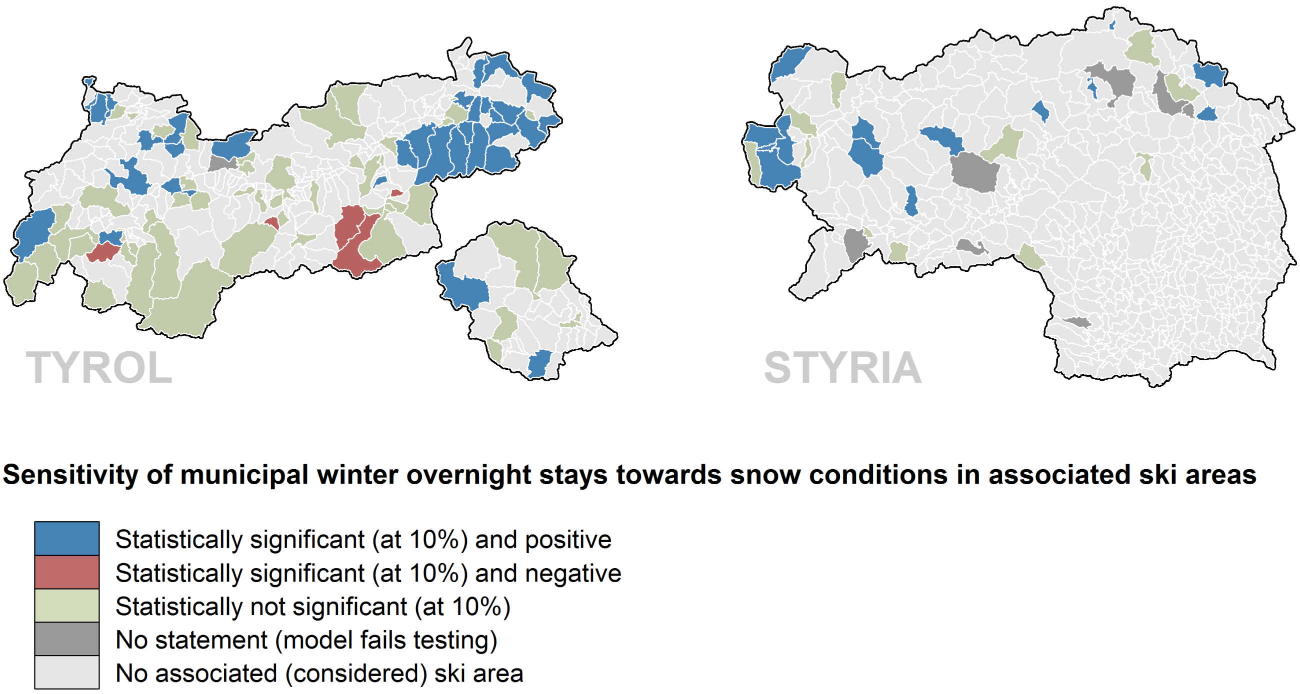

Figure 18: Sensitivity of municipal winter overnight stays (December to March) towards overall (natural and technical) snow conditions in associated ski areas.

Projected overnight stays in the winter season (December-March) in Styria show a decline of 4,200 (or 8 %) per municipality with a maximum loss of 16,100 (36 %) (Figure 19), measured as average over the four climate realizations using the empirically derived best snow index per municipality (“$best_{AVG}$”). The overall reduction of all municipalities with statistically significant results amount to -59,100 overnight stays. Considering average total expenditures per tourist night (€ 135 including travel costs, T-MONA, 2009) this translates to direct revenue reductions of about € 8 million. However, uncertainties with respect to the climate projection and/or the snow index at choice can be considerable, in part indicating remarkably higher, but also noticeably lower potential impacts than the “$best_{AVG}$” impact estimate does.

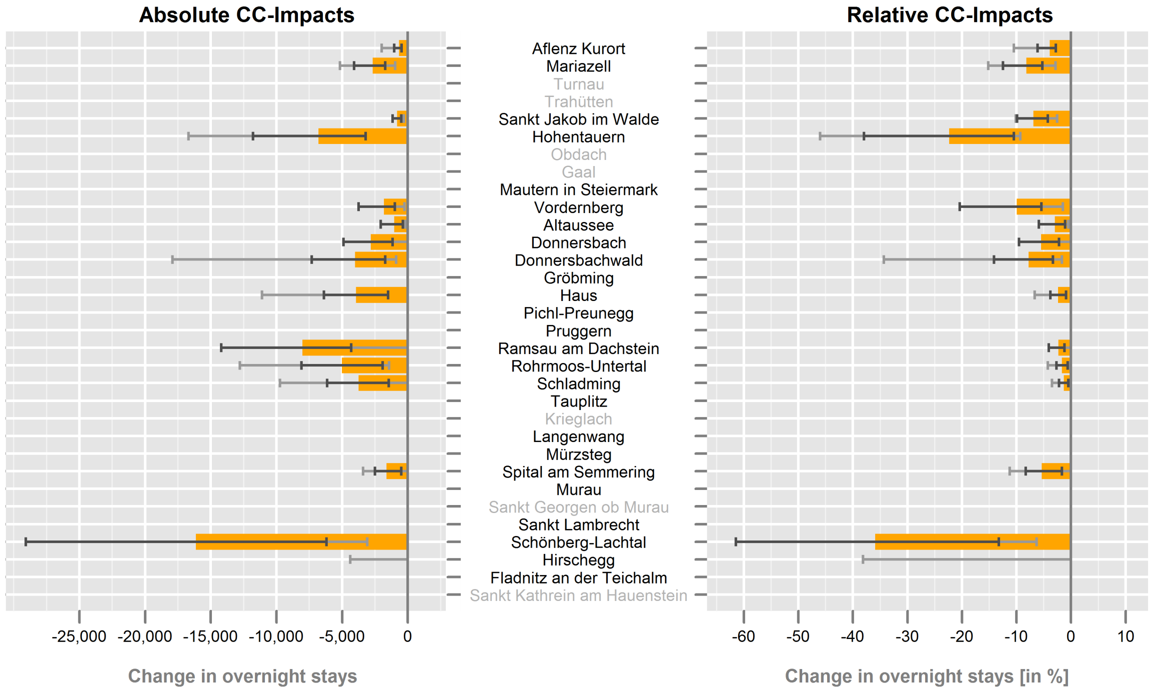

Figure 19: Styria – potential climate change impacts on municipal winter overnight stays through changes in overall snow conditions (black error bars: range of climate realizations; grey error bars: additional uncertainty due to snow index choice).

In Tyrol "*best*$_{AVG}$" impact estimates range from a reduction of -18.600 overnight stays per winter season to a gain of +27,500 overnight stays (Figure 20). Measured in relative terms, the highest change of a municipality's winter overnight stays suggest changes from -12 % to +6 %. An average reduction of -6,700 (or -4 %) per municipality leads to an overall reduction of 222,000 overnight stays per winter season, which translates to direct revenue reductions of about € 30 million. Positive "*best*$_{AVG}$" impact estimates, on the other hand, average to an overnight stays gain of +11,100 (or +4 %) per municipality and sum to an overall increase of +55,300 overnight stays per winter season, which translates to direct revenue gains of about € 7.5 million. However, it needs to be noted that positive impacts – if attributable to the municipality's closeness to comparatively snow reliable ski areas – are likely to be overestimated by the approach chosen in the present analysis, since it does not take into account the fact that these comparative advantages vanish once the snow conditions of the respective ski area fall below a certain threshold.

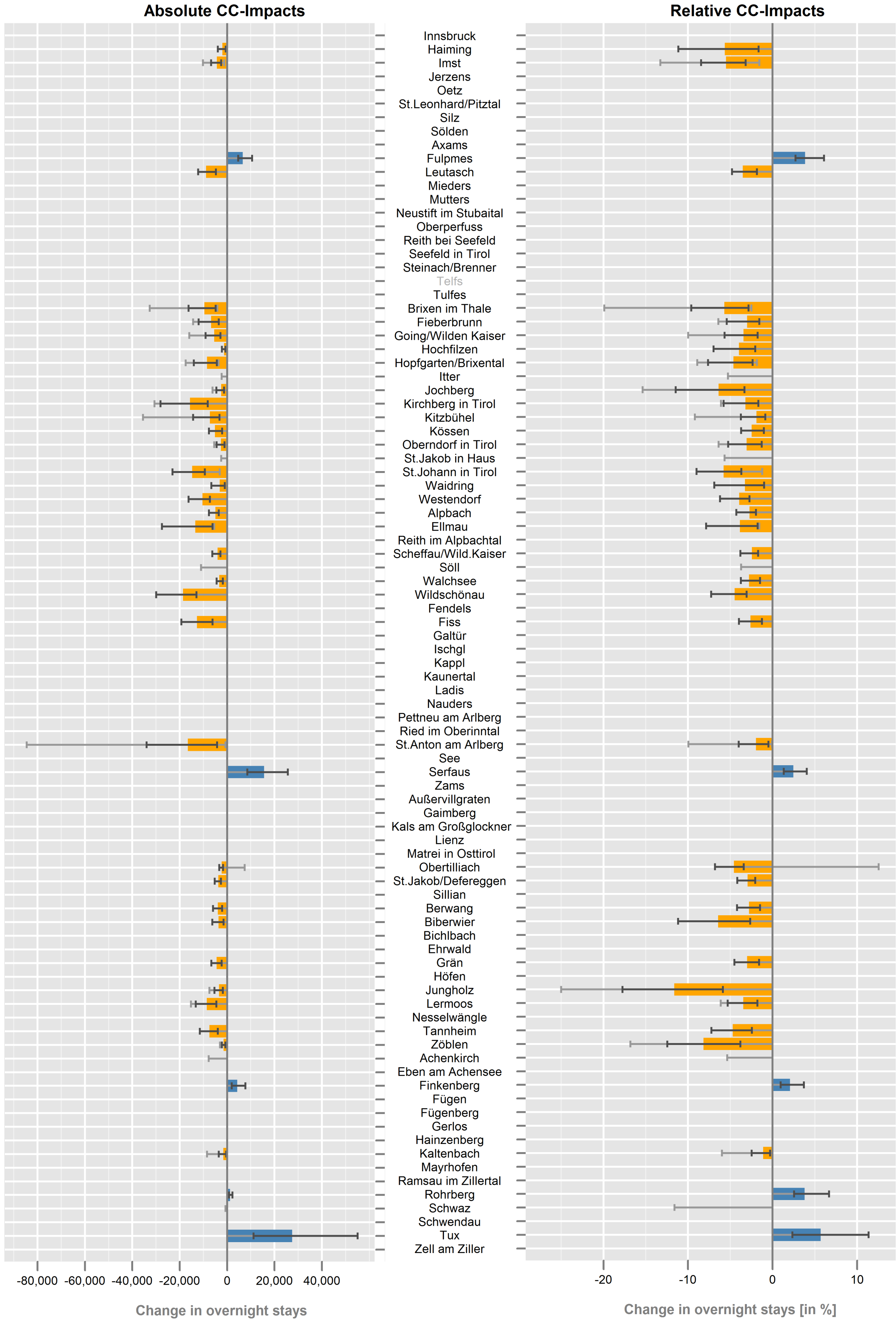

Figure 20: Tyrol – potential climate change impacts on municipal winter overnight stays through changes in overall snow conditions (black error bars: range of climate realizations; grey error bars: additional uncertainty due to snow index choice).

The impact of centrality on snow sensitivity

It was shown that the development of demand can differ greatly between winter tourism destinations. The sensitivity of destinations to deteriorating snow conditions is not only influenced by the snow reliability of the ski area, but also by the quality of the winter tourism product. As it is hard to measure product quality in quantitative ways, we applied a core-periphery concept to winter tourism municipalities. The central objective to be investigated is if winter tourism municipalities with a higher degree of centrality are less snow sensitive than more peripheral municipalities. Therefore, we first tested a range of indicators that could describe winter tourism centrality in the case study regions of Kitzbühel and Schladming. Subsequently, overnight stays data of the extreme warm 2006/07 winter season, where the winter half year temperature was 3°C above the climatic mean (Steiger 2011), was analysed for all winter tourism municipalities to verify or falsify the stated hypothesis. In order to get more qualitative information, a survey with owners of accommodation establishments in the case study regions of Kitzbühel and Schladming was conducted.

Core-periphery

Comparing the study regions, the results show variations in the structure of core and periphery patterns. Kitzbühel has the highest centrality of all municipalities in the case study regions (Figure 21). Due to a comparably high level of tourism infrastructure density in municipalities in the Kitzbühel region, a periphery does not exist. In the Schladming region in contrast, some municipalities in the eastern part of the case study region are defined as peripheral.

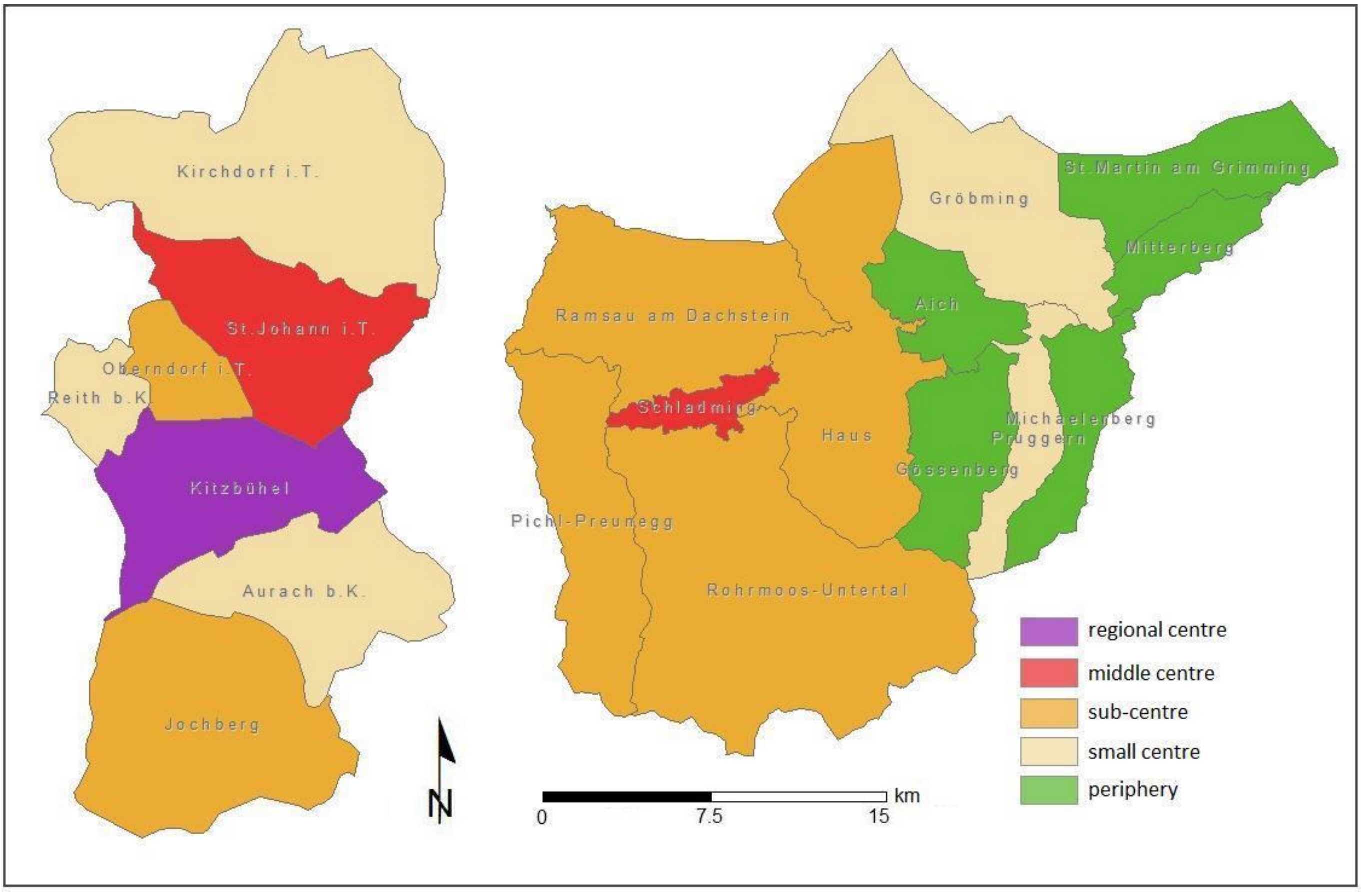

Figure 21: Map of the study regions' centrality at the community scale.

In order to be able to apply the core-periphery concept to Tyrol and Styria, the most relevant indicator describing tourism centrality had to be selected due to data constraints. The amount of beds in 4* and 5* hotels was identified as the most reliable indicator and used for analyses on the province level.

The 2006/07 winter season

In the extraordinary warm and snow deficient winter season 2006/07, modeled operating days (SNOWREG model) dropped from 150 (2003/04-2005/06 average) to 95 in Kitzbühel and from 111 to 22 in the small ski area of St. Johann i.T. Overnight stays in the Kitzbühel region dropped by 8.8 % compared to a three years average of the preceding seasons 2003/04-2005/06. The smallest decline was recorded in Kitzbühel municipality, the highest decline in the sub-centre Jochberg (Figure 22). In the Schladming region, modeled operating days in the ski area dropped from 151 to 84. Overnight stays declined by 4.8 %, though with a less clear core-periphery signal (Figure 22): While overnight stays in Pichl-Preunegg (sub-centre) and Michaelerberg (periphery) increased, they decreased in all other municipalities. Nevertheless, Schladming as the centre of the Schladming region had comparatively little losses and the periphery tends to have higher losses than the centre. Modeled average ski seasons (2021-2050) in the four climate scenarios (METNO/SMHI/ICTP/C41) are close to the warmest scenario in Kitzbühel (122/115/129/70) and close to the moderate scenarios in Schladming (89/97/111/57).

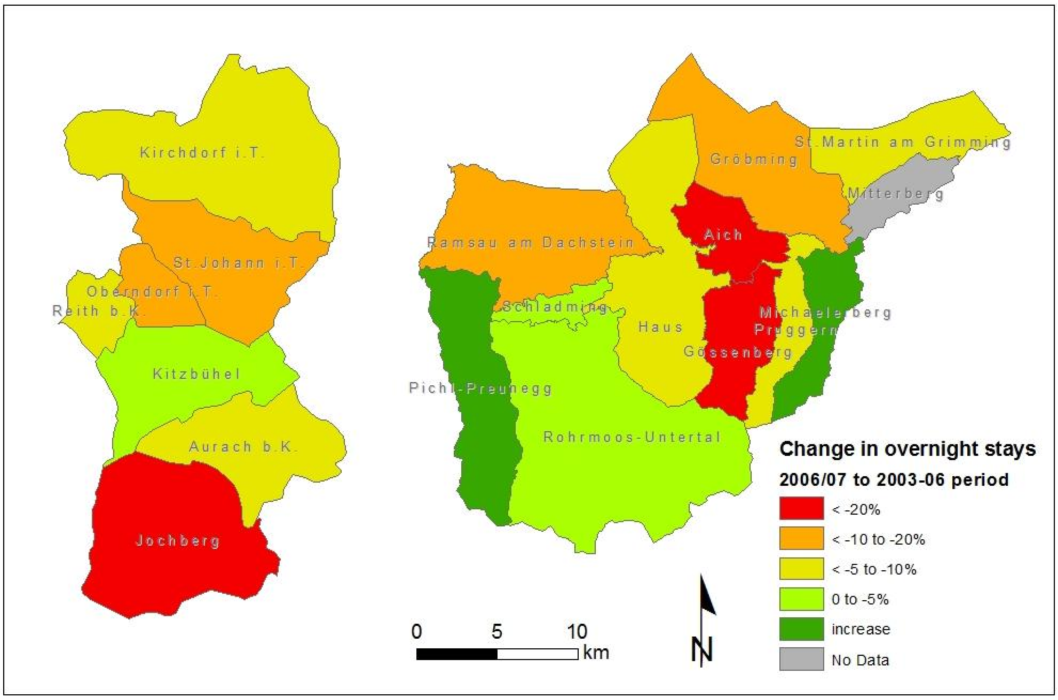

Figure 22: Change in overnight stays in winter 2006/07 compared to the average of 2003-2006.

Regarding the impact of this season on overnight stays in the provinces of Tyrol and Styria, municipalities with a higher centrality are not as sensitive to snow-deficient winters as peripheral municipalities (Figure 22). In Tyrol, losses in municipalities with more than 1.000 beds in the 4*/5* category were only 1.1 %, whereas in municipalities without beds in this category had average losses of 7.4 %. For several communities in Styria, the numbers of beds depending on accommodation categories were not available due to data protection regulations. No significant differences in the change of overnight stays, according to centrality, could be found for Styria. This could be due to the more decentralized structure of the winter touristic infrastructure and the minor importance of ski tourism in general, but can also be attributed to the sparse data base.

It can thus be concluded that winter tourism municipalities with a high centrality have a lower sensitivity to snow deficient winter seasons (and climate change) than peripheral municipalities.

Perception of climate change and adaptation strategies

The results of the survey in both case study regions indicate that in general sales are lower in snow scarce winter seasons whereas the demand for spa and wellness offers increases (see Figure 23). Impacts on different sectors of lodging establishments are very similar in both regions, except restaurant sales, with mostly negative impacts in Kitzbühel and no impacts in Schladming. The month where demand is most sensitive and where guests are most likely to cancel their holiday is December and April in Schladming and March in Kitzbühel.

Figure 23: Lack of snow and its impacts on lodging establishments.

In the case study region of Schladming, lodging establishments in central location are not that vulnerable in terms of a lack of snow (see Table 1) like the ones in semi-periphery and periphery. This, however, isn't the case in Kitzbühel. There's no clear difference in sensitivity for a lack of snow between lodging establishments in central location and semi-periphery; on average and during a mild winter they both have a 20 % decrease.

Table 1: Spatial categories and the decline of overnight stays (%) during winter with lack of snow.

	Schladming				Kitzbühel			
Category	**N**	**Mean**	**Min.**	**Max.**	**N**	**Mean**	**Min.**	**Max.**
Central location	22	12,07	3,0	40,0	19	19,74	5,0	40,0
Semi-periphery	9	17,33	1,0	60,0	11	19,78	5,0	50,0
Periphery	7	17,86	5,0	50,0	2	22,50	5,0	40,0
Total	38	14,38	1,0	60,0	32	19,92	5,0	50,0

Climate change is perceived as noticeable and negative associated with financial losses in both regions (Figure 24). Nevertheless, only a relative small share of respondents (23 % in Schladming and 31 % in Kitzbühel) have reacted to snow-deficient winter seasons by taking soft (services) or hard (investments in infrastructure) adaptation measures, while the majority undertook the later, e.g. constructing or refurbishing the spa and wellness area, which is not surprising as it was stated that demand for wellness increases when there is little snow. Soft adaptation measures are e.g. self-guided hiking tours and excursions, theme afternoons, dancing courses, etc.

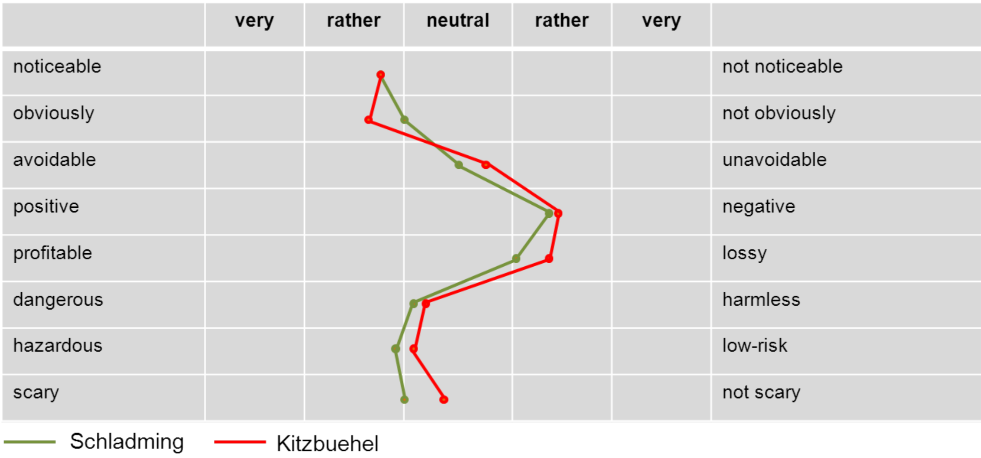

Figure 24: Accommodation provider’s perception of climate change.

When being asked about future challenges in the region, respondents in Schladming most frequently mentioned the reducing and clearing of debts after the Alpine Ski World Championships in 2013. They expect increasing prices for skiing and they’re afraid that it will not be affordable anymore. Other mentioned challenges are sustainable tourism development and the reinforcement of summer tourism where currently the prices in the accommodation sector are perceived as being too low. They also assume that snow security and snow production will be challenges for the next two decades. Measures that should be taken are diversification, creating alternatives to skiing and snow-independent attractions, improving high-quality tourism (“quality instead of quantity”).

In the Kitzbühel region, the perceived challenges are considerable different in the individual municipalities. For the town of Kitzbühel, improving or extending parking facilities was mentioned as important future task. The image of Kitzbühel in the media as VIP destination should be changed to attract all types of tourists, not least to the fact that there is a perceived imbalance between secondary homes (“too many”) and hotel beds. In St. Johann i. T. and Kirchdorf i. T./Erpfendorf, the refurbishment of St. Johann’s skiing area and indoor swimming pool is an important topic. Further challenges are snowmaking, touristic (re)positioning, strengthening the summer season and improving the quality of tourism (mainly by creativity due to a decline of tourism demand and a resulting lack of money for large investments in the accommodation sector). Respondents in Jochberg mentioned the high pricing of lift passes and restaurants and being competitive within the tourist association of Kitzbühel as important future tasks.

A vast majority of respondents (90 % in Schladming and 72 % in Kitzbühel) would favour a discussion platform for regional tourism development. About 71 % prefer “public hearings with experts, regional stakeholders and inhabitants or civil society”. Currently no such platform exists in neither of the study regions. In order to foster sustainable regional development being mentioned as important tasks, such a platform could provide the basis for a critical reflection of current development as well as for innovations for future development.

4 Conclusion and recommendations

Climate and Snow

In CC-Snow II, the technical prerequisites of downscaling a set of future climate change scenario realizations and using these simulations as input for two snow models at different spatial scales that have been set in the CC-Snow project have been built upon. The snow model AMUNDSEN has been further developed towards the explicit simulation of technical snow production setting the basis for a detailed analysis of climate change impacts on winter tourism and economy.

The key findings extracted from the snow simulations for exemplary slopes in the Schladming area are:

- Using an average realization of the A1B scenario (METNO) as input for the snow model the actual time used for snowmaking decreases for most parts of the skiing areas, but increases for the lower elevated parts of the ski area (here snow depth falls below the threshold of 60 cm more often in the future, strongly increasing demand).
- Considering all four realizations of the A1B scenario selected out of the ENSEMBLES pool in CC-Snow, the decrease in snowmaking hours is rather moderate, however the temperature increase decreases the snow producible per time resulting in lower water consumption in the future.
- The analysis of our model results in two representative elevations shows that both natural snow cover and technically produced snow amounts decrease in the future. The more severe temperature increase in higher elevations results in higher decrease rates of snow water equivalent in higher elevations.
- The increased demand for snow production cannot be fully met in the future due to unfavorable temperature conditions causing a strong reduction of the ski season despite usage of technical snow production.

Note that these results have to be interpreted with care as they are influenced by the assumptions made in the model applied for technical snow production. Furthermore, the technical advance in snowmaking that can be expected for the next decades has not yet been considered.

As shown in CC-Snow for natural snow conditions, the results achieved in CC-Snow II including the simulation of technical snow production show a severe shortening of the ski season length.

Economy and tourism

Since the demand on skiing significantly depends on weather and snow conditions, changes in the climate are expected to cause changes in skiing demand and hence in skiing operators' revenues. Analyses for three ski areas in the Schladming region clearly indicate negative potential impacts of climate change on daily visitor numbers and operators' revenues, with the extent of negative impacts being distributed unevenly across the season. Measured in relative terms, the highest climate change impacts are expected for the month April, typically followed by November or March, whereas the smallest losses are indicated for January and February. Measured in absolute terms, by contrast, results suggest impacts to be the highest for March, usually followed by April or February, and the lowest for November. However, results are sensitive to the snowmaking strategy assumed.

Considering the current status and technology of implemented snowmaking infrastructure the total amount of snowmaking hours will decrease because of increasing mean wet temperatures. Nevertheless, electricity prices are expected to rise considerably in future and as a consequence ski area operators will be faced with a substantial increase in energy costs. Since energy costs represent about one third of total snowmaking costs, increasing electricity prices could raise a significant financial problem for ski area operators in future.

In the long run ski visitor numbers will decline, but the number of skier days attributable to snowmaking will rise. Snowmaking considered separately thus will be still profitable. The overall analysis of the profitability of skiing operations is indispensable and reveals that future real ski ticket price changes equivalent to those observed in recent years are inevitable in order to keep skiing operations profitable. This result raises the question to what extent ski visitors are willing to accept price increases of ski tickets in future. However, skiing operations will still be profitable in future if ski tourists are willing to accept annual ski ticket price increases as observed in past years.

The annuity calculation is quite sensitive to the choice of discount rate. Considering Europe's today's financial situation and the decreasing trend of Austrians secondary market yields, the choice of a low discount rate seems natural. But the time horizon of forty years is quite long, hence the uncertainty about future development of interest rates is rather high. So it is reasonable to consider different discount rates taking also into account a risk premium for the uncertainty of future cash flows.

In the present analysis only the status quo of snowmaking infrastructure with respect to number and type of snow cannons is considered. New investments arising from either a densification of snow cannons or from installations of more efficient snowmaking technologies will of course debit the profitability considerations, but at the same time more efficient snowmaking technologies may reduce the operating costs. With the established integrated modeling framework an appropriate instrument to analyse the effects of such different snowmaking strategies and technologies on the profitability of skiing operations has been created.

Changes in snow conditions not only have the potential to affect the demand on skiing itself, but also the demand on winter overnight stays in municipalities located close to ski areas. For some municipalities, negative climate change impacts on their winter overnight stays are likely to be considerable. Others, in contrast, might be able to take advantage of their closeness to comparatively snow reliable ski areas.

Centrality and stakeholder perception

Both on the regional and the local scale, winter destinations and municipalities with a higher degree of centrality turned out to be less sensitive to snow deficiency. Destinations/municipalities with a higher degree of centrality have a higher number of tourism relevant infrastructure (e.g. shopping, restaurants, etc.) and a higher share of high quality beds means that the variety of services and offers in the hotels is advanced (e.g. wellness, beauty) compared to destinations that lack beds in the high quality category.

Respondents in the stakeholder survey stated that although sales generally are lower in snow deficient periods of the winter season, demand for wellness and beauty offers increase. This suggests that in snow deficient periods, guests tend to substitute snow-bound activities with other activities. Destinations and lodging establishments that have a greater variety of tourism relevant infrastructure and services have thus the potential to offer alternatives to snow-bound activities and are less sensitive to snow deficiency, at least in snow deficient periods. The results do not allow to draw conclusions on potential consequences of a series of snow deficient winters (which are likely to become more severe and more frequent in the future) on demand and sales.

Although the respondents mentioned topics like snowmaking, sustainable tourism development and strengthening the summer season as future challenges, the most important topic for respondents in the Schladming region was reducing and clearing of debts after the Alpine Ski World Championships in 2013. In the Kitzbühel region improving or extending parking facilities was mentioned as important future task. This shows that potential climate change impacts are recognized, but for daily business other topics are more relevant and challenging than climate change in the view of the respondents.

Overall

The results of CC-Snow II indicate the necessity to discuss different snow production and management options, and to jointly develop criteria to identify the most sustainable adaptation strategies to cope with the effect of changing climatic conditions, both ecologically and economically. A sophisticated model to perform these tasks and test different adaption strategies in the ski industry has been developed in the framework of the projekt.

The developed integrated modeling framework now allows to define representative sets of future scenarios of climate, snow, and economic conditions for skiing industry and tourism in Austrian regions in an inter-

and transdisciplinary process. This process has only been initially enabled and example-wise tested in CC-Snow II, but it can be a joint scientific challenge in a future project.

Among the key questions identified to be answered in future research activities are:

- What are the ecologically and economically most sustainable management options for technical snow production in the future?
- How can knowledge from science and stakeholders from different societal fields be combined to improve the quality and applicability of research outcomes and to create adaptation abilities, linking scientific knowledge production to policy strategies?
- How does the climate change signal uncertainty quantitatively effect the results of the snow modeling, the economic and the regional analyses?
- What are appropriate temporal horizons, and how can we enrich such future science with probabilities?

An attempt to tackle these research questions has already been proposed to be carried out in the project CC-Snow.*net* (submitted to the 4th Call of the ACRP, but not approved for funding), where our explicit, quantitative and spatially distributed model framework was suggested to be applied to simulate a variety of skiing area management options and their economic and regional effects. Joint criteria for evaluating these options for their potential to become both ecologically and economically sustainable adaptation strategies was part of the proposed project, to be elaborated with stakeholders from different societal fields. The water and energy consumption of the different snowmaking alternatives can now be tracked, translated into costs and related to revenues in a cost-revenue analysis. For that purpose, we are currently developing a new module for explicit local snow production where all technical data of the infrastructure management is considered (Hanzer et al. 2013, *planned*, see Outlook). The series of A1B scenario realizations already provided in CC-Snow and CC-Snow II can be comparatively used to provide a unique and valuable bandwidth of potential lower and upper limits of the climate change signal, and probability measures to be developed represent a scientific challenge for the climate modeling.

It is planned to reorganize and improve the CC-Snow.*net* proposal considering the reviewers comments and resubmit it again to an upcoming ACRP call. First, the outcomes of CC-Snow II will be presented at EGU 2013, and a series of publications currently in preparation will be submitted to international, peer-reviewed journals.

C) Project details

5 Methods

Climate modeling

Climate model evaluation, analysis, and downscaling studies often investigate the variables air temperature and precipitation (e.g. Christensen et al. 2008; Frei et al. 2003; Maraun et al. 2010). However, additional variables, like relative humidity, wind speed, or global radiation, are often needed by climate change impact models as meteorological drivers (e.g. Finger et al. 2012) like in this project. These variables are required on much finer scales and with higher accuracy than available from Regional Climate Models (RCMs) on grid spacing between 50 km and 10 km.

Themeßl et al. (2011) compared various downscaling and error-correction methods and showed that a quantile based method (quantile mapping; QM) performs best for daily precipitation. QM calibrates daily correction functions for a historical period and applies this correction functions on days in a future period (Themeßl et al. 2011; Wilcke et al. submitted). In this project QM has been applied to precipitation, relative humidity, wind speed and global radiation. Minor improvements on QM had to be made, like implementing a frequency adaptation for precipitation (Themeßl et al. 2012), and a physical margin to relative humidity (Wilcke et al. submitted).

The analysis is done in two steps. The first step is a technical approach, meaning with equal calibration period and application period. In a second step a split-sample test was performed to mimic the application situation (application to future scenarios, calibration based on past data) as far as possible. The observation period from 1971 to 2010 is divided in halves for this purpose, taking 1971 to 1990 as calibration period and 1991 to 2010 as application period, and vice versa. The years shown in the plots of this report always indicate the application period.

Snow modeling

As nowadays almost every ski area has installed snowmaking facilities, including snowmaking in models used for analyzing climate change impacts on the winter tourism industry is indispensable (Scott et al. 2003; Steiger 2010). Since CC-Snow II investigates the economic aspects of winter tourism under climate change conditions, which naturally requires the consideration of technical snow production and the related water and energy consumption, the implementation of a snowmaking approach has been defined the major goal in the field of snow modeling.

Snow modeling at the local scale

The pragmatic approach followed to provide the project partners with results of technical snow production in an early stage of CC-Snow II produces the maximum possible amount of snow (only limited by the meteorological conditions, the number of snow guns and the maximum water consumption) from November 1 (start of the snowmaking season) to December 15. From December 16 until the end of the snowmaking season on February 28, the model maintains a minimum snow depth of 60 cm on the slopes (Scott et al. 2008). The production potential for each snow cannon was calculated following Olefs et al. (2010) as a function of the wet-bulb temperature and was subsequently limited by the snow demand and water availability. As this approach has shown to overestimate snow production in higher altitudes (the equal distribution of the snow cannons leads to an overrepresentation of cannons in higher elevations), a more sophisticated, cannon based approach has been developed in a second step. The latter gives the option to more realistically distribute the snow cannons based on data provided by the operators of the skiing sites and further allows to test different adaption strategies (e.g. a demand-based positioning of snow cannons or the implementation of different technical specifications for the individual snow cannons).

The new module allows to specify the number (and possibly type) of snow guns for each slope separately. Each snow gun is assigned to a specific location on the slope and produces snow exclusively for the slope pixels within a certain radius. Water vapor losses during the snowmaking process due to sublimation and evaporation are taken into account, as well as the specific properties of technically produced snow such as the higher initial density, the higher densification rate and the more rapid albedo decline as compared to natural snow. A simple approach for snow compaction due to grooming is already implemented, which will be extended to a more sophisticated method taking into account not only the snow compaction but also the redistribution of the snow on the slopes. In addition to the specification of the maximum water throughput for the entire ski area, the volume of the water reservoirs as well as the flow rate of a possible external water supply can be specified – when the reservoirs are empty, water flow is limited by this external supply.

Figure 25 shows first results of the new approach. The simulated water consumption for the season 2010/11, which was overestimated by the first, simpler snowmaking approach (see Figure 4), is reproduced better now, both on a daily and on a seasonal basis. As these results were only available at the end of the project, a reanalysis of economic objectives with this new data set was not possible, but is planned for future publications.

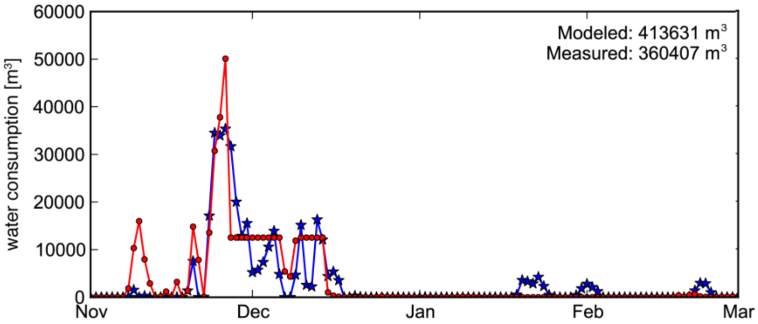

Figure 25: Simulated (red) and measured (blue) daily water consumption for the season 2010/11 (right).

Snow modeling at the regional scale

A solid but static approach for snowmaking was implemented in the SNOWREG model. In the model, snow production is limited to the period from November 1 to February 28 and to days with mean air temperature below -5°C. Snow is produced with a capacity of 10 cm per day and a density of 0.35kg/dm³, if modeled snow depth is less than 60 cm (Scott et al. 2008).

As the spatial resolution of SNOWREG is not sufficiently high to provide information required for snow reliability analysis and economic analyses on the basis of single skiing areas, raster based information was processed to 200m wide elevation bands and four aspect categories. Ski regions with homogeneous climate characteristics within the region were defined (Figure 26). For each ski region, the daily snow depth was averaged for each altitude/aspect class. By using a DTM with higher resolution (50m), the altitude/aspect distribution of ski slopes per ski area could be calculated and the SNOWREG ski region results could be transferred to the ski area level considering the individual altitude/aspect distribution of ski slopes.

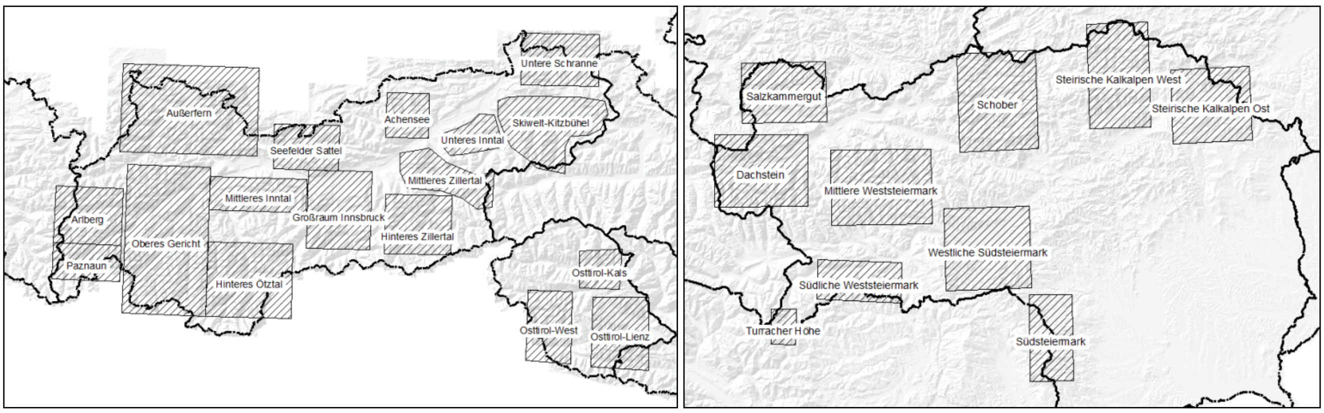

Figure 26: Ski regions analysed at the regional scale.

Economy and tourism

The potential impacts of climate change supply conditions on winter tourism demand were analysed using two different tourism demand indicators. The first indicator was daily visitor numbers to ski areas in the case study region of Schladming with meteorological input data from AMUNDSEN. The second indicator was monthly overnight stays in municipalities hosting an access to one of the Tyrolean or Styrian ski areas with meteorological input data from SNOWREG. In order to be able to assess the potential climate change impacts quantitatively, an approach was chosen that in a first step models the respective tourism demand indicator – thereby estimating its sensitivity towards variations in the supply conditions (i.e. meteorological and snow conditions) – and then in a second step applies the calibrated model on different scenarios of climate caused changes in the supply conditions. Some more details on the method are given separately for each considered winter tourism demand indicator below.

Impacts of climate change supply conditions on skier visits

The method of multiple regression analysis was used to model daily visitor numbers for three different ski areas in the Schladming region subject to various meteorological and snow hydrological parameters derived from AMUNDSEN output, including snow depth, snowfall, mean temperature, rainfall, wind speed and global radiation, as well as several dummy variables, such as the days of the week, particular feast days, school holidays or ski-openings, to control for calendar effects and events. Starting with linear models, which assume a linear relationship between the regressors and the visitor numbers, a variety of nonlinear relationships was tested subsequently by transforming the dependent and/or explanatory variables through taking logarithms, square roots or exponents. Given normally distributed residuals according to the test proposed by Jarque and Bera (1980) and the absence of functional form misspecification subject to Ramsey's (1969) RESET test, the decision on the final functional form was based on the comparison of adjusted R^2 values.[2]

Applying the calibrated skiing demand models on scenario realizations resulting from four different regional climate models (C4I, ICTP, METNO, SMHI) and the associated snow simulations, (i) the potential impacts of climate change were analysed by comparing visitor numbers projected for the climate scenario period 2020/21-2049/50 to visitor numbers simulated for the climate reference period 1970/71-1999/00 and (ii) future daily visitor numbers were simulated for the cost-revenue analyses of snowmaking and skiing operations until the winter season 2049/50.

Economics of technical snow production

The cost-revenue analysis of technical snow production is carried out using the annuity as investment decision criterion. The annuity (*Ann*) represents a calculated average profit of an investment project and is determined by the net present value (*NPV*) and the annuity factor (*AF*) which depend on both, the discount rate (*i)* and the time horizon (*T)*. The net present value compares the present value of future benefits the investors receive from a project against the present value of the investments (*IC*) needed.[3] So, the net present value is calculated by the sum of the initial costs and the present value of expected future operating cash flows. The operating cash flow (*CF*) is calculated by subtracting the operating costs (*OC*) from total revenues (*R*). The discount rate takes into account the time value of money and the risk of the future cash flows that are available from an investment. “The longer it takes to receive a cash flow, the lower the value investors place on that cash flow now. The greater the risk associated with receiving a future cash flow, the lower the value investors place on that cash flow” (Dayananda et al. 2002). The discount rate is often estimated by means of the cost of capital, i.e. the rate of return that could be earned on an investment in the financial markets with similar risk.

By equating monetary values from different years the net present value allows for evaluating long-term investments. The annuity calculation is formulated in equations (1) to (5).

$$NPV = -IC_0 + \sum_{t=1}^{T} \frac{CF_t}{(1+i)^t} \quad (1)$$

$$Ann = NPV \times AF_{T,i} \quad (2)$$

[2] In order to be able to legitimately compare R^2 values of models with differently transformed dependent variables they were corrected following Wooldridge (2000, p. 204).

[3] http://www.valuadder.com/glossary/net-present-value.html

$$Ann = AF_{T,i} \times \sum_{t=1}^{T} \frac{CF_t}{(1+i)^t} - AF_{T,i} \times IC_0 \quad (3)$$

$$AF_{T,i} = \frac{i \times (1+i)^T}{(1+i)^T - 1} \quad (4)$$

$$CF_t = R_t - OC_t \quad (5)$$

Climate change impacts on overnight stays

In order to model municipal winter overnight stays we made use of so called partial adjustment models – a special form of the general Autoregressive Distributed Lag (ADL) model – where the dependent variable is explained by lagged endogenous variables as well as simultaneous exogenous variables. Including snow conditions in corresponding ski areas as one of the explanatory variables derived from SNOWREG, allowed to estimate their influence on municipal winter overnight stays. For each Styrian and Tyrolean municipality that encompasses an entrance to one of the ski areas considered within CC-Snow II, various model specifications were tested, differing in their functional form, the regressors included as well as the kind of snow index applied to represent snow conditions in corresponding ski areas. On condition of passing various diagnostic criteria (e.g. the absence of functional form misspecification or the presence of normally distributed residuals), the most appropriate, i.e. the “best”, model specification (including the most appropriate snow index) out of those at choice was selected for each municipality by means of the Bayesian Information Criterion and the adjusted R^2. The tested snow indices include the monthly mean snow depth at the slope-weighted mean altitude of a ski area, the share of days in a month at which the snow depth at the slope-weighted mean altitude of a ski area amounts to at least 30 (60) cm, the monthly mean share of open slopes, and the share of days in a month at which at least 50% (80%) of a ski area’s slopes are open.

For municipalities, for which none of the tested model specifications passed the diagnostic criteria, no statements on the sensitivity of winter overnight stays towards snow conditions in corresponding ski areas and in further consequence on the potential impacts of climate change were made. Potential impacts of climate change on municipal winter overnight stays were assessed by applying the calibrated overnight-stays-demand models to snow scenario data. Holding all input variables except snow conditions constant – i.e. fixing them at their 2008/09 figures – the parameter estimates from the final “best” model specification of each municipality were used along with scenario data on the municipality-specific final “best” snow index to simulate winter overnight stays under two different climates – the climate of the reference period 1970/71-1999/00 and the climate of the scenario period 2020/21-2049/50. In order to account for uncertainties in climate modeling, impact assessment was carried out using four different sets of snow scenario data based on four different climate realizations (C4I, ICTP, METNO, SMHI).

The impact of centrality on snow sensitivity

Core-periphery

To get the required data for the core-periphery analyses, the most completive sources available have been used. Addresses from tourist association websites and catalogues were used to locate the different entities spatially in Google Earth and to edit the objects in ArcGIS. Although it cannot be assumed that the data source is flawless and complete, the objects recorded in the data base should help to provide a convincing spatial distribution pattern. With 1.876 entities, accommodations represent the most comprehensive category of the assessment. Important additional pieces of information for the analyses are attributes like accommodation type, class or number of beds.

With the cost-distance analysis tool in ArcGIS it can be investigated how far certain objects, e.g. accommodations, are away from the next entrance to the ski area. Only ski lifts that give access to one of the main ski areas in the study region (Kitzbühel, St. Johann i. T./Oberndorf i. T., 4-Mountain Ski Link) are considered. Travel time is calculated based on distance and speed limit information derived from Open Street Map.

The aim of density analysis is to identify spatial clusters of specific objects with touristic relevance in order to be able to demarcate core and periphery spaces. Thereby also small-scale patterns inside of communities can be recorded. In order to illustrate the density analysis, the ArcGIS integrated "Kernel-Density tool" is used. For the density analyses seven different indicators for the spatial patterns of core and periphery are considered with a resolution of 1 km²:

- Number of beds
- Number of high quality hotels (4* and 5*)
- Number of holiday apartments
- Number of shops
- Number of cash machines
- Number restaurants
- Number of nightclubs

These indicators are more or less concentrated in space and thus give evidence of the core-periphery patterns of the regions (see Figure 27).

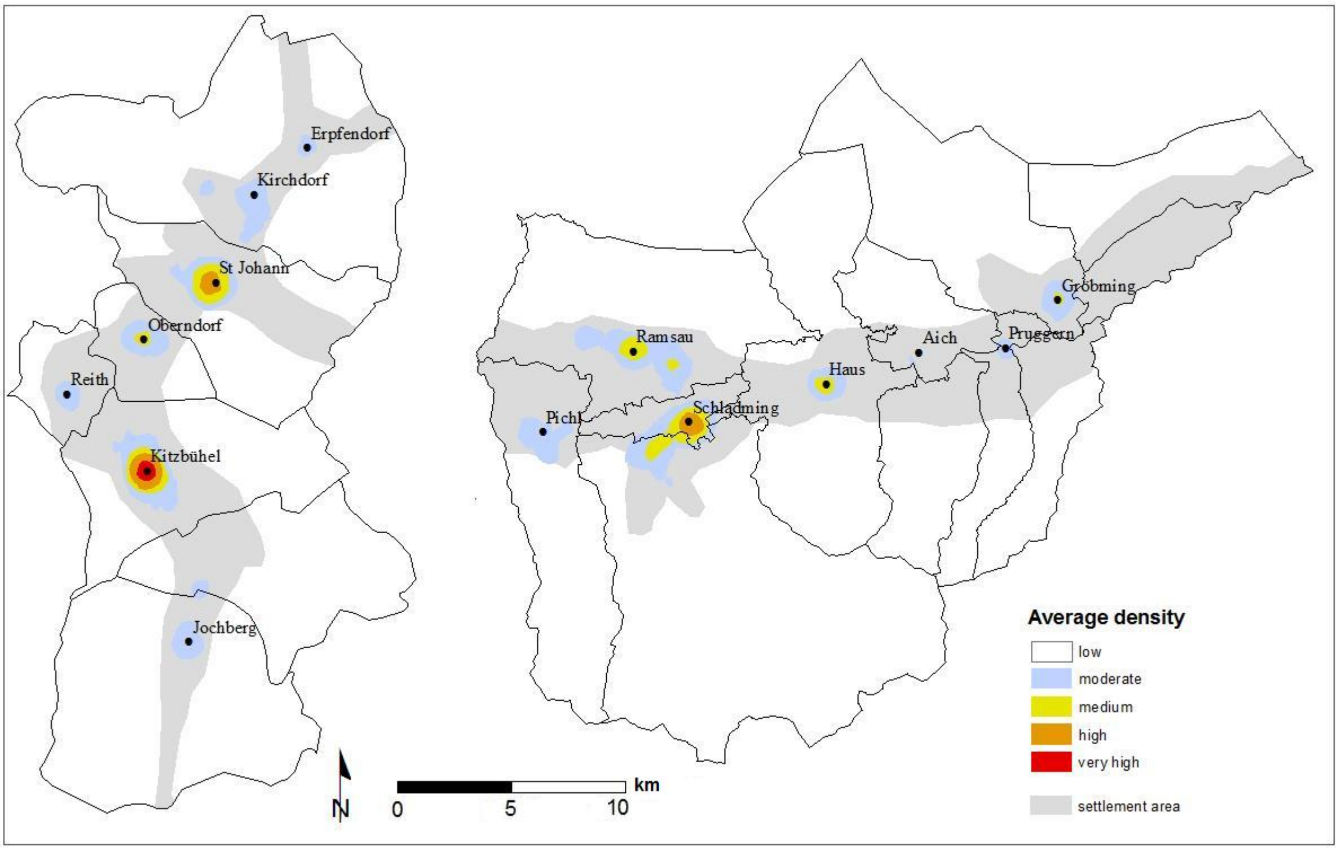

Figure 27: Average density of seven indicators illustrating the spatial core-periphery structure of the study regions.

So the distribution of shops, cash machines, nightclubs or high quality hotels is far more concentrated in certain spaces than the locations of holiday apartments or the gastronomy. It can also be seen, that the spatial clustering of the gastronomy is strongly connected to the distribution of holiday apartments. Thus, touristic facilities with a high concentration in certain spaces are suitable indicators to describe the core-periphery-structure of winter sport regions. To compare the density analyses graphically, a relative description that depends on the maximum density value of the different indicator analyses has been chosen (0-1% → white, >1-10% →blue, >10-20% →yellow, >20-60% → orange, >60% → red). The classes reach from "no or barely touristic facilities" to "very high touristic density". In most cases, the density values in the Kitzbühel region are greater than those in the Schladming region.

Core-periphery-analyses focus mainly on GIS-supported distance- and density analyses. Current "centrality" definitions (e.g.: Christaller 2006; Huter 2011) cannot easily be transferred to core-periphery structures in winter sports regions. As for tourism, it is mainly the provision with essential services (accommodation, shopping) that plays a role. Moreover, the range of touristic services is highly localized. However, even in winter sport communities concentrations of specific services (accommodation in the 4*/5* sector) can be observed that indicate centrality.

The following indicators were used to describe winter tourism centrality: total number of beds, number of beds in 4* and 5* hotels and holiday apartments, distance to ski area access points, the number of shops, cash machines, restaurants, bars and nightclubs. Based on these indicators, the municipalities were assigned a category of centrality:

- regional center: small distance (<5 min) to valley stations (access to one of the main ski areas) and very high density of facilities relevant for winter tourism
- middle center: small distance to valley stations; high infrastructure facilities
- sub-center: small distance; moderate to medium touristic infrastructure facilities
- small center: medium (5-10 min) to large (>10 min) distance; moderate to medium touristic infrastructure
- periphery: medium to large distance; low to moderate touristic infrastructure

Perception of climate change and adaptation strategies

In order to assess potential impacts of past snow scarce winter seasons on the accommodation sector in the case study regions Kitzbühel and Schladming and potential differences between central and peripheral location, and to identify the accommodation operators' awareness of climate change, a questionnaire was sent to 1548 lodging establishments in all municipalities of the case study regions and across all categories of accommodation (appartments, hotels, etc.). The questionnaire includes 26 questions – closed ones as well as open and semi-open questions – and is split into four sections: region, municipality, lodging establishment and tourist (Table 2). In both study areas, the CEOs of the tourist associations (Kitzbühel, St. Johann i. T., Schladming-Dachstein) have been informed about the survey and were asked to check and to complement the questionnaire. After that a pre-test was done in the municipalities of Schladming and Rohrmoos-Untertal. The final questionnaire – one for each study region – and an information letter illustrating the main goals of the survey as well as contact details were sent by e-mail to all tourist associations, asking them to pass the three attached files through to the owners and operators of lodging establishments. Due to a very weak first response, e-mails were sent directly to the lodging establishments in a second round. The e-mail addresses were derived from web pages of the accommodation providers, Kitzbühel.com, kitzalps.cc, and schladming-dachstein.at, a brochure of Schladming-Dachstein tourism marketing and prospectus of the tourist association Ramsau a. Dachstein.

In total, about 512 questionnaires were sent to the study site of Kitzbühel and 1.036 to Schladming. In order to achieve a stronger identification with the study, the subject was adapted to each municipality. So for example an accommodation provider in Ramsau a. Dachstein got an e-mail with subject "research project | lodging establishments Ramsau a. Dachstein | questionnaire". For this time, the response was significantly higher. In order to achieve a better representativeness, the e-mail including the two questionnaire files as well as the information letter was sent a third time. Besides the e-mail method there were also held face-to-face interviews and about 91 questionnaires including the information letter and a return envelope were distributed personally during a two-day stay in the study region of Schladming and a one-day stay in Kitzbühel. In a last step, questionnaires were sent by post to 257 accommodation providers randomly selected from the total of 1548.

Table 2: Questionnaire design.

Study object	Thematic area	
region	• location factors • skiing area • relevance of snow • impact of lack of snow	• relevance of artificial snow • supply structure • snow-independent attractions • discussion platform
municipality	• supply structure • snow-independent attractions	• decision makers • challenges
lodging establishment	• accommodation category • location • employees • bed occupancy rate • facilities and offer • guest structure • impact of lack of snow on the number of overnight stays	• impact of a lack of snow on different accommodation aspects • snow-dependence • winter 06/07 • adaptation strategies • impact of closing slopes • perception of climate change • future prospects
tourist	• snow-sensitivity depending on month • perception of artificial snow	• reaction to lack of snow • future trend

The data evaluation and analysis were carried out with SPSS Statistics. Open answers have been categorized and counted. Due to an unfortunately low return rate of 6 % (93 questionnaires), the results should be interpreted qualitatively rather than quantitatively.

One objective was to link the definition of centrality to the survey results on snow sensitivity. Due to the low response rate, the five categories of centrality had to be reclassified to three categories to get reliable results:

- **central location:** less than five minutes driving time to a ski lift and within a center
- **semi-periphery:** either more than five minutes from a ski lift or out of a dense tourist center
- **periphery:** more than five minutes from a ski lift (ski area Kitzbühel, St. Johann i. Tirol and Four Mountain Ski Link) and out of a dense tourist center (at least “small center”)

6 Work and time schedule

The Gantt-chart in Figure 28 shows the progress of the work packages in the course of the project. Because of the reorganisation of the WP deliverables from former partner 4 to the other partners it slightly differs from the original version in the proposal. Table 3 gives the deliverables, wp’s, partners with related dates of completion and remarks in detail.

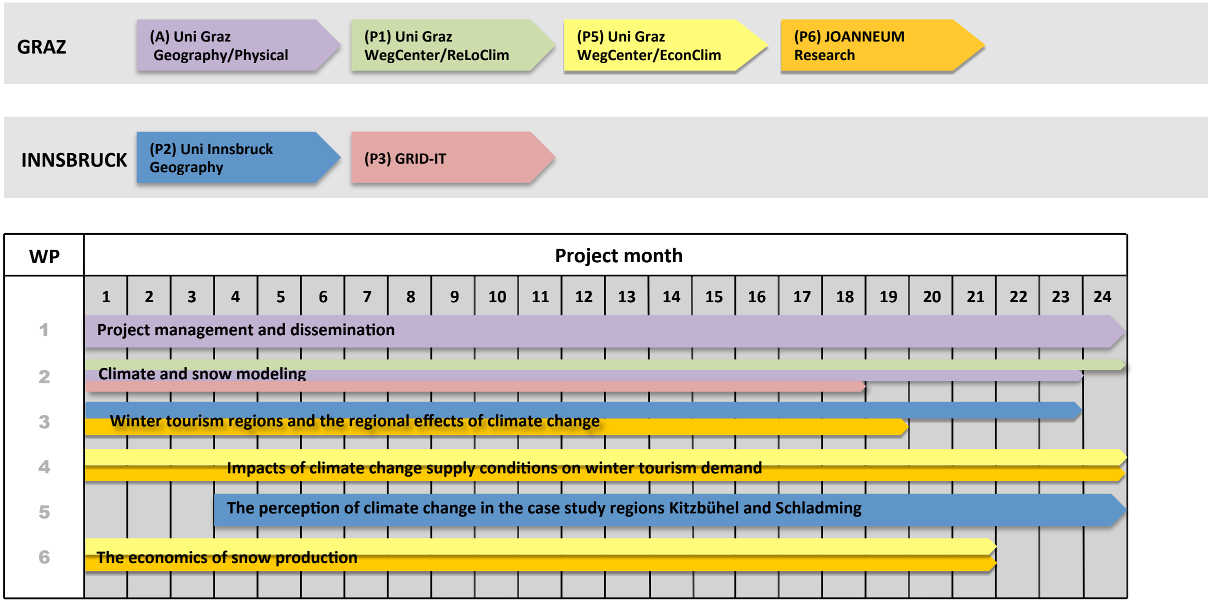

Figure 28: Gantt-chart for the 24 project months, 6 work packages and the partners of CC-Snow II.

Table 3: Overview of the deliverables and their deliverance in CC-Snow II.

Deliverable	WP	Partner	Date of completion (proposal)	Date of completion (reality)	Remarks
Management	1	A	06/2012	12/2012	cost-neutral extension
Dissemination	1	A	06/2012	12/2012	cost-neutral extension
Implementation of simple snowmaking approach in AMUNDSEN	2	A	06/2012	02/2012	
Implementation of extended snowmaking approach in AMUNDSEN	2	A	06/2012	11/2012	cost-neutral extension
AMUNDSEN model runs (met. observations)	2	A	06/2012	03/2012	
AMUNDSEN model runs (climate simulations)	2	A	06/2012	04/2012	
Climate scenario downscaling advanced	2	P1	06/2012	01/2012	
Study on separation between liquid and solid precipitation	2	P1	06/2012	12/2012	cost-neutral extension
Transformation of SNOWREG results to ski area level	2	P2	n.a.	07/2012	cost-neutral extension
Statistical analysis on the effect of the proximity and size of ski areas on municipal winter overnight stays (for core-periphery distinction)	3	P6	03/2012	07/2012	tasks carried over from P4; delayed due to the time needed for becoming acquainted with the new tasks
Core-periphery concept	3	P2	12/2011	12/2012	
Impacts of climate change supply conditions on winter tourism demand	4	P5/P6	03/2012	12/2012	delayed due to a time lag in the supply of regional snow data
Design of questionnaire	5	P2	06/2012	01/2012	tasks carried over from P4; delayed due to the time needed for becoming acquainted with the new tasks
Mailing of questionnaires and conducting personal surveys	5	P2		06/2012	
Analysis and interpretation of survey results	5	P2		08/2012	
The economics of technical snow production	6	P5/P6	03/2012	09/2012	delayed due to a time lag in the supply of economic data as well as local snow data

7 List of publications and presentations

Publications (so far, several are currently in preparation):

Steiger, R. Marke, T., Töglhofer, C., Ragg, H., Damm, A., Hanzer, F., Köberl., J., Leuprecht, A., Wilcke, R., Strasser, U., Gobiet, A., Kleindienst, H., Prettenthaler, F., Steininger, K., Stötter, J. (2012): CC-Snow: ein multidiziplinäres Projekt zu den Einflüssen des Klimawandels auf Wintertourismus in Tirol und der Steiermark. In: Zehrer, A. & Grabmüller A. (Hrsg.), Tourismus 2020+ interdisziplinär. Berlin: ESV Verlag, p. 243-256.

Strasser, U. and Schöner, W. (2013): Schnee. Auswirkungen von Klimaänderungen auf den Wasserkreislauf. In: Blöschl, G., Dokulil, M., Herrnegger, M., Kammerer, G., Kuhn, M., Loiskandl, W., Lukas, A., Merz, R., Nachtnebel, H.P., Parajka, J., Salinas, J.L., Schöner, W., Senoner, T., Strasser, U., and Viglione, A. (Eds.): Austrian Panel on Climate Change (APCC): Climate Change 2013, I. Assessment Report, Volume II.

Strasser, U., Gobiet, A., Stötter, J., Kleindienst, H., Zimmermann, F., Steininger, K. and Prettenthaler, F. (2011): Effects of climate change effects on future snow conditions, winter tourism and economy in Tyrol and Styria (Austria): CC-Snow, an interdisciplinary project, Proceedings of the "Managing Alpine Future 2011" Conference, Innsbruck.

Strasser, U., Gobiet, A., Stötter, J., Kleindienst, H., Steininger, K., Prettenthaler, F., Damm, A., Hanzer, F., Köberl, J., Lang, T., Leuprecht, A., Marke, T., Osebik, D., Ragg, H., Steiger, R., Töglhofer, C. and Wilcke, R. A. I. (2011): CC-Snow: Ein inter- und transdisziplinäres, integratives Projekt zur Untersuchung der Auswirkungen des Klimawandels auf Schneebedingungen, Tourismus und Ökonomie in Tirol und Steiermark. In: Institut für Geographie und Raumforschung der Universität Graz: Nachhaltigkeit- Regionalentwicklung- Tourismus (Hrsg): Festschrift für O.Univ.-Prof. F. Zimmermann, Graz.

Wilcke, R. A. I., Mendlik, T. and Gobiet, A. (2012): Performance and Physical Consistency of Multi-Variable Downscaling and Error-Correction of Regional Climate Models, *Climatic Change*, submitted.

Oral presentations:

Köberl, J., Gobiet, A., Heinrich, G., Leuprecht, A., Prettenthaler, F. and Töglhofer, C. (2011): Impacts of weather variability and climate change on tourism in Austria, Presentation at the "Managing Alpine Future 2011" Conference, Innsbruck (Austria).

Steiger, R., Marke, T., Osebik, D., Töglhofer, C., Kleindienst, H., Wilcke, R. and Strasser, U. (2011): CC-Snow: an interdisciplinary project to investigate climate change effects on winter tourism in Tyrol and Styria (Austria), Tourismus 2020+ interdisziplinär, Deutsche Gesellschaft für Tourismusforschung, Innsbruck (Austria).

Strasser, U., Gobiet, A., Stötter, J., Kleindienst, H., Zimmermann, F., Steininger, K., Prettenthaler, F., Damm, A., Hanzer, F., Köberl, J., Lang, T., Leuprecht, A., Marke, T., Osebik, D., Ragg, H., Steiger, R., Töglhofer, C. and Wilcke, R. (2011): Effects of climate change effects on future snow conditions, winter tourism and economy in Tyrol and Styria (Austria): CC-Snow, an interdisciplinary project, Presentation at the "Managing Alpine Future 2011" Conference, Innsbruck (Austria).

Strasser, U., Hanzer, F., Marke, T., Warscher, M., Hynek, B., Olefs, M. and Schöner, W. (2011): The physically-based Alpine snowcover model AMUNDSEN: current developments and projects, Abstracts of the Alpine Glaciological Meeting, February 2011, Munich (Germany).

Wilcke, R.A.I., Gobiet, A. and Mendlik, T. (2012): Physical Consistency of Multi-Parameter Error-Correction and Downscaling of Regional Climate Models. International Conference on End User Needs for Regional Climate Change Scenarios, March 2012, Kiel (Germany).

Poster presentations:

Damm A., Köberl J., Prettenthaler F. and Töglhofer C. (2011): Economics of Artificial Snow Production Under Future Climate Conditions, NCCR summer school 2011, Grindelwald, 04–09 September 2011.

Damm A., Köberl J., Prettenthaler F. and Töglhofer C. (2012): Economic Impacts of Climate Change on Winter Tourism: Challenges for Ski Area Operators, European Geosciences Union General Assembly 2012, Vienna (Austria).

Egger, C., Schajer, P., Wilcke, R., Marke, T. and Strasser, U. (2011): Change of temperature and precipitation 1961-2050 for the ski resorts in the Schladming area (Styria, Austrian Alps), Austrian Climate Day, September 2011, Vienna (Austria).

Egger, C., Schajer, P., Wilcke, R., Marke, T. and Strasser, U. (2011): Wandel von Temperatur und Niederschlag von 1961-2050 im Skigebiet Schladming (Steiermark, Österreichische Alpen), Jahrestagung des Arbeitskreises Klima der DGfG, October 2011, Graz (Austria).

Hanzer, F., Marke, T., Steiger, R. and Strasser, U. (2012): Modelierung der technischen Beschneiung für Skigebiete in den österreichischen Alpen mit dem physikalisch basierten Schneemodel AMUNDSEN, Austrian Climate Day, June 2012, Vienna (Austria). (rewarded with the 1st price for scientific quality)

Hanzer, F., Marke, T., Steiger, R. and Strasser, U. (2012): Modeling technical snow production for skiing areas in the Austrian Alps with the physically based snow model AMUNDSEN, European Geosciences Union General Assembly 2012, Vienna (Austria).

Ragg, H., Egger, C., Hanzer, F., Marke, T. and Strasser, U. (2011): Application of the snow cover models AMUNDSEN and SNOWREG for the simulation of past and future scenario snow conditions (1971-2050) in Tyrol and Styria, Austrian Climate Day, September 2011, Vienna (Austria).

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Strasser, U., Marke, T., Hanzer, F., Stötter, J. and Steiger, R. (2012): The CC-Snow Projects: Interdisciplinary Research at the Universities of Graz and Innsbruck, International Geographical Congress (IGC), Cologne (Germany).

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Planned Journal Publications:

Damm A. (2013): The analysis of ski lift ticket price developments in an international context, Tourism Economics, Planned date of submission: August 2013.

Damm A., Köberl J., Prettenthaler F. (2013): The profitability of technical snow production under future climate conditions, Tourism Management. Planned date of submission: April 2013.

Hanzer, F. et al. (2013): Explicit modeling of technical snow production with a distributed physically based snow model. Planned for *Cold Regions Science and Technology*.

Marke, T. et al. (2013): Downscaling from global climate models to local scale snow models. Planned for *Hydrology and Earth Systems Sciences*.

Strasser, U. et al. (2013): Future regional snow conditions in Austria. Planned for *Hydrology and Earth Systems Sciences*.

Strasser, U. and Prettenthaler Franz. (2013): Numerical model coupling between natural and economic sciences for estimating climate change effects on future skiing tourism: an integrative perspective. Planned for *Global Planetary Change*.

Wilcke R. A. I., Hanzer F., Marke T., Gobiet A., Strasser U., Effects of Quantile Mapping on Hydrological models, planned submission August 2013.

Planned poster presentations:

Strasser, U., Prettenthaler, F., Gobiet, A., Stötter, J., Kleindienst, H., Steininger, K., Damm, A., Hanzer, F., Köberl, J., Marke, T., Ragg, H.-J., Steiger, R, Wilcke, R., Töglhofer, C., Lang, T., Osebik, D., Zimmermann, F.M. and Leuprecht, A. (2013): Auswirkungen des Klimawandels auf die Schneedecke und den Skitourismus in Tirol und der Steiermark: Ergebnisse der ACRP-Projekte CC-Snow und CC-Snow II, abstracts of the 14th Austrian Climate day, BOKU, Wien.

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