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ORIGINAL PAPER

Climatic potential for tourism in the Black Forest, Germany — winter season

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Abstract Climate change, whether natural or human-caused, will have an impact on human life, including recreation and tourism among other things. In this study, methods from biometeorology and tourism climatology are used to assess the effect of a changed climate on tourism and recreation in particular. The study area is the Black Forest mountainous region of south-west Germany, which is well known for its tourist and recreational assets. Climate model projections for the 2021–2050 period based on REMO-UBA simulations with a high spatial resolution of 10 km are compared to a 30-year reference period (1971–2000) using the IPCC emission scenarios A1B and B1. The results show that the mean winter air temperature will increase by up to 1.8°C, which is the most pronounced warming compared to the other seasons. The annual precipitation amount will increase marginally by 5% in the A1B scenario and 10% in the B1 scenario. Winter precipitation contributes about 10% (A1B) and 30% (B1) to variations in annual precipitation. Although the results show that winter precipitation will increase slightly, snow days affecting skiing will be reduced on average by approximately 40% due to regional warming. Cold stress will be reduced on average by up to 25%. The result is that the thermal environment will be advanced, and warmer winters are likely to lead to an upward altitudinal shift of ski resorts and winter sport activities, thus displacing land-use currently dedicated to nature conservation.

Keywords Climatic tourism potential · Winter tourism · REMO · Black Forest · Highlands · Germany

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Introduction

Global warming in the twentieth and early twenty-first century amounts to about 0.9°C and will likely continue (IPCC 2001, 2007). This increase in air temperature is likely to be more pronounced in winter, thus snow cover and its duration as well as air temperature and other climate variables will be affected. Snow depth and its absence or presence is essential to the financial success of winter tourism in many regions (Koenig and Abegg 1997). Thus, the increased variability expected in the future may have significant repercussions for regional economies. Although stakeholders are aware of the impacts of climate change on a global scale, it is common to assume that these changes will take place only in the distant future. Given that typical resort management planning time frames currently consider only the next 5–10 years, this will have to be extended if such business is to remain competitive in the long term. Therefore, the question arises of what winter conditions are to be expected in the following 30–50 years. A wide range of methods have been employed to anticipate the consequences of future climate change for tourism, but few have focussed on aspects of the winter season other then on snow conditions. Clearly a more comprehensive and inclusive approach is desirable. For example, de Freitas (1990, 2003) has pointed out the need to consider tourism climate holistically using approaches that acknowledge all facets of the tourism climate, namely, aesthetic, physical, and thermal.

The Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung, BMBF) acknowledged the urgent need for action to protect different sectors of German society against climate impact (BMBF 2007). The BMBF identified 23 projects concerned with mitigation and 19 projects dealing with adaptation. One of these is the project “Climate Trends and Sustainable Development of Tourism in Coastal and Mountain Range Regions” (CAST). The current research is part of the CAST project and aims to find answers to how tourism in Germany might react to climate change. In this context, the Black Forest of Germany is of particular interest for several reasons. It is one of the most important areas of the country for tourism and recreation, attracting large numbers of visitors during all seasons. It is particularly attractive to tourists in winter because it is a large upland region where winter conditions are more attractive than elsewhere in Germany.

The Black Forest is located in the far south-west of Germany, a region that is expected to be one of the most affected by global warming. Under future climate conditions, snow can be reliably expected only above 1,500 m (Beniston 2003). Given that the highest elevation in the region is less than 1,500 m, any warming can be considered a threat to the viability of tourism in winter. To date, few studies have assessed this threat, the exceptions being Roth et al. (2005) and Schneider et al. (2009). With the above in mind, this research aims to assess the changed climatic amenity potential for tourism and recreation in a region heavily reliant on a range of climate-dependent activities. Methods are devised to comprehensively assess the full range of facets of climate relevant for tourism and recreation.

Data and methods

Model data

High resolution data for future regional climate scenarios have been generated using the regional climate model REMO of the Max Planck Institute for Meteorology in Hamburg (Jacob 2001; Jacob et al. 2007). The data have a spatial resolution of 10 km and hourly temporal resolution. The region covered by REMO encompasses Germany and the Alps (Fig. 1, left). Details of the study site are shown in Fig. 1 right, including the Upper Rhine Graben and the Vosges mountains. The analysis of relevant climate variables covers the time period 1961 to 2050 using the A1B and B1 emission scenarios (IPCC 2001). The 30-year mean for 1971 to 2000 is the base period for comparison with future climate projections running from 2021 to 2050. Three climate stations were selected for model validation. These are Titisee, Feldberg, and Freiburg run by the German Weather Service (DWD). Data used cover the time period 1961–1990.

Climatic assessment for tourism-related research fields

The method used acknowledges all facets of tourism climate, i.e. aesthetic, physical, and thermal (de Freitas 1990, 2003). The aesthetic facet includes sunshine/cloudiness, visibility, and day length. The physical facet involves rain, wind, snow, severe weather, air quality, and ultraviolet

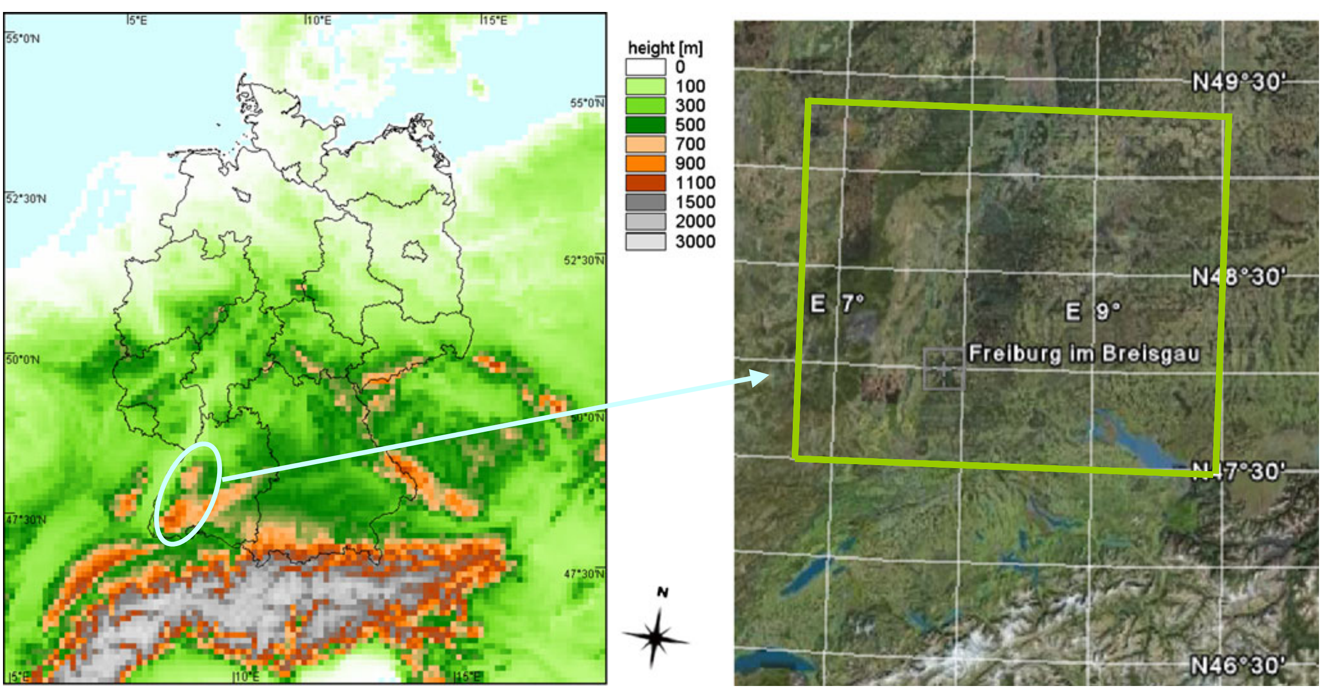

Fig. 1 Region covered by REMO (*left*), and region of interest including the Black Forest (*right*, Google Earth, modified)

radiation. The thermal facet is characterised by integrated effects of air temperature, wind, solar radiation, humidity, long wave radiation, and metabolic rate, which can be expressed by thermal indices that take into account body–environment energy balance measurements such as physiologically equivalent temperature (PET, Höppe 1999). All three facets are highly relevant to tourism and recreation (de Freitas 1990, 2003).

A comprehensive approach was taken to identify the various characteristics of the regional climate. The following lists the data used over the December–February (DJF) study period: mean PET, air temperature (Ta) and precipitation; number of days with cold stress (PET<0°C); number of days with cloud cover<four-eighths; number of days with fog, i.e. relative humidity >93 %; number of days with wind speed >8 ms^{-1}; number of snow days identified as snow water equivalent >5 cm; and number of days suitable for snow-making (Ta<−2°C). In addition, mean November–March (NDJFM) snow days and days suitable for snow-making were computed.

PET is calculated using the radiation and energy balance model RayMan (Matzarakis et al. 2007). REMO outputs snow data as snow water equivalent (SWE), which can be converted to a snow depth using the empirical approach of Brown and Mote (2009), where SWE greater than 5 cm corresponds to 22.6 cm for Germany. For snow-based activities such as Nordic skiing, snow-shoeing, etc., the Organization for Economic Co-operation and Development (OECD) recommends a snow depth greater than 30 cm (Agrawala 2007). However, several researchers (e.g. Beniston 1997; Breiling and Charamza 1999; Roth et al. 2005) have argued that 10 cm is sufficient for general purpose recreational activities, as opposed to specialized competitive sporting activities. Given that recreational activity takes place during daylight hours, data at 1400 hours Central European Time are used as representative of the “tourist day”, except in the case of precipitation and snow cover, where totals are used.

Results

Comparison between modelled and observed data

A comparison between modelled and observed data for the three selected stations is presented in Table 1. Given that uncertainties in the model output can be systematic, only relative changes are used in the future-climate analysis; i.e. data for 2021–2050 is compared to the reference period 1971–2000 expressed as anomaly. Unless explicitly stated, all changes presented are significant at the 95 % confidence level.

The comparison between modelled and measured data reveals large Ta differences of 4–7°C (Table 1). This is due to an underestimation of the effect of topography. Using a generic lapse of +0.65°C per 100 m of elevation, however, an overestimation of 4°C still remains at Feldberg (1,500 m); thus, the model overestimated warming. These findings are also reflected in the frequency distribution of Ta, which shows a slight overestimation above 19°C and a slight underestimation below 19°C at low altitudes. The threshold is about 11°C for high-altitude regions (Fig. 2). This has little relevance to the winter season, except for the derivation of days suitable for snow-making, which is affected by systematically higher values. A pronounced discrepancy is also seen at 0°C due to modelled melting and freezing processes in the soil (Fig. 2).

PET is also overestimated by REMO as much as 2–3°C and shows a similar distribution as Ta, except that the discrepancy at 0°C is less marked. Significant differences are clearly evident

Table 1 Comparison of mean annual air temperature (Ta), physiologically equivalent temperature (PET), precipitation (RR) and the number of snow days and days with cold stress between modelled (REMO) and measured (German Weather Service: DWD) data examined for the time period 1961–1990

Parameter	Region					
	Freiburg		Titisee		Feldberg	
	Modelled (228m)	Observed (269m)	Modelled (935m)	Observed (846m)	Modelled (1,076m)	Observed (1,493m)
Ta (°C)	14.6	10.7	11.0	5.6	10.0	3.3
PET (°C)	14.5	11.9	10.6	9.0	10.4	−1.1
PET<0°C (days)	51	54	100	97	110	201
RR (mm)	1,150	955	1,046	1,329	1,640	1,909
Snow days (snow cover >30 cm)	17[a]	0	48[a] (38)	39	65[a] (105)	122

[a] Modelled snow cover is given in snow water equivalent and corresponds to approximately 23 cm snow depth in Germany (Sturm et al. 1995; Brown and Mote 2009). According to Witmer (1986), a correction of 9.91 snow days per 100 m altitude is applied and is given in brackets

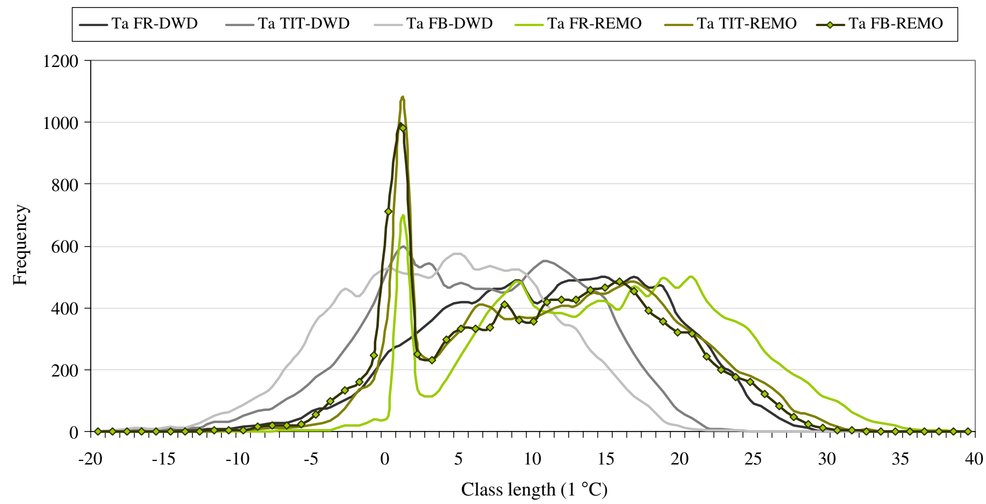

Fig. 2 Frequency distribution of Ta over the time period 1961–1990 based on climate (DWD) and modelled (REMO) data for three stations in the Black Forest: *FR* Freiburg, *TIT* Titisee, *FB* Feldberg

for high-altitude regions such as the Feldberg, with differences of about 10°C. The differences are still large when values are extrapolated for 1,500 m using the generic lapse rate (+0.65°C per 100 m). Although a correction of air temperature can be applied, this is not the case for global radiation or relative humidity. As PET accounts for the integrated thermal effect of these variables, a correction factor for PET as a whole is not possible. Differences between modelled and measured PET are also reflected in the number of days with cold stress (PET <0°C). While the results show a very good agreement between modelled and measured data at low- and mid-altitude regions, they are clearly underestimated by almost 50% elsewhere (Table 1). Applying a linear extrapolation to 1,500 m, the number of days with cold stress is 139 compared to 200 days using climate station (i.e. measured) data.

Precipitation is underestimated by REMO by 15–20% in higher altitudes and overestimated by 20% in lower altitudes (Table 1). The number of snow days is hugely overestimated in the foothills (cf. Freiburg), whereas it is underestimated at higher altitudes. According to Witmer (1986), a correction of 9.91 days per 100 m altitude is appropriate. Using this correction factor, the modelled results are in better agreement with the measured data. At Feldberg, modelled results give 105 snow days compared to 122 days using measured data. At mid-altitudes, for example Titisee, the number of modelled snow days is 38 compared to 39 days using measured data. Comparing modelled and measured results, the number of days suited for snow-making is somewhat underestimated by REMO (not shown). As noted above, this is due to an overestimation of Ta (Table 1).

Future-climate analysis

Changes in mean DJF Ta are between 1.3°C and 1.8°C for the scenario A1B (Fig. 3, Table 2). In this context, higher regions (above 600 m) might experience an increase of up to 1.4°C, while Ta in lower lying regions (< 600 m) might increase by 1.8°C. In B1, changes in mean DJF Ta are somewhat lower, from 1°C to 1.6°C.

REMO shows changes in mean DJF PET between 1.2°C and 1.8°C (A1B) with larger changes at lower altitude regions and small changes at high altitude regions, respectively. This winter warming is more pronounced compared to changes in the annual mean, which shows changes between 0.9°C and 1.1°C. In B1, overall changes in PET are between 0.9°C and 1.4°C, i.e. lower than the results for A1B (Table 3). Differences between present and future PET estimates are somewhat higher in the northern part of the Black Forest compared to the middle and southern parts. By 2050, estimates are that cold stress will decrease by −6 to −14 days (A1B) and −4 to −12 days (B1), respectively (Fig. 4), i.e. there will be a relative reduction of about 20–25% at altitudes below 900 m and of 15–20% at altitudes above 900 m.

Projections of conditions through to 2050 show that annual precipitation will increase by 5% (A1B) and 10% (B1) respectively; while winter precipitation contributes to about 10% (A1B) and 30% (B1) of the change in annual precipitation (Table 3). Changes in the precipitation pattern (A1B) reveal a slight decrease in the outmost northern area of the Black Forest (≈ 20 mm) and a slight increase in the central part and in the foothills. A stronger increase (≈ 40 mm) is projected to occur in the outermost areas of the southern Black Forest region (Fig. 5). Changes in B1 are generally higher compared to A1B. A large increase of about 100 mm might be expected in both the northern and southern areas of the Black Forest. In the remaining study site, an increase of about 40 mm might be expected (Fig. 5).

Like other climatic variables, snow cover also varies naturally. The climate station data shows that over the past 45 years there were some years with snow accumulation of less than 30 cm (e.g. 1961, 1967, 1972, 1975, the 1990s,

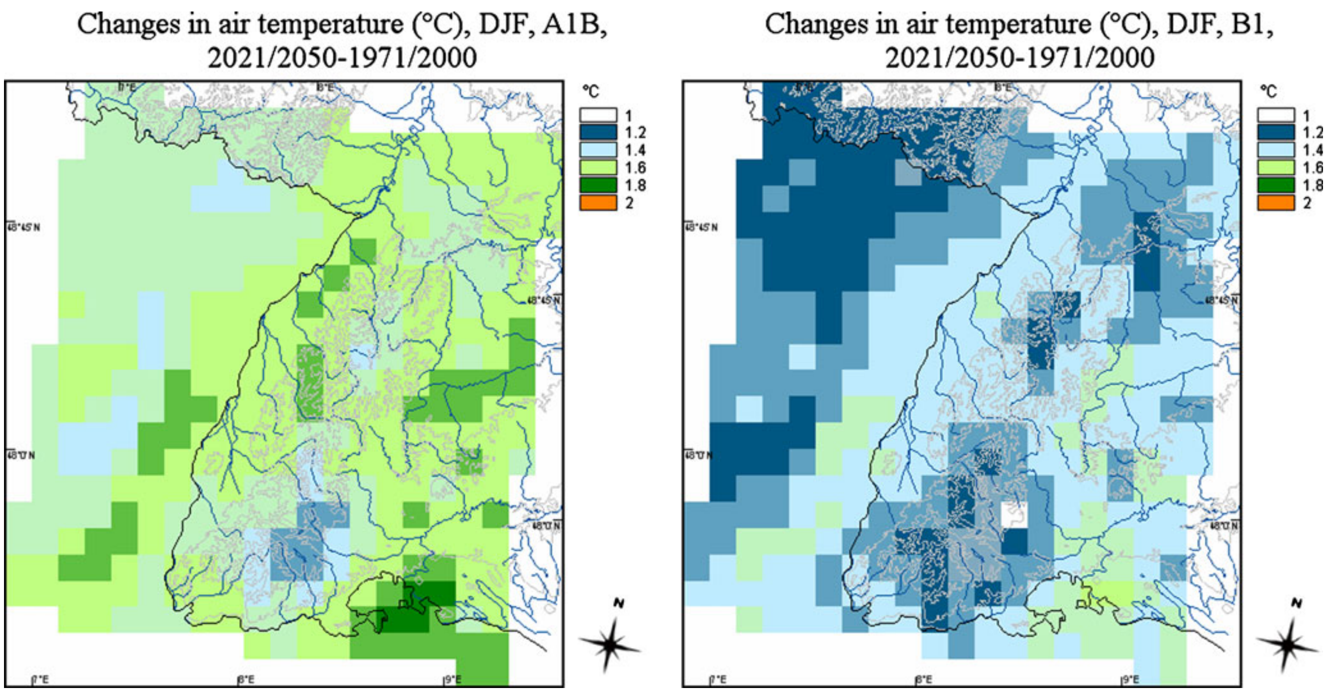

Fig. 3 Changes in winter (DJF) air temperature (°C) for the Black Forest region for the period 2021/2050–1971/2000 based on the SRES scenarios A1B (*left*) and B1 (*right*)

2006, and 2007) and years with more than 30 cm (e.g. 1963, 1965, 1968, 1970, 1973, 1981, and 2008). Averaged over 30 years (1961–1990), measured snow data range from 15 cm to 110 cm for the period December–April (Table 2, Fig. 6). The number of days with adequate snow depth (snow cover >30 cm) is less than 8 days at 900 m and less than 22 days at 1,500 m during low-snow winters; while there are between 100 and 186 days during high-snow winters. The months with the largest snow accumulation and number of snow days are January, February, and March (Table 2). Currently, the higher-altitude ski and winter sport regions, for example Feldberg, Belchen, Kandel, and Rohrhardsberg, have at least 100 snow days per year, which, according to Abegg (1996), defines reliable snow conditions for winter sports.

The model results suggest that snow cover will decline by 30–40%. Snow days will be reduced by up to 21 days (A1B) and 17 days (B1), respectively (Fig. 7) during an "enhanced" winter season (NDJFM). Similar results are given for the DJF period. Although the largest changes might be expected at altitudes between 601 and 900 m, the largest relative changes expressed as a percentage will occur at altitudes below 600 m above sea level (Fig. 8). By 2050, the number of days suitable for snow-making will be reduced by about 25%.

Data output from REMO for cloud cover, fog and wind speed that comprise the aesthetic and physical facet of tourism climate showed that there were only small changes between present and future climate; but these changes are not significant at the 95% confidence level.

Table 2 Monthly snow depths (cm) in Feldberg, Hinterzarten and Titisee, located in the southern part of the Black Forest, based on measured data in the years indicated

Month	Feldberg (1,493m)		Hinterzarten (883m)		Titisee (846m)
	1961–1990	1971–2000	1961–1990	1971–2000	1961–1990
November	14.5	15.0	4.7	5.1	3.2
December	45.5	35.8	18.8	16.5	15.6
January	76.7	53.1	28.4	23.3	27.4
February	105.6	76.6	35.8	30.1	32.2
March	110.8	83.7	29.4	22.2	24.5
April	79.3	64.6	7.2	5.2	4.1

Table 3 Annual and DJF changes in Ta, PET, precipitation and the number of snow days and days with cold stress. Changes are indicated as differences between 2021/2050 and 1971/2000 for the A1B (*left column*) and B1 (*right column*) scenario

Parameter	Δ A1B (2021/2050–1971/2000)	Δ B1 (2021/2050–1971/2000)
Ta (year)	+0.9 to +1.1°C	+0.2 to +0.6°C
Ta (DJF)	+1.3 to +1.8°C	+1.0 to +1.6°C
PET (year)	+0.8 to +1.2°C	−0.2 to +0.3°C
PET (DJF)	+1.2 to +1.8°C	+0.9 to +1.4°C
Cold stress (year)	−9 to −19 days	−3 to −13 days
Cold stress (DJF)	−6 to −14 days	−4 to −12 days
Precipitation (year)	+5 %	+10 %
Precipitation (DJF)	+10 %	+30 %
Snow days[a] (DJF)	−6 to −17 days	−3 to −16 days
Snow days[a] (NDJFM)	−6 to −21 days	−3 to −17 days

[a] Snow days are defined as snow water equivalent (SWE) exceeding 5 cm, which corresponds to approximately 23 cm snow depth in Germany (Sturm et al. 1995; Brown and Mote 2009)

Discussion

Model uncertainties

Climate models and models in general are commonly afflicted with uncertainties because complex interactions within the Earth–atmosphere system cannot be parameterized in detail (Rial et al. 2004; Reichler and Kim 2008). Thus, assumptions are required to model the climate as realistically as possible, taking these limitations into consideration. Characteristic phenomena on a micro or meso scale are not resolved because regional models with a mesh grid of 10 km are still too coarse to portray such small effects. Sources of uncertainty in climate projections are, for example, water vapour, clouds, soil moisture, and ice/snow albedo. Clouds have in particular an impact on climate. They can either — depending on their type and height — cool down or warm the atmosphere. Clouds also control radiation fluxes and precipitation, among other things. Therefore, clouds pose a serious challenge to climate modeling. In that context, model outputs have to be handled, interpreted and discussed carefully, especially for people who are not familiar with model results.

Although the method used is in fact appropriate and applicable, it is limited by model results due to the uncertainties mentioned above. These results show that temperature (Ta and PET) and precipitation are overestimated by the model. Thus, REMO simulates the climate as too wet, except for the higher low mountain range (too dry; cf. Beniston et al. 2007). The snow component is underesti-

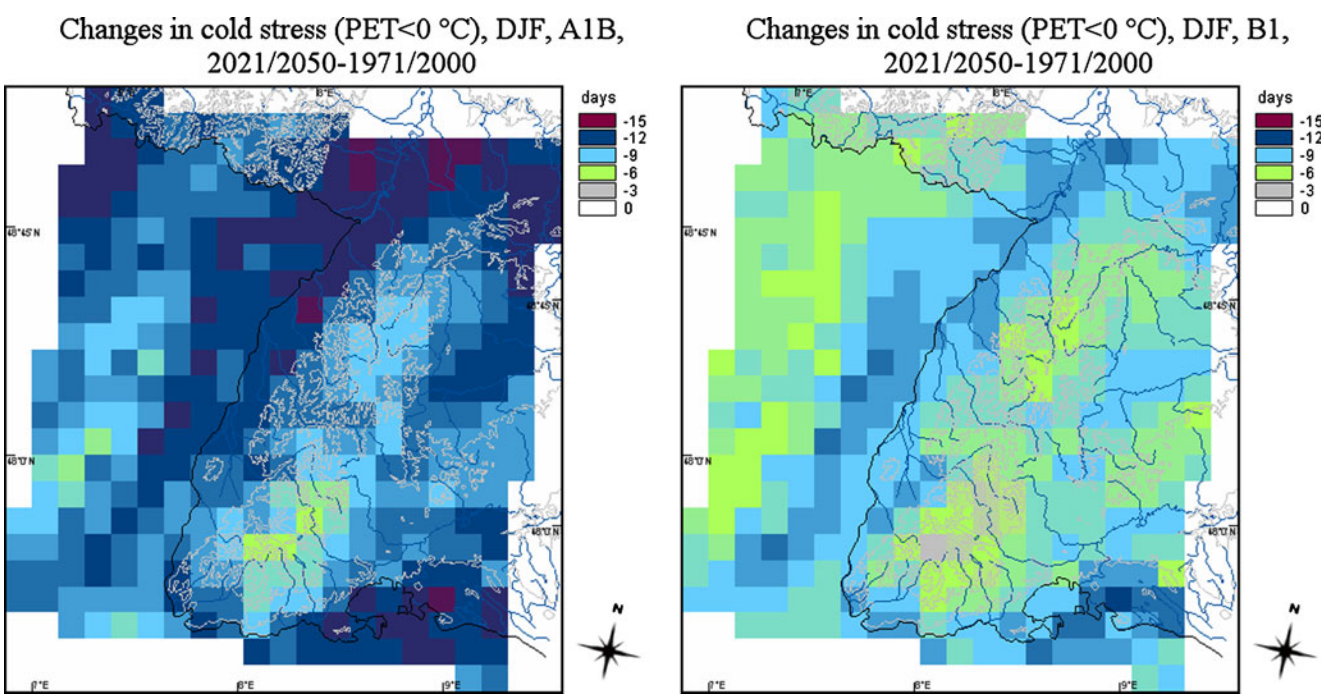

Fig. 4 Changes in winter (DJF) cold stress (PET<0°C) for the Black Forest region for the period 2021/2050–1971/2000 based on the SRES scenarios A1B (*left*) and B1 (*right*)

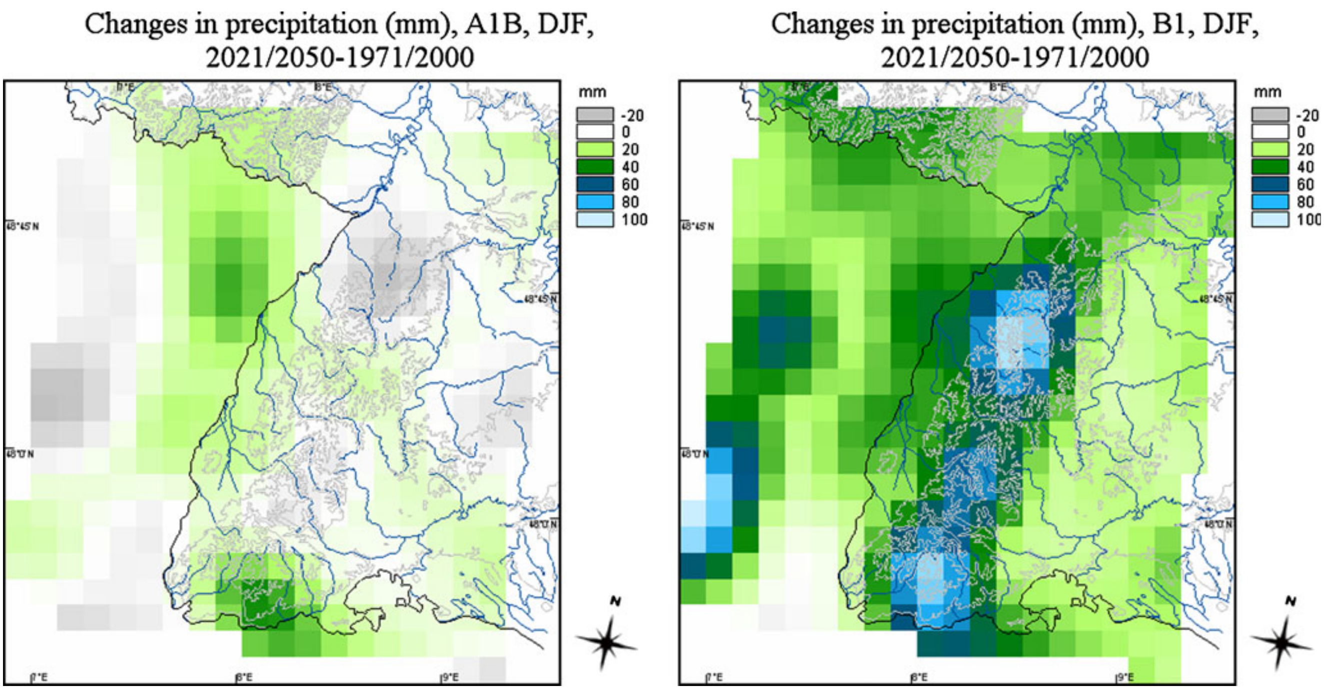

Fig. 5 Changes in winter (DJF) precipitation (mm) for the Black Forest region for the period 2021/2050–1971/2000 based on the SRES scenarios A1B (*left*) and B1 (*right*)

mated by the model. This may be due to air temperature, which rises rapidly in springtime and thus melting processes set in earlier, among other things. The month of March in particular shows the largest discrepancies between models and measurements. March is usually one of the snow-richest months of the year in the study site, while the model shows nearly no snow depth in March for the reference period. Wind and cloud conditions are difficult to model, reflecting a complex of problems (Woth et al. 2006). Given that PET is affected by a multiplicity of variables, a correction factor as a whole is not possible. A detailed analysis would be welcome because the thermal component plays a major role in assessment of climate for tourism (Matzarakis et al. 1999). For example, an underestimation of wind speed can reduce winter PET, while an overestimation of Ta and an underestimation of wind speed can vastly increase PET during the warm period (Matzarakis and Endler 2010). Precise information would be preferable, especially if adaptation strategies are to be employed (BMU 2009; Bartels et al. 2009; Matzarakis et al. 2009; Mahammadzadeh et al. 2009).

Winter warming and its consequences for the Black Forest

By 2050, a winter warming of up to 1.8°C will continue to decrease snow depth and its duration as well as days

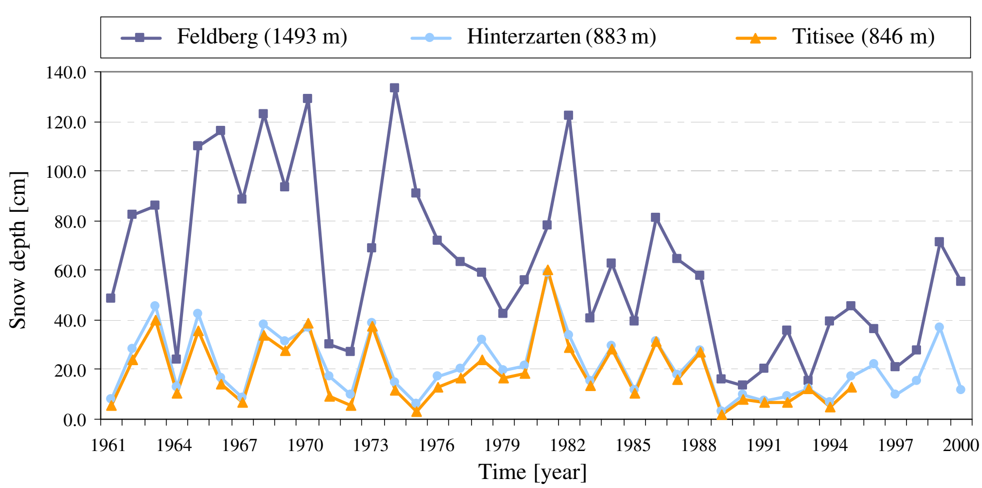

Fig. 6 Mean snow depths at Feldberg, Hinterzarten and Titisee located in the southern part of the Black Forest averaged over the months of November–March. The time series is based on measured data ranging from 1961 to 2000, except for Titisee, which extends only to 1995

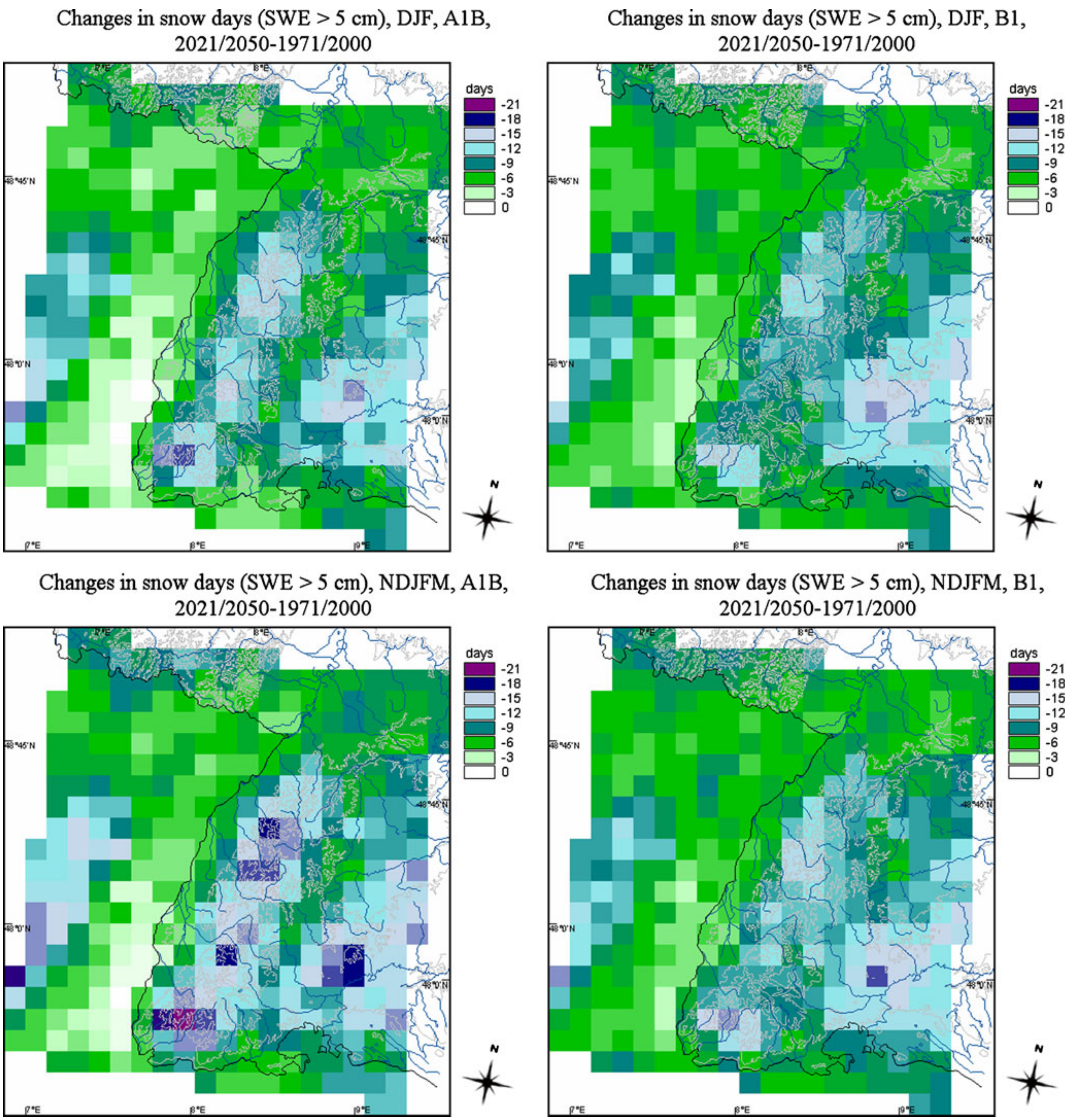

Fig. 7 Changes in winter (DJF) snow days (SWE>5 cm) for the Black Forest region for the period 2021/2050–1971/2000 based on the SRES scenarios A1B (*upper panel*, *left*) and B1 (*upper panel*, *right*); changes in "enhanced" winter (NDJFM) ski potential (snow days) for the same period for A1B (*lower panel*, *left*) and B1 (*lower panel*, *right*)

suitable for artificial snow-making, with maximum changes expected in the northern part of the Black Forest. A reduction in snow also means a reduction in positive snow-albedo feedback, which will consequently bring about milder winter temperatures (Giorgi et al. 2004). But, in a warmer climate, snowfall is limited by air temperature, especially in low-altitude regions. Beniston (1997) found for the Alpine region that anomalously warm winters have resulted from the presence of very persistent high pressure episodes during wintertime that determine the accumulation and amount of snowfall. Uhlmann et al. (2009) pointed out that it is not necessarily always the same type of winter that results in the greatest amount of snow. But on average, cold winters are the sparsest season in terms of snow since cold

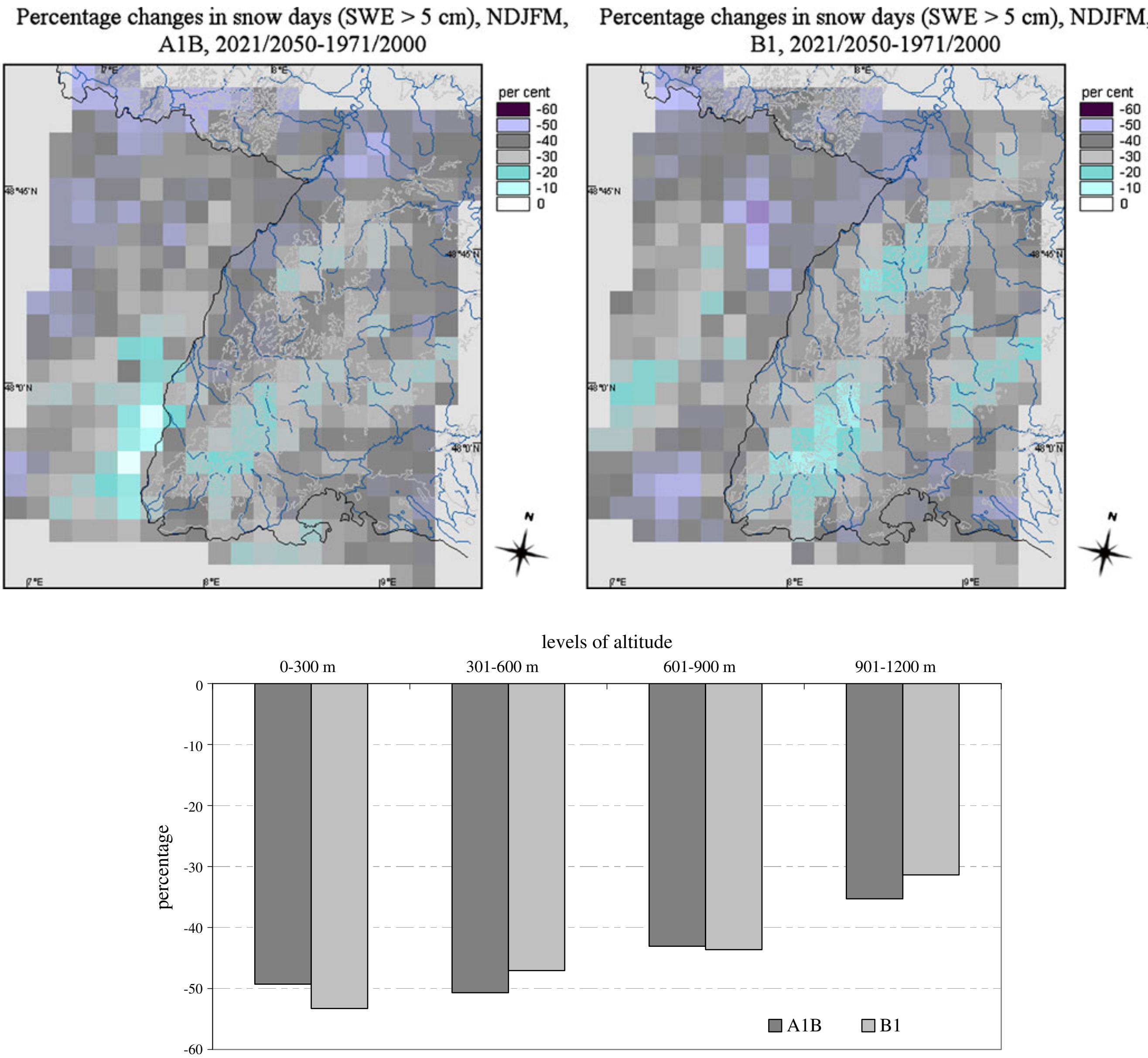

Fig. 8 Percentage changes in snow days (SWE>5 cm) for the Black Forest region for the “enhanced” winter season (NDJFM) for the period 2021/2050–1971/2000 based on the SRES scenarios A1B (*upper panel*, *left*) and B1 (*upper panel*, *right*) and maximum changes in snow days in percent as a function of altitude for same scenarios and the same period (*lower panel*)

air is usually much drier, whereas warm winters are the snow-richest, owing to more moisture potentially leading to more abundant precipitation. In addition, a more westerly circulation is expected. From this it follows that the Black Forest is even more affected because the Vosges Mountains in the west act as a barrier, reducing precipitation and snowfall in the northern part of the Black Forest as well as to the windward side. Even if wind circulation is more northwesterly, the more western mountain ridges will impact on snow conditions, in particular those of the high mountains of the Black Forest, which are in the leeward side; this will mean less snow because the air has already lost moisture. Therefore, higher temperatures and a changed circulation tend to significantly affect the climate of the Black Forest. From the early 1980s onwards, a reduction in monthly mean snow cover over the last 10 years has already been recorded in the Black Forest, in particular from January to March. In the future, altitudes below 600 m with their already reduced snow depths will have particular difficulties in attracting tourists and recreationalists for snow sporting activities. Sauter et al. (2009) examined local snow distributions and their future changes in German low mountain ranges using a “dry” and “wet” scenario. They found similar results for the Black Forest region. By 2050, snow days will be reduced by from 22 to up to 44% above 1,200 m, and by 57–66 % at altitudes between 500 m and 1,000 m (Sauter et al. 2009; Schneider et al. 2009). It can be deduced that the prospective ski potential is hypothetically experienced more at higher altitudes; the snow line will increase up to 1,500 m and reliable snow conditions will no longer occur naturally in the Black Forest. But this does not imply an end to winter sports in this region. There might be still some winters with snow, but low-snow and snow-less winters will become more frequent as has happened in the recent past. For example, the winter of 2008/2009 was profitable for the tourism industry, despite the winter being warmer than the long-term mean of 1961–1990.

Tourism is one of the major industrial sectors in Germany, accounting for 8% of GDP. Tourism in winter is more important for the Black Forest region than tourism in summer, although the overnight stays and revenues during winter have decreased slightly recently. To assure snow further into the season, artificial snow-making has been used since 1980, but its use is limited by a warmer climate; rising costs might not be justified even by the revenues from tourism in winter (Becken and Hay 2007). According to Schmidt (2010), snow days where artificial snow is included will decline by 45% at 1,400 m by 2100. At Feldberg, 100 snow days per winter season will no longer be assured. Thus, artificial snow can only be a short-term solution, although considerable investment involving snow-making facilities to assure winter sporting activities has already occurred. The question arises of what can be done if snow — artificial snow included — is no longer the key factor in tourism in winter in the Black Forest? The implication would be that lower altitude ski resorts would close, and tourists either ski less often or migrate to higher regions of the Black Forest or to regions where snow cover is more reliable, for example the Alps, as proposed by Bürki et al. (2003). Development of higher-altitude regions is not possible in the Black Forest due to topography, among other factors.

However, not only low but also high mountain range regions are already affected and continue to be affected by a warmer climate. Data from satellite monitoring from 1966 to 2005 show that monthly snow cover extent in the northern hemisphere is decreasing by 1.3 % per decade (UNEP 2007). Lowland areas of Central Europe are characterised by recent reductions in annual snow cover duration of about 1 day per year (Falarz 2002). In the Austrian Alps, snow duration at altitudes between 1,000 and 1,500 m has been reduced by 1–2 weeks in the last 10 years (Kromp-Kolb and Formayer 2001). Today, 609 of 666 Alpine ski resorts (i.e. 91%) are naturally snow reliable assured for elevations up to 1,500 m (Beniston 2003; Agrawala 2007). Besides Canada and North America (e.g. Hamilton et al. 2003; Scott et al. 2003, 2006a, b), the Alps are the most studied region for tourism in winter (e.g. Abegg 1996; Koenig and Abegg 1997; Breiling and Charamza 1999; Elsasser and Messerli 2001; Elsasser and Bürki 2002; Hantel and Hirtl-Wielke 2007; Steiger and Mayer 2009; Beniston et al. 2003a, b). The Alps represent a competitive destination for the Black Forest as they are not so far away. Depending on the altitude of a ski region, different ski areas are more or less snow reliable, which can assure a continuous winter season from December to April (Steiger 2007a). Today, snow-making can guarantee snow reliability at elevations above 1,000 m (December–February) for 90% of all winters; for example, some Austrian ski slopes have already covered more than 80% of their slopes (Steiger and Mayer 2009). With the line of snow-reliability rising to 1,500 m as is projected to occur by 2030–2050, the number of snow reliable ski resorts drops to 63%. A rise to 1,800 m results in 44% of larger ski resorts qualifying as snow-reliable (Bürki 2000; Teich et al. 2007). According to the latest OECD report on *Climate Change in the European Alps* (Agrawala 2007) Germany might be the most vulnerable Alpine country, with a reduction in snow-reliability of up to 40%. Snow-making possibilities will be reduced by up to 25% (Tepfenhart et al. 2007). In contrast, Switzerland, where snow conditions for skiing seem reasonably good on average, is less affected (Agrawala 2007; Müller et al. 2007). Lower-altitude Swiss regions are certainly as affected as elsewhere, but they have started to lead the way in matters of adaptability and adaptation by retreating ski resorts, for example. Adaptability to climate change, such as moving away from ski tourism depends rather on the awareness of problems (Arnell and Delaney 2006) and the size of the company than on vulnerability and uncertainty. Awareness already exists in some companies in the Black Forest, but information about precise impacts, which companies require, is difficult to obtain.

One example of such an effect that may threaten local economies is on local cable cars (Harrer 2003). For example, in the Swiss Alps, only a few cable cars succeed in being profitable during summer. Without a “good” winter, most are not financially able to survive (Steiger 2007b). In this context, the focus on short-term profits is understandable as they can be estimated and used for further planning in a better way.

Even if the end of the time period studied (2050) still seems to be quite far away, climate warming is already taking place and increases the difficulties in the tourism sector. For that reason, different adaptation measures and future strategies are necessary on both the short- and the long-term. Indeed, a single-sided tourism management that includes only ski tourism could be highly counterproductive (Agrawala 2007) as discussed earlier. However, a decisive factor for success is that alternatives are a permanent part of the winter offering and not only a short-term alternative (Swoboda 1996).

Nature as the new key factor in winter tourism

Natural beauty and climate are of universal importance in defining destination attractiveness (Hu and Ritchie 1993). Intact nature and environment are highly relevant for a majority of Germans (84%), contributing to satisfaction during their vacation. In addition, human cardiovascular systems are affected in a positive way (Swoboda 1996). If snow is no longer the key factor in tourism in winter, nature as a resource can be used to develop and open up nature-based offerings for experiences (SfTE 2005). Hiking in winter is becoming increasingly popular. Apart from a simple network of roads, "health paths" could be employed. If the thermal environment changes for the better, for example a decrease of cold stress, nature-based and health tourism programs might be successfully implemented. However, other climate variables such as precipitation, wind speed, fog, or sunshine influence human perception of a given destination. Given that winter precipitation is projected to increase in the Black Forest, this could be a negative stimulus for tourists and recreationalists. No statement about changes in wind speed, fog and sunshine can yet be made. Another resource of a destination is nature and landscape, as mentioned earlier. These resources can be affected by direct and indirect climatic changes, such as storm losses or changes in vegetation (Parmesan and Yohe 2003). In addition to a climatic impact, an anthropogenic impact on natural environment can be noted. Nature-based activities are becoming increasingly popular (Garbe et al. 2005), accompanied by an increase in natural development, in particular at higher altitudes. Regions with a high significance for nature conservation have a high impact on tourism, given that the Black Forest is one of the most important tourist and recreation destinations in Germany. About 18% of the Black Forest is legally protected and is designated in Natura 2000. The southern part of the Black Forest is formed by one of the most extensive (4,226 ha), highest located, and oldest nature reserves in Baden-Württemberg since 1937, with particular species such as capercailzies (*tetrao urogallus*). The largest nature park in Germany is located in the central and northern part of the Black Forest, where about 30.4% of the nature park area is protected. The frequency of visitors shows an annual, slightly increasing tendency (Garbe et al. 2005). A focus on more nature-based tourism can be regarded as the second category of adaptation strategies in *Alternatives to ski tourism* drafted by Bürki et al. (2003). In particular, nature parks are consistent with the purposes of tourism and nature and offer the kind of recreation humans are looking for. However, the potential for diversification when faced by regional conditions ought not to be overestimated. It would be unlikely that snow activities could completely be replaced by non-snow offerings, because additional offers come second, and are today not usually decisive in the choice of a destination in winter, with snow sporting activities still taking first place. A focus on year-round tourism would be profitable as seasonality is reduced and the main travel season is still summer. Additionally, tourism in summer is steadily increasing and has greater potential revenues than tourism in winter. However, institutional seasonality is admittedly quite decisive (Butler 1994). Dividing a destination up into favourable and unfavourable regions ought not to depend solely on climatic conditions. Alternatives to traditional winter tourism are conceivable and possible in the Black Forest as elsewhere. However, rethinking and appropriate marketing strategies ought to be strengthened, for example by looking again at available on-site possibilities.

Conclusion

Most climate studies dealing with winter tourism focus on the snow component or, in more general, impact assessments on air temperature and precipitation. A more comprehensive approach is used in the present study, with the Black Forest region used as a case study. To assess winter conditions for tourism in the future, high resolution simulations generated by the regional climate model REMO were analysed for the 30-year period 2021–2050 and compared to the reference period 1971–2000 using the SRES A1B and B1. The results show a maximum winter warming of +1.8°C, which means that the number of cold stress days will decline. Warmer winters will, however, result in a significant reduction in winter sporting opportunities; snow days will decline by up to 50% and the number of days suitable for snow-making will be reduced by up to 25%. In this context, highest relative changes might be expected at altitudes below 600 m. Although winter precipitation will increase by 10% (A1B) and 30% (B1), respectively, precipitation will be in the form of rain rather than snow due to winter warming.

The future prospects for tourism in the winter in mountainous regions such as the Black Forest given a changing climate are fraught with uncertainty. On the one hand, because winter sports rate highly as drawcard for the tourism industry, new investment in technical equipment such as snow-making will be a high priority to assure the profitability of the industry. Low mountain ranges are more vulnerable since the snow line will rise above 1,500 m. Moreover, there will be the risk of tourists migrating to regions where snow cover is more reliable, for example the Alps. On the other hand, technical equipment can only be a short-term solution, at least for as long as climatic conditions remain within the limits in which adaptation is possible. In order to remain competitive in this highly challenging marketplace it is crucial to develop new medium- to long-term strategies such as snow-independent winter activities and year-round tourism. Thus, snow might no longer be the key factor in tourism in winter, as nature-based activities become increasingly popular. The appeal of the landscape itself may become a sufficient resource base on which to develop a tourism industry. However, a change to a higher intensity of nature-based activities could put the environment under pressure. Indeed, tension between tourism and nature conservation already exists, and close cooperation will be required in order to pursue their respective objectives, which may be seen to be in conflict.

In a companion paper (Endler and Matzarakis 2010), the results of a further regional climate model, the CLM – climate version of the Lokalmodell (Steppeler et al. 2003; Böhm et al. 2006) are analysed, discussed and compared with results obtained by REMO.

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