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ORIGINAL PAPER

# Vertical gradient of climate change and climate tourism conditions in the Black Forest

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**Abstract** Due to the public discussion about global and regional warming, the regional climate and the modified climate conditions are analyzed exemplarily for three different regions in the southern Black Forest (southwest Germany). The driving question behind the present study was how can tourism adapt to modified climate conditions and associated changes to the tourism potential in low mountain ranges. The tourism potential is predominately based on the attractiveness of natural resources being climate-sensitive. In this study, regional climate simulations (A1B) are analyzed by using the REMO model. To analyze the climatic tourism potential, the following thermal, physical and aesthetic parameters are considered for the time span 1961–2050: thermal comfort, heat and cold stress, sunshine, humid–warm conditions (sultriness), fog, precipitation, storm, and ski potential (snow cover). Frequency classes of these parameters expressed as a percentage are processed on a monthly scale. The results are presented in form of the Climate-Tourism-Information-Scheme (CTIS). Due to warmer temperatures, winters might shorten while summers might lengthen. The lowland might be more affected by heat and sultriness (e.g., Freiburg due to the effects of urban climate). To adapt to a changing climate and tourism, the awareness of both stakeholders and tourists as well as the adaptive capability are essential.

**Keywords** Physiologically equivalent temperature · Climatic tourism potential · REMO · CTIS · Low mountain ranges

## Introduction

The relationship between tourism and climate has been studied for a long time. In the 1970s, applied climatologists examined the climatic thresholds that defined the season length for a wide range of tourism activities (Besancenot et al. 1978; Yapp and McDonald 1978). In the 1980s, biometeorologists studied how climatic variables affected the physical comfort of tourists and developed rating systems to evaluate and compare the climates of tourism destinations (Mieczkowski 1985; Besancenot 1989; Harlfinger 1991). Some types of tourism require very specific climate conditions, for example beach tourism, winter sports, or health-wellness tourism. Climatic conditions and their suitability to tourism can differ at a microscale, e.g., from one side of a mountain to the other, within a range of a few kilometres according to altitude, or even at a smaller scale under the influence of human developments (e.g., urban heat island) or tourism infrastructure. The tourism industry and destinations are clearly sensitive to climate variability and change and are greatly influenced by the local environment, its climate and its climate-influenced natural resources (Becken and Hay 2007). In this context, mountain regions are important destinations for global tourism (OECD 2007). Snow cover and pristine mountain landscapes are the principal attractions for tourism in these regions. At the same time, these characteristics are the ones that are most vulnerable to climate change (Beniston 2003). Thus, mountains represent unique sites for the detection of climate change and the assessment of climate-related impacts. To

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what extent will recreation, tourism activity, and leisure still be assured in low mountain ranges in the future? In the course of climate change, global and regional warming will affect particularly the winter sports season. According to the Fourth Assessment Report of the IPCC (2007), an increase in air temperature is perceived mainly in the winter months. Mountain ranges are especially vulnerable to climate change, particularly snow conditions. 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 characterized by recent reductions in annual snow cover duration of about 1 day per year (Falarz 2002). For recent climate conditions, 91% of the Alpine ski resorts are naturally snow reliable. These reliable snow conditions are assured for elevations up to 1,500 m. For every degree increase in air temperature, the snow line will rise by about 150 m (Beniston 2003). Thus, the bottom snow line of natural snow assurance will rise up to 1,200 m in Bavaria and 1,350 m in Swabia, respectively. Hence, Germany will be the country in the Alps experiencing the highest impact of climate change with a decrease in naturally snow reliable ski regions by approximately 40% (OECD 2007). Thus, low mountain ranges such as the Black Forest may also be vulnerable to climate change (Roth et al. 2005; Zebisch et al. 2005). Winter sports and ski tourism might be only practicable on the top of the mountains. Additionally, there might be a conflict concerning land use and tourism activity.

Considering the summer season, however, the Black Forest may also be affected by regional warming in a positive way. Increasing temperatures may result in a rise of beneficial climate conditions as well as tourists' outdoor activity over a longer time period. Thus, we can reason that both winter and summer tourism are affected by climate change. But which specific climatic changes are to be expected during summer and winter in the Black Forest? There are only a few studies that deal with climate change and tourism (especially winter tourism) in the Black Forest (e.g., Roth et al. 2001, 2005; Zebisch et al. 2005). The issue of climate change and summer tourism has so far not been discussed at all in scientific literature. There are two regional studies dealing generally with climate change in Baden-Württemberg. In the project KLIWA (*Climate Change and Water Management*) that focused on regional climate change in Bavaria and Baden-Württemberg (Germany), climate simulations (B2, IPCC 2001) were evaluated for the period 2021–2050 based on both dynamical (REMO, 18×18 km) and statistical models (STAR: Werner and Gerstengarbe 1997; WETTREG: Enke 2003). Each model runs with the same general conditions being implemented by the coupled global model ECHAM4/OPYC3 (KLIWA 2006). Another regional study focused on climate change, impacts, risks, and adaptation considering, e.g., human health, agriculture, forestry, and tourism in Baden-Württemberg (KLARA) was conducted by the Potsdam Institute for Climate Impact Research (PIK) and the Regional Office for Environment Protection Baden-Württemberg. The statistical regional model STAR was used (Werner and Gerstengarbe 1997). The analysis compared future climate conditions (2001–2055) to the reference period (1951–2000) based on IPCC 2001 (Stock 2005). The results are not based on as fine a resolution as is needed for applied tourism purposes. Consequently, we reflect on climatic changes related to tourism, especially for outdoor activities, for both winter and summer seasons by using modeled human–biometeorological data and not just air temperature on a regional scale.

The paper is divided into the following sections: after a short description of the study area, the meteorological data and the applied method are outlined. In the subsequent section, the results for variations of the physiologically equivalent temperature and precipitation as well as the integral evaluation for tourism purposes are presented. Afterwards, a discussion is followed by the conclusions.

## Study area

The Black Forest is the Germany's major low mountain range located in the Federal State of Baden-Württemberg in the southwest of Germany (Fig. 1). It ranges from NNE to SSW with a length of about 166 km from Karlsruhe-Durlach to Bad Säckingen. Its width varies between 30 to 60 km and its total area measures 6,000 km$^2$. The averaged afforestation amounts to 66% and is much higher than the averaged afforestation of Germany with 30% (wilmanns 2001). The climate of the Black Forest belongs to the climate of low mountain ranges and depends on topography, altitude, exposition, latitude, and longitude. Changes in climate conditions are limited in altitude. Due to the distance to the Atlantic, the Black Forest is located in the transition zone of marine-continental climate and belongs to the most extensive oceanic influenced low mountain ranges in Germany. The Black Forest is one of the most favored travelling destinations in Germany. The largest intensity of visitors and number of overnight stays are recorded at several locations in the southern Black Forest, e.g., in Feldberg and Hinterzarten. Hence, tourism is a major industrial sector, and the economic situation indirectly depends on climate and climate change. However, the economic development is impeded by its low mountain range character. Winter tourism is still more important than summer tourism. The German Head Office for Tourism (DZT, Deutsches Zentrum für Tourismus) has planned a winter campaign with the objective of also promoting Germany as a winter destination in the future. Besides, the

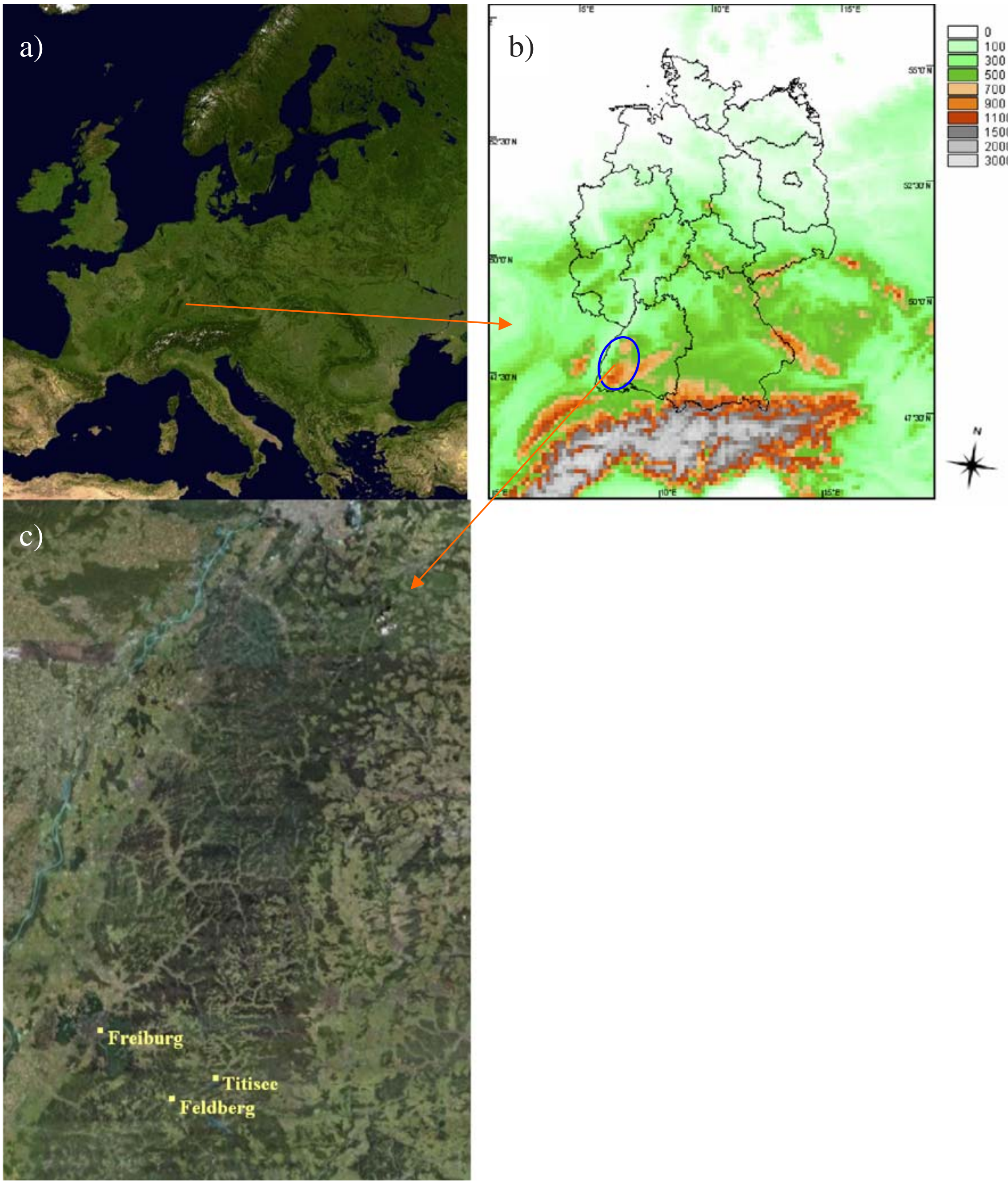


**Fig. 1** Maps for **a** Europe (www.weltkarte.com), **b** Germany, and **c** the study sites in SW Germany (Google Earth)

Black Forest typifies symbolically the image of a landscape as pictured in a fairy tale. Additionally, the southern Black Forest is formed by the most extensive, highest located, and oldest protection area in Baden-Württemberg having particular species like capercaillie (*Tetrao urogallus*).

The climatic analysis implies a vertical gradient from the southern Upper Rhine Graben to the high levels of the southern Black Forest. Hence, the following regions are chosen: Freiburg, Feldberg, and Titisee (Fig. 1). Freiburg (269 m asl), being located at the foothills of the Black Forest and one of the warmest cities in Germany, is quite relevant for tourism and provides climatically an interesting comparison with the cooler high altitude areas. Titisee lies on a medium-high elevation (846 m asl) and Feldberg is the highest mountain of the studied low mountain range. With a height of 1,493 m asl, Feldberg represents the climatic character of high mountains, frequently being referred to as a "subalpine island", due to its rough climate, glacial surface forms as well as flora and fauna comparable to alpine regions. Providing extensive potential for exercising sporting activities such as hiking or skiing, Feldberg is the most popular and frequently visited winter tourism area. Its popularity with tourism, however, is jeopardized by the impact of climate change on the regional climatic conditions.

## Data and methods

### Meteorological data

For the calculation of physical (wind, precipitation, snow conditions, and extreme weather events), thermal (cold and heat stress, thermal acceptance, and sultriness) and aesthetic (cloud cover/sunshine and fog) facets included in the climatic description relating to tourism, the A1B scenario is used. The data used are generated by the regional climate model REMO from the Max-Planck-Institute for Meteorology in Hamburg, having a spatial resolution of 10 km and a temporal resolution of hours. REMO is based on the European model, the former numerical weather prediction model of the German Weather Service (Majewski 1991). REMO can be used in a forecast or climate mode. It cannot be expected that in simulations using REMO in climate mode every single weather event is calculated realistically in time and space, only the climate will be represented. In this study, the climate mode is used. The data is available from 1950 to 2100 (Jacob 2001; Jacob et al. 2006, 2007). Here, the time period 1961–1990 is used for comparison with future climate projections from 2021 until 2050. The analyzed daily values refer to 14 CET, except for precipitation and snow cover that are presented by total annual precipitation amount and daily snow cover, respectively. Since precipitation is a highly sensitive parameter, it is recommended to average at least over 4 to 9 grid points to assure a better representation of climate than by analyzing single grid points (Jacob 2001; Jacob et al. 2006, 2007). In our study, we used an average over 9 grid points.

### Applied method

The effect of climate on tourism is strongly influenced by the perceptions of the tourists. Thermal comfort of clients plays a higher role than average temperature, while frequency and length of rain showers rather than average precipitation affect the quality of a tourism experience. Therefore, research into the impacts of climate change on tourism depends on the performance of regional and local climate scenarios, as well as on the type of parameters that can be modeled at these scales (UNWTO 2008).

The method used in this study combines climatological and tourism-related components. Threshold values of meteorological and climatological parameters are defined for tourism purposes listed in diverse studies (Table 1). The ten most relevant parameters are chosen for our analysis including the abovementioned climate facets in tourism and recreation (physical, thermal and aesthetic) that describe the so-called climatic tourism potential (de Freitas 2003; Matzarakis 2006, 2007). To assess the climatic tourism potential, air temperature and precipitation are not sufficient. For example, winter sports enthusiasts and tourists desire snow as well as sunshine, beneficial thermal conditions, and recreation in their holidays. Thus, besides the two variables most frequently used in impact assessment studies (air temperature and precipitation), we also consider physiologically equivalent temperature (PET; Höppe 1999), cold stress (PET < 0 °C), heat stress (PET > 35 °C), thermal comfort (18 °C < PET < 29 °C), sunshine/cloud cover conditions in terms of the number of days with a cloud cover < 5 octas, vapour pressure > 18 hPa, wind

**Table 1** Parameters relevant for tourism in relation to their threshold values and authors. The threshold values are adjusted to applied climatology and tourism purposes and refer to central Europeans

| Parameter | Thresholds | References |
|---|---|---|
| Thermally acceptable | 18 °C < PET < 29 °C | Matzarakis (2007) |
| Heat stress | PET > 35 °C | Matzarakis and Mayer (1996) |
| Cold stress | PET < 0 °C | Matzarakis (2007) |
| Sunny day | Cloud cover < 5/8 | Gómez Martín (2004) |
| Foggy day | Relative humidity > 93% | Matzarakis (2007) |
| Sultry day | Vapour pressure > 18 hPa | Scharlau (1943) |
| Dry day | Precipitation < 1 mm | Matzarakis (2007) |
| Wet day | Precipitation > 5 mm | Matzarakis (2007) |
| Stormy day | Wind velocity > 8 m/s | Besancenot (1989), Gómez Martín (2004) |
| Ski potential | Snow cover > 10 cm | Beniston (1997), Kulinat and Steinecke (1984), Breiling and Charamza (1999), Roth et al. (2005) |
| | Snow cover > 30 cm | OECD (2007) |
| | Snow water equivalent > 5 cm (≅ 23 cm) | Used here, based on Sturm et al. (1995), Brown and Mote (2009) |

velocity > 8 m/s, relative humidity > 93 %, precipitation < 1 mm as well as precipitation > 5 mm (Matzarakis 2007; Lin and Matzarakis 2008), and snow water equivalent (SWE) > 5 cm. Because SWE as usually outlined by climate models is not so familiar to stakeholders and decision-makers, it is converted into a real snow cover height. Hence, 5 cm SWE is consistent with a snow cover height of about 23 cm using the empirical approach after Brown and Mote (2009) that is based on the snow cover classification by Sturm et al. (1995). Since the regional climate model underestimates the topography, our threshold value differs somewhat from the OECD's guideline that defines the ski potential by a minimum snow cover of 30 cm (OECD 2007). Some studies suggest a snow cover greater than 10 cm as being adequate and sufficient for low mountain ranges from a climatic tourism point of view (cf. Breiling and Charamza 1999; Beniston 1997; Kulinat and Steinecke 1984). Hence, our threshold used in this study lies inbetween. In general, the definitions of the several threshold values do not necessarily correspond to the universal meteorological threshold values and are adjusted to applied tourism climatology. For example, under meteorological aspects, a stormy day is given by a wind strength of at least 8 Bft, which corresponds to a wind velocity greater than 17.2 m/s, while in the tourism climatology a wind velocity of 8 m/s (5 Bft) is perceived as unpleasant and uncomfortable (e.g., Besancenot 1989; Gómez Martín 2004).

The thermal environment expressed in terms of PET is calculated by the radiation and energy balance model RayMan (Matzarakis et al. 2007a). Compared to PMV (predicted mean vote; VDI 1998), PET has the advantage of a user friendly and simple measuring unit (°C) which makes it easier to understand by tourism-stakeholders and the public.

The chosen thresholds and the climatic tourism potential refer to Central Europeans. But which thresholds are optimal or adequate for tourists spending their time in the Black Forest coming from other climates? Until now, other climate backgrounds have not been considered in this context.

For a graphical description of the abovementioned analyzed tourism-related parameters, a useful method is the Climate-Tourism-Information-Scheme (CTIS; Matzarakis 2007; Lin and Matzarakis 2008; Matzarakis et al. 2007b; Zaninovic and Matzarakis 2009) that provides all-seasonal frequency classes and frequencies of extreme weather events on a 10-day or monthly time scale (Matzarakis 2007). This method is preferred for analyzing climate stations or grid points. Since the presented results are based on models and thus affected by the models' uncertainties, a temporal resolution finer than 1 month is not considered useful. The analyzed bioclimatic parameters are presented in frequencies on a percentage basis. The interpretation of CTIS is described in Fig. 2. Each colored column describes the corresponding frequency of a parameter. A frequency of 100% indicates that each day in a month is characterized by the respective condition listed on the right hand side. A frequency of 50% corresponds to an occurrence of the indicated condition during 15 days, 10% to 3 days of the considered month, etc. Considering the first row, thermal comfort occurs from April to September with an average frequency of about 40 % meaning that approximately 12 days are characterized by thermal comfort.

Additionally, PET and precipitation diagrams for both time periods will be presented in frequency classes. The following thermal perceptions are considered:

Frequency classes based on PET:

- ≤ 4 °C – very cold – extreme cold stress
- 4.1–8 °C – cold – strong cold stress
- 8.1–13 °C – cool – moderate cold stress
- 13.1–18 °C – slightly cool – slight cold stress
- 18.1–23 °C – comfortable – no thermal load
- 23.1–29 °C – slightly warm, still comfortable – slight thermal load
- 29.1–35 °C – warm – moderate thermal load
- 35.1–41 °C – hot – strong thermal load
- > 41 °C – very hot – extreme thermal load

In this study, the definition of extreme cold stress is classified in detail. The classes of < −10 °C, −10 °C to 0.1 °C and 0–4 °C are shown separately (Matzarakis and Mayer 1996).

Frequency classes based on precipitation:

- No precipitation
- 0.1–1 mm
- 1.1–3 mm
- 3.1–5 mm
- 5.1–10 mm
- 10.1–15 mm
- 15.1–20 mm
- > 20 mm

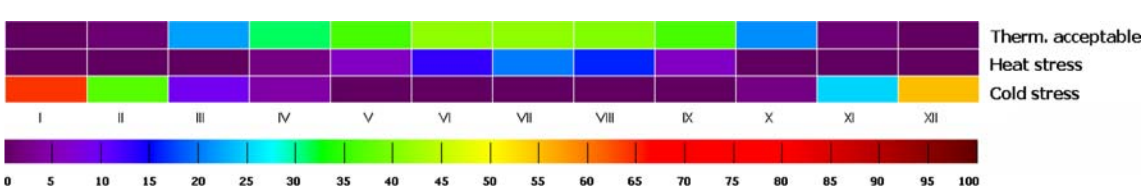


**Fig. 2** Explanation of the climate-tourism-information-scheme (CTIS); see also text

This method regards not only the number of days with reliable snow conditions or with less/more precipitation but also the thermal environment to which tourists are exposed. Further, this method gives detailed information about probabilities of occurrence all year round. This approach is more comprehensive than classic approaches and improves the assessment of climate for tourism and recreation (Matzarakis 2007).

## Results

The analyses of the climatic tourism potential are shown for three chosen areas in the southern Black Forest: Freiburg (269 m asl, modeled height: 228 m asl), Titisee (846 m asl, modeled height: 935 m asl), and Feldberg (1,493 m asl, modeled height: 1,076 m asl). As climate varies rapidly with height, an exact derivation of modeled data for present and future climate cannot be drawn due to the discrepancy between modeled and actual height. Rather, the expected trend and the changes in our climatic parameters for the future time period (2021–2050) compared to the base period (1961–1990) are focused on. First, we present the results for the physiologically equivalent temperature. Afterwards, a detailed analysis of changes in precipitation is given. Finally, we evaluate the climatic tourism potential based on the Climate-Tourism-Information-Scheme.

### Variations of the physiologically equivalent temperature

#### *Freiburg*

In Fig. 3, the monthly distribution of PET frequencies is shown for Freiburg for both periods 1961–1990 and 2021–2050. Extreme heat stress (PET > 41 °C) occurs in the summer season from May to September in both periods while the frequency will slightly increase in the future. The summer months of July and August are the most affected by heat stress with values of 10% corresponding to 3 days per month. The period with extreme heat stress will not be significantly lengthened in the future. PET between 35 and 41 °C occurs at present on 3 days in July. In the future, the frequency of this PET class will be slightly increased. Days with PET values less than −10 °C will be negligible. Days with cold stress (−10 °C < PET < 0 °C) occur in the winter season from November to March with a maximum frequency of 60% in 1961–1990 and 50% in 2021–2050, respectively, in January meaning that half the month is perceived as very cold. The largest changes may be expected from November to February with an average reduction of 10% (≅ 3 days) in the future. Thermal comfort (18 °C < PET < 29 °C) is perceived in the months from March to October. Frequencies of 20% (≅ 6 days) and up to 45% (≅ 14 days) will occur in March and

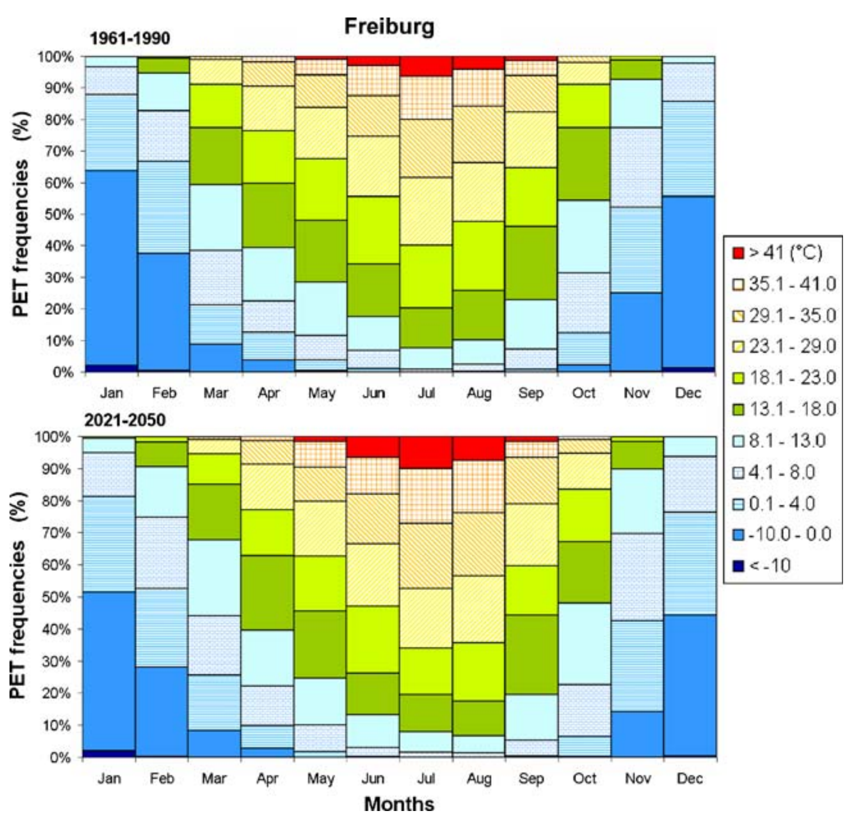


**Fig. 3** PET frequencies for Freiburg (228 m) for both time spans, 1961–1990 and 2021–2050. These frequencies are portrayed in 11 frequency classes on a percentage basis

October and from May to September, respectively. In the future, thermal comfort will be reduced by 5–10% (≅ till 3 days) on average except in October (+5%).

*Feldberg*

In Fig. 4, the monthly distribution of PET frequencies is shown for Feldberg for the present and the future. Heat stress can be neglected in both time spans whereas cold stress (PET < −10 °C and −10 °C < PET < 0 °C) is perceived almost throughout the whole year except in July and August. Maximum frequencies of 90% (≅ 27 days) occur in December and January. The most obvious changes in the frequency of cold stress will be expected in the winter season (from October to December and February) with an average reduction of 15% (≅ 4–5 days). Thermal comfort (18 °C < PET < 29 °C) occurs from March to October on average on 8 days at present (1961–1990) whereas spring and autumn is slightly below average and summer slightly above average. In the period 2021–2050, thermal comfort will be slightly changed indicating a reduction of 5% in several months, such as March, July, and September, and an increase of 5% in June and October. These changes are quite little because changes in frequencies of 5% correspond to changes of about 1–2 days. The increase of variability and the extension of the thermal comfort range are shown to be of higher importance.

*Titisee*

In Fig. 5, the monthly distribution of PET frequencies is shown for Titisee for both periods 1961–1990 and 2021–2050. Extreme heat stress (PET > 41 °C) can be neglected at present and in the future. PET between 35 °C and 41 °C might obviously occur only in July with a frequency of 10 % (≅ 3 days). Cold stress (PET < -10 °C and -10 °C < PET < 0 °C) is and might be present almost the whole year except from May to September. In 1961–1990, approximately 27 days of December and January are perceived as very cold followed by February with approximately 21 days and November with approximately 18 days. In the future, the largest changes in cold stress may be expected in November, December, and February with a reduction of about 10% (≅ 3 days). Thermal comfort (18 °C < PET < 29 °C) occurs at present from March to October with maximum frequencies up to 40% (≅ 12 days) in the summer months of June, July, and August. In the future, thermal comfort will be more frequent in October (10% ≅ 3 days). Changes within the other months are expected to be not significant.

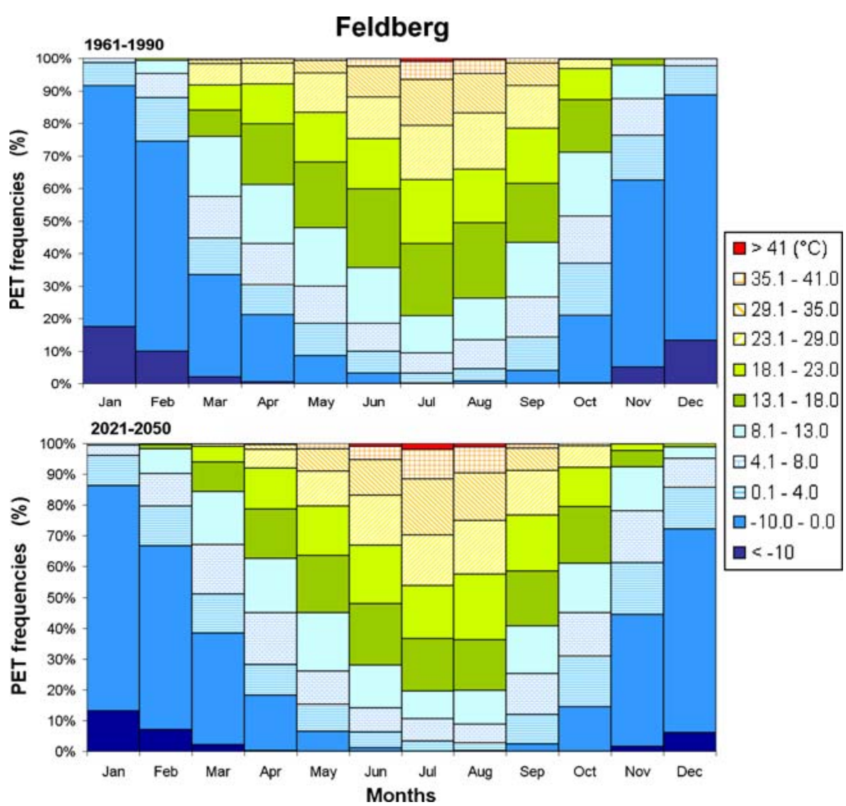


**Fig. 4** PET frequencies for Feldberg (1,076 m) for both time spans, 1961–1990 and 2021–2050. These frequencies are portrayed in 11 frequency classes on a percentage basis

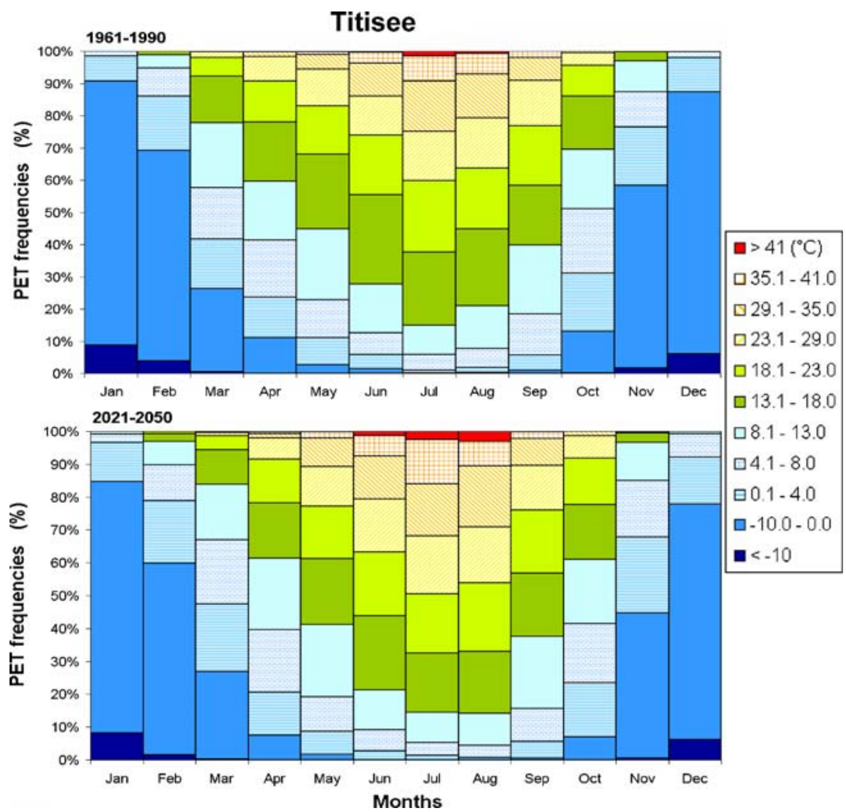


**Fig. 5** PET frequencies for Titisee (935 m) for both time spans, 1961–1990 and 2021–2050. These frequencies are portrayed in 11 frequency classes on a percentage basis

Variations in precipitation

*Freiburg*

In Fig. 6, the monthly distribution of precipitation frequencies is shown for Freiburg for the periods 1961–1990 and 2021–2050. The precipitation is seasonally almost uniformly distributed with slightly higher values in summer (JJA, June–August). In the future, the seasonal precipitation amount will considerably decrease in summer while increasing in spring (MAM, March–May) and slightly in autumn (SON, September–November). Thus, the frequency of no precipitation will slightly increase in summer. The winter precipitation (DJF, December–February) will not change at all. Intense precipitation events will not show any significant changes.

*Feldberg*

In Fig. 7, the frequencies of precipitation are presented for Feldberg for the periods 1961–1990 and 2021–2050 on a monthly scale. At Feldberg, relatively high intensities of precipitation are observed in all seasons. Obvious changes in seasonal precipitation may be expected in spring, being the main contribution to the increase in the total amount. Hence, winter, summer, and autumn precipitation will show marginal changes, and while the summer precipitation will slightly decrease, the autumn precipitation will slightly increase. Intense precipitation events appear in both November and the winter months (DJF) with an intensification in November for the future time span.

*Titisee*

Figure 8 shows the monthly distribution of precipitation frequencies for Titisee at present and in the future. While the annual precipitation amount will marginally vary the seasonal precipitation will be redistributed by a slight decrease in summer and an increase in both spring (especially in March) and slightly in autumn. Changes in intense precipitation events may not be expected, being in general less frequent.

Integral evaluations for tourism

The analysis of the climatic tourism potential for the three studied areas in the southern Black Forest (Freiburg, Feldberg, and Titisee) is based on the following parameters: physiologically equivalent temperature (PET) including cold and heat stress as well as thermal acceptance (comfort), cloud cover < 5 octas (sunny day), vapour pressure > 18 hPa (sultry day), wind velocity > 8 m/s (stormy day), relative humidity > 93% (foggy day), precipitation < 1 mm (dry day), precipitation > 5 mm

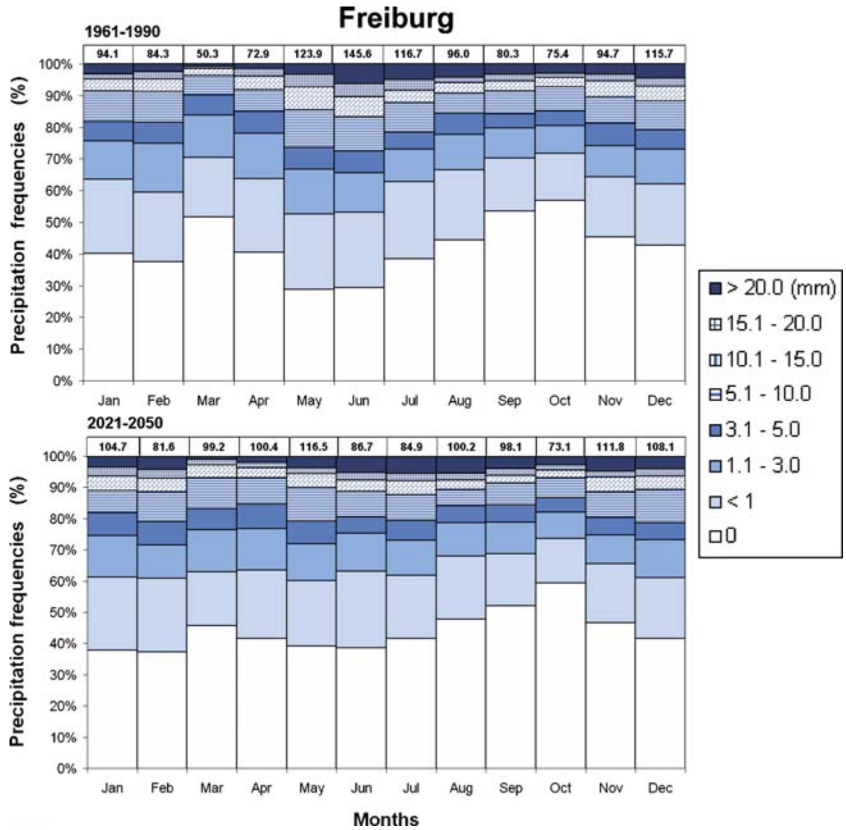


**Fig. 6** Precipitation frequencies for Freiburg (228 m) for both time spans, 1961–1990 and 2021–2050. These frequencies are portrayed in 8 frequency classes on a percentage basis. The monthly totals of precipitation are given above the figure

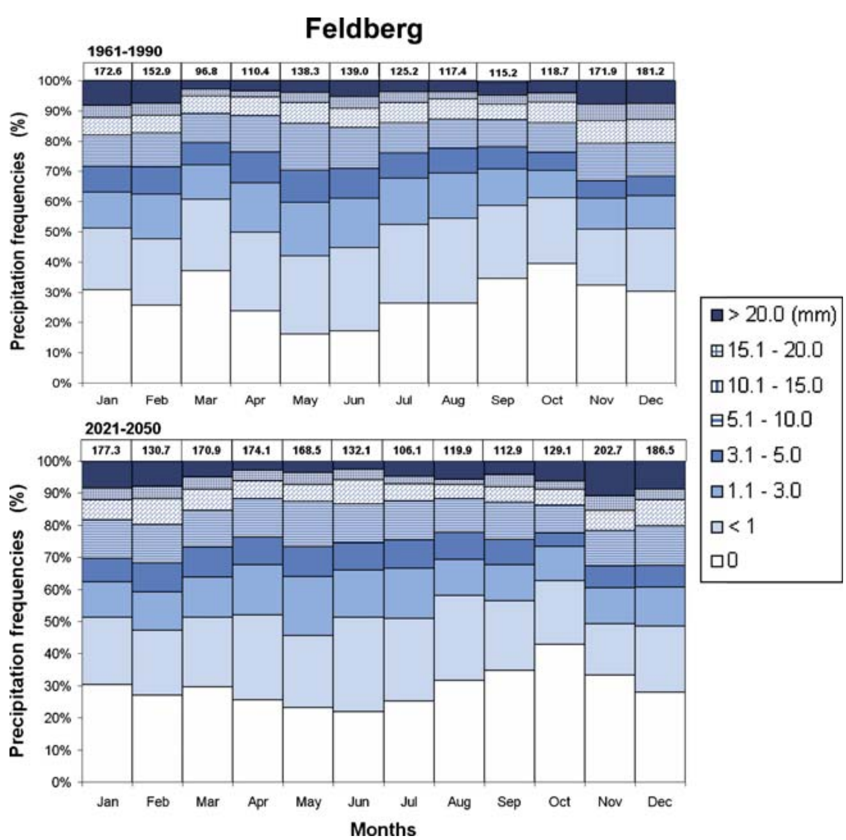


**Fig. 7** Precipitation frequencies for Feldberg (1,076 m) for both time spans, 1961–1990 and 2021–2050. These frequencies are portrayed in 8 frequency classes on a percentage basis. The monthly totals of precipitation are given above the figure

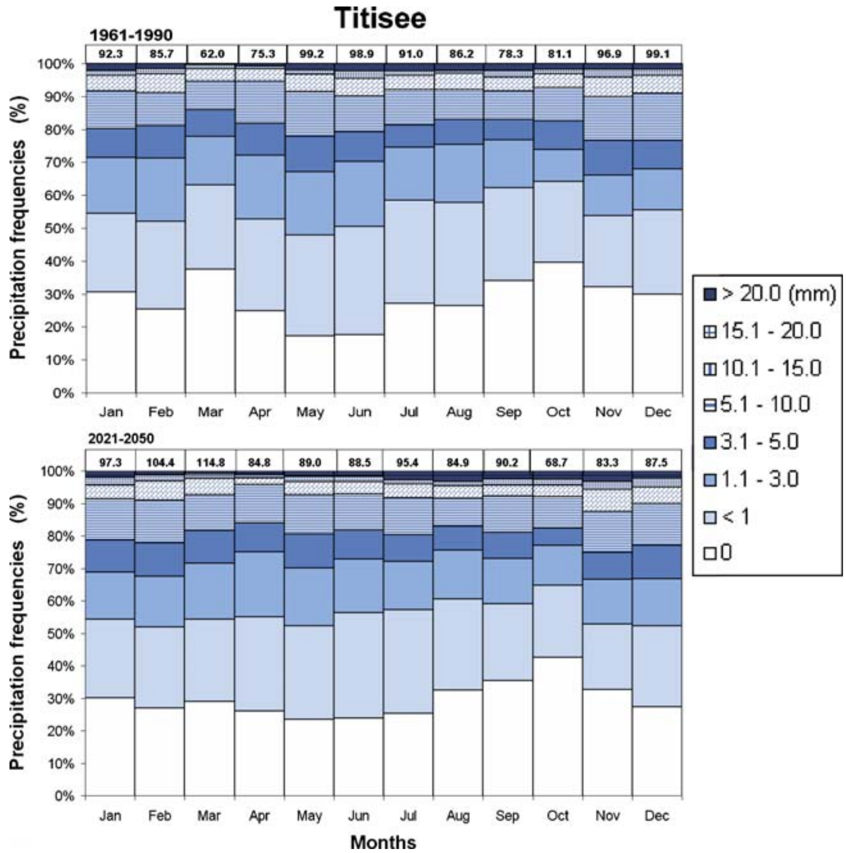


**Fig. 8** Precipitation frequencies for Titisee (935 m) for both time spans, 1961–1990 and 2021–2050. These frequencies are portrayed in 8 frequency classes on a percentage basis. The monthly totals of precipitation are given above the figure

(wet day), and snow cover > 23 cm (ski potential). The frequency of these parameters is summarized in the Climate-Tourism-Information-Schemes (CTIS) on a monthly time scale and on a percentage basis.

*Freiburg*

Figure 9 shows CTIS for Freiburg at present and in the future. Thermal comfort is present in nearly all seasons and will marginally decrease in spring (March/April) and summer. Heat stress days may be somewhat more frequent (+ 3 days) in July and August. Cold stress lasting from November to March with maximum frequencies in January (approximately 70% ≅ 21 days) followed by December (approximately 60% ≅ 18 days) and February (approximately 40% ≅ 12 days) will decrease on average by 10% (≅ 3 days). Sunny days are present throughout the year with frequencies ranging from 40% (≅ 12 days) in winter to 70% (≅ 21 days) in summer. In the future, changes will not be obvious. A similar pattern is given by analyzing dry days occurring almost consistently with a frequency of 60% (≅ 18 days). The period with sultry days lasts principally from June to September in both time spans. In 2021–2050, the frequency of sultriness will increase up to 15% (≅ 4–5 days) in July. Wet days are present on 4–8 days (≅ 15–25%) in both periods. Windy and foggy conditions are observed with a frequency less than 5% in both periods and, hence, they can be neglected. Ski potential is at present simulated for the winter months December, January, and February, but with minor frequencies. In the future, the snow period will be reduced by 2 months; hence, there will only be some days with snow cover in January.

Considering additionally the absolute values of the analyzed parameters, given in Table 2, changes in cold and heat stress as well as in sultriness are obvious. Hence, cold stress will decline by 14 days while heat stress and sultriness will increase by almost 10 and 20 days a year, respectively.

*Feldberg*

Figure 10 describes CTIS for Feldberg for both periods, 1961–1990 and 2021–2050. Thermal comfort lasts from March to October. Thermal comfort will decrease in March and slightly increase in June. Cold stress is perceived from October to April. In the future, the frequency will be intensely reduced by 40% (≅ 12 days) in November and up to 20% (≅ 6 days) in the winter months (DJF). Heat stress and sultriness are irrelevant for the present. For the future time span, the summer season will be affected by increased sultriness (approximately up to 9 days per month). Sunny days occur throughout the year with frequencies ranging

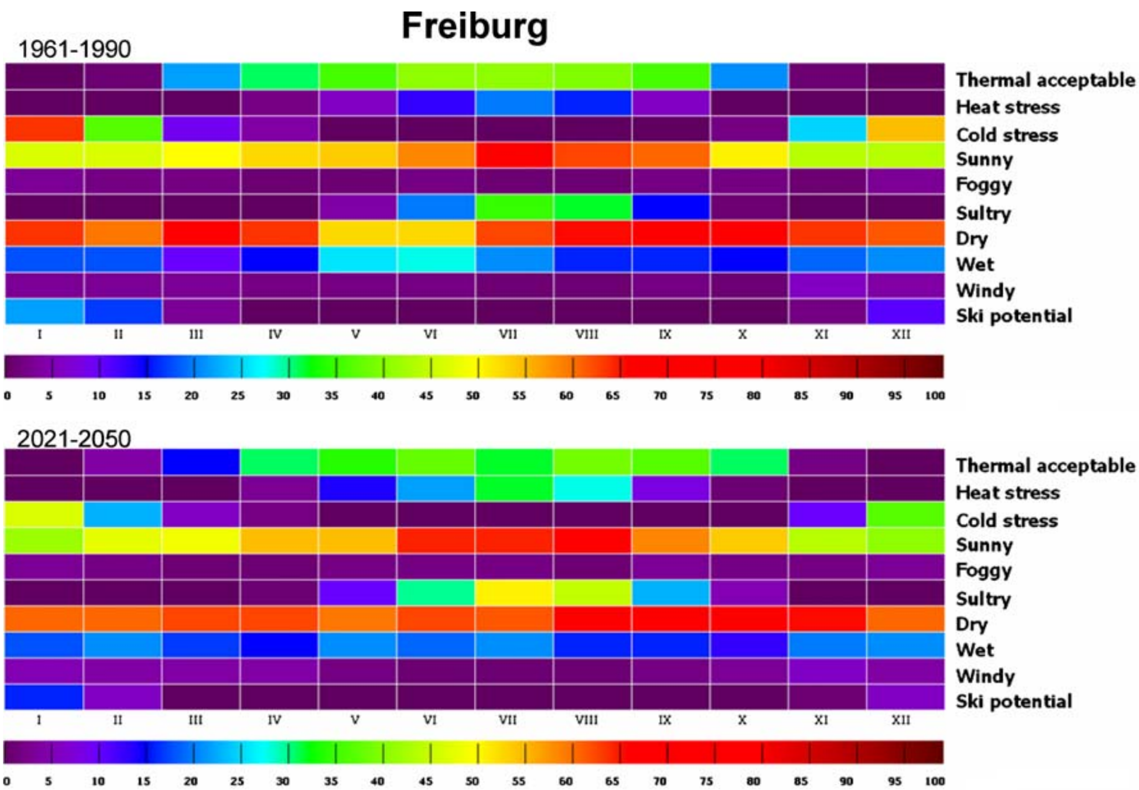


**Fig. 9** Climate-Tourism-Information-Schemes (CTIS) for Freiburg (228 m) for both time spans, 1961–1990 and 2021–2050. The parameters such as thermal comfort (18 °C < PET < 29 °C), heat stress (PET > 35 °C), cold stress (PET < 0 °C), sunny day (cloud cover < 5/8), foggy day (RH > 93%), sultry day (VP > 18 hPa), dry day (RR < 1 mm), wet day (RR > 5 mm), windy day (v > 8 m/s), and ski potential (snow cover > 23 cm) are presented on a monthly time scale and on a percentage basis

from 40% (≅ 12 days) in winter to 60% (≅ 18 days) in summer. In the future, changes will not be obvious. A similar pattern is observed by analyzing fog, however with lower frequencies: 40% (≅ 12 days) in winter and 20% (≅ 6 days) in summer. On average, dry days occur on approximately 15 days per month (50%). The frequencies are above-average in March and October and slightly below-average in May and June. Obvious changes may occur in March with a decrease of dry days (15% ≅ 4–5 days). Windy days occur especially in winter (DJF) with a frequency of approximately 25% (≅ 7–8 days) followed by autumn (approximately 20% ≅ 6 days) and spring (approximately 15% ≅ 4–5 days). Changes in wind conditions may not be obvious. The snow season lasts at present from November to March with maximum frequencies in the months of January and February (≈ 60%). The frequency of snow days will especially decrease in January and February by 10–15% (≅ 4–5 days) in the future. In March, there will be almost no chance of doing winter sports.

**Table 2** Important climatic parameters relevant for tourism for Freiburg, Feldberg, and Titisee for the period 1961–1990 compared to 2021–2050. The values are shown in days per year

| | Freiburg | | Feldberg | | Titisee | |
|---|---|---|---|---|---|---|
| Parameters | 1961–1990 | 2021–2050 | 1961–1990 | 2021–2050 | 1961–1990 | 2021–2050 |
| Cold stress | 59 | 45 | 123 | 110 | 109 | 93 |
| Thermal acceptable | 84 | 79 | 61 | 66 | 63 | 67 |
| Heat stress | 19 | 27 | 5 | 9 | 7 | 12 |
| Dry day | 232 | 234 | 190 | 190 | 205 | 204 |
| Wet day | 68 | 66 | 96 | 99 | 70 | 72 |
| Foggy day | 7 | 7 | 83 | 83 | 13 | 13 |
| Sultry day | 33 | 50 | 12 | 23 | 9 | 18 |
| Windy day | 10 | 11 | 51 | 55 | 41 | 45 |
| Ski potential | 17 | 9 | 65 | 51 | 48 | 37 |

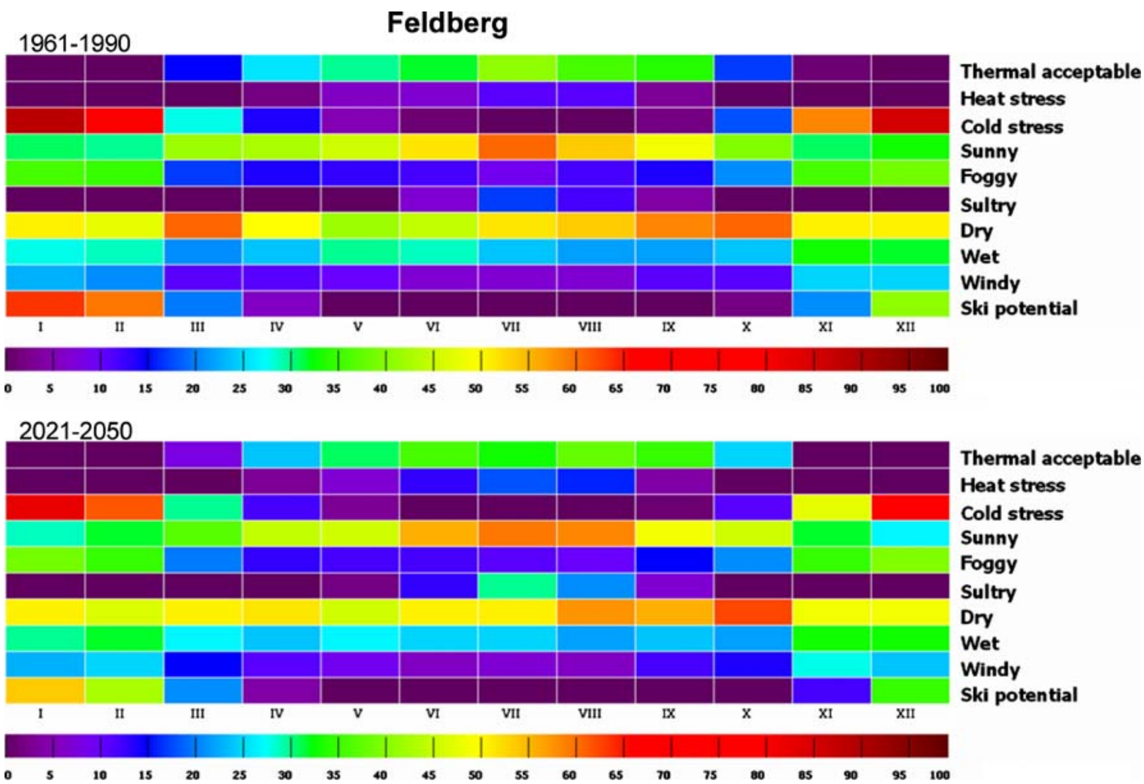


**Fig. 10** Climate-Tourism-Information-Schemes (CTIS) for Feldberg (1,076 m) for both time spans, 1961–1990 and 2021–2050. The parameters such as thermal comfort (18 °C < PET < 29 °C), heat stress (PET > 35 °C), cold stress (PET < 0 °C), sunny day (cloud cover < 5/8), foggy day (RH > 93%), sultry day (VP > 18 hPa), dry day (RR < 1 mm), wet day (RR > 5 mm), windy day (v > 8 m/s), and ski potential (snow cover > 23 cm) are presented on a monthly time scale and on a percentage basis

In general, the most obvious changes are comprised of cold stress by a decrease of 13 days, sultriness by a doubling of sultry days and finally ski potential by a decrease of almost 14 days per year (Table 2).

*Titisee*

Figure 11 presents CTIS for Titisee for the present and future time span. Therein, thermal comfort lasts from April to October with maximum frequencies of 40% (≅ 12 days) in the months of June to September. In the future, thermal comfort will slightly increase, especially in October (+10% ≅ 3 days) whereas cold stress will decline by approximately 10% (≅ 3 days) in November, December, and February. Hence, the occurrence of cold stress may be confined to the months of November–March. Sunny days will generally increase by 10% (≅ 3 days). Thus, the frequency is increased from approximately 50% (≅ 15 days) in summer (JJA) to approximately 70% (≅ 21 days). The occurrence of foggy conditions will be reduced by almost 35%. Considering the frequency of sultriness, only July will be affected with a maximum frequency of 25% (≅ 7–8 days). Dry days occur on average on 15 days per month (50%) except in March, September, and October being slightly above-average (60% ≅ 18 days) as well as in May being slightly below-average (40% ≅ 12 days). The most obvious changes might be expected in March becoming slightly wetter (10% ≅ 3 days) and in the summer months of June and August becoming slightly dryer (10% ≅ 3 days). Windy days occur especially in winter (DJF) with a frequency of approximately 25% (≅ 7–8 days) followed by spring and autumn (approximately 15 % ≅ 4–5 days). Changes in wind conditions might be not obvious. A snow cover of more than 23 cm occurs from November to March with a maximum frequency in January and February (≈ 50%). In the future, the frequency will approximately decline by 10% (≅ 3 days). In March and November, there will be almost no chance of doing winter sports.

The most obvious changes might be perceived by a decrease in cold stress by 16 days, a slight increase in heat stress by 5 days, and a doubling of sultry days per year (Table 2).

## Discussion

In our analysis, climatic changes relevant to tourism are analyzed for a future period ending in 2050. Because climate simulations are mainly evaluated for the 30-year period 2071–2100 and rather for the regional scenarios A2

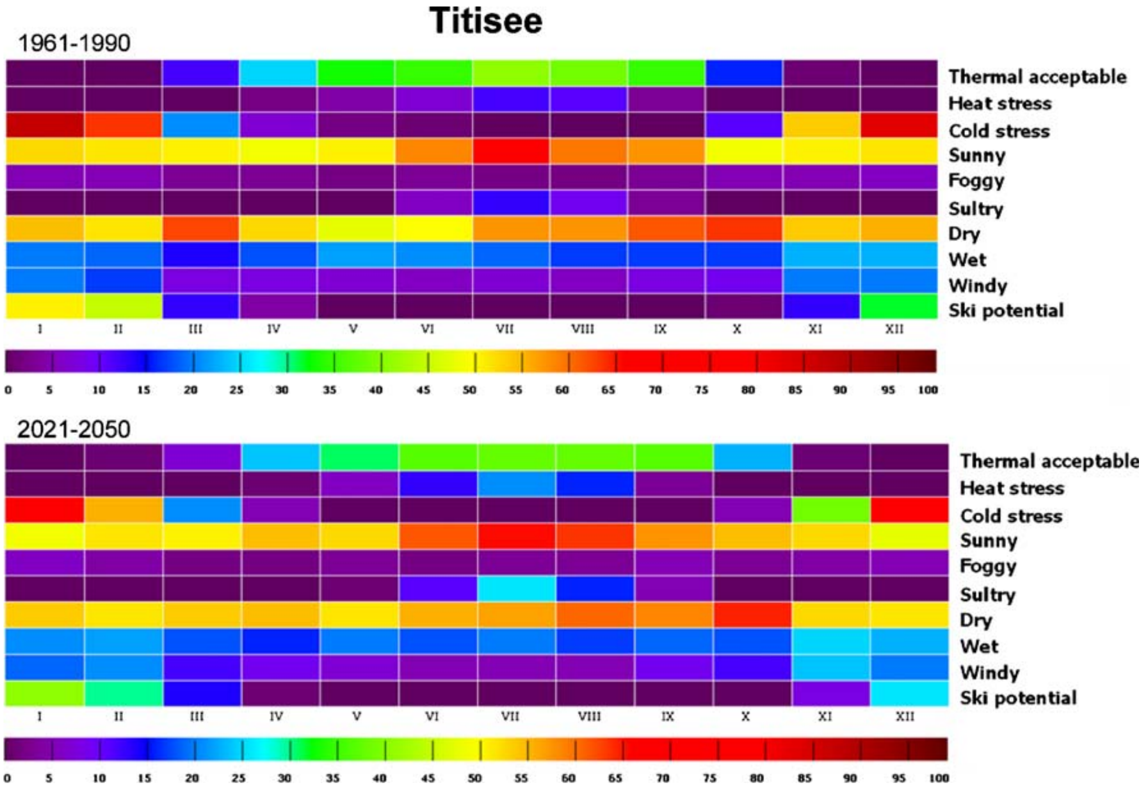


**Fig. 11** Climate-Tourism-Information-Schemes (CTIS) for Titisee (935 m) for both time spans 1961–1990 and 2021–2050. The parameters such as thermal comfort (18 °C < PET < 29 °C), heat stress (PET > 35 °C), cold stress (PET < 0 °C), sunny day (cloud cover < 5/8), foggy day (RH > 93%), sultry day (VP > 18 hPa), dry day (RR < 1 mm), wet day (RR > 5 mm), windy day (v > 8 m/s), and ski potential (snow cover > 23 cm) are presented on a monthly time scale and on a percentage basis

and B2 (e.g., PRUDENCE 2007) showing more prominent changes, the literature does not offer many comparative studies. But the tourism sector is currently not interested in what might be happening at the end of the twenty-first century. Rather, they are interested in the nature of changes and their impact to be expected in the near future. In comparison to the regional studies KLIWA and KLARA, our analyses, indicating only future trends, are in general consistent with the analyses of the aforementioned projects in spite of different model characteristics. The results include a clear increase in summer days (maximum air temperature > 25 °C) and a decrease in freezing days (minimum air temperature < 0 °C) due to regional warming. The winters will become milder and moister due to an increase in western weather situations (KLIWA 2006).

Depending on different SRES scenarios (A1B, B1) and with consideration of regional model characteristics, the present climate is simulated slightly too warm and too wet by REMO, except for the higher low mountain ranges (too dry; Beniston et al. 2007; Endler and Matzarakis 2008; Feldmann et al. 2008). Feldmann et al. (2008) found that REMO is capable of resolving the orographic scales typical for Central Europe. But on the other hand, it is still too coarse to treat important atmospheric processes like convection or valley wind circulations explicitly affecting the regional distribution of precipitation. Difficult regions for the models to simulate are the slopes of the Black Forest due to the steep and complex orography. Since snow cover is highly dependent on altitude, air temperature, precipitation conditions, slopes and their orientation, it is very variable. The orography is underestimated by the REMO model; thus the highest altitude in the Black Forest is only 1,076 m asl, i.e. 419 m lower. Therefore, snow cover is also simulated to be reduced at higher altitudes. A comparison between observed (provided by the German Weather Service, DWD) and modeled data for the climate stations Freiburg, Titisee, and Feldberg shows that the REMO model underestimates snow days for Feldberg by 50% and overestimates them for Freiburg fourfold. A quite good agreement between modeled and observed snow days is revealed for Titisee (not shown). In the model, snowy days only occur in the winter months of December to February (see Figs. 9, 10, and 11), since the melting of snow starts too early due to a stronger increase in air temperature in spring. Based on observed data, a frequency probability of approximately 100% for snow days is guaranteed until April at Feldberg (not shown).

Until 2050, air temperature is expected to increase on average by 1 °C in Germany (Jacob et al. 2008). Hence this warming will influence the hydrological cycle including a redistribution of precipitation and a reduction in reliable snow conditions. However, precipitation is a very sensitive parameter with high local fluctuations. The total amount of annual precipitation will not change markedly, but there will be a temporal redistribution of precipitation meaning that the summer precipitation will decline, except for Titisee being almost unchanged, while the spring and autumn precipitation will increase in every studied area. The changes in autumn precipitation for Titisee are of low relevance. Winter precipitation will also be unchanged. Due to higher air temperatures, the winter precipitation falls rather as rain resulting in a reduction of snow cover and ski potential. Generally, the snow season will be shortened. Decreasing snow cover will reduce the aesthetic of the landscape. It is doubtful whether winter sports enthusiasts will accept the aesthetic impairment of the landscape or look for other regions with reliable snow conditions, for instance, the Alps. Since winter sports in the Black Forest and other low mountain ranges is a sensitive issue in the tourism industry, it is important to sustain the winter sport season. Adaptation measures such as artificial snow-making or grooming ski slopes to reduce snow depth requirements might be considered. But artificial snow-making is limited in its implementation (depending on air temperature, air humidity, water storage, energy costs, etc.) providing only a short-term solution. Thus, the weather conditions in lower regions will not allow artificial snow-making because of rising air temperatures (Zebisch et al. 2005). Furthermore, an artificial snow cover cannot guarantee adequate snow conditions because of the high variability in climate. Otherwise, snow-making needs to be more efficient. Other adaptation measures include moving ski areas to higher altitudes or colder north slopes (UNWTO 2008). Reliable snow conditions are assured for elevations up to 1,500 m (Beniston 2003; Elsasser and Bürki 2002; Zebisch et al. 2005). As shown by Roth et al. (2005), the snow cover duration above 14 days will not be assured for altitudes below 1,200–1,500 m until 2025. Schönbein and Schneider (2003) also expect a negative trend of snow cover especially for the Black Forest compared to other German low mountain ranges. This can be explained by the region's geographical location in the southwest of Germany. Since Feldberg (1,493 m), being the highest elevation of the Black Forest, shows a high vulnerability to future climate scenarios with respect to snow cover duration, moving ski areas to higher altitudes is not considered to be an alternative for the entire region of the Black Forest. Colder north slopes indeed provide sufficient snow cover but winter sports enthusiasts and skiers prefer sunny instead of shady regions (OECD 2007).

However, the local winter sports tourism in the Black Forest might be partially sustained by day trippers who will not compensate for possible accruing losses. Snow conditions in Germany's low mountain ranges creating the requirements for winter sports may not be fulfilled anymore during the past decades. According to the OECD, Germany's reliable Alpine ski regions will decrease by about 40% as a result of an increase in air temperature of 1 °C in the future. Consequently, winter sports enthusiasts and tourists are going to look for reliable ski regions outside Germany's mountains. An increased rainfall in spring and autumn could result in a major danger of flooding events including hazardous floodwaters. Flooded forest paths could reduce outdoor activities, especially in the off-season (spring and autumn) while dryer summer and higher temperatures advance the risk of forest fires or plagues (e.g., insects) resulting in a loss of natural attraction and damage to the tourism infrastructure. Thus, climate and climate change also have an important influence on environmental conditions that can deter tourists, including infectious diseases, wildfires, and insects. Considering the thermal environment, cold stress will decline especially in March and November while thermal comfort will slightly increase in the summer season, especially in higher altitudes (Titisee and Feldberg). In Freiburg, thermal comfort will decline at the expense of heat stress due to a higher urban development and the effects of the urban heat island. Heat stress will be irrelevant at higher altitudes due to local wind systems boosting the prevailing weather conditions. Additionally, the increase of sultry days in both lower and higher altitudes will affect health, well-being, and recreation by limiting, e.g., outdoor activities. While winter seasons might shorten summer seasons might lengthen, especially at higher altitudes, providing opportunities for other types of outdoor activities and tourism businesses that supply them (e.g., trekking, hiking, mountain biking, etc.). Thus, higher parts of low mountain ranges will now be more affected by direct human activities. In this context, the altitude of a township is very important for human well-being as well as outdoor activities. The higher a township lies the lower are the heat stress and sultriness. At higher altitudes of the Black Forest, thermal comfort will increase in the future while thermal comfort will decline at lower altitudes, especially in summer. So the higher altitudes will gain in importance both in summer and winter. Additionally, the climate of the Black Forest is also defined as forest climate because of the high degree of afforestation having positive impacts on human well-being (Jendritzky et al. 1998). The positive conditions for convalescence and recreation will still be present due to the pleasant climatic conditions. Climate affects a wide range of the environmental resources that are critical attractions for tourism, among others biodiversity. Nevertheless, reliable predictions of a changing biodiversity are not possible at the moment. Expert opinion in scientific literature shows the predictions of the future development of severe storms to be contradictory. For example, Lambert and Fyfe (2006) as well as Pinto et al. (2007) expect an increase of such events over the North Atlantic–European region while Kharin and Zwiers (2000) and Finnis et al. (2007) anticipate a decrease of such events. General tendencies point towards an increase in more frequent severe storms over the North Atlantic–European region. The exposure of storms in the Black Forest cannot, however, yet be estimated.

Compared to other German low mountain ranges, e.g., Harz, Fichtelgebirge, or Taunus, tourism is a very important economic factor in the Black Forest. Nevertheless, the accruing losses in winter tourism might not be compensated for by summer tourism (Müller and Weber 2007). Thus, summer and winter tourism might be more and more combined. Although the Black Forest was in the past considered to be an attractive winter sports region, it will be more and more losing its unique selling proposition. The capability admittedly exists, but the economic value was not addressed. The challenge requires more flexibility and adaptability on the part of both the tourism industry and the tourists. Tourists have the greater adaptive capacity (depending on three key resources: money, knowledge, and time) with relative freedom to avoid destinations impacted by climate change or shifting the timing of travel to avoid unfavorable climate conditions. Suppliers of tourism services and tourism operators at specific destinations have less adaptive capacity. Large tour operators, not being owners of the infrastructure, are in a better position to adapt to changes at destinations because they can respond to clients' demands and provide information to influence clients' travel choices. Destination communities and tourism operators with large investments in immobile capital assets (e.g., hotel, resort complex, marina, or casino) have the least adaptive capacity (UNWTO 2008). It seems that stakeholders are indeed aware of a changing climate and a changing tourism but they are holding onto their tradition of keeping the status quo. A change in thinking regarding restructuring the tourism sector is not evident. Adaptation measures being recommended include seasonal diversification, e.g., creating spas, fitness centres, cultural history, all-year tourism, etc. But the potential of diversification is not to be overestimated. It is unlikely that snow activities can completely be replaced by non-snow offerings; and snow-making may only be a short-term solution for the region of the Black Forest. However, overnight tourists tend to plan their holiday several months ahead and, thus, they have particular expectations concerning their holiday. The tourism destination ought to offer alternatives to satisfy their needs. In particular, it has to be considered that a wider range of weather-independent activities, e.g., fitness centres, concerts, and cultural history is needed due to a higher variability of the climate parameters and a limitation of weather-dependent outdoor activities.

## Conclusion

In this paper, we analyzed the climatic tourism potential simulated for three regions in the southern Black Forest: Freiburg, Titisee, and Feldberg. An analysis of its vertical gradient ranging from the southern Upper Rhine Graben to the high levels of the southern Black Forest is implied. The climatic tourism potential is based on climate simulations of SRES A1B conducted by the regional climate model REMO. The base period 1961–1990 and the future period 2021–2050 are considered. Although global and regional warming and hence climate change will be visible more distinctively towards the end of the twenty-first century, the tourism industry is rather interested in what might be expected in the near future.

The methodology used here (Climate-Tourism-Information-Scheme, CTIS) is thought to be a comprehensive and user-friendly scheme for the dissemination of climatically relevant and tourism-related parameters. CTIS can be used on a 10-day or 30-day time scale on a percentage basis. Although the 10-day interval is more convenient for tourism purposes, we applied the monthly time scale to account for modeling uncertainties. Thus, accuracy in simulating the future climate ought not to be assumed. Our primary results can be summarized as follows: with its close connections to the environment and the climate itself, tourism is considered to be a highly climate-sensitive economic sector. Climate change will have both negative and positive impacts on the tourism sector. While winters might shorten summers might lengthen, especially at higher elevations, providing opportunities for other types of outdoor activities and tourism businesses that supply them (e.g., trekking, hiking, mountain biking, etc.). Reduced snow cover might result in an appreciable loss of natural attraction. Thus, climate defines and influences the length and quality of tourism seasons and plays a major role in destination choice and tourist spending. Changes might be perceived rather at lower altitudes than at higher altitudes (e.g., heat stress). The challenge is more flexibility and adaptability on the part of both the tourism industry and the tourists. Altered seasonality, heat stress and sultriness for tourists, especially in the lowland, energy costs for cooling (air condition), infectious diseases, and natural hazards might be expected. A change in tourism, especially in winter tourism, will occur since winter sports will be feasible by using adaptation measures such as snow-making. The accruing losses are not likely to be compensated for by summer tourism. Much remains to be done to incorporate adaptation into future impact assessments in the tourism sector given its high adaptive capacity. Second, knowledge of the capability of current climate adaptations to successfully cope with future climate change is still incomplete, while the awareness of the risks and benefits of climate-sensitive decisions is the basis for pursuing a successful strategy.

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