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Future climate resources for tourism in Europe based on the daily Tourism Climatic Index

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Abstract Climate is an important resource for many types of tourism. One of several metrics for the suitability of climate for sightseeing is Mieczkowski's "Tourism Climatic Index" (TCI), which summarizes and combines seven climate variables. By means of the TCI, we analyse the present climate resources for tourism in Europe and projected changes under future climate change. We use daily data from five regional climate models and compare the reference period 1961–1990 to the A2 scenario in 2071–2100. A comparison of the TCI based on reanalysis data and model simulations for the reference period shows that current regional climate models capture the important climatic patterns. Currently, climate resources are best in Southern Europe and deteriorate with increasing latitude and altitude. With climate change the latitudinal band of favourable climate is projected to shift northward improving climate resources in Northern and Central Europe in most seasons. Southern Europe's suitability for sightseeing tourism drops strikingly in the summer holiday months but is partially compensated by considerable improvements between October and April.

1 Introduction

Climate plays an important role for tourism. It not only codetermines a location's suitability for different types of recreation activities but is often also responsible

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for the seasonality experienced in many tourism destinations (Besancenot 1990). For tourism, a "favourable climate" can be regarded as a resource. Destinations with climate resources of better quality than others enjoy a competitive advantage. Considerable effort has therefore been put into defining a suitable metric for "favourable climate" from the tourist perspective. Such an indicator can assist investors in choosing where to develop new destinations, or help tour operators or holidaymakers to plan their activities (see for instance de Freitas 2003). Since the 1960s, numerous such metrics have been developed and applied (see overviews in Besancenot 1990; de Freitas 2003).

One of these, the Tourism Climatic Index (TCI) developed by Mieczkowski (1985), has more recently been used to analyse the change in climatic resources through climate change. The few studies have shown that climate change can substantially redistribute climate resources across regions and between seasons (see Amelung et al. 2007 for a global scale; Amelung and Viner 2006 for the Mediterranean; and Scott et al. 2004 for North America). The TCI is favoured as an index because it is one of the most comprehensive metrics, integrating all three facets of climate considered relevant for tourism: thermal comfort, physical aspects such as rain and wind, and the aesthetical facet of sunshine/cloudiness. At the same time it is based on climate variables commonly available from weather stations and also climate models, making data provision and calculations fairly simple. However, the TCI also has a number of serious limitations that are currently being addressed by different research groups (de Freitas et al. 2008; Scott et al. 2004, 2008). The most serious limitation of the TCI is its subjectivity and lack of verification. The ratings and weighting of the different facets of climate are to a certain extent based on biometeorological and other literature but also a large portion of expert opinion, which is ultimately subjective. This limitation is currently being addressed by determining preferences with surveys (Scott et al. 2008) or in situ observations (Moreno et al. 2008). Another limitation is that the TCI implicitly assumes that the different facets are independent of each other. However, this does not hold true: de Freitas (1990) has shown that for beach use, rainfall events override all other aspects. A new generation of climate indices for tourism is now being developed that address this shortcoming by designing the index to integrate overriding effects (de Freitas et al. 2008). An alternative is to classify weather according to a limited number of different "weather types" (Besancenot 1990; Gómez Martín 2006).

In the analysis presented here, we contribute to the improvement of such indices by addressing two further important limitations of the TCI and previous applications: temporal scale and climate model uncertainty. We address these limitations in a application of the TCI to assess the effect of future climate change on climate resources for tourism in Europe. On the basis of five regional climate models we compare climate resources in the present (1961–1990) to those projected if the SRES scenario A2 were to be followed to the end of the century (2071–2100). It is important to note that the limitations addressed are not distinctive to the TCI: A low temporal resolution is a feature of many climatic indices for tourism. Also the treatment of climate model uncertainty is an improvement that can be applied to the application of any climate index.

In this application, we address the limitation of temporal scale. A shortcoming of the TCI (and other indices) is that the temporal scale of the variables used—monthly averages—is insufficient for tourism purposes (de Freitas et al. 2008). The choice of monthly resolution was probably the result of lacking daily data. Mieczkowski (1985) compared destinations throughout the world and was therefore dependent on the variables and temporal resolution provided by meteorological stations in developed as well as developing countries. However, what tourists experience and react to is the weather, the *integrated* effect of the different climatic variables on each day (Besancenot 1990). What is the value of knowing, for instance, that in a given place and month it rains 120 ml/m^2? From a tourist perspective it is evidently critical to know whether this means permanent drizzle throughout the whole month or heavy but short rainfalls only on a few days. Also the monthly aggregation of daily values as in the "number of rainy days" or "number of windy days" is only of limited use. It is the combination of all facets for each day which is relevant to the tourist. In this study, we solve this problem by adjusting the original TCI to a daily scale and calculating it on the basis of daily climate model output data. This allows determining the number of favourable days per month instead of merely the average TCI.

The second important limitation addressed in our application is the treating of climate model uncertainty in analyses of future climate change. Previous climate change studies with the TCI have used climate model output rather uncritically. Some studies have only used one climate model, which provides no indication of the associated uncertainties (Christensen et al. 2007b). However, a sense of uncertainty—or robustness—is particularly important for an index such as the TCI. Apart from temperature, which is relatively well simulated in climate models, the TCI also includes variables such as wind, precipitation, and cloud cover, which are less well represented in current climate models (e.g. Räisänen 2007). We address this by basing our analysis on five climate models and using a simple indicator to estimate the robustness of the projected TCI changes. In addition, we test the quality of the models used by comparing the simulated TCI distribution for the present to the distribution calculated on the basis of reanalysis data.

In Section 2 we describe the TCI adjustments and the climate model data used. We then present the current distribution of climate resources in Europe in Section 3, along with an analysis of the skill of models in representing this distribution. In Section 4, projected changes in mean TCI and in number of favourable days per months are shown, followed by projected changes in TCI seasonality in Section 5 and a discussion and conclusion (Section 6). Finally, the applied method is reflected upon in Section 7.

2 Methods and data

2.1 The adjusted Tourism Climatic Index

The basis for the present analysis is the Tourism Climatic Index devised by Mieczkowski (1985). It refers only to the common and general tourism activities of sightseeing and similar light outdoor activities. Evidently, different tourism activities impose different climatic requirements: Sunbathing, skiing and surfing all call for quite specific and different conditions and are not covered by the TCI. It is important to note that the TCI does not attempt to explain the current patterns of tourism activity on its own; it is an indication of whether the climate in a region is potentially suitable for sightseeing tourism, but clearly there are other important factors affecting tourism.

Table 1 Summary of the sub-indices of the Tourism Climatic Index and the climate variables used

Sub-index	Abbreviation	Weight (%)	Variables required for adjusted TCI, all daily	Availability climate model
Daytime thermal comfort	CD	40	Maximum temperature	Yes
			Afternoon water vapour pressure	No, mean water pressure taken (see below)
Average thermal comfort	CA	10	Mean temperature	Yes
			Mean water vapour pressure	No, calculated from daily dew temperature or specific humidity
Sunshine	S	20	Sunshine hours	No, calculated from cloud cover
Precipitation	R	20	Precipitation	Yes
Wind appreciation	W	10	Wind speed	Yes
			Maximum temperature	Yes

The TCI combines five climatic aspects relevant for tourism, listed in Table 1: *daytime comfort* (*CD*), *average (or daily) comfort* (*CA*), *sunshine* (*S*), *precipitation* (*R*) and *wind* (*W*), all of which are calculated in their own specific units and then rated on a scale from −3 to 5 (or 0 to 5 for sunshine and wind).

Both *daytime* and *average comfort* indices combine temperature and relative humidity to an index that reflects thermal comfort. The index used is the "(new) effective temperature" presented by ASHRAE (1972) and originally developed by Gagge et al. (1971). The *daytime comfort* uses maximum temperature and minimum humidity as they are expected to occur in the afternoon, which is when tourists are supposed to be most active. This is also why this sub-index is given most weight in the overall TCI. The *average comfort* uses the same formula but is calculated with 24 hour averages of temperature and humidity in order to include the effects of very hot or cold night-times. In both cases, the maximum rating of 5 is given for new effective temperature between 20 and 27°C. *Sunshine* is considered a positive feature throughout and its score increases with absolute duration of sunshine per day. Equally direct, the unfavourable feature *precipitation* is measured by the mean monthly amount of precipitation. In contrast to the other sub-indices *wind* is rated by means of four different scales. It is generally assumed to be an unfavourable variable, with lowest wind speeds assigned the optimum value of 5. For hot conditions the same principle applies but lowest wind speeds are assigned a maximum of 2. For very cold conditions a wind chill rating is applied. Finally there is a fourth rating system for higher temperatures where moderate wind is expected to have a pleasant effect due to evaporative cooling. By combining all sub-indices the overall TCI is then calculated: $\mathrm{TCI} = 2\,(4\,\mathrm{CD} + \mathrm{CA} + 2\mathrm{R} + 2\,\mathrm{S} + \mathrm{W})$. As all sub-indices have a maximum score of 5, this aggregation leads to an overall maximum score of 100, with acceptable scores lying above 40, good scores above 60 and excellent scores above 80 (see Table 2). For more details we refer the reader to the original paper (Mieczkowski 1985).

We made three small adjustments to this original index. One is necessary for the change from monthly to daily data: Mieczkowski rated monthly precipitation on a scale from 0 to 5. This scheme was changed by simply dividing the monthly values by 30 to obtain a rating scheme based on daily values.

The two additional modifications update the indicators to reflect a more current state of knowledge. Following Scott et al. (2004), the thermal comfort is no longer measured by the "new effective temperature" (Gagge et al. 1971) but instead by the "apparent temperature" (Steadman 1984). In addition, the original "wind chill

Table 2 Rating categories of the Tourism Climatic Index (Mieczkowski 1985)

TCI score	Category	Mapping category
90–100	Ideal	Excellent
80–89	Excellent	
70–79	Very good	Very good and good
60–69	Good	
50–59	Acceptable	Acceptable
40–49	Marginal	
30–39	Unfavourable	Unfavourable
20–29	Very unfavourable	
10–19	Extremely unfavourable	
< 10	Impossible	

index" (Siple and Passel 1945) used for one of the four wind rating schemes suffers from some serious shortcomings and was replaced by the wind chill equivalent temperature (Osczevski and Bluestein 2005).

All climatic variables necessary to calculate the adjusted TCI are listed in Table 1. Three of the variables were not available from climate models in the exact format required and therefore had to be calculated: As the number of sunshine hours were not directly available from climate models, they were derived from cloud cover data as suggested by Amelung (2006). We rejected an alternative calculation method using solar radiation data (Yorukoglu and Celik 2006), as it performed very poorly at high latitudes. Also the humidity data was not available in the right format: mean water vapour pressure had to be calculated from the mean dew temperature with saturation formulas (over ice and over water; Murray 1967) or from specific humidity and atmospheric pressure. Finally, the afternoon water vapour pressure was required. As this variable was not available from climate models, the mean water vapour pressure was used. For days with relatively stable weather conditions, this should not overly distort results, as vapour pressure remains quite stable (while relative humidity decreases with increasing temperatures in the afternoon).

2.2 Calculations

We used the daily data from regional climate models for Europe (see below) to calculate the TCI for present conditions (1961–1990) as well as for projected future conditions. For future conditions, 2071–2100 was the only time frame available for data in daily resolution from multiple models for Europe. From a tourism perspective, this is a horrendously long time frame, well beyond that of tourism researchers let alone entrepreneurs. On the other hand, most climate change patterns tend to scale linearly with increasing temperature (Meehl et al. 2007), so qualitatively similar trends with smaller magnitude can be expected in the nearer future. All future simulations are based on the SRES A2 scenario (Nakicenovic et al. 2000), as this was the scenario that most available models were run with. It also has the advantage of a high signal to noise ratio, as the warming is rather large in that scenario. Main assumptions of this A2 world are a large population growth, regionally oriented economic growth and comparatively slow economic growth and technological change, resulting in a global average surface temperature increase of above 3°C by 2100 compared to 1990 (Meehl et al. 2007; Nakicenovic et al. 2000). As discussed above, projected climate change patterns for most scenarios are qualitatively similar for a given model. On smaller spatial scales and for variables other than temperature, the projection uncertainty is mostly dominated by the model uncertainty. It is therefore less important to include different scenarios, but crucial to use as many models as possible to account for the model uncertainty in these calculations.

In addition, we tested the ability of the models to represent the current climate conditions relevant to tourism. The ideal way of achieving this would be to compare TCI results of the 1961–1990 model run with those calculated with observed data. However, data of observed climate on a grid is not available on a daily basis and therefore of no use in this case. Therefore, the TCI from model runs was compared to the TCI calculated with reanalysis data (see below). Reanalysis data are data generated by a long simulation with a weather forecast model, in which the atmospheric variables are continuously corrected by assimilating observational data. Therefore, the simulated weather and climate is close to observations at times and in areas and for variables where a lot of observations are available. Where no observations are present, the simulated variables are entirely determined by the model physics, and can therefore also have biases. These however are typically smaller than the biases of the regional models. As the reanalysis was only available with a lower spatial resolution, the comparison had to be carried out on this coarser grid.

In order to calculate an ensemble mean, all TCI result data were interpolated from their original (rotated) grids to a common rectilinear latitude-longitude. Two interpolations were necessary for different analyses: one onto a common high resolution grid (CRU domain) for the ensemble means of simulations runs. The second interpolation was onto the much coarser grid of the reanalysis data for the comparison of simulations to reanalysis.

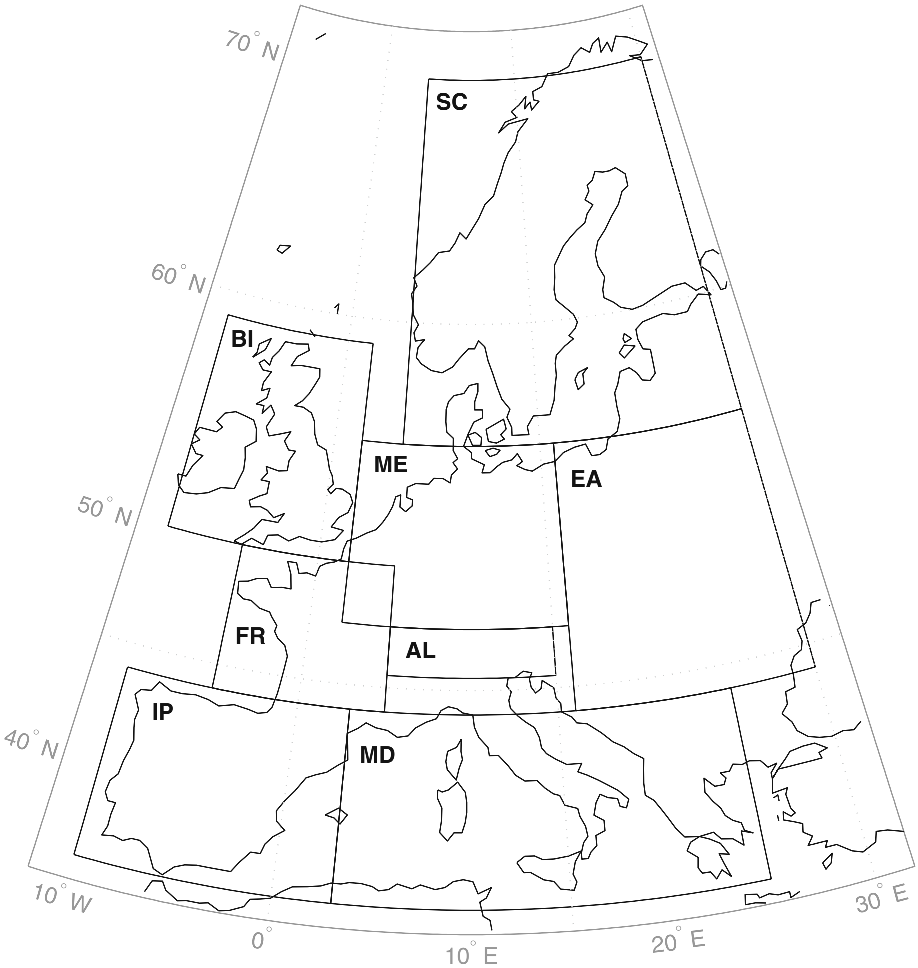

Fig. 1 The eight regions of Europe used to analyse results: British Isles (*BI*), Scandinavia (*SC*), France (*FR*), Mid-Europe (*ME*), Alps (*AL*), Eastern Europe (*EA*), the Iberian Peninsula (*IP*), and the Mediterranean (*MD*)

Table 3 Model combinations chosen for the present analysis

SRES scenario	Regional model	Driving global climate model	Resolution
A2	HIRHAM (Christensen et al. 1996)	ECHAM5	0.44° (50 km)
A2	HIRHAM (Christensen et al. 1996)	HadAM3H	0.44° (50 km)
A2	REMO (Jacob 2001)	HadAM3H	0.5° (55 km)
A2	CHRM (Vidale et al. 2003)	HadAM3H	0.5° (55 km)
A2	HadRM3P (Buonomo et al. 2007)	HadAM3P	0.44° (50 km)

Results were analysed for Europe as a whole but also for regions within Europe. The regions chosen are presented in Fig. 1 and are adapted from Christensen and Christensen (2007). Slight adaptations were made for the Alps and Mid-Europe and for the reanalysis data. Nearest neighbouring cell borders were used where the grids did not coincide. Grid cell results were area-weighted for regional averages.

2.3 Data

Two types of data sets were required for this study: Model simulations of present and projected future climate as well as reanalysis data for present climate. The climate model data were obtained from the EU-funded PRUDENCE project and are presented in Table 3. The PRUDENCE project combined different driving data with regional models, providing a series of high resolution climate change projections for Europe and allowing for a well-founded assessment of uncertainties (Christensen et al. 2007a). An important advantage of regional models is their high spatial resolution, which has shown to improve the ability of models to represent current climate (Iorio et al. 2004; Kimoto et al. 2005).

The HIRHAM/ECHAM5 model combination as well as the reanalysis data have a Gregorian calendar with 365/366 days per year instead of 360 days as all other models. To generate 360 days we rejected interpolation, as it would have systematically smoothened out the data set. Instead, 5 (or 6) days in regular intervals across the year were deleted every year.

For reanalysis, daily averages from the NCEP/NCAR reanalysis data set were used, as all required variables were available in daily resolution (Kalnay et al. 1996). Its horizontal resolution is approx. 210 km. For this data, precipitation is a variable completely determined by the model without assimilation of observational data (Kalnay et al. 1996). Therefore, reanalysis data for this variable are less reliable, as also revealed by a comparison with monthly precipitation data from other reanalysis sets (CMAP, see Xie and Arkin 1997 and ERA-40, see Uppala et al. 2005).

3 Present climate resources for tourism and the skill of models in simulating their distribution

Figure 2 presents the annual cycle of the TCI for each of the eight regions of Europe for the period 1961–1990—once calculated on the basis of the reanalysis data (thick line) and five times calculated with the regional climate models (thin dashed lines). Not surprisingly, the present distribution of climate resources in Europe strongly varies across regions and between seasons. The regional average TCI can range from just above 20 ("very unfavourable") in Scandinavian winter up to nearly 80

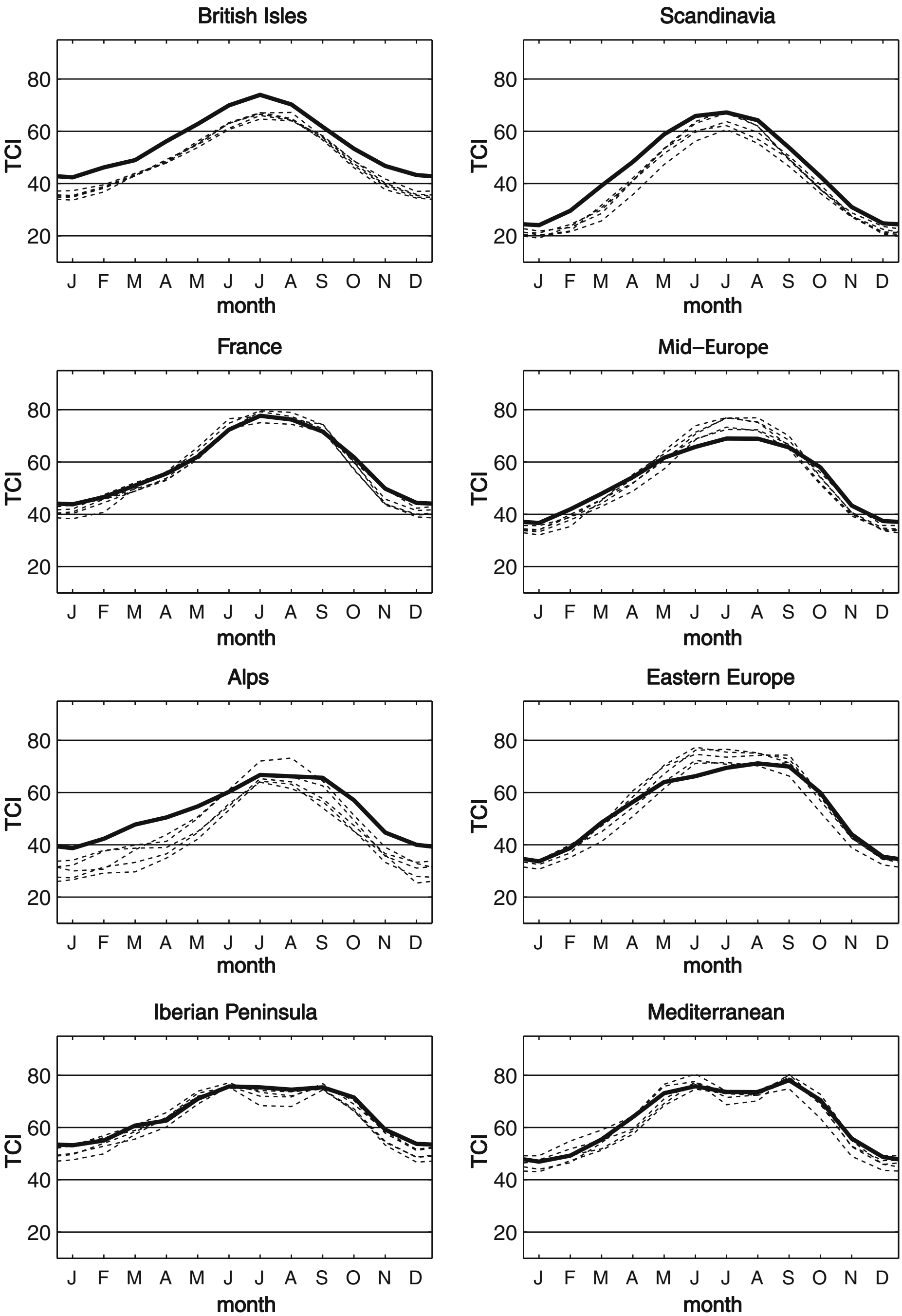

Fig. 2 Comparison of the annual cycle of the Tourism Climatic Index calculated from reanalysis (*thick line*) and model simulations (*thin dashed lines*) for eight European regions from 1961–1990

("very good") for instance in the Mediterranean in September. Most regions can be classified as "summer peak" distributions with the exception of the Iberian Peninsula and the Mediterranean that tend towards "bimodal shoulder peaks" (see Scott et al. 2004 for the typology of distributions) caused mainly by maximum temperatures rising too high in summer to be comfortable for sightseeing activities. Although all regions experience several months of "good" climate resources (TCI > 60), the differences are large: in the two southern regions there are twice as many "good" months as in the Alps or Scandinavia. If the threshold is set at "very good" conditions (TCI > 70), the Mediterranean and the Iberian Peninsula are also in the lead with six months each.

A critical test of climate model quality is to compare how well the models are able to simulate current climate. Large discrepancies between modelled and observed/reanalysis data may point out that important physical processes are not well represented. For the case of the PRUDENCE model data used, comparisons for temperature and precipitation have been carried out (Jacob et al. 2007). It is particularly important to compare simulated to reanalysis TCI results, since for some of the TCI components (in particular precipitation and cloud cover) model uncertainties are still large (Bony et al. 2006; Räisänen 2007).

The comparison between reanalysis and simulations shows that for some regions, the models achieve a very good fit with reanalysis, as for instance for France, the Iberian Peninsula, and the Mediterranean. In other regions there are significant biases. Model simulations for the British Isles and Scandinavia for instance both show a negative bias (up to nearly 10 TCI points for the ensemble mean) throughout the year. In both cases this is mainly due to a constant positive bias in precipitation and cloud cover in all five models. Together, these two variables constitute 40 per cent of the overall index. The situation is similar in the Alps where there is a pronounced negative bias except for the summer months. Here also both cloud cover and precipitation show positive biases from autumn to spring. The five models do not agree at all on seasonal precipitation patterns. The particularly negative TCI bias in spring is caused by maximum temperatures being simulated too low. In Mid- and Eastern Europe the models are a good fit except for a positive bias in summer. This can in both cases be attributed to summer biases in all three variables of maximum temperature, precipitation and cloud cover.

Most of the biases found are related to precipitation, for which reanalysis data are less reliable as mentioned above. As a result, part of the climate model biases might actually be reanalysis biases. All in all though, the models are able to simulate the TCI in Europe reasonably well. They capture both the differences between regions as well as the annual cycle of the TCI.

4 Projected changes in TCI distribution

The simulation results for the four seasons are presented in Fig. 3. It shows the ensemble mean of present and future TCI as well as the difference between the two. The predominant predicted change for many regions and seasons is a light increase of up to 10 TCI points. Only small changes are observed in the British Isles in winter and spring, a stretch from France to southern Sweden in winter, along the southern coast of the North and Baltic Sea in summer as well as the Mediterranean in autumn. The most striking change is the deterioration of the TCI across all Southern Europe

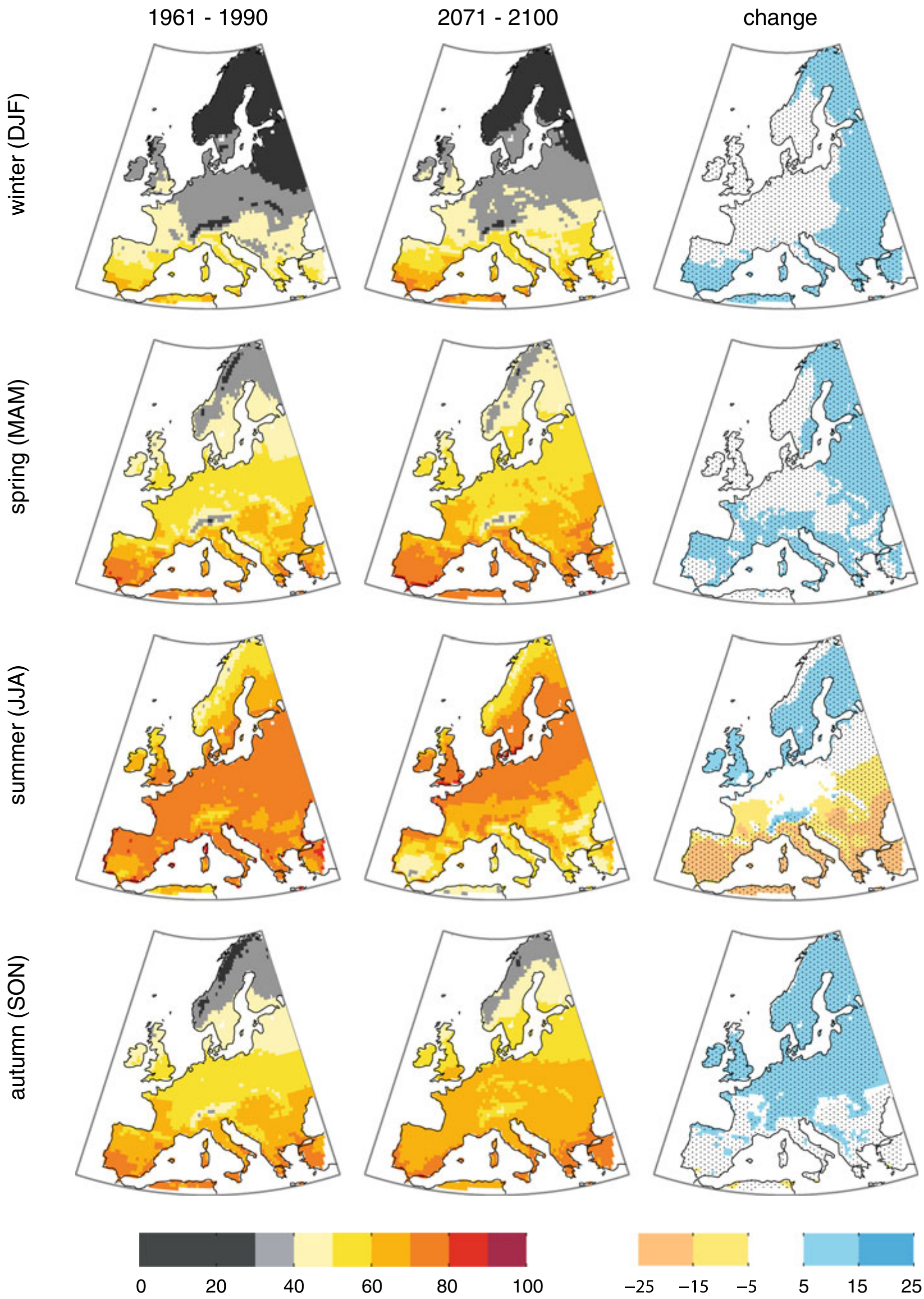

Fig. 3 Comparison of present (1961–1990) and future (2071–2100) TCI (ensemble mean) for the four seasons. Each row presents one season and shows the present TCI, the future TCI and the difference between the two. The stippling in these latter graphs denotes regions where the five models agree on the change. Models "agree" if for the difference field the multi-model mean is higher than the multi-model standard deviation

in the summer months (June, July, and August). It is most pronounced in the most southern countries but extends up to France and Poland. This decline is primarily due to the maximum daily temperature rising too high to be comfortable for light outdoor activities. Also in the summer months, a strong increase in TCI is observed in the Alps. The general change in pattern from present to future is a northwards shift of TCI patterns.

The robustness of these projected changes in TCI is tested for each grid point by calculating the difference between present and future TCI for each model. Then, the mean of these five values per grid point is compared to their standard deviation. If the mean is higher than the standard deviation, models are said to agree on the change. In the graph on projected change, model agreement is denoted by stippling. The stippling shows that in general the five models chosen agree very well on the direction of projected changes.

While the seasonally (or monthly) averaged TCI can give a general impression of climate resources in a region, it also has its shortcomings. It hides the TCI variability within a month: a TCI value of 65 can mean constant "good" conditions or very diverse conditions ranging from unfavourable to excellent. The calculation of the TCI on a daily basis allows circumnavigating this problem by simply calculating the number of "good" days per month. Figure 4 presents the average number of acceptable, good and excellent days per month for eight European regions for present and future conditions. The general form of the curves are very similar to those of mean simulated TCI in Fig. 2 and the change patterns reflect those shown by the maps in Fig. 3. A comparison of TCI change patterns with changes in the basic climate variables (not shown) reveals that the main driving force for the changes is the increase in temperature and maximum temperature across all of Europe and all seasons. Changes in cloud cover and precipitation then either amplify or dampen the temperature effects. In Scandinavia, for instance, temperature is the key cause for the increase in TCI throughout the year, as both cloud cover and precipitation hardly change. Over the British Isles, in contrast, the temperature effect is amplified in summer due to a projected increase in sunshine and decrease in precipitation, and dampened in winter due to an increase in precipitation. France, Mid-Europe, the Alps and Eastern Europe all experience similar changes: a general increase except for summer, where maximum temperature starts climbing over the optimum comfort level, leading to a drop in TCI and a shoulder peak distribution. This drop would be even more striking if it were not for slight decreases of precipitation and increases in sunshine during the summer and adjoining months. Finally, the Iberian Peninsula and the Mediterranean experience a year-through decrease in precipitation and cloud cover leading to an increase in TCI in winter and spring. In summer and the first autumn months, the increasing maximum temperature lead to the largest decreases of simulated TCI.

Our findings confirm the results of previous studies. The northward shift of favourable tourism climate as well as the "bimodal shoulder peak" distribution are changes also reported for the Mediterranean (Amelung and Viner 2006) as well as North America (Scott et al. 2004). For Southern Europe our results are similar to those of Amelung and Viner (2006). However, they state that the region displays a "summer peak" distribution in the reference period of 1961–1990, while our calculations show an attenuated "bimodal shoulder peak" distribution (see Fig. 2). This discrepancy is caused by different temporal resolutions: while our classification

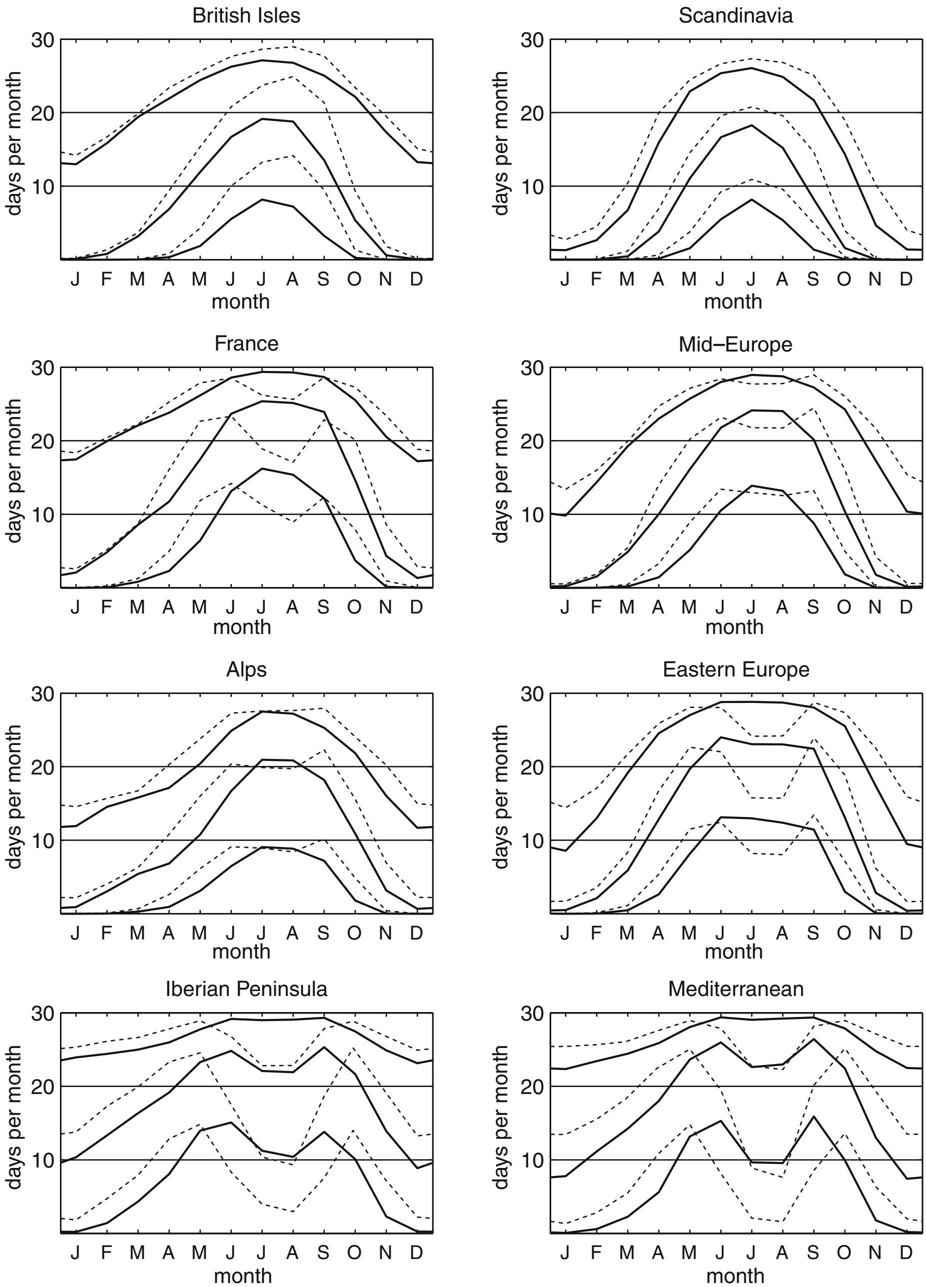

Fig. 4 Comparison of present (1961–1990, *solid lines*) and future (2071–2100, *dashed lines*) number of acceptable, good, and excellent (*top*, *center* and *bottom line pairs* within each panel) days per month for the eight European regions. Acceptable, good and excellent days are defined as having a TCI above 40, 60, and 80, respectively

is based on monthly data, theirs is based on four seasons, which hides the small dent apparent in summer.

5 Projected changes in the "seasonality" of climate resources

Seasonality is "one of the most prominent features of tourism" (Higham and Hinch 2002, p. 76) that strongly influences the character of destinations. It is predominantly viewed as a problem, particularly from an economic point of view. It causes (tourism) facilities to be crowded in high season and under-utilized in off-season and creates seasonal (un)employment with its associated problems (Getz and Nilsson 2004). For these reasons substantial effort has been put into reducing seasonality, albeit often with limited success (Getz and Nilsson 2004; Higham and Hinch 2002). In some cases seasonality has been also viewed as beneficial by allowing the resident population and environment to restore (Hartmann 1986). It is generally accepted that seasonality is caused by climatic factors and institutional factors such as the timing of holidays (Hartmann 1986). How "seasonal" is climate in Europe at present and how is its seasonality projected to change? There are different metrics that summarize the distributions in Fig. 4 from the seasonality perspective (Lundtorp 2001). We use the "seasonality ratio", which is a simple indicator used to measure seasonality in tourism (Yacoumis 1980). It is calculated by dividing the number of tourists per average month by the number of tourists in the month with maximum visitation. The maximum result of 1 would mean that visitors are distributed equally across all months and the lower the number, the higher pronounced is seasonality. The number of visitors is of course not proportional to the TCI, but we can apply this simple concept to the frequency of good days (TCI > 60) in order to determine the projected changes in the seasonality of climate resources.

Figure 5 presents climatic seasonality for the present and future as well as the change field. At present, seasonality increases with increasing latitude or height. The low seasonality of climate resources in the Iberian Peninsula and the Mediterranean, together with its overall high TCI level, explain the high suitability and attractiveness

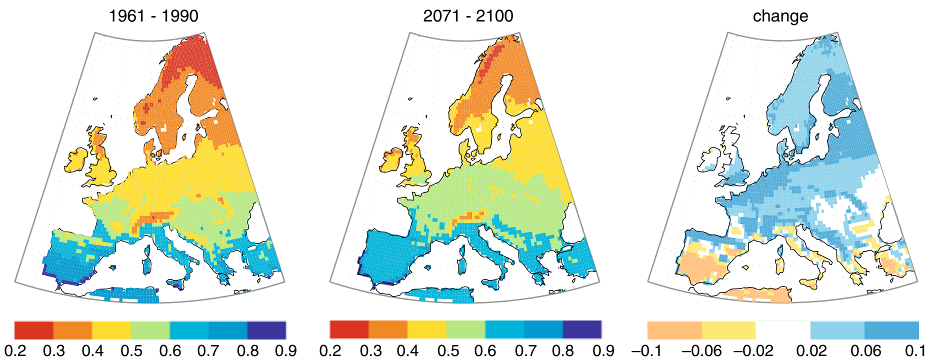

Fig. 5 Comparison of present (1961–1990) and future (2071–2100) "TCI seasonality" (ensemble mean), measured as mean number of goods days (TCI > 60) divided by the number of good days in the best month. A value of 1 represents equal number of good days for each month, the lower the value the stronger the seasonality

of the region for tourism. By the end of the century, tourism climate seasonality in most of Southern Europe is projected to slightly increase (decrease in ratio). This is primarily caused by a decrease in the mean number of good days, while the annual maximum remains the same or only decreases slightly. The decrease in mean is due to the strong drop in the summer months, while the annual maximum shifts from September to October but remains the same in absolute terms. Over the rest of Europe the mean number of good days is projected to increase and seasonality to decrease (increase in ratio). In the Adriatic region, Eastern Europe, France and Mid-Europe the increase in mean is combined with a decrease or no change in the annual maximum (regions changing from a summer peak to bimodal shoulder peaks). In Scandinavia, the British Isles and the Alps the number of good days in the best month also increases, approximately by the same amount of days as the mean. Despite the increase in both mean and maximum, the seasonality declines (the ratio increases), as for seasonality to remain equal the mean and maximum would have to increase *proportionally*. In absolute terms, the maximum would thus have to increase more than the mean.

6 Discussion and conclusion

By substantially redistributing climate resources for tourism, climate change produces "winners" and "losers" in different places and seasons. Most parts of Northern and Central Europe can be regarded as "winners" with an increase in mean number of good days accompanied by a decrease in seasonality. In Switzerland, for instance, mountainous regions sense opportunities to increase summer visitation by promoting their destination as an escape from the heat of the lowlands (Müller and Weber 2007). Most parts of Southern Europe, in contrast, seem to be "losers" with the mean number of good days decreasing on average. Moreover, the sharpest drop occurs during the summer months, when holiday activity in Europe is currently at its highest. Also, southern countries are more sensitive as they are more economically dependent on tourism than the rest of Europe (WTTC 2007). However, Southern Europe is also a "winner" – in the remaining seven months of the year, the number of good days increases. Also in absolute terms, Southern Europe still displays an overall favourable tourism climate. More than 20 days of good conditions are projected to occur in four to five months of the year. And in the winter months Southern Europe's climate is projected to be substantially more favourable than the rest of Europe with 15 good days per month in comparison to less than 5 days. In this context, it has to be kept in mind that climate acts not only as a "pull" factor but also as a "push" factor (Giles and Perry 1998; Hamilton et al. 2005). This means that "winners" of climate change do not only benefit from increases in their "pull" factor but might also experience more domestic tourism due to a reduced "push" factor.

The results we present indicate substantial redistributions of climate resources over space and time, which will undoubtedly influence the future distribution of tourism flows. However, in which way actual tourism flows will be changed can only be speculated upon. For the definition of "favourable climate" can change over time (Besancenot 1990). It seems plausible that with the gradual warming Europeans would (literally) acclimatize and also prefer warmer temperatures. The definition of "favourable climate" also differs between cultures. Lin and Matzarakis (2008), for instance, showed that Taiwanese perceived thermal conditions to be neutral at 26 to 30°C (physiologically equivalent temperature), compared to 18°C to 23°C for Middle Europeans. Where will tourists in Europe come from in 2070 and what will their preferences be? It seems impossible to say. Furthermore, climate change will not only affect tourism by changing the average weather suitability for sightseeing. Depending on the region, the suitability of average weather for skiing, hiking, or lying on the beach are equally if not more important. This might be a key reason why currently tourism flows to the Mediterranean do not match the TCI distribution. For instance in Germany, approx. 40% of all leisure trips abroad are to Southern Europe (FUR 2007). However, as apparent in Fig. 4, Germany displays an equal amount of good days and even more excellent days than Southern Europe in the holiday months of July and August. However, for many of these trips "sand and sea" is probably the main purpose. As stated in Section 2.1, the TCI only refers to general sightseeing and not to sunbathing, for which optimal or favourable climate is naturally defined differently.

It is important to recognize that next to the suitability of average weather, climate (change) also influences tourism in other ways, such as through extreme weather events, water availability, biodiversity, snow cover and sea level rise. In addition, pivotal factors determining the effect of climate change on tourism is the current sensitivity of destinations to changes in climate as well as the adaptive capacity of tourists and service providers (Perch-Nielsen 2009). A destination can fail to take advantage of improved climate resources by clinging to the current infrastructure and offers. Other destinations might flourish despite a decline in climate resources by means of unique attractions, weather independent activities or a great diversity of offers.

Our results can help tour operators and tourism planners assess and compare current climate resources and tailor their marketing accordingly. They also assist tourism planners and investors in thinking about the future. Next to projections of demographic, economic and other developments, the potential changes in climate resources are an important additional piece of information useful for locating and designing hotels and other tourism infrastructure.

7 Methodological reflections

In this paper we have addressed some of the limitations of previous TCI applications by basing our calculations on daily data as well as multiple models. We consider the use of daily data an important improvement, as for tourism it is the integrated effect of the different climatic variables on each day that is important. To test the sensitivity of the results to different temporal resolutions, we calculated the mean monthly TCI based on both daily and on monthly data. For many regions and months differences proved to be quite small. However, precisely when maximum temperatures are near the optimum, changes between daily and monthly calculations became large (10 TCI points and above). When the mean monthly maximum temperature comes to lie in the optimal range, monthly TCI values are very high. In the daily calculations, maximum temperature obviously varies from day to day and does not permanently lie in the optimum, ultimately leading to a substantially lower mean monthly TCI. Despite its clear advantages, using daily data has its drawbacks. While temperature is represented well on a daily scale (e.g. Meehl et al. 2004; Vavrus et al. 2006), models still show difficulty in representing daily precipitation patterns and achieve better results on a more aggregated time scale.

The use of five regional climate models has enabled us to compare simulations and provide a sense of uncertainty for the results. For most places and seasons, there is a good agreement on the direction of projected change. The results of this study can therefore be considered quite robust. However, it also has to be taken into account that the regional models available were driven with only two different global models. As regional models are strongly controlled by their driving models, actual model uncertainty is higher than documented here (Fronzek and Carter 2007). For future research it would therefore be prudent to include a wider range of driving global models.

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