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ORIGINAL PAPER

The 2 °C global warming effect on summer European tourism through different indices

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Abstract Climate and weather patterns are an essential resource for outdoor tourism activities. The projected changes in climate and weather patterns are expected to affect the future state of tourism. The present study aims to quantify the positive or negative effect of a 2 °C global warming on summertime climate comfort in the sense of exercising activities that involve light body activity. The well-established Climate Index for Tourism (CIT) and three variants of the widely used Tourism Climatic Index (TCI) were analyzed. Additionally, a new index based on TCI and CIT was tested and compared against the precious indices. Past and future climate data of five high-resolution regional climate models (RCMs) from different Representative Concentration Pathways (RCP4.5 and RCP8.5) of the European Coordinated Regional Climate Downscaling Experiment (Euro-CORDEX) for a +2 °C period were used. The results indicate improvement in the climate comfort for the majority of European areas for the May to October period. For the June to August period, central and northern European areas are projected to improve, while marginal improvement is found for Mediterranean countries. Furthermore, in specific cases of adjacent Mediterranean areas such as the southern Iberian Peninsula, the June to August climate favorability is projected to reduce as a result of the increase to daytime temperature. The use of a set of different indices and different RCMs and RCPs samples a large fraction of the uncertainty that is crucial for providing robust regional impact information due to climate change. The analysis revealed the similarities and the differences in the magnitude of change across the different indices. Moreover, discrepancies were found in the results of different concentration pathways to the +2 °C global warming, with the RCP8.5 projecting more significant changes for some of the analyzed indices. The estimation of the TCI using different timescale climate data did not change the results on tourism significantly.

Keywords Tourism Climatic Index (TCI) · Climate Index for Tourism (CIT) · Climate change · Two degrees · Europe

Introduction

The tourism industry is the biggest and the fastest growing industry in the world. According to the World Tourism Organization, over the past decades, tourism has become a key part of our global society, increasing wealth and prosperity over the world and shaping a trillion-dollar sector (UNWTO 2014). The tourism sector not only creates new jobs in the tertiary sector but also has a multiplier effect in the economy (Rusu 2011). stimulating the industry of the primary and secondary sectors. The World Tourism Organization reports that international tourist arrivals grow in all regions and especially for arrivals in Europe despite the economic challenges. The European tourist market shares almost 52 %

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of the global arrivals and 43 % of the global receipts corresponding to €356 billion (UNWTO 2013).

Climate plays a leading role on the development of tourism activity (Perry, 1997). as weather conditions are a major factor on the preference of tourism destinations. Questionnaire results in Hamilton and Lau (2005) show that climate is among the two most important factors when deciding a travel destination. In the Eurobarometer (2012) report, more than 50 % of the interviewed tourists say they would go back to a place for its natural features, i.e., weather and landscape. Moreover, about 28 % of respondents also stated that they went on holiday for the sun or the beach.

The assessment of climate comfort for exercise tourism activities is mainly based on the evaluation of climatic variables related to human comfort and human perception. Among others, these are temperature, humidity, sunshine, radiation, precipitation, and wind (Mieczkowski 1985; Matzarakis and de Freitas 2001; Hamilton and Lau, 2005). Statistical analyses shown in Maddison (2001). Lise and Tol (2002). and Hamilton (2004) unveil the relevance of climatic coefficients as determinants of touristic demand. Also important factors reported in de Freitas (2003) are regional features, including visual factors, the physical environment, and thermal comfort, and are important to tourism. Mieczkowski (1985) is among the few that correlated the general findings of human comfort to activities related to recreation and tourism (Amelung and Moreno 2009). The Tourism Climatic Index (TCI) he proposed summarizes and combines seven climate variables in five sub-indices that, through a series of rating systems, provide a systematic basis for assessing the climatic elements that most affect the tourism experience (Mieczkowski 1985). The sub-indices related to thermal comfort are weighted to 50 % of the total sub-index weights, reflecting the pronounced importance of thermal comfort in outdoor activities. In specific, 40 % of the weight is carried by a daytime comfort index which is a measure of daytime comfort. The remaining 10 % is assigned to the mean daily comfort index, because it reflects conditions of thermal comfort over a full 24 h, including the night hours when tourist activity is significantly lower than that in the daytime (Mieczkowski 1985). but is related to the physiological effect of cool night/hot day (Hounam 1967). The construction of the index was originally based on the research of Crowe (1976) and others that explored the correlation of climatic classifications and common tourism activities, along with research from the biometeorological literature that deals with human comfort such as those of Kandror et al. (1974) and others. TCI is favored as an index because it comprises one of the most comprehensive metrics that integrate all the three essential facets of climate relevant to tourism. These facets are comprised of thermal comfort, physical aspects (rain and wind), and aesthetical facets (sunshine/cloudiness) (de Freitas 2003). TCI is used over time in a large number of studies such as those of Scott and McBoyle (2001). Amelung et al. (2007). Scott et al. (2008). Perch-Nielsen (2009). Perch-Nielsen et al. (2010). Goh (2012). Méndez-Lázaro et al. (2014). and Amelung and Nicholls (2014).

For the estimation of TCI, the climatic variables are more often considered in monthly averages, which is one of its strengths due to the ease of estimation (Mieczkowski 1985). At the same time, the monthly time-step is reported as a shortcoming of the index as it cannot describe the extreme climatic events that are largely smoothed through the monthly averaging yet which can affect the tourism attractiveness for an entire tourist season (Scott et al. 2008) or longer. The use of daily time-step climatic variables has been implemented in several studies such as those of Matzarakis (2007) and Perch-Nielsen et al. (2010). The hypothesis that a finer timescale of the climate data leads to better representation of the climate favorability is investigated in the present study. Moreover, the effect of timescale on the projected impact signal and the robustness of the results is investigated.

Another limitation of TCI that has been discussed in Freitas et al. (2008) is the subjective scoring of each sub-index and the subjective weighting of the sub-indices, as they are not validated against observations. This also aligns with Lise and Tol (2002) who state that the rating may differ along time or among different countries of tourists' origin. To resolve the drawback, Morgan et al. (2000) attempted a calibration procedure using on-site surveys in beach environments in Wales, Malta, and Turkey, in order to modify the TCI to better describe specifically the sun-sand-sea tourism. Scott et al. (2008) modified the optimum effective temperature to better describe beach-oriented tourism. Finally, Freitas et al. (2008) mention that TCI does not account for weather events that have an overriding effect on the rest of weather conditions, such as a storm in a warm summer day or very strong winds in a shiny day.

To overcome the points of criticism, Freitas et al. (2008) presented an index called Climate Index for Tourism (CIT). This index integrates the effects of climate as TCI does but also recognizes the overriding effects that certain weather conditions could pose to beach tourism (strong winds, heavy rain). The CIT is based on thermal perception determined by means of bioclimatic indices that takes into account the effect of temperature, humidity, wind speed, and radiation. Moreover, the index was calibrated against questionnaires to overcome the subjectivity in the rating scales of TCI. The results of the survey show that temperature and sunshine were tied as the most important, followed by the absence of rain and finally the absence of wind. Variants of the original methodology can also be found in the literature for different types of activities (Bafaluy et al. 2013).

In the year 2009, the G8 Summit (G8 L'Aquila Declaration 2009) concluded that global temperatures should be held lower than 2 °C above preindustrial levels in order to prevent "disastrous" climate change in several socio-economic aspects. The UNFCCC Conference carried out in the same year underlined that climate change has evolved as the greatest challenge of our time and expressed a strong political will to combat it by stabilizing greenhouse gas concentration in the atmosphere at a level. They also recognized the scientific view that dangerous anthropogenic interference with the climate system should be prevented and the increase in global temperature should be held below 2 °C. Nonetheless, the prospects of limiting the warming to this target have weakened (Sanford et al. 2014) as many experts believe that we are on the 4 °C path (Betts et al. 2010). The best available methods are being utilized by the scientific community to quantify the effect of a 2 °C warming on different social and economic sectors. The EU FP7 project IMPACT2C (Vautard et al. 2014) aims to enhance knowledge and quantify climate change impacts, vulnerabilities, and economic costs in a pan-European scale, from a 2 °C global warming.

Projected changes in climate may pose changes in the tourism industry and consequently have a negative effect on countries that owe a large share of their GDP on tourism. This study focuses on the quantification of the effect of a 2 °C global warming on the summer tourism industry for Europe, in the context of climate comfort to exercise tourism activities. Climate information derived from the most recent Coordinated Regional Climate Experiment (CORDEX) over Europe is used to estimate a series of indices that quantify the effect of climate on summer outdoor tourism. The climate effect on general outdoor tourism that engages light physical activities such as sightseeing tourism or light walk is investigated. Other resources that can be potentially affected by climate change and may pose limitations to tourism (such as water shortage due to climate change) are not analyzed.

Methodology

The TCI is a summary of ratings of five human comfort indices related to general outdoor tourism activities (Eq. 1). The first two sub-indices refer to the day and the average daily thermal comfort, respectively.

$$\mathrm{TCI} = 8 \cdot \mathrm{ClD} + 2 \cdot \mathrm{ClA} + 4 \cdot R + 4 \cdot S + 2 \cdot W \qquad (1)$$

The thermal comfort components of TCI were estimated through the Missenard (1933) equation which is shown in Eq. 2. This index was developed to describe the connection between the identical state of an organism's thermoregulatory capacity (warm and cold perception) and differing temperature and humidity of the surrounding environment (Blazejczyk et al. 2012; Bröde et al. 2012). The index provides the effective temperature as it can be sensed by humans for specific values of air temperature, relative humidity, and wind speed, which determine the thermal exchange between the organism and the environment. Under the assumptions of normal atmospheric pressure and human body temperature of 37 °C, Eq. 2 provides the effective temperature.

$$\mathrm{ET} = 37 - \frac{37 - T}{0.68 - 0.0014 \cdot R_{\mathrm{h}} + \frac{1}{1.76 + 1.4 \cdot v^{0.75}}} - 0.29 \cdot T \cdot (1 - 0.01 \cdot R_{\mathrm{h}}) \qquad (2)$$

where T is the temperature (°C), R_{h} is the relative humidity (%), and v is the wind speed (in m/s). Equation 2 estimates the CID when the maximum temperature and the minimum relative humidity are provided, while the CIA is estimated through the mean temperature and relative humidity. While it is not based on a sophisticated heat budget model, the index has been found to perform very well in comparison to the Universal Thermal Climate Index (UTCI; Broede et al. 2010). even better than some heat budget models (Blazejczyk et al. 2012). The third TCI sub-index R is the mean precipitation in millimeters, the fourth sub-index S is the mean monthly daily sunshine duration, and finally the sub-index W is the monthly mean wind speed in meters per second. Each sub-index was then rated as it is presented in Electronic supplementary material Table S1. For the thermal comfort indices CIA and CID, an optimal range is used, while values higher or lower than that range are rated with lower scores. The nonexistence of rainfall/wind is rated as optimal state for these sub-indices, while as they increase, the rating falls. In contrast, sunshine is rated proportionally to its duration. The rated TCI sub-indices are then weighted according to Eq. 1 by different weights. The summary of the weighted sub-indices is the TCI. According to the weights used, the thermal comfort is the most significant parameter of the model with a "weighting" summary of 10 for the thermal comfort sub-indices. Precipitation and sunshine duration are equally weighted with a weighting factor of 4. Finally, the wind speed is of less importance using a weighting factor of 2. The TCI is finally classified using subjective categorization (Table S2 of the supplementary material) that divides the percent scale of TCI to ten categories, with the worst category to be *impossible* and the highest category to be *ideal*. The TCI was estimated in three different variants. First, the original TCI that uses the monthly aggregates of the seven climatic variables described earlier was estimated ($\mathrm{TCI_m}$). This variant of TCI is simple to be estimated; it is robust and provides an overall picture of the climate comfort for outdoor activities. In the second variant, the daily values of the climate variables were used. This TCI variant ($\mathrm{TCI_d}$) accounts for the climate extremes that are largely moderated in the monthly aggregation of the data, hiding the effect of extreme events on the tourism activity. Similar studies can be found elsewhere (Matzarakis 2007; Perch-Nielsen et al. 2010). The third variant is a new index, a parallax of the TCI that is presented at a later section of the study.

Additionally to the TCI, the CIT (Freitas et al. 2008) was used in this study. The basic strength of this index against TCI is the recognition of overriding effects of strong rain and wind events. The CIT is expressed through the 9-point ASHRAE thermal sensation (TSN—supplementary material Table S3). The thermal sensation is then adjusted to the aesthetic appeal (A) of the sky condition ranging from clear to overcast and the physical thresholds (P) of high wind and rain. Thus, if either physical threshold is exceeded, then P overrides T and A to reduce the satisfaction rating. Thermal and aesthetic states are combined in a holiday weather typology matrix to produce a climate satisfaction rating class, ranked into seven classes, with the lowest rank to be the *very poor*, the mid class *marginal*, and the highest rank *ideal* (Freitas et al. 2008). The estimation of the thermal sensation was performed through the predicted mean vote (PMV), originally developed by Fanger (1970) and later adopted as an ISO standard (ANSI/ASHRAE Standard 55-2010). The PMV includes a series of six environmental and human factors to estimate the thermal sensation of the human body. These are the metabolic rate (met), which expresses the energy generated from the human body; the clothing insulation (clo), expressed by the amount of thermal insulation the person is wearing (see Yan and Oliver 1996). the air temperature, the radiant temperature which is the weighted average of all the temperatures from surfaces surrounding an occupant; wind speed; and relative humidity. For the conducted analysis, a thermal insulation of 0.9clo was considered, following the standard thermal insulation of Matzarakis and Mayer (1996) and Matzarakis (2006). Moreover, a metabolic rate of 2.3met was considered, which corresponds to very light body activities such as walking at a speed of 2.7 km/h on level ground, a very slow stroll according to Ainsworth et al. (2000).

The third TCI variant, TCI_t, is a new modification of the TCI_d. This modification uses thresholds in the same manner that CIT uses them to account for the effect of wind and precipitation on outdoor activities in a more realistic way compared to the original TCI_d. The subscript "t" stands for the "thresholds" that are used in it. The degree in which precipitation and wind reduces the TCI is borrowed from the corresponding percent changes that are used in the CIT scales for wind speeds over 6 m/s and precipitation over 3 mm/day. For example, the mean reduction in the CIT ratings (across all nine TSN scales—Table S3) when the wind speed is higher than 6 m/s is 30 %. The same percent in reduction was used to estimate the TCI_t from the TCI_d, as a post-processing procedure. Thus, when the wind speed is higher than 6 m/s, the TCI_d is multiplied by a factor of 0.7. Regarding the precipitation over 3 mm/day, the respective reduction in the mean CIT ratings for daily precipitation over 3 mm is 64 %. The conversion factors are shown in Table 1.

The purpose of this TCI variant was the examination of the weather condition thresholds over TCI and how this modification would potentially improve the TCI in a way to provide results comparable to the CIT.

Study area and datasets

The change in TCI was estimated for the European domain covered by the Euro-CORDEX. Two 30-year periods were considered, a reference period between 1971 and 2000 and a future +2 °C period defined according to the Representative Concentration Pathways (RCPs) RCP4.5 and RCP8.5 and the corresponding global climate model (GCM). The +2 °C period was explicitly defined for each model as the period in which each driving GCM reaches this specific level of global warming comparing to the preindustrial baseline period 1881–1910 (Vautard et al. 2014). The 30-year time slice around which the +2 °C period is defined for each GCM is shown in Table S4. The horizontal resolution of the RCM data was 25 km × 25 km. For the calculations, mean, minimum, and maximum temperatures; mean and minimum relative humidity; precipitation; wind speed; and sunshine duration data were used. Temperature variables and precipitation were obtained in bias-corrected form by using the model output statistic (MOS) approach as described by Themeßl et al. (2011). Details and theoretical justification of the methodology can be found in Maraun et al. (2010) and Deque (2007). It is shown in Vautard et al. (2014) that this methodology provides stable and better results than the uncorrected model output while it is also very successful in removing biases and adjusting distributions (Themeßl et al. 2011). The observational dataset they used for the bias correction process was the version E-OBS v5.0 (Haylock et al. 2008). The analysis of the indices was carried out for two different periods. The first period considered was May to October that includes the summer months, along with the late spring and early autumn period. In these months, the summary of the summer tourism activities takes place in European countries. Additionally, a second period of summer high season between June and August was considered. These three months represent the high season of summer tourism activities in Europe.

The Electronic supplementary material Figures S1 to S6 present the change in the different climate variables used in the study.

Results

Present climate results

Initially, the baseline climate (1971–2000) results for the different indices are discussed, as regards the ensemble average results between the five RCMs. Figure 1 shows the spatial

Table 1 Conditional application of multiplication factors to estimate TCI_t from TCI_d

	If wind speed ≥6 m/s	If rain >3 mm
TCI_d to TCI_t conversion factor	$TCI_t = 0.7 * TCI_d$	$TCI_t = 0.36 * TCI_d$

distribution of CIT and the three TCI variants' results for the two periods: May to October and June to August. Additionally, Fig. 2 shows the country-level aggregates for the EU-27 countries (Table S5). In this figure, the proximity of the points to the bisectrix of the diagram illustrates the similarity of the two compared indices. A first expected common feature across the different indices is that the June to August (JJA) results show increased climate comfort comparing to the May to October (MJJASO) results (Fig. 1). This is attributed mainly to the higher average

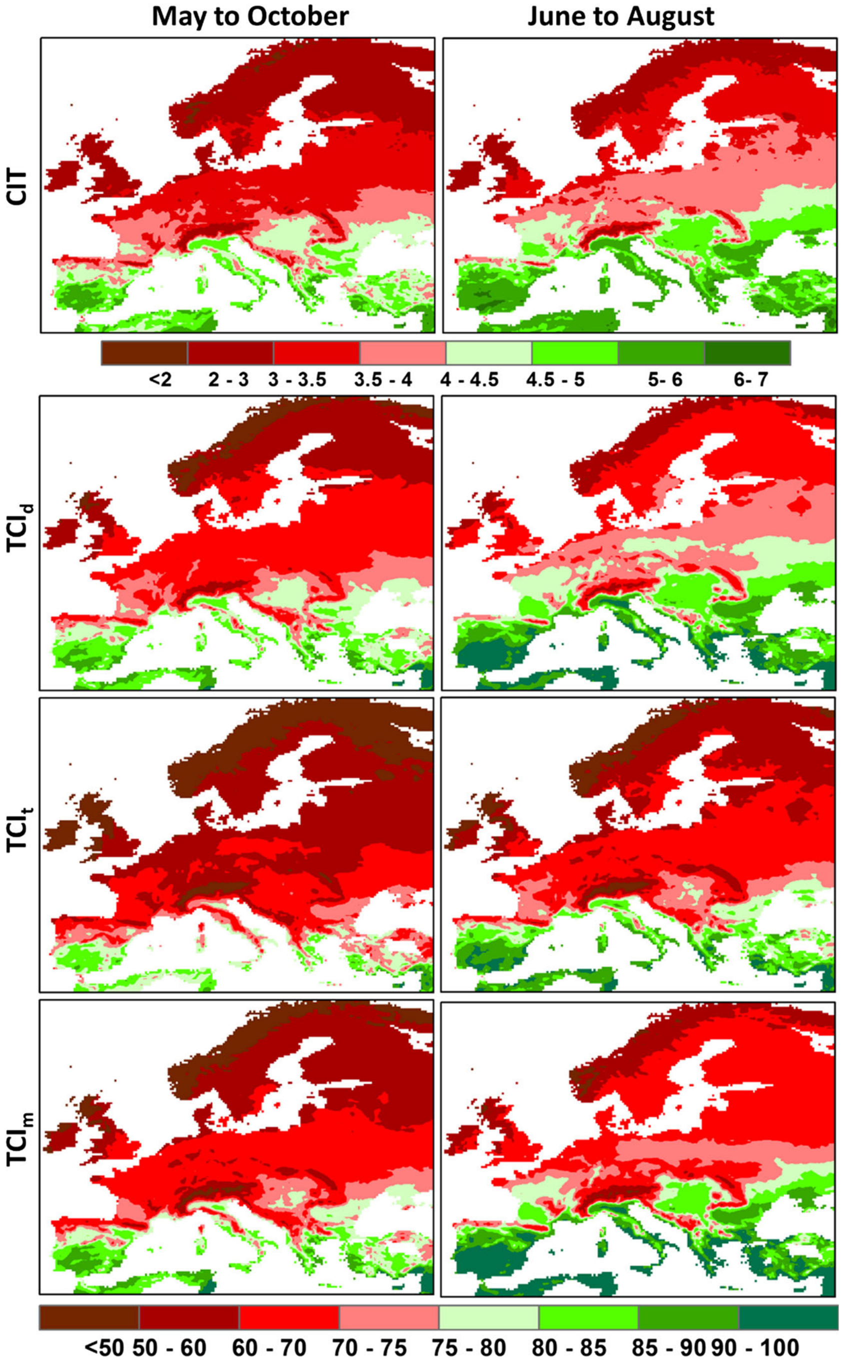

Fig. 1 Comparison of the different index results for the baseline period. The May to October averages (*left*) and the June to August averages (*right*) are shown

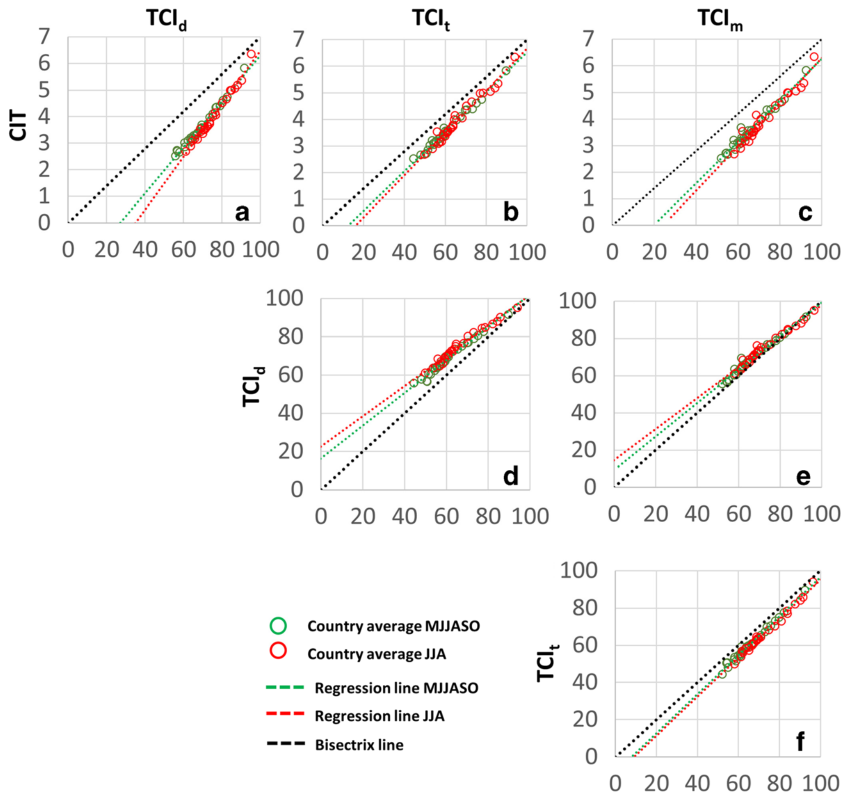

Fig. 2 Comparison of all indices for the baseline (1971–2000) period. *Green dots* refer to the May to October period, while *red dots* refer to the June to August period. Each *dot* represents the country average of each index for the EU-27 countries

temperatures in the JJA period than the respective MJJASO period.

Based on Figs. 1 and 2, the different indices are analyzed one by one, along with the appropriate comparisons between them. First, the CIT is shown to rate the JJA (MJJASO) southern parts of the Mediterranean countries between 5 and 7 (4.5 and 6) in the CIT scale with 7 to be the *ideal* while central and northern Europe are ranked between 3 and 4, which is translated to *marginal* or even lower.

The $\mathrm{TCI_d}$ rates the southern parts of the Mediterranean countries for JJA (MJJASO) between 85 and 100 (80 and 90) that is translated to *excellent* and *ideal*, while central and northern Europe are ranked between 50 and 75 that is translated to *acceptable* and *very good*. Figure 2a compares the aforementioned indices and confirms the more optimistic result of $\mathrm{TCI_d}$ compared to the CIT.

The $\mathrm{TCI_d}$ modification using thresholds, the $\mathrm{TCI_t}$, results in an overall decrease of climate favorability for both periods (Fig. 1). This reduction is found to adjust the $\mathrm{TCI_d}$ towards CIT. This is also seen in the respective section of Fig. 2, which shows that the resulted reduction is larger in northern Europe than in southern Europe (expressed as the affinity of the red and green trend lines to the bisectrix in Fig. 2b compared to Fig. 2a).

Finally, the TCI estimated on the monthly data ($\mathrm{TCI_m}$) shows results similar to those of the $\mathrm{TCI_d}$, as it is shown in Fig. 1. The similarity is higher though in southern Europe, while central and northern Europe are rated a bit stricter in $\mathrm{TCI_m}$. This is also depicted in Fig. 2, where the $\mathrm{TCI_d}$ and $\mathrm{TCI_m}$ country averages are very close to the bisectrix. It has to be noted that the aforementioned indices show the best proximity to the bisectrix (Fig. 2e). This leads to a first indication that the finer temporal scale of $\mathrm{TCI_d}$ does not significantly change the outcome as given by the $\mathrm{TCI_m}$. The robustness of the different RCM results for the baseline period was assessed by estimating the coefficient of variation (CV) between the different climate models' results. The two indices that make use of thresholds in wind and precipitation (CIT and $\mathrm{TCI_t}$) exhibit the higher CV values. This is attributed to the increased variability of wind simulations across different models that can be seen in Figure S7 and the difference in the precipitation simulations shown in Figure S6. The CV of CIT ranges between 2 and 8 % in the majority of Europe, while small areas of eastern Spain, south France, south Greece, Turkey, and Sardinia showed higher CVs. The $\mathrm{TCI_t}$ provided CV values as high as 10 %, mainly in the adjacent Mediterranean areas and Norway, while the rest of Europe showed lower CV values as low as 3 %. The CVs for the $\mathrm{TCI_d}$ and $\mathrm{TCI_m}$ ranged in even lower values. For the majority of Europe, the CV was estimated to be as low as 1.5 %, while the CV for the mountainous regions of Alps, Pyrenees, and Kjolen ranged as high as 3 %. Precipitation variability among different model simulations (even after a bias adjustment) and wind climatology are in some cases more poorly depicted by

RCMs compared to other parameters such as temperature. The spatial distribution of CV can be found in Figure S8.

Results under +2 °C global warming

A comprehensive picture of the European climate at a +2 °C global warming is presented by Vautard et al. (2014). They show that a +2 °C global warming will result in an increase in the European temperature ranging from +2 to +3 °C with regional warming over Europe exceeding the average global warming in most areas except the British Isles and Iceland. According to the same study, summer (JJA) precipitation is also expected to decrease in north Portugal and Spain, the larger part of France, and Balkans; however, it is expected to increase only over the northern Scandinavian Peninsula. These changes in the precipitation and temperature, along with the changes in wind, cloudiness, and humidity, affect the CIT and the three TCI variants that were studied here. Despite the similarities between the studied indices, the projected changes in a +2 °C global warming period vary among them. Figure 3 shows the percent change of each index in the +2 °C Europe for the MJJASO and JJA periods. Comparisons of the percent changes projected from different indices in country aggregates are shown in Fig. 4.

The percent change for each studied index was estimated between the baseline and the +2 °C periods. Positive changes indicate improvement towards a more favorable climate for tourism. The projected change signal in CIT is clearly stronger towards the other indices. The changes in CIT are estimated between 5 and 10 % across the two different RCPs, while all TCI variants project lower changes, between −3 and 8 %. It has to be noted that the three TCI variants provide roughly the same changes in the +2 °C, with small differentiations. The TCI_t projected the most severe among them (Fig. 3) in the RCP8.5. Moreover, TCI_t provides larger positive changes, leading to the conclusion that the threshold-exceeding events

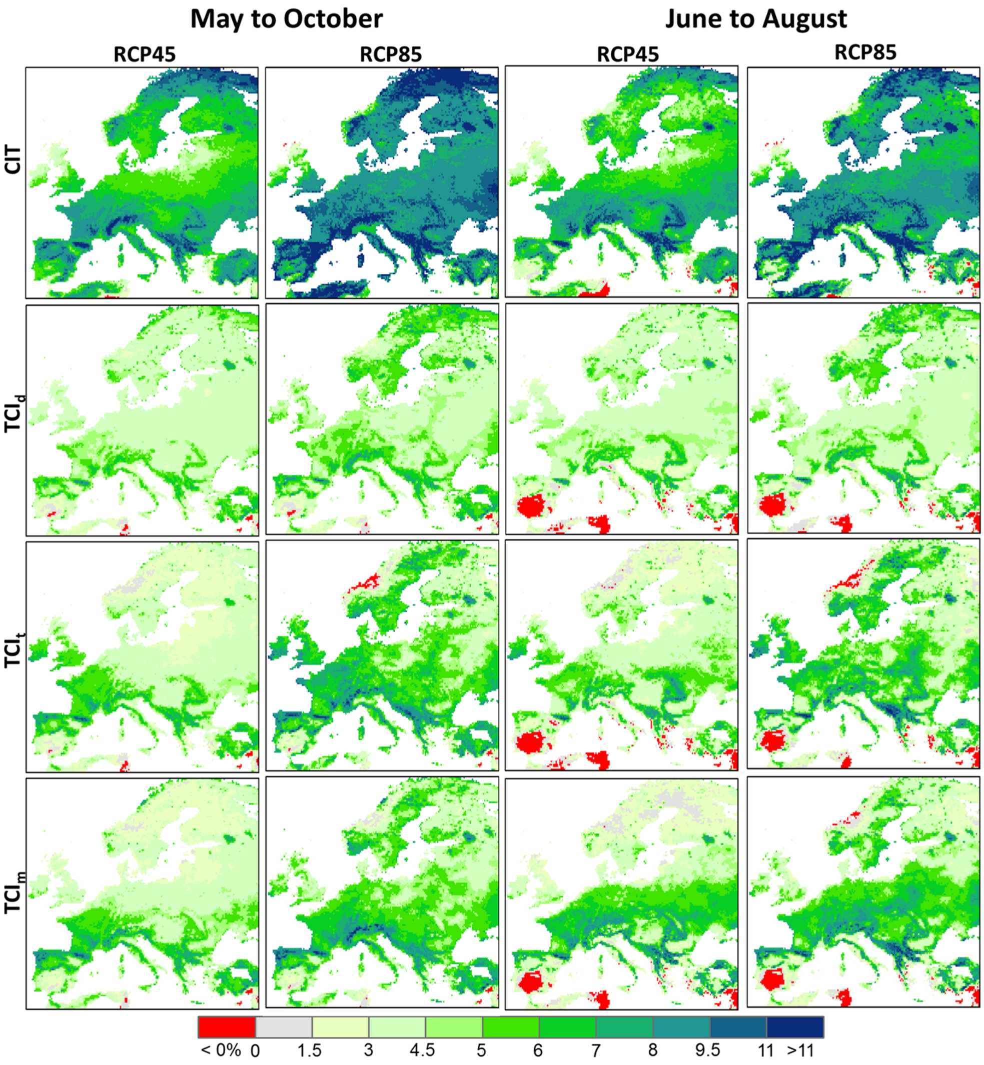

Fig. 3 Change of each index at the 2 °C period compared to the baseline period

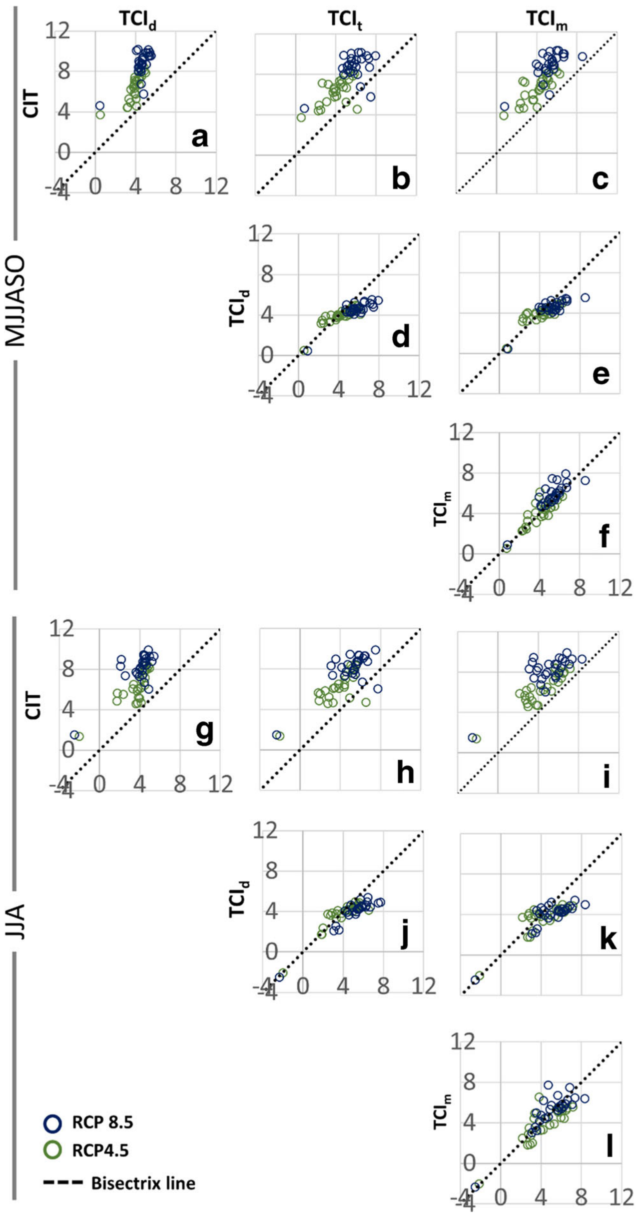

Fig. 4 Comparison of the different indices' projected changes between the 2 °C and the baseline period for May to October (*upper*) and June to August (*lower*). *Blue dots* indicate the RCP8.5 results while *green dots* indicate the RCP4.5 results

of wind and/or precipitation will reduce at the +2 °C period. The TCI_m was found to project changes in the +2 °C period compared to the former.

Some areas though are expected to experience reduced climate favorability under +2 °C relatively to the reference period (Fig. 3). The CIT results show an increase in the climate favorability in all European countries, in both MJJASO and JJA periods with the only exception being Cyprus and small areas of Greece for the JJA period. The TCI-based indices however project a decrease in JJA climate favorability in extended regions, mainly of Spain and Portugal, some regions of Italy, Greece, and Cyprus. The decrease is attributed to the increase in the daytime temperature that leads to thermal comfort level over the optimum in CID (Figure S9).

The comparison between the TCI variants also reveals that TCI_d projects similar change to the TCI_m (Fig. 4(e, k)), indicating that the lower temporal resolution of the latter does not alter the projected signal significantly.

It is important to note the discrepancies between the projected changes of RCP4.5 and RCP8.5, even if both scenarios are focused at the +2 °C global warming. The RCP8.5 scenario projects more pronounced changes in all tested indices, mainly for the MJJASO period and mainly in the CIT and TCI_t indices (Fig. 3). These discrepancies are found to be greater in central and northern Europe than in southern Europe and the Mediterranean region, due to the difference in the wind projections between the two RCPs (Figure S7). Figure 5 presents the latitudinal averages of the projected index change. In both MJJASO and JJA, CIT was found to exhibit the largest deviation between RCP4.5 and RCP8.5. Opposing to the latter, TCI_d-projected changes are found to be very similar, with the JJA period to be almost identical. Nonetheless, the TCI_t is adjusted towards CIT, providing deviation between RCP4.5 and RCP8.5 similar to that in CIT. This indicates that the discrepancies between the RCP4.5 and RCP8.5 are attributed to differences in the frequency of wind events over the thresholds.

Overall, the projections of all the examined indices under the two different RCPs at +2 °C and for both JJA and MJJASO periods summarize that Western European countries will exhibit the largest percent increase in the modeled favorability (6.1 %), followed by Eastern Europe (5.5 %), the Nordic countries, and the UK (4.95 %). The Mediterranean region is expected to substantially increase its climate favorability in the May to October period (5.7 %) but at the same time is expected to have the smallest increase in the June to August period (3.9 %), compared to the other regions.

In order to quantify the contribution of the different climate forces to TCI, the ensemble estimation of each sub-index was estimated for the baseline and the +2 °C period. The estimation was performed on the TCI_d. The sub-index results are presented in Figure S8. The results indicate that the major contribution to the TCI can be attributed to the CID thermal comfort index that accounts for the daytime comfort and is estimated through maximum temperature and minimum relative humidity. Its contribution has a theoretical maximum of 40 units according to the estimation formula. For the JJA period, the sub-index increases in the majority of Europe due to the increase in the maximum temperature (Figure S2) in Europe, while the areas in which a decrease in TCI was earlier identified are also found in the CID sub-index. Next, in terms of contribution, the sub-indices sunshine duration and precipitation (Figure S8) contribute to as high as 20 units to the TCI. The sunshine duration sub-index at the +2 °C period

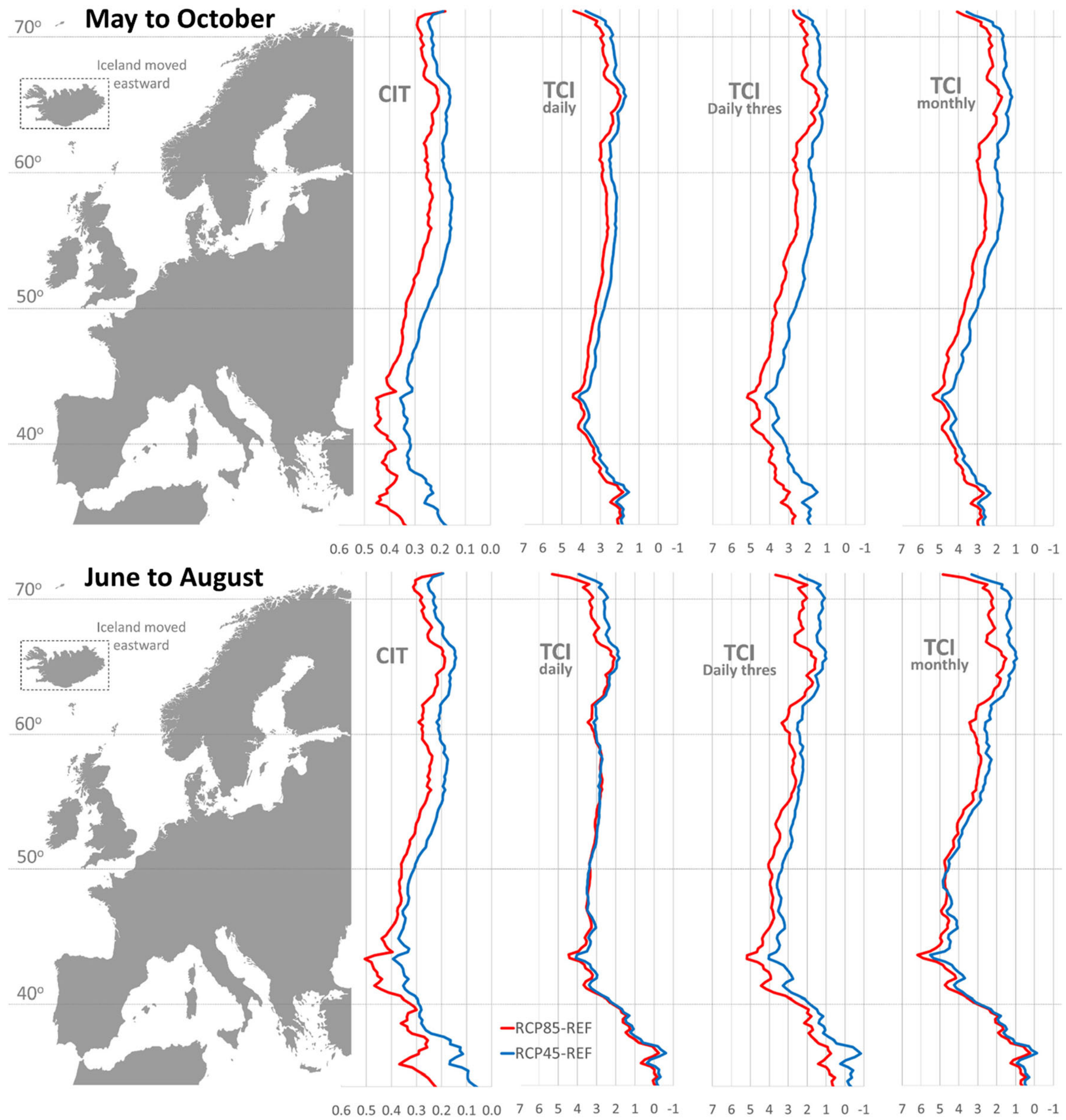

Fig. 5 Latitudinal (*vertical axis*) change of each studied index, scenario, and season. The *lines* indicate the difference between the 2 °C period and the reference period

does not show significant alterations compared to the baseline period. Unlikely, the precipitation-based sub-index shows improvement in southern Europe for the JJA period. This result is in line with the precipitation trends shown in Vautard et al. (2014) and also in Figure S6. Finally, the two parameters that contribute less to TCI is the CIA sub-index that accounts for the average daily comfort and the wind speed. The CIA sub-index is shown to improve in the +2 °C period compared to the baseline, as a result of the increase in the mean daily temperature shown in Figure S1. The last sub-index which is related to wind speed does not show significant changes at +2 °C. As a result of the analysis of the components of TCI-based indices, it can be concluded that the parameters that contribute to the change in the future TCI regime are the maximum temperature and minimum relative humidity that are related to CID and precipitation, mean temperature, and mean relative humidity that are related to CIA. As for the sunshine duration parameter, while it has an increased weight in the TCI formulae, it is not expected to change significantly as a result of +2 °C of global warming.

Conclusions

This study uses well-established methods to quantify the effect of a +2 °C global warming on the European region's summer tourism favorability. Besides a number of discussed differences, the RCMs provided consistent information about the increase in climate favorability related to summer tourism under the +2 °C of global warming in most European regions. The projected changes in the examined climate variables will have profound changes to the climate comfort levels as estimated by the Climate Index for Tourism and three variants of the Tourism Climatic Index. Some areas are likely to exhibit a substantial increase in climate favorability in the entire summer period. Mediterranean countries will be among the least benefited, with the southernmost parts of them to become less appealing in the June to August period due to a shift in temporal patterns of climate favorability. The results verify the direction of change shown in other studies (Amelung et al. 2007; Amelung and Moreno 2009; Perch-Nielsen et al. 2010). Under the simulated pace of climate change, the presented results refer to the period between 2016 and 2045 under the RCP8.5 or 2037–2066 in the case of the RCP4.5. The results of this study quantify the effect of +2 °C global warming on the European summer climate favorability for tourism and emphasize the spatial extent of the most affected areas. These areas should be a priority for adaptation measurements. It should be pointed here that, due to the design of TCI indices, the results describe changes in the favorability of general summer tourism activities that involve light body activity, while the CIT was parameterized to that direction as it is described in the "Methodology" section. Hence, the results may not represent the changes in coastal tourism as is shown in Rutty and Scott (2015), who concluded that optimal beach conditions are much warmer than those considered in the present study and other studies in the literature (Lise and Tol 2002; Hamilton and Lau 2005; Amelung and Viner 2006; Scott et al. 2008; Perch-Nielsen et al. 2010).

Important findings came from the comparison between the results of the TCI estimated using daily and monthly time-step climate data. The TCI based on daily data provided similar information to the TCI based on monthly data, both in the baseline climate and also under the +2 °C period. Considering the difference in the amount of data needed in the TCI estimation on a daily and monthly basis, it can be said that monthly data can be used for the TCI estimation without significant information loss when compared to the daily time-step. Moreover, a new variant of the daily TCI was introduced and tested, using threshold values to account for the overriding effect of strong wind or rainfall. It was found that the TCI_t results approached the respective results of CIT. Overall, the CIT is found to be the most optimistic, showing an increase in the climate favorability in the whole of Europe under +2 °C of global warming.

The comparison of the +2 °C global warming under different RCP scenarios revealed differences in the results, even if both scenarios are focused at +2 °C. Some indices are found more sensitive though. The RCP8.5 scenario projects more pronounced changes in all tested indices for the MJJASO period, mainly in CIT and TCI_t indices that use thresholds in precipitation and wind parameters. This is attributed to the differences in precipitation and wind distribution under or over the thresholds applied.

The conclusions of the presented analysis are subject to a number of limitations. The climate favorability index approach covers only a single aspect of the effect that climate might have on tourism, by not considering changes in water availability, aesthetic parameters, etc. Moreover, the indices used here consider a single view of an optimal climate, while in reality this view differs culturally.

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References

Ainsworth BE, Haskell WL, Whitt MC, et al. (2000) Compendium of physical activities: an update of activity codes and MET intensities. Med Sci Sports Exerc 32:S498–S504

Amelung B, Moreno A (2009) Impacts of climate change in tourism in Europe. PESETA-Tourism study - Publication - IPTS Web Site.

Amelung B, Nicholls S (2014) Implications of climate change for tourism in Australia. Tour Manag 41:228–244. doi:10.1016/j.tourman.2013.10.002

Amelung B, Nicholls S, Viner D (2007) Implications of global climate change for tourism flows and seasonality. J Travel Res 45:285–296. doi:10.1177/0047287506295937

Amelung B, Viner D (2006) Mediterranean tourism: exploring the future with the Tourism Climatic Index.

Bafaluy D, Amengual A, Romero R, Homar V (2013) Present and future climate resources for various types of tourism in the Bay of Palma, Spain. Reg Environ Chang 14:1995–2006. doi:10.1007/s10113-013-0450-6

Betts RA, Collins M, Hemming DL, et al. (2010) When could global warming reach 4 C? Philos Trans R Soc A Math Phys Eng Sci 369:67–84. doi:10.1098/rsta.2010.0292

Blazejczyk K, Epstein Y, Jendritzky G, et al. (2012) Comparison of UTCI to selected thermal indices. Int J Biometeorol 56:515–535. doi:10.1007/s00484-011-0453-2

Bröde P, Fiala D, Błażejczyk K, et al. (2012) Deriving the operational procedure for the Universal Thermal Climate Index (UTCI). Int J Biometeorol 56:481–494. doi:10.1007/s00484-011-0454-1

Broede P, Jendritzky G, Fiala D, Havenith G (2010) The Universal Thermal Climate Index UTCI in operational use

Crowe RB (1976) A climatic classification of the Northwest Territories for recreation and tourism. Environment Canada, Toronto, Canada

de Freitas CR (2003) Tourism climatology: evaluating environmental information for decision making and business planning in the recreation and tourism sector. Int J Biometeorol 48:45–54. doi:10.1007/s00484-003-0177-z de Freitas C, Scott D, Gössling S (2008) Preferred climates for tourism: case studies from Canada, New Zealand and Sweden. Clim Res 38: 61–73

Deque M (2007) Frequency of precipitation and temperature extremes over France in an anthropogenic scenario: model results and statistical correction according to observed values. Glob Planet Change 57:16–26. doi:10.1016/j.gloplacha.2006.11.030

Eurobarometer (2012) Flash Eurobarometer 334: attitudes of Europeans towards tourism. Datasets

Fanger PO (1970) Thermal comfort: analysis and applications in environmental engineering. McGraw-Hill.

G8 L'Aquila Declaration (2009) G8 and newly industrializing countries agree on 2-degree target for the first time

Goh C (2012) Exploring impact of climate on tourism demand. Ann Tour Res 39:1859–1883. doi:10.1016/j.annals.2012.05.027

Hamilton J.M., MA. Lau (2005) The role of climate information in tourist destination choice decision-making.

Hamilton JM (2004) Climate and the destination choice of German tourists. SSRN Electron J. doi:10.2139/ssrn.504362

Haylock MR, Hofstra N, Klein Tank AMG, et al. (2008) A European daily high-resolution gridded data set of surface temperature and precipitation for 1950–2006. J Geophys Res 113:D20119. doi:10.1029/2008JD010201

Hounam CE (1967) Meteorological factors affecting physical comfort (with special reference to Alice Springs, Australia). Int J Biometeorol 11:151–162. doi:10.1007/BF01426842

Kandror I, Demina D, Ratner Y (1974) Fiziologicheskye prin-cipy sanitarno—klimatologicheskogo rayonirovanya terri-toriè SSSR.

Lise W, Tol RSJ (2002) Impact of climate on tourist demand. Clim Change 55:429–449. doi:10.1023/A:1020728021446

Maddison D (2001) In search of warmer climates? The impact of climate change on flows of British tourists. Clim Change 49:193–208. doi:10.1023/A:1010742511380

Maraun D, Wetterhall F, Ireson AM, et al. (2010) Precipitation downscaling under climate change: recent developments to bridge the gap between dynamical models and the end user. Rev. Geophys 48: RG3003. doi:10.1029/2009RG000314

Matzarakis A (2007) Assessment method for climate and tourism based on daily data.

Matzarakis A (2006) Weather- and climate-related information for tourism. Tour Hosp Plan Dev 3:99–115. doi:10.1080/14790530600938279

Matzarakis A, de Freitas C (2001) Proceedings of the first international workshop on climate, tourism and recreation.

Matzarakis A, Mayer H (1996) Another kind of environmental stress: thermal stress. WHO Newsl. 18:7–10

Méndez-Lázaro PA, Terrasa-Soler JJ, Torres-Peña C, et al. (2014) Tourism and climate conditions in San Juan, Puerto Rico, 2000–2010. Ecol Soc 19:11

Mieczkowski Z (1985) The Tourism Climatic Index: a method of evaluating world climates for tourism. Can Geogr Géographe Can 29: 220–233. doi:10.1111/j.1541-0064.1985.tb00365.x

Missenard FA (1933) Température effective d'une atmosphere Généralisation température résultante d'un milieu. In: Encyclopédie Industrielle et Commerciale, Etude physiologique et technique de la ventilation.

Morgan R, Gatell E, Junyent R, et al. (2000) An improved user-based beach climate index. J Coast Conserv 6:41–50. doi:10.1007/BF02730466

Perch-Nielsen S, Amelung B, Knutti R (2010) Future climate resources for tourism in Europe based on the daily Tourism Climatic Index. Clim Change 103:363–381. doi:10.1007/s10584-009-9772-2

Perch-Nielsen SL (2009) The vulnerability of beach tourism to climate change—an index approach. Clim Change 100:579–606. doi:10.1007/s10584-009-9692-1

Perry A (1997) Recreation and tourism. In: Thompson RD, Perry AH (eds) Applied climatology. Routledge, London, pp. 240–248

Rusu S (2011) Tourism multiplier effect. J. Econ. Bus. Res. 17:70–76

Rutty M, Scott D (2015) Bioclimatic comfort and the thermal perceptions and preferences of beach tourists. Int J Biometeorol 59:37–45. doi:10.1007/s00484-014-0820-x

Sanford T, Frumhoff PC, Luers A, Gulledge J (2014) The climate policy narrative for a dangerously warming world. Nat Clim Chang 4:164–166. doi:10.1038/nclimate2148

Scott D, McBoyle G (2001) Using a 'tourism climate index' to examine the implications of climate change for climate as a natural resource for tourism. In: Matzarakis A, de Freitas CR (eds) Proceedings of the First International Workshop on Climate, Tourism and Recreation, International Society of Biometeorology, Commission on Climate, Tourism and Recreation, Halkidi, Greece, pp 69–88

Scott, McBoyle G, Schwartzentruber M (2008) Climate change and the distribution of climatic resources for tourism in North America. Clim Res 27:105–117

Themeßl MJ, Gobiet A, Heinrich G (2011) Empirical-statistical downscaling and error correction of regional climate models and its impact on the climate change signal. Clim Change 112:449–468. doi:10.1007/s10584-011-0224-4

UNWTO (2014) Working together in Europe—a shared leadership. Madrid.

UNWTO (2013) Tourism highlights, 2013 edition.

Vautard R, Gobiet A, Sobolowski S, et al. (2014) The European climate under a 2 °C global warming. Environ Res Lett 9:034006. doi:10.1088/1748-9326/9/3/034006

Yan YY, Oliver JE (1996) The clo: a utilitarian unit to measure weather/climate comfort. Int J Climatol 16:1045–1056. doi:10.1002/(SICI)1097-0088(199609)16:9<1045::AID-JOC73>3.0.CO;2-O