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ORIGINAL ARTICLE

Present and future climate resources for various types of tourism in the Bay of Palma, Spain

D. Bafaluy · A. Amengual · R. Romero · V. Homar

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Abstract The Bay of Palma, in Mallorca, is a leading region for beach holidays in Europe. It is based on a mass tourism model strongly modulated by seasonality and with high environmental costs. Main tourism stakeholders are currently implementing complementary activities to mitigate seasonality, regardless of climate change. But climate is—and will remain—a key resource or even a limitation for many types of tourism. Assessing the present conditions and exploring the future evolution of climate potential for these activities have become a priority in this area. To this end, the climate index for tourism (CIT)—originally designed to rate the climate resource of beach tourism—is adapted to specifically appraise cycling, cultural tourism, football, golf, motor boating, sailing and hiking. Climate resources are derived by using observed and projected daily meteorological data. Projections have been obtained from a suite of Regional Climate Models run under the A1B emissions scenario. To properly derive CITs at such local scale, we apply a statistical adjustment. Present climate potentials ratify the appropriateness of the Bay of Palma for satisfactorily practicing all the examined activities. However, optimal conditions are projected to degrade during the peak visitation period while improving in spring and autumn. That is, climate change could further exacerbate the present imbalance between the seasonal distributions of ideal climate potentials and high attendance levels. With this information at hand, policy makers and regional tourism stakeholders can respond more effectively to the great challenge of local adaptation to climate change.

Keywords Climate indices for tourism · Seasonality · Climate change · Regional modelling · Statistical adjustment · Local scale

Introduction

Tourism is a highly climate-sensitive socioeconomic sector. Climate determines the suitability of destinations for a wide range of tourist activities and influences natural resources, critical for successful outdoor leisure recreation. Many destinations worldwide do not solely depend on weather conditions but also on their environmental assets. Therefore, climate change will definitely be very relevant for these destinations as well as for tourists themselves. Being a necessary condition for the satisfaction of tourists when practicing different outdoor leisure activities, climate has a major influence when choosing a destination. From the perspective of the tourism industry, climate is also fundamental as it defines the quality and length of seasonality (UNWTO 2008).

The Mediterranean is both one of the most visited tourist destinations and sensitive areas to climate change impacts worldwide (IPCC 2007). Tourism is a key gross income resource for most European Mediterranean countries. These countries will have to contend the challenges of climate change through adaptation and mitigation at local and regional scales (UNWTO 2008). Observations have already shown that the global mean surface temperature has increased notably during the twentieth century. For the Mediterranean region, the pace of warming was estimated between 2.5 and 3.5 °C per century (IPCC 2007). A

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D. Bafaluy · A. Amengual (✉) · R. Romero · V. Homar
Grup de Meteorologia, Departament de Física, Universitat de les Illes Balears, 07122 Palma de Mallorca, Spain
e-mail: arnau.amengual@uib.es

redistribution of precipitation and other atmospheric variables has been observed as well. For example, rainfall decreases between 5 and 20 % have been already reported over the Mediterranean from 1901 to 2005 (IPCC 2007). And droughts have already increased in frequency and intensity (Giannakopoulos et al. 2009; Lelieveld et al. 2012).

The proper assessment of the direct and indirect effects of climate change at regional and local scales rises as a topic of paramount interest. The increase of temperatures in northern European countries could result in a poleward shift of the atmospheric conditions for summery recreation, since the European Mediterranean countries could experience unpleasant weather conditions (Amelung et al. 2007; Moreno and Amelung 2009). Tourists from northern European countries would not need to travel abroad for their summery vacation, preferring neighbouring rather than distant (e.g., Mediterranean) emplacements (Hamilton et al. 2005; Amelung and Viner 2006; Kimberly 2009). Indirect climate change effects on water availability, energy prices, rising sea level and beach erosion, or fire frequencies are expected to negatively affect tourism as well (Kimberly 2009). For example, energy demand is projected to increase during summer due to a warmer climate (Giannakopoulos et al. 2009).

A key issue when assessing climate change effects on tourism is to express these by using suitable quantitative indicators. Some indices have been designed to assess climate attractiveness to tourists. For example, the Tourism Climate Index (TCI) was developed to quantify climate suitability for general tourism engaged in light physical activities (Mieczkowski 1985). But climate change will unevenly impact tourist activities, as different kinds of tourism need different weather requirements and differ in physical demand. De Freitas et al. (2008) developed a second-generation climate index for tourism (CIT) to specifically rate the weather asset for sun, sea and sand (3S) tourism. CIT is theoretically developed and empirically adjusted. Furthermore, it assesses the daily weather asset by merging its thermal (T), aesthetic (A) and physical (P) facets.

Nowadays, most outdoor leisure activities remain uncharacterized in terms of suitable quantitative indicators. Here, we analyse the present climate resource for several types of tourism in the bay of Palma, Mallorca (Fig. 1). A compulsory requirement to derive useful tourism climate indices is that they should be specifically designed for and relevant to the particular type of tourism being examined (De Freitas et al. 2008). To this end, we modify the original 3S weather typology matrix to specifically rate the kinds of tourism which are currently practiced in the bay of Palma: cycling, cultural, football, golf, motor boating, sailing and hiking. First, we assess their present climate potentials by using observed daily series for maximum temperature, precipitation, relative humidity, cloudiness and wind speed. Second, we explore their possible future evolutions. To this end, projected daily-averaged data have been obtained from several Regional Climate Models (RCMs) run under the A1B emissions scenario (SRES; Nakićenović et al. 2000). A challenge to local analyses is the need of accurate quantitative estimates at very small spatial and temporal scales. Therefore, we calibrate raw RCM data by applying a quantile–quantile adjustment to the continuous CIT cumulative distribution functions (CDFs) for each tourist activity (Amengual et al. 2012a).

The paper is structured as follows: Sect. 2 outlines the main social and economic activities as well as the climatological features of the study area; Sect. 3 summarizes the observed and simulated databases as well as the methods used to explore climate change impacts at local scale; Sect. 4 presents the observed and projected changes in annual and seasonal regimes for climate resources and finally, Sect. 5 reviews the main results and offers further remarks.

A brief description of the study area

Main climatic features

The Balearic Islands own a climate characteristic of the western Mediterranean region (Fig. 1). The archipelago is affected by a wide range of synoptic flows and is strongly influenced by both the Mediterranean Sea and Atlantic Ocean. In summer, the Azores high-pressure system is prevalent, resulting in a steady increase of both air and sea surface temperatures. Summery precipitation is scarce, leading to a moderate drought period. In early autumn, the eastward extension of the Azores high-pressure system moves equatorwards, facilitating the arrival of Atlantic cold air masses. Heavy rainfalls are common during this season as a result of the confluence of the Atlantic cold air masses, the presence of moist and warm Mediterranean air, the relatively high sea surface temperature and the complex orography of the region (Romero et al. 1999; Amengual et al. 2008). Mean annual daily minimum and maximum temperatures, rainfall and sunshine for the Balearic Islands are 12.8, 21.8 °C, 560 mm and 2810 hours, respectively (Homar et al. 2010).

Main social and economic aspects

Tourism is of major social and economic importance in Spain, leading the number of nights spent by foreign visitors among all the European countries. In 2010, it was both the fourth most visited country—with up to 52.7 million visitors—and the second tourist destination in

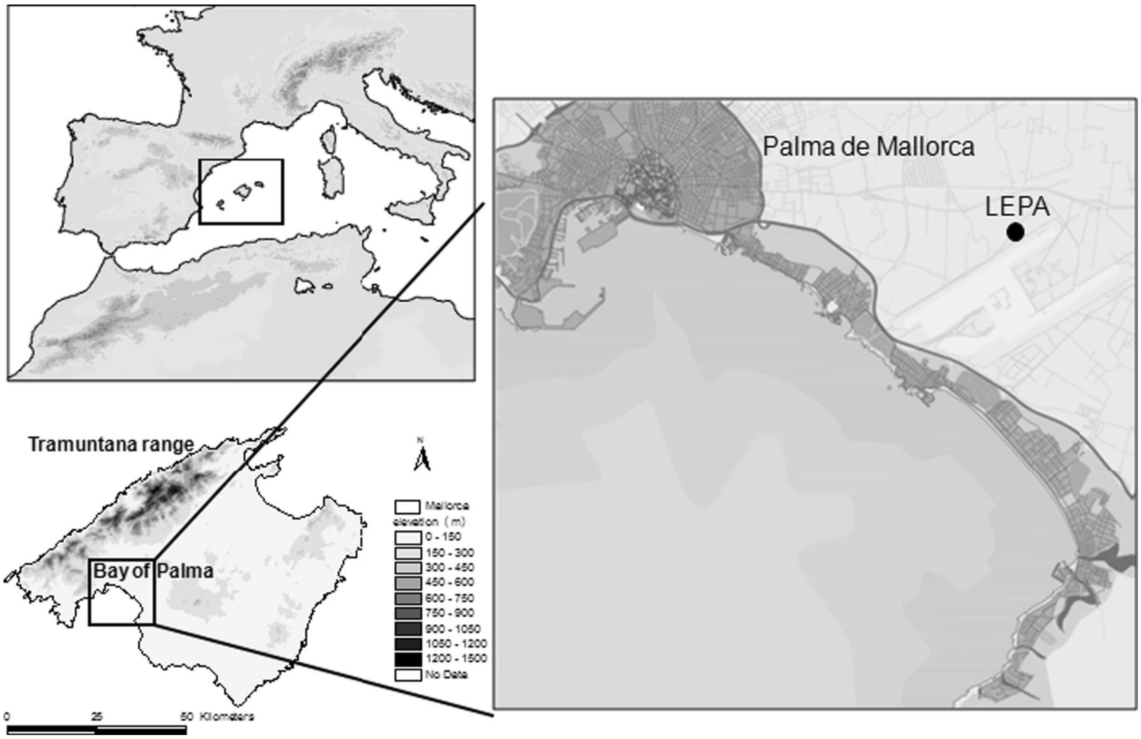

Fig. 1 Geographical location of the Bay of Palma in the western Mediterranean region. It is located in Mallorca, the largest of the Balearic Islands. Major topographic features of the entire region are shown. Also shown is the location of the autonomic weather station (denoted as LEPA)

profits—amounted \$52.5 billion—worldwide (UNWTO 2011). Furthermore, the tourism industry employs about 13 % of the whole state work force. The Balearic Islands are the fourth most visited region in Spain: the total amount of nights spent in hotels reaches 37 million with an annual average stay of 6.5 days. The highest attendance season spans from June to September, with values ranging from 5.4 to 7.2 millions overnights (INE 2010).

The Balearic Islands are one of the world's leading markets for beach tourism. However, Mallorca is considered a mature destination based on a mass tourism model withstanding high environmental costs (Aguiló et al. 2005, 2006; Alcover et al. 2011). In addition, tourists are becoming more stringent, demanding complementary leisure activities to the traditional 3S product (Barceló et al. 2010). Therefore, main tourism stakeholders are currently promoting additional outdoor activities as a key strategy for diversifying supply (Marchena and Repiso 1999; Forcades and Martorell 2003). In this study, we examine the following tourist activities: cycling, cultural, hiking, golf, football and nautical sports. The expansion of some of them is expected to further reduce the strong seasonality of 3S tourism, the main handicap for the current tertiary sector in the Balearics (Barceló et al. 2010). However, the local and regional policy makers and tourism sector have paid little attention to climate change impacts when addressing all these topics. Briefly, the main socioeconomic characteristics of these tourist activities in the Balearics are (Marchena and Repiso 1999; Forcades and Martorell 2003; Aguiló et al. 2006; OET 2008; Barceló et al. 2010):

- *Cycling.* The number of cyclists has steadily grown: from close to 35,000 in 1995 to 88,500 in 2008. Practitioners have a medium purchasing power and most of them travel between February and May. This kind of tourism is considered of high importance to reduce seasonality.
- *Cultural.* Although this tourism encompasses a wide range of activities offered by a destination, we solely refer to those carried out outdoors. No information is available on the number of tourists travelling specifically for this motivation, since it remains as a minor leisure activity. Although cultural tourism can be practiced all year round, it is only an alternative to rainy, cloudy or wintry days during the warm season. Couples with high educational level and medium to high purchasing power are the standard practitioners.
- *Football.* This type of tourism is a minority and relatively unknown. It mainly consists of semi- and professional sport teams coming from north-western European countries during the cold season in order to keep training and playing football outdoors.

- *Golf*. Over 20 golf courses exist in Mallorca. An important increase has been experienced in the number of golfers during the last decade: from about 57,000 in 1999 to more than 110,000 in 2008. Practitioners have medium to high purchasing power. Spring and autumn are their preferred seasons, being winter the less demanded.
- *Nautical*. This kind of tourism encompasses numerous outdoor leisure activities. We have focussed exclusively on two: sailing and motor boating. Mallorca has a large number of marinas with nearly 20,000 moorings for vessels. In recent years, practitioners have steadily increased, reaching up to 315,000 in 2007. Nautical tourists have a high purchasing power and commonly visit Mallorca in summer, thus accentuating seasonality.
- *Hiking*. Mallorca owns many hiking routes, mostly located in the Tramuntana range (Fig. 1). No data are available on the number of tourists travelling to the island for hiking. Practitioners are mainly young people with medium purchasing power, and they usually travel in groups. Hikers show a preference for springs and autumns.

In this study, we focus our attention exclusively on the Bay of Palma. It is located in the south-western Majorcan coastal area and comprises an extension of roughly 500 km^2 (Fig. 1). Palma—the capital of the Balearics—is located within this area as well as the main 3S tourist resort of the islands (the System of Platja de Palma; for further details, see Amengual et al. 2012b). The Bay of Palma accounts almost for half of the whole population in the Balearic Islands (close to 560,000 inhabitants in 2010). It is interesting to explore climate potentials over this geographical region as it exemplifies all the aforementioned issues. The predominant social and economic activities are devoted to beach tourism, even though the area is equipped with infrastructures and environmental resources for carrying out all the examined kinds of tourism. That is, the bay of Palma has nautical facilities, bike and hiking routes, outdoor sport venues and the ancient centre of Palma as tourist assets.

Database and methods

Climate indices for tourism

CIT was developed to encompass not exclusively an optimal range of daily temperatures, but also for the effects of relative humidity, wind speed, short- and long-wave radiation and cloudiness. Furthermore, CIT expresses the integrated body–atmosphere energy balance as a thermal sensation, implicitly accounting for physical activity and clothing insulation. For CIT, human comfort and subjective perception of weather do not solely rely on its thermal (T) aspect, but on its aesthetical (A) and physical (P) facets as well (De Freitas 1990; De Freitas et al. 2008; Fig. 2). In order to determine the overall weather comfort perception, daily atmospheric variables are combined in a weather typology matrix that ranks this resource from very poor (i.e., CIT = 1: unacceptable) to very good (i.e., CIT = 7: optimal). This index pioneers in recognizing the dominating effects of the weather facets when exceeding certain thresholds. That is, CIT assumes that the integrated effect of some particular weather condition is not just the sum of its various facets but a nonlinear function of three factors.

Under the assumption that previous findings on which the definition of CIT for beach tourism is founded can be generalized to other kinds of outdoor leisure activities, we build analogous indices for the aforementioned kinds of tourism. What is needed is to determine the thermal, physical and aesthetical aspects characterizing the suitability of these activities. We have specifically designed a new suite of weather typology matrices in order to rate the weather asset for each type of tourism (Fig. 2). To this end, we have carried out a set of exploratory tasks in order to derive a sensible estimate of the integrated effect of the weather facets on each recreation type.

First, outdoor leisure activities have been divided into two groups depending on whether they require certain gear to be practiced in order to estimate the set of weather thresholds for the thermal, aesthetical and physical facets. For cycling, golf and nautical sports (first group), experts and practitioners were consulted. Then, this information was compared against monthly climatic data for leading tourist destinations worldwide and for each activity. This step allowed us refining the previous ratings and thresholds in order to generate more reliable weather typology matrices (Fig. 2). Since cultural, football and hiking tourism (second group) do not depend on any specific gear, suitable and overriding meteorological facets were somehow more difficult to determine. After gathering field information and reaching consensus with experts and practitioners, a set of thermal, aesthetic and physical thresholds were also established to rate the climate resource for each outdoor leisure activity (Fig. 2).

General tourist activities are not so strongly subject to such a narrow range of thermal, aesthetic and physical conditions as 3S. The new weather typology matrices are more flexible than the original, allowing a wider range of weather facets for satisfactorily practicing these recreations. In particular, cloudiness and rainfall are not so overriding when carrying out other kinds of outdoor leisure activities. Overriding effects for weak or strong winds depend on each specific activity. For example, wind speed

(a) Cycling

ASHRAE scale TSN [T]		Cloud (<45%) [A]	Cloud (≥45%) [A]	Rain (≥10mm/d) [P]	Wind (≥8m/s) [P]
Very hot	(+4)	3	2	3	2
Hot	(+3)	4	3	3	2
Warm	(+2)	6	5	4	2
Slightly warm	(+1)	7	7	4	3
Indifferent	(0)	7	6	4	2
Slightly cool	(-1)	6	5	3	2
Cool	(-2)	5	4	3	1
Cold	(-3)	4	3	2	1
Very cold	(-4)	3	2	1	1

(b) Cultural

ASHRAE scale TSN [T]		Cloud (<45%) [A]	Cloud (≥45%) [A]	Rain (≥5mm/d) [P]	Wind (≥10m/s) [P]
Very hot	(+4)	3	3	2	2
Hot	(+3)	4	3	3	3
Warm	(+2)	6	5	4	4
Slightly warm	(+1)	7	6	4	4
Indifferent	(0)	7	6	4	4
Slightly cool	(-1)	6	5	4	4
Cool	(-2)	5	4	3	3
Cold	(-3)	4	4	2	2
Very cold	(-4)	3	2	1	1

(c) Football

ASHRAE scale TSN [T]		Cloud (<45%) [A]	Cloud (≥45%) [A]	Rain (≥10mm/d) [P]	Wind (≥8m/s) [P]
Very hot	(+4)	3	3	2	2
Hot	(+3)	4	4	3	2
Warm	(+2)	6	6	4	3
Slightly warm	(+1)	7	7	5	4
Indifferent	(0)	7	7	4	3
Slightly cool	(-1)	6	6	3	2
Cool	(-2)	5	5	2	1
Cold	(-3)	4	4	1	1
Very cold	(-4)	3	3	1	1

(d) Golf

ASHRAE scale TSN [T]		Cloud (<45%) [A]	Cloud (≥45%) [A]	Rain (≥10mm/d) [P]	Wind (≥4m/s) [P]
Very hot	(+4)	3	2	3	1
Hot	(+3)	5	4	3	1
Warm	(+2)	6	5	4	2
Slightly warm	(+1)	7	6	4	2
Indifferent	(0)	7	6	4	3
Slightly cool	(-1)	6	5	3	2
Cool	(-2)	5	4	3	2
Cold	(-3)	4	3	2	1
Very cold	(-4)	3	2	1	1

(e) Motor boating

ASHRAE scale TSN [T]		Cloud (<45%) [A]	Cloud (≥45%) [A]	Rain (≥20mm/d) [P]	Wind (≥15 m/s) [P]
Very hot	(+4)	5	4	3	1
Hot	(+3)	6	5	3	2
Warm	(+2)	7	6	4	2
Slightly warm	(+1)	7	6	4	3
Indifferent	(0)	6	5	4	2
Slightly cool	(-1)	5	4	2	2
Cool	(-2)	4	3	2	1
Cold	(-3)	3	2	1	1
Very cold	(-4)	2	1	1	1

(f) Sailing

ASHRAE scale TSN [T]		Cloud (<45%) [A]	Cloud (≥45%) [A]	Rain (≥20mm/d) [P]	Wind (≤1.5 or ≥15m/s)
Very hot	(+4)	5	4	3	1
Hot	(+3)	6	5	3	2
Warm	(+2)	7	6	4	2
Slightly warm	(+1)	7	6	4	3
Indifferent	(0)	6	5	4	2
Slightly cool	(-1)	5	4	2	2
Cool	(-2)	4	3	2	1
Cold	(-3)	3	2	1	1
Very cold	(-4)	2	1	1	1

(g) Hiking

ASHRAE scale TSN [T]		Cloud (<45%) [A]	Cloud (≥45%) [A]	Rain (≥5mm/d) [P]	Wind (≥10m/s) [P]
Very hot	(+4)	3	3	2	2
Hot	(+3)	4	3	3	3
Warm	(+2)	6	5	4	4
Slightly warm	(+1)	7	6	4	4
Indifferent	(0)	7	6	4	4
Slightly cool	(-1)	6	5	4	4
Cool	(-2)	5	4	3	3
Cold	(-3)	4	4	2	2
Very cold	(-4)	3	2	1	1

(h)

CIT						
1	2	3	4	5	6	7
Unacceptable			Acceptable		Ideal	

Fig. 2 Weather typology matrices for the different kinds of tourism (**a**–**g**) and the CIT rating scale (**h**)

can act as a different limiting factor depending on sailing or motor boating. Both minimum and maximum wind speed thresholds limit adequate practice for the former, while only strong winds act as a physical overriding aspect for the latter (Fig. 2e, f). Wind speed is not a determinant physical factor exclusively for sea sports. It is also important for golf and, to a lesser extent, for cycling and football (Fig. 2a, c and d). Since football players are

Table 1 List of transient RCM experiments driven within the European ENSEMBLES project for the 1951–2100 period. Note that all the models have a spatial resolution of 25 km and have been run under SRES A1B

Driving GCM	RCM	Acronym	Institute
ECHAM5	RCA3	C4IRCA3	C4I
ARPEGE	HIRLAM	DMI-HIRLAM5	DMI
ECHAM5	HIRLAM	DMI-HIRLAM5	DMI
BCM	HIRLAM	DMI-HIRLAM5	DMI
HadCM3	CLM	ETHZ-CLM	ETHZ
ECHAM5	RegCM	ICTP-REGCM	ICTP
ECHAM5	RACMO	KNMI-RACMO	KNMI
HadCM3	HadRM3Q0	METO-HC-HadCM3Q0	HC
HadCM3	HadRM3Q3	METO-HC-HadCM3Q3	HC
HadCM3	HadRM3Q16	METO-HC-HadCM3Q16	HC
BCM	RCA	SMIRCA	SMHI
ECHAM5	RCA	SMIRCA	SMHI
HadCM3	RCA	SMIRCA	SMHI

willing to train in a wider range of thermal, physical and aesthetical weather facets than other tourists do, its weather typology matrix has been designed to be the most permissive (Fig. 2c).

Databases and models

Observed atmospheric variables were obtained from the automatic weather station denoted as LEPA (39.37°N, 2.43°E) maintained by the Spanish meteorological Agency (AEMET). This station is situated at Palma's International airport (Fig. 1) and collects daily data series since 1973. Throughout this period, no significant changes have occurred near this station, because it is located far away from urban development, at the head of the first airport runaway. Thus, local effects from urbanization such as heat island warming or precipitation sheltering are negligible. Furthermore, LEPA data can safely be considered as representative of the climatic conditions in the Bay of Palma. To quantify climate potentials, complete daily series of the following observed atmospheric variables have been used from 1979 to 2008 (30 years): 2 m maximum temperature, accumulated precipitation, 2 m mean relative humidity, mean cloud cover and 10 m mean wind speed. Regarding projected variables, the database of regional climate simulations available from the ENSEMBLES European project was used. This database contains daily-averaged climate data from 13 different RCMs run under the SRES A1B (Table 1). Daily-simulated variables from each model have been bilinearly interpolated to the LEPA location from the four nearest grid points (Akima 1978, 1996). Further technical details can be found in the supplementary online resources.

Thermal sensations have been computed through the Physiological Equivalent Temperature (PET) by using the RayMan model (Matzarakis and Rutz 2007; Table 2). Computing CIT for each activity requires expressing PET as a thermal sensation by means of the standard nine-point ASHRAE scale (ASHRAE 2004; Fig. 2). The set of daily thermal sensations are combined together with the associated atmospheric parameters for the aesthetical and physical facets (i.e., cloud cover, rainfall and wind speed) through the weather typology matrices in order to derive daily CITs for each type of tourism. To properly use projected daily CITs at such local scale, we have applied a quantile–quantile adjustment to each individual simulated CIT daily data series (Amengual et al. 2012a). Note that we first compute CIT values from raw data of each individual RCM to avoid losing individual model extremes. After interpolating the simulated meteorological variables to LEPA and deriving CITs, these daily data series are calibrated against CITs based on observations. Finally, we consider a multimodel mean ensemble strategy by averaging daily data series for all the RCMs. Further technical details can be found in the supplementary online resources.

Table 2 Thermal and physiological parameters used for setting up the RayMan model depending on each activity. Thermal isolation (in clo) and metabolic rates (in W) are assessed according to ASHRAE standards

	Cycling	Cultural	Football	Golf	Nautical	Hiking
Clothing isolation (clo)	0.7	0.6	0.7	0.6	0.4	0.7
Activity level (W)	250	115	365	205	205	205

Results

Changes in annual regimes of climate potentials for tourism

After calibrating daily CIT data at local scale, we assess the climate potential for the different kinds of tourism in the Bay of Palma throughout the twenty-first century. According to De Freitas et al. (2008), the following categories are used to simplify subsequent discussions: CIT = 1, 2, 3: *unacceptable*; CIT = 4, 5: *acceptable* and CIT = 6, 7: *ideal conditions*, respectively. Recall that the observed baseline spans a 30-year period from 1979 to 2008 and that the three future time-slices are as follows: 2010–2039 (early twenty-first century), 2040–2069 (mid-twenty-first century) and 2070–2099 (late twenty-first century).

The main results for each activity are (see Fig. 3 and Table A in the supplementary online resources) as follows:

- *Cycling.* Ideal perceptions are projected to maintain the present annual mean relative frequency throughout the twenty-first century, together with a transition from acceptable to unacceptable conditions. Therefore, a slight degradation on the annual climate resource is expected.
- *Cultural.* Ideal conditions would prevail, being predominant. That is, according to projections, this kind of tourism can be classified as a steady and valuable tourist asset in the Bay of Palma.
- *Football.* Present ideal conditions show the highest relative frequency among all the outdoors leisure activities. It is expected to continue being the most suitable outdoor activity, since more than half of the annual days are projected to exhibit ideal conditions.
- *Golf.* Present annual relative frequencies for ideal conditions show the lowest percentage among all the tourist activities. No significant changes are projected in the future evolution of the annual climate resource.
- *Motor boating.* Ideal conditions are nowadays prevalent. These are projected to noticeably increase throughout the century. Climate change could greatly enhance tourism potential for motor boating during the twenty-first century in the Bay of Palma.
- *Sailing.* Ideal and acceptable annual relative frequencies are dominant for the present climate regime. Both are projected to evenly increase, thus further encouraging its future practice.
- *Hiking.* Although annual ideal conditions are projected to remain constant, the acceptable category noticeably decreases, revealing a degradation of the climate resource for this kind of tourism.

Changes in seasonal regimes of climate potentials for tourism

The beach-based tourism sector in Mediterranean Europe is characterized by a strong seasonality, with large differences in occupancy rates between the cold and warm seasons. Note that the peak demand for the summery season (i.e., June, July and August) is also strongly influenced by institutional holidays, and not just climate. Several studies have indicated that summery weather conditions could deteriorate in European Mediterranean countries, whereas it could improve in north-western Europe. This fact might imply a major modification in tourist flows and might lead to more domestic tourism in northern European countries (Amelung and Viner 2006; Amelung et al. 2007; Hein et al. 2009).

We have carried out a first exploration of changes in seasonality for the activities of interest through the analysis of the seasonal CIT distributions. Note that seasons are defined as follows: winter (December, January and February), spring (March, April and May), summer (June, July and August) and autumn (September, October and November). Only the main results are summarized here (see Figs. 4, 5, 6, and 7 and Table B in the supplementary online resources). Further results and discussions are available in the supplementary online resources.

- *Cycling.* Optimal conditions are projected to slightly increase at the expense of the acceptable perceptions in the shoulder seasons while decreasing in the peak attendance season. Climate change would demotivate cycling during the warm season, but would further encourage its practice during spring and autumn. No significant changes are expected in winter.
- *Cultural.* Spring and autumn would remain as the most suitable seasons for carrying out cultural tourism in the Bay of Palma. Minor changes in winter and a distinct

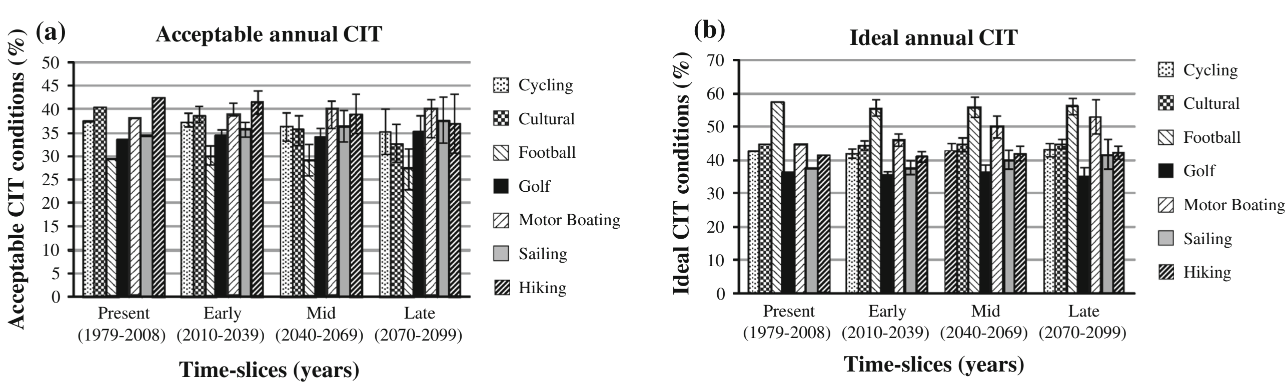

Fig. 3 Annual acceptable (**a**) and ideal (**b**) relative frequencies (in %) for climate potentials in the Bay of Palma. Climate resources are displayed depending on the activity and for the present, early, mid and late future time-slices. Also displayed is the standard deviation of the ensemble model

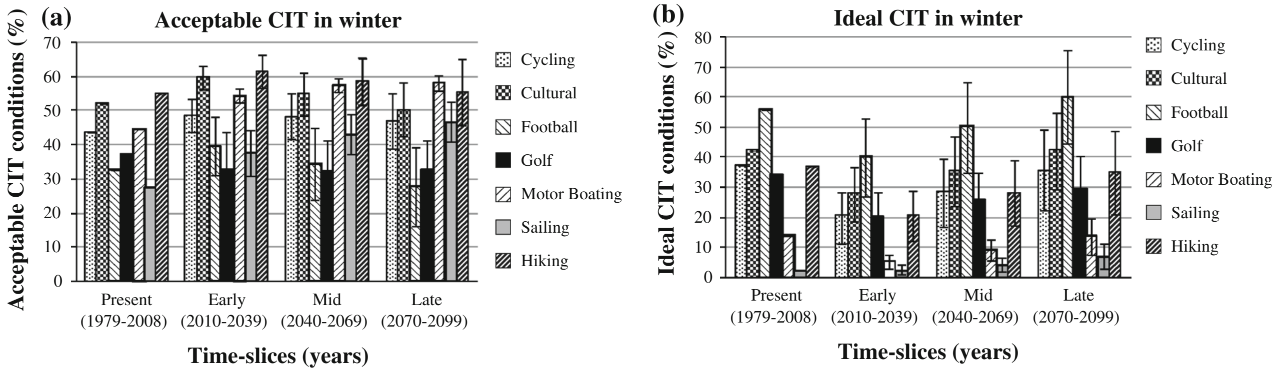

Fig. 4 As in Fig. 3, except for winter

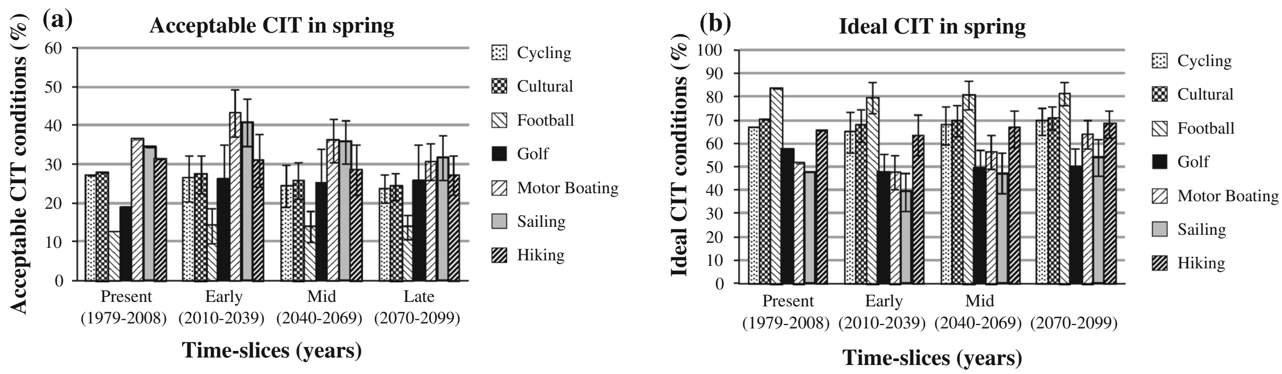

Fig. 5 As in Fig. 3, except for spring

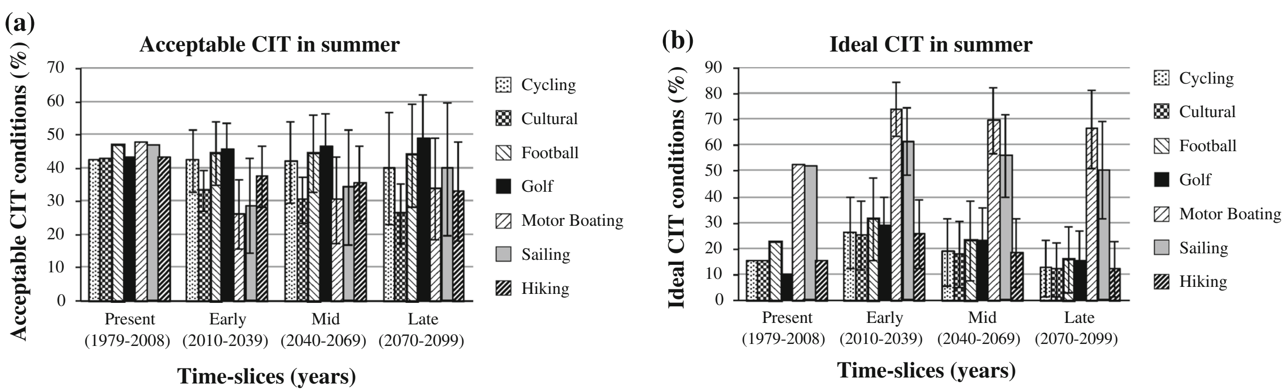

Fig. 6 As in Fig. 3, except for summer

degradation in summer are expected for this climate resource.

- *Football*. Projections indicate that springs and autumns will remain as the best seasons for this kind of tourism. No significant changes are projected in winter either. On the contrary, summery climate potential would noticeably degrade from the second half of the century.
- *Golf*. No significant impacts are projected on the temporal distribution of climate potential. Ideal climate conditions could slightly increase in summer and decrease in winter. The shoulder seasons are likely to remain as the most suitable periods for practicing golf.
- *Motor boating*. An overall improvement of climate potential in all seasons is projected. Climate change could further encourage the practice of this outdoor leisure activity, especially in spring, summer and autumn.
- *Sailing*. Nowadays, this activity is mainly carried out in summer, even when autumn exhibits a considerable climate potential as well. Projections indicate autumn

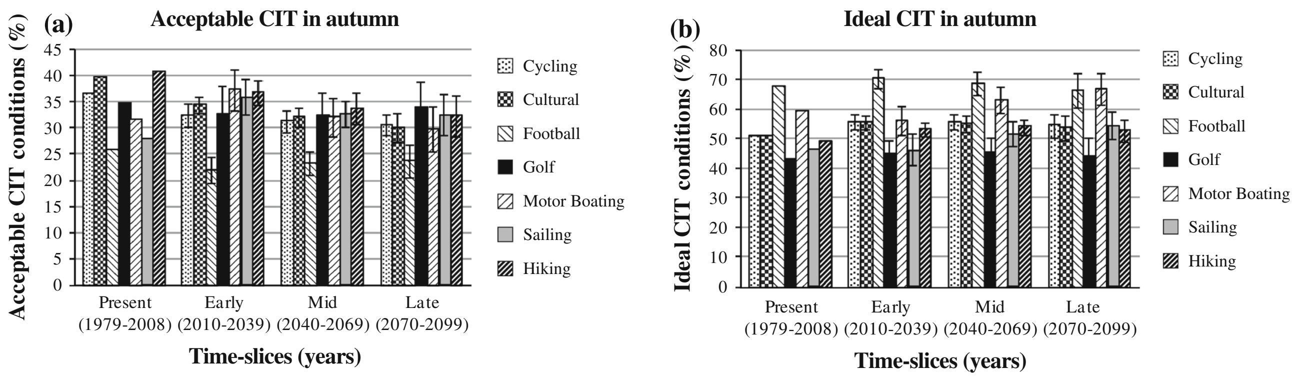

Fig. 7 As in Fig. 3, except for autumn

and, to a lesser extent, spring as the most favoured seasons due to local climate change impacts. Ideal conditions in summer are projected to significantly degrade by 2070–2099, being the shoulder seasons the best period for sailing.

- *Hiking*. Although acceptable and ideal relative frequencies are expected to reduce in all seasons, losses in climate resource are projected to be small except for summer. In addition, optimal conditions could increase during the shoulder seasons, whereas ideal perceptions in winter are projected to remain in the long term. Therefore, no significant changes could be expected in the temporal distribution of attendance levels as a consequence of regional climate change impacts.

Intercomparison of tourism modes

Climate arises as a paramount tourism asset in the Bay of Palma (Fig. 3; Table A). Projections do not show significant shifts in the annual relative percentages of the optimal conditions for most of these activities, except for nautical sports. The latter could experience an important increase in the annual number of days rated as ideal. Because annual mean regimes mask the intra-annual variability of the climate resources for different types of tourism, we carry out an intercomparison on a seasonal basis. Thus, we identify the most suitable activities to carry out seasonally in the present and we explore their future evolution. Note that the most suitable activities are defined as those showing ideal climate conditions for at least half of the days in a season.

In winter, football presents the highest present ideal relative frequencies. Only slight changes in these are projected for this season, except a noticeable increase for sailing and football. However, climate will continue as a marginal asset for sailing (Fig. 4; Table B). In spring, present climate resource for football has the highest ratings. Cultural, cycling and hiking also exhibit high ideal relative percentages (Fig. 5; Table B). Climate potential is projected to slightly improve in most activities for this season. Projections point out the most notable increase in the ideal relative frequencies for sea sports. In summer, nautical sports exhibit the highest ideal relative frequencies for present. The remaining outdoor leisure activities have solely few days with optimal conditions. Apart from nautical sports, a general degradation in climate assets for tourism is projected in summer (Fig. 6; Table B). For the present, football has the highest ideal relative percentages in autumn. In fact, climate potentials in this season are lower than those found in spring for most outdoor leisure activities (Table B). An overall improvement in the climate resources is projected for autumn by 2070–2099. The increases in the ideal relative frequencies for nautical activities are especially important. By 2070–2099, motor boating, sailing and football could remain as the most profitable tourist products in the Bay of Palma (Fig. 7).

It is worth to note that all tourist activities have the highest ideal relative frequencies in winter than in summer, except for nautical sports. The shoulder seasons exhibit the most suitable climate resources for practicing almost all the activities in the present. Spring, closely followed by autumn, exhibits the highest ideal relative frequencies (Table 3). Projections suggest that football will remain as the only outdoor leisure activity adequately practiced during the cold season. Furthermore, sailing could be practiced at the end of the century not just in the peak visitation period, but in the shoulder seasons as well. On the other hand, hiking could be more conveniently practiced in autumn (Table 3). According to the present seasonal attendance levels (Sect. 2.2), no significant changes in these can be expected for cycling and golf. In brief, an overall deterioration of the optimal climate resources for all the inland activities is projected in summer, while spring and autumn could benefit of an enhancement in climate asset. That is, a general degradation in most of climate potentials is projected in summer while improving in the

Table 3 Present and future seasonal distributions of the most suitable outdoor leisure activities

Most suitable activities	Present (1979–2008)	Early (2010–2039)	Mid (2040–2069)	Late (2070–2099)
Winter	Football	–	Football	Football
Spring	Cycling	Cycling	Cycling	Cycling
	Cultural	Cultural	Cultural	Cultural
	Football	Football	Football	Football
	Golf	–	Golf	Golf
	Motor boating	–	Motor boating	Motor boating
	–	–	–	Sailing
	Hiking	Hiking	Hiking	Hiking
Summer	Motor boating	Motor boating	Motor boating	Motor boating
	Sailing	Sailing	Sailing	Sailing
Autumn	Cycling	Cycling	Cycling	Cycling
	Cultural	Cultural	Cultural	Cultural
	Football	Football	Football	Football
	Motor boating	Motor boating	Motor boating	Motor boating
	–	–	Sailing	Sailing
	–	Hiking	Hiking	Hiking

Tourist activities have been defined as suitable when at least half of the whole days for each season are classified as ideal

shoulder seasons. These results are consistent with the findings of previous researches devoted to climate change impacts on tourism. In particular, temperatures during the warm season for the European Mediterranean are likely to be too high for carrying out general—or even beach—tourism in comfortable conditions (Amelung and Viner 2006; Amelung et al. 2007, 2012b; Perch-Nielsen et al. 2010).

Conclusions and further remarks

In the Balearic Islands, tourism is mainly devoted to a beach-based mass model. Nowadays, 3S is losing strength in mature destinations as a result of the emergence of new tourist products, destinations and changes in demand. Furthermore, the strong seasonality of such climate-dependent activity modulates fundamental socioeconomic aspects. The 3S industry is the main driving force of employment and gross income for the inhabitants of the Balearics. Seasonality is one of the major challenges that this sector must contend in the future. Main tourism stakeholders agree that this can be overcome by effectively achieving the exploitation of other kinds of tourism. Mallorca has already implemented alternative outdoor leisure activities to 3S to remain as one of the leading tourist destinations in Europe. However, local and regional policy makers and stakeholders have paid little attention to climate change. Being aware of the effects of regional environmental change in the climate resource, we have focused our attention on the Bay of Palma, the most important beach-based destination in the Balearics instantiating all these issues. Furthermore, assessing the direct and indirect consequences of climate change at such local scale is a topic of the greatest interest to effectively respond to the challenge of local adaptation and mitigation.

First, we have quantified the close relationship between several outdoor leisure activities and climate resources through the generation of new climate indices for tourism. To this end, we have examined seven outdoor leisure activities in the Bay of Palma: cycling, cultural tourism, football, golf, motor boating, sailing and hiking. Next, we have modified the original weather typology matrix for beach holidays to properly rate the climate resources for these activities. The new weather typology matrices have been specifically developed for each type of tourism after consulting experts and practitioners. Admittedly, these are expert-based and subjectively assessed and thus have not yet been empirically tested. For the moment, the proposed suite of CITs should be considered as a grounding step towards a more empirical validation of the thermal, aesthetical and physical thresholds to the overall climate ratings. Further research is still necessary since the CITs should rely on actual observations of the atmospheric conditions rather than on averaged climatic data: tourists' satisfaction is a direct effect of the actual environmental conditions at any given time (De Freitas et al. 2008). This future research should consist of interviewing practitioners on-site—whenever possible—in order to compare their responses against detailed weather data monitored on-site. Eventually, CITs adequately quantify climate assets for practicing these outdoor leisure activities when compared against current high-level attendance periods on a seasonal basis.

Results show present suitable annual climate potentials for practicing all the examined types of tourism. Seasonally, their practice is feasible, being a valuable complement to 3S beyond its current peak attendance period. That is, we have identified shifts between the present timing of the most suitable climate resource and current peak demand period for some kinds of tourism. Projections indicate a general decrease in the optimal relative frequencies in summer together with an increase in spring and autumn for the ground-based outdoor leisure activities. Furthermore, an overall enhancement of the climate resource is projected for sea sports in all seasons. Local and regional policy makers and tourism stakeholders should be aware of the present and expected evolution of the climate resources in the Bay of Palma. A longer temporal exploitation or a shift in the high attendance period for some types of tourism would be advisable, thus allowing a better optimization of the climate asset.

Recall that such mass tourism destinations result in important drawbacks: a lack of availability of drinkable and irrigation water during the drought season—requiring the use of desalination plants, a steady increase in electric power consumptions in summer, waste management problems or losses on land and sea biodiversity. The gradual implementation of alternative outdoor leisure activities to 3S could alleviate the current strong seasonality in the Bay of Palma tourist sector and its impacts on its natural resources and socioeconomic structures. Amengual et al. (2012b) have already suggested important regional climate change impacts on this seasonally adjusted industry. Ideal conditions for beach tourism are projected to shift from the highest attendance months to the beginning and ending of the high-visitation period in the Bay of Palma. However, climate change could also offer new opportunities for a corporate restructuring of this sector. Deseasonalization could alleviate the aforementioned drawbacks. To further promote other kinds of tourism—not so strongly climate sensitive—and to optimize their temporal exploitation could mitigate both seasonality and regional climate change impacts, improving sustainability and integral profits to the region from its main socioeconomic engine.

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