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

(Electronic supplementary material)

D. Bafaluy, A. Amengual, R. Romero and V. Homar

Grup de Meteorologia, Departament de Física, Universitat de les Illes Balears, Palma, Mallorca, Spain

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Correspondence to: A. Amengual, Dept. de Física, Universitat de les Illes Balears, 07122, Palma de Mallorca, Spain

E-mail: arnau.amengual@uib.es

1. Rayman model and thermal sensation calculation

The Rayman model accounts for the integrated body-atmosphere energy budget scheme by means of the mean radiant temperature (T_{mrt}). It integrates environmental and physiological thermal variables such as solar heat load, heat loss by convection (i.e. wind), heat loss by evaporation (i.e. perspiration), long-wave radiation exchanges and metabolic heat (i.e. level of activity). After computing T_{mrt}, the Physiological Equivalent Temperature (PET) has been also obtained from RayMan (Matzarakis et al. 2007). T_{mrt} is calculated by setting up the following daily meteorological variables: maximum temperature, relative humidity, wind speed, short- and long-radiation and cloud cover. We use the daily maximum temperature rather than the daily mean temperature as a more accurate proxy to the actual temperature, since most outdoor leisure activities take place around noon, when temperatures are frequently close to their daily maximum. The RayMan model also requires the subsequent thermo-physiological parameters: human activity, body heat production and heat transfer resistance of clothing; these parameters depend on each tourist activity (Table 2). T_{mrt} and PET were obtained by setting up the following standard personal parameters for all the types of tourism: height=1.75 m; weight=75 kg; age=35 years; sex=male. Clothing and activity parameters are obtained from standardized values provided by ASHRAE (ASHRAE 2004). These data characterizes the mean metabolic rates according to different human activities. Cloth insulation is also standardized according to typical ensemble clothing depending on each particular outdoor activity. Finally, computing CIT requires expressing PET as a thermal sensation by using the standard nine-point ASHRAE scale (ASHRAE 2004).

2. Quantile-quantile adjustment approach

The regional simulations database available from the ENSEMBLES European project was used to explore climate change impacts on the tourism resources. This database contains daily climate data from 13 different RCMs run from 1951 to 2100 under the SRES A1B emissions scenario (Table 1; Nakićenović et al. 2000). Numerical experiments were performed by using a 25 km horizontal grid-length resolution over an area that covers Europe, the eastern Atlantic, northern Africa and western Asia. Daily simulated variables from each model have been bilinearly interpolated to the LEPA location from the four nearest grid points (Akima, 1978 and 1996) in order to derive the corresponding value of CIT. To properly use this index at such local scales, we have applied the quantile-quantile (Q-Q) adjustment, developed by Amengual et al. (2012a), to each individual CIT daily data series.

Q-Q adjustment consists of considering a baseline or control period for CIT based on observed and simulated daily data. Successive future CITs based on daily simulated series of the same length that our control period are used as well. Next, we build the cumulative distribution functions (CDFs) from the series and differences between future and control simulated CDFs are computed, quantile by quantile. These differences are added to the control observed (i.e., baseline) CDF to obtain the projected CDFs. Thus, changes between the control and future RCM daily simulated series are locally rescaled in basis of the observed CDF baseline. This method was already successfully applied for beach-based tourism in the Bay of Palma (Amengual et al. 2012b). The authors also verified the performance of the Q-Q adjustment by comparing for a test period the raw and calibrated CDFs for the ensemble-mean against the observed CIT distribution. An overall improvement of the calibrated versus uncalibrated CDFs was found. That is, the adjustment amended systematic errors of the daily CIT based on RCM series when assessing the climate resource at local scales.

Note that the discrete distribution of daily CIT indices for each kind of tourism must be first transformed into a continuous distribution. Accordingly, we have applied a uniform kernel function of one unit width and centred on each discrete CIT value in order to implement the statistical adjustment. The Q-Q method has been applied for each individual RCM to three successive 30-year future simulated periods (2010-2039; 2040-2069; 2070-2099) and using the 1979-2008 period as the observed and simulated baseline. We have adopted a multimodel ensemble approach to encompass the uncertainties arising from model and boundary conditions errors (Table 1; Hewitt and Griggs, 2004; further information at: http://ensembles-eu.metoffice.com). However, we do not account for the inter-SRES variability as all RCMs were exclusively run for the SRES A1B.

3. Changes in annual regimes of climate potentials for tourism

	Annual CIT	Present (1979-2008)	Early (2010 - 2039)	Mid (2040 - 2069)	Late (2070 - 2099)
Cycling	Unacceptable	20	21 ± 1.6	21 ± 2.7	22 ± 4.1
	Acceptable	37	37 ± 1.5	36 ± 2.9	35 ± 4.7
	Ideal	43	42 ± 1.5	43 ± 2.4	43 ± 2.1
Cultural	Unacceptable	15	17 ± 1.2	20 ± 2.2	22 ± 3.2
	Acceptable	40	38 ± 1.7	36 ± 3.2	33 ± 4.1
	Ideal	45	44 ± 1.4	44 ± 2.0	45 ± 1.6
Football	Unacceptable	14	15 ± 1.8	16 ± 3.1	17 ± 4.1
	Acceptable	29	30 ± 2.0	29 ± 3.3	27 ± 4.5
	Ideal	57	55 ± 2.4	55 ± 3.0	56 ± 2.3
Golf	Unacceptable	31	30 ± 1.0	30 ± 1.8	30 ± 2.5
	Acceptable	33	34 ± 1.1	34 ± 1.8	35 ± 3.4
	Ideal	36	36 ± 1.0	36 ± 2.3	35 ± 2.8
Motor boating	Unacceptable	16	14 ± 0.8	11 ± 1.2	9 ± 2.2
	Acceptable	40	40 ± 1.4	39 ± 2.9	38 ± 4.0
	Ideal	44	46 ± 1.8	50 ± 3.4	53 ± 4.9
Sailing	Unacceptable	29	26 ± 1.0	24 ± 1.8	21 ± 2.8
	Acceptable	34	36 ± 1.7	36 ± 3.4	37 ± 5.0
	Ideal	37	38 ± 1.9	40 ± 2.8	42 ± 4.6
Hiking	Unacceptable	16	18 ± 1.7	19 ± 3.7	21 ± 5.4
	Acceptable	42	41 ± 2.5	39 ± 4.2	37 ± 6.3
	Ideal	42	41 ± 1.5	42 ± 2.1	42 ± 2.2

Table A. Relative frequencies (in %) for the present and future annual distributions of the climate indices for tourism in the Bay of Palma. Also shown is the standard deviation from the ensemble-mean.

4. Changes in seasonal regimes of climate potentials for tourism

4.1 Cycling

Spring and autumn are in the present climate the most suitable seasons for cycling, with ideal frequencies up to 67% and 51%, respectively. Practitioners mainly visit Mallorca from late winter to late spring (Table B, Figs. 5 and 7). Therefore, the most appropriate climate conditions do not coincide with current maximum visitation levels. Cycling is considered by the tourism sector as one of the most valuable outdoor leisure activities to reduce seasonality. The Bay of Palma industry could increase the temporal length of this activity by further promoting and encouraging it during autumn.

Projections suggest that unacceptable conditions may increase in winter at the expense of optimal perceptions, whereas appropriate conditions could have a moderate increase (Table B, Fig. 4). A degradation of the climate resource in winter is projected until mid-century. However, this trend could be reversed onwards. No significant changes are expected on climate potential in spring, despite the transition from acceptable towards unacceptable and ideal conditions (Table B, Fig. 5). In summer, acceptable conditions are projected to remain constant together with a noticeable decrease in inappropriate conditions. This fact may lead to an increase in the optimal climate resource by 2010-2039. However, a later degradation is expected (Table B, Fig. 6). In autumn, a remarkable increase of optimal relative perceptions is projected. That is, a general redistribution from acceptable to unacceptable and optimal conditions (Table B, Fig. 7).

4.2 Cultural

The highest present climate resource for this kind of tourism is obtained during the shoulder seasons. In particular, the frequency of ideal days is of 70% in spring. The number of days having ideal conditions in summer is residual. Recall that the most popular alternative outdoor activity to 3S when weather conditions are not appropriate during the high attendance period is cultural tourism. Note that even winter exhibits a greater climate potential than summer.

Although redistribution among the categories is projected throughout the century in winter, appropriate conditions could continue prevailing. Until mid-century, inappropriate and acceptable classes could increase, but optimal conditions may recover afterwards (Table B, Fig. 4). In spring, ideal conditions could continue being dominant, while the acceptable relative frequencies could slightly decrease (Table B, Fig. 5). In summer, unacceptable relative frequencies are expected to steadily increase owing to the degradation of appropriate and, to a lesser extent, ideal conditions (Table B, Fig. 6). In autumn, ideal conditions are projected to dominate. A redistribution in the number of days with acceptable conditions could happen. As a consequence, the climate resource for cultural tourism in autumn could deteriorate at long-term (Table B, Fig. 7).

4.3 Football

The weather typology matrix for this activity is the most permissive in terms of the weather facets (Fig. 2c). When rating the present climate resource, the cold and especially the transition seasons are quite favourable for training outdoors. The ideal relative frequencies are as high as 56%, 83% and 68% in winter, spring and autumn, respectively. On the contrary, the frequency is only of 22% in summer (Table B). Although winter is nowadays the most benefited season to train football, the tourism industry could also extend the visitation period towards spring and autumn.

Ideal conditions are projected to predominate in winter, even though these could remarkably decrease by 2010-2039. A redistribution among all the classes is projected until mid-century, to later recover similar climate potential ratings as in present (Table B, Fig. 4). In spring, the climate resource for football is projected to remain almost steady (Table B, Fig. 5). Acceptable conditions could remain approximately constant in summer, while redistribution between the unacceptable and ideal classes could occur. The projected increase in the unacceptable relative frequencies may result in a remarkable loss of climate resource in summer (Table B, Fig. 6). The inter-class variability is projected to be lower in autumn: ideal conditions could continue as prevalent, even though small variations in the relative frequencies for all the categories are projected (Table B, Fig. 7).

4.4 Golf

In spring and autumn, the present acceptable and ideal relative frequencies add up to 75%. And these are as high as 71% in winter. Summer exhibits the lowest climate potential. Even so, acceptable and ideal conditions occur in more than half of the days. Thus, the high attendance period coincides with the most suitable climate potential in the Bay of Palma. Note that although winter is the less demanded season for practitioners, the ideal (unacceptable) relative frequencies are well above (below) those found in summer (Table B, Figs. 4 to 7). There is a clear margin in present climate to promote golf tourism during the cold rather than the warm season.

In winter, projections indicate an overall increase of the unacceptable perceptions. Thus, the climate resource for golf could degrade considerably in this season (Table B, Fig. 4). In spring, ideal conditions are foreseen to be prevalent, despite the moderate transition from optimal to acceptable conditions (Table B, Fig. 5). Projections suggest a remarkable transition from unacceptable to acceptable and, to a lesser extent, ideal conditions in summer. Acceptable conditions are expected to dominate at long-term, resulting in an enhancement of the present climate resource (Table B, Fig. 6). In autumn, climate potential is expected to remain constant: ideal conditions could continue dominating the seasonal mean regime (Table B, Fig. 7).

4.5 Motor boating

Seasonally, the highest present climate resource is exhibited in summer. Autumns have slightly higher climate potential than springs. Since practitioners mainly visit the Balearics during the high attendance period, there is a temporal match with the most appropriate climate conditions. In winter, future acceptable conditions could predominate (Table B, Fig. 4). In the remaining seasons, ideal conditions are projected to prevail or increase (Table B, Figs. 5, 6 and 7).

The projected enhancement of this climate asset during the shoulder seasons could promote a redistribution of the summery peak visitation levels towards spring and autumn. Nowadays, motor boating is a very suitable complementary activity to 3S during summer, but its practice is feasible in the transition seasons as well. Furthermore, local and regional tourism stakeholders could encourage its practice in the present and a temporal extension of motor boating calendar in the future.

4.6 Sailing

Unlike motor boating, for practitioners to obtain a satisfactory experience, sailing is restricted not only by a maximum but also a minimum wind speed threshold (Fig. 2f). Thus, present climate potential for sailing is lower than for motor boating: the acceptable and ideal relative frequencies are higher for the latter in all seasons (Table B). In the present, summer shows the highest climate resource, followed by spring and autumn as expressed by the frequency of days with ideal conditions. The most important differences between both nautical activities are found in winter and, to a lesser extent, in autumn.

In winter, unacceptable conditions are projected to remain dominant until mid-century. Later, an equitable distribution between the unacceptable and acceptable perceptions is expected due to the continuous transition from the former to the latter categories. Ideal conditions may continue being marginal (Table B, Fig. 4). In spring, ideal perceptions could remain prevalent, despite the uneven redistribution between this categorization and the appropriate conditions throughout the century. Furthermore, a remarkable decrease in the unacceptable relative frequencies is expected by 2070-2099 (Table B, Fig. 5). In summer, acceptable conditions could decrease by 2010-2039, enhancing the extreme (i.e., unacceptable and ideal) classes. A steady transition from ideal to appropriate conditions is foreseen onwards, although ideal conditions may continue prevailing. The remarkable increase in the unacceptable relative frequencies could result in a slight deterioration of the summery climate resource (Table B, Fig. 6). In autumn, the relative frequencies for the excellent (poor) conditions are expected to constantly increase (decrease). Thus, the gradual redistribution from unsuitable towards excellent conditions would result in an improvement of climate potential for sailing (Table B, Fig. 7). The enhancement of the optimal climate conditions in the shoulder seasons at the expense of degradation in the warm season could encourage deseasonalisation in the Bay of Palma. Practitioners could somehow benefit from the projected enhancement of climate potential in winter as well.

4.7 Hiking

The Bay of Palma has the maximum optimal potential in spring, with a present relative percentage of ideal days up to 66%. Since hikers show their visitation preference during spring and autumn, a good temporal correspondence between suitable potential climate distributions and high attendance levels is found for the present. It is worth noting that winter exhibits a slightly greater amount of days being classified as acceptable and ideal than autumn. In addition, summer depicts the lowest rating for ideal conditions (Table B).

In winter, projections suggest uneven redistributions among categories, mainly enhancing acceptable and, to a lesser extent, inappropriate conditions. Hence, a slight loss in the climate resource for hiking could occur by 2070-2099 (Table B, Fig. 4). Such inter-class variability is not expected in spring: smoother evolutions in the relative frequencies could result in a small decrease in climate potential for this kind of tourism (Table B, Fig. 5). In summer, unacceptable conditions could become predominant. That is, a shift from both ideal and acceptable conditions towards inappropriate categories is foreseen, resulting in a degradation of this climate asset (Table B, Fig. 6). In autumn, ideal conditions could exceed half of the days during the present century. However, the acceptable relative frequencies are projected to roughly shift towards the extreme classes, slightly degrading this climate potential (Table B, Fig. 7).

CIT			Present (1979-2008)	Early (2010-2039)	Mid (2040-2069)	Late (2070-2099)		Present (1979-2008)	Early (2010-2039)	Mid (2040-2069)	Late (2070-2099)
Cycling	Unacceptable	**Winter**	20	31 ± 8.3	24 ± 8.4	18 ± 8.3	**Spring**	6	9 ± 4.7	8 ± 4.1	7 ± 3.5
	Acceptable		43	48 ± 5.1	48 ± 6.6	47 ± 8.2		27	26 ± 5.9	24 ± 5.4	24 ± 3.6
	Ideal		37	21 ± 8.2	28 ± 11.3	35 ± 14.0		67	65 ± 8.7	68 ± 8.1	69 ± 6.0
Cultural	Unacceptable		6	13 ± 7.3	10 ± 6.7	8 ± 5.9		2	5 ± 2.5	5 ± 2.2	5 ± 2.3
	Acceptable		52	59 ± 3.5	55 ± 6.3	50 ± 8.0		28	27 ± 4.8	25 ± 4.8	24 ± 3.4
	Ideal		42	28 ± 8.9	35 ± 11.6	42 ± 12.8		70	68 ± 7.0	70 ± 6.7	71 ± 5.0
Football	Unacceptable		12	20 ± 6.0	16 ± 6.5	13 ± 6.5		4	6 ± 3.9	6 ± 3.5	5 ± 3.0
	Acceptable		32	40 ± 8.5	34 ± 10.5	27 ± 11.5		13	14 ± 4.4	14 ± 4.0	14 ± 3.1
	Ideal		56	40 ± 13.1	50 ± 14.9	60 ± 15.7		83	80 ± 6.6	80 ± 6.2	81 ± 4.8
Golf	Unacceptable		29	47 ± 10.2	42 ± 8.7	37 ± 7.7		24	26 ± 3.4	25 ± 4.2	24 ± 4.5
	Acceptable		37	33 ± 10.6	33 ± 8.7	33 ± 8.5		19	26 ± 8.8	25 ± 8.9	26 ± 9.2
	Ideal		34	20 ± 8.2	25 ± 9.2	30 ± 10.5		57	48 ± 8.1	50 ± 7.5	50 ± 8.1
Motor boating	Unacceptable		42	41 ± 2.4	34 ± 3.3	29 ± 6.5		12	9 ± 2.1	8 ± 1.8	6 ± 1.8
	Acceptable		44	54 ± 2.1	57 ± 1.9	58 ± 2.3		36	43 ± 6.1	36 ± 5.7	31 ± 4.7
	Ideal		14	5 ± 2.3	9 ± 3.6	13 ± 6.2		52	48 ± 7.3	56 ± 7.1	63 ± 6.1
Sailing	Unacceptable		70	60 ± 6.8	53 ± 6.4	47 ± 7.3		18	20 ± 3.6	17 ± 3.4	14 ± 2.6
	Acceptable		28	38 ± 6.8	43 ± 6.0	46 ± 5.7		34	41 ± 6.0	36 ± 5.6	32 ± 5.7
	Ideal		2	2 ± 1.5	4 ± 2.3	7 ± 4.1		48	39 ± 8.2	47 ± 8.6	54 ± 7.9
Hiking	Unacceptable		8	18 ± 8.2	14 ± 6.7	10 ± 5.0		3	6 ± 2.5	5 ± 1.8	5 ± 1.5
	Acceptable		55	62 ± 4.9	58 ± 6.8	55 ± 9.8		31	31 ± 6.7	29 ± 6.4	27 ± 5.0
	Ideal		37	20 ± 8.3	28 ± 10.9	35 ± 13.9		66	63 ± 8.6	66 ± 7.8	68 ± 6.0
Cycling	Unacceptable	**Summer**	43	32 ± 13.6	40 ± 17.3	49 ± 21.4	**Autumn**	12	12 ± 2.1	13 ± 3.0	15 ± 4.8
	Acceptable		42	42 ± 9.3	41 ± 12.0	40 ± 16.9		37	32 ± 2.3	31 ± 2.1	30 ± 1.9
	Ideal		15	26 ± 13.8	19 ± 13.1	12 ± 11.0		51	56 ± 2.4	56 ± 2.7	55 ± 4.0
Cultural	Unacceptable		42	42 ± 11.8	52 ± 13.6	62 ± 14.4		9	10 ± 1.8	13 ± 3.5	16 ± 5.8
	Acceptable		42	33 ± 6.2	30 ± 6.9	26 ± 8.9		40	34 ± 1.4	32 ± 1.9	30 ± 2.7
	Ideal		16	25 ± 13.3	18 ± 12.9	12 ± 10.4		51	56 ± 2.5	55 ± 2.9	54 ± 4.3
Football	Unacceptable		31	24 ± 11.7	33 ± 16.5	41 ± 20.5		6	8 ± 2.1	8 ± 2.5	10 ± 3.6
	Acceptable		47	45 ± 9.6	44 ± 11.6	43 ± 15.5		26	22 ± 2.5	23 ± 2.2	24 ± 3.1
	Ideal		22	31 ± 15.8	23 ± 15.4	16 ± 12.8		68	70 ± 3.1	69 ± 4.0	66 ± 5.9
Golf	Unacceptable		47	26 ± 7.0	31 ± 9.0	36 ± 12.2		22	22 ± 3.8	22 ± 3.9	22 ± 3.8
	Acceptable		43	45 ± 8.1	46 ± 10.1	49 ± 13.2		35	33 ± 5.3	32 ± 4.4	34 ± 4.9
	Ideal		10	29 ± 11.2	23 ± 12.7	15 ± 11.9		43	45 ± 4.6	46 ± 4.9	44 ± 5.9
Motor boating	Unacceptable		0	0 ± 0.1	0 ± 0.0	0 ± 0.1		9	7 ± 1.1	5 ± 1.3	3 ± 1.4
	Acceptable		48	26 ± 10.4	30 ± 12.8	34 ± 15.3		31	37 ± 4.0	32 ± 3.6	30 ± 4.3
	Ideal		52	74 ± 10.4	70 ± 12.8	66 ± 15.3		60	56 ± 4.8	63 ± 4.6	57 ± 5.3
Sailing	Unacceptable		1	10 ± 8.2	10 ± 7.4	10 ± 7.6		26	18 ± 3.3	16 ± 4.4	13 ± 4.7
	Acceptable		47	29 ± 14.2	34 ± 17.1	40 ± 19.9		28	36 ± 3.3	32 ± 2.5	32 ± 3.9
	Ideal		52	61 ± 12.9	56 ± 15.9	50 ± 19.9		46	46 ± 5.3	52 ± 4.4	55 ± 4.6
Hiking	Unacceptable		42	37 ± 14.0	46 ± 17.9	55 ± 21.2		10	10 ± 2.0	12 ± 4.2	15 ± 6.4
	Acceptable		43	37 ± 9.1	36 ± 11.2	33 ± 14.8		41	37 ± 2.3	34 ± 3.0	32 ± 3.8
	Ideal		15	26 ± 13.3	18 ± 13.4	12 ± 10.8		49	53 ± 2.3	54 ± 2.5	53 ± 3.9

Table B. As in Table A, but for the present and future seasonal distributions.

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