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# Projections for the 21st century of the climate potential for beach-based tourism in the Mediterranean

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**ABSTRACT:** Climate is a primary resource for beach-based tourism. It defines the length and quality of the tourist season and plays a major role in destination choices and revenues. The Mediterranean is coincidentally one of the most visited tourist destinations and sensitive areas to climate change worldwide. Social, economic and environmental adaptation to climate change in this region should necessarily evaluate the Mediterranean and European climate resource for beach-based tourism as well as its projected changes. To this end, the second-generation climate index for tourism (CIT) has been adopted. ERA-Interim reanalysis have been used as the regional observed baseline, thus providing daily atmospheric data to derive CIT. For projections, meteorological variables have been obtained from a set of regional climate models (RCMs) within the ENSEMBLES European project. A quantile–quantile adjustment has been applied to the CIT cumulative distribution functions based on each individual RCM output to properly correct biases at regional and local scales. Furthermore, an ensemble strategy is adopted to further cope with uncertainties arising from RCM errors and boundary conditions. The spatial distribution of present climate potential confirms the Mediterranean coast as the most suitable region in Europe for carrying out beach leisure activities. Excellent climatic conditions prevail in most of this coastal region during summer. However, the optimal climate asset is projected to noticeably deteriorate in summer across the Mediterranean, whereas only slightly improving in northwestern Europe by 2075–2094. On the other hand, a general enhancement of ideal climate potential is expected for the shoulder seasons in the former region. That is, optimal climatic conditions may shift from the present peak demand season to spring and autumn. These potential impacts might lead to important drawbacks for the current strongly seasonal-adjusted beach-based tourism industry in the Mediterranean. Therefore, main tourism stakeholders will likely need to face these challenges through adaptation and mitigation strategies.

KEY WORDS Mediterranean beach tourism; climate change; regional climate modelling; statistical adjustment; ensemble strategy

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## 1. Introduction

Climate is a fundamental resource for beach-based tourism, being a major factor in setting the market demand. This type of tourism is one of the main socio-economic sectors for many European Mediterranean countries, being a key gross income source. Southern and Mediterranean Europe is currently one of the most visited tourist destinations worldwide: it accounted for more than 169 million international tourist arrivals, with revenues reaching close to US$ 158 billion in 2010 (UNWTO, 2012). Sun, sea and sand (3S) tourism dominates travel motivation in the Mediterranean, as about half of the total amount of tourists travel to its coastal areas. 3S tourism is a very highly climate-sensitive human activity which relies on a diverse set of atmospheric variables such as temperature, rainfall, relative humidity, hours of sunshine and wind speed (De Freitas, 1985, 1990). Moreover, climate does not solely determine the suitability of beach-based destinations, but strongly influences their supplementary natural resources which are very important tourist assets as well.

Climate change will be very relevant for beach-based destinations and for tourists' own comfort. The Mediterranean is projected to be one of the most sensitive areas to climate change impacts worldwide. Its rate of warming was estimated at 2.5 to 3.5 °C per century during the 1979–2005 period (IPCC, 2007). A redistribution of precipitation and other atmospheric variables (e.g. surface pressure, wind or cloudiness) has also been observed over the Mediterranean. For instance, rainfall decreases between 5 and 20% have been already reported from 1901 to 2005 (IPCC, 2007). The direct impact of an increase in temperatures at high latitudes may result in a poleward shift of the adequate atmospheric conditions for summery recreation. Indirect impacts on European Mediterranean countries related with water scarcity, land and marine biodiversity loss, coastal erosion, desertification or increased energy demand and prices will negatively affect tourism (IPCC, 2007). Therefore, to properly assess the direct and indirect

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impacts of climate change at regional and local scales has nowadays arisen as a topic of paramount interest.

Climate also defines the quality and length of the 3S tourism seasonality alongside with other relevant factors like institutional holidays for many regions worldwide. Destinations are clearly sensitive to climate variability. In Europe, the seasonal contrast acts as a primary pull and push factor for the currently peak summer demand of holidays and it modulates tourist flows (Viner, 2006). Some previous studies focused on general tourism activities and climate change have pointed out that future climatic conditions during the current peak demand season in the Mediterranean may deteriorate, whereas improving in northern Europe. If a poleward shift in temperatures occurs, tourists coming from the latter regions may not travel so far if enjoying more appealing climatic conditions in the summer, thus preferring domestic rather than Mediterranean emplacements. On the other hand, climatic conditions in the shoulder seasons could improve in the European Mediterranean countries (Hamilton *et al.*, 2005; Amelung and Viner, 2006; Amelung *et al.*, 2007; Hein *et al.*, 2009; Amelung and Moreno, 2012). Thus, changes in the length and quality of seasonality for highly-dependent climate tourist activities (i.e. beach or winter sports holidays) could have important implications for competitive relationships among destinations and their profitability (UNWTO, 2008). And the potential consequences of climate change may be relevant not only in the destination countries, but also in countries of origin as they currently are the major source of 3S tourists to the Mediterranean.

Several studies have suggested optimal temperatures for beach-based tourism, but without quantifying the crucial role of other atmospheric variables when assessing the weather resource. For example, Scott *et al.* (2008) indicated that the ideal temperature was on average 26.8 °C. Rutty and Scott (2010) identified that the ideal daily maximum temperatures were between 27 and 32 °C. Moreno (2010) found that ideal weather is associated with temperature of approximately 28 °C, light breeze and a blue sky. But a key issue when quantifying climate change impacts on tourism is to express these in suitable physical indicators. For instance, some climate indices for tourism can be used to evaluate climate attractiveness to tourists. De Freitas *et al.* (2008) developed a second-generation climate index for tourism (CIT) to specifically rate the weather asset for 3S tourism. CIT was theoretically developed and empirically adjusted and it characterizes the daily weather resource by merging all the aspects relevant to tourism. Within this framework, we first assess the present climate potential for beach-based tourism over the entire European and Mediterranean coastal areas. To this aim, CIT has been derived from the ECMWF Re-Analysis (ERA)-Interim reanalysis. Next, we explore its future evolution by employing daily data coming from several regional climate models (RCMs) run under the A1B emissions scenario.

Prior to proper evaluation of climate change impacts at regional and local scales, it would be advisable to calibrate the climatic variables, or their derivatives, in order to correct model biases rather than using raw model outputs (Déqué, 2007; Ho *et al.*, 2012). To this end, we apply a quantile–quantile adjustment to the continuous CIT cumulative distribution functions (CDFs) derived from each individual model outputs (Amengual *et al.*, 2012a). Furthermore, we adopt a multimodel ensemble approach to further encompass uncertainties arising from RCM errors and boundary conditions. We also assess climate change impacts on beach-based tourism potential at local scales by selecting eight automatic weather stations located along the northwestern European and Mediterranean coasts. These stations are representative of local climate features for various popular seaside tourist destinations (Figure 1). Finally, we verify the regional

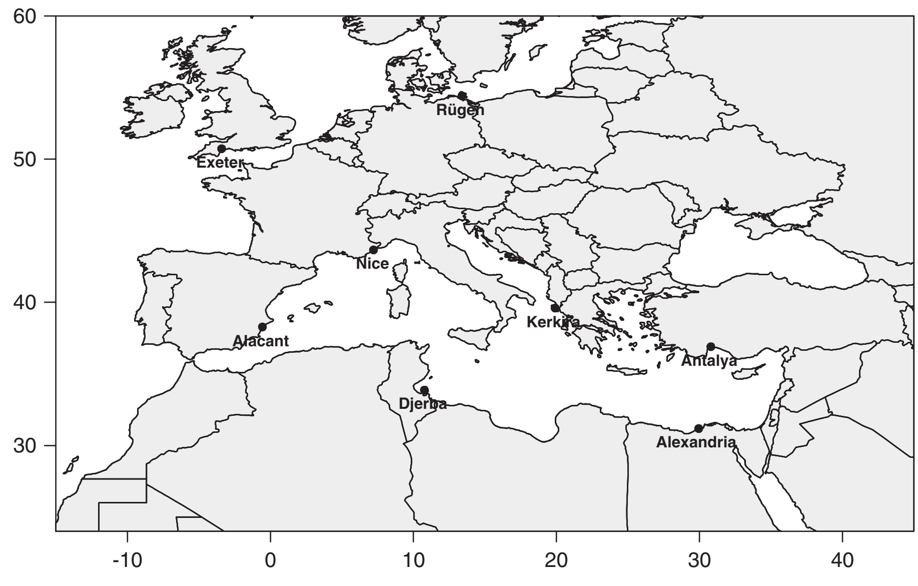



Figure 1. Geographical location of the automatic weather stations analysed in the European and Mediterranean coastlines. The stations are located near important seaside tourist destinations.

climate potential based on ERA-Interim reanalysis at local scales by comparing these against CITs derived from the automatic meteorological stations.

The rest of the paper is structured as follows: Section 2 exposes a general overview of climate indices for tourism and a more detailed discussion of the CIT; Section 3 describes the observed and simulated databases and methods used; Section 4 details the present annual, seasonal and monthly mean regimes of the climate potential for 3S tourism as well as its projected changes. It also presents the verification results of the ERA-Interim at local scales; and finally, Section 5 reviews the main results of the study and offers additional remarks.

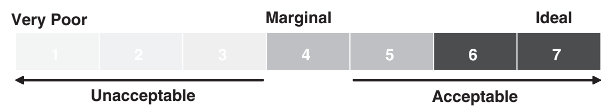
## 2. Climate indices for tourism

The close relationship between climate and tourism allows to quantify this link through climate indices for tourism. Originally, climate indices for tourism only considered a single element, the thermal facet. Later, the tourism climate index accounted for several facets of the weather (TCI; Mieczkowski, 1985). TCI was developed to quantify climate suitability for general tourism engaged in light physical activities by accounting for thermal comfort, precipitation, wind speed and hours of sunshine based on monthly mean climatic data. But climate unevenly affects diverse outdoor leisure activities as these have different optimal temperature ranges and climatic requirements. Moreover, although TCI is theoretically sound and expert-based, its empirical validation is relatively weak. Morgan *et al.* (2000) developed a beach climate index (BCI) based on TCI, but empirically adjusted. However, BCI does not take into account the overriding effects of precipitation when rating the climate asset (Moreno and Amelung, 2009).

More recently, De Freitas *et al.* (2008) proposed a second-generation CIT to specifically rate the weather resource for 3S tourism. For CIT, the perception of the weather resource does not exclusively rely on an optimal range of daily temperatures, but also on the effects of relative humidity, wind speed, short- and long-wave radiation and cloudiness. Moreover, this index accounts for the fact that human comfort depends on non-environmental effects such as the level of activity or clothing. CIT expresses the integrated body–atmosphere energy balance as a thermal sensation. And it assesses the weather asset by merging all the aspects relevant to this kind of tourism on daily, rather than on monthly basis. Thermal (T), aesthetic (A) and physical (P) facets are combined in a weather typology matrix that ranks tourist comfort (Figure 2). This index also recognizes the dominating effects of these aspects 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 (De Freitas *et al.*, 2008).

CIT rates the weather resource for beach-based tourism by using a scale from very poor (i.e. CIT = 1: unacceptable) to very good (i.e. CIT = 7: optimal; Figure 2(a)).

(a)




(b)

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

Figure 2. (a) CIT rating scale, and (b) the weather typology matrix used to derive climate satisfaction rating classes, after Amengual *et al.* (2012b).

CIT also encompasses the following environmental and physiological variables through the thermal aspect: solar heat load, heat loss by convection (i.e. wind), evaporation (i.e. sweating), short- and long-wave radiation exchanges and metabolic heat (i.e. activity level). Aesthetic and physical facets refer to the sky condition and to the effects of precipitation or disturbing wind, respectively (De Freitas *et al.*, 2008). Originally, the weather typology matrix did not rate the climate resource for thermal conditions below slightly cool owing to their inappropriateness for 3S tourism. Amengual *et al.* (2012b) rated those CIT values that were deliberately left blank to avoid dealing with incomplete data series when assessing climate change impacts on the tourism potential (Figure 2(b)). Furthermore, original thresholds for the aesthetic facet were also slightly modified,that is, cloud from ≤40 to <45% and from ≥50 to ≥45%, to avoid inconsistencies with the observed and simulated databases.

De Freitas *et al.* (2008) also reported some limitations when testing this index: CIT was originally examined for a relatively narrow tourist-market segment and over a restricted spatial coverage. We have further verified CIT by correlating monthly mean visitation levels and climate potentials for the System of Platja de Palma (SPdP) in Mallorca, Spain (for more details, see Amengual *et al.*, 2012b). Being aware that a straightforward relationship between the climate resource and visitation levels for a 3S destination is elusive, as many factors can influence its frequentation, such as exchange rate, economic situation, costs, accessibility or land/seascape (Ceron *et al.*, 2009); we consider attendance levels as a suitable and primary demand indicator to measure tourist comfort under the present climatic conditions for this major seaside resort.

Table 1. Correlation coefficients (r) and their confidence level (p) for the monthly mean CIT conditions against the average number of nights spent per month in the SPdP, Spain. Also shown in brackets are the 95% confidence intervals for r. Note that monthly mean visitation levels and climate resources were obtained from the 10-year (1999–2008) and 36-year (1973–2008) periods, respectively. For further information, see Amengual *et al.* (2012b).

| CIT conditions | *r* | *p* |
|---|---|---|
| Ideal | 0.81 (0.45, 0.95) | >99% |
| Acceptable | 0.84 (0.52, 0.95) | >99% |
| Ideal + Acceptable | 0.95 (0.82, 0.98) | >99% |

Thus, we have been able to validate CIT when accounting for both a wider segment of the tourist market, including different ages and family status, and a larger spatial coverage of the visitor's source (several northwestern European countries). Note that the following categorization is used to simplify subsequent discussions: CIT = 1, 2 , 3: *unacceptable*; CIT = 4, 5: *acceptable*; and CIT = 6, 7: *ideal* conditions, respectively (De Freitas e*t al*., 2008). Table 1 shows very strong positive correlations between the monthly mean CIT conditions and the average number of nights spent per month; that is, high visitation periods coincide with those months exhibiting the highest ratings of the climate asset in the SPdP. This indicates that its current beach-based tourist model is well adjusted to the climatic factors throughout the year and that the tourist sector in SPdP is already mature and does not present imbalances in the sense of underexploited monthly climate potentials.

## 3. Data and methods

### 3.1. Input data

Impact studies of regional climate change require long-term atmospheric databases at high spatial and temporal resolutions. In this study, ERA-Interim reanalysis produced by the European Centre for Medium-Range Weather Forecasts (ECMWF) have been used to represent the observed climate baseline. ERA-Interim currently covers a period starting from 1 January 1989 till present. The reanalysis system is configured with 60 levels in the vertical, a grid spacing of 0.7°, 3-hourly surface and 6-hourly upper-air data output (Dee *et al.*, 2011). Daily gridded data of 2-m temperature, accumulated precipitation, 2-m dewpoint temperature, total cloud cover and 10-m wind speed have been obtained for the 20-year 1990–2009 period. Daily precipitation amounts were obtained from 24-hour forecasts, wheras the remaining variables came from reanalyses at 12 UTC. The Bolton equation was applied to obtain 2-m relative humidity from air and dewpoint temperatures (Bolton, 1980).

Regarding projections of climate potential for tourism, the regional simulations available from the ENSEMBLES European project have been used. Daily climatic data from 13 different RCMs run from 1951 to 2100 for the A1B SRES emissions scenario have been considered (Table 2; Nakicenovic *et al.*, 2000). The experiments were performed by using a grid spacing of 25 km that spans Europe and includes the easternmost part of the Atlantic ocean, northern Africa and western Asia (Hewitt and Griggs, 2004; http://ensembles-eu.metoffice.com). ERA-Interim and simulated variables have been bilinearly interpolated from the four nearest gridpoints of both meshes to a common user-defined grid which covers the Atlantic European, Black Sea and Mediterranean coastal areas (Akima, 1978, 1996). This mesh has a spatial resolution of $0.5^\circ \times 0.5^\circ$, with an extension being determined by the smallest spatial domain of the whole considered set of RCMs.

Table 2. List of transient RCM experiments driven within the ENSEMBLES European project for the 1951–2100 period. Note that all the models have a spatial resolution of 25 km and have been run under the A1B SRES.

| Driving General Circulation Model (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 |

Finally, we have selected eight seaside tourist resorts to assess and explore in detail the differences in climate change impacts on 3S tourism at local scales across the Mediterranean. These locations are well-known beach tourist destinations representative of local climate features of the Western (Alacant and Nice), Central (Djerba and Kerkira) and Eastern (Alexandria and Antalya) Mediterranean, as well as from northwestern (Exeter and Rügen) Europe (Figure 1). Atmospheric data for each individual emplacement have been obtained from the nearest weather station with complete daily observed series available for the 1990–2009 period (Table 3). These automatic weather stations belong to the Global Telecommunication System (GTS) of the World Meteorological Organization (WMO). ENSEMBLES meteorological daily data series have been linearly interpolated to the weather stations from the nearest four model gridpoints.

### 3.2. Thermal sensation

Thermal sensation has been computed by using the Pro version of the RayMan model (Matzarakis and Rutz, 2007). RayMan Pro accounts for the body–atmosphere energy budget schemes and yields the mean radiant

Table 3. Automatic weather stations collected from the GTS system network. Note that the stations have been selected from criteria of proximity to leading tourist destinations and completeness of daily observed meteorological series.

| Location | Country | International Civil Aviation Organization (ICAO) code | Longitude | Latitude |
|---|---|---|---|---|
| Exeter | England | EGTE | −3.41 | 50.73 |
| Alacant | Spain | LEAL | −0.56 | 38.28 |
| Nice | France | LFMN | 7.21 | 43.66 |
| Djerba | Tunisia | DTTJ | 10.77 | 33.87 |
| Rügen | Germany | WMO 12200 | 13.40 | 54.42 |
| Kerkira | Greece | LGKR | 19.91 | 39.60 |
| Alexandria | Egypt | HEAX | 29.95 | 31.18 |
| Antalya | Turkey | LTAI | 30.80 | 36.90 |

temperature ($T_{\text{mrt}}$). $T_{\text{mrt}}$ is the most important parameter affecting the human energy balance during sunny weather conditions. The model derives the physiologically equivalent temperature (PET) from the mean radiant temperature (Matzarakis and Rutz, 2007; Matzarakis *et al.*, 2007). $T_{\text{mrt}}$ is obtained by setting up the following daily meteorological parameters in RayMan Pro: air temperature, relative humidity, wind speed, short- and long-radiation and cloud cover. RayMan Pro also includes the subsequent geographic and thermo-physiological parameters: longitude, latitude, local time, human activity, body heat production and heat transfer resistance of clothing. PET has been employed to obtain the thermal facet of weather according to CIT. Finally, computing the CIT requires expressing this feature as a thermal sensation by using the standard 9-point ASHRAE scale (ASHRAE, 2004; Figure 2). Note that PET has been computed by considering the following standard personal and thermo-physiological parameters: height = 1.75 m; weight = 75 kg; age = 35 years; sex = male; clothing = 0.1 clo (1 clo = 0.155 $\text{Km}^2\text{W}^{-1}$) and physical activity = 46 W.

### 3.3. Quantile–quantile adjustment approach

Reliable projections of weather variables and their derivatives are required from climate models in order to estimate precise impacts from future climate change. The optimal use of model outputs at local and regional scales requires to correct for possible biases and other systematic errors. Even if dynamical downscaling improves the representation of regional features in climate projections, inaccuracies still remain. Several procedures exist to calibrate these projections such as the bias correction or change factor approach (Déqué, 2007; Ho *et al.*, 2012). We apply the quantile–quantile adjustment first introduced and successfully verified in Amengual *et al.* (2012a). This calibration method is based on a non-parametric function that amends mean, variability and shape errors in the simulated CDFs, being more versatile than former procedures. Formulation details can be found in Amengual *et al.* (2012a). Moreover, the improvement of the quantile–quantile adjustment when applied to CIT distributions was confirmed in Amengual *et al.* (2012b). In addition, the spread among the models was adequately reduced. That is, the quantile–quantile adjustment amends systematic biases and variability errors of each RCM, thus allowing all RCMs to be safely considered equiprobable. Next, we adopt a multimodel ensemble approach.

### 3.4. Regional baseline verification

Although reanalysis have substantially improved in recent years, some uncertainties still remain. Limitations during the assimilation process arise from several sources: the general difficulty in combining heterogeneous observations onto a regular grid, uncertainties regarding the assimilation model and the quality and distribution of the underlying observations (Reichler and Kim, 2008; Vidal *et al.*, 2010). Furthermore, local climate aspects can remain uncharacterized owing to a lack of both, a more detailed description of small-scale orographic features and land-sea distribution, and model representation of local forcings and sub-grid processes. Therefore, ERA-Interim spatial resolution would advise against directly using them for local impact assessment. For a further clarification of this issue, we have carried out a verification of our regional climate potential baseline derived from ERA-Interim by comparing this against local climate potentials obtained from the weather station databases (Table 3, Figure 1). Note that daily ERA-Interim data series have also been linearly interpolated at the weather stations from the nearest gridpoints.

## 4. Results

### 4.1. Changes in annual regimes of climate potential for tourism

Although changes in the annual mean absolute frequencies of acceptable and ideal conditions among the 20-year present baseline (1990–2009) and three 20-year future ensemble mean time slices (i.e. early 21st century (2015–2034), mid 21st century (2045–2064) and late 21st century (2075–2094)) have been calculated, we only discuss the absolute changes between late future and present intervals in order to summarize this subsection. Note that further information on the evolution of 3S climate potential for the remaining future time slices is available at: http://cliturmed.uib.es.

Figure 3(a) and (b) displays the European and Mediterranean coastal distribution of the present climate resource. The best ratings for both acceptable and ideal conditions are found over the Mediterranean. Present climatic conditions also exhibit a gradual deterioration polewards as well as over the interior European coastline. The absolute frequencies of acceptable conditions are as high as half of annual days for extensive regions of the southeastern Mediterranean coast. In addition, almost the entire Mediterranean exhibits above 90 days per year with acceptable conditions (Figure 3(a)). Ideal

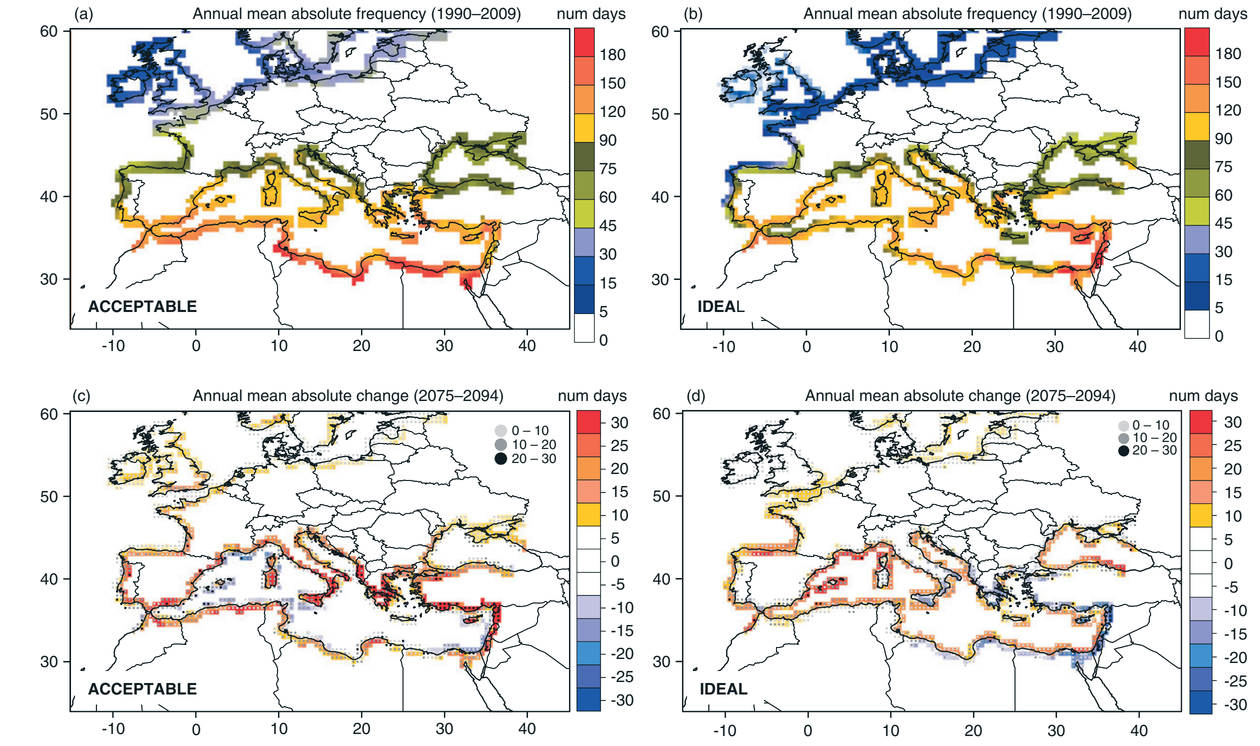



Figure 3. Mean annual frequencies of present (1990–2009) (a) acceptable and (b) ideal; and annual ensemble-mean absolute changes of late 21st century (2075–2094) (c) acceptable and (d) ideal conditions of the European and Mediterranean climate resource for beach tourism. Shaded circles show the ensemble-standard deviation according to the scale. Absolute changes and standard deviations are expressed as number of days.

conditions show their maximum values in the easternmost Mediterranean, with absolute frequencies above 180 days per year. Most of the remaining Mediterranean coastline exhibits ideal absolute frequencies above 90 days per annum (Figure 3(b)). The European Atlantic and Black Sea coastal areas depict lower present absolute frequencies: both acceptable and ideal conditions are roughly 30 or less days per year in the former, and 60 days per year in the latter. Only the southernmost Atlantic coastline of the Iberian peninsula owns annual climate potentials similar to those found over the Mediterranean.

Regarding projections, Figure 3(c) depicts an overall future increase in the annual number of days rated as acceptable for both the European Atlantic and Black Sea coastal areas. However, these increases would barely exceed 15 days per year. The absolute frequencies of acceptable conditions are projected to increase for most of the Mediterranean coastline as well. These increases could be close to – or above – a month per year for some coastal areas of Spain, Italy, Croatia, Greece, Turkey and Middle East. More moderate rises are expected for extensive parts of the southern Mediterranean. Regarding the optimal climatic resource, annual mean absolute frequencies could experience noticeable increases in Portugal, the northernmost Spanish Atlantic area and the southernmost France (Figure 3(d)). In the central and eastern Mediterranean, a general deterioration in the climate resource rated as ideal is projected. The optimal absolute frequencies could decrease more than a month per year for the easternmost part. On the other hand, no significant changes are projected in the western Mediterranean by late 21st century. Uncertainties of the projected CIT frequencies among the RCMs increase along the century for all categories, a natural consequence of the increasing spread with time observed in multimodel climate scenarios. The smallest ensemble-standard deviations for acceptable and ideal conditions are found over large areas of the Atlantic Europe (Figure 3(c) and (d)).

### 4.2. Changes in seasonal regimes of climate potential for tourism

Climate imposes seasonality on beach-based tourism in the European Mediterranean. Therefore, future changes in seasonal climate potential could have a major impact on the spatial and temporal distribution of 3S tourism flows within Europe. Furthermore, this economic sector is currently characterized by a strong seasonality, with large contrasts in occupancy rates between the cold and warm seasons. To specifically assess present and future seasonal climatic resources, we define seasons as: winter (December, January and February), spring (March, April and May), summer (June, July and August) and autumn (September, October and November).

#### *4.2.1. Spring*

Acceptable conditions prevail across the Mediterranean for the present mean regime, with the highest absolute frequencies over large southern and eastern coastal areas. The acceptable absolute frequencies are as high as half of the seasonal days for these regions (Figure 4(a)). Ideal

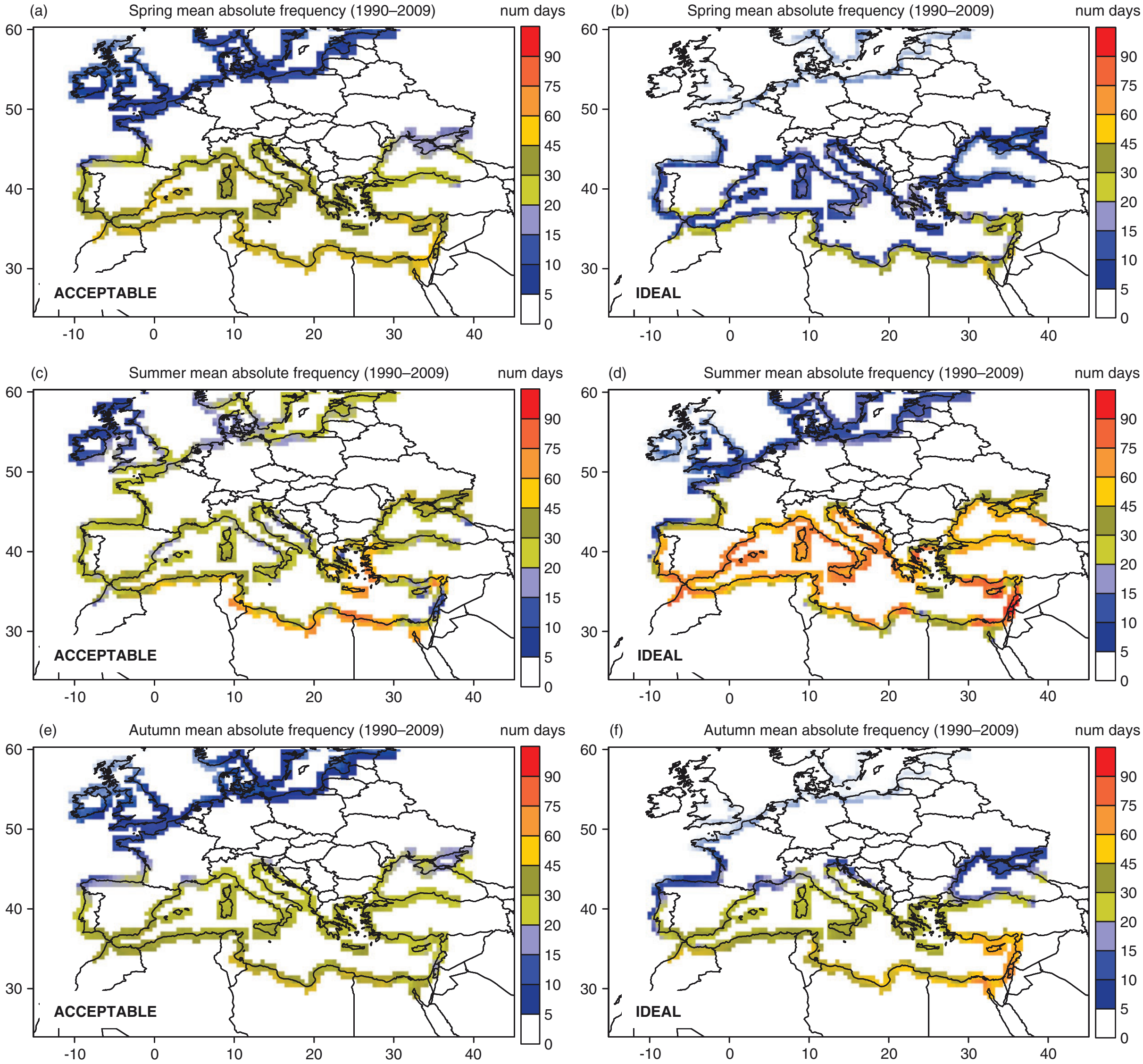



Figure 4. Mean seasonal frequencies of present (1990–2009) (a) spring acceptable, (b) spring ideal, (c) summer acceptable, (d) summer ideal, (e) autumn acceptable and (f) autumn ideal conditions of the European and Mediterranean climate resource for beach tourism. Absolute frequencies are expressed as number of days.

conditions are residual except for the northeastern African and easternmost Mediterranean coastlines (Figure 4(b)).

Projections indicate moderate decreases in the number of days with acceptable conditions for a substantial part of the Mediterranean coast. These losses may be more remarkable in the eastern- and, to a lesser extent, westernmost coastlines (Figure 5(a)). No significant changes are expected for most of the Atlantic and Black Sea coasts. The highest increases could occur in the northeastern Aegean Sea. Changes in the ideal absolute frequencies may exhibit a remarkable contrast between the Mediterranean and Atlantic Europe. The former could noticeably increase ideal climate potential in some regions, especially over the western- and easternmost parts, whereas the latter may remain with no appreciable changes (Figure 5(b)). Figure 5(a) and (b) depicts a strong spatial correlation among changes for acceptable and ideal conditions in spring: increases in the ideal absolute frequencies can be partly attributed to decreases in the acceptable mean regimes. Thus, redistributions between both categories could result in a net enhancement of the Mediterranean climate potential for beach-based tourism by 2075–2094. Wide areas of the whole coastal domain show small ensemble-standard deviations (Figure 5(a) and (b)).

### *4.2.2. Summer*

Summery optimal conditions for 3S are predominant in the present for almost the entire Mediterranean (Figure 4(c) and (d)). Up to 60 days per season have excellent climatic conditions in most coastal lands of Spain, Italy, Croatia, Greece, southern Turkey and northeastern Egypt. The highest optimal ratings are found in Middle East, whereas the smallest are located in the lowest latitude North African coastline. Presumably, the latter sub-region is too warm for carrying out 3S leisure

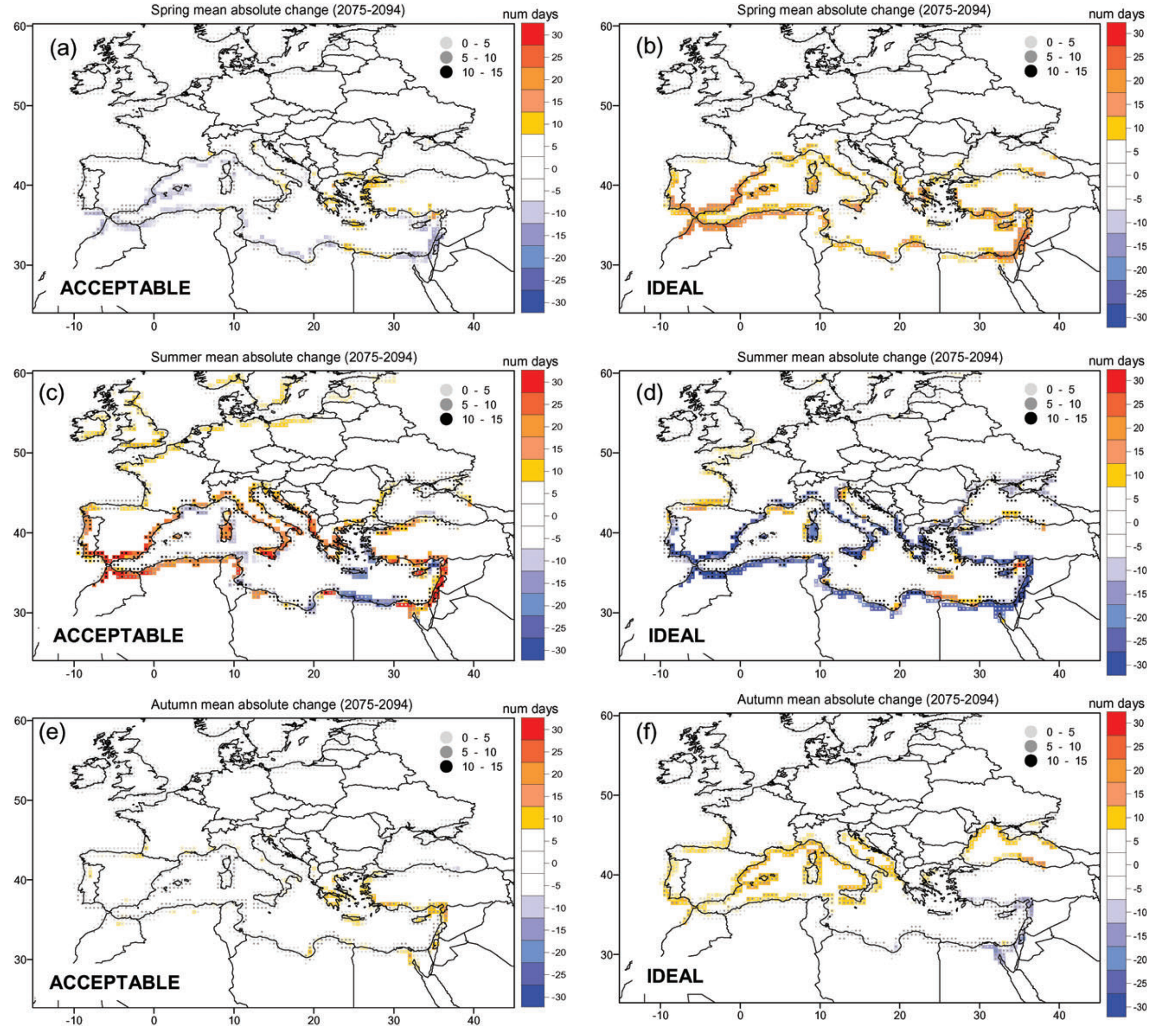



Figure 5. Seasonal ensemble-mean absolute changes of late 21st century (2075–2094) (a) spring acceptable, (b) spring ideal, (c) summer acceptable, (d) summer ideal, (e) autumn acceptable and (f) autumn ideal conditions of the European and Mediterranean climate resource for beach tourism. Shaded circles show the ensemble-standard deviation according to the scale. Absolute changes and standard deviations are expressed as number of days.

activities under optimal conditions in summer, but it exhibits the highest absolute frequencies for acceptable conditions. These spatial patterns are consistent with previous findings by Moreno and Amelung (2009) when rating the climate asset for beach tourism over Europe, but using the BCI index. Note also that the present latitudinal differences in the acceptable absolute frequencies are rather small, appearing to be a minor factor on travel motivation for 3S tourists.

While no significant differences are found in the present distribution of the acceptable absolute frequencies between the Atlantic and Mediterranean Europe, these are very noticeable for optimal perceptions. It appears that the large differences in excellent, rather than in acceptable, climatic conditions between high and low latitude European countries would act as a primary push and pull factor for 3S tourism flows during the high visitation season. Even so, recall that frequentation is also strongly modulated by several aspects such as: political stability, socio-economic infrastructures, environmental resources, cultural heritage, travel costs and time or standard of living in destination countries (Gössling and Hall, 2006; Ceron *et al.*, 2009).

Acceptable absolute frequencies are projected to increase in most of the entire domain. Most Mediterranean countries, the Atlantic Spain and Portugal could exhibit increments close to – or above – 30 days per season, but mainly at the expense of important losses in ideal climatic conditions (Figure 5(c) and (d)). These general losses could be as high as a month and, even more in the easternmost Mediterranean with decreases up to two months. Therefore, an overall deterioration of the ideal climatic resource for beach-based tourism is projected over the Mediterranean by 2075–2094.

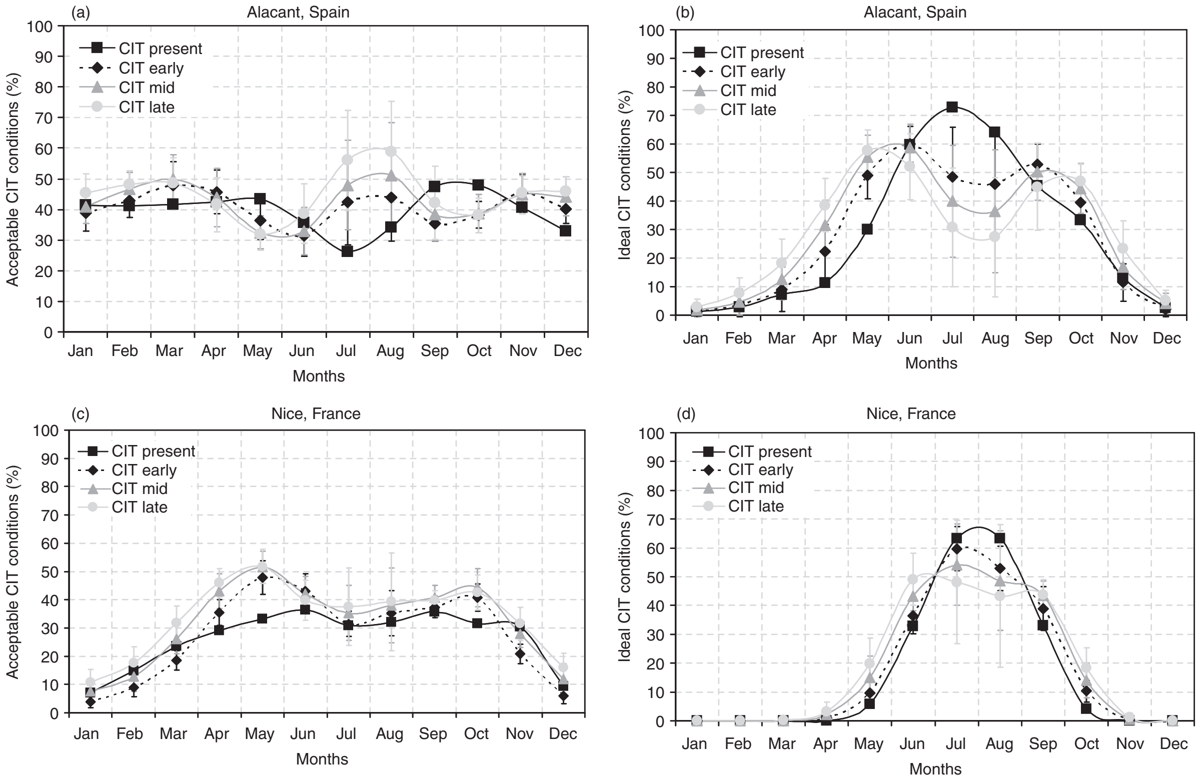



Figure 6. Monthly ensemble-mean relative frequencies of present (1990–2009), early (2015–2034), mid (2045–2064) and late (2075–2094) time slices in the Western Mediterranean for (a) acceptable and (b) ideal conditions in Alacant; and (c) acceptable and (d) ideal conditions in Nice. Also displayed is ensemble-standard deviation.

Figure 5(c) and (d) also shows a strong spatial correlation between Mediterranean regions increasing/decreasing acceptable/ideal climatic conditions. Unlike spring, the projected redistribution would be from ideal to acceptable conditions, thus resulting in a net degradation of the present summery climate asset. The Atlantic coastal areas of Europe may somewhat be favoured by this poleward shift on climatic conditions. However, this enhancement would be only significant for appropriate conditions, being rather imperceptible for ideal categories excepting the Cantabrian coast. For both categories, the smallest ensemble-standard deviations are mainly located over large areas of the European Atlantic.

These results complement those obtained by Moreno and Amelung (2009) when examining projections coming from two different RCMs run under the A1FI SRES. They suggested substantial reductions in the climatic asset for beach tourism, but over limited parts of the Mediterranean by mid 21st century. In addition, they obtained remarkable improvements in climatic conditions along the Atlantic coast just for the more drastic scenario. Here, projections point out a significant deterioration in the optimal climate resource over the entire Mediterranean together with no significant increases along Atlantic Europe by late 21st century. Moreover, even if general increases in appropriate conditions are projected for the latter region, these are expected to be smaller than for the former area. This complementary information is just an expression of the range of uncertainty in global change that is found among different scenarios and models, besides the use of different climate indices for tourism and future time slices, and the application of a statistical adjustment.

### 4.2.3. *Autumn*

Present ideal conditions for beach tourism are prevalent in the southeastern and easternmost Mediterranean. Spatial distributions of the acceptable and optimal absolute frequencies are rather similar for the rest of the Mediterranean, roughly representing each class a third of the whole amount of seasonal days (compare Figure 4(e) and (f)). The large differences found in ideal conditions between low and high latitude European countries during the summer are drastically reduced in autumn. In general, the seasonal climate asset for 3S tourism gradually degrades polewards. Note also that the present optimal absolute frequencies are higher in autumn than in spring over the Mediterranean, but the opposite applies for acceptable conditions.

No appreciable changes are projected for the acceptable absolute frequencies for almost the entire domain. Only slight and scattered increases might occur in some regions of the northeastern Mediterranean (Figure 5(e)). These regions could again experience equivalent decreases in the ideal mean regimes. Wide coastal areas of the western and central European Mediterranean and some of the southern European Atlantic and the Black Sea could slightly benefit from an increase in the

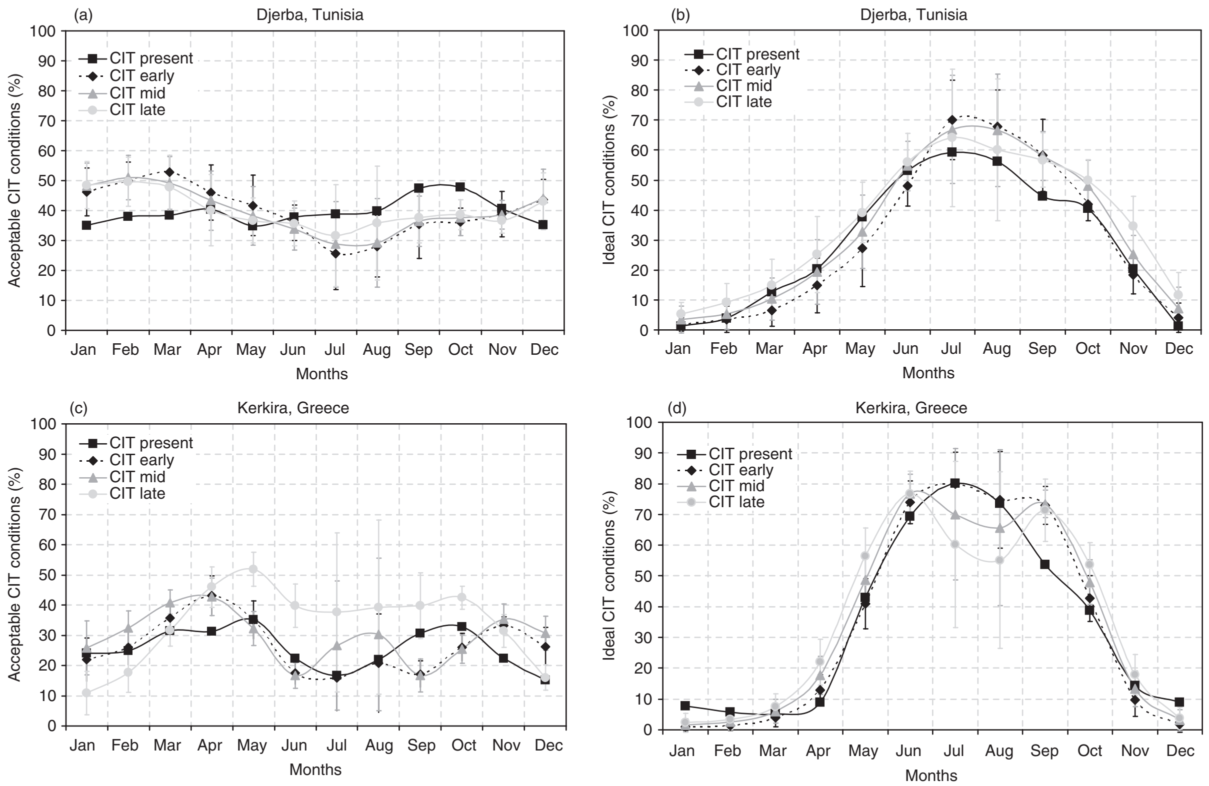



Figure 7. As in Figure 6, but in the Central Mediterranean for (a) acceptable and (b) ideal conditions in Djerba; and (c) acceptable and (d) ideal conditions in Kerkira.

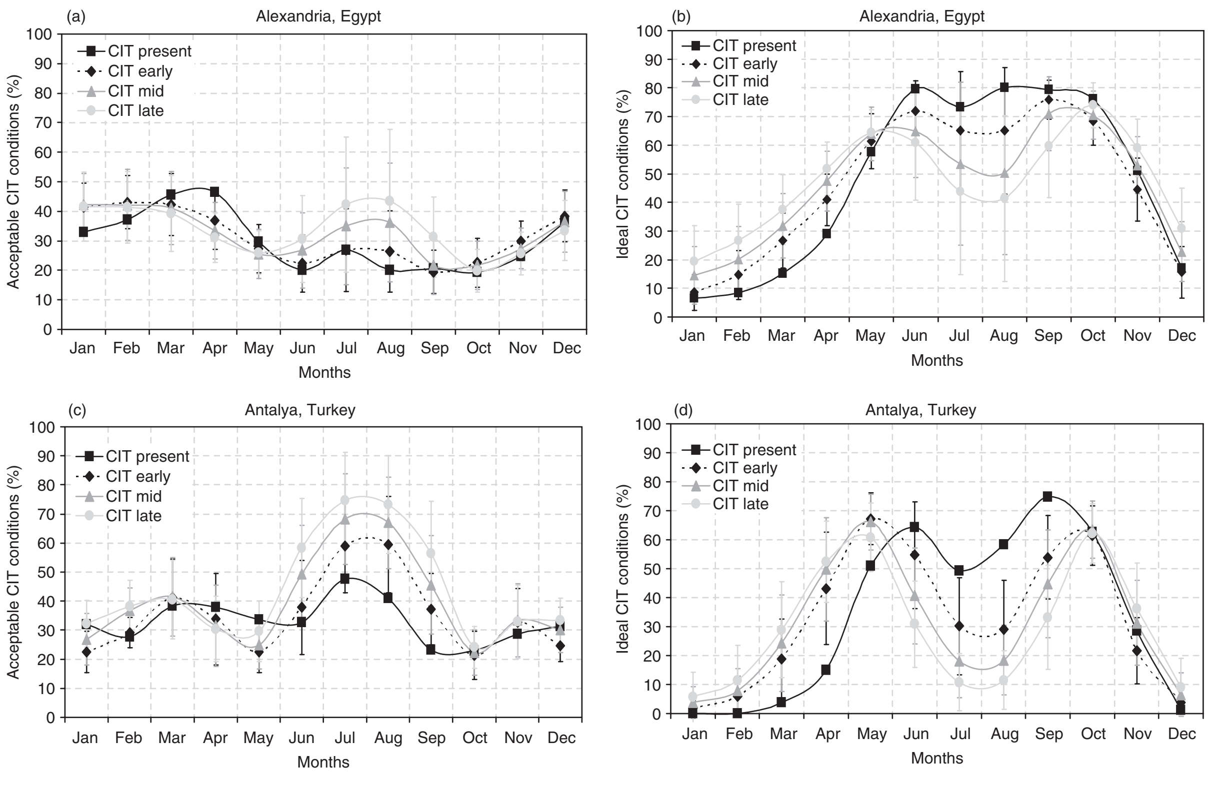



Figure 8. As in Figure 6, but in the Eastern Mediterranean for (a) acceptable and (b) ideal conditions in Alexandria; and (c) acceptable and (d) ideal conditions in Antalya.

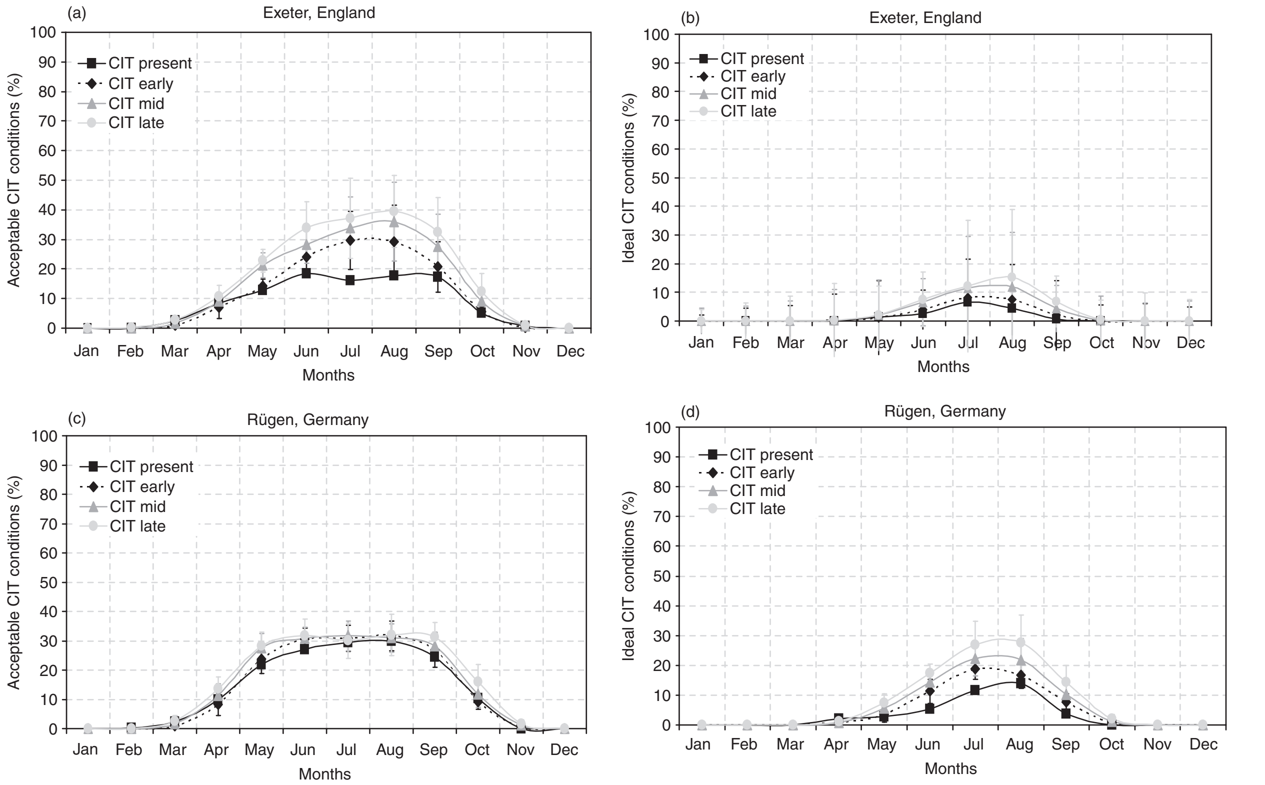



Figure 9. As in Figure 6, but in Northwestern Europe for (a) acceptable and (b) ideal conditions in Exeter; and (c) acceptable and (d) ideal conditions in Rügen.

ideal absolute frequencies (Figure 5(f)). Note that the ensemble variability for both categories is rather small for almost the entire coastal domain.

In summary, seasonal projections outline redistributions of the present climate resource for 3S tourism in the Mediterranean. That is, climatic conditions could improve in spring, whereas the summery prevalence of the excellent weather asset could be significantly reduced. In autumn, changes might be unevenly distributed: climatic conditions could enhance in western and central Mediterranean Europe, whereas degrading in the easternmost part. Finally, note that the lowest spatial variability among CIT scores based on RCMs are found in autumn and, to a lesser extent, in spring.

### 4.3. Changes in monthly regimes of climate potential for tourism

As aforementioned, the excellence of climatic potential in summer acts as one of the major drivers for seasonality in the Mediterranean beach-based tourism demand. Although the CIT is a proxy for 3S tourism comfort rather than actual visitation levels, strong correlations exist between climate potential and attendance levels for 3S tourism throughout the annual cycle at least in SPdP (Section 2; Amengual *et al.*, 2012b). High attendance months (i.e. June, July and August) coincide with the most suitable climatic conditions. Thus, everything else being equal, the assessment of climate change impacts in the monthly mean climate potentials for the selected seaside resorts could hint, as a first-order approximation, the future evolution of their tourism flows.

Present monthly ideal climate potentials in Western Mediterranean destinations are characterized by summer peak distributions in the annual cycle, with relative frequencies above 60% and 70% at the high and low latitude weather stations, respectively. Note that the peak distribution is wider in Alacant than in Nice (Figure 6). For the latter, ideal conditions only prevail clearly in July and August, while the acceptable relative frequencies are relatively high from May to October. The former has higher monthly climate potentials (compare Figure 6(a) and (b)). In Central Mediterranean, the ideal distributions depict a wide summery peak, from May to October, in the annual cycle. In Djerba and Kerkira, the monthly peaks are as high as 60% and 80% of all days in July, respectively (Figure 7). Note that acceptable conditions are relatively high during the shoulder seasons in both destinations as well. For the present monthly mean regimes, Alexandria and Antalya do not exhibit such peak distributions in summer. Rather, Alexandria has an uniform monthly distribution of very high ideal relative frequencies from July to October. Antalya depicts a bimodal distribution, with maximum values in June and September. Both destinations possess ideal relative frequencies above 50% of monthly days virtually from May to October (Figure 8).

Presently, temperate destinations have no significant climate potential for 3S tourism. The ideal relative frequencies barely exceed 10% during the summer months in Rügen, and are even lower in Exeter. The acceptable relative frequencies are also small in summer, with maximum values of roughly 20% and 30% in Exeter and Rügen, respectively (Figure 9). Therefore, the easternmost Mediterranean destinations exhibit the highest climate asset for beach-based tourism in the present period. These locations are characterized by both the highest peaks and the widest amplitudes in the annual optimal distributions of the monthly mean climate regimes. Therefore, this analysis at local scales reinforce the previous results suggesting the importance of spatial and temporal distributions on the excellent climatic resource in Europe as a primary driver for current peak beach tourism demand.

Projections point out a general climate potential deterioration for almost all Mediterranean destinations during the current high 3S frequentation period. In summer, the ideal relative frequencies may drastically diminish throughout this century, favouring important increases for acceptable conditions in most seaside resorts (Figures 6–8). On the other hand, the ideal relative frequencies could remarkably increase during late spring and early autumn. That is, the monthly mean frequency of optimal regimes are projected to shift from the present summery peaks to future bimodal distributions in the annual cycle, thus resulting in a general displacement of the ideal relative frequencies towards the beginning and ending of the current high attendance period. In addition, some Mediterranean emplacements could exhibit future acceptable peak distributions in summer. Therefore, monthly climate potentials for beach-based tourism in these destinations are expected to abide a summery net degradation as well as a clear off-season improvement. On the contrary, temperate destinations may experience a remarkable enhancement in their annual climate potentials. Although the ideal relative frequencies may notably increase in summer, would still remain small on the monthly mean regimes (Figure 9). In Exeter, acceptable conditions could even double the present relative frequencies.

### 4.4. Validation of regional climate potential for tourism

The verification of regional climate potential at local scales has been carried out by means of a twofold approach. First, we evaluate the annual and seasonal continuous CIT CDFs based on ERA-Interim against those based on weather station daily data by means of the linear error in probability space (LEPS) and root mean square error (RMSE) skill scores. LEPS is doubly equitable, with values ranging from 0, when databases being compared are independent, to 1, when their correspondence is perfect (Jolliffe and Stephenson, 2003). Next, we also carry out a climatological validation for ERA-Interim dataset and the 1990–2009 baseline on an annual and seasonal basis. Table 4 shows the yearly percentile-wise statistical indices. LEPS and RMSE skill scores are well above 0.5 and below 0.9, respectively, for all automatic weather stations. Therefore, a good agreement is found between the annual CIT CDFs derived from ERA-Interim data interpolated to the destinations and those directly based on weather station data. The correspondence is particularly high for Alacant, Djerba and Antalya, with LEPSs above 0.9 and RMSEs not exceeding 0.4 (Table 4).

Table 4. Percentile-wise LEPS and RMSE statistical skill scores for the annual CIT CDFs based on ERA-Interim reanalysis when compared against CIT derived from weather stations for the 1990–2009 baseline.

| Location | Country | LEPS | RMSE |
|---|---|---|---|
| Exeter | England | 0.72 | 0.40 |
| Alacant | Spain | 0.93 | 0.37 |
| Nice | France | 0.82 | 0.49 |
| Djerba | Tunisia | 0.92 | 0.33 |
| Rügen | Germany | 0.66 | 0.67 |
| Kerkira | Greece | 0.71 | 0.76 |
| Alexandria | Egypt | 0.59 | 0.85 |
| Antalya | Turkey | 0.93 | 0.40 |

Figure 10 depicts the annual climatological verification in terms of climate ratings for the baseline. In general, a good agreement is found when comparing unacceptable, acceptable and ideal relative frequencies of the CITs based on regional or local data. For most tourist destinations, the weather asset ratings are very similar, prevailing the same classes in their annual mean regimes. The most important differences are found in Alexandria: HEAX shows a clear predominance of ideal conditions, whereas ERA-Interim exhibits a more evenly distribution among categories (Figure 10(g)). Table 5 tabulates the seasonal percentile-wise skill scores. An overall agreement is also found when verifying ERA-Interim on a seasonal basis. The best agreement is found in Alacant, Nice and Djerba, whereas the worst corresponds to Rügen and Alexandria. The seasonal histograms also display a good reproduction of climate potentials at local scales for those CITs derived from the regional baseline (Figures 11–13). That is, unacceptable, acceptable and ideal distributions are very similar for both databases and most locations. Again, the greatest differences among the relative frequencies are found in Alexandria: ideal conditions are systematically underestimated by reanalysis (Figures 11(g), 12(g) and 13(g)). Despite these discrepancies, an overall agreement is found among CIT distributions based on reanalyses and weather stations on annual and seasonal basis, thus ensuring the reliability of the results derived from ERA-Interim.

Note that the best performance in terms of the percentile-wise skill scores does not always correspond to the most similar climatological ratings. As aforementioned, temperate stations exhibit a very good climatological correspondence among classes when comparing CITs based on ERA-Interim against those derived from automatic weather stations, but LEPS are relatively low in comparison with some lower latitude destinations (Figure 10(a) and (e)). Unlike RMSE, LEPS penalizes

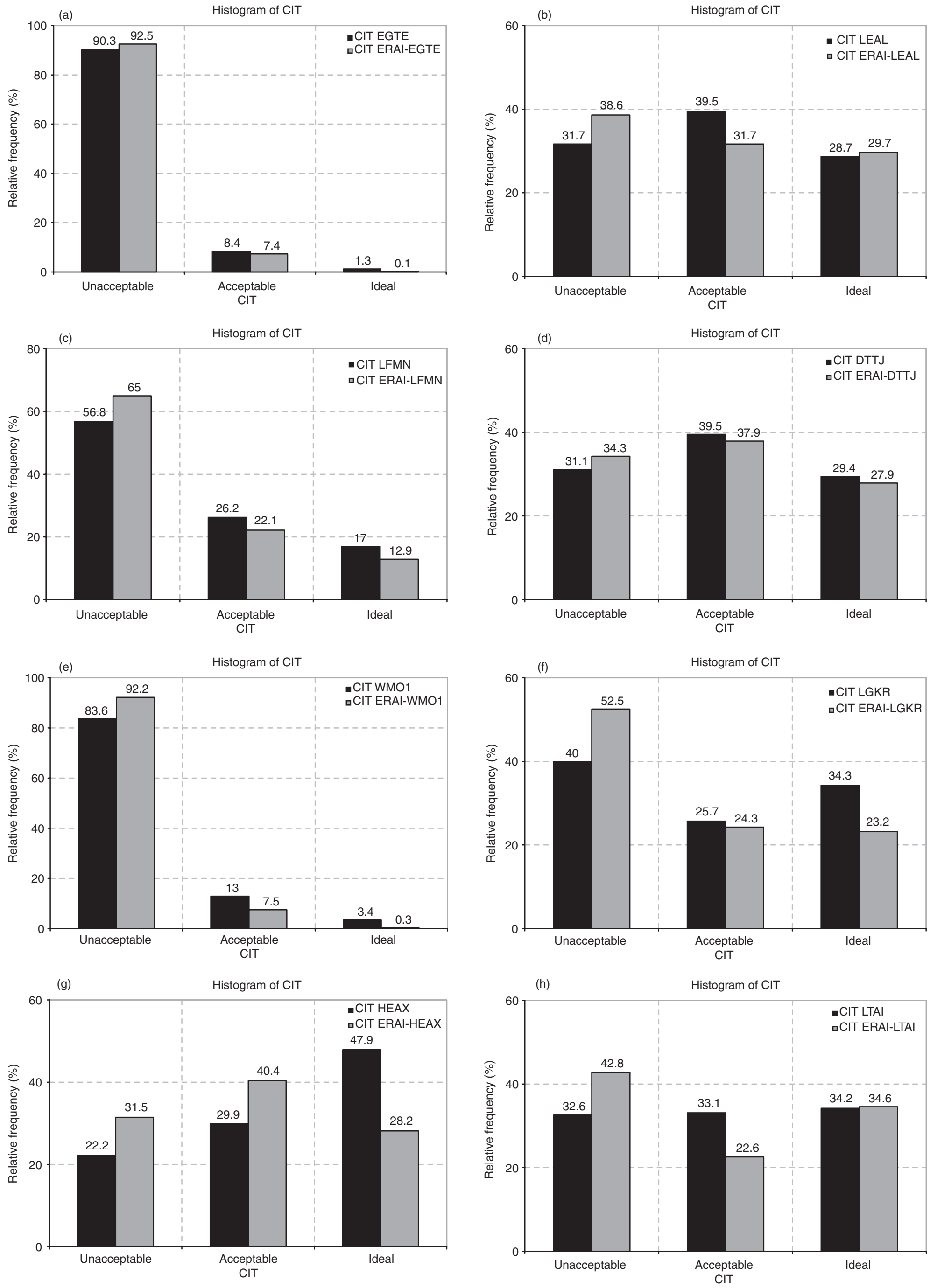



Figure 10. Unacceptable, acceptable and ideal mean relative annual frequencies (%) of the 3S climate resource derived from the automatic weather stations and ERA-Interim reanalysis in (a) Exeter, (b) Alacant, (c) Nice, (d) Djerba, (e) Rügen, (f) Kerkira, (g) Alexandria and (h) Antalya.

more the discrepancies near the climatological mean than it does for the extremes. Most daily weather perceptions are classified as unacceptable for northwestern European destinations, being clearly predominant in the present annual and seasonal mean regimes (Figure 10). Therefore, small errors in their continuous CIT CDFs based on reanalysis are more penalized in term of LEPS, but not in terms of RMSE. When the individual CITs are aggregated into the different categories for climatological verification purposes, slight biases among those CITs derived from ERA-Interim and weather stations that belong to the same class are removed.

## 5. Discussion and conclusions

The Mediterranean is both one of the most visited tourist destinations and highly sensitive areas to climate change worldwide. Beach-based tourism is currently a major mainstay of the gross domestic product in many Mediterranean countries. Therefore, it is crucial to

Table 5. As in Table 4, but for the seasonal CIT CDFS.

| Location | Country | Spring | | Summer | | Autumn | |
|---|---|---|---|---|---|---|---|
| | | LEPS | RMSE | LEPS | RMSE | LEPS | RMSE |
| Exeter | England | 0.63 | 0.48 | 0.73 | 0.50 | 0.73 | 0.35 |
| Alacant | Spain | 0.89 | 0.33 | 0.85 | 0.38 | 0.88 | 0.54 |
| Nice | France | 0.80 | 0.45 | 0.84 | 0.73 | 0.80 | 0.43 |
| Djerba | Tunisia | 0.83 | 0.42 | 0.97 | 0.22 | 0.96 | 0.35 |
| Rügen | Germany | 0.53 | 0.77 | 0.57 | 0.86 | 0.57 | 0.70 |
| Kerkira | Greece | 0.64 | 0.76 | 0.74 | 0.53 | 0.66 | 0.84 |
| Alexandria | Egypt | 0.55 | 1.00 | 0.41 | 1.09 | 0.58 | 0.78 |
| Antalya | Turkey | 0.72 | 0.66 | 0.66 | 0.70 | 0.83 | 0.36 |

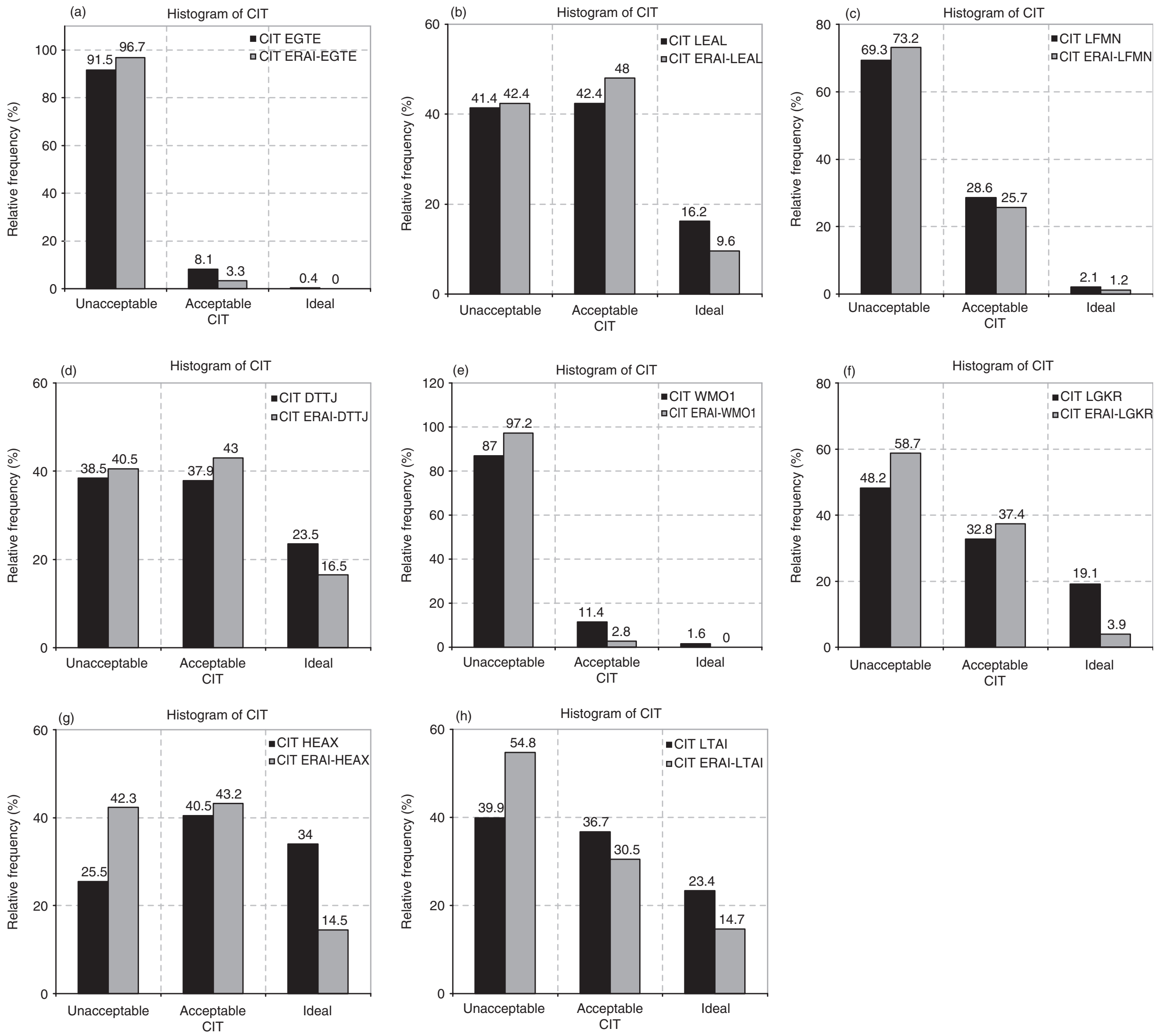



Figure 11. As in Figure 10, but for spring mean relative frequencies.

anticipate climate change impacts on this socio-economic sector. An assessment of the present and possible future evolution of the climate resource for 3S tourism has been carried out by means of CIT. Although a direct relationship between climatic suitability and attendance levels is elusive, the index has shown robust when correlating monthly climate potentials and frequentations, at least for the SPdP. Thus, the strong spatial contrast in the quality of this climate asset between high and low latitude European coastal areas would strongly modulate current 3S tourism flows southwards.

Acceptable and ideal climatic conditions show a clear prevalence for the present annual mean regime in the Mediterranean and optimal conditions improve eastwards across the region. In summer, ideal perceptions occur during the entire season for most Mediterranean coastline.

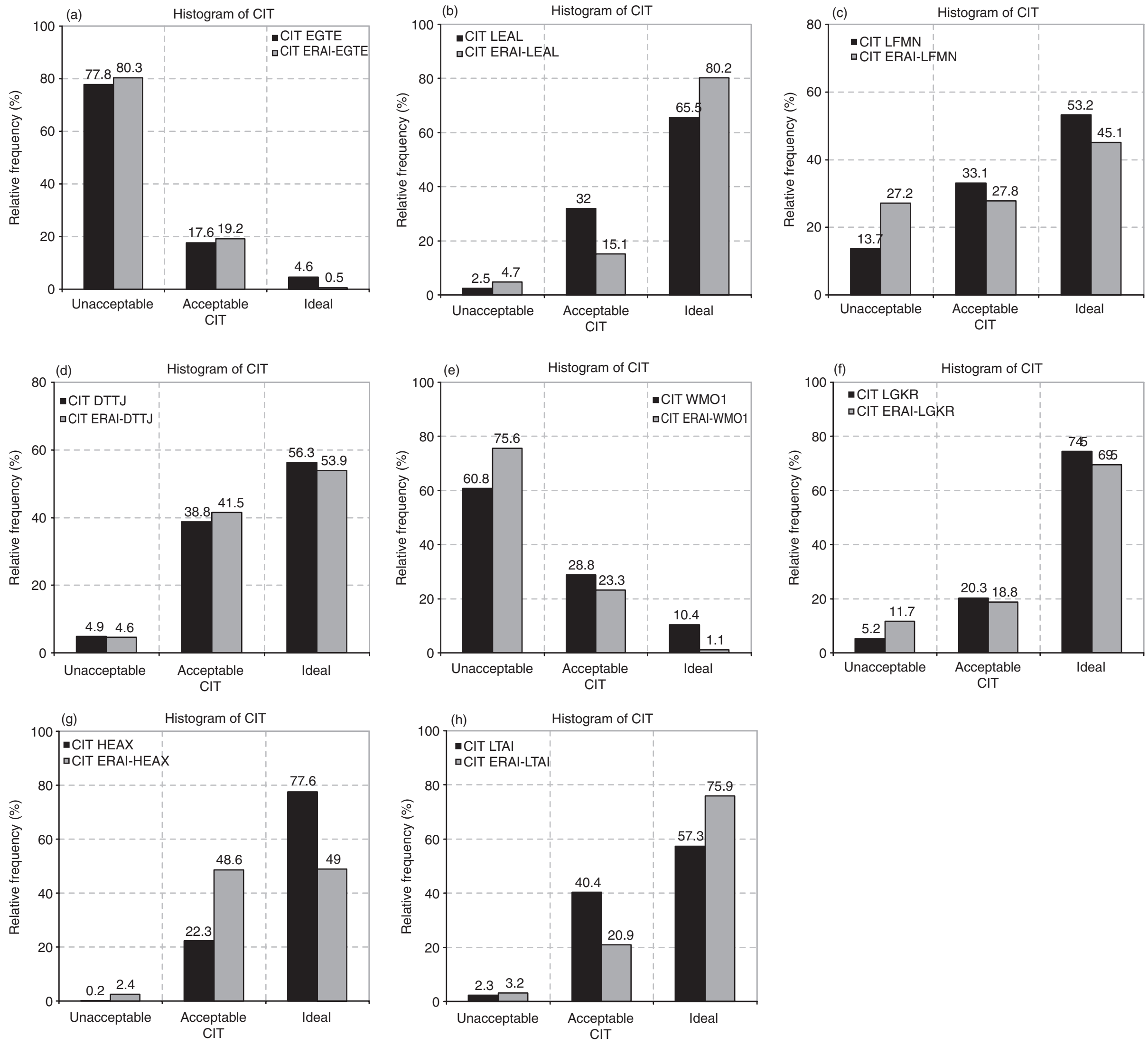



Figure 12. As in Figure 10, but for summer mean relative frequencies.

In addition, several seaside tourist destinations have been investigated to assess differences in climate change impacts across the Mediterranean. For most of the examined locations, monthly ideal relative frequencies exhibit present summery peak distributions in the annual cycle. The analysis of these tourist resorts have also allowed us to validate the present climate potential derived from ERA-Interim data. Reanalyses are shown to be a very suitable regional-observed baseline to derive the annual and seasonal European climate resource for beach-based tourism even at local scales.

The potential implications of climate change for beach-based tourism in the Mediterranean are remarkable. Projections suggest an important deterioration of the summery optimal climate resource together with an overall improvement in the shoulder seasons. That is, a seasonal redistribution in the excellence of the climate resource may occur in the Mediterranean, whereas no significant changes in seasonal optimal climate potentials are projected in most of the Atlantic European coasts. These findings further detail some conclusions already revealed in previous studies. After exploring the future climatic asset for more general tourist activities, some works have indicated a sharp deterioration of climatic suitability in the Mediterranean, but also a remarkable improvement of climatic conditions in northern Europe (Amelung and Viner, 2006; Amelung *et al.*, 2007; Nicholls and Amelung, 2008; Amelung and Moreno, 2012). On the other hand, Moreno and Amelung (2009) suggested a lower rate of change in climatic suitability in northern Europe, but also in the Mediterranean, after specifically focusing on beach tourism. At local scales, the monthly ideal relative frequencies are expected to consistently shift from a summer peak to an off-season bimodal distribution in the annual cycle for most Mediterranean destinations. Similar conclusions were drawn by Rutty and Scott (2010) after examining five popular Mediterranean beach destinations under the A1B SRES.

As the climatic resource will remain as one of the main forcing factors for 3S tourism flows in the future (Amelung and Viner, 2006), the projected seasonal changes in Mediterranean climate potential might lead

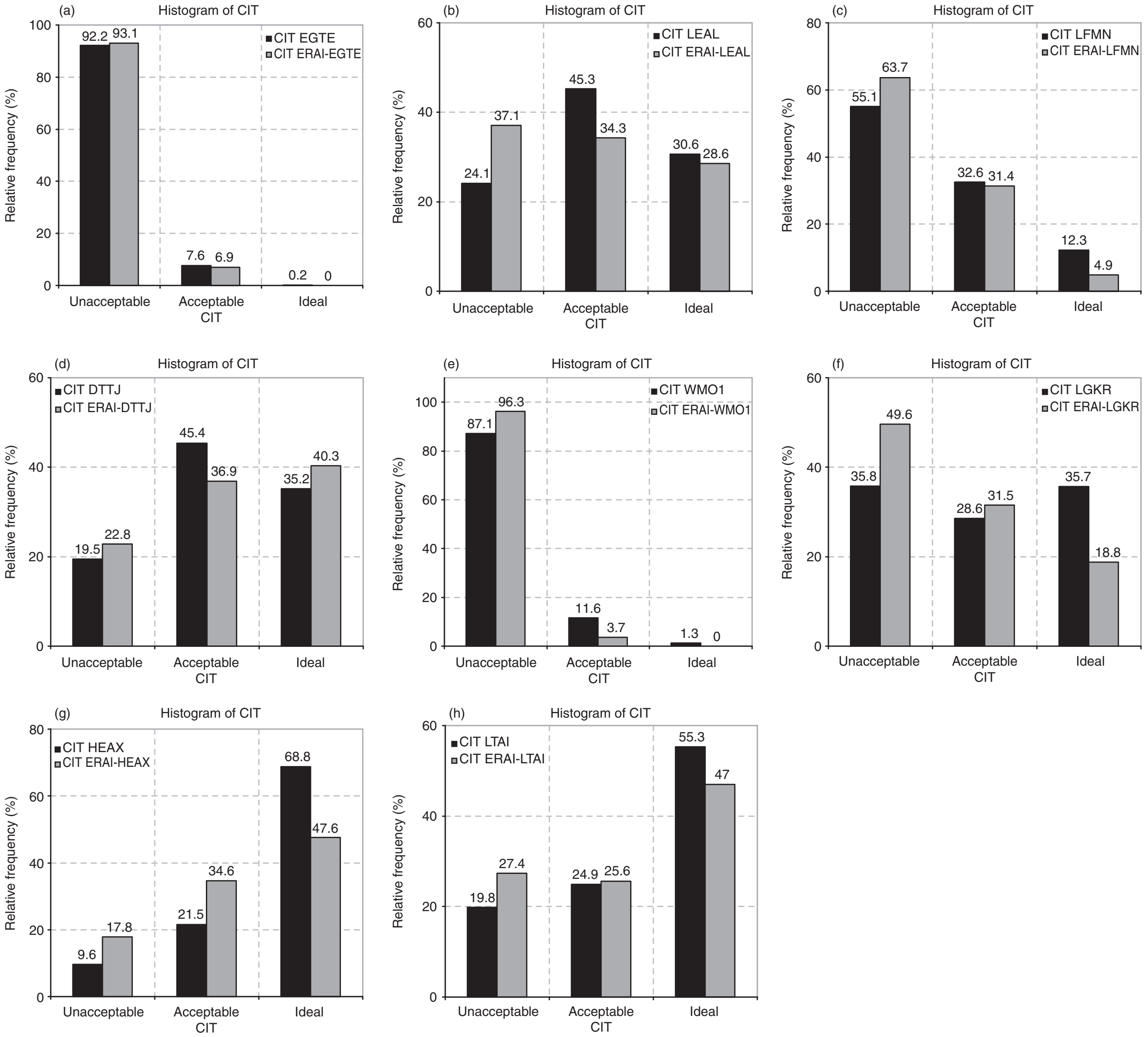



Figure 13. As in Figure 10, but for autumn mean relative frequencies.

to significant redistributions in tourism traffic within Europe. Nowadays, northwestern European countries are the major 3S tourism sources. The expected imbalance between natural and institutional seasonality in the Mediterranean may have significant impacts on current peak attendance levels, at least for captive markets as families with school-age children. However, although temperate locations could improve their summery climate assets for beach tourism, their optimal relative frequencies are not expected to be high enough to compete with those projected in the Mediterranean destinations. Even then, the overall enhancement (degradation) on summery tourist comfort in northwestern (Mediterranean) European countries could lead to an increase of domestic holidays in the former at the expense of travelling to the latter. Amelung and Moreno (2012) quantified redistributions of visitation among European countries due to climate change impacts on general tourism activities by the end of this century. Visitation was projected to significantly increase in several northern and northwestern European countries whereas decreasing in various southern European countries. They suggested that an amount up to 53 million bed nights per year may be redistributed across European countries, equivalent to some 14 billion euros of expenditure, because of the relative changes in climate resources among the European countries.

Seasonality has nowadays important consequences for the Mediterranean seaside resorts. Summery peak demand entails important socio-economic and environmental stress. Beach-based tourism is one of the main driving forces for employment and revenues in these destinations. Their patterns are strongly bounded to tourist demand, thus leading to significant increases in off-season unemployment. Environmental impacts also encompass a wide range of problems such as summery peak demand in water supply or electric power. Although the projected seasonal redistribution in the excellence of

Mediterranean climate asset might entail important consequences for the currently seasonally-adjusted tourism sector, climate change could also offer new opportunities for a further extension of the beach-based activities towards late spring and early autumn.

Rutty and Scott (2010) have indicated that demand may not necessarily decline, but rather contribute to a shift in the timing tourists would visit the Mediterranean. Amelung and Moreno (2012) suggested that in spite of a net loss of potential for general tourism activities in southern Europe, improvements in spring and autumn are likely to offset a significant share of the deteriorations in summer. Thus, climate change could encourage deseasonalization in the Mediterranean tourism industry. Deseasonalization could be achieved, for example, by introducing alternative outdoor leisure recreation not so highly climate-dependent during the peak demand season and/or by shifting 3S activities to the shoulder seasons. The adaptation of all-year less weather-dependent types of tourism could alleviate some of the aforementioned stresses during the current peak tourist demand (Amelung and Moreno, 2012; Bafaluy *et al.*, 2013).

For many Mediterranean destinations, main tourism stakeholders are focusing their efforts on product and market diversification in order to deseasonalize beach-based tourism industry. These emplacements currently offer alternative off-season outdoor leisure recreation such as sightseeing, shopping, sport or cultural tourism. Some preliminary efforts have already been done to evaluate some of these outdoor activities through climate indices for tourism, but further efforts are still needed (Bafaluy *et al.*, 2013). As climate change will unevenly impact tourist activities as different kinds of tourism need different climatic requirements, the quantification of the relationship between different types of tourism and the weather resource through suitable physical indicators is compulsory to effectively respond to the challenge of regional and local adaptation to climate change. Research is still required to further develop and empirically adjust a new generation of climate indices specifically designed for each kind of tourism, such as those defined in Bafaluy *et al.* (2013). These indicators would help better understand and address key issues for tourism industry as climate change and seasonality.

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