

Article

Future Holiday Climate Index (HCI) Performance of Urban and Beach Destinations in the Mediterranean

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Abstract: Tourism is a major socioeconomic contributor to established and emerging destinations in the Mediterranean region. Recent studies introducing the Holiday Climate Index (HCI) highlight the significance of climate as a factor in sustaining the competitiveness of coastal and urban destinations. The aim of this study is to assess the future HCI performance of urban and beach destinations in the greater Mediterranean region. For this purpose, HCI scores for the reference (1971–2000) and future (2021–2050, 2070–2099) periods were computed with the use of two latest greenhouse gas concentration trajectories, RCP 4.5 and 8.5, based on the Middle East North Africa (MENA) Coordinated Regional Downscaling Experiment (CORDEX) domain and data. The outputs were adjusted to a 500 m resolution via the use of lapse rate corrections that extrapolate the climate model topography against a resampled digital elevation model. All periodic results were seasonally aggregated and visualized on a (web) geographical information system (GIS). The web version of the GIS also allowed for a basic climate service where any user can search her/his place of interest overlaid with index ratings. Exposure levels are revealed at the macro scale while sensitivity is discussed through a validation of the climatic outputs against visitation data for one of Mediterranean's leading destinations, Antalya.

Keywords: Holiday Climate Index (HCI); beach tourism; urban tourism; climate modeling; climate change; Antalya; Mediterranean

1. Introduction

Tourism is one of the largest economic sectors worldwide with 10.4% share in global GDP, supporting one in every ten jobs on the planet [1]. In 2018, international tourist arrivals grew 5% and reached 1.4 billion which is two years ahead of United Nations World Tourism Organization (UNWTO) forecast and the revenue from tourism receipts saw an extra USD\$121 billion compared to 2017, reaching USD\$1.45 trillion. Europe was the world's most visited region with 710 million international tourist arrivals (51% market share) and with international tourism receipts reaching USD\$570 billion (39% market share) in 2018 [2]. The Mediterranean region is the predominant factor for

Europe's leading position in tourism with a growth higher than Western, Central Eastern, and Northern Europe [2]. The region, with a total 46,000 km coastline shared by 22 countries, welcomed more than 330 million international tourists in 2016, which is more than double the number recorded in 1995 [3]. Although beach tourism has provided the major offer in positioning such growth, urban tourism is an increasingly important element for the region. The popularity of the Mediterranean for tourism is mostly due to its favorable climatic conditions, especially during summer [4–6].

Climate has long been known to affect the attractiveness of tourist destinations [7–10], and tourism industry should be more aware and prepared for the climate change [11–13]. For this reason, climate assessment for recreation and tourism has increasingly become a dynamic research area of sustainable tourism especially in the age of anthropogenic climate crisis. The foci of different studies investigating the relationship between tourism and climate change include the change in tourism demand [14–17], impact, mitigation and adaptation [16,18,19], case studies [20–22], tourist preferences and decision-making [23–27] and review research projects [28–31]. One of the world's major tourism regions, the Mediterranean, is also expected to be substantially affected by climate change although the impacts of which have been a source of significant debate [32]. Although tourism in the region continues to grow, there is overwhelming evidence that the climatic conditions will be altered in the region due to the anthropogenic climate change. The Intergovernmental Panel on Climate Change (IPCC), the main body for assessing the science related to climate change, has classified the Mediterranean Region as being highly vulnerable to climate change [33]. Studies of climate change impacts have commonly stated that the increase in temperature may become a major threat for Mediterranean tourism in the future [34,35], because of not only worsening climatic conditions at the destination but also climatic improvements in some of the major tourist generating countries and regions, especially in northern Europe [36].

Climate indices have been developed to assess the potential present and future climatic attractiveness of destinations for tourism. These indices, the first of which was the Tourism Climate Index (TCI) [37], combine and score climatic components that are significant for tourist comfort such as temperature, humidity, precipitation, cloud cover, and wind speed, according to their suitability for human-environment systems. In this study, an improved version of TCI, Holiday Climate Index (HCI) [38,39] for beach and urban tourism is used to assess the climatic performance of various destinations in the greater Mediterranean region throughout the 21st century and under different representative concentration pathways (RCPs). The underlying spatial extent and projections complement a Caribbean beach tourism study [39] with a Mediterranean perspective and significantly update the former A1B emissions scenario of the IPCC's Special Report on Emission Scenarios [40] on the urban case [38] with two of the latest greenhouse gas concentration trajectories, RCP 4.5 and 8.5 [41].

2. Progress with Tourism Climate Indices

Following the unprecedented growth of international tourism in the 1960s and 1970s, a number of studies sought to investigate the relationship between destination climate and tourism demand [11,42–45]. Among these studies, Mieczkowski [37] first identified the need for an index that evaluates the climatic conditions of destinations for tourists. Tourists, who are generally not concerned about the annual climate of a destination, are greatly interested in the climatic conditions during their visit. Therefore, Mieczkowski developed the first index for the relationship between tourism and climate, the Tourism Climate Index (TCI), to assess the favorable and unfavorable climatic conditions according to the needs of visitors. Since its development, the TCI has been used extensively as a research tool for many regions and countries in the world, such as Europe [46–48], the Mediterranean [49], South Africa [50,51], Algeria [52], Australia [53], China [3,54–57], Egypt [58], Georgia [59], Hungary [60], Iran [61–65], Turkey [66]. TCI merges seven climatic variables in five additive sub-indices. Two thermal comfort sub-indices that are calculated with the use of maximum daily temperature, minimum relative humidity, mean daily temperature and mean daily relative

humidity have a weight of 50% in total. Precipitation (P) is calculated from the monthly data and it has a weight of 20%. Sunshine (S) is the hours of bright sunshine during the day. The wind sub-index (W) combines temperature and wind speed data and is rated accordingly. (For more detailed explanation, see [37]).

The PESETA Project (Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis), used TCI to assess the possible future physical and economic impacts of climate change on tourism in Europe with the use of two different GCMs (HadAM3 and ECHAM4) and with A2, B2 SRES scenarios [67,68]. The results from the two models presented substantial differences although they generally agreed on the direction of change. By pointing out the fact that this study does not involve any insights about the actual climatic preferences of tourists, the study concludes that climate change is expected to have significant effects on tourism in Europe. By 2080s, excellent conditions are expected to expand in the Mediterranean coastal areas in spring seasons and good conditions are expected to spread toward North while climatic conditions for tourism in Mediterranean would deteriorate in summer seasons. Simulations of bed nights in the 2080s showed improved conditions for most regions in Europe with the only exception of Mediterranean region which showed decline in bed nights.

Scott et al. [38] and Rutty et al. [39] state that although TCI has been used in many studies, it has several deficiencies which are frequently criticized and some of which apply to many climate indices. First, the rating scales and the weighting schemes of the sub-indices are ultimately subjective and based solely on Mieczkowski's expert opinion and arguably also from the North American climatic and cultural context in which they were written. They do not reflect any kind of empirical information about what particular groups of tourists actually want from specific destinations. For example, from surveys and revealed preferences of tourists for some markets, it is now known that the absence of rain is usually more important than a comfortable temperature [5,10,21,69,70], which makes the 50% weight of thermal comfort in the equation unreasonable. Secondly, the equation does not account for the overriding effects of physical variables; intensive precipitation and wind may cancel out all other positive weather conditions [38,39]. Thirdly, TCI has low temporal resolution, it uses mean monthly data for all its sub-indices since daily or diurnal data was not widely available in the 1980s. Finally, TCI is a general index only for sightseeing activities and does not differentiate the specific requirements of major tourism segments such as beach, urban or winter sports tourism [38,39].

As Rutty et al. [39] reports, there is now a growing field of research seeking to overcome the deficiencies of the TCI in relation to the more than 200 climate indices found in applied climatology and human biometeorology [71]. To account for the actual preferences and threshold perceptions of tourists in the indices many in situ and ex-situ surveys have been conducted. A study by Rutty and Scott [6] investigated the perceptions of "too hot" conditions for beach and urban destinations with a questionnaire among 850 university students in northern Europe and found that the temperatures greater than 37 °C are identified as unacceptably hot, less than 22 °C unacceptably cold and between 27–32 °C ideal for beach tourism whereas temperatures greater than 30 °C are defined as unacceptably hot, less than 17 °C unacceptably cold and between 20–26 °C ideal for urban tourism by the majority of respondents. Bearing in the mind that thresholds of northern European tourists may alter in the future since they may acclimatize to warmer average temperatures at home, the authors compared the thresholds of "unacceptably hot" against the thermal conditions of mid and late century projections with A1B scenario for 10 Mediterranean destinations and concluded that there is no evidence that the Mediterranean will become "too hot" for tourism in the future [6]. The study of Friedrich et al. [72] focused on the influence of temperature and precipitation changes on beach tourism based on a survey ($N = 562$) in South Africa. The projections with RCP 4.5 and RCP 8.5 scenarios showed increase in temperature and decrease in precipitation for many beach destinations in South Africa and the study concluded that based on the current scientific perceptions of climatic suitability, climate change impacts might have a net positive effect on beach tourism in South Africa (by explicitly omitting the sea level rise (SLR) effects).

Morgan et al. [73] introduced a slightly modified version of TCI to evaluate 3S tourism (sun, sea and sand), i.e., beach, destinations. Their Beach Climate Index (BCI) employed in situ questionnaire surveys in Wales, Malta and Turkey with the respondents from Northern Europe ($N = 1354$) and Mediterranean. Since the survey found differences in aspects of climate preferences among respondents from Northern Europe origin and Mediterranean origin, and because northern Europe is the main tourism market for the Mediterranean [6] the index was developed to account particularly for the preferences of North European beach users. The BCI was devised by making improvements in TCI's daytime comfort index ratings [37] to allow for the thermal sensations involving bathing water temperature of sedentary beach users in swimsuits as identified from participants' responses. The BCI disregards the mean daily temperature component of TCI since a 24-h comfort index makes little contribution to beach tourism and conveys a mean daily maximum temperature with monthly mean relative humidity. Instead of total sunshine hours, therefore the BCI uses the *proportion* of sunshine hours for the day since sunshine at 5–6 a.m. is no concern for most beach holiday makers. For precipitation, BCI does not employ any modifications to TCI ratings but changes its weight according to survey results. For wind, BCI defines new scoring categories that are not associated with the temperature as TCI does because wind speeds above 6 m/s have an overriding effect and are uncomfortable in any weather conditions [74,75]. Finally, the BCI equation is constructed by giving weights of 18% thermal sensation, 26% wind speed, 27% sunshine and 29% absence of rain. The weakness of this index is that it is based on the responses of north European beach users and is not applicable to beach users from other locations since their thermal preferences differ from those identified in other studies [75]. Moreover, the BCI is created only for sedentary beach use and is not an index that can be used for other daytime activities of beach users or for any other leisure tourist activities in general [73]. Moreno and Amelung [76] used BCI to analyze the future impact of climate change on Europe's beach tourism specifically in summer, by the use of SRES A1FI scenario and two global climate models, HadCM3 and CSIRO2. While drawing attention to the methodological limitations, the authors conclude that climate change impacts on the Mediterranean coasts may be less severe than previously anticipated even under one of the former worst case scenarios [76].

Another index for 3S recreation, the Climate Index for Tourism (CIT), was devised in 2008 [77]. The study declares there are essential features for a tourism climate index to be comprehensive and universal and that it should be theoretically sound, simple to calculate, easy to use and understood by users in the tourism sector, and integrate the effects of all facets of climate while recognizing the overriding effect of certain weather conditions. The CIT employs a university student ($N = 331$) survey for pleasantness ratings of thermal, aesthetic (sky conditions) and physical (precipitation and wind) facets. The strength of CIT comes from the fact that it is not simply the sum of sub-indices. CIT sets thresholds to precipitation and wind speed to account for their overriding effect. If either threshold of 6 m/s of wind speed and 3 mm or 1 h duration of precipitation is exceeded, then the physical facet overrides any positive thermal or aesthetic weather conditions. Moreover, and contrary to the aforementioned indices, the study finds that scattered cloud is preferred rather than clear sky and light breeze is essential for most of the respondents. The major weaknesses of CIT are that it lacks cross-cultural information since all the respondents are from only one country and the survey sample group has a narrow age distribution (university students) and, similar to BCI, it can only be used for 3S tourism. Yu et al. [78] further revised the CIT and devised a Modified Climate Index for Tourism (MCIT) which made profound changes to the index. MCIT adds two different climatic variables, visibility and significant weather (such as rain, lightning, hail, snow) which can preclude many tourist activities, and removes sunshine and cloud cover from the equation since they are not determinants of whether the activity will be realized or not. The final form combines four sub-indices, namely perceived temperature (calculated with wind-chill), wind speed, visibility and significant weather yielding unsuitable, marginal, ideal conditions for tourism. Instead of using daily mean or daily maximum data, MCIT employs hourly data to obtain high temporal resolution. This way, MCIT can display the difference of the same amount of rain pouring in one hour or drizzling in 10 h

which makes a great difference in terms of tourist comfort. The index is also applicable to different tourism segments such as sightseeing and winter sports [79]. The major limitations of MCIT are that it did not employ the available literature on tourist preferences while devising the variable ratings and weighting schemes, and that the unavailability of hourly data for many locations in the world creates a major obstacle for the use of this index.

Another prominent work is the design of the Relative Climate Index (RCI) in 2018 [80] which measures the attractiveness of a destination relative to that of the tourist origin with the use of push and pull framework. The study claims tourists tend to visit a warm destination when their origin country is cold and vice versa because most people want to experience something different. Therefore, the study makes use of the TCI of the destination and the TCI of the tourist origin country and constructs a relative tourism climate index to measure the climatic differences between the destination and origin country. It is stated that tourists may visit less comfortable destinations in terms of climate since they also seek novelty in selecting destinations; however, contrary to what this study is based on, the “backyard hypothesis” in the literature states that urban snow conditions accelerate tourist decisions to go on a winter holiday and that the snow in the urban backyard is as important as the snow in the mountains for this decision [81].

Georgopoulou et al. [82] conducted both in situ (13 Greek islands) and ex-situ (airports, hotels, restaurants, cafés) surveys ($N = 253$) since in situ surveys alone cannot account for the perceptions of those who find the conditions at the place in question unacceptable. Survey results showed that the absence of rain is the most important criterion while cloudiness and wind are the least important parameters for beach tourists; however respondents were asked to assess five pre-established wind profiles in terms of attractiveness in the survey. The weights of the Beach Utility Index that involves ambient temperature, rain, cloudiness and wind [82] were estimated according to the survey results. The limitations of this study are that the index does not account for humidity, the sample size and stratification may not be enough to represent all beach users in Greek islands, preferences of tourists may be more complicated than giving answers to pre-established survey questions and the index itself may not be applicable to other beach destinations even in the Mediterranean.

The subject of this study, the Holiday Climate Index (HCI) [38], was developed in 2016 to attempt to overcome the various deficiencies of climate indices for tourism. The major improvement of HCI over TCI and other indices is that it makes use of the available literature on tourist climatic preferences from a range of surveys compiled over the previous decade to determine the rating scales and weights of the sub-items so that it is not based on subjective opinions. In accordance with the stated tourist preferences, HCI increases the weight of precipitation to 30% and removes the CIA component since the likely intensive use of air conditioners at many destinations makes the evening comfort index irrelevant. To be able to address specific climatic requirements of different tourism segments, HCI:Beach and HCI:Urban have different weights for thermal comfort and cloud cover, again in accordance with stated tourist climatic preferences. To overcome the low temporal resolution limitation of TCI, HCI uses daily data instead of monthly data. Finally, HCI accounts for the overriding effects of physical facets by assigning a score of 0, and even negative ratings, if the determined thresholds are exceeded. The design of HCI is consistent with all the essential features of a comprehensive and universal index [77]. Perhaps most importantly, HCI was empirically tested by comparing mean monthly HCI:Urban scores with hotel occupancy in Paris [38] and by validating mean monthly HCI:Beach scores with Canadian tourist arrivals to three Caribbean destinations (Antigua and Barbuda, Barbados, Saint Lucia) [39]. Furthermore, Matthews et al. [83] used an optimization algorithm to maximize the explanatory power of HCI:Beach and its sub-index values on visitation data of two provincial beach parks in Ontario, Canada. The process required different rating schemes and weights for each sub-index in HCI:Beach for different parks. This way, the authors provide a methodological approach to optimize HCI to better account for the revealed climatic preferences of specific destinations.

As a complement to the work of Scott et al. [38] and Ruttty et al. [39] the present study examines the HCI scores for the greater Mediterranean region, extending to its hinterlands and the Red Sea and

the Persian Gulf in the east and the Canary Islands in the west. HCI scores are calculated for both the historical and future projection data in order to bring a new study to the existing literature for a major tourism region, which some researchers acknowledge as threatened by climate change [34,35,47,49], as well as to further validate the HCI.

3. Materials and Methods

The data and methodology employed in this study are grouped under five areas: retrieval of dynamically downscaled climate data, temperature adjustments based on environmental lapse rates, GIS-based computations of HCI ratings and their visualizations at the greater Mediterranean extent with a closeup to Antalya, a Web GIS-based preparation of a basic climate service to interactively share the entire results set with third parties, and validation and calibration of HCI:Beach through the case of Antalya.

3.1. Climate Data

The study uses climate data, dynamically downscaled from a Global Circulation Model (GCM) via the regional climate model (RCM), RegCM, to deliver grid-based inputs for computations of HCI scores for the greater Mediterranean region, which is a sub-domain of the Middle East and North Africa (MENA) domain. As the driving GCM, MPI-ESM-MR (Max Planck Institute Earth System Model Mixed Resolution) was chosen since the performance of MPI-ESM-MR, as well as that of the HadGEM2-ES (Met Office Hadley Center Earth System Model), is relatively better than other GCMs for the MENA region [84]. Moreover, RegCM, which was used to dynamically downscale the GCM resolution to 0.44° , was recently proven to deliver outputs in better agreement with observational datasets, when the simulations are based on MPI-ESM-MR, rather than the HadGEM2-ES, for the MENA domain [85]. Last but not least, HadGEM2-ES uses a “360-day” calendar where every year has 12 months of 30 days, whereas MPI-ESM-MR uses a “365-day” calendar, also taking account of the leap years, setting a more realistic stage for the purpose of this study since HCI is a daily data-driven index.

Besides temporal resolution, spatial resolution plays a crucial role in delivering as realistic as possible tourism climatology information that will make use and sense for different stakeholders such as policymakers, businesses and consumers. For this purpose, initially the use of 0.22° resolution MENA-CORDEX (Coordinated Regional Climate Downscaling Experiment) data was intended, but RCP 4.5 pathway datasets were not available for the MNA-22 domain on the Earth System Grid Federation (ESGF) servers at the time of the analysis. Therefore, data on climate variables needed for HCI computations were obtained from the MPI-ESM-MR dataset of Boğaziçi University Center for Climate Change and Policy Studies (iklimBU) for historical, RCP 4.5 and RCP 8.5 scenarios, dynamically downscaled to a 0.44° resolution grid over the MENA-CORDEX domain (MNA-44) using version 4.3 of the regional climate model RegCM [86] (iklimBU’s RegCM4.3 daily outputs of maximum temperature and precipitation for the MENA-CORDEX region are also available on the ESGF data node). The two future scenarios are used to project the change of atmospheric composition in the future [41]. RCP 4.5 and RCP 8.5 scenarios represent 4.5 W/m^2 and 8.5 W/m^2 radiative forcing in the end of the century with respect to pre-industrial conditions, respectively. RCP 8.5 is generally referred as “business-as-usual” scenario which indicates a no-policy driven mitigation for the future. RCP 4.5 represents a medium stabilization scenario for the future.

As a final major step of climate data retrieval, the climate variables per grid of the MNA-44 domain were calculated for the 30-year reference period of 1971–2000, and 30-year future projections for 2021–2050 and 2070–2099 for RCP 4.5 and RCP 8.5 scenarios. Daily maximum temperatures, daily total precipitation, daily maximum wind speed and daily total cloud fraction were calculated from three-hourly RegCM outputs using Climate Data Operators (CDO) version 1.9.5 [87]. Daily relative humidity was calculated using the Clausius-Clapeyron Equation from temperature, air pressure and specific humidity.

3.2. Temperature Adjustments

Since the study aims to deliver results that are meaningful for the tourism sector, the spatial resolution requires some adjustments as to capture details especially at urban and coastal zones which may share a topographically heterogeneous grid that leads to under- or overestimations of climatic outputs. One way of dealing with this is to refine the temperature outputs by extrapolating them through lapse rates [88] and vertical residuals derived from differences between the model topography and a high resolution Digital Elevation Model (DEM). For this purpose, elevation deviations between MNA-44 topography and SRTM (Shuttle Radar Topography Mission version 4.1) DEM at 500 m resolution [89] are calculated to correct the projected temperature values by an environmental lapse rate value of $0.5\text{ }^{\circ}\text{C}/100\text{ m}$ for the whole study area. Figure 1 illustrates the improvements gained by this technique, using the example of Antalya and refinements on the spatial resolution of maximum summer temperatures as well as their resultant HCI scores for the reference period 1971–2000. Following the adjustment of temperature projections, the lower band of the range is extended, by $12.7\text{ }^{\circ}\text{C}$, indicating that mountainous landscapes are better distinguished. Since rest of the geoprocessing workflow (see Section 3.3 and Figure 2 for more information) can now be realized on the cell size (500 m) of the adjusted temperature raster, all throughput and outputs, including the critical ones such as Humidex and HCI values, can also be spatially refined. This is exemplified in Figure 1 with the contrasting details of the HCI Scores that represent (slightly larger) climate model grids on the preadjusted side, and DEM resolution on the adjusted.

3.3. GIS-Based HCI Computations and Visualizations

To compute and visualize HCI results for the greater Mediterranean, the geoprocessing model (Figure 2) was created in ArcGIS Pro version 2.5. The daily CDO outputs on the five gridded climate variables (maximum temperature, relative humidity, cloud cover, precipitation, wind speed) were aggregated to seasonal averages and summarized in spreadsheets for each of the five time periods (1971–2000; 2021–2050 and 2070–2099—RCP 4.5 and RCP 8.5). These tables formed the initial inputs to the model. Climate variables for each grid point was first vectorized and then rasterized. The latter process was realized at an optimal resolution of 0.61° to ensure a continuous cellular coverage for each curvilinear point with minimal loss of granularity. These raster layers were then reclassified for the four sub-indices of the HCI, namely Thermal Comfort, Aesthetics, Precipitation and Wind, according to the rating schemes on Table 1 for HCI:Beach and Table 2 for HCI:Urban. Regarding Thermal Comfort, temperature values were first adjusted according to the procedure in Section 3.2 and further corrected to account for the effects of humidity. For the latter purpose, Scott et al. [38] used the Effective Temperature formula to yield results comparative to Mieczkowski's TCI [37]. Later in 2020, Rutty et al. [39] modified the calculation procedure for the Thermal Comfort sub-index/facet by using the Humidex Equation (1) [90] developed in Canada [91]. In this study, this recent approach is also pursued as Humidex underscores the additive effects of relative humidity on perceived temperature while Effective Temperature indicates the opposite.

The final HCI scores are computed with weighted sum analyses based on the Equations (2) and (3) in the original articles [38,39], with the output cell size set to the 500 m resolution of the Thermal Comfort layer. The scores are further reclassified according to the identical HCI rating schemes on Tables 1 and 2. It should be noted that the original articles state an HCI score range between 0 and 100 while extreme cases according to the equations, as well as the results of this study, do yield some negative scores. In this study, these extreme cases are also rated as “dangerous” for tourism. Moreover, “great discomfort” and “dangerous” ratings of the Humidex layers [91] are also visualized to set the stage for risk discussion from both HCI and apparent temperature perspectives. The final results are organized as separate figures (Figures 3–6) for each of the four seasons. Each figure portrays the five periods for the greater Mediterranean extent with an inset for the case of Antalya. HCI:Urban ratings cover the entire lands while HCI:Beach ratings are clipped along the 2 km wide shorelines of seas (including some minor islands) and major lakes, as digitized by Natural Earth [92].

$$\text{Humidex} = T + \frac{5}{9} \times \left(\left(6.112 \times 10^{\left(\frac{7.5 \times T}{237.7 + T} \right)} \times \frac{H}{100} \right) - 10 \right) \quad (1)$$

$$\text{HCI:Beach} = 2(TC) + 4(A) + 3(P) + (W) \quad (2)$$

$$\text{HCI:Urban} = 4(TC) + 2(A) + 3(P) + (W) \quad (3)$$

3.4. Climate Service

As the breadth of results from climate modeling—geoprocessing chain is extensive, a basic climate information service, Holiday Climatology of the Mediterranean (HCM), was created. Such platforms tailored for tourism stakeholders are on the rise, despite the initial challenges to their use [93], and already some macro-regional products [94–96] are being launched. In this first version of the HCM, all 60 layers (4 seasons, 5 periods, 3 indices) in Figures 3–6 were shared within a web map with a visualization configuration that enables fast rendering by using pre-generated tiles, hosted by Umeå University’s ArcGIS Online (AGOL) organization. The three index layers were integrated per period and scenario and further aligned in AGOL Map Viewer Beta and embedded into iklimBU’s web site [97] to provide a public interface (Figure 7) where any user can zoom into or search her/his place of interest, according to ArcGIS World Geocoding Service, overlaid with index ratings, and toggle, move or transparentize layers.

3.5. Validation and Calibration

Although the performance of HCI:Urban [38], compared to that of the TCI [37], was found to be satisfactory in the case of major urban destinations of the Mediterranean, such as Barcelona and Istanbul, HCI:Beach remains more urgently to be validated for different destinations and source markets. As introduced earlier, an initial attempt was carried out by Matthews et al. [83] to improve the coefficient of determination (R^2) when HCI:Beach scores are treated as regressors to predict destination visitation. By modifying rating schemes and weights of sub-indices in the context of the markets in question, they were eventually successful to bring the R^2 values from 0.67 and 0.43 to 0.73 and 0.66, respectively, for two different beach destinations of the Canadian Great Lakes.

In this study, we extend these attempts to validate the HCI:Beach against arrivals to one of the world’s most visited leisure destinations, Antalya [98]. For this purpose, initial simple linear regression analyses reveal correlation values (r) that indicate the direction and the magnitude of relationships between the visits and the HCI:Beach scores as well as their constituent variables and sub-indices and the r^2 values as indicators of model fit. The visitation data is obtained from the Turkish Ministry of Culture and Tourism [99] and contains monthly arrivals information regarding the top source markets and the total arrivals, excluding the domestic market, for the period 2007–2015. Corresponding climate data to calculate the HCI:Beach scores and their components was generated from the nearest grid point of ERA5 reanalysis dataset to Turkish State Meteorological Service’s (MGM) Antalya Bölge station (WMO id: 17302) coordinates (lat: 36.8851°, lon: 30.6828°) [100,101]. As an alternative for the maximum temperature variable and its derivatives, in situ observations available (with some gaps) from the station [102] were also used. The station has a representative location in close proximity to the main public beach, Konyaaltı, and the city’s touristic downtown, Kaleiçi.

As a final, and critical, step, HCI:Beach breakdown and visitation relationships are carefully examined to look for improvement areas. Consequently, the HCI:Beach-Med is proposed for the Mediterranean, as represented by Antalya, and its future performance are displayed in comparison to HCI:Beach, HCI:Urban and Humidex results. The comparison is also extended to a scenario analysis, where the performance of one of Black Sea’s leading beach destinations, Sochi, is benchmarked against Antalya in competition for the Russian market in a changing climate.

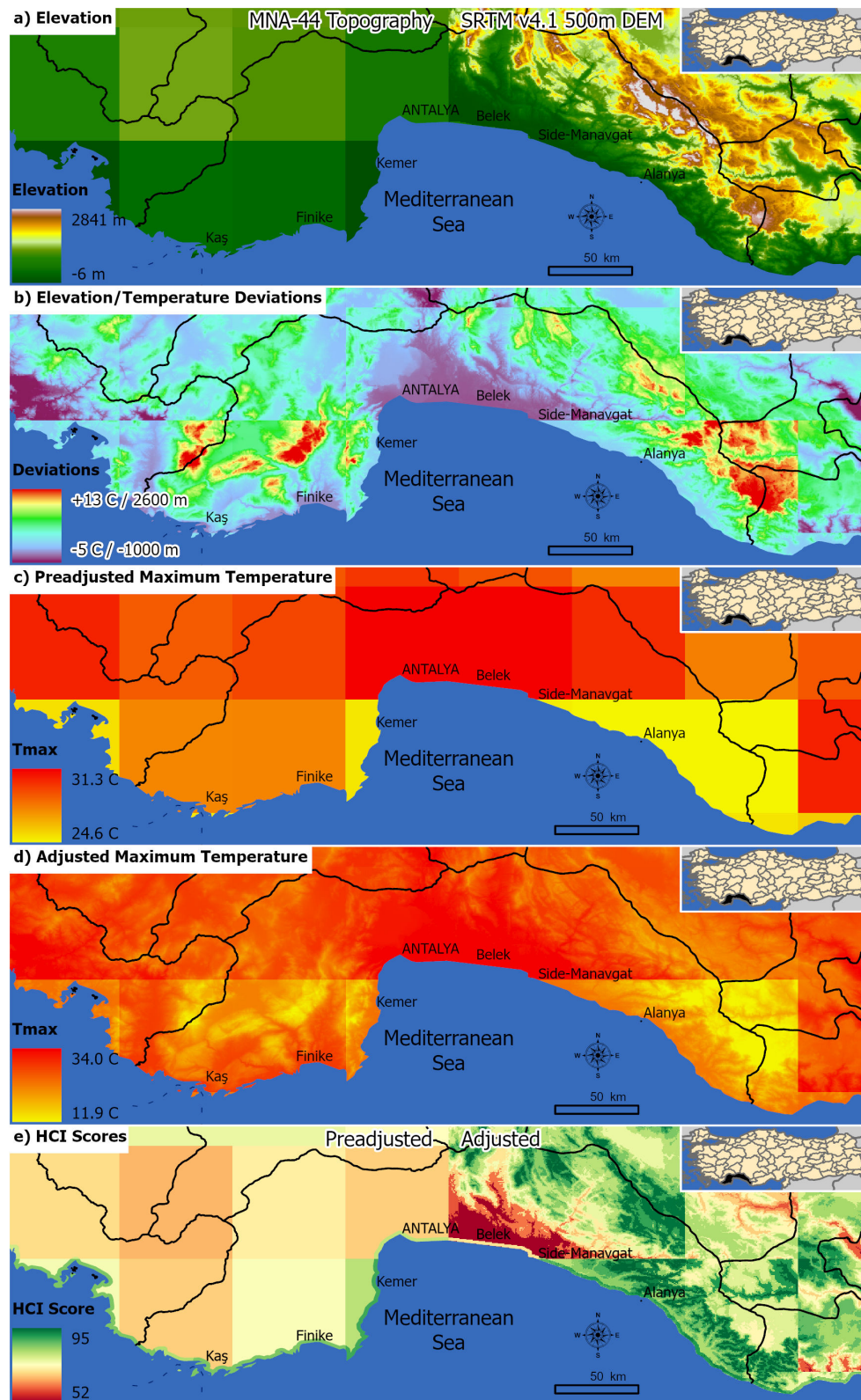


Figure 1. Showcase (Antalya Province, Turkey) of DEM-based lapse rate adjustments on the Summer (1971–2000) maximum temperature outputs. (a) MNA-44 Topography vs SRTM v4.1 500 m Elevations (b) Elevation/Temperature Deviations (c) Preadjusted Maximum Temperature (d) Adjusted Maximum Temperature (e) MNA-44 Topography vs SRTM v4.1 500 m HCI Scores.

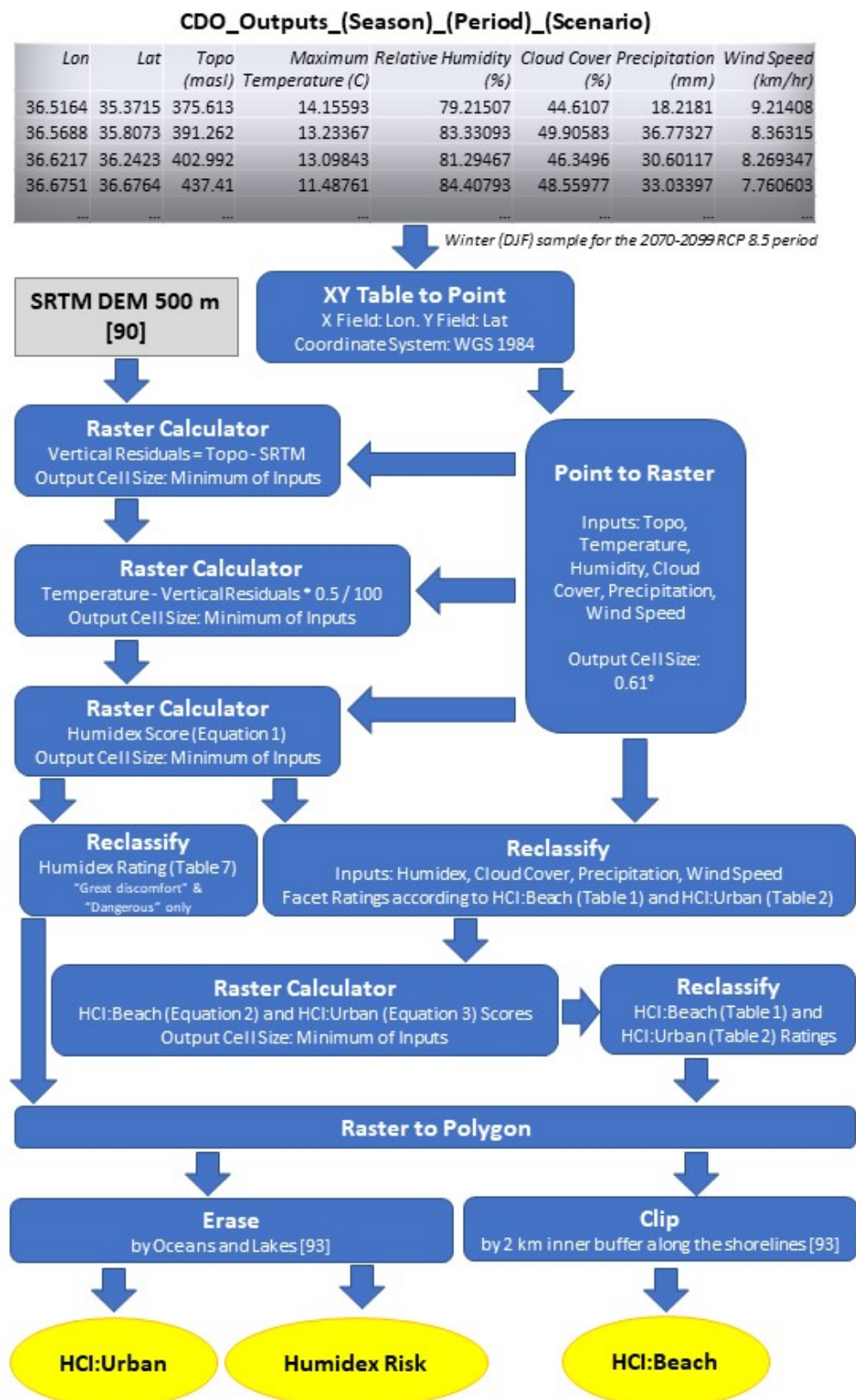


Figure 2. Stages of the Batch Geoprocessing Model Workflow on CDO Outputs for the HCI Variables. The model is iterated for each dataset representing different seasonal averages, periods and scenarios.

Table 1. The ratings of thermal comfort (according to Humidex), aesthetic (according to cloud cover), precipitation, wind facets and HCI:Beach scores.

Thermal Comfort (TC)			Aesthetic (A)			Precipitation			Wind			HCI Beach Score		
Humidex			Cloud Cover											
Min	Max	Rate	Min (%)	Max (%)	Rate	Min (mm)	Max (mm)	Rate	Min (km/hr)	Max (km/hr)	Rate	Min	Max	Rate
−9999	9.9	−10	0	0.99	8	0	0.01	10	0	0.59	8	−25	19.99	Dangerous
10	14.99	−5	1	14.99	9	0.01	2.99	9	0.6	9.99	10	20	39.99	Unacceptable
15	16.99	0	15	25.99	10	3	5.99	8	10	19.99	9	40	49.99	Marginal
17	17.99	1	26	35.99	9	6	8.99	6	20	29.99	8	50	59.99	Acceptable
18	18.99	2	36	45.99	8	9	11.99	4	30	39.99	6	60	69.99	Good
19	19.99	3	46	55.99	7	12	24.99	0	40	49.99	3	70	79.99	Very Good
20	20.99	4	56	65.99	6	25	9999	−1	50	69.99	0	80	89.99	Excellent
21	21.99	5	66	75.99	5				70	9999	−10	90	100	Ideal
22	22.99	6	76	85.99	4									
23	25.99	7	86	95.99	3									
26	27.99	9	96	9999	2									
28	30.99	10												
31	32.99	9												
33	33.99	8												
34	34.99	7												
35	35.99	6												
36	36.99	5												
37	37.99	4												
38	38.99	2												
39	9999	0												

Compiled from Scott et al. [38] and Rutty et al. [39].

Table 2. The ratings of thermal comfort (according to Humidex), aesthetic (according to cloud cover), precipitation, wind facets and HCI:Urban scores.

Thermal Comfort (TC)			Aesthetic (A)			Precipitation			Wind			HCI Urban Score		
Humidex			Cloud Cover											
Min	Max	Rate	Min (%)	Max (%)	Rate	Min (mm)	Max (mm)	Rate	Min (km/hr)	Max (km/hr)	Rate	Min	Max	Rate
−9999	−6	1	0	0.99	8	0	0.01	10	0	0.01	8	−11	19.99	Dangerous
−5.99	−0.01	2	1	10.99	9	0.01	2.99	9	0.02	9.99	10	20	39.99	Unacceptable
0	6.99	3	11	20.99	10	3	5.99	8	10	19.99	9	40	49.99	Marginal
7	10.99	4	21	30.99	9	6	8.99	5	20	29.99	8	50	59.99	Acceptable
11	14.99	5	31	40.99	8	9	11.99	2	30	39.99	6	60	69.99	Good
15	17.99	6	41	50.99	7	12	24.99	0	40	49.99	3	70	79.99	Very Good
18	19.99	7	51	60.99	6	25	9999	−1	50	69.99	0	80	89.99	Excellent
20	22.99	9	61	70.99	5				70	9999	−10	90	100	Ideal
23	25.99	10	71	80.99	4									
26	26.99	9	81	90.99	3									
27	28.99	8	91	99.99	2									
29	30.99	7	100	101	1									
31	32.99	6												
33	34.99	5												
35	36.99	4												
37	38.99	2												
39	9999	0												

Compiled from Scott et al. [38] and Rutty et al. [39].

4. Results

The results at the greater Mediterranean scale—reaching the Canaries in the southwest, the Bay of Biscay in the northwest, the Caspian Sea in the northeast and the Persian Gulf in the southeast—are presented by referring to Figures 3–6 or the HCM service [97], both of which display the seasonally aggregated HCI:Urban and the HCI:Beach ratings, as well as the Humidex risks, for the reference period 1971–2000 and the projections of 2021–2050 and 2070–2099 periods under RCP 4.5 and RCP 8.5 scenarios. Regarding the case of Antalya, inset maps on Figures 3–6 are accompanied by displaying trends (Figure 8) and linear relationships (Table 3) of climatic and touristic data, Humidex-based Thermal Comfort Rating Scheme (Table 4), the results (Table 5) and application (Tables 6 and 7) of the calibrated HCI:Beach-Med index.

4.1. HCI:Urban Performance in the Greater Mediterranean

The greater Mediterranean region has a clear spatiotemporal diversity for urban tourism climatology. During the fall season (Figure 3) of the 1971–2000 reference period, the best (Excellent and Ideal) conditions are found beyond the main basin, namely in emerging destinations such as Baku, Tehran, Isfahan and Shiraz [103,104]. Likewise, in the western extreme, the Canary Islands constitute the most suitable climatic conditions for urban tourism. The archipelago is better known for 3S tourism but also hosts many second homes owned by Europeans. In fact, the Canary Islands hold suitable conditions for tourism during almost all four seasons and all five periods. Such comparative advantage has and will have certain implications when other core Mediterranean competitors lose their relative climatic attractiveness. Accordingly, the superiority of the Canary Islands and the Caspian region is projected to be more or less maintained throughout the century for the fall season. They are joined by Malaga by the first half of the century and Van by the 2070s. The least suitable (Unacceptable and Dangerous) destinations, on the other hand, pertain to either mountainous landscapes, such as the Alps, the Caucasus and the Pyrenees, with too cold temperatures and poor aesthetics (high cloud cover) and high precipitation, or those areas, such as Northern Cyprus and Jeddah, with too hot apparent temperatures that would also be classified as “Dangerous” by the Humidex, indicating severe health risks such as high heat stroke possibility [91]. Many other Humidex-Dangerous zones (e.g., Dubai) are not captured as least suitable by the HCI:Urban, since their overall scores are marginal or above by scoring higher on the other facets. In fact, HCI:Urban rates nowhere as Dangerous in the Fall of 2070–2099 (RCP 8.5) while Humidex identifies a vast region in the MENA as Dangerous.

The winter season (Figure 4) has a clear distinction in terms of HCI:Urban ratings along all periods and no Humidex risk is projected. The poor scoring northern regions, especially at their highest elevations, will continue to do so, while the best conditions remain in the southern parts, yet with the advantage shifting from the Gulf destinations such as Dubai and Doha, as well as Mecca, to the Egyptian Nile including the Delta and parts of Cairo. Springtime (Figure 5) has some similar pattern in terms of north-south distinction in all periods. The historical period favors a combination of Jordan (especially around the ancient city of Petra) and northwestern Saudi Arabia, the latter of which is home to a giant destination development project in the Tabuk region [105]. In this reference period, other single urban cases such as Baku and Alicante are also prominent. The favorable winter destinations of the Gulf, however, are now rated lower on HCI:Urban scheme and face a growing “Great Discomfort” rating by Humidex, calling for avoidance of physical activities [91]. The summer season (Figure 6) highlights the most European destinations such as Barcelona, Genoa, Rome and Mostar, in addition to the Canaries and Algiers, in terms of their competitive urban tourism climatology. The least suitable destinations start with Bucharest in the reference period and spread out throughout the century through a belt from Transcaucasia to Iberia. By the end of the century, under the business-as-usual scenario (RCP 8.5), the leading destinations partly retain their advantages, but the Humidex risk zone reaches its greatest extent with few places in the entire greater Mediterranean not being subject to high levels of climatological risk. For instance, Saudi Arabia’s summer capital, Ta’if, is mostly characterized by Good to Very Good (and even Excellent at its highest elevations) HCI:Urban

ratings in the reference period, but becomes a tiny patch with minor Acceptable to Good conditions surrounded by a vast zone of Humidex risks by the end of the century (RCP 8.5).

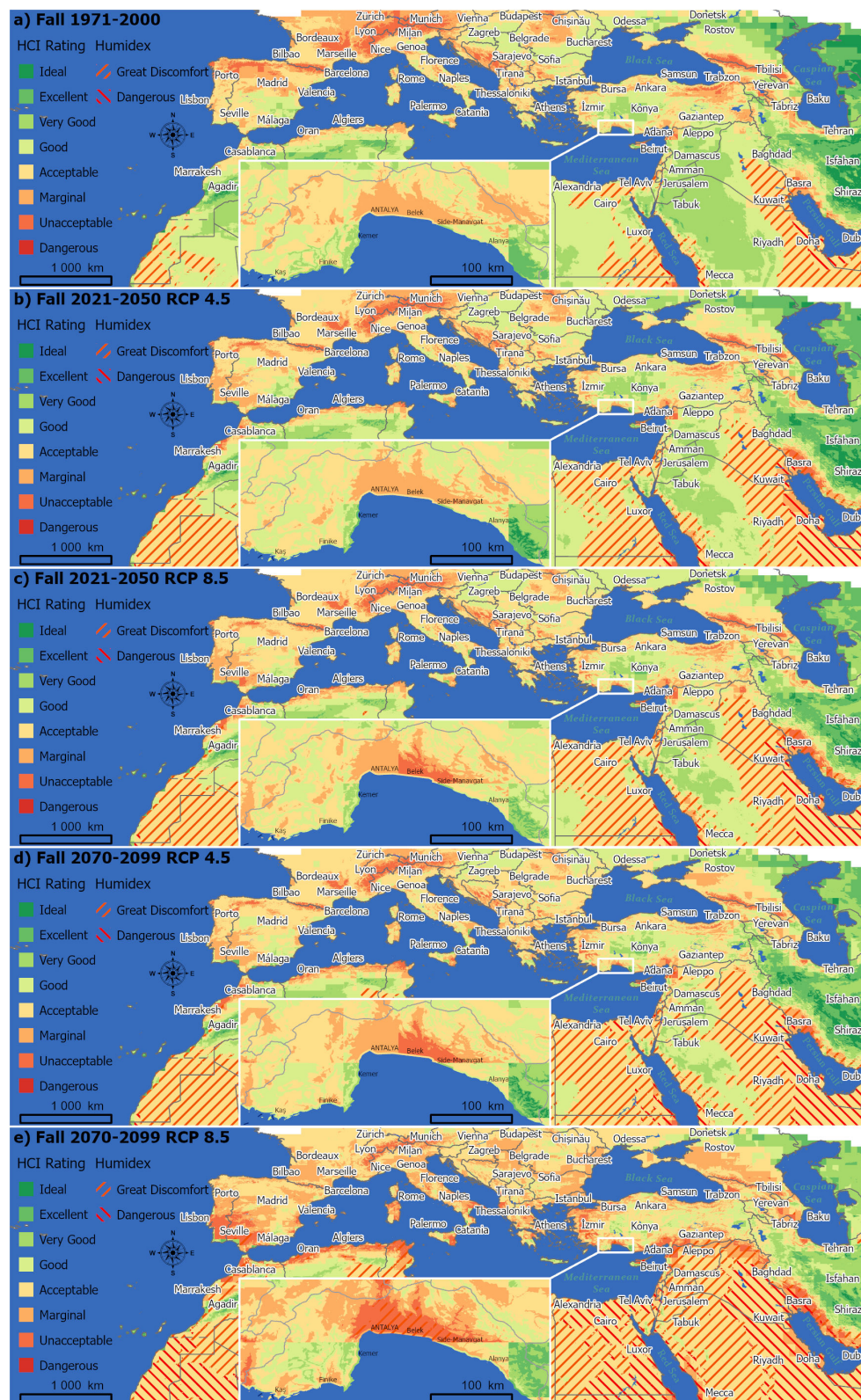


Figure 3. Fall season Holiday Climate Index (HCI) ratings and Humidex risks in the greater Mediterranean region for the projection periods (a) 1971–2000 (b) 2021–2050 (RCP 4.5) (c) 2021–2050 (RCP 8.5) (d) 2070–2099 (RCP 4.5) (e) 2070–2099 (RCP 8.5).

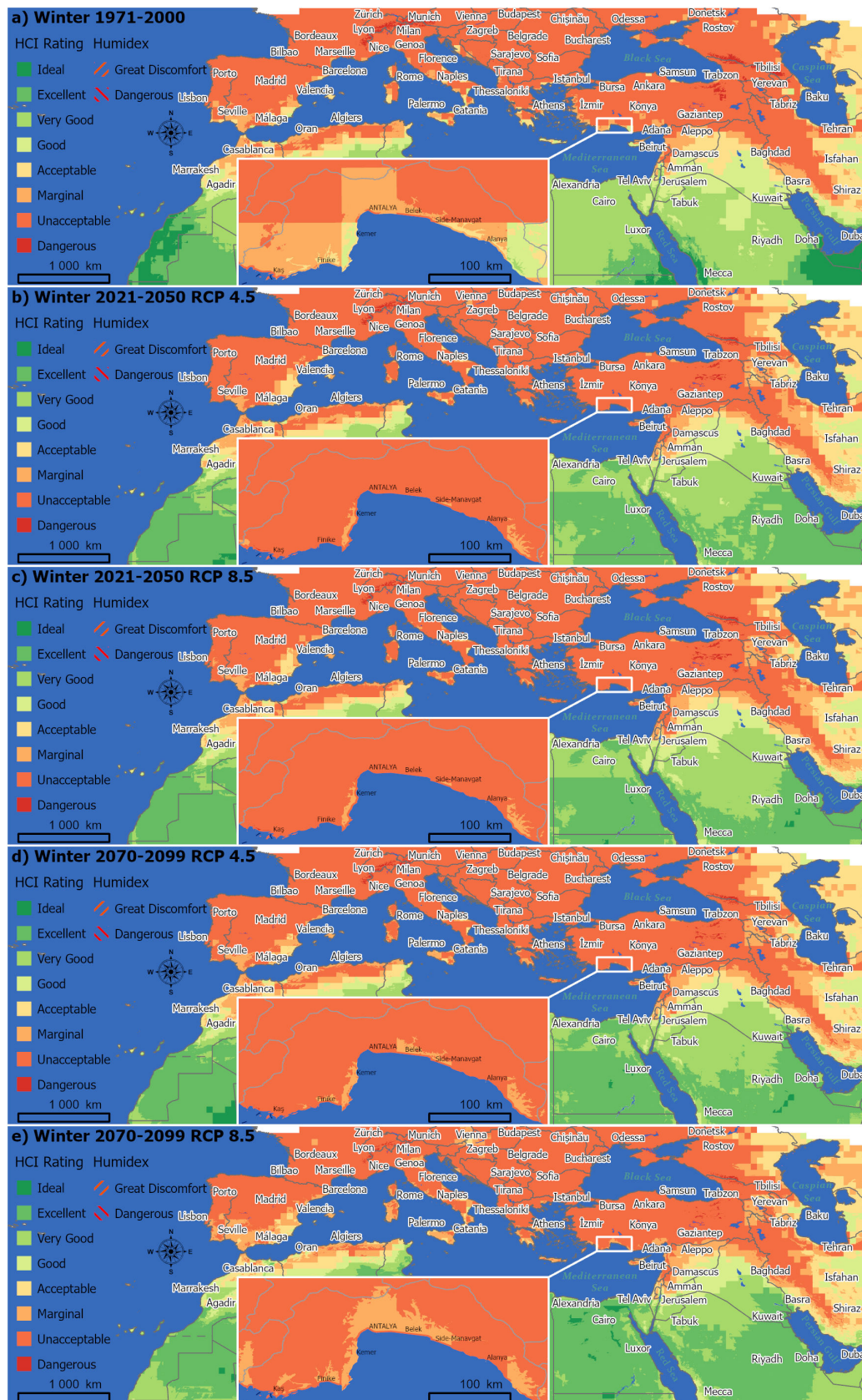


Figure 4. Winter season Holiday Climate Index (HCI) ratings and Humidex risks in the greater Mediterranean region for the projection periods (a) 1971–2000 (b) 2021–2050 (RCP 4.5) (c) 2021–2050 (RCP 8.5) (d) 2070–2099 (RCP 4.5) (e) 2070–2099 (RCP 8.5). Please note that a Humidex risk was not detected for any of the periods.

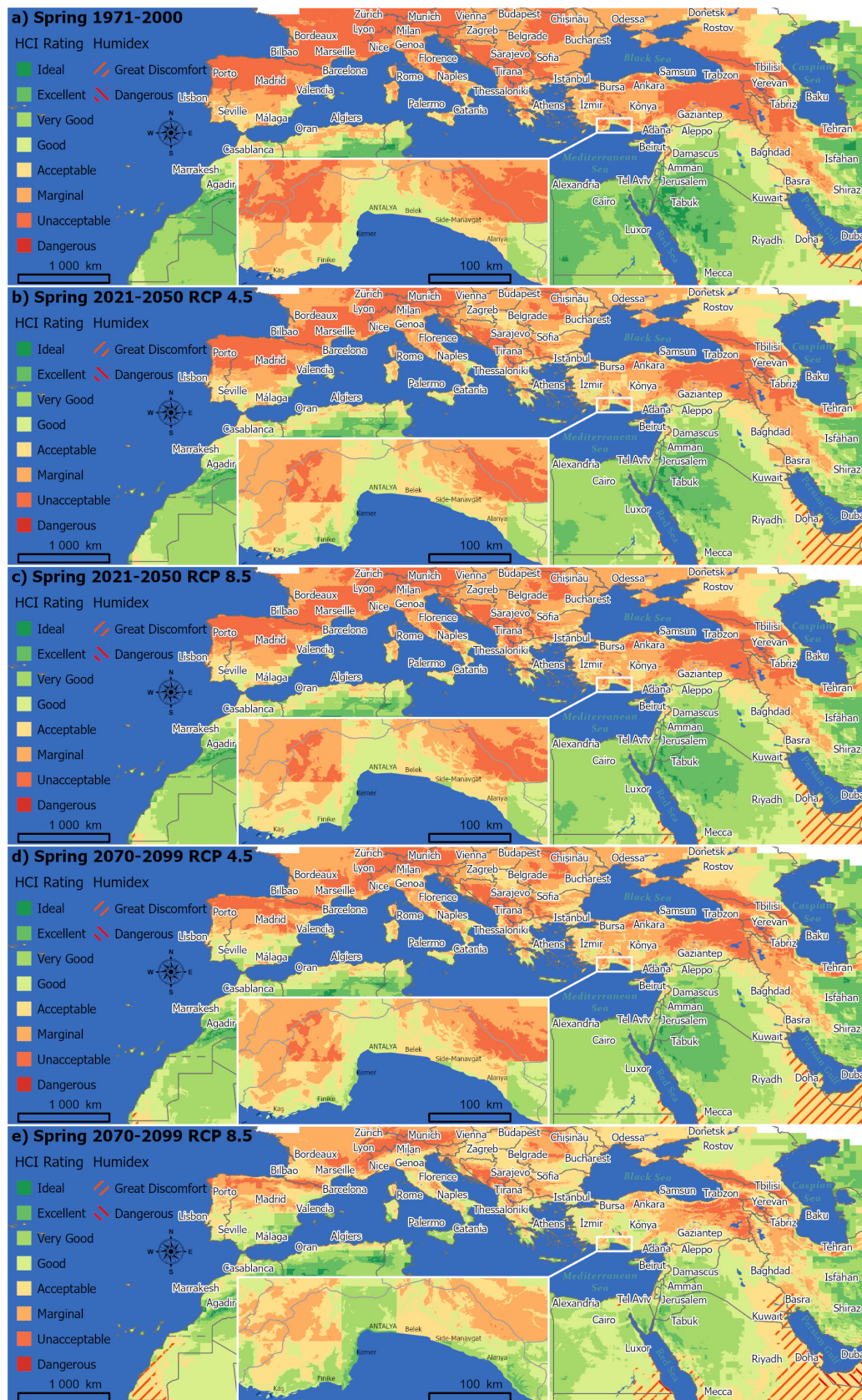


Figure 5. Spring season Holiday Climate Index (HCI) ratings and Humidex risks in the greater Mediterranean region for the projection periods (a) 1971–2000 (b) 2021–2050 (RCP 4.5) (c) 2021–2050 (RCP 8.5) (d) 2070–2099 (RCP 4.5) (e) 2070–2099 (RCP 8.5).

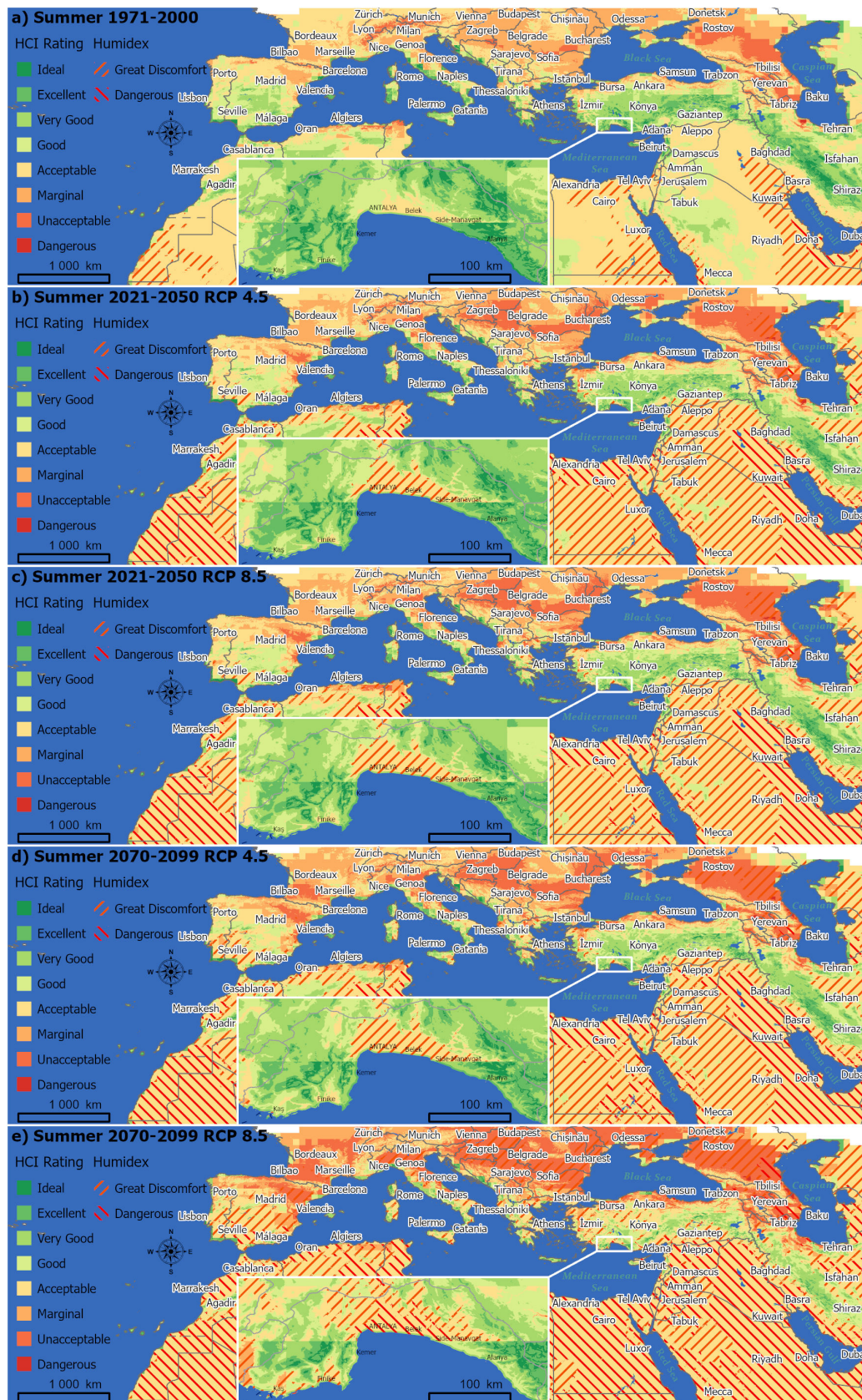


Figure 6. Summer season Holiday Climate Index (HCI) ratings and Humidex risks in the greater Mediterranean region for the projection periods (a) 1971–2000 (b) 2021–2050 (RCP 4.5) (c) 2021–2050 (RCP 8.5) (d) 2070–2099 (RCP 4.5) (e) 2070–2099 (RCP 8.5).

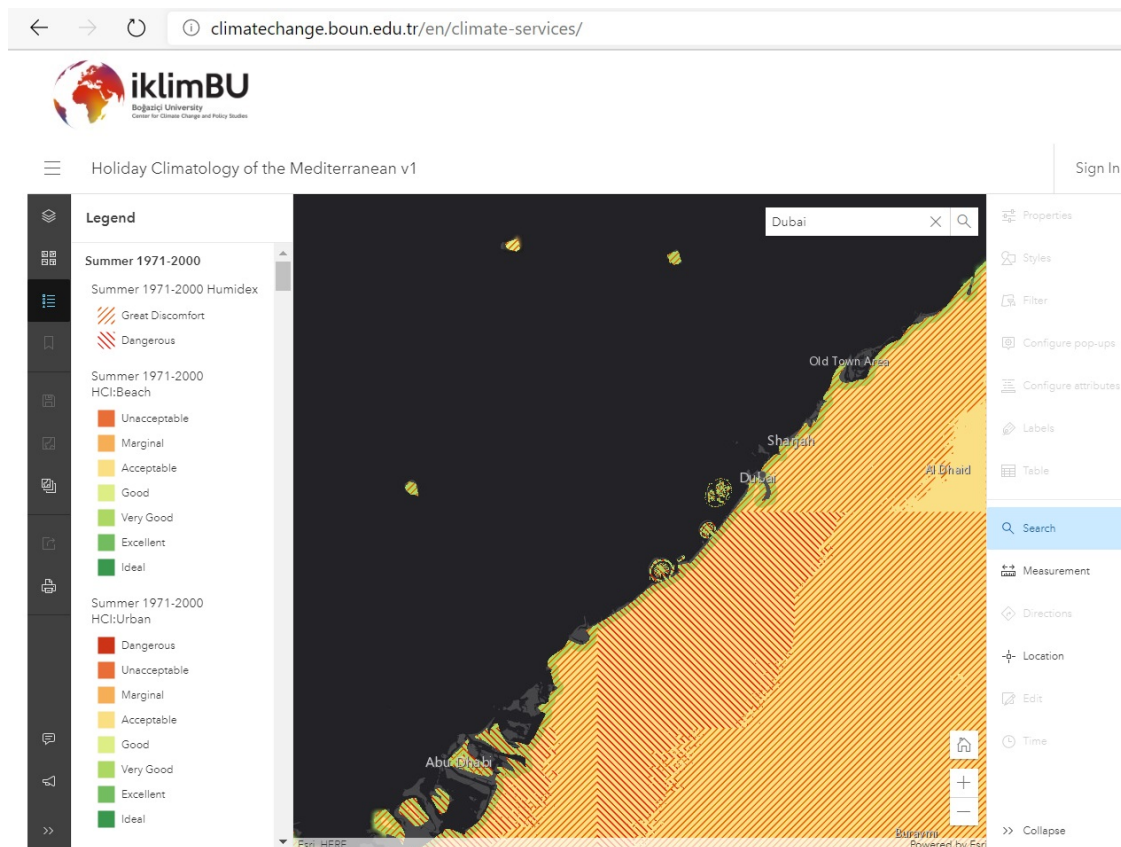


Figure 7. A snapshot of the climate service—Holiday Climatology of the Mediterranean.

4.2. HCI:Beach Performance in the Greater Mediterranean

The Mediterranean is best known for beach tourism in the summer season. It also competes with other warm-winter or year-round beach and urban destinations in the Caribbean, Southeast Asia and the Southern Hemisphere [106]. The recently developed HCI:Beach index has so far not been validated for the Mediterranean, but this study does present some preliminary results on seasonal projections for some selected spots and goes on to carry out the first validation attempt in the next section.

Among the preliminary cases, Ideal ratings are found along Las Canteras (Gran Canaria, Spain), Excellent conditions on Playa del Alicate (Costa del Sol, Spain), Myrtos (Cephalonia, Greece), Golden Sands (Varna, Bulgaria) and Edremit (Lake Van, Turkey), and Very Good conditions on Pampelonne (Saint Tropez, France), Tabuk (The Red Sea Project, Saudi Arabia) and Jumeirah (Dubai) for the reference period. The last two relate also to Humidex risks besides their shared HCI:Beach ratings. In the same period's winter season, Las Canteras still holds suitable conditions with an Excellent rating, now joined by Jumeirah and Tabuk (Very Good to Excellent)—without any Humidex risks. All other beaches lose their attractiveness with Alicate classified as Acceptable, Myrtos as Marginal, Pampelonne and Golden Sands as Unacceptable, and Edremit as Dangerous, as its high altitude (1640 masl) leads to cold and snowy conditions. In the extreme future scenario (2070–2099 RCP 8.5), winter conditions remain almost unchanged with only Varna downgraded one class to Dangerous and Excellent conditions consistently prevailing along the shorelines of Tabuk and Dubai, reinforcing their climatic edge in competition against Gran Canaria and other warm-winter or year-round beach destinations. In the summer season of the same period and scenario; Las Canteras, Alicate, Pampelonne, Myrtos, Golden Sands and Edremit all pose Very Good to Excellent conditions without any Humidex risks. Dubai and Tabuk, on the other hand, show Very Good conditions but with increased Humidex risks.

4.3. The Case of Antalya

Antalya is one of the most visited destinations in the Mediterranean and the world [98]. In 2019, the province hosted 15 million of Turkey's 52 million visitors from abroad, with the Russian Federation constituting the primary source market. With its 640 km shoreline stranded by beach resort facilities, Antalya's unique selling proposition is 3S, enhanced and complemented by other offers such as culture, nature and sports. Recent years have also seen a major growth in golf, especially around Belek, and football camps became popular attracting thousands of clubs to nearly 200 facilities during the winter breaks, matching the region's seasonally ideal climatic conditions. Albeit not as popular, Antalya's diverse topography with coastal mountains reaching over 3000 masl peaks has also made ski tourism possible during the winters. In terms of 3S tourism, the coastal areas register 300 sunny days a year, with most precipitation in December–January and daily summer temperatures around 30–34 °C and maximum temperatures exceeding 40 °C, accompanied by an annual relative humidity of 64% [107].

Besides its significant climate-dependent tourism economy and data availability for validation, Antalya makes a useful case as it sits in between high HCI ratings and Humidex risks (see Figure 6). At a first glance, the monthly visits from the primary source markets to Antalya do not seem to be best explained by the HCI:Beach, but the Humidex, for the 2007–2015 period (Figure 8). Under HCI:Beach approach, a sudden decrease is easily noticed for the two peak months of July–August, while most visits seem to follow the Humidex trends well. Indeed, regression analysis results (Table 3) show that total arrivals to Antalya are best explained by Humidex or maximum temperature values while the coefficient of determination for Thermal Comfort Rating is among the lowest, and even insignificant when based on MGM data. This misfit stems from the Thermal Comfort rating scheme of HCI:Beach (see Table 1) that favors a 28–31 Humidex range as the highest rated and treats all values above 39 as too hot for beach tourism, based on the Caribbean experience [39]. In the case of Antalya, all observed July–August Humidex values in the 2007–2015 period exceed the 39 break with an average of 40.7, while visitation is maximized.

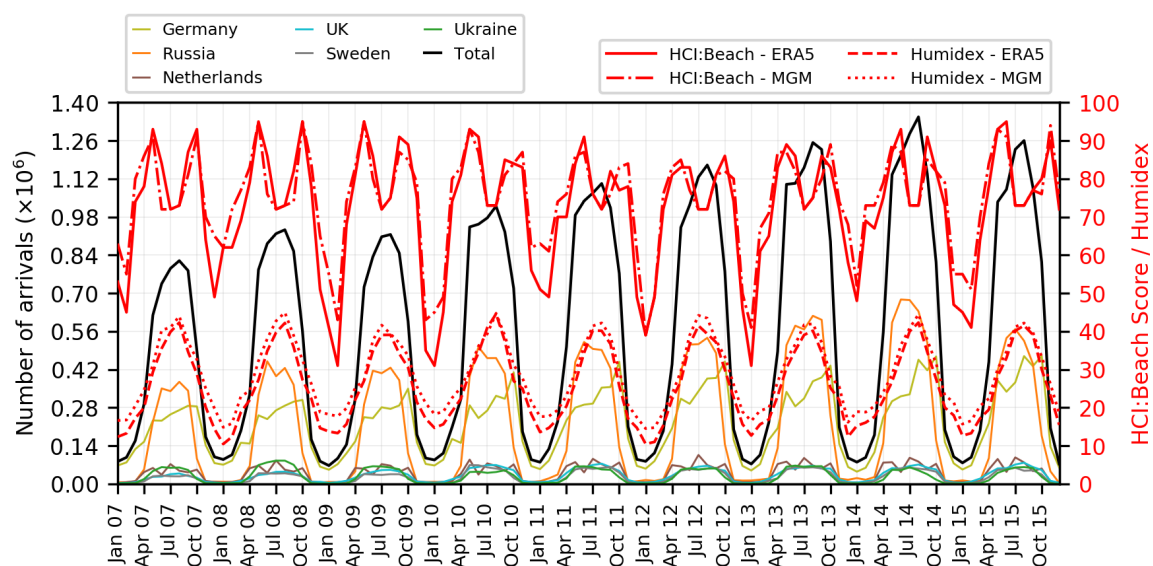


Figure 8. Comparison of HCI:Beach and Humidex scores (from ERA5 reanalysis & MGM observation data) with arrivals from top source markets to Antalya, Turkey.

Table 3. HCI:Beach Scores and Their Components as Estimators of Monthly Arrivals to Antalya (Turkey) from the Top Source Markets (2007–2015).

		Germany	Russian Federation	The Netherlands	United Kingdom	Sweden	Ukraine	Total
Cloud Cover	<i>r</i>	−0.665	−0.777	−0.633	−0.732	−0.733	−0.795	−0.81
	<i>r</i> ²	0.442	0.603	0.401	0.525	0.538	0.633	0.657
Relative Humidity	<i>r</i>	−0.438	−0.485	−0.393	−0.446	−0.443	−0.561	−0.524
	<i>r</i> ²	0.192	0.235	0.154	0.191	0.196	0.315	0.274
Precipitation	<i>r</i>	−0.533	−0.632	−0.568	−0.608	−0.608	−0.654	−0.654
	<i>r</i> ²	0.284	0.4	0.323	0.37	0.37	0.428	0.428
Wind Speed	<i>r</i>	−0.416	−0.35	−0.388	−0.407	−0.402	−0.336	−0.379
	<i>r</i> ²	0.173	0.122	0.151	0.166	0.161	0.113	0.144
Maximum Temperature (ERA5)	<i>r</i>	0.816	0.879	0.772	0.868	0.855	0.896	0.929
	<i>r</i> ²	0.667	0.773	0.595	0.754	0.73	0.803	0.864
Maximum Temperature (MGM)	<i>r</i>	0.814	0.863	0.757	0.848	0.834	0.889	0.916
	<i>r</i> ²	0.662	0.745	0.573	0.719	0.696	0.791	0.839
Humidex Score (ERA5)	<i>r</i>	0.818	0.888	0.775	0.878	0.863	0.892	0.935
	<i>r</i> ²	0.67	0.788	0.6	0.771	0.744	0.795	0.875
Humidex Score (MGM)	<i>r</i>	0.822	0.874	0.764	0.861	0.846	0.888	0.925
	<i>r</i> ²	0.675	0.764	0.583	0.741	0.715	0.789	0.856
Thermal Comfort Rating (ERA5)	<i>r</i>	0.581	0.339	0.482	0.436	0.469	0.39	0.396
	<i>r</i> ²	0.338	0.115	0.223	0.19	0.22	0.152	0.157
Thermal Comfort Rating (MGM)	<i>r</i>	0.247	0.081 ****	0.211 ***	0.073 ****	0.085 ****	0.041 ****	0.02 ****
	<i>r</i> ²	0.061	0.007 ****	0.044 ***	0.005 ****	0.007 ****	0.002 ****	0.000 ****
Aesthetic Rating	<i>r</i>	0.594	0.584	0.49	0.584	0.603	0.599	0.621
	<i>r</i> ²	0.352	0.341	0.24	0.341	0.364	0.358	0.386
Precipitation Rating	<i>r</i>	0.461	0.498	0.491	0.511	0.496	0.517	0.529
	<i>r</i> ²	0.213	0.248	0.241	0.261	0.246	0.267	0.28
Wind Rating	<i>r</i>	0.401	0.281 *	0.38	0.375	0.362	0.265 **	0.322 *
	<i>r</i> ²	0.161	0.079 *	0.144	0.141	0.131	0.070 **	0.104 *
HCI:Beach Score (ERA5)	<i>r</i>	0.686	0.547	0.605	0.612	0.633	0.588	0.604
	<i>r</i> ²	0.471	0.3	0.366	0.375	0.4	0.346	0.365
HCI:Beach Score (MGM)	<i>r</i>	0.577	0.39	0.527	0.49	0.498	0.427	0.455
	<i>r</i> ²	0.333	0.152	0.278	0.24	0.248	0.182	0.207

Unless otherwise stated, $p < 0.001$; * $p < 0.005$; ** $p < 0.01$; *** $p < 0.05$; **** $p > 0.05$.

The above finding provides a major hint for an optimization of HCI:Beach specification in the case of Antalya and the Mediterranean tourism. Another major clue rests with beach tourist surveys in Europe (see Table 1 in [39]) which have identified a range of ideal temperatures from 25–28 °C to a consistent maximum of 32 °C. This maximum, under a relative humidity of 55% (the reanalyzed summer relative humidity for Antalya in the 2007–2015 period is 54% [100]), translates into a Humidex value of 41 [91]. Departing from these thresholds, a Thermal Comfort rating scheme for the optimized HCI:Beach, i.e., HCI:Beach-Med, is proposed on Table 4. Consequently, regression analyses examining the relationships between HCI:Beach-Med scores and arrivals to Antalya return much higher r^2 results (Table 5) with 74% of the variance in total arrivals explained by HCI:Beach-Med - slightly above its Caribbean (69%) [39] and Canadian (73%) [83] counterparts.

Table 4. Humidex-based Thermal Comfort Rating Scheme of HCI:Beach-Med.

Min	Max	Rating
−9999	9.99	−10
10	14.99	−5
15	23.99	0
24	24.99	1
25	25.99	2
26	26.99	3
27	27.99	4
28	28.99	5
29	29.99	6
30	30.99	7
31	31.99	9
32	40.99	10
41	42.99	9
43	43.99	7
44	44.99	6
45	9999	0

Table 5. Regression Results on the Effects of Monthly HCI:Beach-Med Scores to Visitor Arrivals (2007–2015) to Antalya.

Source Market	r	r^2
Germany	0.77	0.59
Russian Federation	0.82	0.67
The Netherlands	0.70	0.48
United Kingdom	0.81	0.65
Sweden	0.82	0.66
Ukraine	0.83	0.69
Total	0.86	0.74

All results are significant at $p < 0.001$ level.

Finally, the proposed HCI:Beach-Med is applied to historical and future projections for Antalya, and a (potential) substitute, Sochi, in the context of the Russian market. Sochi is the most visited domestic beach destination on the eastern Black Sea shores of the Russian Federation, and similar to Antalya, situated by a high mountain range, the Caucasus, where ski tourism is also on the rise especially since hosting the 2014 Winter Olympic Games [108]. Taking 36.885° N 30.7° E and 43.58° N 39.72° E as the reference points representative of main public beaches and touristic quarters in Antalya and Sochi, respectively, historical and future monthly HCI performances and Humidex risks are presented on Tables 6 and 7.

Table 6. A Comparison of Projected HCI Scores and Humidex Risks of Antalya and Sochi.

Index	Destination	Period	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
HCI:Beach-Med	Antalya	1971–2000	19	23	23	36	54	76	91	91	91	91	70	33
	Antalya	RCP 4.5 2021–2050	23	23	23	40	62	88	91	89	89	91	70	33
	Antalya	RCP 8.5 2021–2050	23	23	26	36	56	88	92	89	89	88	56	33
	Antalya	RCP 4.5 2070–2099	23	23	26	40	58	88	91	85	85	88	58	36
	Antalya	RCP 8.5 2070–2099	33	30	36	52	70	86	85	71	71	86	80	40
	Sochi	1971–2000	13	3	7	17	27	27	47	62	62	50	31	27
	Sochi	RCP 4.5 2021–2050	17	17	17	17	27	33	49	59	62	60	33	27
	Sochi	RCP 8.5 2021–2050	14	13	17	17	27	35	53	59	62	56	35	27
	Sochi	RCP 4.5 2070–2099	17	17	17	17	27	35	57	64	62	58	37	27
	Sochi	RCP 8.5 2070–2099	27	17	17	27	31	43	57	62	66	62	41	27
HCI:Beach	Antalya	1971–2000	19	15	23	36	66	82	81	71	71	83	80	35
	Antalya	RCP 4.5 2021–2050	23	15	23	44	72	84	71	71	71	81	80	39
	Antalya	RCP 8.5 2021–2050	23	15	26	38	66	84	72	71	71	76	64	39
	Antalya	RCP 4.5 2070–2099	23	15	26	46	70	84	71	71	71	72	64	44
	Antalya	RCP 8.5 2070–2099	33	22	36	62	78	76	71	71	71	68	76	54
	Sochi	1971–2000	13	-3	7	17	29	41	55	60	58	58	45	29
	Sochi	RCP 4.5 2021–2050	17	11	17	17	31	45	55	51	54	60	45	31
	Sochi	RCP 8.5 2021–2050	14	7	17	17	29	47	53	51	52	56	45	33
	Sochi	RCP 4.5 2070–2099	17	11	17	17	33	45	55	54	50	56	49	35
	Sochi	RCP 8.5 2070–2099	27	11	17	27	41	53	49	42	46	52	51	37
HCI:Urban	Antalya	1971–2000	37	33	37	46	68	67	71	53	53	71	73	43
	Antalya	RCP 4.5 2021–2050	37	39	39	50	79	70	55	53	53	69	64	47
	Antalya	RCP 8.5 2021–2050	37	37	42	46	70	70	52	53	53	60	54	47
	Antalya	RCP 4.5 2070–2099	37	39	42	50	64	70	55	53	53	60	54	58
	Antalya	RCP 8.5 2070–2099	43	42	46	66	67	57	55	53	53	52	52	62
	Sochi	1971–2000	33	29	29	33	39	55	45	46	44	50	55	37
	Sochi	RCP 4.5 2021–2050	33	33	33	33	41	55	45	35	40	46	57	41
	Sochi	RCP 8.5 2021–2050	30	29	29	33	39	57	41	35	40	46	57	41
	Sochi	RCP 4.5 2070–2099	33	33	33	33	43	55	45	42	32	46	51	49
	Sochi	RCP 8.5 2070–2099	37	33	33	37	51	51	37	24	24	38	49	49
Humidex	Antalya	1971–2000	12	10	12	16	24	31	37	40	40	35	27	17
	Antalya	RCP 4.5 2021–2050	13	12	13	18	26	33	39	42	42	36	29	20
	Antalya	RCP 8.5 2021–2050	13	12	14	18	25	33	39	43	43	37	29	20
	Antalya	RCP 4.5 2070–2099	14	12	15	19	27	33	40	43	44	39	30	20
	Antalya	RCP 8.5 2070–2099	16	14	16	21	30	37	44	48	48	42	34	23
	Sochi	1971–2000	13	10	10	11	18	23	29	33	34	30	23	17
	Sochi	RCP 4.5 2021–2050	14	11	11	13	19	25	31	35	36	32	25	19
	Sochi	RCP 8.5 2021–2050	13	11	11	13	18	25	31	35	37	32	26	19
	Sochi	RCP 4.5 2070–2099	15	12	12	14	20	25	32	37	37	33	26	20
	Sochi	RCP 8.5 2070–2099	16	13	13	15	22	29	36	41	41	36	29	22

Table 7. HCI and Humidex color scale.

0–19	Dangerous	< 20	No discomfort
20–39	Unacceptable	20–29	Little discomfort
40–49	Marginal	30–39	Some discomfort
50–59	Acceptable	40–45	Great discomfort
60–69	Good	> 45	Dangerous
70–79	Very Good		
80–89	Excellent		
90–100	Ideal		

HCI:Beach-Med results show that nowhere in the future can Sochi outperform Antalya, even when the latter starts entering Humidex-Dangerous zone during July–August months in the 2070–2099 period under a weak mitigation trajectory (RCP 8.5). Both Sochi and Antalya, but especially the latter, may have their peak season extended to the shoulder seasons. Sochi’s beach season reaches its excellence by the end of the century under the RCP 8.5 scenario but still cannot get anywhere above a “Good” rating. In general, Sochi suffers from relatively high precipitation and high cloud cover. By the same period and scenario, Antalya loses its ideal conditions, especially since July–August conditions become nullified in Thermal Comfort facet, yet maintains Very Good to Excellent conditions from April to October. In terms of urban tourism climates, both destinations register less months with higher suitability, and in the case of Antalya, a seasonal shift from late spring and early fall to early spring and late fall is most apparent.

5. Discussion and Conclusions

Climate index application and validation for tourism is a complicated issue and presents several challenges [38,39,77]. First, the lack of consistent high granularity and diverse climatic data has so far been limiting development and use of high-quality indices in a wider geographic context. Secondly, the common method of validating with visitation data may not represent tourist satisfaction with climatic conditions since visitation also shows institutional seasonality, such as school holidays, public holidays and long weekends, and climate seasonality. Therefore, de Freitas et al. [77] stated that surveys are better to understand climate satisfaction of tourists. However, in situ surveys also have limitations because they cannot account for the perceptions of those who find the weather conditions in question unacceptable [18]. For this reason, both in situ and ex-situ surveys should be employed [18], while revealed preferences should also be accounted by index calibration. This study presents macro-regional and future scenario outputs from the HCI index, which was devised by the use of the available literature on tourist preferences in the surveys, and the outputs are also validated and calibrated with the visitor arrivals for Antalya. As a result, the study complements the Caribbean case by Rutty et al. who state that [39] (p. 13) “the development of data-driven climate indices for specific tourism markets (domestic and international), particularly those considered to be particularly influenced by climate variability, remains an important area of continued research and climate services development, with positive correlations between arrivals data and indices an initial movement in the right direction”. Significantly for the present study, they also suggest that “as climate data becomes increasingly available, the application of the HCI:Beach to other popular coastal-beach tourism markets at varying temporal and spatial scales, including an assessment of future climatic conditions, remains an important area for continued research” [39] (p. 14). In doing so, it also uses the CORDEX data, replacing its antecedent ENSEMBLES [109] data used by Scott et al. [38] for the only existing future application of the HCI.

To better contribute to destination decision-making and understanding of the implications of climate change, assessments on urban tourism climatology will require a more sophisticated approach that segments tourists of their specific purposes of visits in origin-destination matrices. In essence, “leisure cities” such as Antalya are easier to validate due to their distinct seasonality [98] but, even then, more specific indices such as HCI:Beach or HCI:Beach-Med will yield better correlated results (Table 6). In contrast, at cities like Dubai (Figure 7), where air-conditioned indoor attractions and infrastructure are common, demand sensitivity may not be as high. This would also be true for Kyrenia, where in addition to the climatically endangered summer 3S offer (Figure 6), casinos that pay particular attention to indoor thermal comfort are the primary sources of tourism receipts. On another note, destinations like Mecca that offers the essentials of faith tourism, in this case the Hajj pilgrimage as one of the Five Pillars of Islam, may have the least climatic elasticity of their demand no matter what the weather conditions are [110]. Current research [111] has already assessed extreme climatic danger for the future of Hajj events, which seasonally shift according to the lunar Islamic calendar, based on the Heat Index developed by the US National Weather Service [112], and called for aggressive adaptation measures. The HCM service [97] also signals for climatic risks throughout the 21st century, except for winters where Good to Very Good HCI:Urban conditions without any Humidex risks prevail. Future springs are characterized by Good conditions with Great Discomfort, regardless of the time range or the mitigation efforts, while falls and summers hold Marginal to Acceptable conditions within a Humidex-Dangerous zone, posing severe health threats especially given the older visitor profile of the Hajj, as well as the Umrah [113–115].

The question of “what is too hot for tourism?” [6,116] remains on the agenda for further research from a revealed, if not stated, preferences perspective that provides analogues for the future. As Rutty and Scott [6] note, early studies (e.g., [10,14,24,28,33,49]) project a shift of suitable temperature conditions for tourism in the Mediterranean to the current shoulder seasons of spring and autumn. This study, however, has found out that (beach) tourists to Antalya keep returning in an ever-growing trend despite the relatively high July–August Humidex values that are classified under the Great

Discomfort rating during the 2007–2015 period (Figure 8). This difference may be due to understated preferences, sub-diurnal adaptation (avoiding heat exposure for longer times during the day), technical compensation (e.g., air-conditioning), the still strong push factor of the origin climate [80] or the fact that some of those “returning” are those with higher tolerances. The institutional and structural factors such as calendar effects and the business-as-usual of tour operations may also be the major determinants of such a trend. The crucial point for the future would be at what threshold range and what persistence the thermal conditions could become uncomfortable enough to reverse visitation. For instance, in the case of ski tourism in Norway [117], using a curvilinear regression model with a quadratic term for the wind-chill factor, a threshold of $-9.5\text{ }^{\circ}\text{C}$ was estimated as the turning point where visitor numbers are optimized and start dropping due to either too cold or too warm (usually less snow-reliable) conditions. Such empirical findings are also crucial from a beach tourism perspective to plan for the future, for instance in the case of Antalya, which is projected to experience two months of Humidex-Dangerous conditions by the end of the century and under a weak mitigation scenario (Table 6). Understanding optimal thermal ranges would not only help calibrate index thresholds but also set any restriction parameters in the final overlay, emphasizing overriding effects to a nullifying degree, if needed. Similar approaches should also be followed for other sub-indices and variables.

It may be claimed that urban tourism is usually a one-time consumption product, especially when heritage sightseeing is the purpose, while beach tourism attracts more repeat visitors [118]. Therefore, beach destinations may benefit more from loyalty to build resilience. This may even be reinforced at regions where second home tourism is significant and is therefore related to some form of place attachment, and even inelasticity. However, as loyalty is also a function of satisfaction, future climatic characteristics will be vital to the vulnerability of these regions and their stakeholders. Along with some of the technical and behavioral adaptations mentioned above, business practices such as travel and health insurance packages taking account of weather-based guarantees and compensations will need to be enhanced [18]. Otherwise, many destinations will need to plan for any temporal substitution (sticking to the same destination, but choosing another vacation period) by the consumers towards their shoulder seasons, if calendar effects (e.g., school holidays) and other institutional factors allow. They will also need to be ready for the threat (or, for some, opportunity) of spatial substitution when consumers will want to stick to the same vacation period, but choose other destinations. At this stage, double trouble may manifest itself for Mediterranean destinations, should the origin climates of the source markets (assuming that the direction of the European beach tourism flows will remain constant throughout the century) improve for coastal recreation [67,68]. Alternatively, switching to climatically more suitable conventional destinations such as the Canary Islands will have its implications in terms of rebound effects, such that increased travel distances will also mean increased emissions, setting a vicious cycle of climate change feedback loops.

The results and implications of this study are well limited by its methodological constraints and choices. Future research will need to make use of more RCPs and GCM-RCM couples as well as their ensembles to provide alternative solution sets, emphasizing the consequences of different mitigation efforts. The latter selection process will now be even more critical as much larger temperature differences have been found between driving GCMs in phase 6 of the Coupled Model Intercomparison Project (CMIP) [119]. Regarding spatiotemporal resolution, the already existing 3-hourly outputs of GCM-RCM projections can be used to examine sub-diurnal changes in climatic suitability, while spatial resolution can be enhanced as the results of non-hydrostatic RCMs become more common. Further statistical downscaling methods such as the basic lapse rate correction technique followed in this study will need to become more sophisticated to account for seasonal temperature deviations in different regions, as well as factors pertaining to land-surface characteristics, vegetation, microclimatic processes, slope and aspect [120], using higher resolution DEMs or LiDAR (Light detection and ranging) data, if possible. Further adjustments can also be applied on the other key variables, should empirical evidence exist on their lapse rates (see [88] for an application on precipitation data in the case of ski tourism). In addition to all these refinements in index computations,

there is major room to fill in for service development, with addition of monthly and seasonal sub-index and their underlying variable layers to the next version of the HCM on the top of the agenda. Finally, it should be noted that climatic comfort is one essential component of destination attractiveness, and wider suitability analyses would need to consider other climate impacts such as sea/lake surface temperatures, sea level rise, extreme events, effects on aquatic flora and fauna (e.g., coral bleaching, and invasions of alien species), as well as the non-climatic ones (e.g., land cover and use change with major implications from coastal geomorphology and urban heat islands) to drive conclusions within an integrated resilience framework.

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