Thermal bioclimate analysis for Europe and Italy

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Summary. — Thermal bioclimate indexes (as thermal comfort or heat stress indexes) are one of the main issues concerning tourism and health conditions especially for expected climate change. The Mediterranean area and countries such as Italy, Spain, France, Turkey and Greece, whose economies are markedly dependent on tourism, are vulnerable regions concerning climate change. In the present study thermal comfort and heat stress (here with the thermal index physiologically equivalent temperature—PET) are analysed in order to quantify the monthly conditions in this area. Additionally, based on climate change scenarios, the seasonal pattern of PET for the period 2070-2100 has been calculated. The results show that the expected conditions of thermal comfort especially for the Mediterranean and Italy will be higher, during summer, about two to three classes of thermal stress for the "business as usual" climate scenarios, and one class of thermal stress for winter. Adaptation and mitigation strategies are hence required for the protection of human health and tourism state and potentialities.

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PACS `92.70.Kb` – Regional climate change.

1. – Introduction

An increasing awareness concerning Anthropogenic Global Warning (AGW) induced Governments to take actions to prevent and mitigate the effects on local climate and environment. IPCC analysis reported in the 4AR shows a differentiated heating for different parts of the globe which presumable will induce also differentiated impacts [1,2].

Prior to the publication of the IPCC-4AR, a document produced by the European Commission titled document "Limiting global change to 2 degrees Celsius: the way ahead
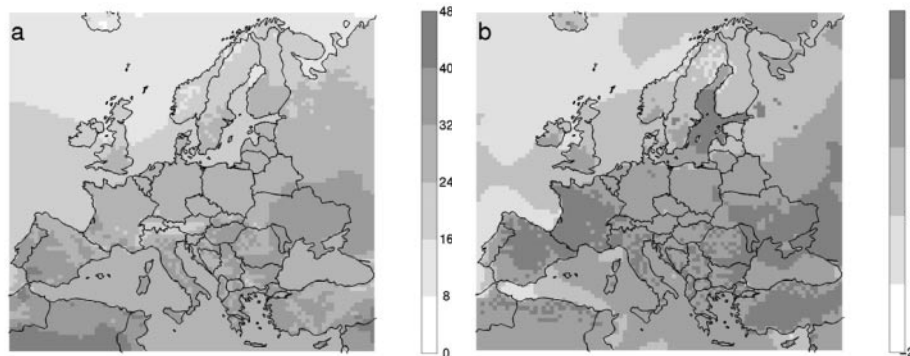

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Fig. 1. – Current distribution (a) and projected changes in the distribution (b) of the 90th percentile for maximum temperature across Europe [3].

from 2020 and beyond" highlighted specific impact on various economic issues referred to specific regions of Europe. The Mediterranean area resulted the more markedly affected by AGW impacts of the whole European region (fig. 1) and the highest economic risks were evidenced in southern countries.

For the bioclimatic evaluation of a specific location or area the analysis of single meteorological parameter is not sufficient, but a complex evaluation of climate conditions and thermo-physiological values is needed in order to describe the effects of the thermal environment on humans. Several models and indices were developed to calculate the extent of thermal stress during the last decades. The earlier bioclimatic indices (Discomfort Index, Windchill, thermohygrometric index—THI) consider only some meteorological parameters [4-7]. Newer models, based on human energy balance equation, produce the so-called comfort indices—for example, Predicted Mean Vote—PMV, Physiologically Equivalent Temperature—PET, Outdoor Standard Effective Temperature—OUT_SET*—to evaluate the thermal stress on the body [7-15]. These indices can be applied in different time and spatial resolutions [9, 13, 14]. For example, describing a small area (*e.g.*, surroundings of a building, part of a street) with a high resolution can be useful for architects and urban designers [15, 16]. Micro-scale studies (*e.g.*, bioclimatological description of a town) provide data for urban planning [7]. Examining even larger areas (*e.g.*, a whole region or country) has not only scientific value: in fact the results of these studies can be at the basis of planning regional recreation and tourism development [6, 7, 14, 17, 18].

Several studies have been run on the global and local scale for different locations of the world [6, 16]. Also some studies for Italy indicate the importance and the need of this kind of studies [19, 20] in order to prepare and offer decision possibilities for governmental authorities, decision makers and stakeholders.

The aim of this study is to present a bioclimatic analysis of the Mediterranean, especially Italy, by means of bioclimatological mapping with the aid of geo-statistical methods. The present study links geographical information [21, 22] with climatological data [23-25] in order to generate a spatial distribution of PET values of a region. The calculation of PET is performed with the aid of the RayMan Model, which calculates the thermal indices mentioned above [26, 27].

The results and tools of this study can be useful for diverse approaches concerning public health protection and tourism needs.

TABLE I. – *Physiologically Equivalent Temperature (PET) for different grades of thermal sensation and physiological stress on human beings (during standard conditions: heat transfer resistance of clothing: 0.9 clo and internal heat production: 80 W)* [29].

PET (°C)	Thermal sensation	Physiological stress level
4	very cold	extreme cold stress
8	cold	strong cold stress
13	cool	moderate cold stress
18	slightly cool	slight cold stress
23	comfortable	no thermal stress
29	slightly warm	slight heat stress
35	warm	moderate heat stress
41	hot	strong heat stress
> 41	very hot	extreme heat stress

2. – Study area and methods

2˙1. *Applied bioclimatic index*. – In this study, one of the most widely used bioclimatic indexes, the PET, is used as it has a widely known unit (°C) as an indicator of thermal stress and thermal comfort. This makes the results easily understandable and comprehensible for potential users. This is especially the case for planners, decision-makers, and even the public who might not be familiar with modern human-biometeorological terminology. PET evaluates the thermal conditions in a physiologically significant manner [11, 13]. It is defined as the air temperature at which the human energy budget for the assumed indoor conditions is balanced by the same skin temperature and sweat rate as under the actual complex outdoor conditions to be assessed. PET enables various users to compare the integral effects of complex thermal conditions outside with their own experience indoors (table I). In addition PET can be used for the entire year and in different climates [11, 28]. Meteorological parameters influencing the human energy balance, such as air temperature, air humidity, wind speed and short- and long-wave radiation, are also represented in the PET values. PET also considers the heat transfer resistance of clothing and the internal heat production.

2˙2. *RayMan model*. – One of the recently used radiation and bioclimate models, RayMan, is well suited to calculate radiation fluxes [29, 30] and was chosen for all our calculations for the mean radiant temperature and PET. The RayMan model, developed according to the Guideline 3787 of the German Engineering Society [12] calculates the radiation flux in easy and complex environments on the basis of various parameters, such as air temperature, air humidity, degree of cloud cover, time of day and year, albedo of the surrounding surfaces and their solid-angle proportions [26, 27].

2̇3. *Data*. – The climate data used to fit RayMan and calculate PET for this analysis [27] were provided by the data collection program at the Climatic Research Unit [23-25]. The required data (air temperature, relative humidity, sunshine and wind speed) are available at monthly resolution for the climate period 1961 to 1990 at ten minute resolution for the study area. The available monthly data have been used which, although not performing for daily observations since lacking of the demanded resolution, fit well in offering mean monthly conditions of human-biometeorological conditions as basic information.

The dataset of future climatic conditions was based on an integration of the Hadley Centre's HadCM3 model forced with the SRES emissions scenarios. The HadCM3 model produces gridded data with a spatial resolution of 2.5° latitude ×3.75° longitude, which is significantly coarser than that of the CRU 1.0 dataset. The used HadCM3 dataset consists of monthly averages for two time slices: 1961-1990 and 2070-2099. The uncertainties and difficulties of the climate projections data are described in [31] and [32].

2̇4. *Study area*. – The Mediterranean area is one of the most appreciated regions for tourism, and at the time, one of the more vulnerable concerning the expected climate conditions for the future. Most of the economies of the countries of the Mediterranean basin are dependent on tourism, both during summer holidays and through the year as cultural trips and visits.

For Italy, an analysis of the thermal conditions over the entire territory is important. In the interior, the cultural and monumental heritages offer a variety of different journeys capable to satisfy the requirements of thousands of guests (millions over a whole tourist season). In addition to major itineraries (important big cities and monuments), main touristic tools come from some attractive characteristic of the national landscape, as small historical towns that came to us unchanged from the Middle Age, maintaining original materials in terms of buildings and pavements and, sometimes, the same way to "live" the town itself through centuries. The economic importance of the Italian coasts is not lower that the in-land one because, starting from the second world war, tourist activities in these areas has been increasing step by step, assuming nowadays a paramount importance for visiting people and local population. Consequently, changes in thermal patterns, mainly during the summer, can strongly affect not only the human health conditions but, also, the local economies [33].

3. – Results and discussion

Based on the described methods and models and the use of the geo-statistical methods, mean monthly maps of physiologically equivalent temperature have been constructed. The maps presented here show the conditions for Europe and the Mediterranean for a direct comparison between the conditions of the western and north European countries, which are the main sources for tourists for the target area. Figure 2 illustrates the PET conditions for January, which represents the coldest month of the year, and fig. 3 the same for July, the warmest month of the year. In January, PET values in North Europe (Scandinavian countries and the Alps) are between 0 and −20 to −30. For the Mediterranean area and the coasts, the range of the PET values goes from +5 up to 15 °C in the North Africa zones. From fig. 2 is can be derived that, for the 1961-1990 situation, the conditions are lying in the area of light to strong cold stress in the Mediterranean.

For July (fig. 3) the conditions show that thermal comfort conditions can be obtained only in the Northern Europe countries and high-lying areas such as the Alps. For the
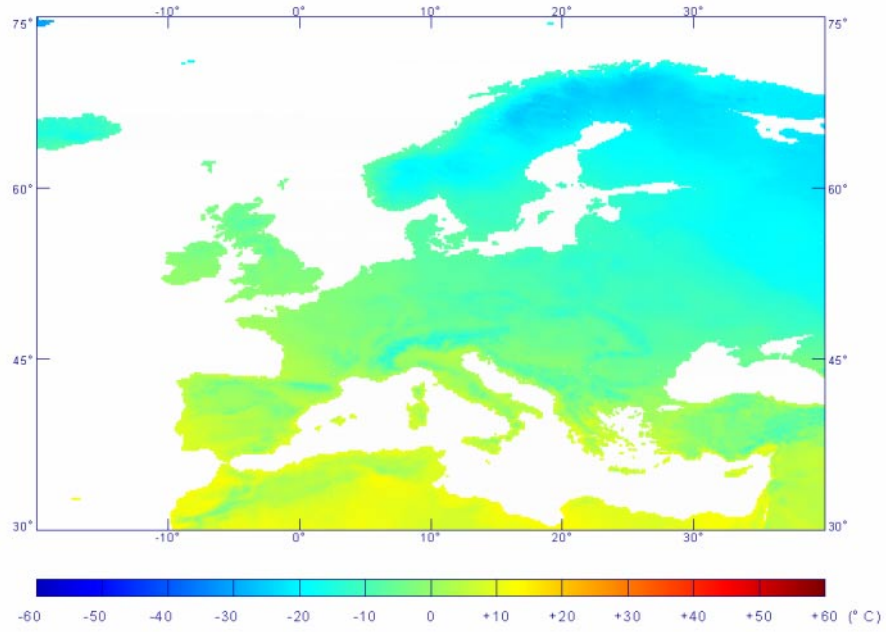
Fig. 2. – Map of physiologically equivalent temperature for January for the period 1961-1990.
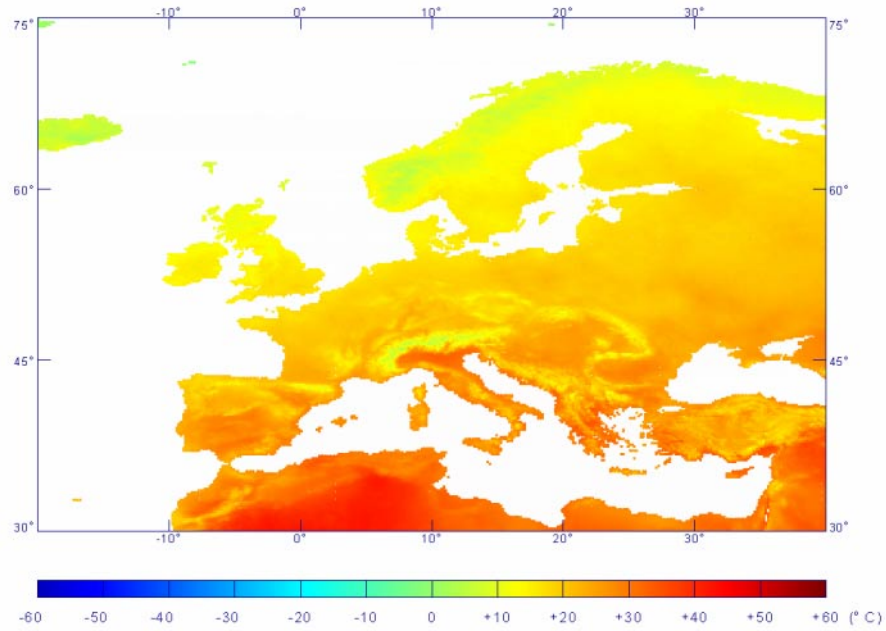

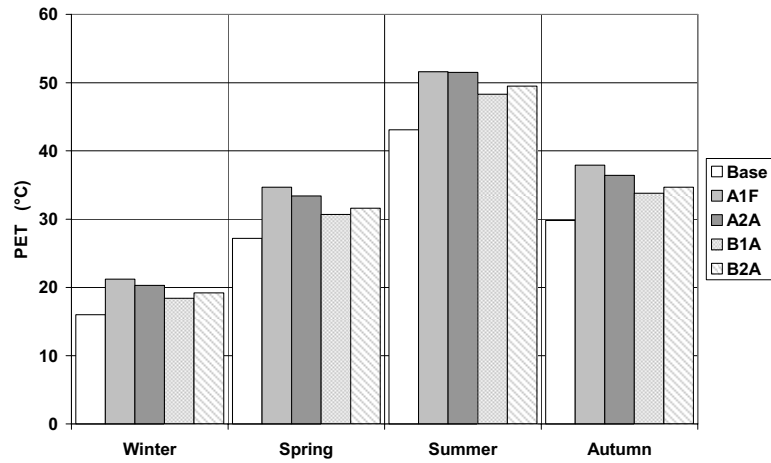Fig. 3. – Map of physiologically equivalent temperature for July for the period 1961-1990.

Fig. 4. – Maximum seasonal values of PET for Base and four IPCC-scenarios for 1960-1990 and 2070-2100 for Europe.

Mediterranean coast, the PET values are in the range of 30 to 40 °C and higher, evidencing the extreme heat stress occurring in most of the target areas. For southern countries the PET values are higher than 35 or 41 °C, values that, according to table I, are qualified as strong and extreme heat stress. So, the conditions during July are, currently, quite bad as far as heat stress is concerned.

Based on the IPCC-emission scenarios [34], four scenarios have been chosen and the PET values calculated on monthly and seasonal resolution. The scenarios represent respectively two "worse scenarios" (A1F and A2A) and "two moderate emission scenarios" (B1A and B2A) conditions. Additionally, the base conditions for 1961-1990 are also calculated. For the scenarios the simulations represent the period 2070-2100 based on the
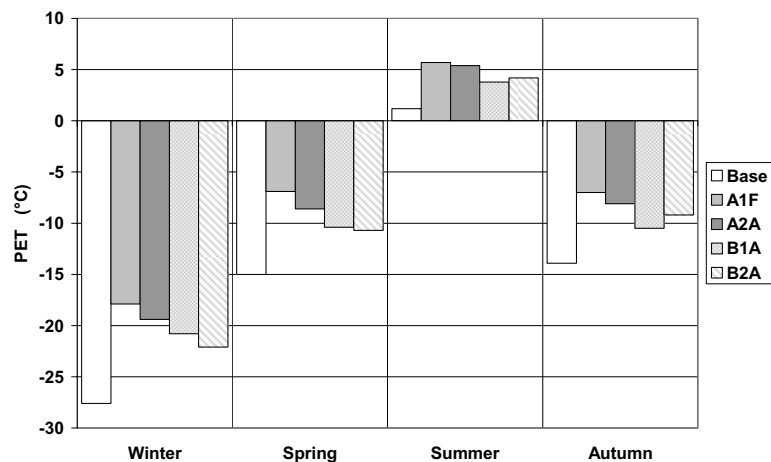

Fig. 5. – Minimum seasonal values of PET for Base and four IPCC-scenarios for 1960-1990 and 2070-2100 for Europe.
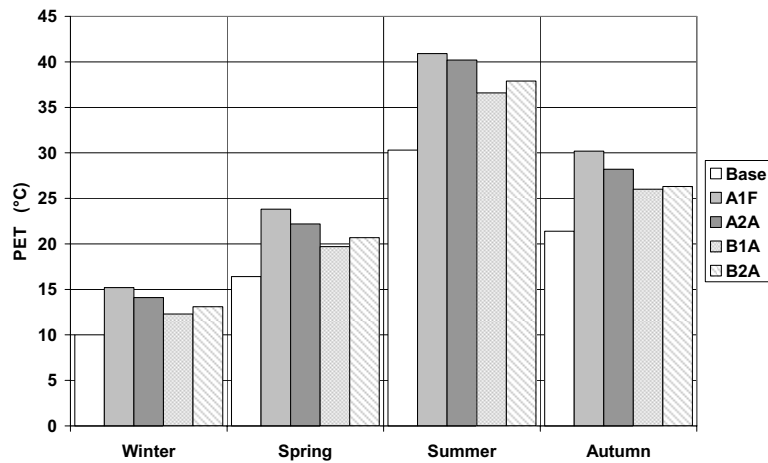
Fig. 6. – Maxima seasonal values of PET for based and four IPCC-scenarios for 1960-1990 and 2070-2100 for Italy.

data described in the methods section. Figures 4 and 5 represent the seasonal values of maxima and minima PET conditions for all Europe and the mentioned scenarios. The differences of PET in relation to the base conditions are, for the two A-scenarios, about $5\,°C$ higher than present for winter, which is equal in terms of range of thermal comfort. For spring and autumn, the increases are up to $8\,°C$ PET, and lying in the range between one and two thermal stress classes. For summer, the increase is similar in values as for spring and autumn. The highest values for the base are about $43\,°C$, and higher than $51\,°C$ PET for the A-scenarios. When more moderate scenarios are simulated, the increase is lying in the range of one thermal stress class for winter, spring and autumn and up to more than one thermal stress classes for the summer.
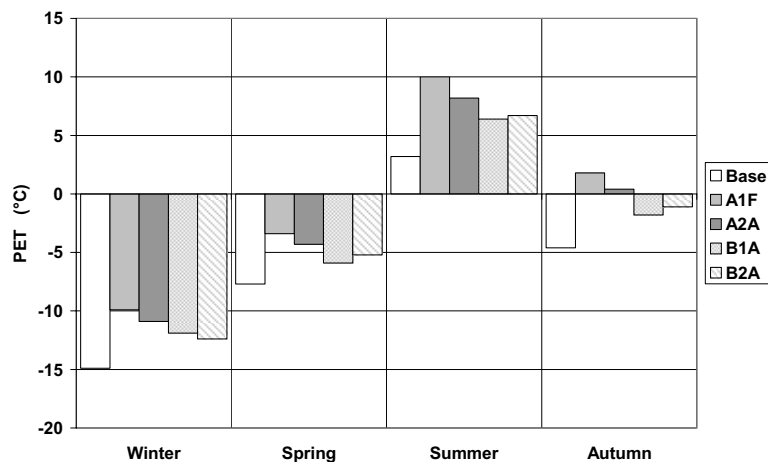

Fig. 7. – Minima seasonal values of PET for based and four IPCC-scenarios for 1960-1990 and 2070-2100 for Italy.

The seasonal conditions of PET for Italy are summarized in figs. 6 and 7. The highest present values in Italy occur in summer, with 30.3 PET and the lowest during winter −14.9 in the Alps area. So according to the mean monthly and seasonal values, Italy suffers are less than those of southern or western Mediterranean countries.

In this country, for the future climate conditions (2070-2100) based on the two A-scenarios, the conditions will be in the range of one and two thermal stress classes during winter, spring and autumn and about two and higher classes of thermal stress during summer. When compared to the eastern and western Mediterranean zones, the predicted increase of PET for summer in Italy is little lower. For the moderate scenarios in winter, the increase is quantified at one thermal comfort class and for summer the range of up to 1.5 classes of thermal stress.

From figs. 4 to 7, it can be expected that in summer more intense thermal stress in the coastal areas of the Mediterranean, Italy included, will occur. The expected thermal comfort and stress conditions will change, with a shifting of the thermal comfort conditions to northern areas and high-lying regions.

4. – Conclusion

The analysis of the thermal indicators on humans, when applied to the present climate conditions and to climate change may deliver information which can assist decision making on various levels, including health, tourism and regional planning. Changes in the overall bioclimatic conditions for humans (here PET has been used as an exhaustive indicator) are expected to be considerably greater than changes in air temperature alone.

In many regions of Europe and the Mediterranean sea, the projected climate change will produce more stressful bioclimatic conditions (the calculated PET values of more than 35 mean extremely hot conditions for Europeans) to people and will affect their health and well being, also changing tourism behaviour. Regions with PET $> 35\,°$C will increase when compared to those in the present bioclimatic conditions, and the possibility of heat waves will concomitantly grow, reflecting on tourists who will avoid these regions. In addition, the changed thermal conditions will presumably lead to higher energy consumption (and higher emissions of greenhouse gases) as a result of the increased need for cooling. These needs will set regional and local authorities under pressure, because of the increased energy demand and higher negative impacts due to climate.

The results presented in this paper have to be considered as preliminary. Additional analyses, based on daily data from regional models, able to describe in more details the climate conditions and predict the extreme events for sensible and vulnerable areas can be helpful in the development of adaptation strategies for tourism planning and protection of tourism facilities. Additional information can be strategic in the detection of extreme events, *i.e.* heat waves and possible mitigation strategies on the regional and urban planning level.

Nevertheless, the information and results in their current form are satisfactory in order to address towards the main climate impacts on human health, tourism management and planning at a regional scale level.

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