HEAT WAVES IN ATHENS

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Abstract

Heat waves and their impact on humans are analyzed using humanbiometeorological indices that are based on the energy balance of the human body. The implications for humans are not only described through the intensity of the heat wave, but also through their duration using consecutive days. Both intensity and duration were analyzed for the area of Athens for the period of time 1955 to 2001. The analysis was carried out using the daily physiologically equivalent temperature PET and the daily minimum air temperature. Based on these two parameters the results show an increase in the average duration of heat waves. Furthermore, the use of Gaussian filter allows the calculation of the inter-annual variation of the heat stress conditions and their relevance for humans. Based on SRES scenarios, the PET for the area of Athens was calculated. The results show that the future bioclimate conditions will be more strengthen severe, as thermal stress and air temperature will increases at a higher rate than expected.

Bioclimate, heat waves

1. Introduction

Heat waves, a phenomenon that is not only of interest for the scientific community, occur regularly in Greece and also in the Mediterranean and Western Europe. In the last three decades, the study of heat waves in Greece has been very popular using different methods of analysis. Synoptical, climatological and human-biometeorological methods have been applied (Giles et al. 1990, Giles and Balafoutis 1990, Matzarakis and Mayer 1991, Prezerakos 1989).

But, what is a heat wave and should it be quantified using meteorological parameters or information on the impacts only? There is no existing definition of heat waves by the World Meteorological Organization.

Heat Wave is understood as a period of abnormally and uncomfortably hot weather with high air humidity. Typically, a heat wave lasts two or more days.

Robinson (2001) describes a heat wave as an extended period of uncommon high atmosphere-related heat stress, which causes temporary modifications in lifestyle habits and adverse health related problems for affected residents and visitors. Thus, although a heat wave is a meteorological event, it cannot be assessed without reference to impacts on humans. An analysis of weather elements should always include the assessment of the human sensation of heat. Appropriate thresholds must be established for this combined analysis, considering both daytime high and overnight low temperature values. The thresholds should also relate to the usual climatic variability of the area as well as the duration of the heat wave and its consequences for humans.

A variety of heat stress indices that relate atmospheric conditions to human heat sensations have been developed so far. Driscoll (1985) lists 11 independent indices, and since then, Kalkstein and Valimont (1986) and Höppe (1999) have produced new ones. All thermal indices emphasize that the whole heat balance of the human body should be considered, which requires meteorological information about air temperature, air humidity, wind speed, turbulence, and short and long wave radiation in addition to the non meteorological components of fitness and activity level, clothing type, and physiologic adaptation to a particular environment.

The various indices combine individual components in a way that is appropriate for a particular meteorological application. For any long-term analysis of heat waves, an index that relies entirely on routine observations (synoptical or climatological) is desirable (Robinson 2001).

In this analysis we paid special attention to the daily physiologically equivalent temperature and the daily minimum air temperature in order to analyze and describe the heat waves in Athens. Furthermore, an attempt was made to describe the short time or inter annual adaptation of humans. It is known that the effect of thermoregulation is dominant in warm and hot conditions, while in cold conditions the behavioural regulation is more dominant (Khosla and Guntupallim 1999).

In addition, an approach using climate scenarios to obtain the thermal stress levels for the area of Athens has been applied to assess potential climate change and future bioclimate conditions.

2. Methods

The presented study uses daily data of the Hellinikon station for the period 1.1.1955 to 31.12.2001 in order to detect and quantify heat waves in Athens. Based on the climatic record of this station, relevant meteorological parameters have been included in the analysis. These are: mean, maximum and minimum air temperature, relative humidity, wind speed and cloud cover. In order to describe and quantify heat waves using a human-biometeorological approach, the thermal index physiologically equivalent temperature (PET) has been calculated and accessed (Höppe 1999, Matzarakis et al. 1999, 2000, Matzarakis and Rutz 2005). The analysis was not solely based on values, but also included the quantification of consecutive days of climatological and human-biometeorological parameters (Matzarakis and Mayer 1997).

Additionally, based on the climate data collation program at the Climatic Research Unit (New et al. 1999, 2000, 2002), maps of Athens were produced. The required data for the thermal bioclimate analysis -these are air temperature, relative humidity, sunshine and wind speed- are available at a monthly resolution for the climate period 1961 to 1990, while ten minute resolution for the specific area has been used for the PET analysis. The calculated PET grid values have been used as dependent variables. They have been recalculated into a higher spatial resolution (1 km) through the use of geo-statistical methods (independent variables were latitude, longitude and elevation). For this purpose, digital elevation data of the GLOBE data set (Hastings et al. 1999) were used.

To get an impression of the range of possible climate conditions that may be common by the end of this century, a range of scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) have been utilized. IPCC undertook an exploration of the possible changes in socio-economical conditions and population (IPCC 2000, 2001), which resulted in a range of plausible scenarios (known as the SRES scenarios). Based on these, GHG emissions and atmospheric concentrations of greenhouse gases could be estimated, which in turn have been used to explore the response of the climate system. Among the four main SRES scenarios, A1F and A2A represent cases of rapid climate change, while B1A and B2A represent rather moderate levels of change.

The dataset of future climatic conditions was based on an integration of the Hadley Centre's HadCM3 model, forced with the SRES emissions scenarios (Johns et al. 2003). The HadCM3 model produces gridded data at a spatial resolution of 2.5º latitude x 3.75º longitude, which is significantly coarser than that of the CRU 1.0 dataset. The used HadCM3 dataset consists of monthly averages for four time slices: 1961-1990, 2010-2039, 2040-2069, and 2070-2099. All variables needed for the analysis were available from the CRU 1.0 and HadCM3 datasets or could be calculated from them. The analyses have been carried out for two seasons and two time slices (i.e. intervals). The time segments represent seasons consisting of the combined months of December, January, and February, and the combined months of June, July, and August, coinciding with the winter and summer seasons in the northern hemisphere and in the southern hemisphere respectively. For the northern hemisphere, spring consists of the combined months March, April and May and autumn consists of September, October and November. The analysis has been carried out for the historical period 1961-1990 (CNTRL) and for the future period 2071-2100.

3. Results

3.1 Bioclimate diagram for Athens

For the PET-based analysis of the general bioclimate conditions, a bioclimate diagram, which includes ten days frequencies of the daily PET values for the period 1955 to 2001 was produced (Figure 1).

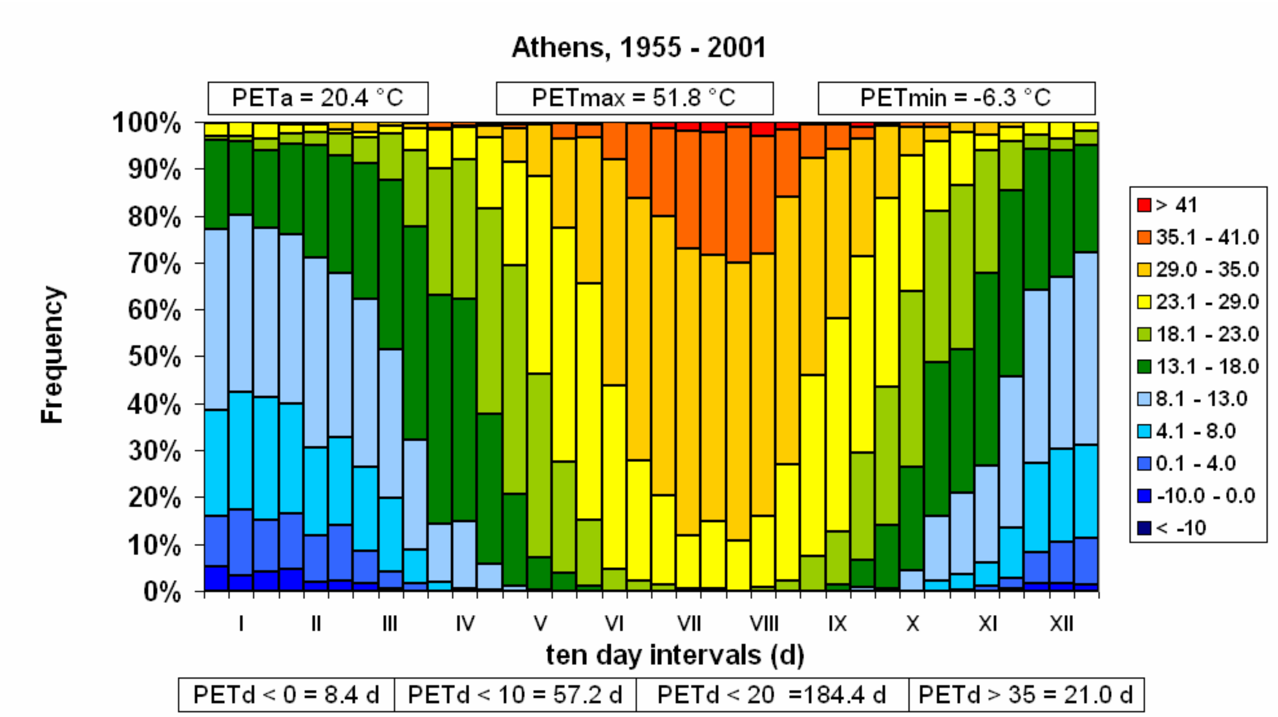

Figure 1. Bioclimate diagram for Athens for the period 1955 – 2001.

The thermal human-bioclimate conditions are expressed in percentages of the occurrence of classes for ten day intervals. Figure 1 depicts that 50 % of the days from the 8^{th} dekas (middle of March) to the 34^{th} dekas (end of November) are within the PET classes of 18 °C and above. It has to be mentioned that the results of Figure 1 are based on daily mean values for the meteorological variables. From the 7^{th} to 34^{th} dekas extreme thermal stress can also be observed for the study region. Additionally, the mean PET, the absolute maximum and minimum value and also the frequencies of cold days (days with PET < 10 °C), thermal comfort and slight stress days (days with PET between 15 and 25 °C) and heat stress days (days with PET > 35 °C) are presented in Figure 1. A good assessment of the general thermal bioclimatic regime is possible using this type of bioclimate diagram.

3.2 Consecutive days

In our study, we used consecutive days (three and more) in order to quantify the duration of heat waves and their impacts. For this purpose, we chose thresholds for PET and T_{amin}. From the variety of thresholds we selected the days with PET ≥ 35 °C, which describe conditions of extreme heat stress (Matzarakis et al. 1999) and T_{amin} ≥ 23 °C, which represents PET values of thermal neutrality. The T_{amin} has been used for the minimum conditions of a day

(Figures 2, 3). The amount of consecutive days and the duration of each episode (heat waves) for PET ≥ 35 °C and T_{amin} ≥ 23 °C are also shown in the two figures. There is no clear picture for the number of consecutive days but an increasing trend of duration since the late 1980s of the 20th century in the PET and T_{amin} values.

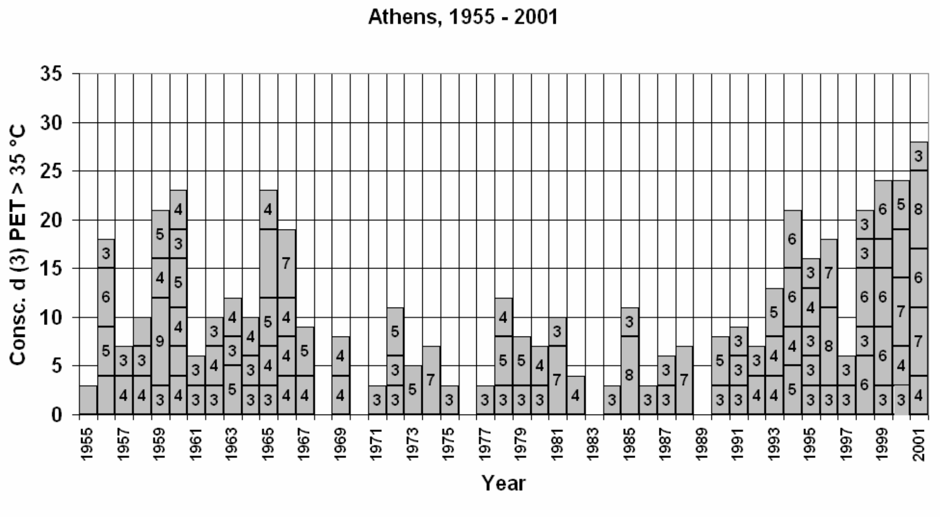

Figure 2. Consecutive number of days with PET ≥ 35 °C for Hellenikon/Athens, during the period 1955-2001. The number in the bars indicate the duration in days of each episode.

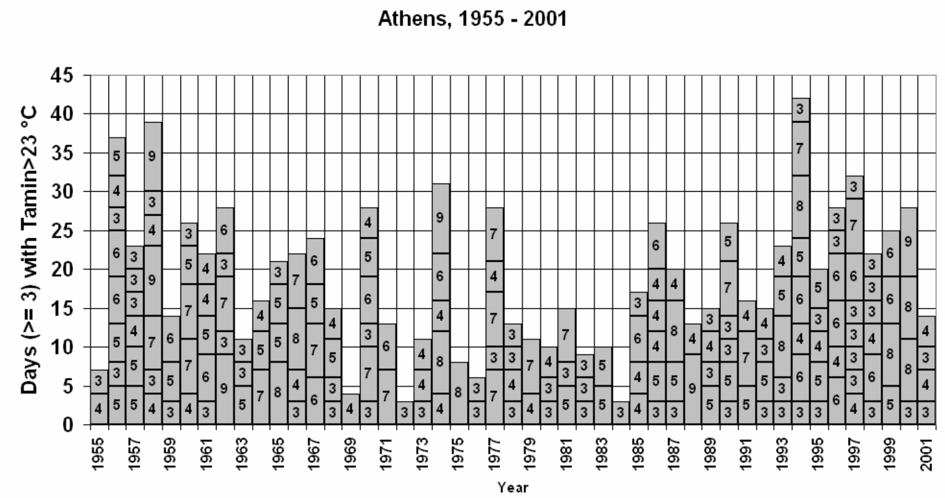

Figure 3. Consecutive number of days with T_{amin} ≥ 23 °C for Hellenikon/Athens, during the period 1955-2001. The number in the bars indicates the duration in days for each episode.

3.3 Inter annual thermal adaptation

The previous figures describe the thermal comfort and thermal stress conditions without considering the adaptation of humans. In order to quantify the short time or inter annual adaptation of humans to the thermal component of the climate, the following analysis was carried out. A two fold Gaussian filter of 41 days, which corresponds to a filter of 81 days was applied. This one side filter has 30 significant filter weights (Schönwiese 1992), which is in accordance of a time frame, where physiological changes are still active concerning the heat effect on humans. The 41 days filter represent the variable part (short time adaptation) the daily PET and daily T_{amin} values have been applied. The PET values represent the upper limit of the thermal perception and the daily minimum temperature the lower limit. The adapted values PET_a and T_{amina} have been calculated using the following formula. The formula expresses the constant part of thermal stress and a variable part which represents the short time thermal adaptation.

PET_a = limit + (PET_{41F} – limit)*1/3 with limit of PET=30 °C and PET=35 °C.
T_{amina} = limit + ($T_{amin41F}$ – limit)*1/3 with limit of T_{amin}=20 °C and T_{amin} = 23 °C.

where, PET_a is the PET value with short time adaptation, PET_{41F} is the PET with Gaussian filter and limit is the upper of the PET limit. T_{amina} is the T_{amin} value with short time adaptation, $T_{amin41F}$ the T_{amin} with Gaussian filter and limit the upper of the T_{amin} limit.

Figure 5 illustrates the inter annual variability of the daily PET values, the Gaussian filtered PET-values PET_{41F}, the PET_a for a limit of 35 °C (Heatwave35) and 30 °C (Heatwave33), for 1987 to 1989 in Hellinikon/Athens. The courses of Heatwave35 and Heatwave30 showed that there is a pattern, which describes the variability of the thermal adaptation. It can also be described as a memory of thermal perception or heat stress of humans.

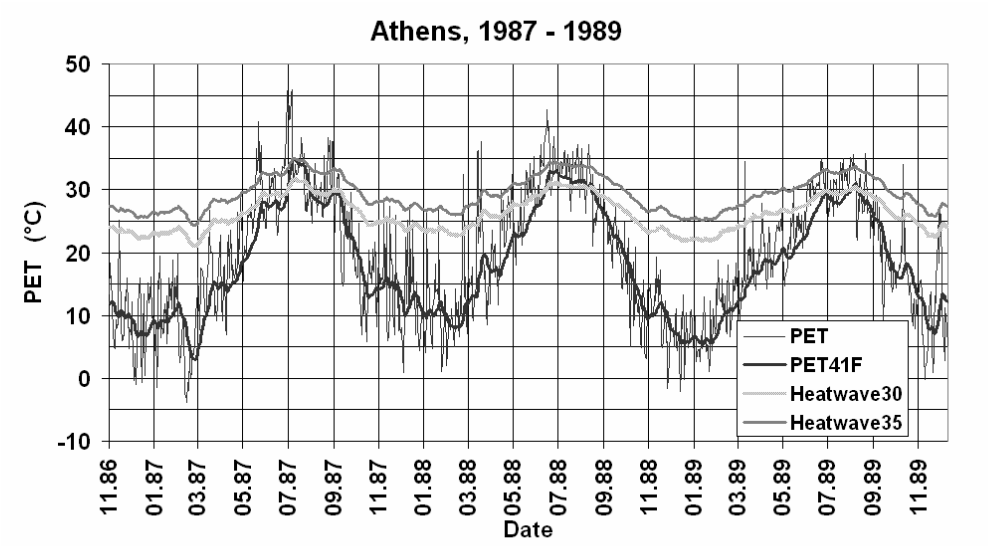

Figure 5. Inter annual variability of thermal adaptation based on PET for 1987 to 1989 in Athens.

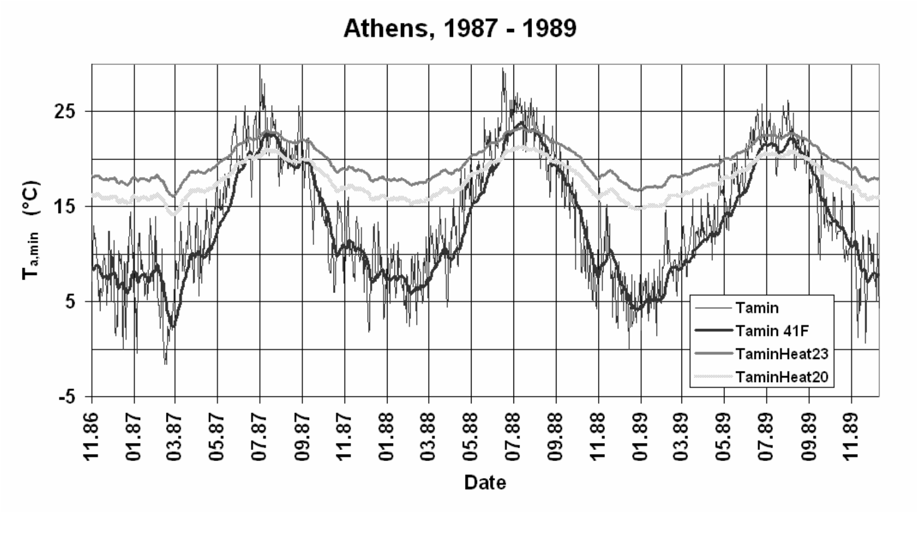

Figure 6. Inter annual variability of thermal adaptation based on minimum air temperature for 1987 to 1989 in Athens.

Besides, the inter annual variability of the daily T_{amin} values, the Gaussian filtered T_{amin}-values $T_{amin41F}$, the T_{amin} for a limit of 20 °C ($T_{aminHeat20}$)and 23 °C ($T_{aminHeat23}$) for 1987 to 1989 in Hellinikon/Athens are presented in Figure 6. The courses of $T_{aminHeat20}$ and $T_{aminHeat23}$ are similar to those of Heatwave35 and Heatwave30 of Figure 5.

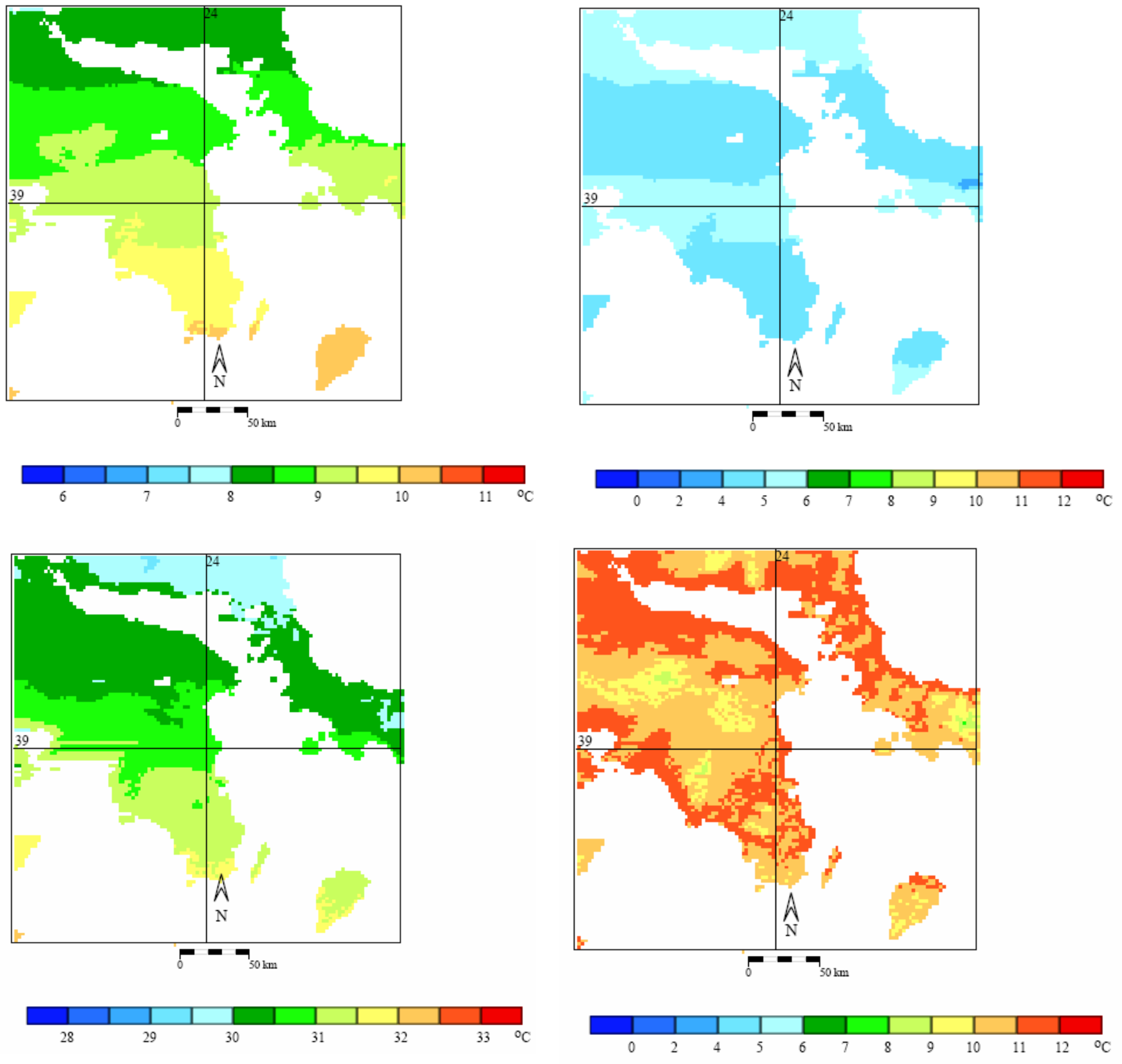

Figure 5. Seasonal maps for winter (upper left panel) and summer (bottom left panel) and the differences of PET between the A1F scenario for the time slice 2070 –2100 minus control period (1961 – 1990) for winter (upper right panel) and summer (bottom right panel).

3.4 Climate change and thermal bioclimate for Athens

Based on the IPCC SRES Scenarios (IPCC 2000), the PET values for the CLINO 1961 – 1990 and the period 2070 – 2100 have been calculated for expected future climate conditions. Figure 7 shows the winter (upper left) and summer (bottom left) spatial distribution for CNTRL conditions (1961 – 1990) of PET for the wider area of Athens in 1 km spatial resolution based on the Hastings et al. (1999) data. The upper and the bottom figure on the right side of Figure 5 show the differences of the A1F scenario minus the CNTRL conditions of the left side figures for winter and summer. It can be extracted that the thermal bioclimatic conditions are expected to change strongly based on the A1F scenario for summer, covering changes more than two to three stress levels for summer in the whole area, while in winter, the expected changes range between one and two stress levels.

4. Conclusions

In spite of the absence of a heat waves definition, several methods are appropriate for analyzing and quantifying them. Thus, the analysis of heat waves can be carried out focusing either on air masses and weather type approaches or on human-biometeorological methods. An analysis, however, should include mean conditions, extremes and frequencies for the quantification of the intensity and the duration. The analysis of consecutive days has provided valuable details of heat waves and explanations for time series.

Additionally, the thermal adaptation of humans can be included in both approaches using appropriate statistical methods i.e. Gausssian filters and human-biometeorological threshold values.

Based on climate models, the analysis of climate change indicated that heat stress conditions will occur much more frequently in the future, The question of mitigation and adaptation is of vital importance for the Mediterranean and especially for metropolitan areas, which are also suffering from urban climate related problems.

Adaptation will also lying on the meso and micro scale level of cities i.e. urban planning measures (green areas and air paths, roof greening and facade greening) and urban heat island reduction especially during the night time.

Finally, in a definition of heat waves, disciplines like meteorology, thermo-physiology, socio-ecology and medicine should be included. Existing heat warning systems do not consider specific local or regional information i.e. land use and local wind systems. Also little is known about the synergetic effects between extreme heat conditions, air pollution and other influencing environmental factors, like noise and UV.

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