RAYMAN: A TOOL FOR TOURISM AND APPLIED CLIMATOLOGY

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ABSTRACT The „RayMan" model presented here is developed to calculate short wave and long wave radiation fluxes that affect the human body. "RayMan" estimates the radiation fluxes and the effects of clouds on short and long wave radiation fluxes. The model, which takes complex building structures into account, is suitable for various planning purposes in different micro to regional levels. The final output of the model is the calculated mean radiant temperature, which is required in the human energy balance model and, thus, also for the assessment of thermal bioclimate. It is also relevant for thermal indices that facilitate the human-biometeorological assessment of the thermal component of the climate.

Additional features, which can be used for the evaluation of climate in a region or for diverse other applications, are: calculation of sunshine duration with or without sky view factors; estimation of daily mean, max or sum of global radiation; calculation of shade for existing or future complex environments. Here, several analyses for different scenarios, i.e. urban climatology and tourism climatology, and different locations (Freiburg and Athens) are presented.

KEYWORDS: *Tourism, applied climatology, radiation, thermal comfort*

INTRODUCTION

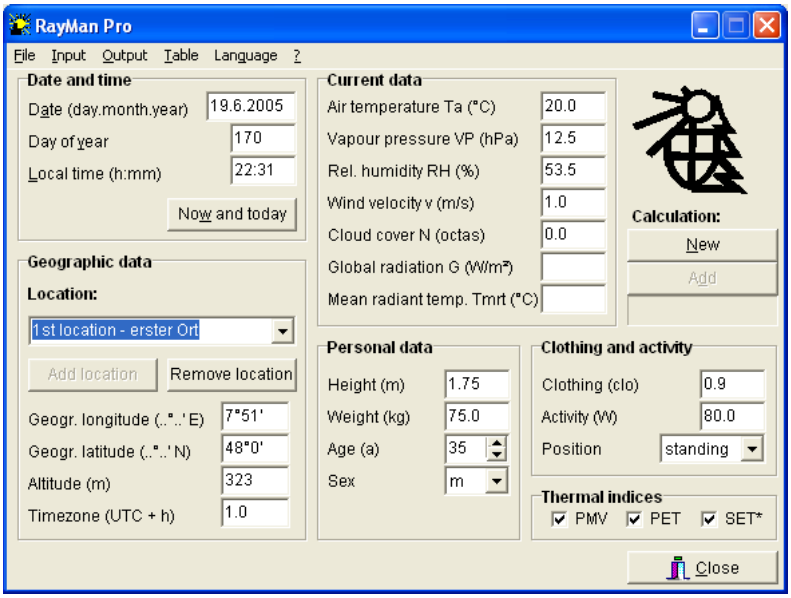
Many climatic parameters and conditions are affected in their temporal and spatial behaviour by the natural and artificial morphology on a meso- and micro scale. These effects are significant on different levels of regional and urban planning, i.e. the tourism industry and also the owners of holiday homes, but they are also of importance for the planning and design of tourism buildings, recreational facilities, urban parks, and a variety of other applications. With some modifications, existing methods for assessing climate in human biometeorology and applied climatology can be applied, a.e. to tourism climatology (Matzarakis, 2001, Matzarakis et al., 2004).

For example, thermal indices that are derived from the energy balance of the human body can be of great advantage for tourism and regional/urban planning. Standard climate data, such as air temperature, air humidity and wind speed, are needed to calculate and quantify thermal bioclimatic conditions (Höppe, 1999, Matzarakis et al., 2001). The most important environmental parameters used to derive modern thermal indices, however, are short and long wave radiation (and the derived mean radiant temperature). These can be determined using special techniques that have been implemented in several models. The RayMan model, which was developed for urban climate studies, has a broader use in applied climatology (Matzarakis et al., 2004). Further outputs, such as sunshine duration and shade, can assist in the design and planning of recreation areas and the design of urban structures.

METHODS AND DATA

The model „RayMan“ estimates the radiation fluxes and the effects of clouds and solid obstacles on short wave radiation fluxes (Fig. 1). The model, which takes complex structures into account, is suitable for utilization and planning purposes on a local and regional level (Fig. 2 left). The final output of this model is the calculated mean radiant temperature, which is required in the energy balance model of humans. Consequently, it is also required for the assessment of urban bioclimate and thermal indices, such as Predicted Mean Vote (PMV), Physiologically Equivalent Temperature (PET), and Standard Effective Temperature (SET*). The development of the model is based on the German VDI-Guidelines 3789, Part II: Environmental Meteorology, Interactions between Atmosphere and Surfaces; Calculation of the short- and long wave radiation and VDI-3787: Environmental Meteorology, Methods for the human-biometeorological evaluation of climate and air quality for the urban and regional planning at regional level. Part I: Climate (VDI, 1994, 1998). For the calculation of thermal indices based on the human energy balance, meteorological (air temperature, wind speed, air humidity and short and long wave radiation fluxes) and thermo-physiological (activity and clothing) data are required. Data on air temperature, humidity and wind speed are required to run RayMan (Matzarakis et al., 2000, 2007, Matzarakis and Rutz, 2005).

Additional features, which are included in the output of RayMan and that can be used for the evaluation of a region’s climate or the development of new tourism facilities, are: a) calculation of sunshine duration with or without sky view factor; b) estimation of daily mean, maximum or total global radiation; and c) determination of shaded areas.



Date and time
Date (day.month.year) 19.6.2005
Day of year 170
Local time (h:mm) 22:31

Geographic data
Location: 1st location - erster Ort
Geogr. longitude (..°..' E) 7°51'
Geogr. latitude (..°..' N) 48°0'
Altitude (m) 323
Timezone (UTC + h) 1.0

Current data
Air temperature Ta (°C) 20.0
Vapour pressure VP (hPa) 12.5
Rel. humidity RH (%) 53.5
Wind velocity v (m/s) 1.0
Cloud cover N (octas) 0.0
Global radiation G (W/m²)
Mean radiant temp. Tmrt (°C)

Personal data
Height (m) 1.75
Weight (kg) 75.0
Age (a) 35
Sex m

Clothing and activity
Clothing (clo) 0.9
Activity (W) 80.0
Position standing

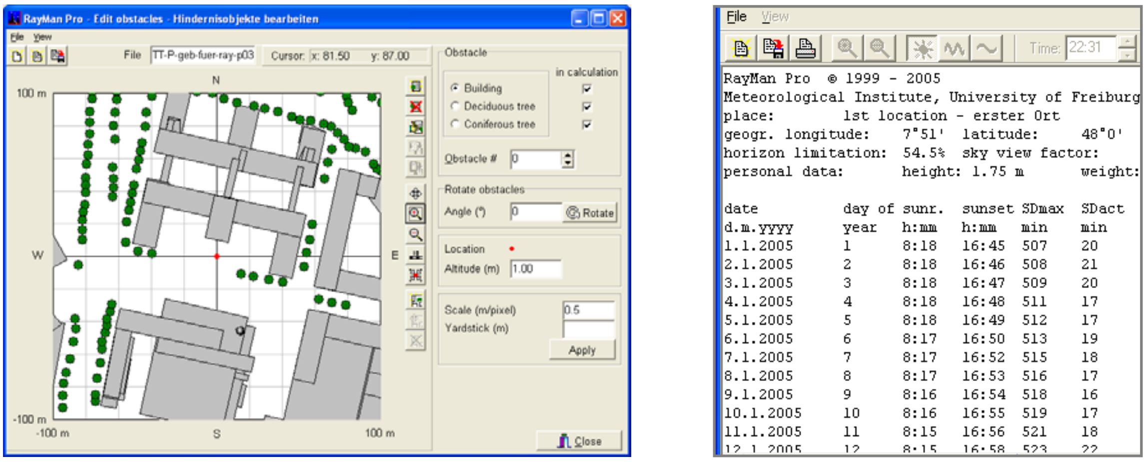
Thermal indices
☑ PMV ☑ PET ☑ SET*

Figure 1: Main window of RayMan

When using the computer software "RayMan" (Fig. 2, left) an input window for urban structures (buildings, deciduous and coniferous trees) appears. The opportunity of free drawing and output of the horizon (natural or artificial) are included for the estimation of sky view factors (Fig. 2, right). The implementation of fish-eye-photographs for the calculation of sky view factors is also possible. The amount of clouds covering the sky can be included by free drawing, while their impact on the radiation fluxes can be estimated (Matzarakis, 2001).

The most important question regarding radiation properties on a micro scale in the field of applied climatology and human-biometeorology is whether or not an object of interest is positioned in the shade. Hence, in the presented model, shading by artificial and natural obstacles is included.

Horizon information (in particular the Sky View Factor) is required to obtain sun paths (Fig. 3 left). Calculation of hourly, daily and monthly averages of sunshine duration, short wave and long wave radiation fluxes with or without topography, and obstacles in urban structures can be carried out with RayMan (Fig. 3, left). Data can be entered through manual input of meteorological data or pre-existing files. The output is given in form of graphs and text (Fig. 2 right, Fig. 3, left and right).



File: TT-P-geb-fuer-ray-p03
Cursor: x: 81.50 y: 87.00
● Building ☑
○ Deciduous tree ☑
○ Coniferous tree ☑
Obstacle #: 0
Angle (°): 0
Altitude (m): 1.00
Scale (m/pixel): 0.5
Yardstick (m):
Time: 22:31

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RayMan Pro  © 1999 - 2005
Meteorological Institute, University of Freiburg
place:         1st location - erster Ort
geogr. longitude:    7°51'  latitude:     48°0'
horizon limitation:  54.5%  sky view factor:
personal data:       height: 1.75 m       weight:

date          day of sunr.  sunset SDmax  SDact
d.m.yyyy      year   h:mm   h:mm   min    min
1.1.2005      1      8:18   16:45  507    20
2.1.2005      2      8:18   16:46  508    21
3.1.2005      3      8:18   16:47  509    20
4.1.2005      4      8:18   16:48  511    17
5.1.2005      5      8:18   16:49  512    17
6.1.2005      6      8:17   16:50  513    19
7.1.2005      7      8:17   16:52  515    18
8.1.2005      8      8:17   16:53  516    17
9.1.2005      9      8:16   16:54  518    16
10.1.2005     10     8:16   16:55  519    17
11.1.2005     11     8:15   16:56  521    18
12.1.2005     12     8:15   16:58  523    22
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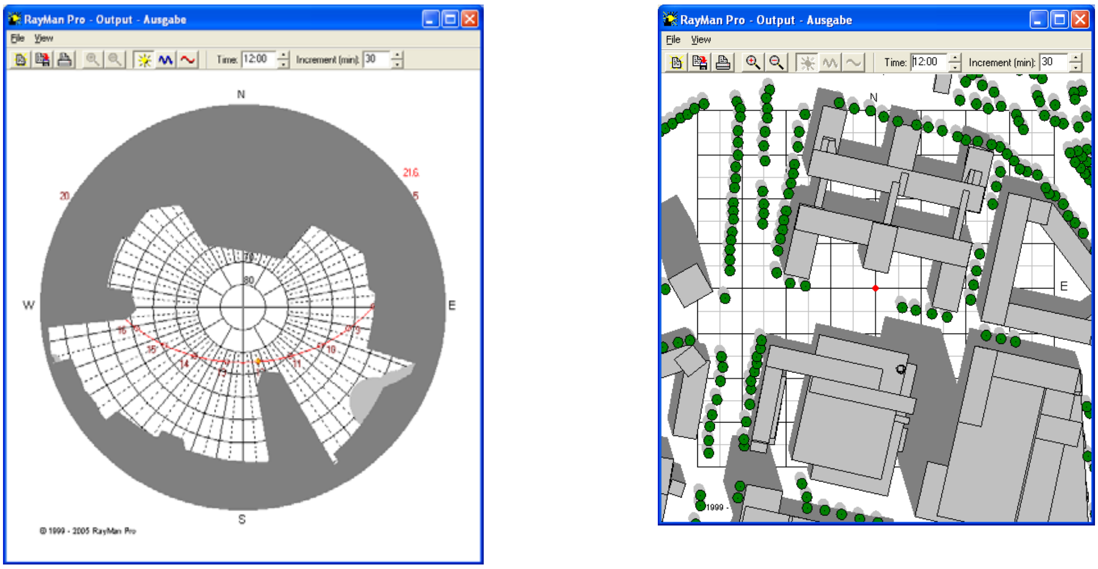
Figure 2: Window for buildings and vegetation input (left) and data output for SVF and sunshine duration in RayMan



Time: 12:00
Increment (min): 30

Figure 3: Example of sun path (left) and shade (right) on June 21 for a complex environment

RESULTS AND EXAMPLES

The RayMan model can be applied in various contexts. Results for radiation fluxes can even be produced without any meteorological or climatological data. Thus, it can also be used for the quantification of sunshine duration in a given location with and without limited horizon (Fig. 3). Results for mean or total monthly sunshine duration can easily be presented for a variety of environments (Tab. 1 based on the building and vegetation data from Fig. 2 and 3). The calculations for a potential building and vegetation morphology presented in Table 1 were carried out for Freiburg, Germany, in a latitude of 48° N and for Athens, Greece (Tab. 2), in a latitude of 38° N.

Table 1: Mean monthly daily sunshine duration without (Sdmax) and with horizon limitation (Sdmn), Sum of monthly sunshine hours without (Dsumax) and with (Dsumn) horizon limitation in h and the ratio between Dsumn and Dsumax for Freiburg, Germany, in a latitude of 48 °N . Urban morphologies (horizon limitations) are shown in Figure 2

Month	1	2	3	4	5	6	7	8	9	10	11	12
Sdmax (h)	8.9	10.2	11.9	13.7	15.2	16.0	15.6	14.3	12.6	10.9	9.3	8.5
Sdmn(h)	1.0	4.4	7.5	8.0	8.3	8.6	8.5	7.8	8.2	5.7	1.9	0.3
Dsumax (h)	276	286	369	410	471	479	484	443	378	337	279	262
Dsumn (h)	30	122	232	240	257	258	265	243	245	176	59	9
Ratio (%)	11.0	42.5	62.8	58.6	54.6	53.7	54.7	55.0	64.9	52.2	21.0	3.4

Table 2: Mean monthly daily sunshine duration without (Sdmax) and with horizon limitation (Sdmn), Sum of monthly sunshine hours without (Dsumax) and with (Dsumn) horizon limitation in h and the ratio between Dsumn and Dsumax for Athens, Greece, in a latitude of 38 °N. Urban morphologies (horizon limitations) are given in Figure 2

Month	1	2	3	4	5	6	7	8	9	10	11	12
Sdmax (h)	9.9	10.8	12.0	13.2	14.2	14.8	14.5	13.6	12.4	11.2	10.1	9.6
Sdmn(h)	4.3	6.1	8.4	8.2	8.1	8.2	8.1	8.2	8.3	7.1	5.1	3.3
Dsumax (h)	306	302	371	396	441	443	450	422	373	348	304	297
Dsumn (h)	134	171	261	245	252	246	252	255	250	219	154	103
Ratio (%)	43.8	56.7	70.3	61.9	57.1	55.5	56.1	60.4	66.8	63.1	50.5	34.7

Fig. 4 shows the trend of the Physiologically Equivalent Temperature (PET) based on daily data for Athens for the time period 1955 – 2001. The figure also shows calculations of PET for individual seasons, the whole year and the tourism period (April to October) based on monthly means.

Several scenarios were used to determine the meteorological parameters needed to predict PET values. Future climatic conditions cannot be predicted with any degree of certainty, as several unpredictable factors are involved. Future socio-economic and technological developments will mainly determine the amount of human-induced emissions of greenhouse gases. To get an impression of the range of possible climate conditions that may be common by the end of the century, a range of scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) were used. IPCC analysed the possible changes in socio-economic 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, the A1F and A2A represent cases of rapid climate change, while the B1A and B2A scenarios represent more moderate levels of change.

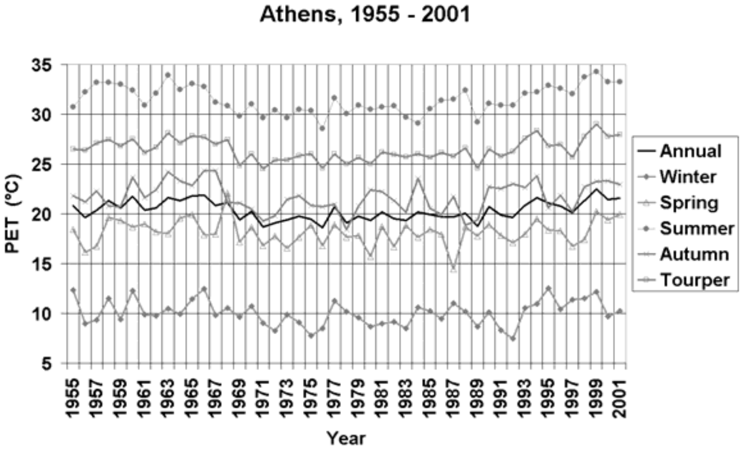


Figure 4: Seasonal, annual and tourism period (April to October) trend of PET for Athens, Greece for the period 1955-2001

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 with a spatial resolution of 2.5° latitude x 3.75° 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 were 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 the southern hemisphere respectively.

Table 3: Mean, maximum and minimum seasonal PET values for the Base, A1F and B2A scenarios for the area of Figure 5

		Winter	Spring	Summer	Autumn
Base	Max	12	20	32.4	23.8
	Min	-5.1	6.8	18.8	8.1
	Mean	3.9	14.2	26.8	16.7
A1F	Max	17.7	25.7	43.5	32.3
	Min	-0.7	11.4	30.8	16.1
	Mean	9.2	19.4	38.3	24.5
B2A	Max	14.8	23.5	40.3	28.7
	Min	-2.6	9.9	26.9	12.5
	Mean	6.7	17.5	34.8	21.3

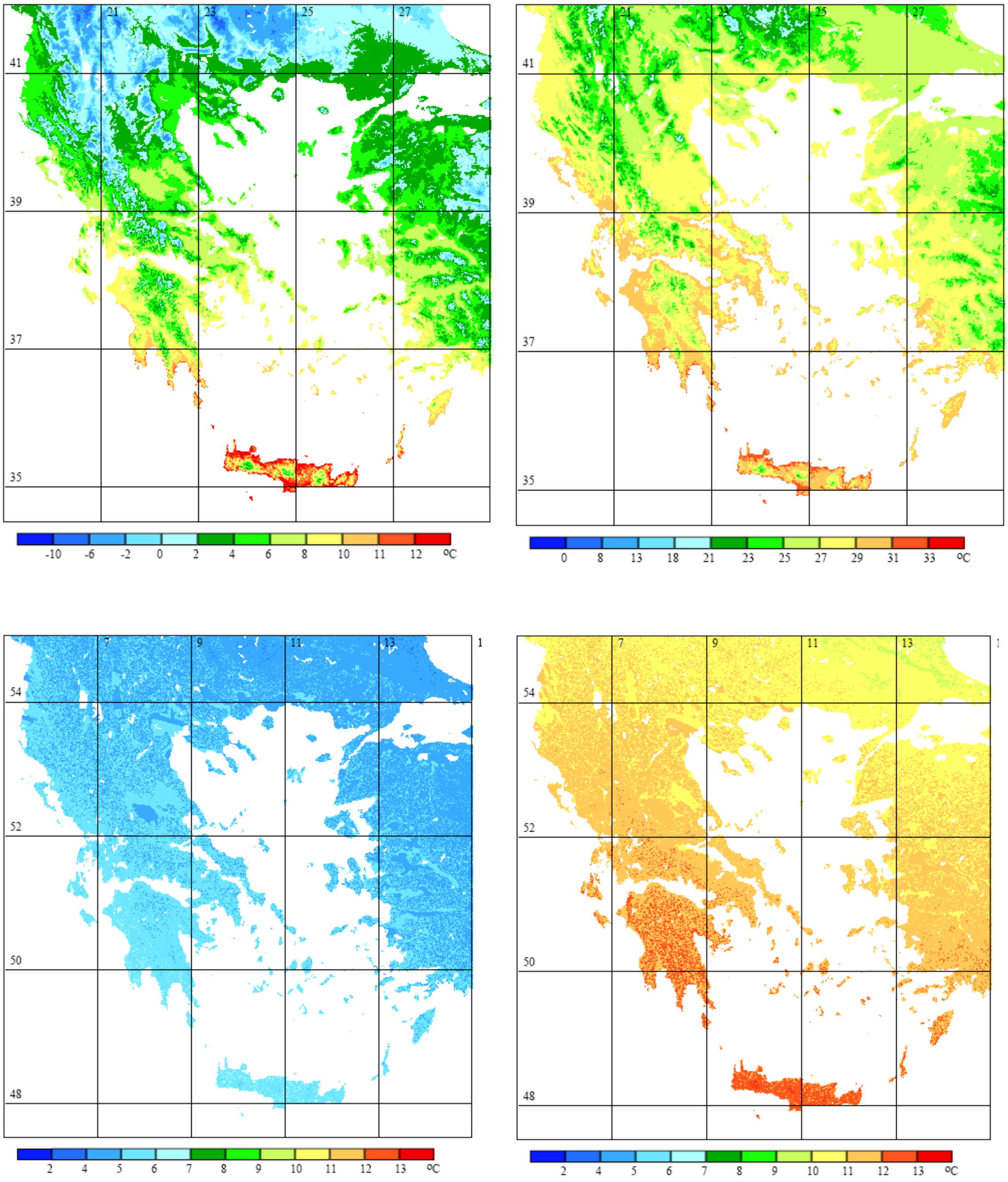


Figure 5: Seasonal maps for winter (upper left panel) and summer (upper right panel) and the differences of PET between the A1F scenario for the time slice 2070 –2100 minus control period (1961 – 1990) for winter (bottom left panel) and summer (bottom right panel)

For the northern hemisphere spring is represented through the combined months of March, April and May and autumn is represented through September, October and November. The analysis was carried out for the historical period 1961-1990 (CNTRL) and for the future period 2071-2100. The PET data was 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 the digital elevation data of the GLOBE datasets (Hastings et al., 1999) built the basis.

In Table 3 the maximum, mean and minimum values of PET for the seasons in the geographical area are presented. The mean values for the CNTRL conditions are 6.3 °C lower for winter and for 12.5 °C lower for the summer months. For spring and autumn the differences are 5.2 °C and 7.8 °C, respectively. For the B2A scenario the differences are lower and range between 3.8 °C for winter, 8.2 °C for summer, 3.3 °C for spring and 4.6 °C for autumn.

Figure 5 shows the geographical distribution for CNTRL conditions (1961 – 1990) of PET for the area of longitude between 19° and 29° E and latitude between 34.5° and 42 °N for winter (upper left) and summer (bottom left). The upper and 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. From Table 4 and Figure 5 it can be extracted that the thermal bioclimatic conditions are expected to change drastically based on the A1F scenario. For summer covering changes more than three stress levels in the southern part of the study area and less than two levels for the northern part of the area. For winter the expected changes are ranging between one and two stress levels in the south and one in the northern parts.

CONCLUSIONS

The presented model provides diverse opportunities for research in applied climatology and also for education. Radiation fluxes, as well as thermal indices for simple and complex environments can be estimated with readily available climate or meteorological data, such as air temperature, air humidity, and wind speed. Additional information about clouds and global radiation included into the model can built the basis for a more appropriate estimation of radiation fluxes. Useful information an a higher level of detail can be derived in order to create climate-oriented dwellings and facilities for tourism resorts and urban planning. It can also be used for the calculation of shade to be provided by special devices in tourism areas and resorts in order to create more comfortable thermal conditions with protection from direct sunlight for tourists and visitors.

From a human-biometeorological point of view the presented thermal indices can describe and quantify not only mean conditions but also extremes like heat waves and other climate and health issues.

In order to quantify bioclimate conditions for future scenarios, the model can produce information through the use of global and regional climate model outputs. Through the use of geo-statistical techniques and tools, the data can be regionalized and provide more detailed information on the spatial conditions of present and future climate conditions. Through the implementation of different land use patterns and their surface properties, a more appropriate and realistic picture can be created.

When used for education purposes, the model can be applied in exercises as to how to operate these models and in what way land and urban morphology influences short and long wave radiation fluxes in simple and complex environments. Additionally, it can be used for the comparison between experimental and modelling studies in teaching.

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