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Collaborative Project

CLIM-RUN

Climate Local Information in the Mediterranean region Responding to User Needs

WP 3 – Observational support and downscaling methods
Task 3.4 Downscaling methods and portal

Deliverable 3.4: Transfer functions

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1. Introduction to transfer functions

Many stakeholders request local climate information to assess the relationships between climate forcing and impacts on ecosystems in different sectors. The term 'transfer function' within the CLIMRUN project refers to functions, mathematical equations or relations that link pure meteorological and climatic variables with impacts on activity sectors. As such they can be seen as simple impact models for several economic sectors and activities such as tourism, human comfort, fire risk and energy demand. Other definitions for transfer functions, for example in relation to proxy reconstructions and downscaling, also exist, but in CLIMRUN the above definition has been used to describe the use of transfer functions.

Throughout the CLIMRUN project, transfer functions have been widely used. As an example we refer to the use of transfer functions for fire and apparent temperature in Deliverable 3.5. In this deliverable, a fire weather index (FWI) was used as transfer function for fire risk (extensively analysed in the present deliverable, too) and physiological equivalent temperature (PET) as transfer function for apparent temperature. Additionally, in Deliverable 4.5, the potential economic cost of fires in Spain and Greece is estimated using linear regression between FWI and annual burned area with the final aim to calculate average annual reconstruction costs (based on damage level, restoration cost, restoration period and discount rate. Moreover, the concept of heating and cooling degree days (also described in detail here) has been used as transfer function for energy demand in Deliverable 3.7 dealing with extremes. Finally, transfer functions for tourism have been used in Deliverable 5.2 where the tourism climatic index (TCI) has been used to assess the climate suitability for tourists during the bathing season. This index is fairly similar to the more standard TCI and BCI indices described in this deliverable.

The sections that follow describe first in detail the theory and the physics behind the transfer functions used for tourism, human comfort, fire risk and energy demand and then present an application of these transfer functions for the case study of Cyprus. The reader is referred to the deliverables mentioned above for applications of the transfer functions to other regions in the Mediterranean.

2. Transfer functions for tourism

To explore the impacts of projected climate change on tourism, both the "Tourism Climate Index" (TCI) and "Beach Climate Index" (BCI) have been used.

2.1. *TCI*

The tourism climatic index as a concept has evolved from more general knowledge about the influence of climatic conditions on the physical wellbeing of humans. In the 1960s and 1970s systematic research in this field yielded many insights, ranging from preferred temperatures and the role of relative humidity to the appreciation of wind effects. It should be noted that the appreciation of climatic conditions is also dependent on a host of non-climatic factors, such as the level of activity, clothing, and genetic setup.

Mieczkowski (1985) was among the first to apply the general findings about human comfort to the specific activities related to recreation and tourism. He devised a tourism climatic index consisting of five sub-indices, describing daytime thermal comfort, daily thermal comfort, precipitation,

hours of sunshine, and wind speed. The mapping of raw data to sub-index values depends on the kind and level of tourist activity. Beach holidays require climatic conditions different from ski holidays; in his article, light activities, such as touring, are used as a reference. The five sub-indices and their relative contribution to the TCI are outlined in Table 2-1.
The thermal comfort sub-indices are based on effective temperature, which is a measure of temperature that takes the effect of relative humidity into account. According to the latest bio-meteorological literature, both short and long wave radiation are essential for deriving modern thermal indices (Matzarakis, 2001a, 2001b; Skinner & De Dear, 2001). Information on these environmental parameters is, however, not generally available in observed climate datasets. The wind sub-index combines information about wind speed and temperature. The other sub-indices are based on single variables and reflect either the empirical findings of physiological research or qualitative assessments of tourist preferences, for example in relation to precipitation. A standardized rating system, ranging from 5 (optimal) to 0 (extremely unfavourable), was devised to provide a common basis of measurement for each of the sub-indices. Mieczkowski (1985) proposed the following equation for calculating the TCI for outdoor recreational activities:

$$\mathrm{TCI} = 8\mathrm{CID} + 2\mathrm{CIA} + 4\mathrm{R} + 4\mathrm{S} + 2\mathrm{W}$$

Where:
CID = daytime comfort index

CIA = daily comfort index

R = precipitation index

S = sunshine index

W = wind speed index

The weights used in the equation are ultimately subjective, although they do have a basis in scientific knowledge. In the equation proposed by Mieczkowski (1985), the highest weight is given to the daytime comfort index to reflect the fact that tourists are generally most active during the day. The amount of sunshine and the amount of precipitation are given the second-highest weights, followed by daily thermal comfort and wind speed. Tables 2-2 & 2-3 summarize the TCI weighting scheme. After summing the weighted individual components, the result is multiplied by two, so that a TCI maximum score of 100 is reached.

Table 2-1: Sub-indices within the tourism climate index.

Sub- Index	Daily Variables	Climate Influence on TCI	Weighting in TCI
Daytime Comfort Index (CID)	Maximum daily temperature & minimum daily relative humidity	Represents thermal comfort when maximum activity occurs	40%
Daily Comfort Index (CIA)	Mean daily temperature and relative humidity	Represents thermal comfort over the full 24h period (including sleeping hours)	10%
Precipitation	Total precipitation	Reflects the negative impact that	20%

(P)		this element has on outdoor activities	
Sunshine (S)	Total hours of sunshine	Rated as positive for tourism-but can be negative because of the risk of sunburn and added discomfort on hot days	20%
Wind (W)	Average wind speed	Variable effect depending on temperature (evaporative cooling effect in hot climates rated positively, while "wind chill" in cold climates rated negatively)	10%

Table 2-2: TCI Weighting Scheme for Effective Temperature, Precipitation and Sunshine.

Rating	Effective Temperature (°C)	Precipitation (mm)	Sunshine (hrs)
5.0	20-27	0.0-14.9	10h or more
4.5	19-20 27-28	15.0-29.9	9h-9h59min
4.0	18-19 28-29	30.0-44.9	8h-8h59min
3.5	17-18 29-30	45.0-59.9	7h-7h59min
3.0	15-17 30-31	60.0-74.9	6h-6h59min
2.5	10-15 31-32	75.0-89.9	5h-5h59min
2.0	5-10 32-33	90.0-104.9	4h-4h59min
1.5	0-5 33-34	105.0-119.9	3h-3h59min
1.0	-5-0 34-35	120.0-134.9	2h-2h59min
0.5	35-36	135.0-149.9	1h-1h59min
0.0	-10- -5	150.0 or more	<1h

Mieczkowski (1985) proposed a classification of TCI scores, with values in excess of 60 corresponding to "good" conditions, scores exceeding 70 representing "very good" climatic conditions, levels of over 80 corresponding to "excellent" conditions, and scores of 90 or more standing for "ideal" circumstances. The detailed classification scheme of TCI is outlined in Table 2-4.

Table 2-3: TCI Weighting Scheme for Wind Speed.

km/h	Beaufort scale	Normal System	Trade Wind System	Hot Climate System
<2.88	1	5.0	2.0	2.0
2.88-5.75	2	4.5	2.5	1.5
5.76-9.03	2	4.0	3.0	1.0
9.04-12.23	2	3.5	4.0	0.5
12.24-19.79	3	3.0	5.0	0
19.80-24.29	4	2.5	4.0	0
24.30-28.79	4	2.0	3.0	0
28.80-38.52	5	1.0	2.0	0
>38.52	6	0	0	0

Table 2-4: Classification of TCI score.

Numeric value of index	Description of comfort level for tourism activity
90-100	Ideal
80-89	Excellent
70-79	Very Good
60-69	Good
50-59	Acceptable
40-49	Marginal
30-39	Unfavorable
20-29	Very Unfavorable
10-19	Extremely Unfavorable
<9	Impossible

2.2.*BCI*

Based on the work by Mieczkowski (1985), Morgan et al. (2000) developed a user-based climate index to assess the climate suitability of coastal destinations specific for beach recreation. Similar to Mieczkowski's TCI, Morgan et al.'s beach climate index (BCI) is made up of smaller components (sub-indices) that, after weighting, add up to a maximum score of 100 (ideal conditions). The weights are based on the importance that the beach users attached to each of the four components.

The resulting equation is as follows:

$$\mathrm{BCI} = 0.18\mathrm{TS} + 0.29\mathrm{P} + 0.26\mathrm{W} + 0.27\mathrm{S}$$

where BCI is the beach climate index, TS, P, W, and S are the components of thermal sensation, precipitation, wind, and sunshine, respectively. Each of the four components is itself represented by an index, with values ranging from 0 to 100. These values are the beach users' evaluation of the underlying weather conditions. The four sub-indices and their relative contribution to the BCI are outlined in Table 2-5. In the equation proposed by Morgan, the highest weight is given to the precipitation index to reflect the negative impact that this element has on outdoor activities. Wind speed and the amount of sunshine are given the second-highest weights, followed by thermal sensation. Tables 2-6, 2-7 & 2-8 summarize the BCI weighting scheme. After summing the weighted individual components, the result is multiplied by two, so that a TCI maximum score of 100 is reached.

Table 2-5: Sub-indices within the beach climate index.

Sub- Index	Daily Variables	Climate Influence on BCI	Weighting in BCI
Thermal Sensation (Ts)	Maximum daily temperature, minimum daily relative humidity, proportion of daylight hours in which there is sunshine & wind speed	Represents beach users' preferred thermal sensation	18%
Precipitation (P)	Total precipitation	Reflects the negative impact that this element has on outdoor activities	29%
Sunshine (S)	Total hours of sunshine	Rated as positive for tourism- but can be negative because of the risk of sunburn and added discomfort on hot days	26%
Wind (W)	Average wind speed	Occurrence of high wind on beaches can cause annoyance in terms of disruption of personal belongings (so that they have to be secured or weighted down) and indirect effects of blowing sand	27%

Table 2-6: BCI Weighting Scheme for Thermal Sensation.

Rating	Effective Temperature (°C)
100	32.5-34.4
77	34.5–35.4
39	29.0–32.4
24	35.5–36.4
21	26.0–28.9
2	21.0–25.9

Table 2-7: BCI Weighting Scheme for Precipitation, Sunshine and Wind.

Rating	Precipitation (mm)	Sunshine (hrs)
100	<15	10h or more
90	15-30	9h-9h59min
80	30-45	8h-8h59min
70	45-60	7h-7h59min
60	60-75	6h-6h59min
50	75-90	5h-5h59min
40	90-105	4h-4h59min
30	105-120	3h-3h59min
20	120-135	2h-2h59min
10	135-150	1h-1h59min
0.0	>150	<1h

Table 2-8: BCI Weighting Scheme for Wind Speed.

Rating	Wind Speed (m/s)
100	> 4
50	4–6
0	> 6

The final Beach Climate Index (BCI) can attain values ranging from 0 to 100. Morgan et al. (2000) divides this range as suggested by Mieczkowski (1985), with values below 40 seen as unfavourable, the range between 40 and 60 as acceptable, values from 60 to 70 as good, between 70 and 80 as very good, and scores above 80 as excellent for beach tourism (Table 2-9).

Table 2-9: Classification of BCI score.

Numeric value of Index	Description of comfort level for beach activity
> 80	Excellent
70-80	Very Good
60-70	Good
40-60	Acceptable
< 40	Unfavourable

3. Transfer functions for human comfort

To further examine the potential negative impacts of climate warming on human life in Cyprus, the humidity index (Humidex) (Masterton and Richardson, 1979) - a parameter employed to express the temperature perceived by people - has also been examined.

Humidex is applied in summer and generally warm periods and describes the temperature felt by an individual exposed to heat and humidity. More specifically, the humidex parameter (in °C) is calculated by the following equation:

$$T\,(h) = Tmax \;+\; {}^{5}/_{9} \times (e - 10)\,,$$

Where *e* is the vapour pressure:

$$e = 6.112 \times 10^{\left(7.5 \times {}^{Tmax}/_{(237.7\, + Tmax)}\right)} \times {}^{h}/_{100}$$

Tmax is the maximum 2m air temperature (°C) and *h* is the humidity (%).

Furthermore, 6 classes of humidex ranges are established to inform the general public for discomfort conditions:

- <29°C comfortable
- 30–34°C some discomfort
- 35–39°C discomfort; avoid intense exertion
- 40–45°C great discomfort; avoid exertion
- 46–53°C significant danger; avoid any activity
- >54°C imminent danger; heat stroke.

4. Transfer functions for fire risk

The FWI model is non-dimensional, based on physical processes and has been used at several locations, including the Mediterranean basin (Viegas et al., 2004; Moriondo et al., 2006, Carvalho et al., 2008; Dimitrakopoulos et al., 2011; Giannakopoulos et al., 2012); actually, since 2007 the FWI has been adopted at the EU level by the European Forest Fire Information System (EFFIS) of the Joint Research Centre of the European Commission (http://forest.jrc.ec.europa.eu/effis). This was done following a test phase of 5 years, during which different fire danger methods were implemented in parallel by EFFIS, until the FWI was selected as the method to assess the fire danger level in a harmonized way throughout Europe.

Table 4-1: FWI classes used by EFFIS

Fire Danger Classes	FWI ranges (upper bound excluded)
Very low	< 5.2
Low	5.2 - 11.2
Moderate	11.2 - 21.3
High	21.3 - 38.0
Very high	38.0 - 50.0
Extreme	>= 50.0

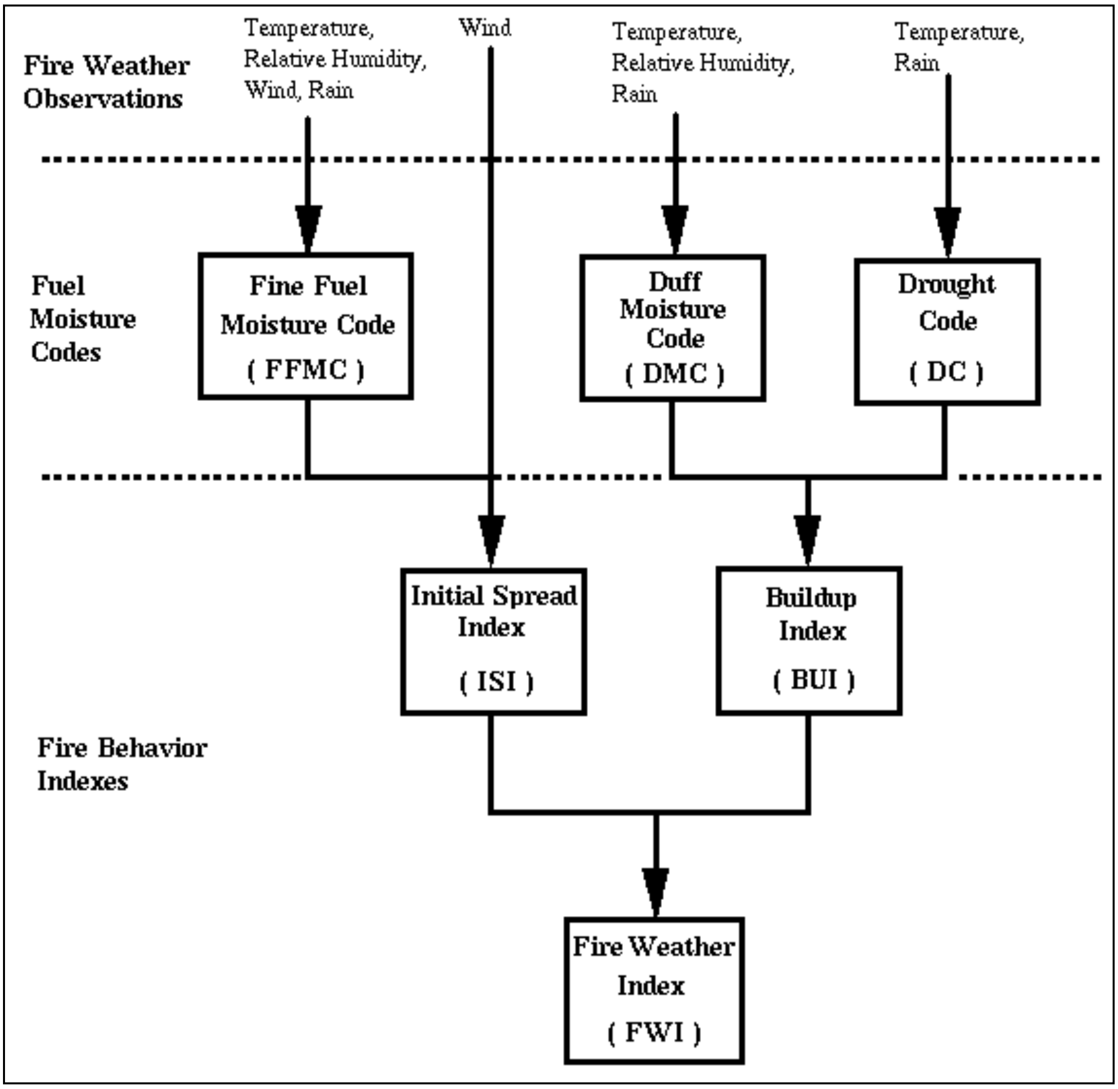
The Canadian Forest Fire Danger Rating System (CFFDRS) was formed by the analysis of field data of three kinds: weather, fuel moisture and test fire behaviour, all collected over several decades (Simard and Main, 1982). The FWI System (van Wagner, 1987) was the first subsystem developed in the CFFDRS and it provides numerical ratings of relative fire potential based solely on weather observations.

FWI is a daily meteorologically-based index used worldwide to estimate fire danger in a generalized fuel type. The FWI System provides numerical ratings of relative fire potential based solely on weather observations. The meteorological inputs to the FWI System are daily noon values of temperature, relative air humidity, 10m wind speed and precipitation during the previous 24 hours and are described in detail in van Wagner (1987).

The FWI system consists of six standard components each measuring a different aspect of fire danger.

The first three primary sub-indices are fuel moisture codes and are numerical ratings of the moisture content of litter and other fine fuels (FFMC), the average moisture content of loosely compacted organic layers of moderate depth (DMC) and the average moisture content of deep, compact organic layers (DC). Moisture code values for the current day are calculated from the day's observed weather and the previous day's fuel moisture code values.

The two intermediate sub-indices (ISI, BUI) are fire behaviour indices. The Initial Spread Index (ISI) is a numerical rating of the expected fire rate of spread. It combines the effect of wind and FFMC on rate of spread without the influence of variable quantities of fuel. The Buildup Index (BUI) is a numerical rating of the total amount of fuel available for combustion that combines the DMC and the DC. The resulting index is the Fire Weather Index (FWI) which combines ISI and BUI. FWI represents the frontal fire intensity and is used to estimate the difficulty of fire control.



The index is divided into the following standard categories that need to be recalibrated for different ecosystems at various geographical locations:

- FWI = 0 – 7 : low
- FWI = 8 – 16 : moderate
- FWI = 17 – 31 : high
- FWI = > 32 : extreme

5. Transfer functions for energy

Energy demand is linked to climatic conditions (Giannakopoulos and Psiloglou, 2006) and the relationship of energy demand and temperature is non-linear. The variability of ambient air temperature is closely linked to energy consumption, whose maximum values correlate with the extreme values of air temperature (maximum or minimum). In the Mediterranean region, during January, the maximum values of energy consumption are related to the appearance of the lowest temperatures. During the transient season of March–April, energy consumption levels are kept nearly constant until about May, while air temperatures are constantly rising. From mid-May onwards, and throughout the summer period, any increase in air temperature corresponds to an

increase in energy consumption mainly due to the extensive use of air conditioning systems. An exception is found for August when most local people tend to take their summer holidays, and hence the demand for air conditioning is reduced especially in large Mediterranean cities. Another transient period exists during September and October where energy demand and consumption are kept at constant levels. This transient period is followed by a period of continually increasing energy demand with a peak before the Holiday Season. Therefore, it is anticipated that warmer climate conditions will lead to decreased demand in winter, while increased demand should be typical during summer time (Valor et al., 2001; Giannakopoulos and Psiloglou, 2006). Moreover, the effect of higher temperatures in summer is likely to be considerably larger on peak energy demand than on net demand, suggesting that there will be a need to install additional generating capacity over and above that needed to cater for underlying economic growth.

Since the energy–temperature relationship is non-linear and has two branches, it would be more convenient to separate these two branches. The easiest way to achieve this is to use the idea of Degree-Day, which is defined as the difference of mean daily temperature from a base temperature. Base temperature should be the temperature where energy consumption is at its minimum. If this temperature is chosen, then the degree-day index is positive in the summer branch and negative in the winter branch. Instead of having both positive and negative values for this index, the definition of two indices is used: heating (HDD) and cooling degree days (CDD).

For the calculation of the HDD and CDD indices, the following equations were used:

$$\text{HDD} = \max(T^* - T, 0)$$

$$\text{CDD} = \max(T - T^{**}, 0)$$

where T^* and T^{**} are the base temperatures for HDD and CDD respectively, which can be either the same or different and T is the mean daily temperature.

HDD (CDD) is a measure of the severity of winter (summer) conditions in terms of the outdoor dry-bulb air temperature, an indication of the sensible heating (cooling) requirements for the particular location. Kadioğlu et al. (2001) used different base levels of 15°C and 24°C for the calculations of HDD and CDD respectively in Turkey. In our study we used 15°C for the calculation of HDDs and 25°C for the calculation of CDDs.

6. Applications of transfer functions – the case study of Cyprus

The ensemble mean of six RCM datasets, after availability of the appropriate data was secured, was used in order to calculate the aforementioned indices for the present day conditions (1961-1990). These regional climate models were developed within the framework of the ENSEMBLES project. All model fields are interpolated to a 25km horizontal grid. A brief description of the models follows:

(1) The first model 'C4IRCA3' is provided by the Community Climate Change Consortium for Ireland (C4I). This is based on the third version of the Rossby Centre regional Atmospheric Climate model (RCA3) driven by the HadCM3Q16 high-sensitivity simulation (Kjellström et al., 2005, Jones et al., 2004).
(2) The second RCM used 'CNRM-RM4.5' is the ALADIN-Climate which is developed at Météo-France/CNRM (Centre National de Recherches Météorologiques) and it is described in Déqué and Somot (2007) and Radu et al. (2008).

(3) The third model 'KNMI-RACMO2', used in this work, was provided by the Royal Netherlands Meteorological Institute (KNMI). The KNMI regional climate model RACMO2 (Lenderink et al., 2003; van den Hurk et al., 2006) is forced with output from a transient run conducted with the ECHAM5 GCM.

(4) The fourth model 'METNOHIRHAM' was developed at the Norwegian Meteorological Institute and it is based on Version 5 of the HIRHAM regional climate model (Christensen et al., 1996; Haugen and Haakenstad, 2006) driven by the Bergen Climate Model (BCM), a fully-coupled, global climate model.

(5) The fifth model 'METO-HC_HadRM3Q' was produced at the UK Met Office and it based on the HadCM3Q global climate model. The RCM is projected on a rotated pole projection, with regular latitude/longitude.

(6) The sixth model used is the 'MPI-M-REMO' (Jacob, 2001; Jacob, et al., 2001) has been developed at the Max Planck Institute for Meteorology (MPIM), Hamburg in Germany. The parent GCM is the ECHAM5 and the RCM has been projected on a rotated spherical coordinate system.

6.1. *TCI*

Figure 6-1 shows that southeastern (Larnaca) and inland (Nicosia) areas present during summer lower values for the TCI of about 55-60 in other words “acceptable” conditions for the tourists according to Table 2-4. Mountain areas of Troodos as well as western and southern regions present more elevated values for the TCI of about 70-75 and classified as “very good” for tourism activities (Table 2-4).

Concerning spring in the present-day climate, Figure 6.2 illustrates that the mountain region of Troodos shows TCI of about 65 while western and southern areas show TCI of about 71. Southeastern and inland regions present the most increased values for the TCI of around 75. According to the Ensemble model mean, spring is classified as “good” and “very good” for tourism activities.

Regarding the TCI during autumn, Figure 6.3 depicts that the TCI in mountain regions varies from 65 to 73 depending on the elevation. In addition, southeastern and inland regions present a TCI of about 72. Along the southern and western coastlines the TCI reaches 74. The classification with regard to comfort level for tourism activity is “good” at the high altitudes and “very good” at the remaining area.

As concerns winter TCI, Figure 6.4 shows that in mountain regions, the TCI varies from 45 to 53 depending on the elevation while in western areas TCI reaches 53. On the contrary, inland, southern and southeastern regions present the higher TCI of around 58. The classification with regard to comfort level for tourism activity is “marginal” for mountain and “acceptable” for the remaining areas.

As for the annual pattern of the TCI, Figure 6.5 illustrates that at present-day climate, the TCI varies from 60 to 66 in the Troodos Mountains, depending on the altitude. In inland and coastline areas (from west to east) the TCI reaches 66 and 68, respectively. Consequently, according to Ensemble model mean results, all areas of Cyprus are classified as “good” with regard to comfort levels for tourism activity.

Apart from seasonal and annual variability of the TCI, two further important parameters i.e. the number of days with TCI>70 (classification is “very good”) and TCI>80 (classification is “excellent”), have also been examined. Regarding the number of days with TCI>70, the Ensemble model mean (Fig. 6-6) shows that in most areas of Cyprus the number of days with TCI>70 varies from 150 to 165. The highest number of days, approximately 195, is shown both in western and southern coast areas.

Finally, Figure 6-7 shows that according to Ensemble model mean results there are about 85 days with TCI>80 in inland and southeastern areas while in mountain areas the number reaches 90 days in the present-day climate. The western coast areas show the highest number of days with TCI>80, approximately 120 days.

The overall findings of the analysis of TCI in Cyprus regarding present-day climate are summarized in Table 6-1.

Table 6-1: Ensemble model mean TCI concerning present-day climate in Cyprus.

	Western Regions	Mountain Regions	Inland Regions	Southern Regions	Southeastern Regions
Average Summer TCI	75	70	55-60	70	55-60
Average Spring TCI	71	65	75	71	75
Average Fall TCI	74	65-73	72	74	72
Average Winter TCI	53	45-53	58	58	58
Average Annual TCI	67	60-66	66	67	67
Nb of days TCI>70	195	160	160	165	165
Nb of days TCI>80	120	90	85	100	85

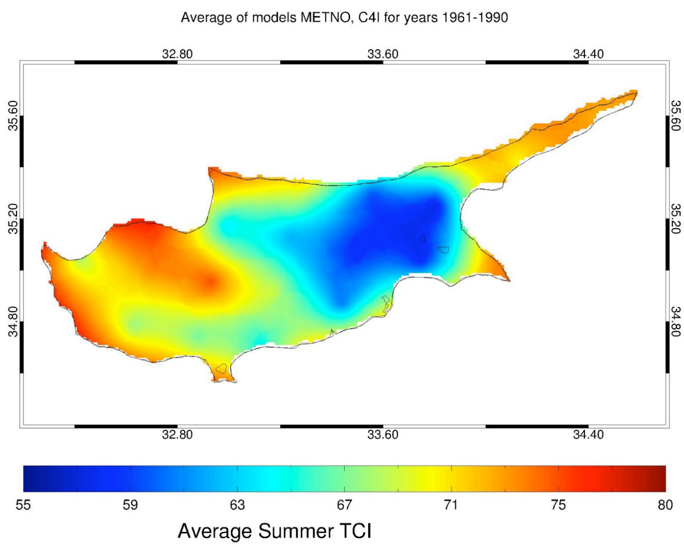


Figure 6-1: Ensemble model mean average summer TCI for the present period.

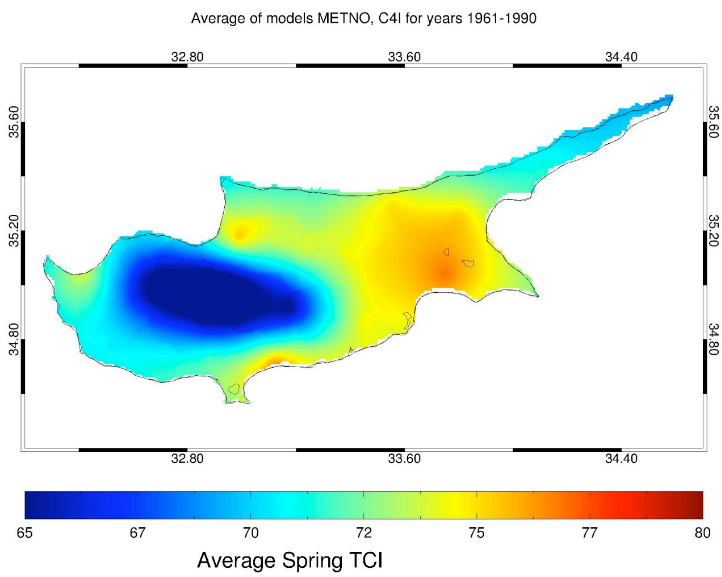


Figure 6-2: Ensemble model mean average spring TCI for the present period.

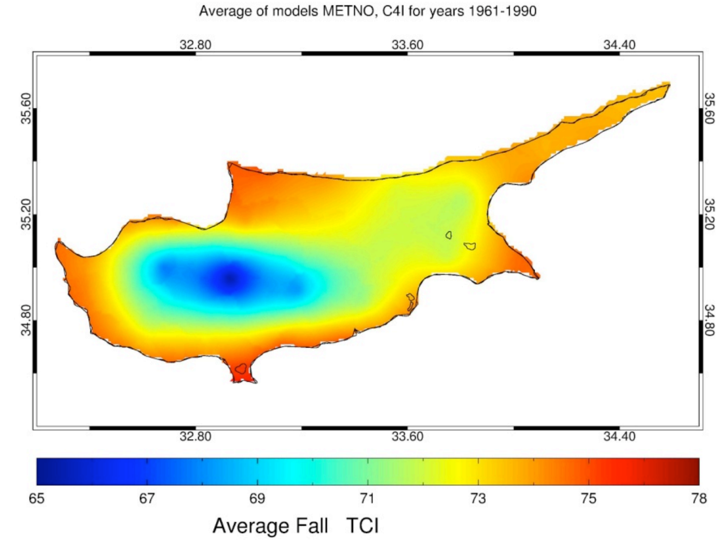


Figure 6-3: Ensemble model mean average fall TCI for the present period.

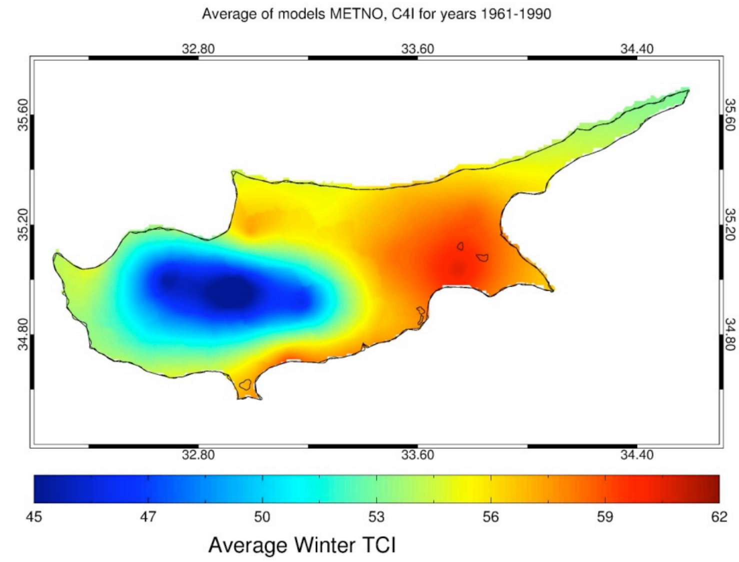


Figure 6-4: Ensemble model mean average winter TCI for the present period.

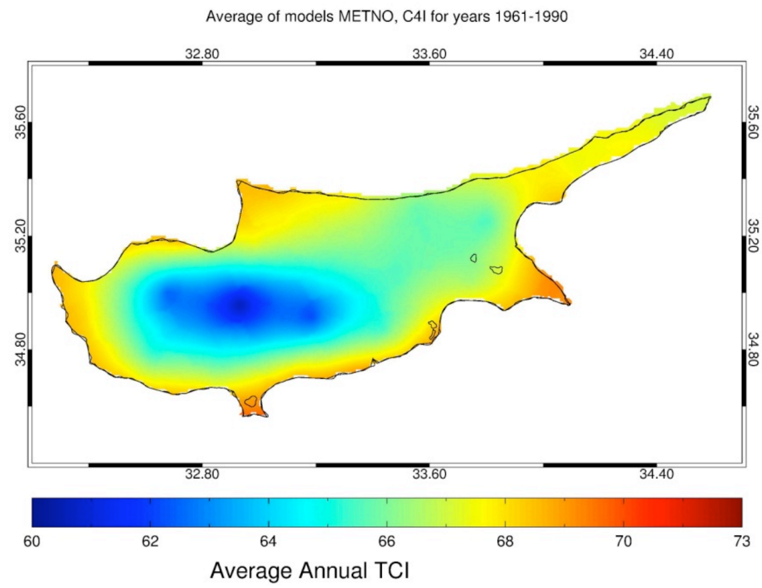


Figure 6-5: Ensemble model mean average annual TCI for the present period.

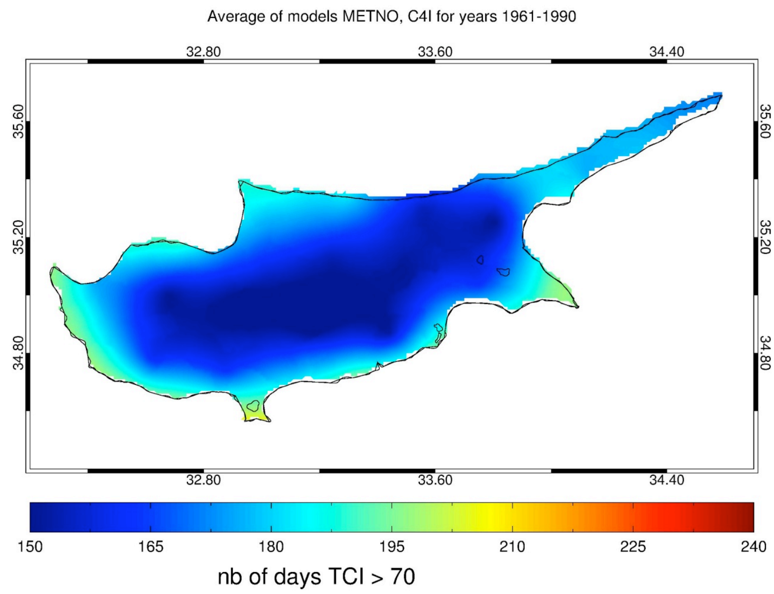


Figure 6-6: Number of days with TCI>70 for the present period using Ensemble model mean.

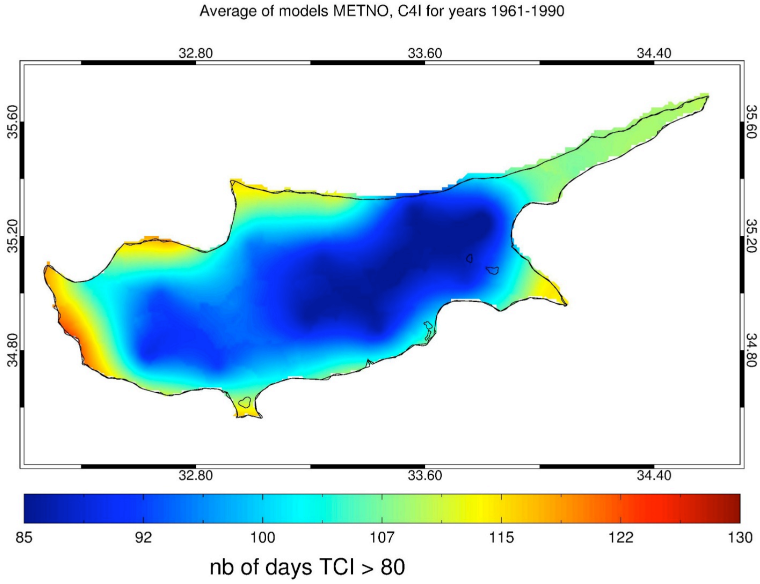


Figure 6-7: Number of days with TCI>80 for the present period using Ensemble model mean.

6.2.*BCI*

To begin with, since the BCI was constructed to assess the climate suitability of coastal destinations specific for beach recreation, the analysis of BCI will be confined to the coastal zone of Cyprus from west (Paphos District) to southeast (Larnaca and Famagusta District).

Figure 6-8 (Ensemble model mean) illustrates the average summer BCI for the present-day climate. More precisely, it is shown that western coastal zone presents a BCI of about 76 and is classified as “very good” while in southern and southeastern zone BCI is approximately 80 and is classified as “excellent”.

Regarding spring BCI (present-day climate), Ensemble model mean, (Figure 6-9) testifies that BCI reaches 67 in western coastline and approximately 72 in southern and southeastern areas. Spring BCI is classified as “good” in western areas and “very good” in southern and southeastern areas.

BCI during autumn, in the present-day climate, is presented in Figure 6-10. It is shown that according to the Ensemble model mean results in western coastline BCI is about 67 (classified as “good”) while in southern and southeastern coastal zone is approximately 72 (classified as “very good”).

As concerns winter BCI, Ensemble model mean plot (Fig. 6-11 – present period) shows that BCI is about 54 in western coastal zone (classified as “acceptable”) while in southern and southeastern coastal areas, BCI varies from 60 to 63 (classified as “good”).

The average annual BCI in the present-day climate is presented in Figure 6-12. Specifically, it is shown that in western coastal areas BCI is about 67 and is classified as “good” while in southern and southeastern areas BCI varies from 70 to 72 and is classified as “very good”.

Similarly with TCI’s analysis, apart from seasonal and annual variability of the BCI, the parameters namely the number of days with BCI>70 (classification is “very good”) and BCI>80 (classification is “excellent”), have also been examined. Figure 6-13 (Ensemble model mean – present-day climate) shows that in western coastal areas the number of days with BCI>70 is 180 and in southern and southeastern coastal zone varies from 230 to 250 days.

Finally, Figure 6-14 presents the number of days with BCI>80 in the present-day climate concerning Ensemble model mean. More precisely, it is shown that western areas present 115 days with BCI>80 whilst southern and southeastern coastal regions show approximately 150 days. The overall findings of the analysis of BCI in Cyprus regarding present-day climate are summarized in Table 6-2.

Table 6-2: Ensemble model mean BCI concerning present-day climate in Cyprus.

	Western Coastal Regions	Southern Coastal Regions	Southeastern Coastal Regions
Average Summer BCI	76	80	80
Average Spring BCI	67	72	72
Average Fall BCI	67	72	72
Average Winter BCI	53	61	63
Average Annual BCI	67	71	72
Nb of days BCI>70	180	230	250
Nb of days BCI>80	115	150	150

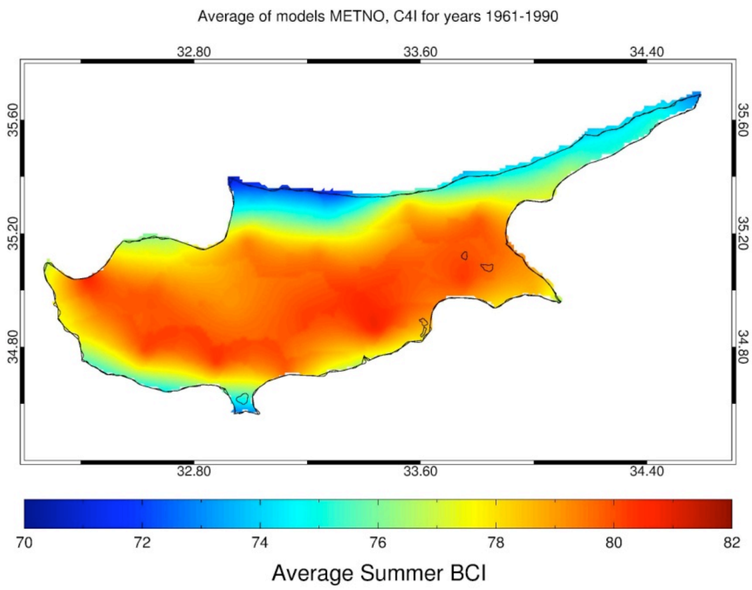


Figure 6-8: Ensemble model mean average summer BCI for the present period.

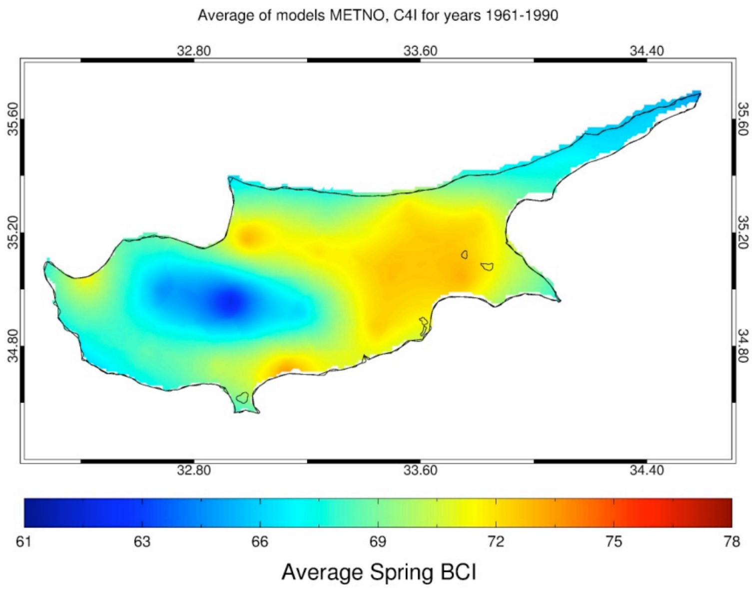


Figure 6-9: Ensemble model mean average spring BCI for the present period.

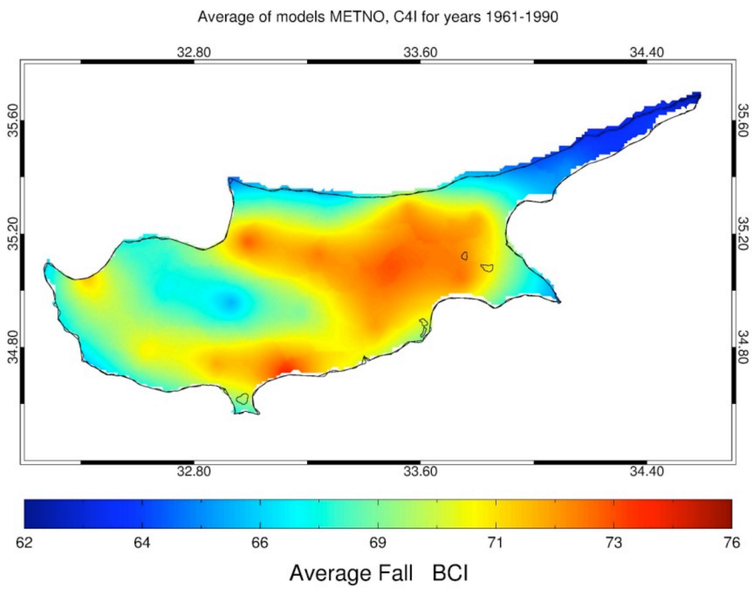


Figure 6-10: Ensemble model mean average fall BCI for the present period.

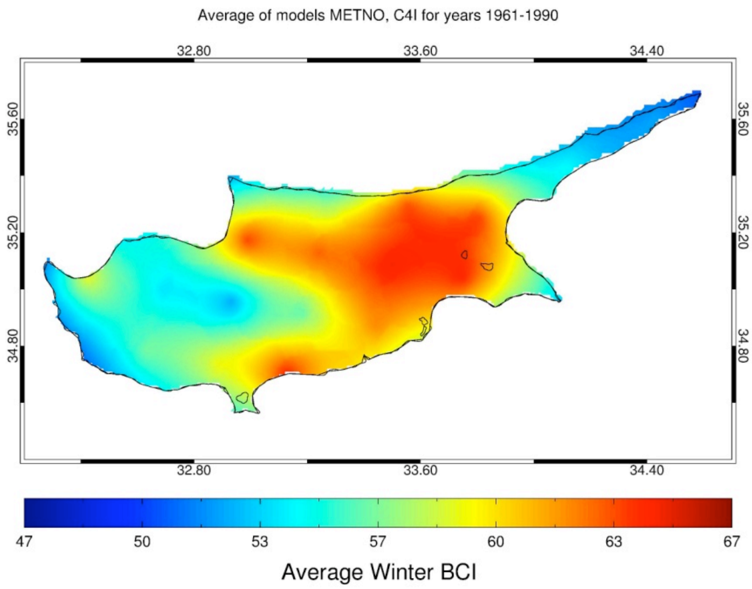


Figure 6-11: Ensemble model mean average winter BCI for the present period.

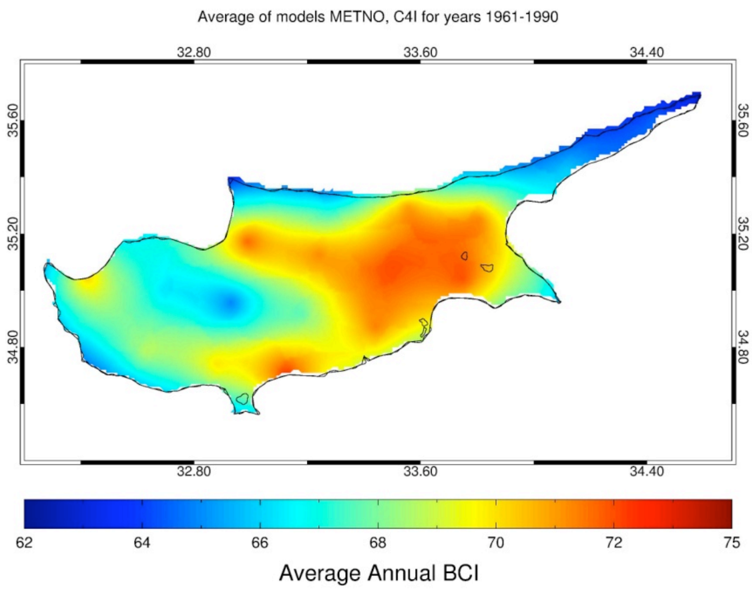


Figure 6-12: Ensemble model mean average annual BCI for the present period.

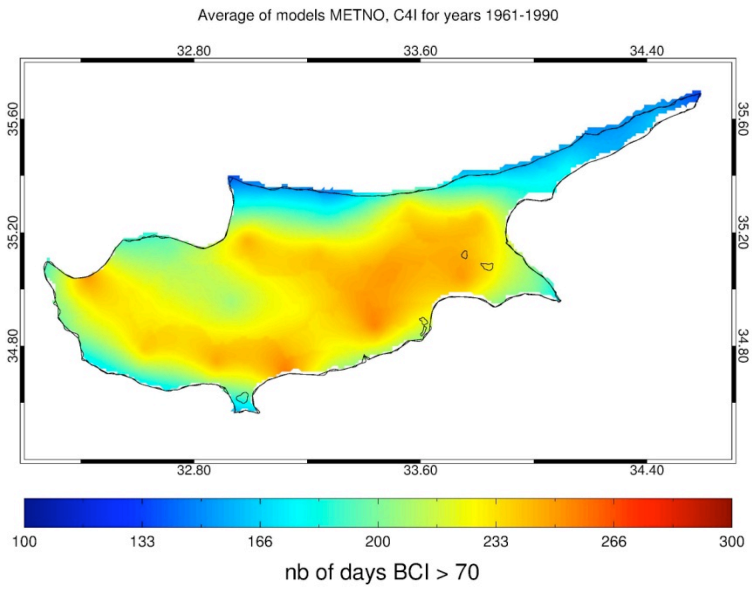


Figure 6-13: Number of days with BCI>70 for the present period using Ensemble model mean.

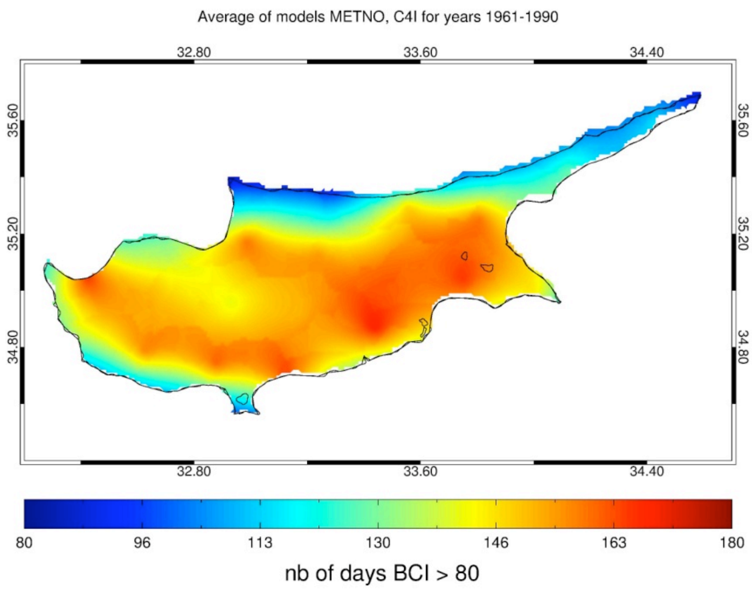


Figure 6-14: Number of days with BCI>80 for the present period using Ensemble model mean.

6.3. *Human comfort*

To begin with, Figure 6-15 illustrates the average summer humidex for the present period as calculated by the Ensemble model mean. In inland (Nicosia) and southeastern (Larnaca) regions, humidex varies from 40 to 42°C revealing significant levels of discomfort for people. Less discomfort is presented in mountain regions of Troodos as well as in southern and western parts of Cyprus, since humidex reaches approximately 37 - 38°C.

Regarding spring humidex in the present-day climate, Figure 6-16 (Ensemble model mean) illustrates that humidex varies below 29°C – 20°C in western, southern and mountain areas and approximately 25°C in inland and southeastern areas – revealing comfortable conditions for residents.

Autumn, in contrast with spring, presents higher humidex as Figure 6-17 shows. In particular, inland and southeastern regions show the higher humidex of about 32°C testifying some discomfort for people. Mountain, southern and western regions show the lower humidex varying from 28 to 30°C, in other words comfortable conditions.

As for the annual pattern of humidex in the present-day climate, Figure 6-18 shows higher humidex in inland and southeastern regions and lesser in southern, western and mountain regions. More specifically, in inland and southeastern regions annual humidex varies around 26-28°C while in southern, western and mountain regions humidex varies around 24-26°C. Consequently, humidex is classified as “comfortable” for the residents.

Apart from seasonal and annual distributions of humidex, three additional important parameters have also been studied i.e. the number of days with humidex > 38°C (high discomfort), the number of days with humidex > 40°C (great discomfort) and the maximum length of humidex > 38°C (consecutive days with high discomfort). Figure 6-19 depicts that in the present-day climate there are approximately 90 days with humidex > 38°C in inland and southeastern regions while in southern, western and mountain regions there are approximately 60.

As regards the number of days with great discomfort for people, in other words with humidex > 40°C, Figure 6-20 (present-day climate) illustrates that, the inland and southeastern parts present the higher number of days of about 70 while mountain, southern and western parts show approximately 40-45 days.

Finally, the very important parameter of the maximum length of humidex above 38°C (consecutive days with high discomfort) is shown in Figure 6-21. The Ensemble model mean shows that the maximum length is about 60 days in inland and southeastern parts of Cyprus while southern, western and mountain regions present a maximum length of about 25.

The overall findings of the analysis of humidex in Cyprus regarding present-day climate are summarized in Table 6-3.

Table 6-3: Ensemble model mean HUMIDEX concerning present-day climate in Cyprus.

	Western Regions	Mountain Regions	Inland Regions	Southern Regions	Southeastern Regions
Average Summer HUMIDEX	37	38	42	38	41
Average Spring HUMIDEX	22	22	25	23	24
Average Fall HUMIDEX	30	28	32	30	32
Average Annual	26	24	28	26	28

HUMIDEX					
Nb of days with HUMIDEX > 38 deg	60	60	90	60	90
Nb of days with HUMIDEX > 40 deg	40	45	70	40	70
Max length of HUMIDEX > 38 deg	25	25	60	25	60

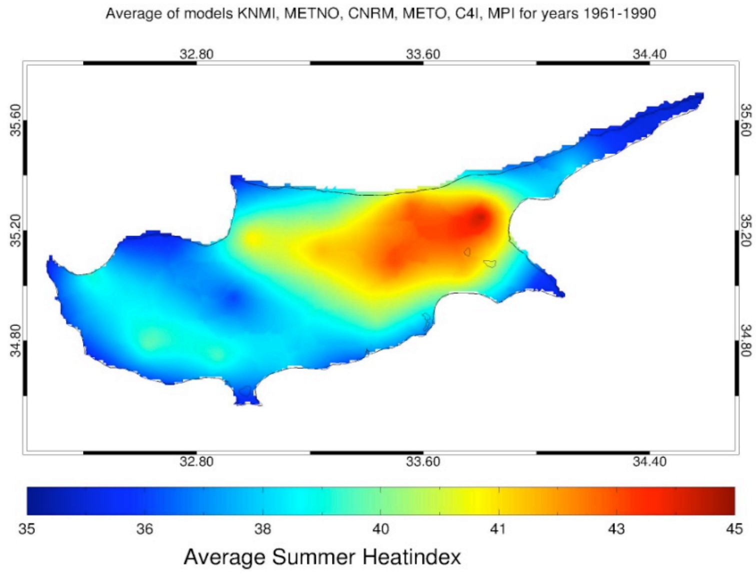


Figure 6-15: Ensemble model mean average summer HUMIDEX for the present period.

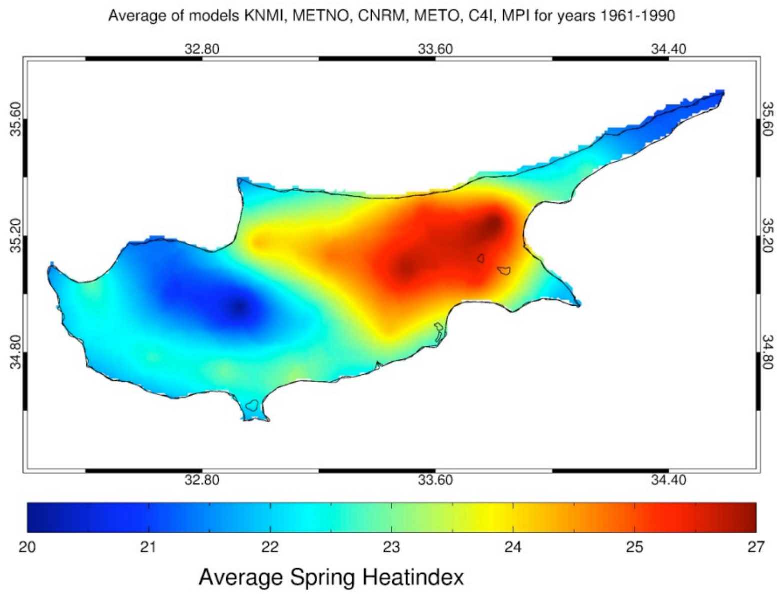


Figure 6-16: Ensemble model mean average spring HUMIDEX for the present period.

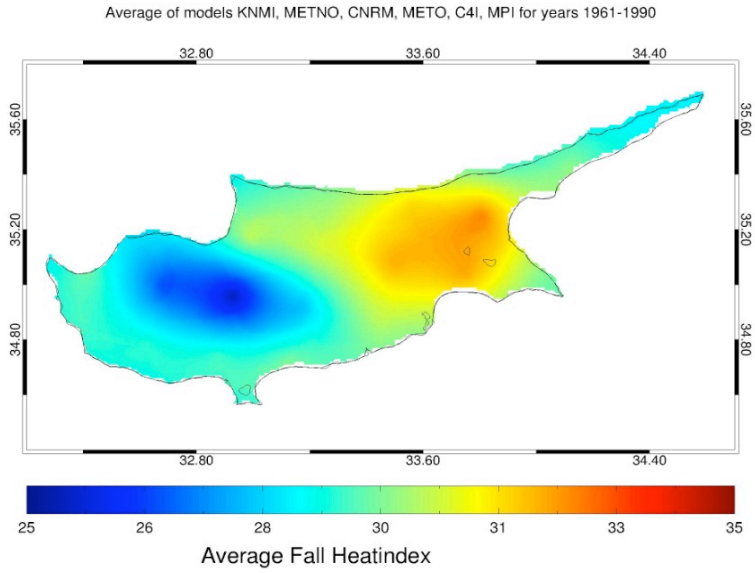


Figure 6-17: Ensemble model mean average fall HUMIDEX for the present period.

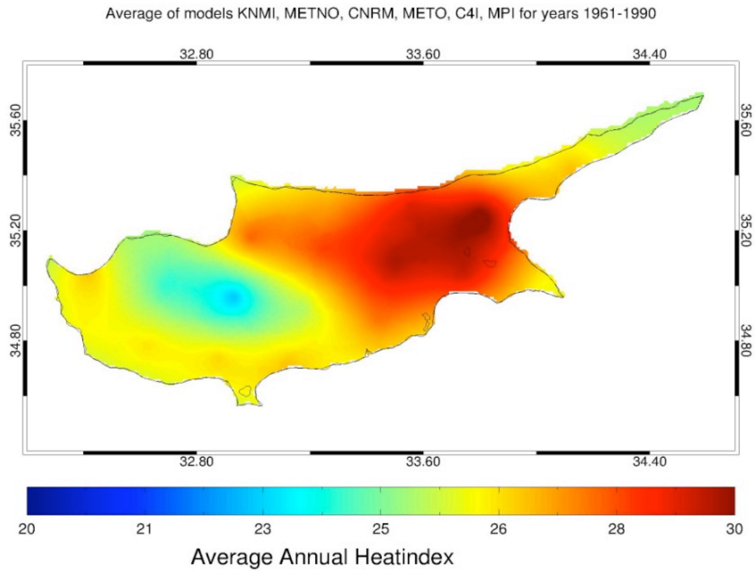


Figure 6-18: Ensemble model mean average annual HUMIDEX for the present period.

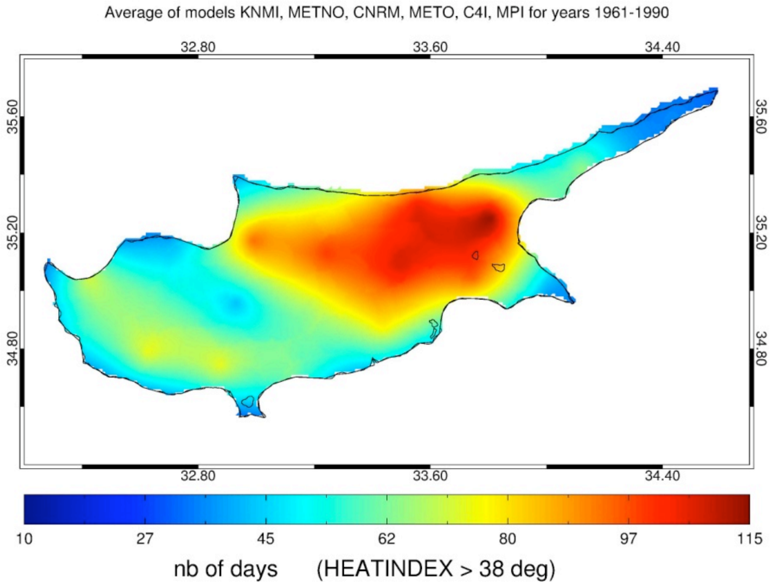


Figure 6-19: Number of days with HUMIDEX>38 deg for the present period using Ensemble model mean.

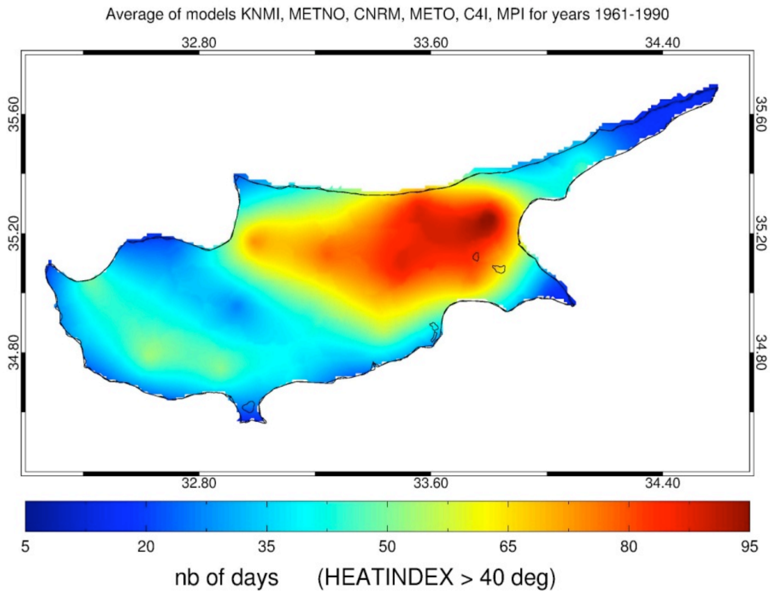


Figure 6-20: Number of days with HUMIDEX>40 deg for the present period using Ensemble model mean

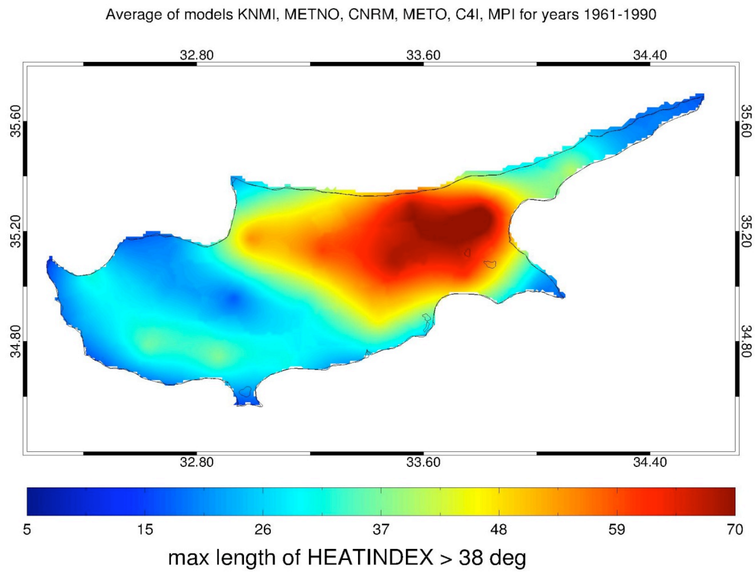


Figure 6-21: Maximum length of HUMIDEX for the present period using Ensemble model mean

6.4. *Fire risk*

Regarding the Ensemble model mean, results for present-day climate for July (Figure 6-22), FWI varies from 25 in western areas to 36 in forested southern, southeastern and inland areas. Also, Troodos Mountain presents an FWI of about 30. Therefore all areas present high fire risk during July.

As for August FWI, Figure 6-23 illustrates that Troodos Mountain presents an FWI of about 30 while the forested southern, inland and southeastern areas show an FWI of about 33. Also in western areas FWI reaches 23. Consequently, all areas present high fire risk during August.

However, fire risk is not confined during the summer period. There is elevated fire risk in late spring and early autumn too. To study fire risk before and after summer, April average FWI and October average FWI plots were carried out. Ensemble model mean results testify, for the case of April (Fig. 6-24) that the Troodos Mountain area shows low fire risk with FWI values of about 5-10. Also, southeastern and inland areas present a higher FWI of about 12 while in western areas FWI is about 7. On the other hand, Figure 6-25 shows that FWI is higher during October in contrast to April. More precisely, it shows that in southern, southeastern and inland regions FWI is about 20-22 revealing high fire risk while in western and mountain areas FWI is lower and reaches 15-17, namely moderate fire risk.

In analyzing fire risk it is very important to investigate the number of days during the year, with an increased fire risk, in other words, with an increased FWI. For the case of Cyprus, two parameters have also been examined: the number of days with FWI>15 i.e. days with moderate fire risk and the number of days with FWI>30 i.e. days with extreme fire risk. As evidenced by Figure 6-26, there are approximately 180 days with FWI>15 in the forested areas of southeastern, southern and inland regions and approximately 120 days in Troodos Mountain as well as in western regions.

Finally, Figure 6-27 shows the number of days with extreme fire risk i.e. FWI >30 for the present period regarding Ensemble model mean. It is presented that forested areas of Larnaca and Nicosia District (southeastern and inland areas) shows approximately 80 days of extreme fire risk while

Troodos Mountain and western areas show approximately 50 and 25 days of extreme fire risk respectively.
The overall findings of the analysis of FWI in Cyprus regarding present-day climate are summarized in Table 6-4.

Table 6-4: Ensemble model mean FWI concerning present-day climate in Cyprus.

	Western Regions	Mountain Regions	Inland Regions	Southern Regions	Southeastern Regions
July average FWI	25	30	36	36	36
August average FWI	23	30	33	33	33
April average FWI	7	5-10	12	10	12
October average FWI	17	15-17	20	22	22
Nb of days with fire risk (FWI>15)	120	120	180	180	180
Nb of days with extreme fire risk (FWI>30)	25	50	80	70	85

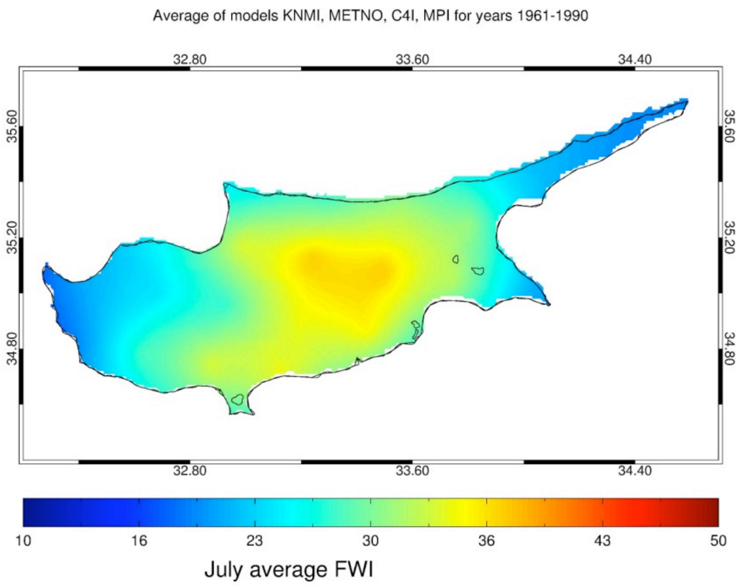


Figure 6-22: Ensemble model mean July average FWI for the present period.

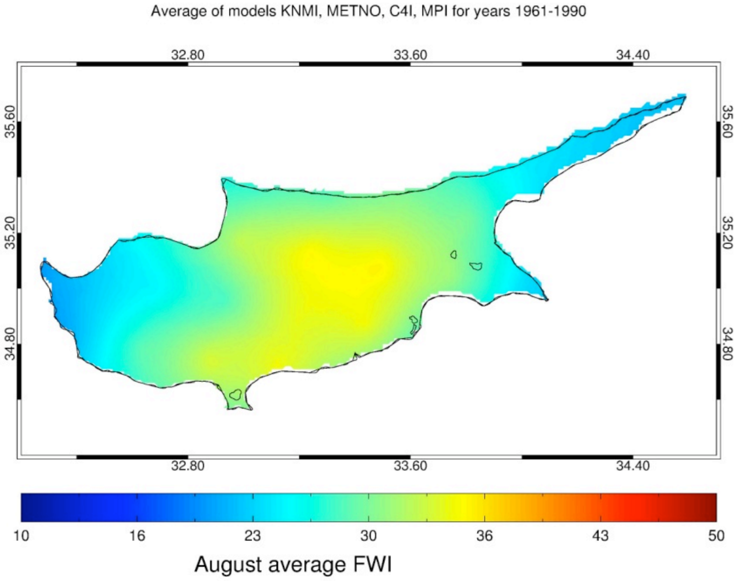


Figure 6-23: Ensemble model mean August average FWI for the present period.

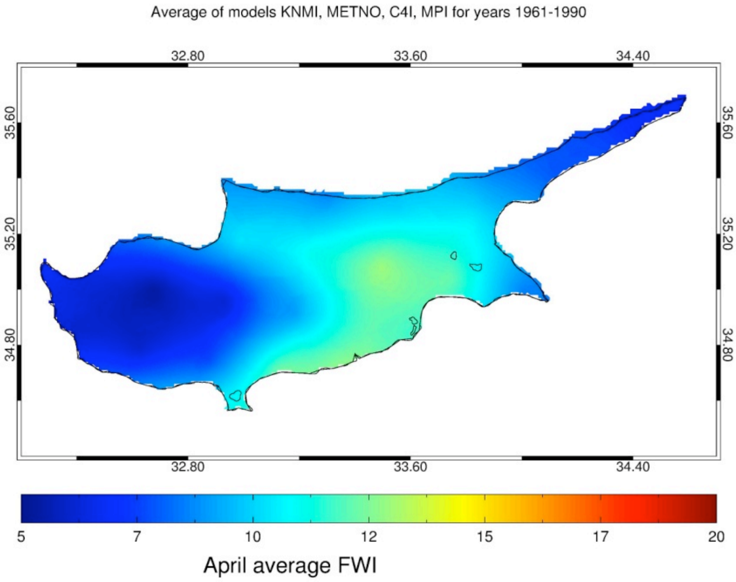


Figure 6-24: Ensemble model mean April average FWI for the present period.

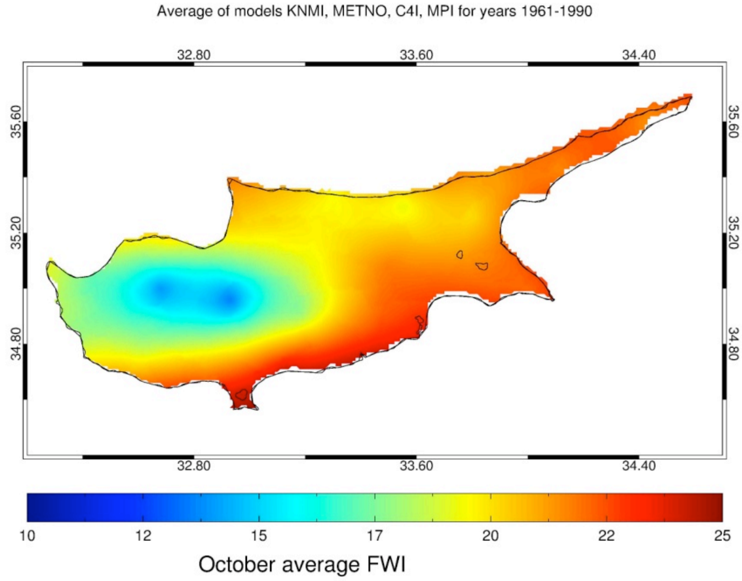


Figure 6-25: Ensemble model mean October average FWI for the present period.

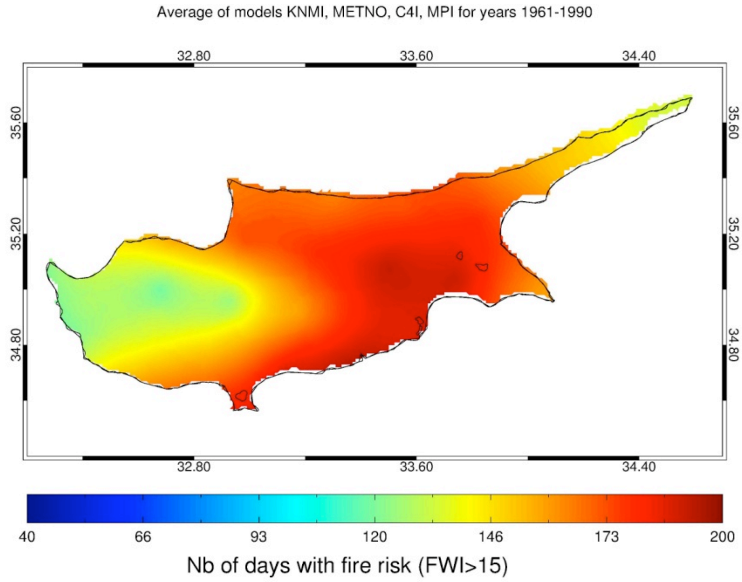


Figure 6-26: Number of days with moderate fire risk (FWI>15) for the present period using Ensemble model mean.

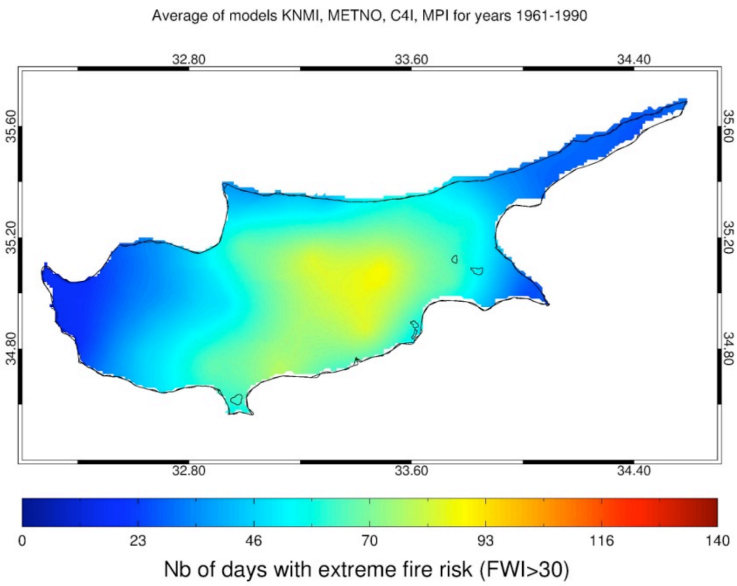


Figure 6-27: Number of days with extreme fire risk (FWI>30) for the present period using Ensemble model mean.

6.5. *Energy*

6.5.1. Heating Degree Days (HDD)

To begin with, Ensemble model mean results regarding spring (Fig. 6-28) show that in the present-day climate low energy demand of about 45 degree-days is presented in southeastern areas (Larnaca) of Cyprus while western (Paphos) and inland areas show a demand of about 100 degree-days. Area of Troodos Mountain shows the maximum energy demand, approximately 200 degree-days.

In addition, Figure 6-29 depicts HDD for the case of winter in the present-day climate. It shows that in Cyprus, the greatest energy demand for heating is observed during winter months. More precisely, higher elevation areas show the higher energy demand for heating which varies from 600 to 700 degree days. Furthermore inland, southeastern as well as southern and western areas present a demand of about 450 degree-days.

Apart from seasonal distribution of energy demand for heating, the annual distribution of it has also been studied. As Figure 6-30 shows, maximum energy demand for heating of about 950 degree-days derives from high elevation areas (Troodos Mountain). In addition inland, southeastern as well as southern and western areas present lower energy demand of about 550 degree-days.

Finally, Figure 6-31 shows the number of days per year requiring heavy heating i.e. days requiring heating of more than 5°C from the base temperature of 15°C. It shows that mountain regions of Troodos demand approximately 100 days of heavy heating while inland and southern areas require approximately 55 days. Southeastern and western regions require fewer days for heavy heating of the order of 35.

The overall findings of the analysis of the Heating Degree Days in Cyprus regarding present-day climate are summarized in Table 6-5.

Table 6-5: Ensemble model mean HDD concerning present-day climate in Cyprus.

	Western Regions	Mountain Regions	Inland Regions	Southern Regions	Southeastern Regions
Spring cumulative HDD	100	200	100	45	45
Winter cumulative HDD	350	650	450	450	450
Annual cumulative HDD	550	950	550	550	550
Nb of days with high HDD (>5)	35	100	55	55	35

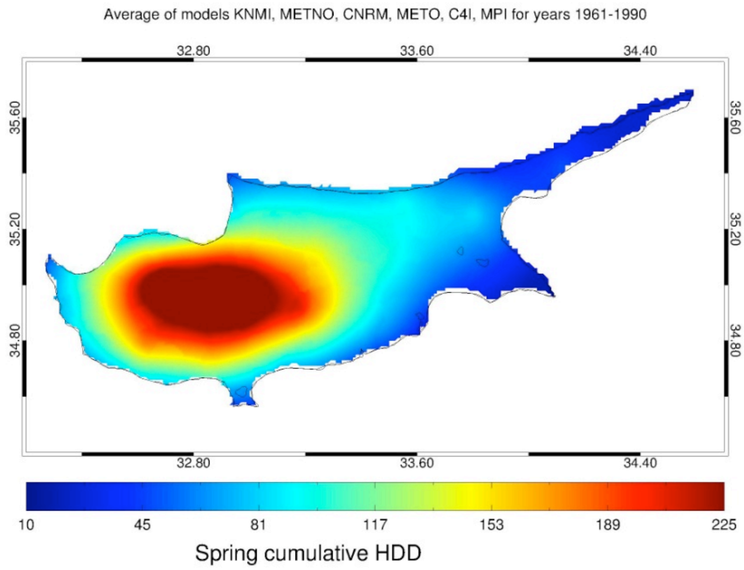


Figure 6-28: Ensemble model mean spring cumulative HDD for the present period.

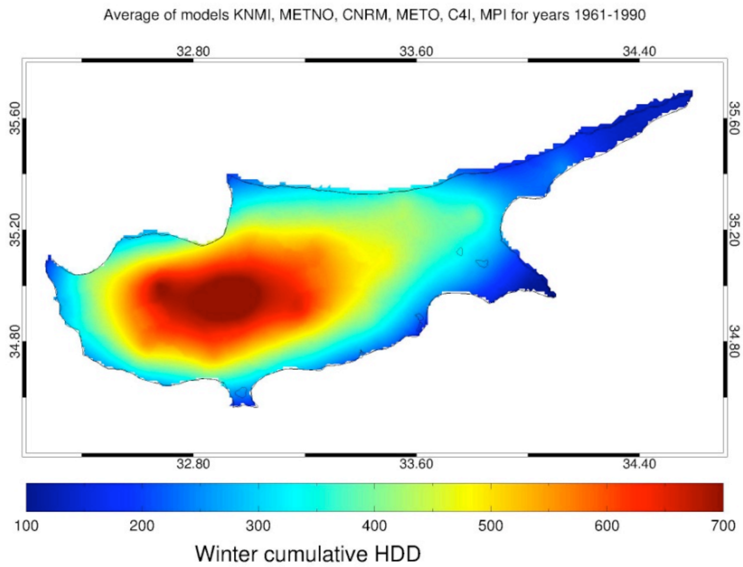


Figure 6-29: Ensemble model mean winter cumulative HDD for the present period.

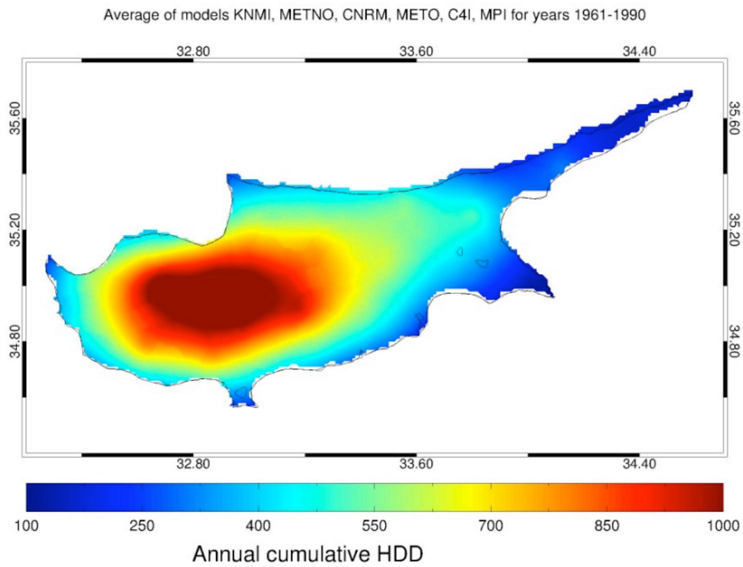


Figure 6-30: Ensemble model mean annual cumulative HDD for the present period.

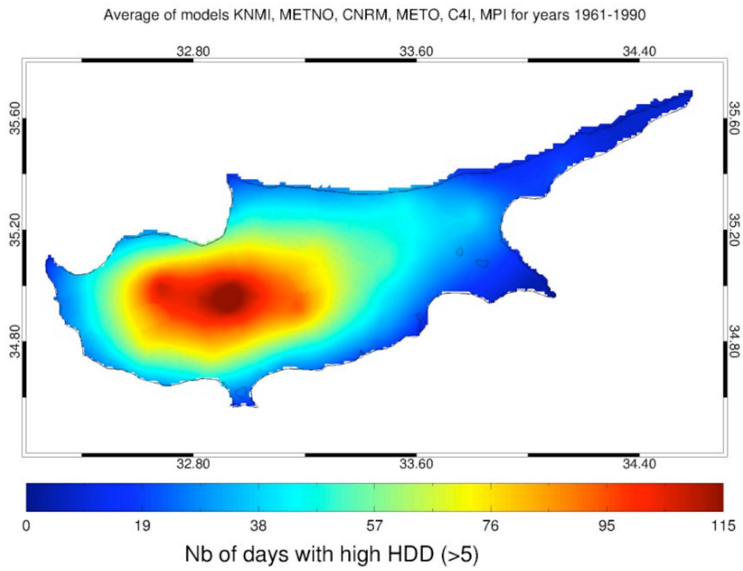


Figure 6-31: Number of days with high HDD (>5) for the present period using Ensemble model mean.

6.5.2. Cooling Degree Days – CDD

Regarding cooling degree days during summer for the present-day climate in Cyprus, Figure 6-32 depicts that greater energy demands for cooling, of around 300 degree-days are presented in southeastern (Larnaca District) and inland (Nicosia District) regions. On the other hand, lower energy needs are shown in mountain and much lower in western regions where energy demands reaches 100-200 degree-days and 50-100 degree-days, respectively.

In addition, Figure 6-33 indicates that in the present-day climate, energy demand for cooling during the autumn is at low levels. Specifically, southern, southeastern and inland regions show approximately 30-35 degree-days while western and mountain areas show 5-10 degree-days.

To examine the annual pattern of energy demand for cooling, an annual cumulative CDD parameter has also been investigated. Figure 6-34 depicts that at present-day climate, the yearly maximum energy demands of about 350 degree-days are evident in the southeastern and inland regions while mountain and western regions show lower demands of about 200-260 degree-days and 100 degree-days, respectively.

Finally, an important parameter in assessing the changes in energy demand for cooling was examined, namely the number of days per year requiring excessive cooling of more than 5°C from the base temperature of 25°C. Figures 6-35 shows that, nowadays, 25-30 days per year of heavy cooling mainly in southeastern and inland regions are required, while in the southern region, 12 days are required. In Mountain and western regions the number of days with heavy cooling is around 5 days.

The overall findings of the analysis of the Cooling Degree Days in Cyprus regarding present-day climate are summarized in Table 6-6.

Table 6-6: Ensemble model mean CDD concerning present-day climate in Cyprus

	Western Regions	Mountain Regions	Inland Regions	Southern Regions	Southeastern Regions
Summer cumulative CDD (degree-days)	50-100	100-200	300	150-200	300
Fall cumulative CDD	10	10-20	35	25	35
Annual cumulative CDD (degree-days)	100	200-260	350	190-220	350
Nb of days with high CDD (>5)	5	5	25-30	12	25-30

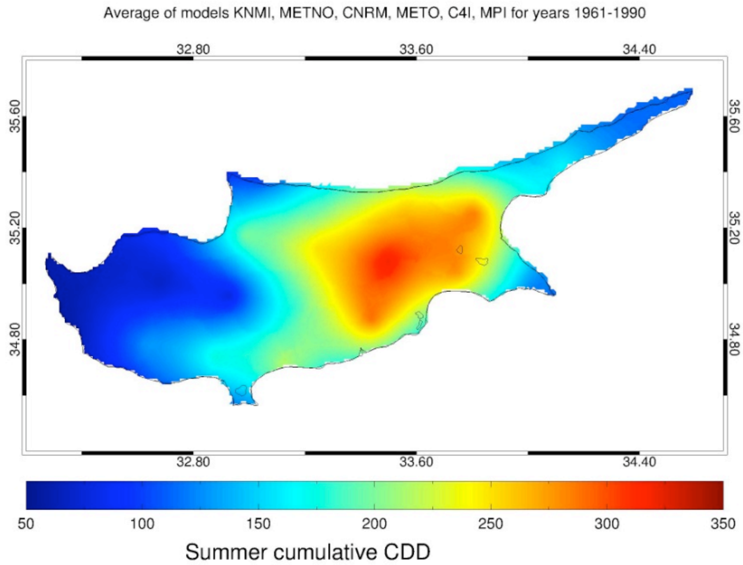


Figure 6-32: Ensemble model mean summer cumulative CDD for the present period.

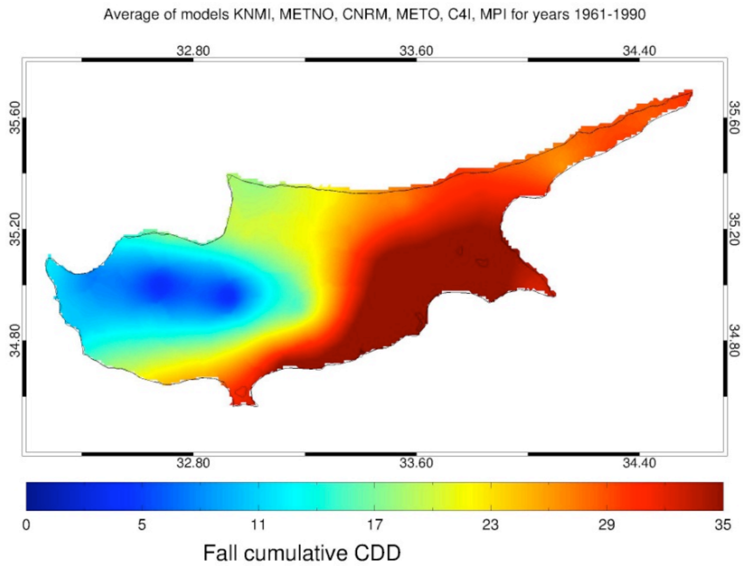


Figure 6-33: Ensemble model mean fall cumulative CDD for the present period.

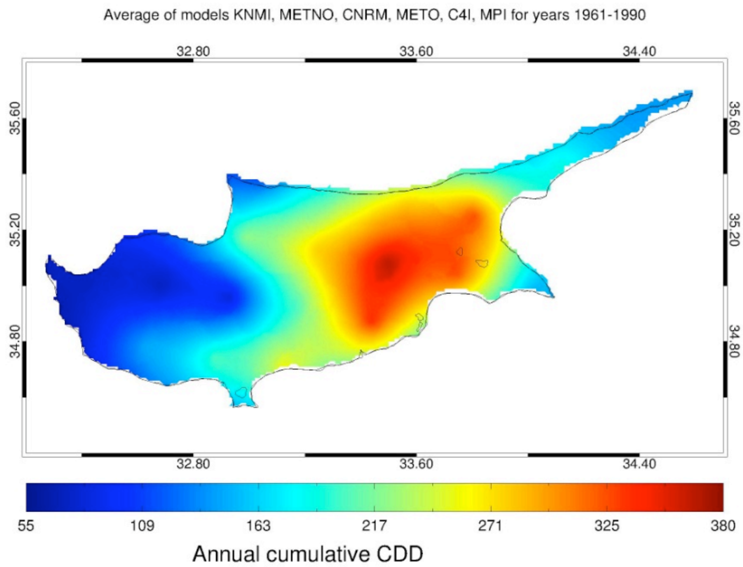


Figure 6-34: Ensemble model mean annual cumulative CDD for the present period.

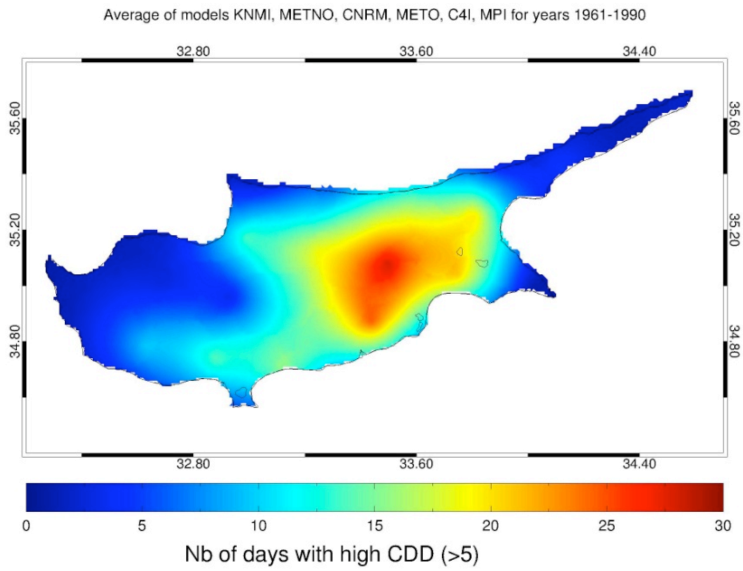


Figure 6-35: Number of days with high CDD (>5) for the present period using Ensemble model mean.

7. Issues in presenting results to users

The application results in the previous section are only for guidance and reference and the main purpose was to show the application and use of transfer functions for the various sectors considered. They should not be used as sole source of information since they have not been validated. The reason for this is that obtaining observation data for these types of indices/functions is not straightforward, given the range of variables used. However, some validation work regarding cooling and heating degree days has been performed in Deliverable 3.7 where cold biases of models have been revealed, highlighting the need for bias correction.

Moreover, in some cases the ensembles size, i.e. the number of models used, is rather small (e.g. only two models for TCI). In an ideal situation, larger ensembles would be used and/or higher spatial resolution be needed (e.g., 12 km MED-CORDEX runs). The next step would be to calculate projected future changes, which falls outside the scope of this deliverable.
With regard to the results shown for heating and cooling degree days, it is worth mentioning that in the case of Cyprus, the great numbers depicting cooling demands are seen in areas with relative high population density. In contrast, elevated heating demands are seen in regions of higher elevations that are characterized by lower population densities.
Another issue the user should be aware of is the colour scales used in the plots. They tend to imply a higher spatial resolution than is actually the case. The actual models resolution is 25km, which means that the whole island of Cyprus is covered by around 20 grid boxes.

8. Acknowledgement

The application of the transfer functions for the present climate of the case study site of Cyprus were performed in the framework of EU LIFE+ project CYPADAPT (http://uest.ntua.gr/cypadapt/) which aims to develop the national adaptation strategy for climate change adverse impacts in Cyprus.
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