ECMWF COPERNICUS REPORT

Copernicus Climate Change Service

Urban SIS
D441.6.3.2 Use case urban heat

Issued by: Swedish Meteorological and Hydrological Institute (SMHI)

Date: 30/11/2017

Ref: C3S_D441.6.3.2_UrbanSIS_201711_Urban_heat.docx

Official reference number service contract: C3S_441_Lot3_SMHI_2017/SC2

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Table of Contents

1. Introduction

During the last years the frequency of extreme events of temperature and precipitation has increased over many parts of the world. In Italy, the summer of 2017 was characterized by high temperature and a high number of consecutive dry days. Temperature of about 35°C had been registered in Emilia-Romagna for many days and, values of 42.5°C had been recorded in the first week of August. These events determined an increase of the heat waves and the heat island effect, tropical nights and hot days, with a negative impact on different urban sectors, activity and especially on human health. Understanding how these events will change in the future, especially at urban scale, is an important issue.

Bologna, the capital and largest city of the Emilia-Romagna region placed in Northern Italy, is one case study of the project. It is the seventh most populous city in Italy, at the heart of a metropolitan area of about one million people such as information about future changes of climate are very important. The present report describes the projections of urban heat island and health indices, over Bologna case study, derived from URBAN-SIS climate model in the framework of RCP8.5 concentration pathway. The present and future climate are described by 5-years windows. As regards present climate, the years describe 1981-2010 conditions while, the future are referred to 2030-3065.

2. Findings and outcomes by making use of Urban SIS data

2.1 Urban heat island

The activities were dedicated to the demonstration of the use of present and future scenarios downscaled climate data (HCLIM-AROME data). These data have been used as initial and boundary meteorological conditions to run the ENVI-met model, a 3D Computational Fluid Dynamics (CFD) model which proved to be an excellent tool in order to simulate the temporal evolution of the meteorological variables inside an urban area, taking into account the complex interactions between atmosphere, urban surfaces and vegetation (Bruse and Fleer, 1998).

ENVI-met model version 3.1 has been used, at 5 meter resolution in the horizontal directions and 2 meter resolution in the vertical; in the latter direction the first layer above the ground is further split into 5 more layers in order to properly represent the near ground interactions. In addition, ENVI-met model domain is characterized by the presence of the so-called “receptor points”, where ENVI-met model collects all the information related to the variables in the atmosphere and in the soil and where it is relatively easier to extract relevant quantities.

The study area is again a very small portion within the urban area in the Municipality of Modena, Emilia-Romagna, in Northern Italy: in particular, the so-called *Villaggio Artigiano*, a former industrial area where most factories already ceased or are currently ceasing their activity. The choice of this area is twofold, since it was one of the pilot area in the framework of the EU Interreg Project named

UHI (related to the counteraction of the urban heat island phenomenon) and it is the object of an urban regeneration intervention plan by the municipality of Modena (Marchesi et al., 2014).

As a first step, the analysis is focused on the selection of the warmest episodes characterizing each period considered in the analysis. The “historical period” (2006, 2007, 2012, 2013 and 2014) was initially considered and the episode 20-22 August 2012 was simulated using ENVI-met model, comparing HARMONIE-AROME and observed data. Recently, HCLIM-AROME simulations were available covering two different periods, namely the “present scenario (1981-2010) and the “future scenario” (2030-2065). Only five years during each of these periods have been selected for the analysis. The selection of the years was made in order to take into consideration years that can be representative of different meteo-climatic conditions during the whole period. In the following, only the 5 years representing the “time window” of each period have been considered, namely 1987, 1996, 2005, 2006, 2010 for the “present scenario” and 2037, 2044, 2050, 2053, 2063 for the “future scenario”. In particular, the selection of the years was made in order to take into consideration “warm” and “cold” conditions, “wet” and “dry” conditions and “neutral“ (i.e., average) conditions as well.

In Table 1, a descriptive analysis of summer seasons (defined as June, July and August) for the different time windows (historical and scenarios) is shown. “Type” columns indicate neutral years (“N”), warm&wet years (“WW”), warm&dry years (“WD”), cold&wet years (“CW”), cold&dry years (“CD”). It clearly emerges from Table 1 the exacerbation of the severity of summer conditions for the “future scenario” with respect to the “present scenario” for all the years according to the previous classification, regardless of their type. In Table 1(a) the corresponding values for the historical period is shown for comparison.

(a) “historical period”

Year	Type	Min	25 perc	Median	75 perc	Max
2006		7.4	20.0	23.9	28.5	37.3
2007		10.2	19.8	23.4	28.1	36.4
2012		12.5	22.0	25.6	30.5	38.3
2013		11.4	20.3	23.8	28.2	37.6
2014		10.5	19.2	22.7	26.5	35.2

Table 1 - Statistical descriptive analysis of the selected time windows in each period as indicated in the various panel.

(b) “present scenario”

Year	Type	Min	25 perc	Median	75 perc	Max
1987	CW	8.2	18.1	22.9	28.4	40.2
1996	CD	6.0	19.6	24.2	29.5	40.0
2005	N	8.6	19.4	23.8	28.3	40.4
2006	WD	12.2	22.6	27.3	323.0	42.8
2010	WW	8.8	21.6	26.0	31.0	42.1

(c) “future scenario

Year	Type	Min	25 perc	Median	75 perc	Max
2037	CW	11.3	21.1	25.2	30.3	43.4
2044	WD	10.6	25.2	29.8	35.3	45.4
2050	N	12.7	23.2	27.2	32.6	40.1
2053	CD	10.5	23.2	27.8	32.8	44.6
2063	WW	11.4	24.5	29.5	35.5	45.3

In this respect, the afore-mentioned time windows have been analyzed in order to select the warmest episodes: after this analysis, summer 2006 was selected in the “present scenario” time window, while summer 2044 was selected in the “future scenario” time window, that means the “warm&dry” year of both time windows. Meteorological initial and boundary conditions for the

ENVI-met simulations are obtained from HARMONIE simulations for the 3 warmest episodes in the selected summer within each time window, namely:

- 20-22 August 2012 for the “historical period” (HARMONIE-AROME set-up);
- 22-24 July 2006 for the “present scenario” (HCLIM-AROME set-up);
- 16-18 July 2044 for the “future scenario” (HCLIM-AROME set-up).

and the simulations using ENVI-met model for these episodes have been performed. These specific episodes are characterized by an increase of air temperatures for 2-4 days in a row in order to be representative of the severity of the specific summer season. In Figure 1 a temporal cross-section of the air temperature in one of the receptor points inside ENVI-met domain (the most “central” one, called “r1”) during the course of the simulation (60 hours in total).

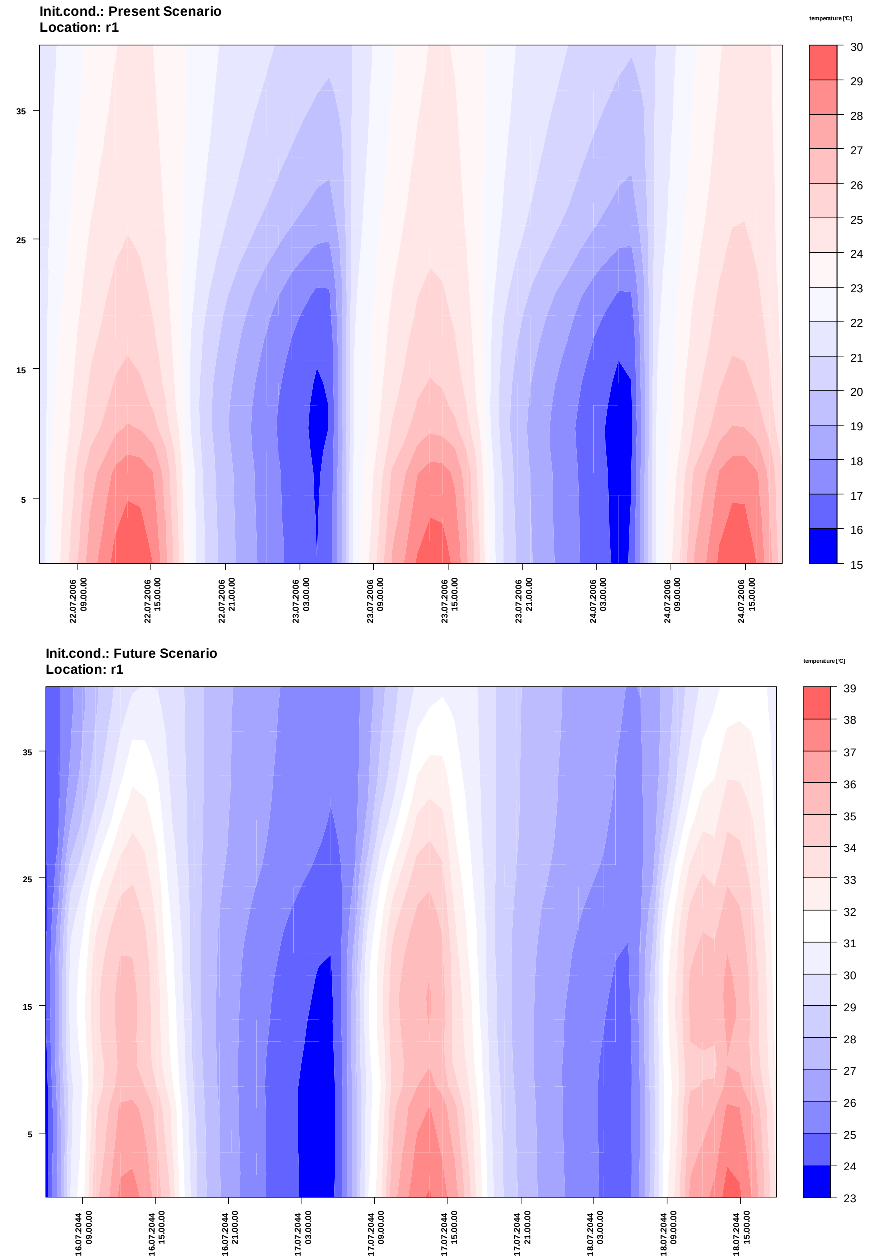

Figure 1 - Temporal cross-section of air temperature for the receptor point at the centre of ENVI-met domain (“r1”) for the “present scenario” run (top panel) and for the “future scenario” run (bottom panel).

In Figure 2 the distribution of the 60 hourly values of air temperature in all the receptor points within the ENVI-met domain is shown. It clearly emerges from the comparison of the two episodes that the modal maximum temperature in the “future scenario episod” simulated using ENVI-met model is far higher than in the “present scenario episod” (about 35°C with respect to 27°C).

The same consideration holds for the Thom index, which is an indicator of the bioclimatic conditions in the outdoor environment. The use of Thom index is twofold, since its value is a function of both atmospheric temperature and relative humidity (not only air temperature) and, in addition, threshold values of the Thom Index can be associated to bioclimatic discomfort conditions. In fact, values of the Thom Index below 21 indicates absence of bioclimatic discomfort, up to values above greater than or equal to 32 indicating the possibility of an health emergency due to severe bioclimatic discomfort conditions eventually associated with heat strokes. However, values of the Thom Index greater than or equal to 27 are associated to bioclimatic discomfort conditions for most of the population, regardless of concurrent vulnerability factors.

The distribution of the 60 hourly values of the Thom Index in all the receptor points within the model domain for the 2 ENVI-met simulations is shown in Figure 3. The various distributions are quite similar, with the presence of two modes, one associated to night time (towards lower values) and the other associated to day time (towards the highest values). The comparison between present and future scenario clearly indicates a shift towards higher values of the distribution of Thom Index, which ranges from 16 to 25 in the “present scenario” run and from 21 to 33 in the “future scenario”. In addition, modal values are characterized by an increase of comparable size: from 17 to 24 during night-time and from 23 to 30 during day-time.

In this respect and according to the values of the Thom Index, such situations are associated with widespread bioclimatic discomfort conditions for most of population during day time as well as with a very difficult nocturnal recovery with all its consequences on the quality of life.

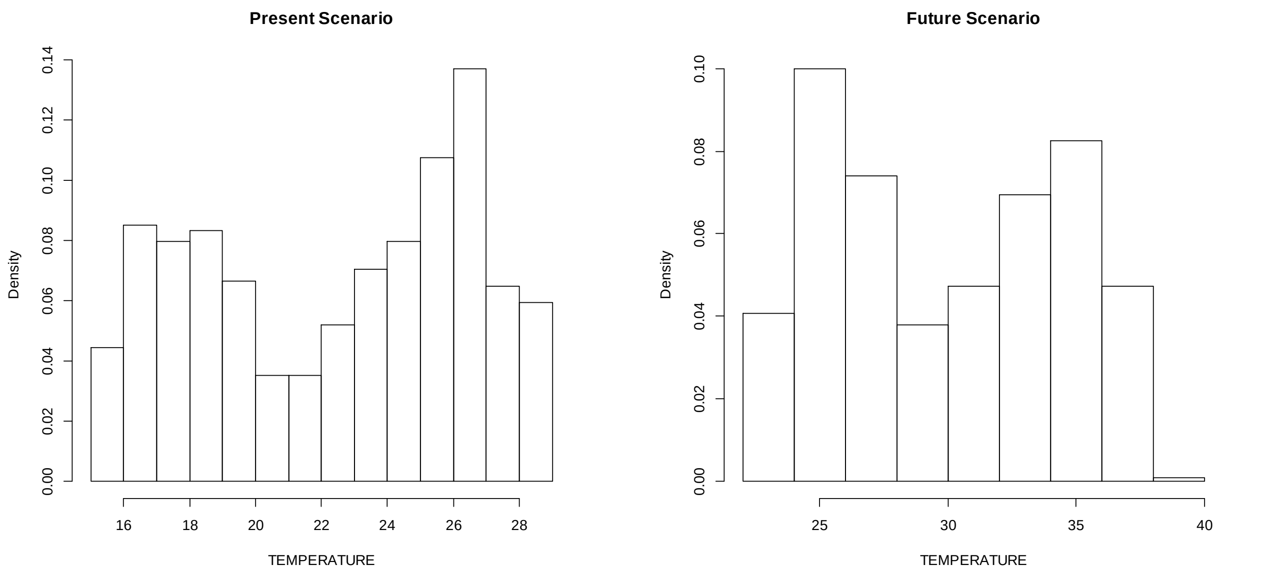

Figure 2 - Probability density function of the hourly values of air temperature at 1.8 m (level 5 in ENVI-met atmosphere) in all the receptor points within ENVI-met domain during the 60 hours of the simulation for the “present scenario” (left panel) and the “future scenario” (right panel) runs.

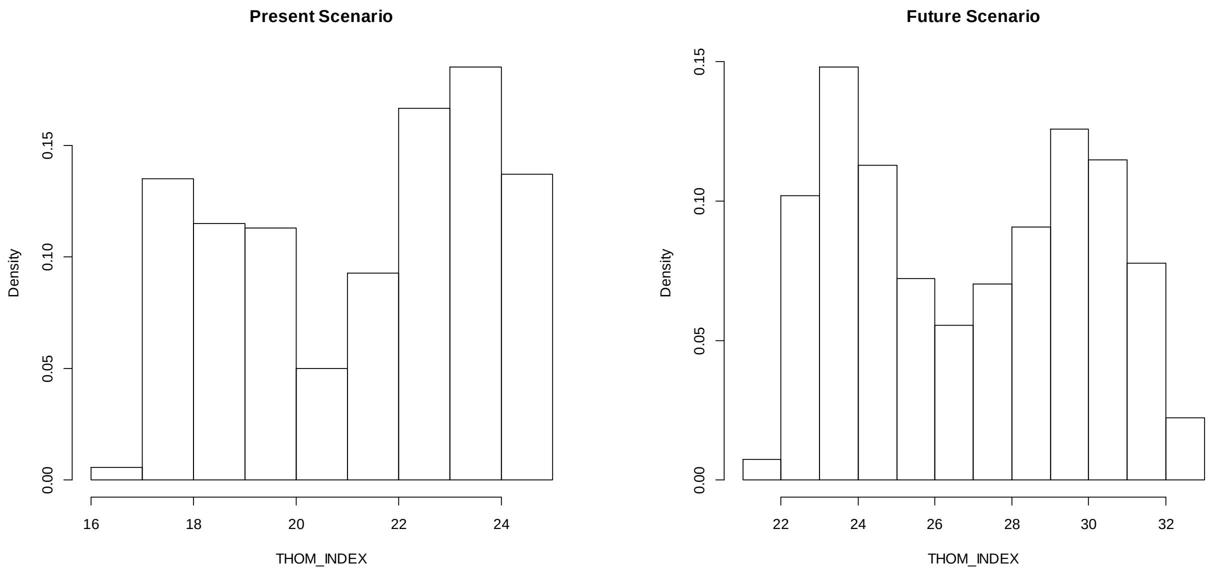

Figure 3 - Probability density function of the hourly values of Thom index at 1.8 m (level 5 in ENVI-met atmosphere) in all the receptor points within ENVI-met domain during the 60 hours of the simulation for the “present scenario” (left panel) and the “future scenario” (right panel).

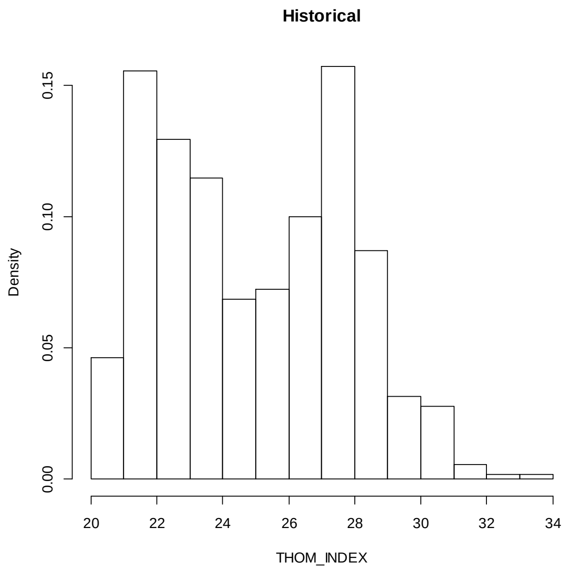

Figure 4 - The same as Figure 3, for the simulation in the “historical period” (20-22 August 2012).

2.2 Health indices

Urban-SIS climate simulations produced by the regional climate model HARMONIE, delivered also data concerning health indicators, for 5 year time-periods, as follows:

- historical period: 2006, 2007, 2012, 2013, 2014 - HARMONIE-AROME set-up;
- present scenario: individual years taken from a climate scenario representing today conditions (1981-2010) - HCLIM-AROME set-up;

- future scenario: individual years taken from a climate scenario representing conditions around 2050 (period 2030-2065) - HCLIM-AROME set-up.

Tropical nights, heat wave duration and Thom discomfort index are the main health indices identified and analyzed in the present work for Bologna case study, using the Urban-SIS outputs produced at 1kmx1km resolution.

The tropical nights index is defined as the number of “nights” when minimum temperature is greater than 20°C*.*

Heat wave duration index characterized periods of sustained extreme heat. There are different definitions of the heat waves, some of them based on percentile of daily climatological maximum temperature (90th, 95th or 99th), while others are based on consecutive days when the maximum temperature is greater than fixed values of maximum temperature (for example 33°C, 35°C, 40°C). The heat wave index selected in the present project is defined as a period of consecutive days that satisfy the following conditions (Meehl and Tebaldi, 2004):

1. daily Tmax is above 97.5th percentile for at least three days,
2. the average Tmax is above 97.5th over the entire period and,
3. the daily Tmax must be over 81th percentile every day of the period. The total heat wave period may be longer than three days.

The Thom discomfort index, as pointed out before, is a physiological thermal stress indicator, based on dry-bulb and wet-bulb temperature (Thom, 1959). High temperature causes human discomfort, the knowledge of human discomfort conditions are necessary particularly for people who live in large cities. The conditions associated to different thresholds are presented in Table 2. Changes in the number of days exceeding the two thresholds, 24 and 28 Thom index, are analyzed in the present report.

Table 2 - Thom discomfort index (thresholds).

Up to 21	No discomfort
From 21 to 24	Less than half population feels discomfort
From 25 to 27	More than half population feels discomfort
From 28 to 29	Most population feels discomfort and deterioration of psychophysical conditions
From 30 to 32	The whole population feels an heavy discomfort
Over 32	Sanitary emergency due to the very strong discomfort which may cause heat strokes

The future changes of the above health indices are computed as the difference between the mean of the full 5 years window of future and present. Data from URBAN-SIS portal are downloaded (http://urbansis.climate.copernicus.eu/access-data/) and analyzed in different grid points (see Table 3) over Bologna metropolitan area.

Table 3 - Position of the grid points where future projections of health indices are analyzed.

Name	Height(m)	Lon°	Lat°
BOLOGNA AEROPORTO	32.76	11.27723	44.5425
CASALECCHIO	66.21	11.27723	44.4975
BORGONUOVO DI PONTECCHIO	140.96	11.27723	44.4525
SASSO MARCONI EST	165.77	11.27723	44.4075
CASTELMAGGIORE	22.81	11.34028	44.5875
CORTICELLA	30.07	11.34028	44.5425
BOLOGNA	68.14	11.34028	44.4975
RASTIGNANO	184.79	11.34028	44.4525
PIAN DI MACINA	207.36	11.34028	44.4075
BOLOGNA INTERPORTO	20.16	11.40333	44.5875
CADRIANO	29.34	11.40333	44.5425
VILLANOVA DI CASTENASO	47.44	11.40333	44.4975
S.LAZZARO	110.73	11.40333	44.4525

The projections of *annual tropical nights* over Bologna case study simulated by HCLIM-AROME model emphasis a possible increase of the index everywhere, over 2030-2065 period. Figure 5 presents the mean over 5-years simulations over the present (1981-2010) and mean over 5-years simulations over future (2030-2065). The future simulations are done in the framework of RCP8.5 scenario. As could be noted from figure 5, the signal of changes put in evidence a significant increase in both urban area (Bologna, Corticella) and in the surrounding area (for example S. Lazzaro or Casalecchio). The projected annual future values of the index are almost twice with respect to present climate values (1981-2010).

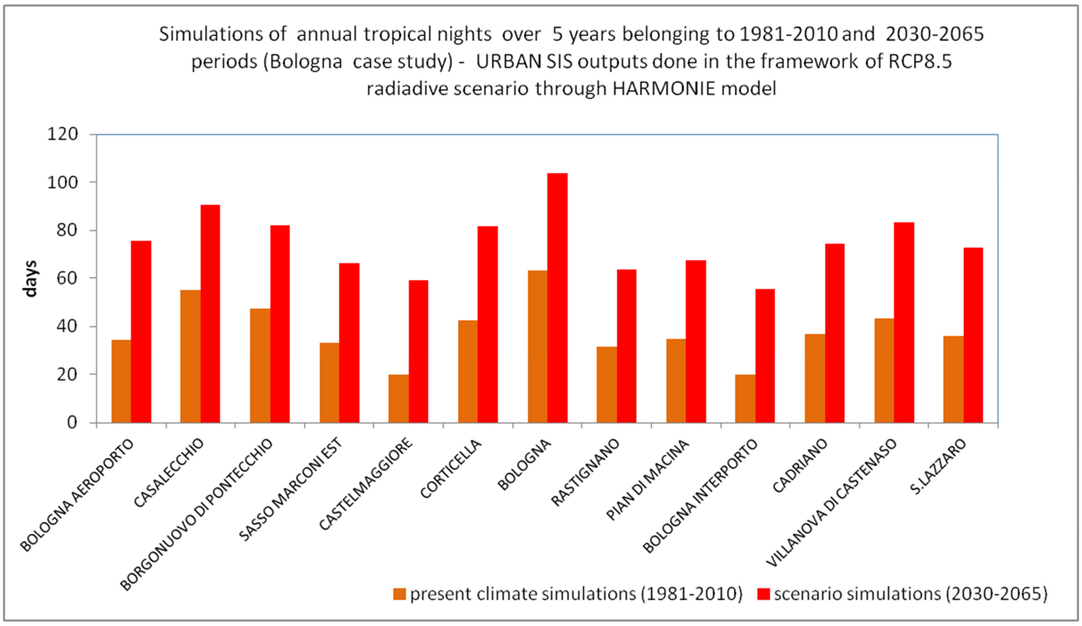

Figure 5 - Projections of annual tropical nights over Bologna metropolitan area, mean of 5-years simulations that covers 1981-2010 and 2030-2065 (RCP8.5 scenario) periods

Similar signal is projected for *heat wave duration* (Figure 6), namely an increase of the index between 16 to 30 days in the future with respect to maximum 10 days registered over present period (see figure 6). As could be noted from figure 6, the grid points situated in the hill area will expect an increase slightly lower than those situated in the urban area of Bologna.

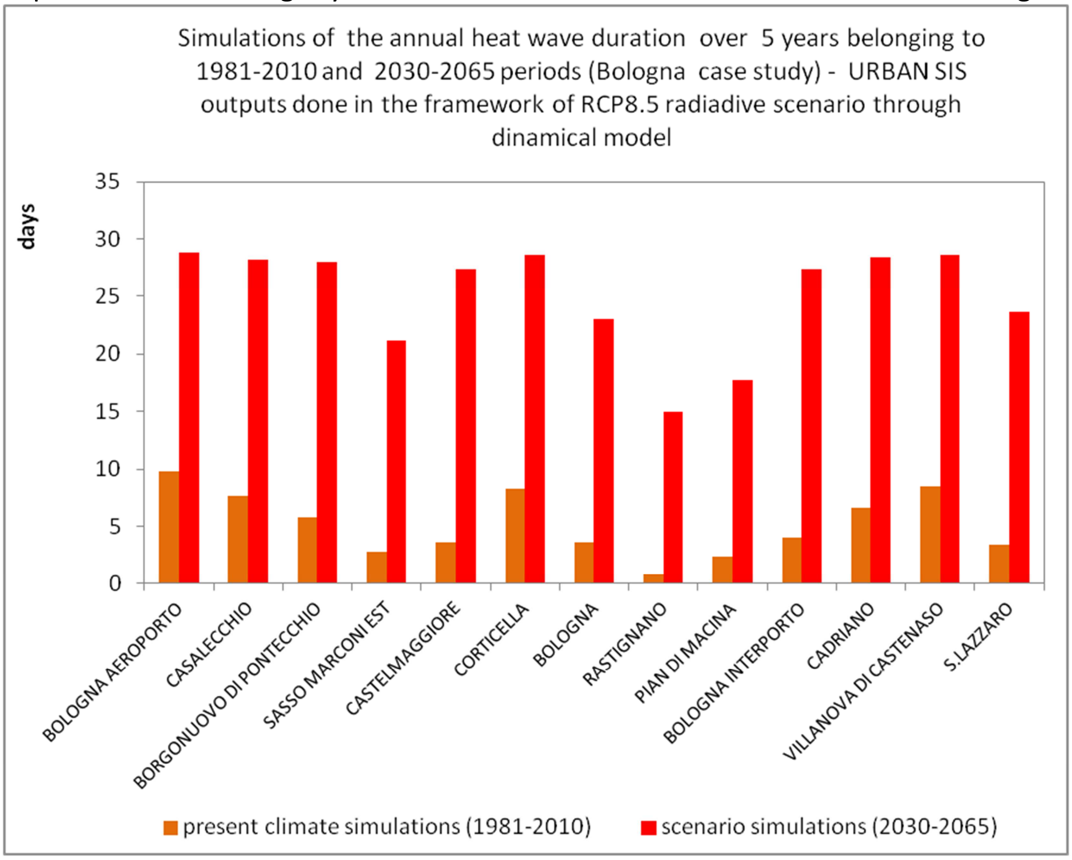

Figure 6 - Projections of heat wave duration over Bologna metropolitan area, mean over 5-years simulations that covers 1981-2010 and 2030-2065 (RCP8.5 scenario) periods

The changes detected in tropical nights are associated with an increase in minimum temperature while those detected in heat wave duration are associated with an increase in maximum temperature (results not displayed).

The analysis of *Thom discomfort index* simulated over future, 2030-6065, underlies possible increases for both thresholds (24 and 28). Figure 7 presents as an example, the simulations of Thom index at Bologna grid point (lat.=44,4975 and long.=11.37028) for the thresholds of 24 and 28. As could be noted, in both cases it is projected an increase to 110 cases for Thom greater than threshold of 24 (period 2030-2065) with respect to 70 cases during present (period 1981-2010) and, 50 cases for Thom greater than 28 (2030-2065) with respect to 18 cases during present (1981-2010).

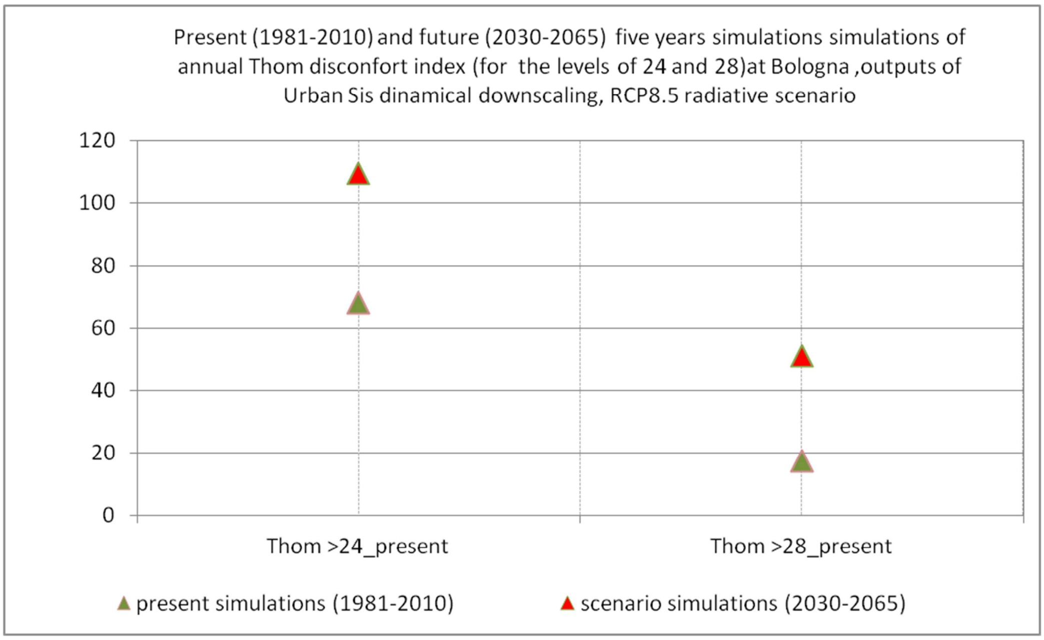

Figure 7 - Projections of Thom index for Bologna grid point (lat.=44,4975 and long.=11.37028), mean over 5-years simulations that covers 1981-2010 and 2030-2065 (RCP8.5 scenario) periods

3. Evaluation of Urban SIS portal

Time series of essential climate values (ECVs) at different temporal and spatial resolution, as well as indices could be downloaded from the URBAN–SIS portal http://urbansis.climate.copernicus.eu/access-data/.

Simulations include 5 years from historical, current and future period. Data from individual grid points have been downloaded for evaluation of future changes over Bologna metropolitan area. Figure 8 presents one example of products downloaded for tropical nights for present (8a) and future (8b). The portal is friendly user.

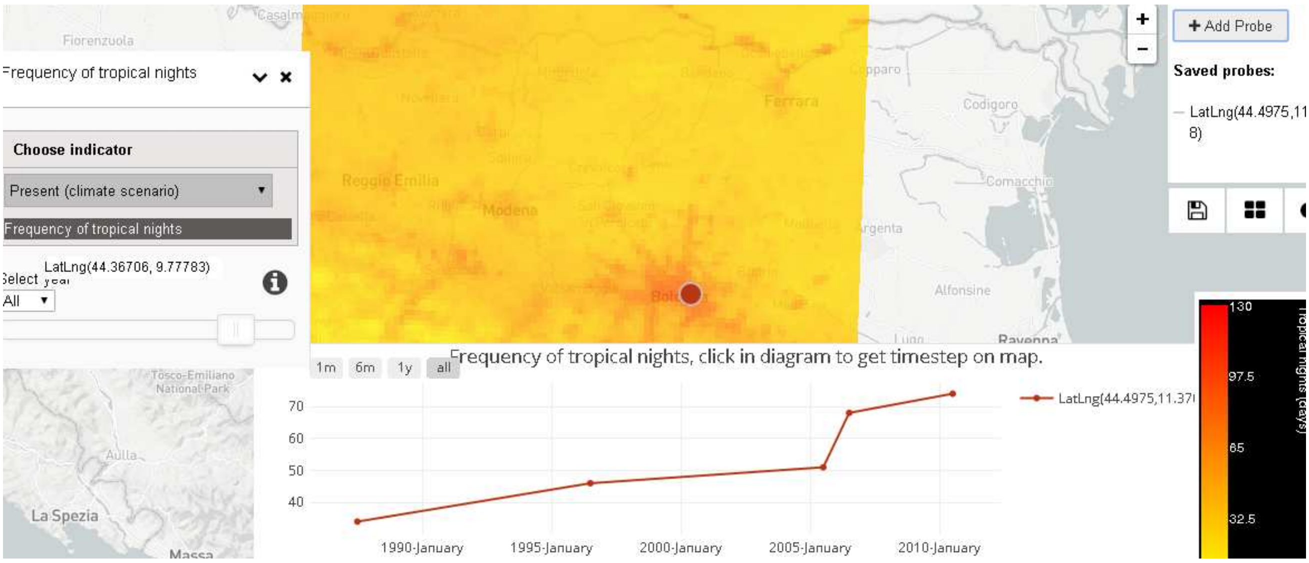

Figure 8a – Urban SIS portal (present climate simulation)

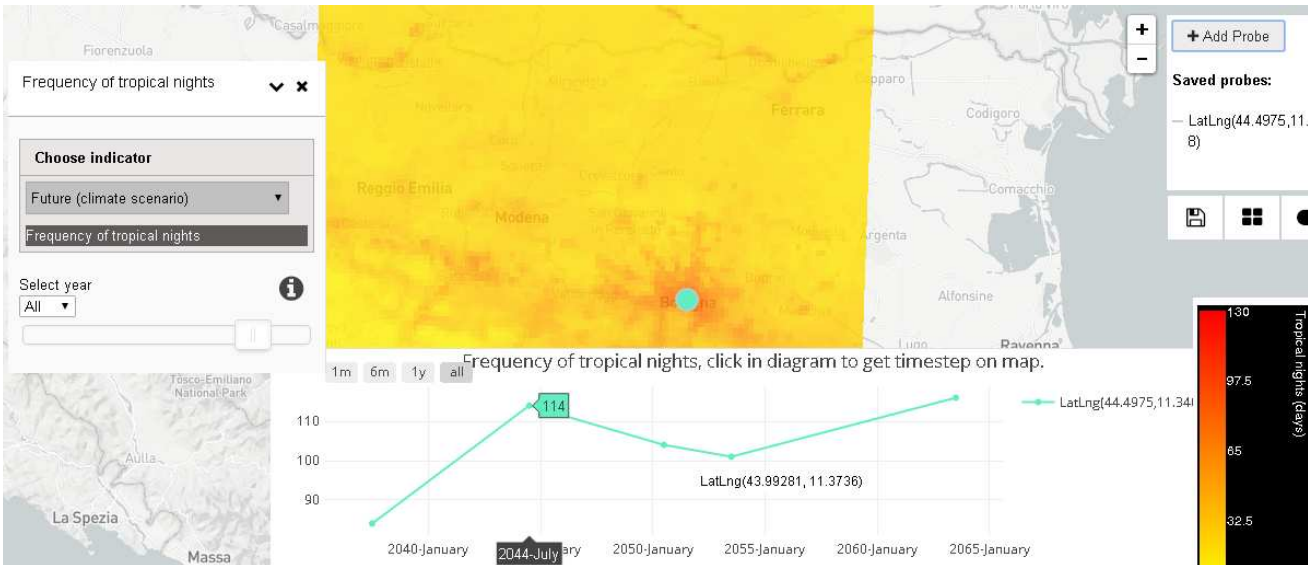

Figure 8b – Urban SIS portal (future climate simulation)

4. Conclusions

The results presented so far are showing the effectiveness and the usefulness of urban downscaled model data in the specific framework related to Bologna case study.

As for the numerical simulations in the urban environment by ENVI-met micro-meteorological model, it was initially shown the goodness of the representation of the main features in the historical period (Urban SIS data vs observed data). In addition, the results are rather satisfactory also in terms of the representation of present and future scenarios, as it is shown in the present document, with a clear indication of the worsening of environmental conditions.

The future projections of health indices over Bologna metropolitan area, shows significant changes over 2030-2065 period. Taking into account the spatial resolution of these simulations, the outputs of Urban SIS are very important for impact studies.

5. References

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