Carpathian Journal of Earth and Environmental Sciences, August 2018, Vol. 13, No. 2, p. 595 - 603; DOI:10.26471/cjees/2018/013/050

SUMMER THERMAL DISCOMFORT CONDITIONS IN ROMANIA UNDER CLIMATE CHANGE SCENARIOS

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Abstract: We use temperature-humidity index (THI) and the Net Effective Temperature (NET) index to estimate the occurrence of thermal stressful conditions during summer in Romania under the RCP 4.5 and RCP 8.5 climate change scenarios. We employ results from four regional climate models for the periods 2021-2050 and 2071-2100, obtained within EURO-CORDEX initiative. The reference interval is 1971-2000 and we use a high-resolution (0.1° x 0.1°) dataset for Romania to validate the modelled historical runs. The indices are computed using daily values of maximum air temperature, relative humidity and wind speed at 10 m. The results show that the ensemble mean of historical runs captures well the spatial patterns of THI and NET, but their magnitudes are significantly underestimated due to underestimation of maximum air temperature and relative humidity over Romania. As expected, there is an increase in the number of days with thermal discomfort expressed by both indices, which is larger towards the end of this century, under the RCP 8.5 scenario. The largest increase in the number of warm episodes associated with discomfort conditions is found for the Western and Southern parts of Romania.

Keywords: heat stress, thermal discomfort, climate change, regional modeling, public health

1. INTRODUCTION

Human body adjusts to weather and climate conditions through complex processes in order to attain or preserve an optimal state. When pre-existing factors impede the adjustment, health issues may appear or be enhanced, even leading to death. Among the weather conditions which affects, directly or indirectly, the human health, the extreme temperatures episodes are the most important, as documented in the scientific literature (e.g. Basu and Samet, 2002; WMO, 2004; Iñiguez et al., 2010). The response plans for hot/cold weather episodes focus on short-term needs and actions based on short-term weather forecasts. Information on longer time scales about the probability of occurrence of health-affecting weather episodes are very helpful for developing effective adaptation plans, including the increase of the population awareness with regard to these natural hazards, and informed decisions for a sustainable development (e.g. reducing the urban heat island effect).

The increase in the number of weather episodes with high temperatures is ‘virtually certain’ in the coming years, as indicated by the fifth report of Intergovernmental Panel on Climate Change (IPCC) (2014) and associated with this a reduction in the occurrence of cold temperature extremes over most land areas on daily and seasonal timescale will be observed, due to the increase in the mean air. At regional scale, this will translate in more frequent heatwaves, especially in the Southern Europe (Jacob et al., 2014). Several studies involving long-term measurement data over the Romanian territory (e.g. Marin et al., 2013; Piticar & Ristoiu, 2012; Croitoru & Piticar, 2013; Dumitrescu et al., 2015) indicate an increasing trend of air temperature in the last half century; the number of heat waves also increased (Bojariu et al, 2015), with high costs in terms of human lives (102 deaths during 2000-2018) and wellbeing (800 persons affected, during the same period) according to The International Disaster Database (www.emdat.be). The climate change projections for Romania also highlight the increase of mean air temperature (e.g. Busuioc et al., 2010, Bojariu et al., 2015), the increase in the number of heatwaves and in the number of tropical nights (Bojariu et al., 2015). In this context, it is expected that thermal discomfort will also be experienced more frequently during the warm season. The variability in time and space of thermal discomfort in the recent and current climate conditions was investigated in several studies focusing on the entire Romanian territory (e.g. Dobrinescu et al., 2015) or on limited areas and/or periods (Vlăduţ 2011; Leontie et al., 2008). However there are no studies exploring the impact of climate changes on the thermal comfort conditions for our territory. The analysis of changes in the occurrence of thermal stressful weather conditions in the context of climate change scenarios with regard to their magnitude and spatial variability is of practical interest for the development of long-term adaptation strategies and for reducing the climate-related health risks.

This study investigates the changes in the thermal discomfort conditions over Romania during summer under the moderate and high scenario for greenhouse gases (GHGs) concentration, based on high-resolution regional numerical experiments. Two indices – the Temperature-Humidity Index and the Net Effective Temperature – are computed using daily values of maximum air temperature, mean relative humidity and mean wind speed at 10 m. The analysis focuses on the relative changes in the periods 2021-2050 and 2071-2100 compared to the reference period 1970-2000. Details about the data and the methodology used here are presented in Section 2. The results are shown in Section 3 and some discussions and conclusions are given in Section 4 and Section 5, respectively.

2. DATA AND METHODS

In order to investigate the future potential changes in the summer thermal discomfort conditions in Romania, we used results of high resolution numerical simulations performed within EURO-CORDEX framework (Jacob et al, 2014). The EURO-CORDEX projections downscale the global climate simulations from the CMIP5 long-term experiments up to the year 2100. The results currently available are based on greenhouse gas concentration scenarios (Representative Concentration Pathways, RCPs): (a) one corresponding to stabilization of radiative forcing after the 21st century at 4,5 W/m² (RCP 4.5) and (b) the other with radiative forcing reaching 8,5 W/m² at the end of 21st century (RCP 8.5); a limited number of projections consider also the third scenario, characterized by peaking radiative forcing within the 21st century at 3,0 W/m² and declining afterwards (RCP 2.6) (Moss et al., 2010 and 2008; Nakicenovic et al., 2000; Van Vuuren et al., 2008).

In this study we use the results of four regional climate models (Christensen et al., 1998; Meijgaard van et al., 2012; Kupiainen et al., 2011; Farda et al., 2010) provided by the EUROCORDEX experiment (Giorgi et al., 2009; Jacob et al., 2014). The results of the historical runs (1971-2000) are used to establish the model climatology and further, as a reference for changes in the near-future (2021-2050) and on longer term (2071-2100). A high-resolution observation-based dataset, representative for the Romanian territory, is used as an independent reference for the period 1971-2000. ROCADA (Romanian ClimAtic Dataset; Dumitrescu & Birsan, 2015) provides a daily gridded climatology at the spatial resolution of 0.1x0.1 degrees for 9 meteorological parameters, based on long-term observational records from 150 Romanian meteorological stations. The data is freely available on request on the PANGAEA data portal (doi.pangaea.de/10.1594/PANGAEA.833627)

The analysis makes use of two thermal indices - the temperature-humidity index (THI) and the net effective temperature (NET).

THI is one of the thermal stress indices recommended by WMO (2004) and defined (e.g. Dobrinescu et al., 2015) by the formula:

$$THI = (T*1.8+32) - \\ -(0.55-0.55*RH/100)*(T*1.8-26) \quad (1)$$

where T is the air temperature (°C) and RH is the relative humidity (%). THI gives an estimate of the temperature felt by human body, being relevant for the warm season and especially for conditions with high humidity, when the adjustment of human body to the heat stress through the transpiration process is impeded. In Romania, THI is used to characterize thermal discomfort during warm season and it is routinely forecasted and disseminated to population from May to September. It is also used in the Romanian legislation to define extremely high temperature episodes: these conditions are met when either air temperature exceeds 37°C or the equivalent felt temperature, expressed through THI values, exceeds 80 units. For the Romanian territory, long term changes and physical mechanisms controlling the variability of THI for the period 1961-2010 have been analyzed by (Dobrinescu et al, 2015). They show a significant upward trend of this index over the entire country and a significant increase in the frequency of high values of THI after 1985. In the present study, the occurrence of cases with THI≥80 units expressed as long-term average seasonal number of days (nTHI) is analyzed, thus corresponding to the practical use of the index in Romania.

The Net Effective Temperature (Li & Chan, 2000) takes into account, along with air temperature and humidity, the effect of wind on the temperature felt by the human body, being valid for both warm and cold seasons. NET is computed according to the following formula (2) (Li & Chan, 2000), where T is the air temperature (°C), v denotes the wind speed (m/s), and RH is the relative humidity (%):

$$NET = 37 - \frac{37 - T}{0.68 - 0.014RH + \frac{1}{1.76 + 1.4v^{0.75}}} - 0.29T(1 - 0.01RH) \quad [^{o}C] \quad (2)$$

NET, just like THI, depends closely on temperature and humidity, but the inclusion of wind effect makes this index usable for cold conditions too.

We use NET index to outline extreme thermal discomfort situations compared to the local climatological conditions. More specifically, we determine the 97.5% percentile of NET (p97.5) for each grid point and each month during the warm season (May-September). As this threshold is closely related to the local climatic conditions, it is considered that people of a particular place will feel stressfully hot when the value of NET is higher than this threshold (WMO 2004; Li & Chan, 2000). In this study, we first determine the monthly distribution of NET threshold values based on modelled and observational-based data for the reference period 1971-2000. Next, we compute the frequency of occurrence of NET values above this threshold (fNET) in the context of climate change scenarios in comparison with the frequency during reference period 1971-2000. Changes of fNET in the context of climate change scenarios may be interpreted as the occurrence of events considered ‘rare’, in terms of thermal discomfort, in the past (1971-2000).

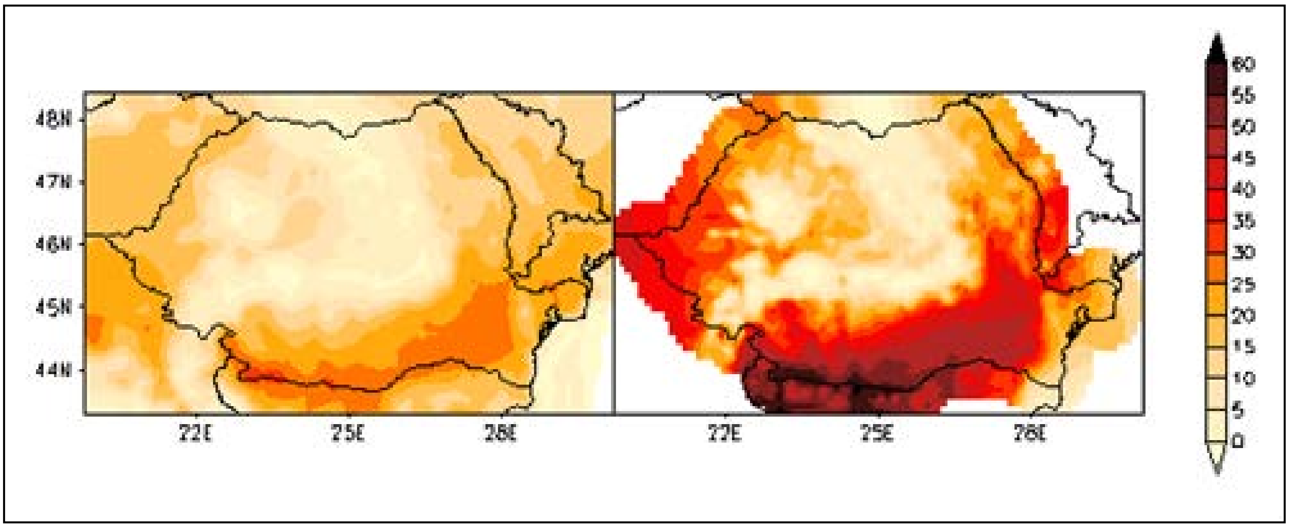
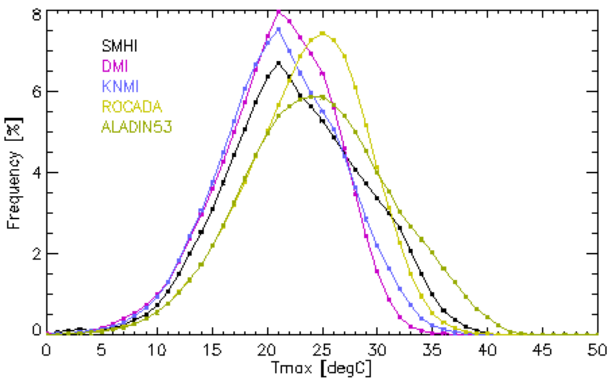
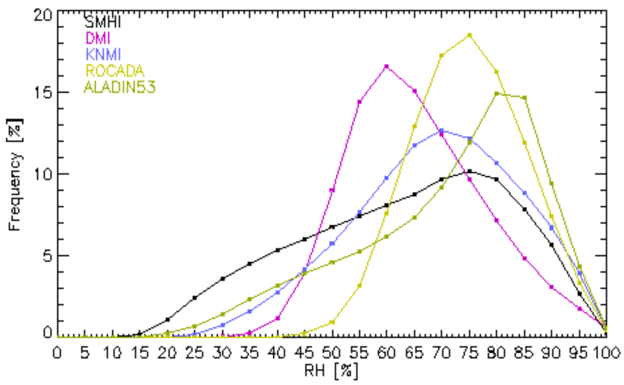


Figure 1. Seasonal mean number of days with THI≥80 for May-September during 1971-2000, from EURO-CORDEX simulations (mean of 4 models) (left) and ROCADA dataset (right).



(a)



(b)

Figure 2. Distribution of (a) daily maximum temperatures and (b) daily mean relative humidity over the Romanian territory during May-September 1971-2000, based on 4 EUROCORDEX simulations and ROCADA dataset.

3. RESULTS

The analysis of numerical simulations for the reference period 1971-2000 shows the highest seasonal number of days with pronounced thermal discomfort (THI ≥80 units) in the south-south-east (25-30 days) (Fig. 1), followed by the western part of the country (20-25 days).

There is a good agreement with results based on ROCADA dataset regarding the spatial pattern of the seasonal number of days with pronounced thermal discomfort. However, ROCADA indicates a much larger seasonal number of these situations –up to 55 days in the extreme south-west, gradually decreasing to 30-40 days in the west, south and south-east. At monthly scale (not shown) ROCADA indicates that S-SW regions experience, in July and August, up to 20 days with THI above the warning values, while in May and September there are up to 6 days, on average, with thermal discomfort. The lower values of nTHI in the numerical simulations are probably due to the underestimation of maximum air

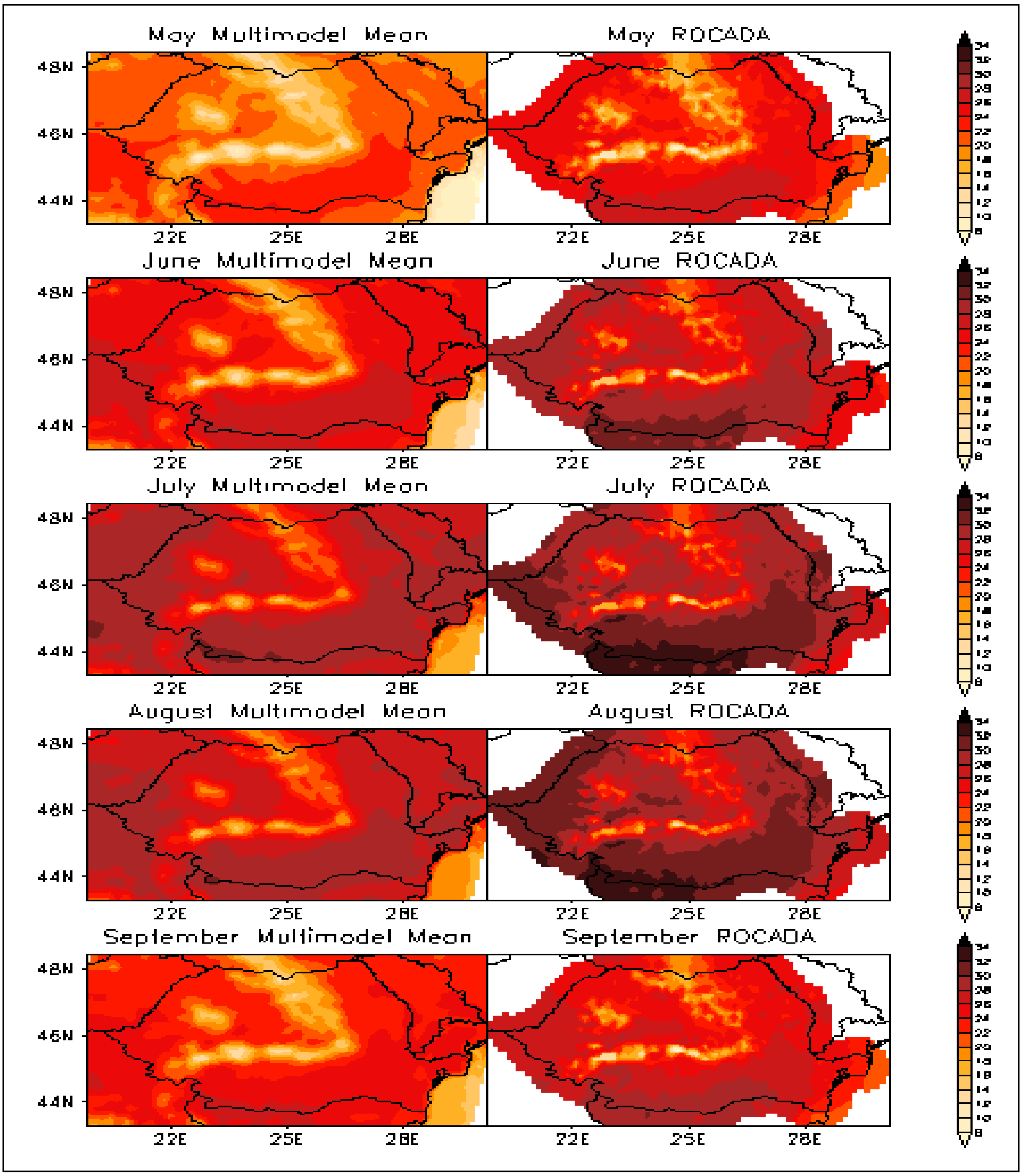


Figure 3. Spatial distribution of the 97.5% percentile of NET for period 1971-2000, based on EURO-CORDEX simulations (left column: mean of four models) and ROCADA dataset (right column).

temperature, as shown for example by (e.g. Kotlarski et al, 2014), which indicates SMHI and KNMI models among the coldest of EURO-CORDEX members analyzed there. The distribution frequencies of daily mean values of maximum air temperature and mean relative humidity from the datasets employed here, for the period 1971-2000 and only for the Romanian territory (Fig. 2) also indicates that all RCM employed are colder and drier than ROCADA.

The spatial distribution of the 97.5% percentile of NET for period 1971-2000 is shown in figure 3. The largest values are found in July and August, in the southern regions, both in the numerical simulations (p97.5 around 30-32 ºC), as well as in the observation-based dataset (p97.5 above 32 ºC). The underestimation in the numerical simulations compared with ROCADA is visible for this index too. It may be explained, just like for THI, by lower air temperatures in the simulations, as for both indices the air temperature has the larger weight in the respective formulas. The underestimation of the modelled p97.5 values is more pronounced in the western part of the country and over mountainous areas, during May and June (up to 4ºC).

The results of the numerical simulations are further investigated with respect to nTHI and fNET by comparison with the reference period, for climate change scenarios RCP 4.5 and RCP 8.5 (Fig. 4). In the near term (2021-2050) the number of days with thermal discomfort situations described by THI increases during May-September with up to 9-12 days, mainly in the western and southern regions, under both scenarios. On longer term (2071-2100) the results based on the RCP 8.5 scenario suggest a dramatic increase of cases with pronounced thermal discomfort over almost the entire territory, with maximum values in the southern region – up to 42 additional days with high THI values in the Baragan area. The increase is reduced to about half of these values, especially for the southern area, under RCP 4.5 scenario. Overall, both climate change projections suggest a significant increase of cases with strong thermal discomfort over the entire territory, more pronounced in the southern and western areas and during 2071-2100 period.

Another perspective on the potential changes in the occurrence of thermal discomfort situations during the warm season is given by the analysis of cases with NET values considered rare during the reference period. The monthly spatial distribution of fNET under RCP 4.5 and RCP 8.5 scenarios is presented in figure 5. During June-August, an increase of fNET with up to 10% is found for most of the territory, under both scenarios, for period 2021-2050. In May and September, the western region (RCP 4.5) or even the entire territory (May, RCP 8.5) experiences more often stressful weather conditions in terms of high NET values (fNET between 5-10%) although the increase in nTHI for these regions in the respective months is negligible (not shown).

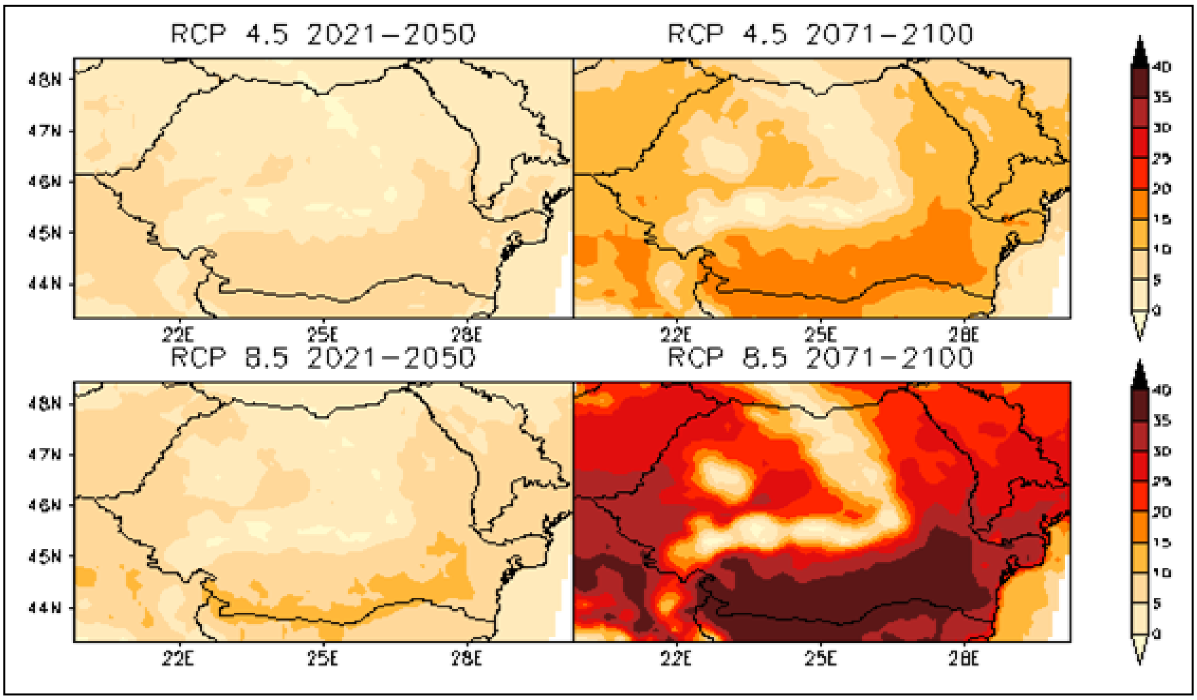


Figure 4. Seasonal relative changes in the number of days with THI≥80 for May-September during 2021-2050 (left column) and 2071-2100 (right column), under scenarios RCP 4.5 (upper row) and RCP 8.5 (lower row), compared to 1971-2000, based on simulations from EURO-CORDEX of four RCM models (mean of the four models).

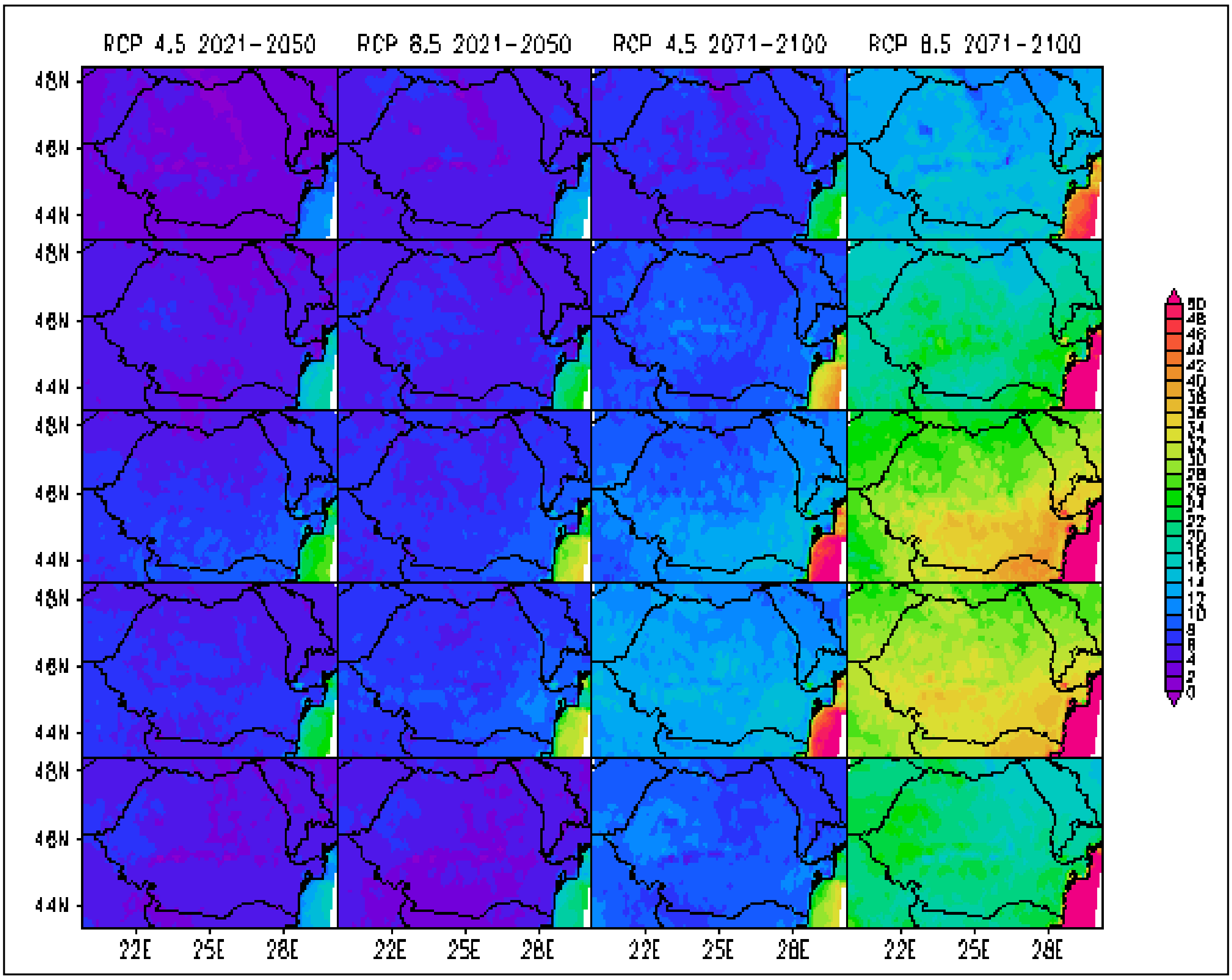


Figure 5. Relative changes [%] of frequency of occurrence for NET ≥ p97.5% for May-September (rows) during 2021-2050, scenarios RCP 4.5 and RCP 8.5 (left columns) and 2071-2100, scenarios RCP 4.5 and RCP 8.5 (right columns), compared to 1971-2000, based on simulations from EURO-CORDEX of four RCM models.

A similar result is found for the 2071-2100 period under RCP 4.5 scenarios: during May and September a higher occurrence of thermal discomfort situations, as defined by NET, is found for large areas, while the nTHI for the same months does not show noticeable changes compared to the reference period. For the RCP 8.5 scenario, the changes of fNET, just like for nTHI, are the strongest, with maximum values in the western and southern regions during July, followed by August. During May and September, under both scenarios, the changes in fNET are larger than those in nTHI over the entire territory.

It should be noted that over mountainous and surrounding areas changes in nTHI values are close to zero, while fNET show significant increases (up to 35% during July, under RCP 8.5 scenario for period 2071-2100) compared to the reference period. Thus, meteorological conditions considered 'rare' in these regions in the summer during the reference period will occur more often and will possibly be experienced as associated with thermal discomfort, although not matched by THI values above the threshold.

4. DISCUSSIONS

Overall, the analysis based on bio-meteorological thermal indices THI and NET indicates a continuously amplifying heat stress over the Romanian territory toward the end of the century, more noticeable in the context of RCP 8.5 scenario. The results are in agreement with other studies focusing on global scale (e.g. Zhao et al., 2015, Scoccimaro et al., 2017, Coffel et al., 2018) although they employ different thermal stress indices (wet bulb temperature, humidex, apparent temperature etc.)

The impact of elevated heat stress will be even higher in the urban areas (e.g. Wouters et al, 2017), where the urban heat island (UHI) effect adds on the environmental conditions leading to higher air temperatures in the inner parts of the cities than in the surrounding areas. The most evident impact relates to the health sector, where issues like aggravation of pre-existing health-conditions, increased air-pollution, and increased number of heat-related deaths are likely to become more pronounced with the intensification or prolonged duration of heat-stress conditions (Petkova et al., 2014; Gasparini et al., 2017). As an example, Romanian media reports indicate that an increase of about 20-30% in the emergency solicitations (ambulance calls) was recorded during the intense heat periods in July 2015 in the major cities of Romania affected by these weather conditions; in the same time, medical assistance was provided 'on the spot' to a large number of people, by the medical teams and volunteers based in the tents installed by the local authorities in the cities. The projected evolution of population in urban areas for Romania (Bojariu et al., 2015) suggests that more people will be exposed in the future to the combined effect of hot meteorological conditions and that of the urban heat island. In addition, the increasing trend in elderly population (from 15% of total country population in 2012 to up to 26.8% in 2060, according to (NIS, 2014)) will contribute to the increase of cities vulnerability to heat-related hazards, requiring effective strategies for reduction of social impact of climate changes in urban areas.

5. CONCLUSIONS

The analysis of climate change projections under RCP 4.5 and RCP 8.5 scenarios shows that conditions of thermal discomfort during the warm season are likely to become more frequent over the Romanian territory in the future. Weather situations characterized by THI index above the threshold of 80 units will have a higher frequency in the western and southern areas. Under the RCP 8.5 scenario, the period 2071-2100 is marked by the largest increase in the seasonal number of cases with THI $\geq$ 80 compared to the reference period: more than 40 additional days in the Baragan Plain, slowly decreasing to 20-30 days in the other regions, except for the mountainous areas where the increase is in the range 2-10 days. The RCP 4.5 scenario for the same period describes a more moderate increase yet reaching almost 20 days in the south.

The investigation of changes in the occurrence of high NET values indicates that even for regions where THI does not present a significant increase, hot stressful weather situations will also become more frequent. Both climate change scenarios suggest that combinations of temperature, humidity and wind occurring rarely during the reference period will be experienced more often over almost the entire territory. This is more relevant for the months May and September, when the occurrence of these situations is not associated with high THI values. In the mountainous and surrounding regions, changes in the occurrence of THI above the threshold are negligible under both scenarios, but the frequency of NET values considered rare in the past increases during all months in the warm season. For regions where frequencies of both THI and NET above the thresholds show a noticeable increase, the thermal discomfort may be significantly accentuated, as these regions – especially the western and southern areas – already presented a large number of hot-weather events during the reference period.

The soundness of these findings is limited by the number of RCM models employed. The uncertainty induced by these limitations regards in particular the magnitude of increase in the number of events with strong thermal discomfort, but it relates also to the spatial distribution and variability of the indices analyzed. For urban areas, other thermal indices (e.g. PET - Physiological Equivalent Temperature, UTCI – Universal Thermal Climate Index) may be more appropriate to describe the intensity of thermal discomfort at the scale and in the specifics of built-in environments.

Acknowledgements

This study was partially carried out in the frame of the ERA4CS-INDECIS project, GA690462/2016. The authors thank the climate modelling groups of the EURO-CORDEX initiative for producing and making their model output available.

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Received at: 17. 04. 2018
Revised at: 09. 05. 2018
Accepted for publication at: 10. 05. 2018
Published online at: 14. 05. 2018