PAST AND FUTURE HEAT WAVES IN CENTRAL/EASTERN EUROPE - CASE STUDY FOR HUNGARY USING PRECIS SIMULATIONS

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1. INTRODUCTION

Human health is very likely affected by regional consequences of global warming. One of the most severe impacts is probably associated to temperature-related climatological extremes, such as heat waves. In the coming decades hot conditions in most regions of the world (including Central/Eastern Europe) are very likely to occur more frequently and more intensely than in the recent decades (IPCC, 2007, 2012). Our previous studies (e.g., Bartholy et al., 2009a, 2010, Pieczka et al., 2010, 2011, Pongracz et al., 2011a) already evaluated the projected temperature changes for the selected European region. However, in order to develop adaptation and mitigation strategies on local scale, it is essential to analyze the projected changes related to warming climatic conditions including heat waves.

In this paper, the heat health watch warning system developed in Hungary is introduced in the next section. Then, the regional climate model (RCM) experiments are briefly described, which considered three different emission scenarios, namely, SRES A2, A1B, and B2 (Nakicenovic and Swart, 2000). Moreover, the necessary bias correction of the raw simulation outputs is justified. Finally, the results for the Central/Eastern Europe are discussed and summarized with special focus on the grid points representing Hungary.

2. WARNING LEVELS OF HEAT WAVES

Definition of heat wave has not been standardized yet, several different definitions exist and are used throughout the World. They generally refer to a definite period of time, during which the air temperature is above a threshold. This threshold varies geographically, since different countries, different regions applies different threshold values. For instance, the World Meteorological Organization (WMO) recommended the following definition: heat wave is considered for the period when the daily maximum temperature for more than five consecutive days exceeds the 1961-1990 average daily maximum temperature by 5 °C. This definition is used in the analysis accomplished and suggested in the frame of the European Climate Assessment & Dataset (ECA&D) project (Klein Tank and Können, 2003) as well, as the regional analysis completed for the Carpathian basin (Bartholy and Pongrácz, 2007).

In 2004, a Heat Health Watch Warning System was developed on the basis of a retrospective analysis of mortality and meteorological data (Páldy et al., 2005) in Hungary to anticipate heat waves that may result in a large excess of mortality. In the frame of this recently introduced Health Watch System, three levels of heat wave warning are applied. They are associated to the daily mean temperature values, as presented in Table I.

Table I: Heat wave warning levels applied in Hungary (T_{mean} indicates the daily mean temperature)

Levels	Criteria
Level 1: Advisory signal (Internal use)	T_{mean} > 25 °C
Level 2: Warning signal (Public alert)	T_{mean} > 25 °C for min. 3 consecutive days
Level 3: Alarm signal (Strict control)	T_{mean} > 27 °C for min. 3 consecutive days

In the frame of the Health Watch System, the following preventive actions are listed and suggested to take within the country.

Level 1: The emergency services should prepare for the expected increase in patient traffic.

Level 2: (i) Use of media communications (TV, radio), web site, newsletters, flyers, (ii) Telephone emergency service, (iii) Distribution of water and fan on public places, (iv) Air conditioned rooms open for public use, (v) Water and electricity suppliers suspend the cut-off of not paying clients.

Level 3: Strict control of the actions must be taken in case of Level 2.

3. DATA AND METHODOLOGY

For the presented analysis simulated temperature outputs of RCM PRECIS experiments are used. PRECIS is a high resolution limited area model with 19 vertical atmospheric levels and 4 soil layers (Wilson et al., 2007). The model was developed at the Hadley Climate Centre of the UK Met Office (Wilson et al., 2007), and it has been adapted (Bartholy et al., 2009b) for the domain shown in Fig. 1 using 0.22°×0.22° horizontal resolution (~25 km). The entire integration area contains 123x96 grid cells. The initial and the lateral boundary conditions for the RCM experiments are taken from the HadCM3 ocean-atmosphere coupled

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GCM (Gordon et al., 2000) using ~150 km as a horizontal resolution. Model PRECIS is based on the atmospheric component of HadCM3 using a hydrostatic approach and substantial modifications to the model physics (Jones et al., 2004). Our PRECIS experiments take into account the SRES A2, A1B, and B2 scenarios (Nakicenovic and Swart, 2000). Among them A2 scenario is the least optimistic, and B2 is the most optimistic, which is indicated by the global CO_2 concentration level estimated for 2100 (A2: 856 ppm, A1B: 717 ppm, and B2: 621 ppm).

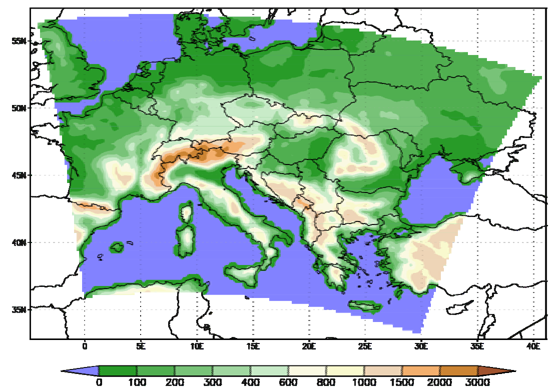

Fig. 1: Topography of the selected Central European integration domain of model PRECIS used in the present analysis.

In order to estimate the bias of the RCM simulation, raw outputs from the 1961-1990 reference period are compared to the E-OBS datasets (Haylock et al., 2008) containing gridded daily mean temperature values. For instance, significant overestimation of temperature has been found in summer (Fig. 2) when heat waves potentially might occur, thus, raw simulated data needed to be corrected before determining the heat wave warning levels.

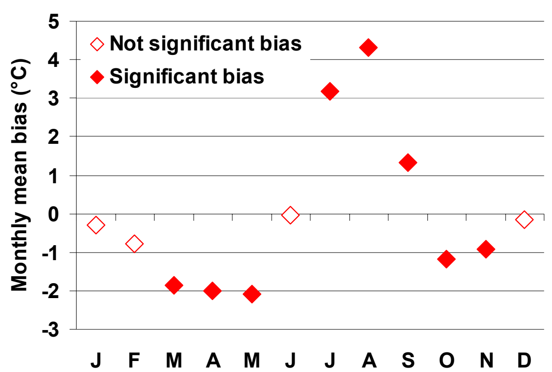

Fig. 2: Monthly mean temperature bias values (°C) for the grid cell representing Budapest (Hungary) 1961-1990.

The bias of the raw PRECIS outputs are corrected using the monthly empirical distribution functions (Formayer and Haas, 2010), and then, calculations of heat wave occurrence are accomplished from the corrected temperature data sets for each grid cell. For instance, in the grid cell close to Budapest, Hungary (geographical latitude and longitude of the RCM grid cell are 47°34' N and 19°2' E, respectively), daily mean temperature values averaged over the month during 1961-1990 are overestimated in July and August (by 3.1 °C and 4.2 °C, respectively). In June temperature simulations do not contain significant bias in this grid cell (Fig. 2).

After applying the additive bias correction factor to the monthly distribution of daily temperature, the corrected simulation data perfectly fit to the control measurements (Fig. 3).

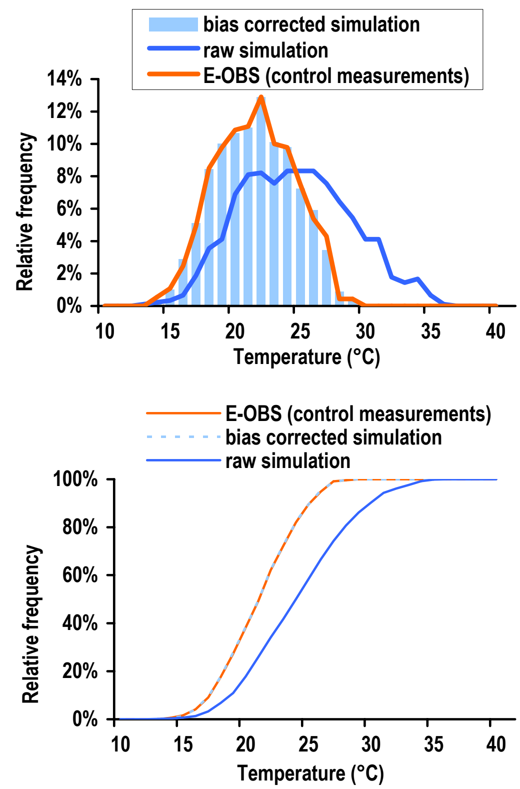

Fig. 3: Effect of bias correction on the distribution of daily mean temperature data for the grid cell representing Budapest (Hungary) in July, 1961-1990.

The applied bias correction to raw temperature outputs of PRECIS model experiments substantially improved our previous analysis (Pongracz et al., 2011b).

4. ANALYSIS OF FUTURE TRENDS IN HEAT WAVE OCCURRENCE FREQUENCY AND SCHEDULE

Heat wave occurrences are calculated from the bias corrected simulated temperature time series of PRECIS experiments for three periods (1961-1990, 2021-2050, and 2071-2100) for all the three warning levels. Moreover, frequency values for 2071-2100 are determined for the three different emission scenarios. Then, the projected changes by 2021-2050 and by

2071-2100 are determined relative to the 1961-1990 reference period for each grid cell of the domain.

At the grid cell representing Budapest heat wave warning conditions occurred 7 times (Level 1) in a year, once per year (Level 2), and only once per decade (Level 3) on average in the reference period (1961-1990). During the last three decades of the 21st century heat wave warning level 1 conditions are projected to occur 39 times, 39 times, and 56 times in a year on average taking into account B2, A1B, and A2 scenarios, respectively. Naturally, level 2 and 3 conditions are likely to occur fewer times in the future than level 1 conditions, however, similarly to level 1, significantly more frequent warning events are projected by 2071-2100 than in 1961-1990. The future annual average level 2 occurrences are 4, 5, and 5 in case of B2, A1B, and A2 scenarios, respectively. The future annual average level 3 occurrences are 2, 3, and 4 in case of B2, A1B, and A2 scenarios, respectively. The 30-year variances are illustrated by the Box-Whisker plot diagram of Fig. 4. The small rectangles indicate the middle half of the simulated annual occurrences, and the vertical lines are drawn from the minimum to the maximum projected annual occurrences.

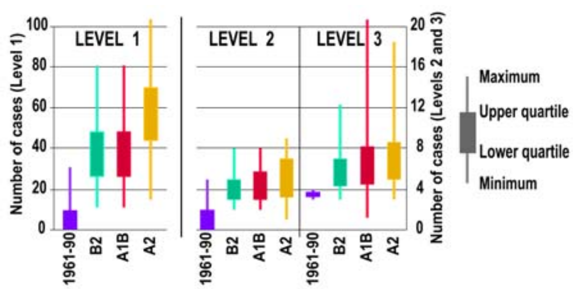

Fig. 4: Simulated occurrences of heat wave warning levels at the grid cell representing Budapest during 2071-2100 compared to the 1961-1990 reference period

The simulated average durations of level 2 and 3 conditions for the grid cell representing Budapest are summarized in Tables II and III, respectively. The remarkable intensity increase can be clearly identified both for the middle and the end of the century compared to the 1961-1990 reference period. In case of A2 scenario the projected increase rates by 2071-2100 are 100%. The standard deviation values indicate the variability of length of different warning level conditions.

Table II: Simulated lengths of heat wave warning level 2 at the grid cell representing Budapest.

Period/scenario	Average (days)	Standard deviation (days)
1961-1990/CTL	5	2
2021-2050/A1B	6	4
2071-2100/B2	8	5
2071-2100/A1B	9	5
2071-2100/A2	10	5

Table III: Simulated lengths of heat wave warning level 3 at the grid cell representing Budapest.

Period/scenario	Average (days)	Standard deviation (days)
1961-1990/CTL	4	1
2021-2050/A1B	5	1
2071-2100/B2	6	2
2071-2100/A1B	7	7
2071-2100/A2	7	3

The spatial structures of the average annual number of heat warning cases based on simulated temperature, and thus, the projected changes for the whole country are shown in Figs. 5, 6 and 7 for level 1, 2 and 3, respectively.

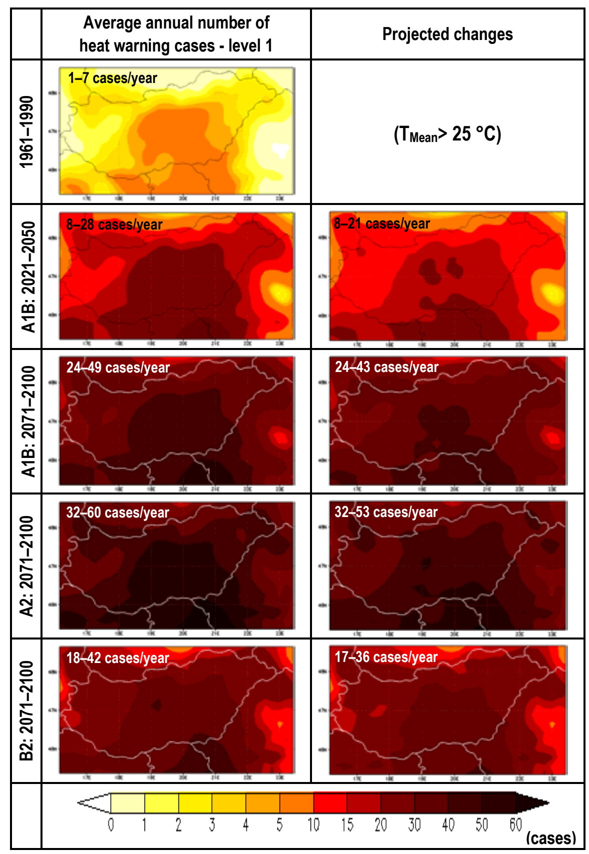

Fig. 5: Simulated occurrences of heat wave warning level 1. Projected changes are calculated relative to the 1961-1990 reference period

In general, zonal structure can be recognized in all levels, namely, from North to South the number of heat warning cases is increasing and the projected changes are also increasing. Furthermore, due to the increasing warming, simulated changes are larger for 2071-2100 than for 2021-2050. By the end of the 21st century, simulated changes are larger when considering a scenario with larger estimated CO_2 concentration by 2100.

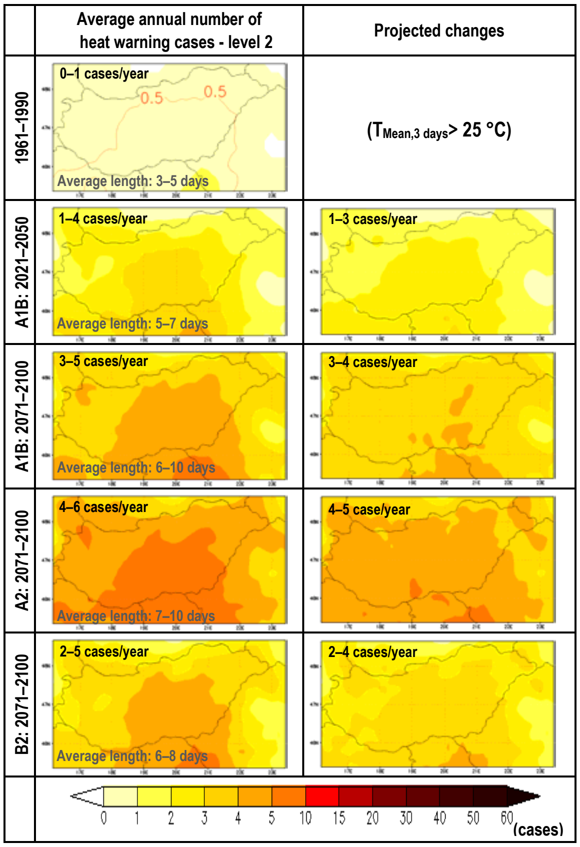

Fig. 6: Simulated occurrences of heat wave warning level 2. Projected changes are calculated relative to the 1961-1990 reference period

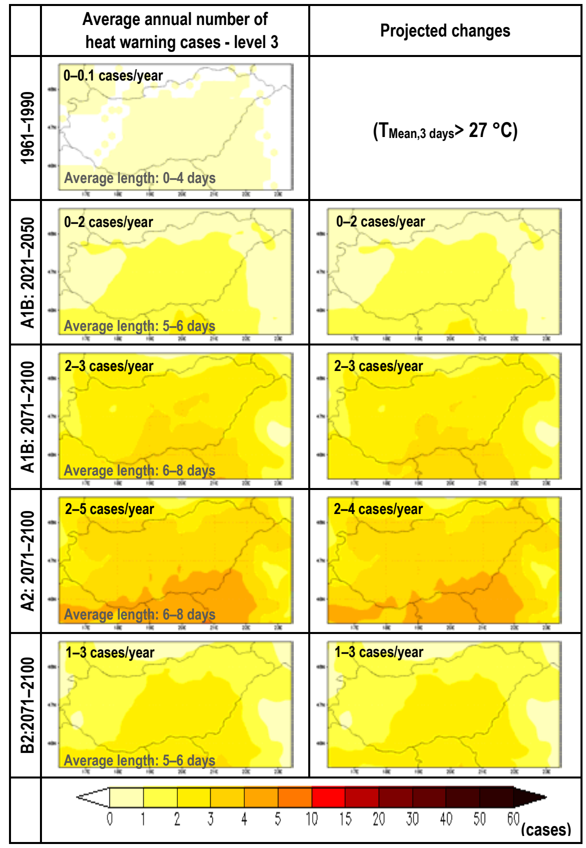

Fig. 7: Simulated occurrences of heat wave warning level 3. Projected changes are calculated relative to the 1961-1990 reference period

Besides the evaluation of heat wave occurrence frequency, dates of the first and the last occurrences of different heat wave warning levels are also analyzed for the integration domain with special focus on Hungary. The Box-Whisker plot diagrams of Figs. 8 and 9 show the results for the 229 grid cells located within the country. Letters at the right side of the diagrams indicate the 30-day long simulation month (from April to August in Fig. 8, and from May to September in Fig. 9).

The results suggest that although the interannual variability of the simulated time series during 2071-2100 are larger than in the 1961-1990 reference period, by the end of the 21st century the average start of the possible occurrence of heat warning days is simulated to shift earlier by about 1-2 months, in the meanwhile, the average last possible occurrence are very likely to shift later by about 0.5-1 month. Thus, the length of the potential heat wave season is projected to become remarkably larger in Hungary.

Similarly to the mean annual number of heat waves, the spatial structure of the occurrence schedule can also be characterized by zonal and topographical features superponed. Heat waves tend to occur earlier and last until later in the lower elevated southern regions of Hungary than in the higher elevated hilly regions.

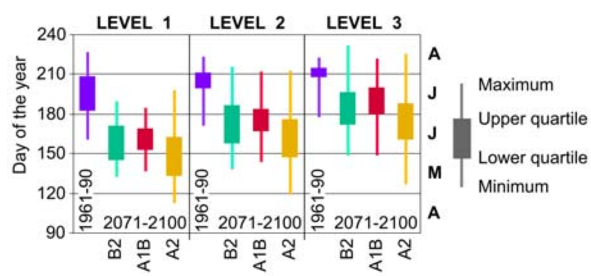

Fig. 8: Simulated first occurrences of heat wave warning levels for 1961-1990 and for 2071-2100 considering three different emission scenarios

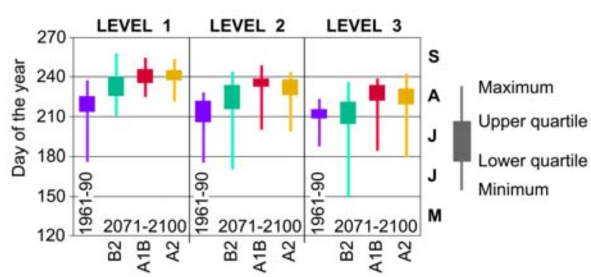

Fig. 9: Simulated last occurrences of heat wave warning levels for 1961-1990 and for 2071-2100 considering three different emission scenarios

During the 21st century these occurrence timing are likely to extend, namely, the first (last) heat wave occurrence within year is projected to shift earlier (later) than during the reference period, 1961-1990. Fig. 10 illustrates the results for heat wave warning level 1. By the end of the 21st century heat warning level 1 is possible from mid-May until mid-September, unlike in the reference period (when it occurred from mid-June until mid-August). Thus, the total length of the possible occurrence is likely to extend by about 1-2 month.

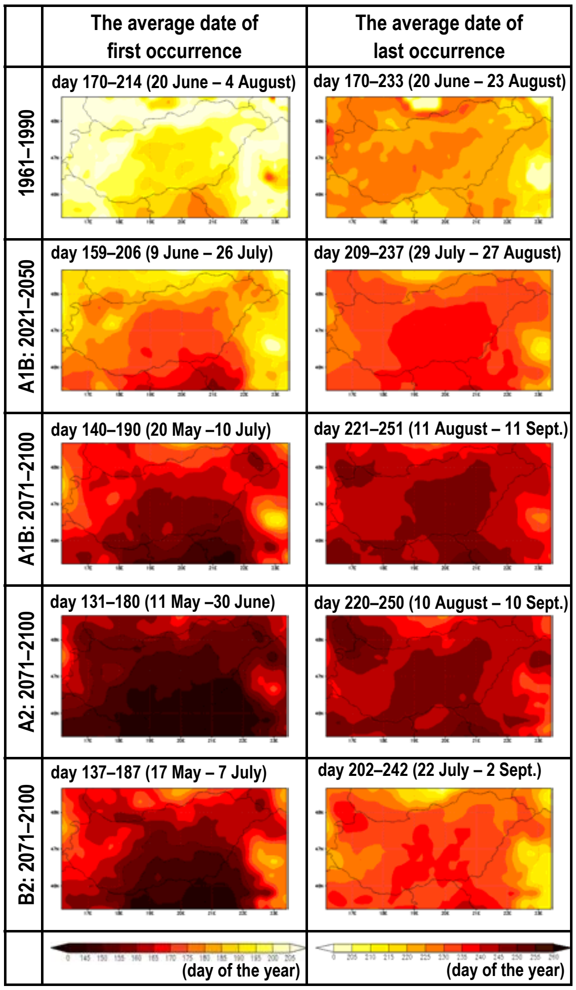

Fig. 10: Possible start and end of heat wave warning level 1 occurrence season using the bias-corrected temperature outputs of PRECIS simulation for 1961-1990, 2021-2050, and 2071-2100

6. CONCLUSIONS

Heat wave related climatic conditions of the 1961-1990 (reference), 2021-2050 and 2071-2100 (future) periods have been simulated using RCM PRECIS experiments. In the present paper the projected changes of regional heat waves in Hungary (located in Central/Eastern Europe) for the 21st century (compared to 1961-1990) have been analyzed in case of three different emission scenarios (B2, A1B, and A2). Based on the results, the following main conclusions can be drawn.

(i) Heat waves in the region are very likely to occur significantly more frequently in the 21st century than in the reference period, 1961-1990. By 2071-2100 heat wave warning level 1 and 2 conditions are projected to occur 5-7 times more frequently than during 1961-1990. Simulated frequency increase of level 3 conditions is 230-370% on average. The larger the estimated CO_2 level by 2100, the larger the projected increase.

(ii) By the end of the 21st century the average first occurrence of the heat warning days is simulated to shift earlier, and the average last occurrence later, than in the reference period – thus the length of the heat wave season is projected to become remarkably larger.

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