161 PROJECTED CHANGES OF REGIONAL HEAT WAVES IN CENTRAL/EASTERN EUROPE USING CLIMATE MODEL SIMULATIONS

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1. INTRODUCTION

The results from coarse resolution global climate models (GCM) can only be considered as a first-guess of regional climate change consequences of global warming. Regional climate models (RCM) nested in GCMs may lead to better estimations of future climate conditions in the European subregions since the horizontal resolution of these RCMs is much finer than the GCMs' (IPCC, 2007). For regional climate change studies focusing to the Carpathian basin (located in Central/Eastern Europe) four different RCMs have been adapted and used (Szepszo et al., 2008; Bartholy et al., 2009d). Two of them (PRECIS and RegCM) are run by the Department of Meteorology, Eötvös Loránd University, Budapest (Bartholy et al., 2009b; Torma et al., 2008). The other two RCMs are run by the Hungarian Meteorological Service (Csima and Horanyi, 2008, Szepszo and Horanyi, 2008): ALADIN (developed by Meteo-France) and REMO (developed by the Max Planck Institute, Hamburg).

The present paper discusses the results from the regional climate modeling experiments using PRECIS and RegCM. First, models PRECIS and RegCM are introduced, which are then used to analyze and compare the simulated heat wave frequency for three different time slices (1961-1990, 2021-2050, and 2071-2100) for Hungary. The simulations consider the A1B scenario, which projects the global population to reach 9 billion within a few decades, and then, to decrease to about 7 billion by the end of the 21st century (Nakicenovic and Swart, 2000). Furthermore, fast economical and technological growths are projected, and the estimated CO_2 concentration levels are 532 ppm (by 2050) and 717 ppm (by 2100). Besides the evaluation of heat wave frequency, estimated dates of the first and last occurrences are also discussed. Finally, the main conclusions are summarized in the last section.

2. REGIONAL CLIMATE MODEL PRECIS

PRECIS is a high resolution limited area model with 19 vertical atmospheric levels and 4 soil layers (Wilson et al., 2005). The model was developed at the Hadley Climate Centre of the UK Met Office (Wilson et al., 2005), and it has been adapted (Bartholy et al., 2006) for the domain shown in Fig. 1 using 0.22°×0.22° horizontal resolution (~25 km). The entire integration area contains 123x96 grid points. The PRECIS regional climate model is based on the atmospheric component of HadCM3 (Gordon et al., 2000) using a hydrostatic approach and substantial modifications to the model physics (Jones et al., 2004).

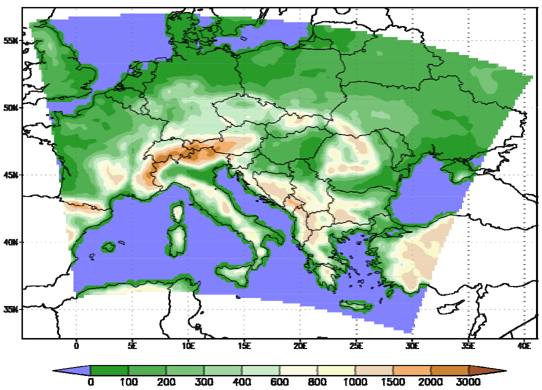

Fig. 1: Topography of the selected Central European integration domain of model PRECIS used in the present analysis.

In case of the control period (1961-1990), the initial and the lateral boundary conditions for the regional model are taken from (i) the ERA-40 reanalysis database (Uppala et al., 2005) using 1° horizontal resolution, compiled by the European Centre for Medium-range Weather Forecasts (ECMWF), and (ii) the HadCM3 ocean-atmosphere coupled GCM (Gordon et al., 2000) using ~150 km as a horizontal resolution. Detailed validation of the PRECIS results for Central/Eastern Europe can be found in Bartholy et al. (2009b). According to the simulation outputs, PRECIS is able to sufficiently reconstruct the climate of the reference period in the Carpathian Basin (Bartholy et al., 2009a, 2009b). Temperature bias of PRECIS simulations (i.e., the difference between simulated and observed annual and seasonal mean temperature) is found mostly within (-1 °C;+1 °C), which can be considered acceptable if compared to other European RCM simulations (Jacob et al., 2007, Bartholy et al., 2007).

PRECIS model experiments for A2 and B2 scenarios are evaluated in Bartholy et al. (2009c, 2010) and Pieczka et al. (2010). In this paper, transient model experiment for the Central/Eastern European domain is used covering the 1951-2100 period taking into account the A1B scenario (Nakicenovic and Swart, 2000).

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3. REGIONAL CLIMATE MODEL REGCM

Regional climate model RegCM stems from the National Center for Atmospheric Research/ Pennsylvania State University (NCAR/PSU) Mesoscale Model version MM4 (Dickinson et al., 1989; Giorgi, 1989). It is a 3-dimensional, sigma-coordinate, primitive model. It was originally developed by Giorgi et al. (1993a, 1993b) and later modified and improved by Giorgi and Mearns (1999) and Pal et al. (2000). The latest version of this model is RegCM3.1 and it is currently available from the Abdus Salam International Centre for Theoretical Physics (ICTP). Model RegCM has been adapted (Torma et al., 2008) to the domain shown in Fig. 2 containing 120x100 grid points with 10 km horizontal resolution and 18 vertical atmospheric levels using σ-coordinates.

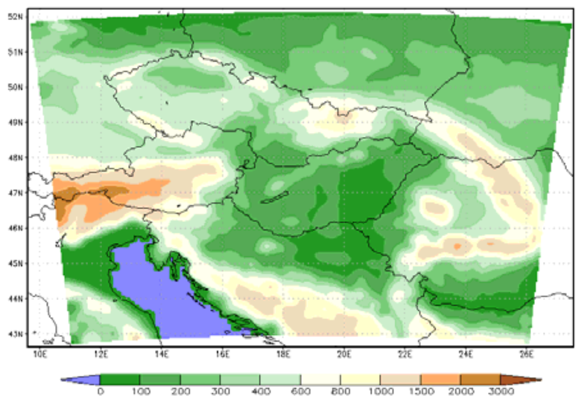

Fig. 2: Topography of the selected Central European integration domain of model RegCM used in the present analysis.

Validation of the model experiments using ERA-40 driving data (Uppala et al., 2005) can be found in Torma et al. (2008). The annual mean temperature bias is less than 0.05 °C for Hungary. Moreover, the seasonal bias values are -0.5 °C in spring and summer, and -0.2 °C for fall (Pongracz et al., 2010). Detailed analysis of the results of the model experiments for 2021-2050 and 2071-2100 using driving data provided by ECHAM5 GCM (Roeckner et al., 2006) are evaluated in Pongracz et al. (2010) and Torma et al. (2011).

4. WARNING LEVELS OF HEAT WAVES

Heat wave events are important temperature-related climatological extremes due to their impacts on human health. In the future, they are very likely to occur more frequently and more intensely not only in the Carpathian Basin located in Central/Eastern Europe, but in most regions of the world because of global warming. In order to develop adaptation and mitigation strategies on local scale, it is essential to analyze the projected changes related to heat waves. However, there is no standardized definition of a heat wave. The existing definitions generally refer to a definite period of time, during which the air temperature is above a threshold. This threshold varies geographically, different countries, different regions use different threshold values. For instance, the World Meteorological Organization (WMO) recommended definition is the following: 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 forecasted daily mean temperature)

Heat wave warning levels	Criteria
Level 1 Advisory signal -- Internal use	T_{mean} > 25 °C
Level 2 Warning signal -- Public alert	T_{mean} > 25 °C for at least 3 consecutive days
Level 3 Alarm signal -- Strict control	T_{mean} > 27 °C for at least 3 consecutive days

In the frame of the Health Watch System, the following preventive actions should be taken.

Level 1:

- The emergency services prepare for the expected increase in patient traffic.

Level 2:

- Use of media communications (TV, radio), web site, newsletters, flyers
- Telephone emergency service
- Distribution of water and fan on public places
- Air conditioned rooms open for public use
- 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.

5. ANALYSIS OF FUTURE TRENDS IN HEAT WAVE OCCURRENCE FREQUENCY

Heat wave occurrences are calculated from the simulated temperature time series of models RegCM and PRECIS for all the three periods (1961-1990, 2021-2050, and 2071-2100) for all the three warning levels. Then, the projected changes by 2021-2050 and by 2071-2100 are determined relative to the 1961-1990 reference period for each grid points of the selected domain. Figs. 3 and 4 illustrate the results for heat wave warning level 1 using the RegCM and the PRECIS simulations, respectively. In the left column of the figures the annual average number of heat warning cases is presented for the three time slices, and in the right column the projected changes can be seen for 2021-2050 (upper map) and 2071-2100 (lower map).

Using the RegCM temperature outputs in all the three periods zonal structure can be observed (Fig. 3), which is a consequence of the zonal structure of the solar radiation. The annual number of heat wave warning level 1 is larger in the southern part of Hungary than in the northern regions. In addition to this zonality, the topography of the country also affects the spatial structure. Thus, less heat wave occurs in the higher elevated hilly regions (Transdanubian and Northern Hills in the western and in the northern parts of the country, respectively, and Mecsek Hills near the southwestern border) than in the lower elevated plain areas. For instance, in the reference period (1961-1990) the average annual number of the heat wave warning cases is 1-3 days in the northern hilly part, and 9-12 days in the plain southern part.

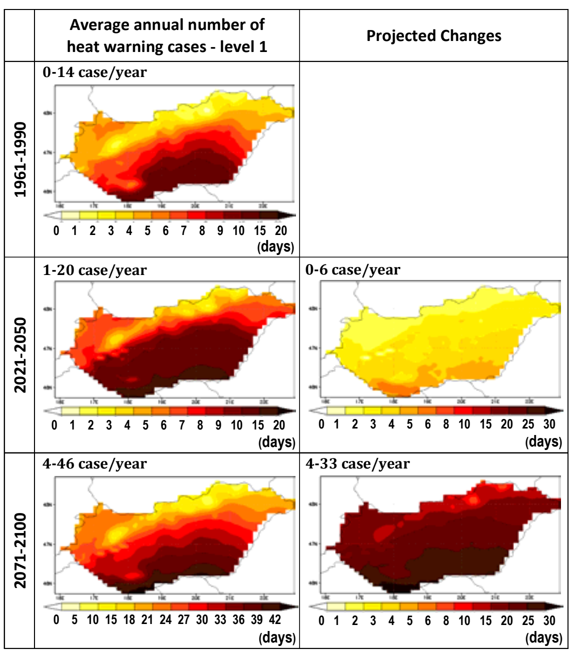

Fig. 3: 30-year average (on the left), and the projected difference (on the right) of heat wave warning cases level 1 (T_{mean} > 25 °C) using RegCM simulations for 1961-1990, 2021-2050, and 2071-2100

The heat wave occurrence is clearly projected to increase over the whole country (right maps of Fig. 3): the frequency of heat wave warning cases is likely to increase by 2-5 days (10-20 days) by 2021-2050 (by 2071-2100) relative to 1961-1990. The projected changes are evidently much larger by the late-century than the mid-century. The largest changes (30 days increase by 2071-2100) are simulated for the southern Transdanubian region.

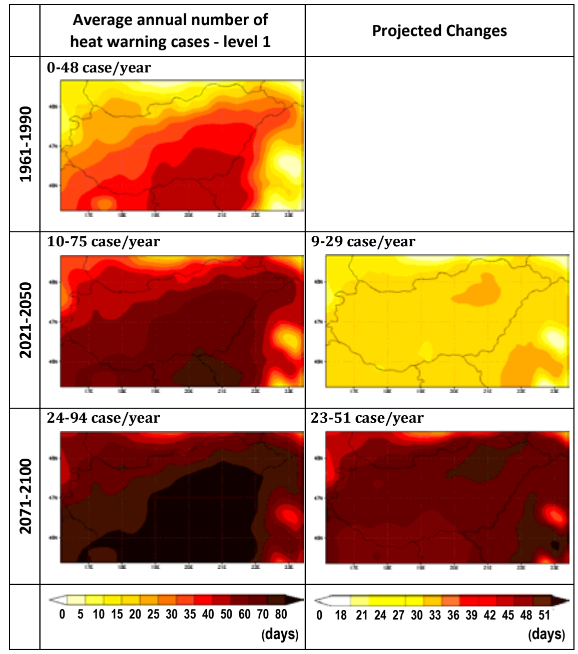

Fig. 4: 30-year average (on the left), and the projected difference (on the right) of heat wave warning cases level 1 (T_{mean} > 25 °C) using PRECIS simulations for 1961-1990, 2021-2050, and 2071-2100

The spatial structures of annual number of heat wave warning level 1 for all the three periods using the simulated temperature outputs from PRECIS experiment (Fig. 4) are similar to those using RegCM outputs. However, the annual values are larger using the PRECIS outputs than the RegCM outputs. Consequently, the projected increase both by the mid- and the late-century are larger on these maps than what can be seen in Fig. 3. The frequency of heat wave warning cases is likely to increase by 24-30 days by 2021-2050, and by 40-50 days by 2071-2100 in Hungary.

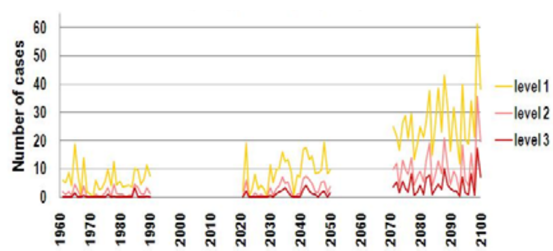

Fig. 5: Average number of heat wave warning cases in Hungary (average of 977 grid points) using RegCM simulations

Time series of the spatial average for the grid points located within Hungary are shown in Fig. 5

using the RegCM simulations, and in Fig. 6 using the PRECIS transient run. The positive trends can be clearly seen on both graphs for all the warning levels. For instance, around the late-century heat wave warning level 3 is likely to occur as frequent as the heat wave warning level 1 in the reference period. Since the PRECIS simulation is a transient run, the linear regression trend equations for all the three warning levels are calculated using least squares fitting technique. The trend coefficients based on the 140-year-long simulation are shown in Fig. 6; the decadal increases are 4.6, 4.3, and 3.7 in case of level 1, level 2, and level 3, respectively.

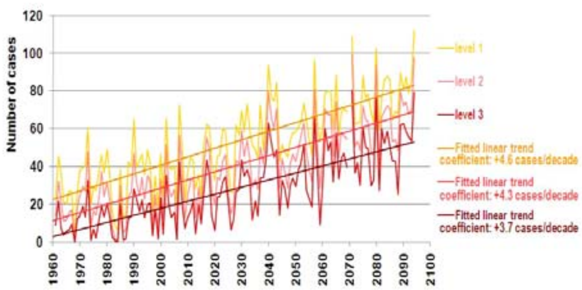

Fig. 6: Average number of heat wave warning cases in Hungary (average of 229 grid points) using PRECIS simulations

6. ANALYSIS OF FUTURE TRENDS IN HEAT WAVE OCCURRENCE TIMING

Besides the evaluation of heat wave occurrence frequency, dates of the first and the last occurrence of different heat wave warning levels are also analyzed.

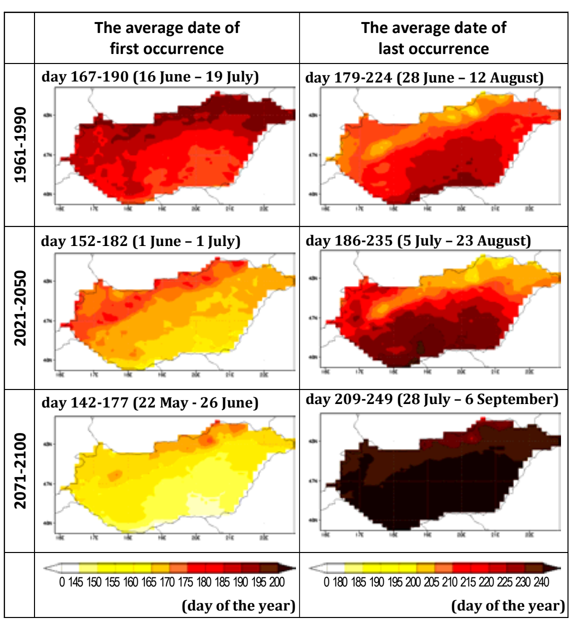

Fig. 7: Average date of the first and the last occurrence of heat wave warning level 1 using the RegCM simulations for 1961-1990, 2021-2050, and 2071-2100

Figs. 7 and 8 illustrate the analysis for level 1 using the RegCM and the PRECIS simulated temperature data sets, respectively. The left (right) column shows the first (last) occurrence of simulated heat waves within the year.

Similarly to the mean annual number of heat waves, the spatial structure of the occurrence schedule can also be characterized by a superponed zonal and topographical feature (either using RegCM or PRECIS experiment outputs). Heat waves tend to occur earlier and last until later in the lower elevated southern regions than in the higher elevated hilly regions. 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. This extension is projected by both the RegCM and the PRECIS simulation. For instance, heat wave warning level 1 will possibly be observed from late-May until early-September in the last three decades of the 21st century, whilst in the reference period it occurs from mid-June until mid-August when using RegCM simulations (shown in Fig. 7). So the total length of the possible occurrence is likely to extend by about a month by 2071-2100 according to the RegCM outputs. This extension is projected to reach 5-10 days by 2021-2050 using RegCM simulations.

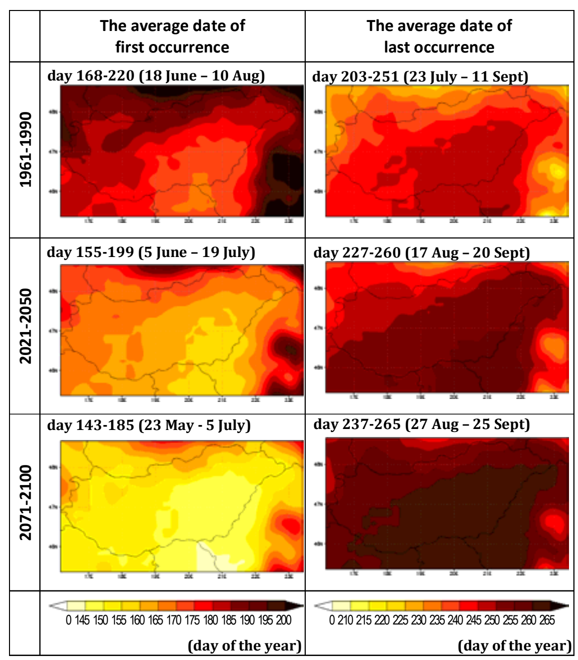

Fig. 8: Average date of the first and the last occurrence of heat wave warning level 1 using the PRECIS simulations for 1961-1990, 2021-2050, and 2071-2100

The annual values of spatial average occurrences calculated for the Hungarian grid points are shown in Fig. 9 when using RegCM simulations, and in Fig. 10 when using PRECIS simulations. Similar conclusions can be drawn from these average time series than from the 30-year temporal averages shown on the maps. According to both model simulations

(RegCM and PRECIS), by the end of the 21st century the average first occurrence of the heat warning days in Hungary is simulated to shift earlier (upper panel of Figs. 9 and 10) and the average last occurrence is likely to shift later (lower panel of Figs. 9 and 10) than in the reference period. Thus the length of the heat wave season is projected to become remarkably larger.

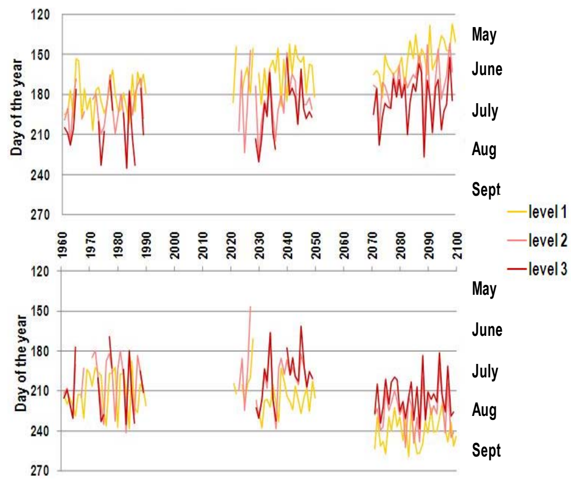

Fig. 9: Average date of the first (upper panel) and the last (lower panel) occurrence of different heat wave warning levels in Hungary (average of 977 grid points) using RegCM simulations

The results of the RegCM simulations suggest about a month extension of heat wave warning level 1 by the end of the 21st century relative to the reference period (1961-1990). The extension is projected to be about 3 weeks in case of the heat wave warning level 2. The possible start of the heat wave warning level 3 is simulated to occur 2 weeks earlier, and the possible end is projected to shift with 1-1.5 weeks later by 2071-2100, than in the reference period (Fig. 9).

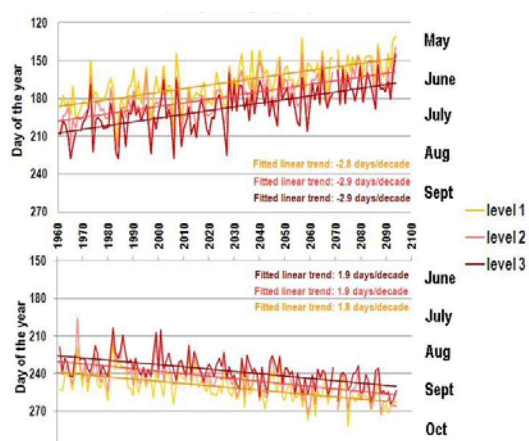

Fig. 10: Average date of the first (upper panel) and the last (lower panel) occurrence of different heat wave warning levels in Hungary (average of 229 grid points) using PRECIS simulations

Fitted linear trend is calculated based on the 140-year-long PRECIS-outputs. Thus, the results of the PRECIS simulations suggest that the heat wave warning level 1 occurs by 2.8 days/decade earlier than in the reference period (upper panel of Fig. 10). Furthermore, both warning levels 2 and 3 are tend to occur earlier by 2.9 days/decade. The heat wave warning levels 1 and 2 tend to shift later by 1.9 days/decade, and level 3 is projected to occur by 1.8 days/decade later than in 1961-1990 (lower panel of Fig. 10).

7. CONCLUSIONS

Heat wave related climatic conditions of the 1961-1990 (reference), 2021-2050 and 2071-2100 (future) periods have been simulated using the RegCM and PRECIS regional climate models. In the present paper the projected changes of regional heat waves in Central/Eastern Europe for the 21st century (compared to the mean of 1961-1990) have been analyzed. The following main conclusions can be drawn from both model simulations.

(i) In the 21st century heat waves are very likely to occur more frequently than in the reference period.

(ii) By the end of the 21st century heat wave warning level 3 has similar frequency as the heat wave warning level 1 in the reference period.

(iii) Simulated changes are larger for 2071-2100 than for 2021-2050.

(iv) 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

(v) PRECIS simulations suggest a more often occurrence of heat wave warning cases in Central/Eastern Europe than the RegCM outputs.

Acknowledgements. Research leading to this paper has been supported by the following sources: the Hungarian Academy of Sciences under the program 2006/TKI/246 titled Adaptation to climate change, the Hungarian National Research Development Program under grants NKFP-3A/082/2004 and NKFP-6/079/2005, the Hungarian National Science Research Foundation under grants T-049824, K-78125, K-67626, and K-69164, the Hungarian Ministry of Environment and Water under the National Climate Strategy Development project, the CECILIA project of the European Union Nr. 6 program (GOCE-037005), the CC-WATERS project of the European Regional Development Fund (SEE/A/022/2.1/X), and the European Union and the European Social Fund joint support (TÁMOP-4.2.1/B-09/1/KMR-2010-0003).

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