Journal of Env. Geogr. Vol. II. No. 3-4. (2009) pp. 49-55

GLOBAL WARMING INDUCED CHANGES IN THE MEANS AND EXTREMITIES OF TEMPERATURE AND PRECIPITATION IN HUNGARY

Mika, J.[1,2] **– Lakatos, M.**[2]

[1]Department of Geography, Eszterházy Károly College, 3300 Eger, Leányka 6., Hungary, e-mail: mika.j@met.hu, lakatos.m@met.hu

[2]OMSZ, Hungarian Meteorological Service, 1024 Budapest, Kitaibel P. 1., Hungary

Abstract

Regional climate changes are still one of the most difficult problems of the climate change issue. Results by three scientific approaches, the raw General Circulation Models (GCM), the mesoscale models, compiled from the *PRUDENCE* project, and an empirical method, called *Natural experiment* are compared. The latter approach provides estimations of the future changes based on regression coefficients between the local and global variables in the monotonously warming 1976-2007 period. The global model results comprise results of 9 AOGCMs, whereas in the PRUDENCE set of 5 model outputs are analysed. The listed results start with changes in the seasonal temperature and precipitation averages. Here the signs and the magnitudes are similar according to all approaches: Faster than global mean temperature increases in all seasons, with strongly decreasing precipitation in summer and autumn but increased amounts in winter and spring. There is also a fair agreement of the three approaches in the temperature extremes of the warm half-year in Hungary, with much less unequivocal picture in the frequency of frozen days in the cold half of the year. For precipitation, again, the summer maxima of diurnal totals behave similarly according to the three approaches in all regions of the country. Namely, they exhibit unequivocal increase, whereas no clear picture is seen for frequency of wet/dry days.

Key words: climate change, GCM; mesoscale modelling; statistical downscaling; Hungary

1. INTRODUCTION

Despite the recent significant improvement in regional climate modelling (RCM, see e.g. in Christensen et al., 2007), regional impacts of the ongoing and projected global climate change are more difficult to estimate than the global effects. Current global climate models still do not incorporate important scales of physical processes that are significant in formulating regional and local climate. Another problem for the impact community is the lack of comparison between the different regional scenarios prepared by different methodologies in the past.

Present GCMs are too coarse to yield regional details of climate change, especially in the case of the extremes. Combination of a GCM and a regional model may promise better results, but one should not forget the governing role of the applied mainframe GCM, which determines the boundary conditions for the regional model. This role is clearly demonstrated in Fig. 11.6 of the IPCC (2007) Scientific Report, where two different mainframe models (Hadley Centre of the British MetOffice and Max Planck Institute for Meteorology, Hamburg) led to different response of the same regional model (Rossby Centre, Stockholm).

Despite these shortcomings of the regional modeling the authors do not question that meso-scale modeling is the most perspective way to obtain valid and physically plausible projections of future climate states, especially if considering short life-time and extreme weather events. Moreover, we recommend a set of state of the art European model studies, including those by Csima G. and Horányi A. (2008); Szépszó G. and Horányi A. (2008) and Torma Cs. et al. (2008) presenting the newest generation of the RCMs run in Hungary. Besides these papers two further papers can be recommended from the same special issue, complied from the results of European PRUDENCE project by Bartholy J. et al. (2008) and Szépszó G. (2008). Some results of the latter study, provided by Szépszó G. (2008), will also be reflected here in our comparison.

The aim of the present paper is to compare selected scenarios with respect to four precipitation and temperature extremities. They are dry/wet days, precipitation, frost and heat-wave. The changes are investigated by three parallel methods:

- average changes in 9 coupled AOGCMs, directly derived from Tebaldi C. et al (2006);
- changes in 5 models of the PRUDENCE Project, provided by both B2 and A2 scenarios (Christensen J. H. – Christensen O. B. 2007), specially elaborated for Hungary;
- empirical linear trends in the monotonously warming 1976-2007 period.

The applied precipitation extreme indices (following Frich P. et al. (2002, later F02) are:
1. Maximum number of consecutive dry days (*dry days*, or CDD in F02).
2. Frequency of dry days ($R < 0.1$ mm or 1.0 mm)
3. Number of days with precipitation higher than 10 mm (*precip*$\geq$ 10 or 20; R10, R20 in F02).
The applied indices to describe temperature-related extremes:
4. Total number of frost days, defined as the annual total number of days with absolute minimum temperature below 0 °C (*frost days*, or Fd in F02).

5. Heat wave duration index, defined as the maximum period of at least 5 consecutive days with maximum temperature higher by at least 5 °C than the climate normal for the same calendar day (*heat-waves*, or HWDI in F02).

6. Frequency of hot days ($T_{max} > 30$ °C).
Summary of the compared indices are displayed in *Table 1.*

Table 1. Model-related frequency (e.g. R > 0.1 mm) of the given event. *CDD* is for the maximum number of *c*onsecutive *d*ry *d*ays, *HWDI* means *h*eat *w*ave *d*uration *i*ndex, i.e. maximum number of consecutive days with $T_{max} \geq T_{norm}+5^{o}C$, where T_{norm} is the climate normal for the given calendar day

Model	*Wet (dry) days*	*Precipitation*	*Frost*	*Heat-wave*
GCM	CDD	R>10 mm	$T_{min} < 0$ °C	HWDI
PRUDENCE	R ≥ 0.1 mm	R>20 mm	$T_{min} < 0$ °C	$T_{max} > 30$ °C
Empirical	R ≥ 1.0 mm	R>20 mm	$T_{min} < 0$ °C	$T_{max} > 30$ °C

2. METHODS PROVIDING EXTREME INDEX SCENARIOS

2.1 General Circulation Models

In the recent IPCC (2007) Report (Meehl G. A. et al. 2007) displays maps of extreme indices with reference on Tebaldi C. et al. (2006). We simply downloaded four graphical maps of the indices from www.cgd.ucar.edu/ccr/publications/tebaldi-extremes.html. Three maps are as in Fig. 10.18-19 of the Report (i.e. those, normalized against standard deviations by the IPCC), but for precipitation we used R10 instead of the mean intensity. The models used by Tebaldi C. et al. (2006) are the DOE/NCAR Parallel Climate Model (PCM; Washington W. et al. 2000) and Coupled Climate System Model (CCSM3), the CCSR MIROC medium and high resolution models (Hasumi H. – Emori S. 2004), INM-CM3 (Diansky N. A. – Volodin E. M. 2002), CNRM-CM3,6 GFDL-CM2.0 and 2.1 (Delworth T. L. et al. 2002, Dixon K. W. et al. 2003) and MRI-CGCM2 (Yukimoto S. et al. 2001). The model grid resolutions vary from 5°×4° to 1.125°. Model simulations are used from the A1B (mid-range) SRES scenarios (Nakicenovic N. – Swart R. 2000). The projected and control periods are 2080-2099 and 1980-1999, respectively.

2.2 Mesoscale models

Results of two times 5 RCM experiments, carried out in the framework of PRUDENCE Project (Christensen et al., 2007), which provided both A2 and B2 runs for 2071-2100 are further analysed. These models are: HIRHAM (DMI), RegCM (ITCP), HadRM3P (HC), RCAO (SMHI), PROMES (UCM).

The main objective of the PRUDENCE project was to provide high resolution climate change scenarios for Europe at the end of the 21th century by dynamical downscaling of global climate simulations. A total of 9 RCMs were used at a spatial resolution of roughly 50 km x 50 km for the time windows 1961-1990 and 2071-2100. More than 30 experiments were conducted with respect to the A2 and B2 SRES emission scenarios. Further details concerning the experimental setup are given in Christensen J. H. and Christensen O. B. (2007).

2.3 Empirical regression

Linear trend estimations of the local extreme indices are performed for the 1976-2007 period which is monotonously warming at the Northern Hemisphere. We may call it “natural experiment”, hence these three decades are mainly driven by anthropogenic greenhouse gas forcing, similarly to that one should expect in the following decades, at least. 15 temperature stations and 58 precipitation stations of Hungary are used to estimate the trends (regression coefficients). Since the precipitation results were quite different in their signs and significance, the 58 stations were sorted into 6 groups, according to the administrative numbers to ensure regionality of this amalgamation. The derived trend values (^{o}C/yr) are then multiplied by 110 years, which is the span of the PRUDENCE results. (The GCM-based changes correspond to 100 years, see 2.1.) Before the extreme index calculations, the daily time series were homogenised with the MASHv3.01 procedure (Szentimrey T. 1999, 2006).

Before we provide the results of this comparison, we hereby include the results of the similar analysis for seasonal maxima and minima.

3. COMPARISON OF CHANGES IN THE LOCAL AVERAGES

In this Section some earlier results (Mika J. 1988, 2006) are compared to more recent approaches of the IPCC AR4 (2007) and the PRUDENCE results. In Table 2 there are the expected changes for 2030 in the order of the three above approaches. More specifically, the *first line (IPCC, 2007)* contains the GCM-based results from the maps published in the Report and the Supplementary Materials ti the Chapter 10. The number of available models is 22. The *second line (PRUDENCE)* contains mean regional estimates from 25 different experiments. The gridpoint distance of the RCMs is ca. 50 km, which is much better than the ca. 200 km in case of the given GCM-s. The third line averages two simple statistical approaches (Mika J. 1988, 2006) and three paleoclimate analogies, i.e. 6 thousand, 122 thousand and 4 million years BP, (Mika J. 1991), i.e. five calculations. In majority of the results, when the experiment or the analogy did not refer to exactly 1 K global change, linear interpolation of the results were performed to obtain the scenario for 2030, when 1 K global warming is expected in majority of the global expectations comparing to 1961-1990.

Temperature exhibits higher changes in Hungary than the global averages (Table 2), though the three approaches give different orders of the seasons in this respect. The annual totals of precipitation do not change substantially, but its values decrease with the global warming in summer and autumn, whereas increased precipitation is expected in winter and spring.

The coincidence among the above changes means, that considering the 25, 21 and 5 individual scientific approaches, the similarity of the changes of the methods concerning their sign and order of magnitude can be seen as robust consequences of the anthropogenic global warming at least for the annual and seasonal averages of temperature and precipitation.

Table 2 Changes of annual and seasonal means of temperature and precipitation in Hungary for 2030 compared to 1961-1990. The average changes represent 25, 21 and 5 approaches. The global mean change is ca. 1.0 K according to the IPCC (2007) A2 projections

A2 scenario	Global change = 1.0 K for 2030					
Approach	Temperature change (K)	Annual	DJF	MAM	JJA	SON
IPCC 2007	Mean	0.9	1.0		1.3	
PRUDENCE	Mean	1.4	1.3	1.1	1.7	1.5
EMPIRICAL	Mean	1.6	2.0		1.1	
A2 scenario	Global change = 1.0 K for 2030					
Approach	Precipitation change (%)	Annual	DJF	MAM	JJA	SON
IPCC 2007	Total	-0.7	1.9		-3.7	
PRUDENCE	Total	-0.3	9.0	0.9	-8.2	-1.9
EMPIRICAL	Total	-2.2	7.6		-19.7	

4. COMPARISON OF SELECTED WEATHER EXTREMES

Weather extremes are even more problematic components of the projected regional climate changes, since, as our analysis demonstrates below, for them no unequivocal similarity exists. The four different extreme events are briefly analised in the following pages, where the maps and figures are found. Here, as general experience, we can conclude that two global and the regional models give fairly similar results for Hungary, despite the fact that the former source is used in average of the 9 models, whereas the PRUDENCE set is analised model-by-model.

Contrary to the similarity of the behaviour in the two modeling approaches, the empirical analyses differ from the model results in some respects. Frequency of dry days clearly increases according to the modeling approaches, but no clear trends appear empirically. The more frequent occurrence of heavy precipitation seems to be a common feature of climate in all approaches. Frequency of frost days should decrease according to both modeling tools, but the empirical analysis, again, does not support this consequence. For the hot extremes, however, all the three approaches give substantial increase of such days or events.

To assess significance of the empirical trends, one should know that only the frequency trends of hot days are significant at the 95 % level for all the 15 stations, compared to the inter-annual variability, with respect to the t-test. Contrary to this, frost days did not show significant trend in any station. Precipitation and extremity (R>20 mm/day) trends were also rare, 10 and 26 %, respectively. This is why we applied the sub-regional averages.

In the case of the diverging results, we need further investigations to explore the origin of these differences. One reason may be the remaining inhomogeneity in the diurnal series. Another reason for the deviations may be that statistical extrapolation of the trends presumes that the established relations remain unchanged in the future. However, the different forcing factors of various time periods may cause different regional changes. Hence, the results of the various approaches should ideally be intercompared for identical time periods.

4.1 Precipitation existence

Frequency of dry days increases in both modeling approaches. In the “natural experiment”, the results are less unequivocal and just in 10 % of the stations significant. In 3 regions the wet days became more frequent, in 2 regions less frequent and 1 region showed no trend.

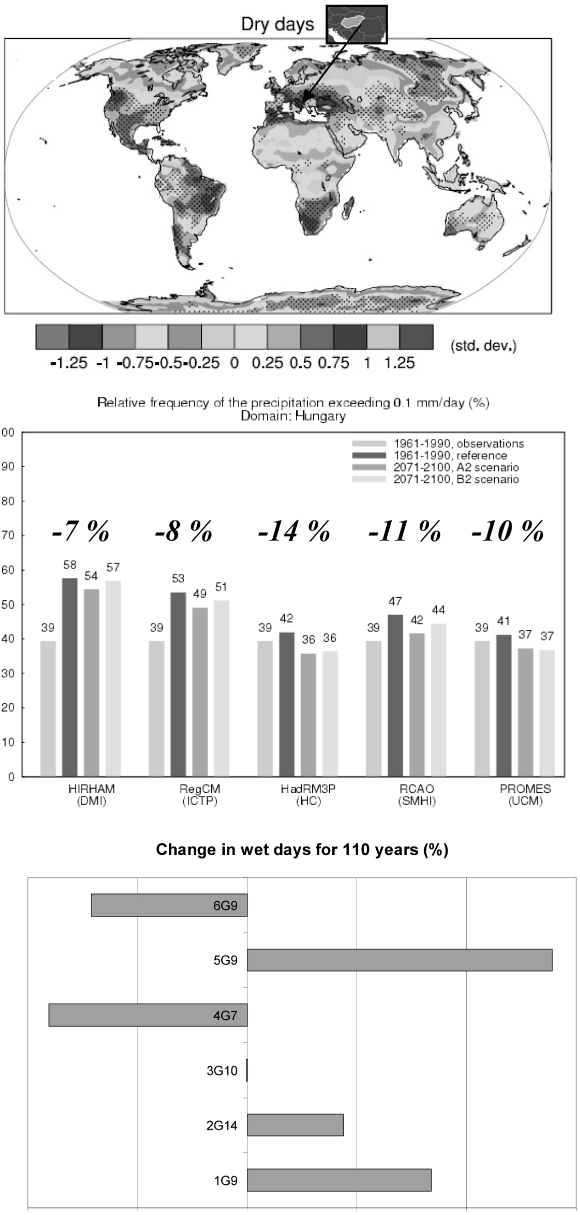

Fig. 1 Changes in the precipitation frequency, based on annual maxima of dry days in 9 GCMs for 2080-2099 vs. 1980-1999 (upper panel), frequency of wet days (R ≥ 0.1 mm/day) in coupled meso-scale PRUDENCE simulations for 2071-2100 vs. 1961-1990 (middle); and of R ≥ 1.0 mm/day for 110 years extrapolated from the trend analysis of 1976-2007 (lower)

4.2 Precipitation extremes

Frequency of heavy precipitation substantially increases according to all approaches. The empirical trends, significant in 26 % of the stations, yield even stronger increase than meso-scale modeling. In both cases there are strong inter-model and inter-region differences, respectively. The R>10 mm threshold and weaker GCM resolution mean clear but smaller changes.

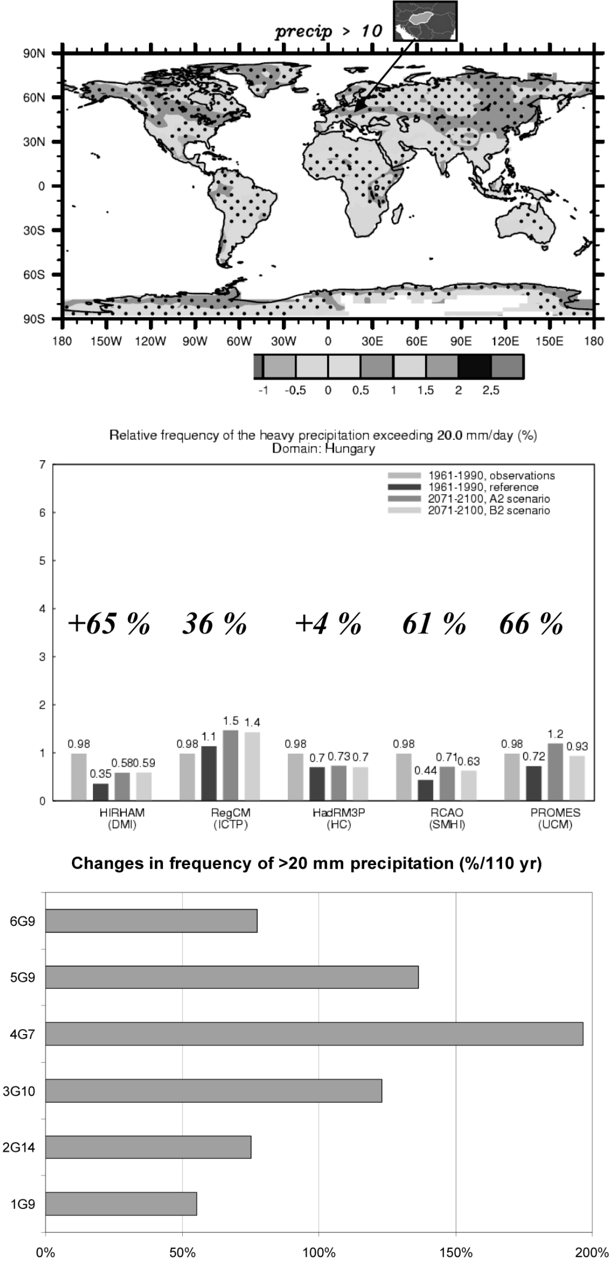

Fig. 2 Same as Fig. 1, but for the frequency of heavy precipitation, based on R>10 mm/day threshold (upper) and on R>20 mm/day threshold (middle and lower)

4.3 Low temperature extremes

Frequency of frost days substantially decreases according to both model approaches. But, 7 of the 15 stations involved into the trend analysis, however, indicate increase of the frost day frequency. But, none of the changes are significant at any individual station!

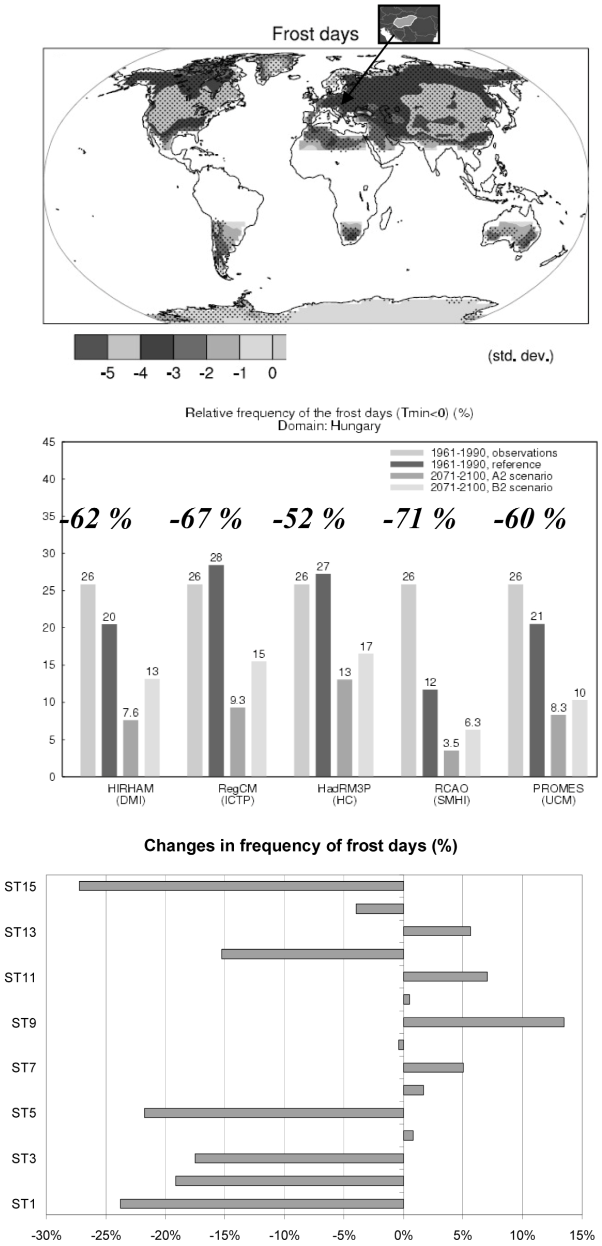

Fig. 3 Same as Fig. 1, but for changes in the number of frost (Tmin <0 °C) days (all panels)

4.4 High temperature extremes

Frequency of heat waves or hot days increases dramatically by all methods. The empirical approach gives even stronger changes than the PRUDENCE models. The GCM experiments yield very strong changes, indicating that not resolved meso-scale processes do not strongly contribute to the positive temperature anomalies.

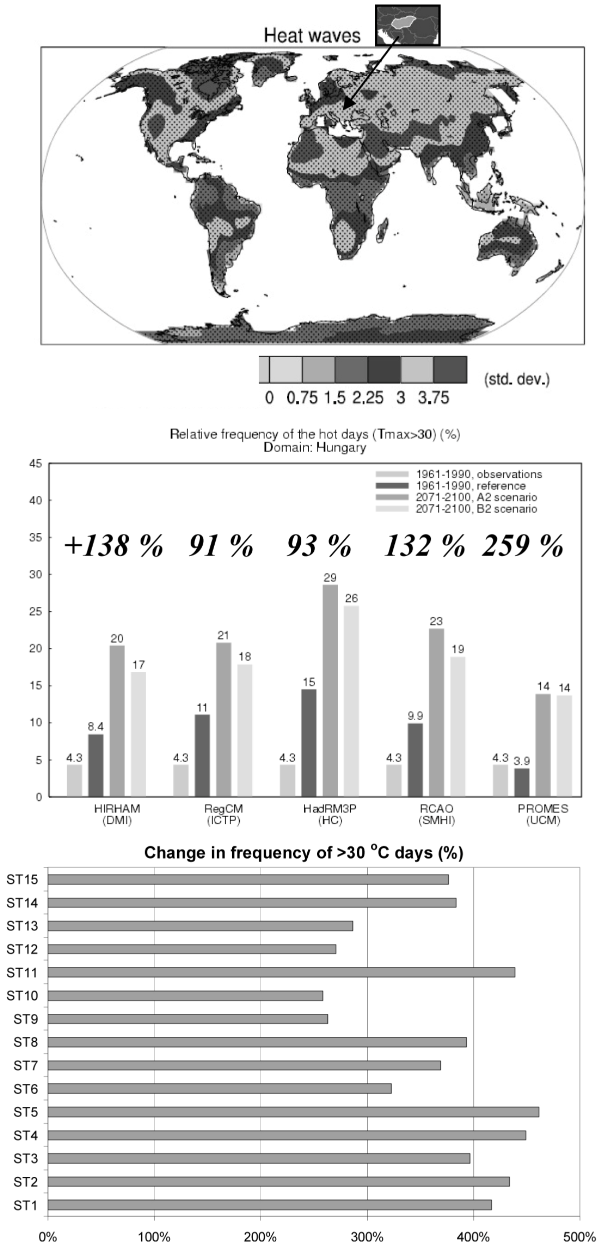

Fig. 4 Same as Fig. 1, but for changes in frequency of heatwaves based on frequency of the events when at least 5 consecutive days with T_{max} higher than the climate normal of the same day by at least 5 °C (upper); on frequency of hot days (T_{max}>30 °C) (middle and lower).

5 DISCUSSION

Changes in seasonal averages and in daily extremities of temperature and precipitation were analised parallel to the past and future global warming tendencies in three different methodologies. The changes in the seasonal and annual averages behave similarly according to these approaches. This means faster than global mean temperature increases in all seasons, with strongly decreasing precipitation in summer and autumn, but with increased amounts in winter and spring.

There is also a fair agreement among the approaches in the frequency of high temperature extremes and in the maxima of diurnal precipitation totals in all regions of the country. For these regional changes one may conclude that even if the applied individual methodologies are not absolutely exact (see below), the similarity of the results is convincing.

No ideal coincidence is established, however, in frequency of the frozen days and in frequency of the wet days. The two modeling approaches indicate decrease in both variables, but the empirical analysis yields cracked spatial picture with areas of both increasing and decreasing frequencies within the country.

In these two cases one should analise the shortcomings of the approaches before the particular conclusion. The shortcomings of the *GCM modeling* approaches are the coarse resolution with the lack of significant physical processes, especially of those driving the occurrence of the extremes. For the *RCM modeling*, the still insufficient (ca. 50 km) grid resolution should be mentioned, which is bounded by single mainframe models, not reflecting the full variability of the projections at the boundary of the imbedded model. The *Natural Experiment* empirical approach is based on observed data which are homogenised on monthly basis, hence one may not be sure that the inhomogeneities of the observations, that may be enhanced in extreme circumstances, did not influence the observed trend too strongly. In case of all investigations based on past data, one may also doubt that the difference in the causes among the two time sequences did not affect the result also in case of the diurnal extremes.

At present, the authors have no definite answer on the question if one should believe the majority of the results, i.e. one should accept that both the wet and the frozen days become less frequent with the global warming. A better strategy is to develop for all the approaches. This means that a new post-AR4 generation of the GCMs will gradually be available. The RCMs are even now much better resolved even in Hungary (their validation is already presented in the papers published in 2008, as referred in Section 1. Finally, the homogeneity of the diurnal series should specially be checked for the behaviour of the extremities.

Before these steps one can only make a practical, but not a scientific conclusion about the sign of the changes in case of these extremities.

Acknowledgements

The authors thank Gabriella Szépszó for post-processing of the PRUDENCE model results for Figs. 1b, 2b, 3b and 4b. Tamás Szentimrey made the homogenization of the temperature and precipitation data.

REFERENCES

Bartholy J. – Pongrácz R. – Gelybó Gy. – Szabó P. 2008: Analysis of expected climate change in the Carpathian Basin using the PRUDENCE results. *Időjárás* 112(3-4): 249-264

Christensen J. H. – Carter T. R. – Rummukainen M. – Amanatidis G. 2007 Predicting of regional scenarios and uncertainties for defining European climate change risks and effects: The PRUDENCE Project. Climatic Change 81: Supplement 1, May 2007, 371 p

Christensen J. H. – Christensen O. B. 2007. A summary of the PRUDENCE model projections of changes in European climate by the end of this century. *Climatic Change* 81: 7-30

Csima G. – Horányi A. 2008. Validation of the ALADIN-Climate regional climate model at the Hungarian Meteorological Service. *Időjárás* 112(3-4): 155-177

Delworth T. L. – Stouffer R. – Dixon R. – Spelman M. J. – Knutson Th. R. – Broccoli A. J. – Kushner P. J. – Wetherald R. T. 2002. Review of simulations of climate variability and change with the GFDL R30 coupled climate model. *Climate Dynamics* 19: 555-574

Diansky N. A. – Volodin E. M. 2002. Simulation of present-day climate with a coupled atmosphere-ocean general circulation model. *Izvestiya* 38: 732-747

Dixon K. W. – Delworth T. – Knutson T. – Spelman M. – Stouffer R. 2003. A comparison of climate change simulations produced by two GFDL coupled climate models. *Global and Planetary Change* 37: 81-102

Frich P. – Alexander L. V. – Della-Marta P. – Gleason B. – Haylock M. – Klein A. M. G. – Peterson T. 2002. Observed coherent changes in climatic extremes during the second half of the twentieth century. *Climate Research* 19: 193-212

Hasumi H. – Emori S. 2004. K-1 Coupled GCM (MIROC) Description. K-1 Technical Report No 1, 39 pp. (http://www.ccsr.u-tokyo.ac.jp/kyosei/hasumi/MIROC/tech-repo.pdf)

Solomon S. – Qin D. – Manning M. – Chen Z. – Marquis M. – Averyt K. B. – Tignor M. – Miller H. L. (eds.) 2007. Climate Change 2007: The Physical Science Basis. Contribution of WG-I to the Fourth Assessment Report of the IPCC. Cambridge, New York: Cambridge University Press. 996 p.

Meehl G. A. – Stocker T. F. – Collins W. D. – Friedlingstein P. – Gaye A. T. – Gregory J. M. – Kitoh A. – Knutti R. – Murphy J. M. – Noda A. – Raper S. C. B. – Watterson I. G. – Weaver A. J. – Zhao Z. C. 2007. Global Climate Projections. In: Solomon S. – Qin D. – Manning M. – Chen Z. – Marquis M. – Averyt K. B. – Tignor M. – Miller H. L. (eds.) IPCC Climate Change 2007: The Physical Science Basis. Contribution of Working Group I. to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, New York: Cambridge University Press, pp. 747-845

Mika J. 1988. Regional features of global warming in Hungary. *Időjárás* 92: 178-189

Mika J. 1991. Expected regional features of larger global warming in Hungary *Időjárás* 95: 265-278

Mika J. 2006. Global warming, regional features in Hungary. In: Fekete G. – Varga Z. (eds.) Fauna and flora of the landscapes in Hungary. HAS Society Center, Budapest, pp. 397-408

Nakicenovic N. – Swart R. (eds.) 2000. Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change IPCC. Special Report on Emissions Scenarios. Cambridge, New York: Cambridge University Press, 612 p.

Szentimrey T. 1999. Multiple Analysis of Series for Homogenization (MASH). Proceedings of the Second Seminar for Homogenization of Surface Climatological Data, Budapest, Hungary. WMO, WCDMP-No. 41, pp. 27-46

Szentimrey T. 2006. Manual of homogenization software MASHv3.01

Szépszó G. 2008. Regional change of climate extremes over Hungary based on different regional climate models of the PRUDENCE project. *Időjárás* 112(3-4): 265-284

Szépszó G. – Horányi A. 2008. Transient simulation of the REMO regional climate model and its evaluation over Hungary. *Időjárás* 112(3-4): 203-231

Tebaldi C. – Hayhoe K. – Arblaster J. M. – Meehl G. A. 2006. Going to the extremes: An intercomparison of model-simulated historical and future changes in extreme events. *Climate Change* 79: 185-211

Torma Cs. – Bartholy J. – Pongrácz R. – Barcza Z. – Coppola E. – Giorgi F. 2008. Adaptation of the RegCM3 climate model for the Carpathian Basin. *Időjárás* 112(3-4): 233-247

Washington W. – Weatherly M. – Meehl J. W. – Semtner G. A. – Bettge A. J. – Craig T. W. – Strand A. P. – Arblaster W.G. – Wayland J. M. – James V. B. – Zhang Y. 2000. Parallel climate model (PCM) control and transient simulations. *Climate Dynamics* 16: 755-774

Yukimoto S. – Noda A. – Kitoh A. – Sugi M. – Kitamura Y. – Hosaka M. – Shibata K. – Maeda S. H. – Uchiyama T. 2001. The New Meteorological Research Institute Coupled GCM (MRI-CGCM2). Model Climate and Variability. *Papers in Meteorology and Geophysics* 51(2): 47-88