SIMULATED TREND OF WET AND DRY CLIMATIC CONDITIONS IN CENTRAL/EASTERN EUROPE USING PRECIS OUTPUTS

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1. INTRODUCTION

Global warming may be recognized both in shifts of regional mean climate, and also, in the frequency and intensity changes of different climatological extremes associated to both temperature and precipitation (IPCC, 2007). Regional climate models (RCMs) nested in global climate models (GCMs) can be applied to assess future trends of climatic conditions on national and regional scales. In this study, model PRECIS developed at the UK Met Office Hadley Centre is used for the Carpathian basin located in Central/Eastern Europe. The main focus is on the analysis of precipitation-related climatic conditions. For this purpose different types of drought indices (summarized in Dunkel, 2009) are used, namely, precipitation index, standardized precipitation anomaly index (SAI), De Martonne aridity index, Thornthwaite index, Lang's rainfall index, Ped's drought index and Foley's anomaly index (FAI). In order to calculate the time series of these indices, monthly temperature and precipitation datasets of PRECIS simulations (Bartholy et al., 2009b) are used. Simulations for the periods 1961-1990 (as the reference period), 1951-2100 (using the SRES A1B emission scenario), and 2071-2100 (using the SRES A2 and B2 emission scenario) are analyzed.

First, model PRECIS is introduced, which is then used to calculate the indices for Hungary located in the Carpathian basin. Here, only two of the indices are discussed in details. Finally, the main conclusions are summarized in the last section.

2. REGIONAL CLIMATE MODEL PRECIS

The installation and the adaptation of the regional climate model PRECIS at the Department of Meteorology, Eötvös Loránd University (Budapest, Hungary) has started in 2004. At the beginning of our studies, version 1.3 was used but the results presented in this paper are from an updated model version (1.4.8). The PRECIS is a high resolution limited area model with both atmospheric and land surface modules. The model was developed at the Hadley Climate Centre of the UK Met Office (Wilson et al., 2005), and it can be used over any part of the globe (e.g., Hudson and Jones, 2002, Rupa Kumar et al., 2006, Taylor et al., 2007, Akhtar et al., 2008). The PRECIS regional climate model is based on the atmospheric component of HadCM3 (Gordon et al., 2000) with substantial modifications to the model physics (Jones et al., 2004). The atmospheric component of PRECIS is a hydrostatic version of the full primitive equations, and it applies a regular latitude-longitude grid in the horizontal and a hybrid vertical coordinate. The horizontal resolution can be set to 0.44°×0.44° or 0.22°×0.22°, which gives a resolution of ~50 km or ~25 km, respectively, at the equator of the rotated grid (Jones et al., 2004). In our studies, we used 25 km horizontal resolution for modeling the Central European climate. Hence, the target region contains 123x96 grid points (Fig. 1). There are 19 vertical levels in the model, the lowest at ~50 m and the highest at 0.5 hPa (Cullen, 1993) with terrain-following σ-coordinates (σ = pressure/surface pressure) used for the bottom four levels, pressure coordinates used for the top three levels, and a combination in between (Simmons and Burridge, 1981). The model equations are solved in spherical polar coordinates and the latitude-longitude grid is rotated so that the equator lies inside the region of interest in order to obtain quasi-uniform grid box area throughout the region. An Arakawa B grid (Arakawa and Lamb, 1977) is used for horizontal discretization to improve the accuracy of the split-explicit finite difference scheme. Due to its fine resolution, the model requires a time step of 5 minutes to maintain numerical stability (Jones et al., 2004). In the post processing of the RCM outputs, daily mean values are used.

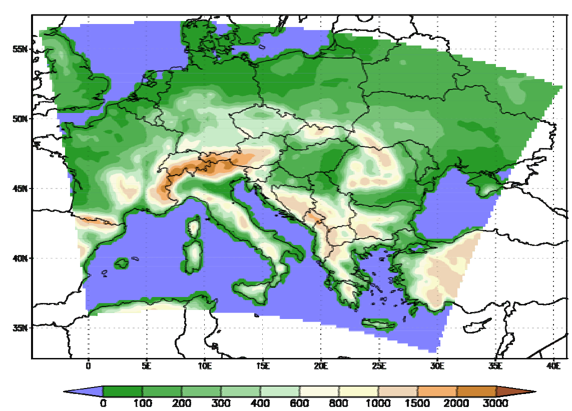

Fig. 1: Topography of the selected Central European integration domain used in model PRECIS

In case of the control period (1961-1990), the initial and the lateral boundary conditions for the regional

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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 using ~150 km as a horizontal resolution. For the validation of the PRECIS results CRU TS 1.2 (Mitchell and Jones, 2005) datasets are used.

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 and precipitation bias fields of the PRECIS simulations can be considered acceptable if compared to other European RCM simulations (Jacob et al., 2007, Bartholy et al., 2007). Therefore, model PRECIS can be used to estimate future climatic change of the Carpathian Basin. For the future (2071-2100), three experiments have been completed so far, namely, considering A2, B2 and A1B global emission scenarios (Nakicenovic and Swart, 2000). A2 scenario is the least optimistic and B2 is the most optimistic, which is indicated by the CO_2 concentration level projected by 2100 (856 ppm and 621 ppm, respectively). CO_2 concentration level estimated by 2100 is 717 ppm (Nakicenovic and Swart, 2000). Results of the PRECIS experiments considering A2 and B2 scenarios are evaluated in detailed in Bartholy et al. (2010).

3. DROUGHT INDICES

The so-called **Precipitation Index** (Kane and Trivendi, 1986) is the simplest drought index, which considers the precipitation anomaly:

$$P_i - m(P),$$

where P_i is the actual monthly precipitation amount, and *m(P)* is the average monthly precipitation amount for 1961-1990. Negative and positive values are associated with dry and wet climatic conditions, respectively. The main advantage is the simple calculation using only one climatic variable. However, precipitation by itself may not be sufficient to characterize drought events.

Precipitation can be normalized by using the standard deviation, and thus, the **Standardized precipitation Anomaly Index (SAI)** is defined (Katz and Glantz, 1986) as follows

$$\frac{P_i - m(P)}{d(P)},$$

where P_i is the actual monthly precipitation amount, *m(P)* and *d*(*P*) are the average monthly precipitation amount and standard deviation for 1961-1990. Similarly to the precipitation index, negative and positive values are associated with dry and wet climatic conditions, respectively. Normalization helps to compare dry and wet months intensity in case of non-homogeneous annual distribution. However, this index still uses only one climatic variable.

Besides precipitation data, temperature is also used when **Lang's Rainfall Index** (Lang et al., 1999) is calculated as the simple ratio of the monthly precipitation amount (P_i) and the monthly mean temperature (T_i). The applied formula is the following:

$$\frac{P_i}{T_i}.$$

The simple ratio is somewhat modified in case of **De Martonne Aridity Index** (De Martonne, 1926), which can be used to determine the potential regions with lack of water. The applied formula is the following:

$$\frac{12 \cdot P_i}{T_i + 10}.$$

Agrometeorological studies often use the more sophisticated **Thornthwaite Index** (Thornthwaite, 1948), which considers an important agricultural effect, the evaporation determined from temperature. Index values can be calculated as follows:

$$1.65 \cdot \left(\frac{P_i}{T_i + 12.2} \right)^{\frac{10}{9}}.$$

Standardized values of temperature and precipitation define **Ped's Drought Index** (Bagrov, 1953):

$$\frac{\Delta T}{d(T)} - \frac{\Delta P}{d(P)},$$

where ΔP (ΔT) is the difference of actual monthly precipitation amount (mean temperature) and the average monthly precipitation (temperature) during 1961-1990; *d(P)* and *d(T)* are the 1961-1990 standard deviation values of precipitation and temperature, respectively. The main advantage of this index is that it can be used for identifying short dry/wet periods. This index is different from the others indices because negative values imply wet conditions and positive values indicate dry climatic conditions.

The **Foley's Anomaly Index (FAI)** is a recursive index (Foley, 1957), which is able to consider the cumulative effects of moisture surplus or deficiency, thus, the meteorological "memory" is included.

The applied formula is the following:

$$FAI_1 = \Delta P_1$$
$$FAI_k = FAI_{k-1} + \Delta P_k.$$

4. SUMMARY OF THE PROJECTED TRENDS

The spatial average of the projected seasonal change of drought indices by 2071-2100 (relative to the reference period, 1961-1990) for Hungary is summarized in Table I. The largest changes are projected for summer and winter. Summer is projected to become drier and winter is projected to become wetter. In case of the other two seasons, the projected changes are slight and the signs are different if considering all the indices. Overall, the 21st century is likely to become drier in Hungary.

In this paper, only two of the above drought indices are discussed in details, namely, the simple precipitation index, and de Martonne aridity index.

Table I: Spatial average of projected seasonal change of drought indices by 2071-2100 taking into account the gridpoints located within Hungary (reference period: 1961-1990)

Index	Season	A2	B2	A1B
Precipitation index (mm)	Winter	+4.7	-2.1	+14.7
	Spring	-8.2	-4.9	+2.7
	Summer	-37.4	-27.7	-18.7
	Fall	-3.5	-7.5	-1.8
SAI index	Winter	+0.2	-0.1	+0.6
	Spring	-0.3	-0.2	+0.1
	Summer	-1.0	-0.7	-0.6
	Fall	+0.0	-0.2	-0.1
De Martonne aridity index (mm/°C)	Winter	-11.3	-14.7	-7.3
	Spring	-9.3	-7.0	-5.8
	Summer	-16.6	-13.1	-9.6
	Fall	-5.3	-6.4	-7.6
Thornth-waite index (mm/°C)	Winter	-1.4	-1.9	+2.9
	Spring	-1.3	-1.0	-0.6
	Summer	-2.5	-2.0	-1.2
	Fall	-0.7	-0.9	-0.9
Ped's drought index	Winter	-0.1	-0.1	-0.5
	Spring	-0.1	-0.0	-0.3
	Summer	+0.1	+0.2	+0.4
	Fall	-0.1	+0.1	+0.1
Lang's rainfall index (mm/°C)	Winter	–	–	–
	Spring	-3.1	-2.7	-4.0
	Summer	-2.6	-2.6	-1.3
	Fall	-2.2	-1.8	-3.6
FAI (mm)	Winter	-38.9	+52.2	+29.0
	Spring	+2.3	-33.6	+15.7
	Summer	-93.1	-103.0	+12.2
	Fall	-141.9	-149.4	-10.0

5. ANALYSIS OF THE PRECIPITATION INDEX

In case of the precipitation index positive changes imply wetter conditions, and negative trends indicate drier climate. The simulated seasonal time series of the precipitation index is shown in Fig. 2. Spatial average values for the 229 grid points located within Hungary are shown in the graphs. In case of the A1B scenario experiment due to the transient run for 1951-2100, linear regression is used to estimate the seasonal trends. The winter increasing trend (+1.2 mm/decade) and the summer decreasing trend (-1.6 mm/decade) indicate future wetter and drier climate conditions, respectively. Spring and fall trends are not significant for the country.

The 30-year average and the standard deviation values are shown in Table II. for the three time slices (1961-1990 as the reference, 2021-2050 and 2071-2100 future periods).

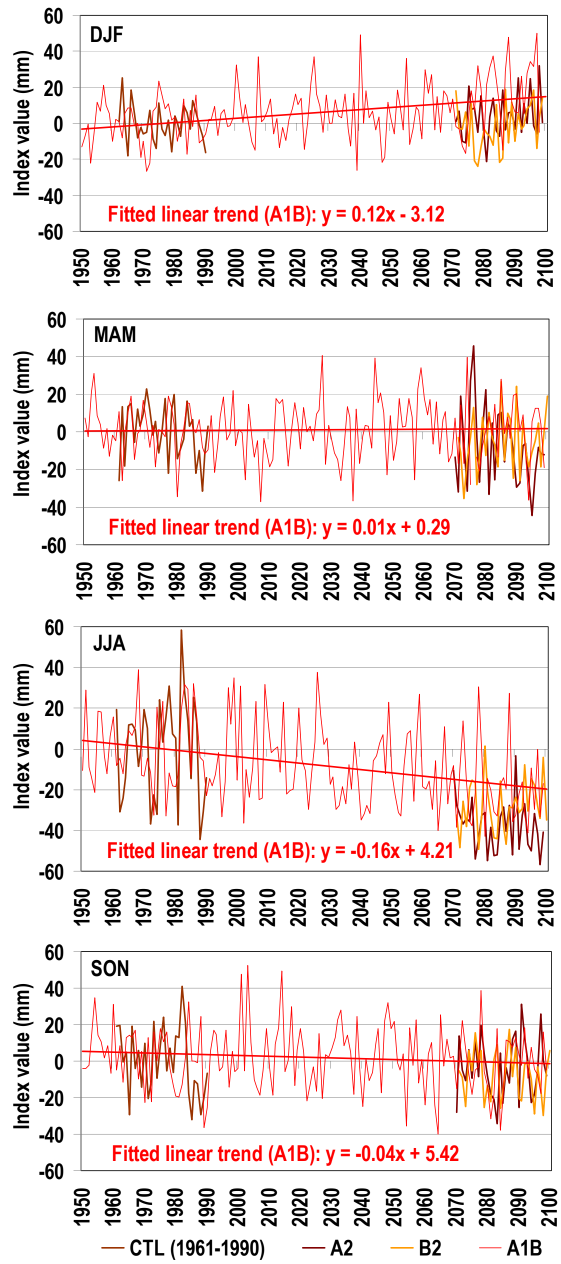

Fig. 2: Seasonal time series of the seasonal precipitation index (spatial average values for the 229 grid points located within Hungary)

In general, precipitation decrease is projected for Hungary for all the seasons, the largest decrease is likely to occur in summer. Furthermore, a large decrease of inter-annual variability is projected for summer. Smaller decrease is projected for fall (especially for B2). An increase of inter-annual variability is projected for spring, especially, for A2 scenario. Only a slight increase is projected for winter. For the transient

A1B scenario run, in summer and fall the fitted linear trend is decreasing, implying drying processes, while in winter and spring it is increasing, and the seasons are likely to become wetter in the future. The largest decreasing and the largest increasing trends are projected for summer and for winter, respectively.

Table II: The 30-year average ± standard deviation values (mm) of the precipitation index for the selected time slices (1961-1990, 2021-2050, 2071-2100)

		1961-1990	2021-2050	2071-2100
Winter	**CTL**	0.0±10.2		
	A2			4.7±12.4
	B2			-2.1±12.8
	A1B	-0.0±11.9	-5.2±16.0	15.0±18.5
Spring	**CTL**	0.0±14.8		
	A2			-8.2±20.5
	B2			-4.9±15.6
	A1B	0.0±12.8	0.9±17.3	0.3±17.4
Summer	**CTL**	0.0±24.8		
	A2			-37.4±12.8
	B2			-27.7±12.9
	A1B	0.0±19.3	-9.7±17.5	-19.0±18.8
Fall	**CTL**	0.0±18.2		
	A2			-3.5±16.5
	B2			-7.5±13.4
	A1B	0.0±16.6	3.9±16.3	-1.3±16.7

The projected seasonal change of the precipitation index is mapped for 2071-2100 in Fig. 3. The projected change is calculated as the difference between the scenario and the reference period.

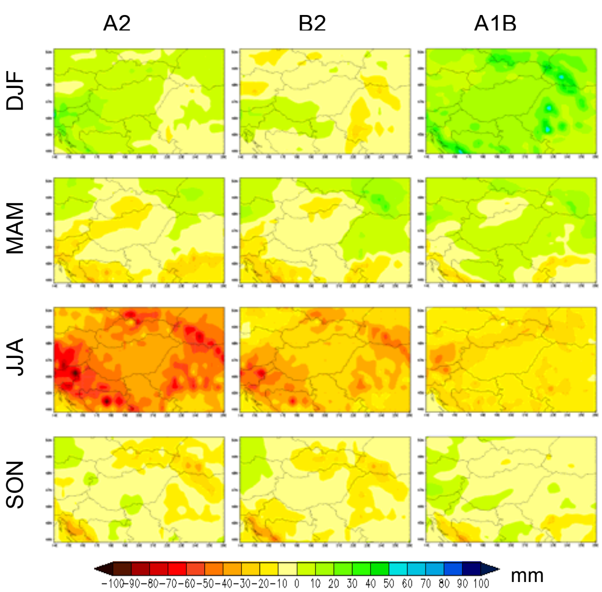

Fig. 3: Spatial structure of the projected seasonal change of precipitation index for the three scenario by 2071-2100 relative to 1961-1990

Summer is projected to become significantly drier in the whole territory of Hungary for all the three scenario. The projected drying in case of A2 is larger than that either in case of B2 or A1B. Spring and fall are likely to become slightly drier in the country, except in the case of A1B when spring is likely to become slightly wetter. Winter is likely to become wetter in Hungary in case of A2 and A1B scenario and slightly drier in case of B2 scenario compared to the reference period.

6. ANALYSIS OF DE MARTONNE INDEX

De Martonne aridity index considers both precipitation and temperature. In winter, the applied formula may result spurious values (when the monthly mean temperature is less than -10 °C). Different climate conditions can be categorized on the basis of De Martonne aridity index as shown in Table III.

Table III: Climate categories indicating by De Martonne aridity index

Criteria	Climate conditions
60 > index value	very wet
60 > index value > 30	wet
30 > index value > 20	sightly wet
20 > index value > 15	semi-arid
15 > index value > 5	dry
5 > index value > 0	extremely dry

The simulated seasonal time series of De Martonne aridity index is shown in Fig. 4. Spatial average values for the 229 grid points located within Hungary are shown in the graphs. The transient run of A1B scenario experiment can be used to fit a linear regression trend, the equations are included in the graphs. The fitted trends are decreasing in all seasons, the largest trend coefficient is projected for fall and summer (-0.9 and -0.8 mm/°C/decade, respectively).

The 30-year average and standard deviation values of De Martonne index are summarized in Table IV. for all the three time slices, namely, the reference period (1961-1990), and the future target periods (2021-2050 and 2071-2100). Decrease of the 30-year mean index value is projected for Hungary for all seasons. The largest decrease is projected for summer. Furthermore, a large decrease of inter-annual variability is projected for summer.

The spatial structures of the projected seasonal change of De Martonne aridity index by 2071-2100 relative to the 1961-1990 are mapped in Fig. 5. In general, the index values are projected to decrease in all seasons both for Hungary and the entire domain, which implies dryer climatic conditions in the area for the future compared to the reference period. The only exeption to this general characteristics can be found in winter in case of A1B scenario, when the index values are projected to decrease only at the eastern part of the country.

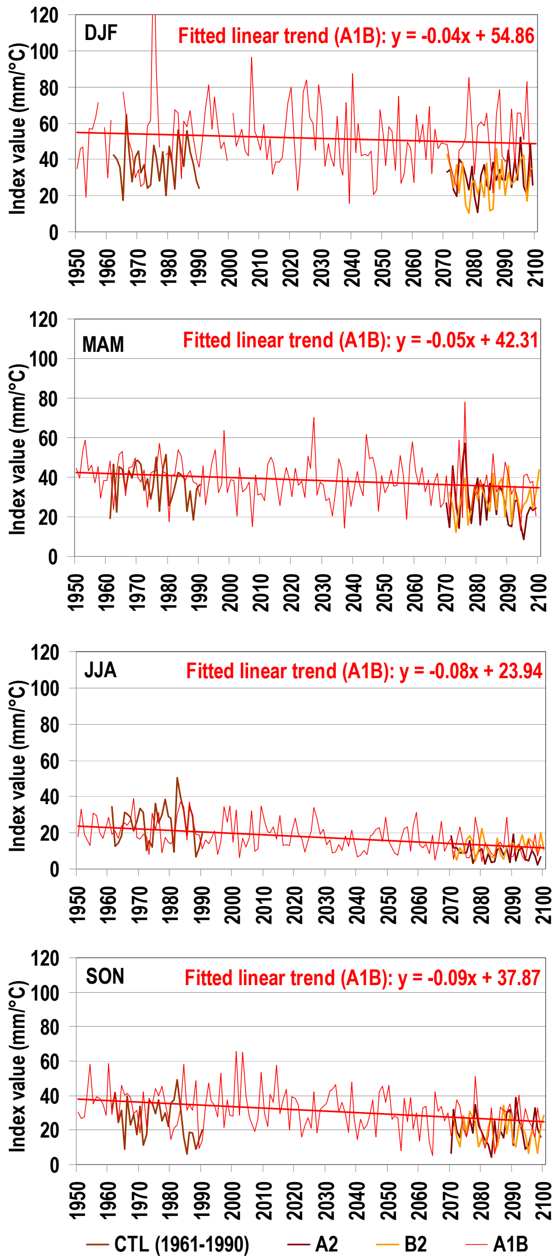

Fig. 4: Seasonal time series of the seasonal De Martonne aridity index (spatial average values for the 229 grid points located within Hungary)

The projected decrease is larger in absolute value in case of A2 than either in case of B2 or A1B. The largest decrease for Hungary is projected in summer and winter.

In spring and fall the projected decrease is smaller for Hungary than that in summer or winter. Larger decrease is simulated for the higher elevated mountainous regions of the target domain than for the lowlands.

Table IV: The 30-year average ± standard deviation values (mm/°C) of De Martonne aridity index for the selected time slices (1961-1990, 2021-2050, 2071-2100)

		1961-1990	2021-2050	2071-2100
Winter	CTL	37.9±11.4		
	A2			30.9±9.3
	B2			28.5±10.2
	A1B	55.8±19.7	50.0±19.3	51.0±17.2
Spring	CTL	36.6±9.6		
	A2			27.3±11.3
	B2			29.6±8.4
	A1B	41.3±9.0	38.3±11.8	35.4±13.0
Summer	CTL	25.3±10.6		
	A2			8.7±11.3
	B2			12.2±4.6
	A1B	22.1±8.3	16.6±6.6	12.3±6.5
Fall	CTL	26.2±11.0		
	A2			20.2±8.8
	B2			19.1±7.9
	A1B	33.0±11.3	31.5±10.3	25.7±9.6

In winter in some of the grid points the simulated changes are largely positive because of the seasonal mean temperature is being less than -10 °C in the reference period, thus resulting in negative index values, which are due to the index definition itself.

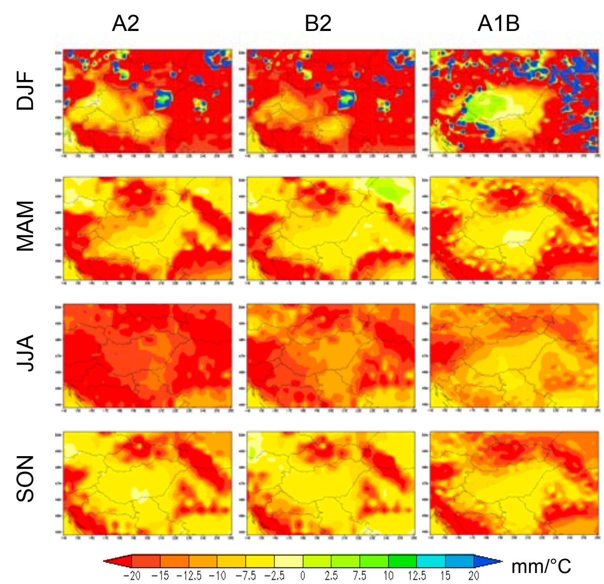

Fig. 5: Spatial structure of the projected seasonal change of De Martonne aridity index for the three scenario by 2071-2100 relative to 1961-1990

7. CONCLUSIONS

In this paper the main focus was on the analysis of precipitation-related climatic conditions using the results from the regional climate modeling experiments of PRECIS. For this purpose we used different types of drought indices. The results suggest that the climate of the Carpathian basin is projected to become wetter in winter and drier in the other seasons. The largest drying in the 21st century is very likely to occur in summer.

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REFERENCES

Akhtar, M., Ahmad, N., Booij, M.J., 2008: The impact of climate change on the water resources of Hindukush-Karakorum-Himalaya region under different glacier coverage scenarios. *J. Hydrology,* 355, 148-163.

Arakawa, A., Lamb, V.R., 1977: Computational design of the basic dynamical processes of the UCLA general circulation model. In: *Methods in Computational Physics*, 17, 173-265.

Bagrov, N.A., 1983: On the meteorological index of yields. *Met. Gidrol.*, 11, 92-99.

Bartholy, J., Pongracz, R., Gelybo, Gy., 2007: Regional climate change expected in Hungary for 2071-2100. *Applied Ecology and Environmental Research,* 5, 1-17.

Bartholy, J., Pongrácz, R., Torma, Cs., Pieczka, I., Hunyady, A., 2009a: Regional climate model experiments for the Carpathian basin. In: *Proceedings, 89th AMS Annual Meeting/21st Conference on Climate Variability and Change*. http://ams.confex.com/ams/pdfpapers/147084.pdf

Bartholy, J., Pongrácz, R., Pieczka, I., Kardos, P., Hunyady, A., 2009b: Analysis of expected climate change in the Carpathian Basin using a dynamical climate model. *Lecture Notes in Computer Science*, 5434, 176-183.

Bartholy, J., Pongracz, R., Pieczka, I., 2010: Evaluation of simulated climate trends of the Carpathian Basin using PRECIS outputs for 2071-2100. *90th AMS Annual Meeting on „Weather, Climate, and Society: New Demands on Science and Services"/22nd Conference on Climate Variability and Change*. http://ams. confex.com/ams/pdfpapers/158376.pdf

Cullen, M.J.P., 1993: The unifed forecast/climate model. *Meteorological Magazine*, 122, 81-94.

Dunkel, Z., 2009: Brief surveying and discussing of drought indices used in agricultural meteorology. *Időjárás,* 113, 23-37.

Foley, J.C., 1957: Droughts in Australia: Review of Records from Earliest Years of Settlement to 1955. *Australian Bureau of Meteorology*, Bull. 43, 281p.

Gordon, C., Cooper, C., Senior, C.A., Banks, H., Gregory, J.M., Johns, T.C., Mitchell, J.F.B., Wood, R.A., 2000: The simulation of SST, sea ice extents and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments. *Climate Dynamics,* 16, 147-168.

Hudson, D.A., Jones, R.G., 2002: Regional climate model simulations of present-day and future climates of Southern Africa. Technical Notes No. 39. UK Met Office Hadley Centre, Bracknell, 42p.

IPCC, 2007: *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Edited by S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller. Cambridge University Press, Cambridge, UK and New York, NY, 996p.

Jacob, D., Bärring, L., Christensen, O.B., Christensen, J.H., de Castro, M., Déqué, M., Giorgi, F., Hagemann, S., Hirschi, M., Jones, R., Kjellström, E., Lenderink, G., Rockel, B., Sánchez, E., Schär, Ch., Seneviratne, S.I., Somot, S., van Ulden, A., van den Hurk, B., 2007: An inter-comparison of regional climate models for Europe: Model performance in Present-Day Climate. *Climatic Change,* 81, 21-53.

Jones, R.G., Noguer, M., Hassell, D.C., Hudson, D., Wilson, S.S., Jenkins, G.J., Mitchell, J.F.B., 2004: Generating high resolution climate change scenarios using PRECIS. UK Met Office Hadley Centre, Exeter, 40p.

Kane, R.P., Trivedi, N.B., 1986: Are droughts predictable? *Climate Change*, 8, 209-223.

Katz, R.W., Glantz, M.H., 1986: Anatomy of a rainfall index. *Mon. Wea. Rev.*, 114, 764-777.

Lang, M., Ouardab, T.B.M.J., Bobee, B., 1999: Review: Towards operational guidelines for over-threshold modeling, *J. Hydrol.*, 225, 103–117.

de Martonne, E., 1926: Une nouvelle fonction climatologique: L'Indece d'aridite. *La Meteorologie*, 2, 449–458.

Mitchell, T.D., Jones, P.D., 2005: An improved method of constructing a database of monthly climate observations and associated high-resolution grids. *Int. J. Climatol.*, 25, 693-712.

Nakicenovic, N., Swart, R., Eds., 2000: *Emissions Scenarios.* A Special Reports of IPCC Working Group III, Cambridge University Press, Cambridge, UK. 570p.

Rupa Kumar, K., Sahai, A.K., Krishna Kumar, K., Patwardhan, S.K., Mishra, P.K., Revadekar, J.V., Kamala, K., Pant, G.B., 2006: High-resolution climate change scenarios for India for the 21st century. *Current Science*, 90, 334-345.

Simmons, A.J., Burridge, D.M., 1981: An energy and angular-momentum conserving vertical finite difference scheme and hybrid vertical coordinates. *Monthly Weather Review,* 109, 758-766.

Taylor, M.A., Centella, A., Charlery, J., Borrajero, I., Bezanilla, A., Campbell, J., Rivero, R., Stephenson, T.S., Whyte, F., Watson, R., 2007: Glimpses of the Future: A Briefing from the PRECIS Caribbean Climate Change Project. Caribbean Community Climate Change Centre, Belmopan, Belize. 24p.

Thornthwaite, C.W., 1948: An Approach Toward a Rational Classification of Climate. *Geogr. Rev.,* 38: 55-94.

Uppala, S.M., Kallberg, P.W., Simmons, A.J., Andrae, U., da Costa Bechtold, V., Fiorino, M., Gibson, J.K., Haseler, J., Hernandez, A., Kelly, G.A., Li, X., Onogi, K., Saarinen, S., Sokka, N., Allan, R.P., Andersson, E., Arpe, K., Balmaseda, M.A., Beljaars, A.C.M., van de Berg, L., Bidlot, J., Bormann, N., Caires, S., Chevallier, F., Dethof, A., Dragosavac, M., Fisher, M., Fuentes, M., Hagemann, S., Holm, E., Hoskins, B.J., Isaksen, L., Janssen, P.A.E.M., Jenne, R., McNally, A.P., Mahfouf, J.-F., Morcrette, J.-J., Rayner, N.A., Saunders, R.W., Simon, P., Sterl, A., Trenberth, K.E., Untch, A., Vasiljevic, D., Viterbo, P., Woollen, J., 2005: The ERA-40 re-analysis. *Quart. J. R. Meteorol. Soc.,* 131, 2961-3012.

Wilson, S., Hassell, D., Hein, D., Jones, R., Taylor, R., 2005: Installing and using the Hadley Centre regional climate modelling system, PRECIS. Version 1.3. UK Met Office Hadley Centre, Exeter, 131p.