Zeitschrift: Geographica Helvetica : schweizerische Zeitschrift für Geographie = Swiss journal of geography = revue suisse de géographie = rivista svizzera di geografia

Herausgeber: Verband Geographie Schweiz ; Geographisch-Ethnographische Gesellschaft Zürich

Band: 54 (1999)

Heft: 3: Global change issues = Globaler Wandel = Problématique du changement globale

Artikel: Current regional climate change studies in Hungary : a review

Autor: Matyasovszky, István / Weidinger, Tamás / Bartholy, Judit

DOI: https://doi.org/10.5169/seals-872414

Current Regional Climate Change Studies in Hungary: a Review

István Matyasovszky, Tamás Weidinger, Judit Bartholy and Zoltán Barcza, Budapest

1 Introduction

The possible effect increasing concentrations of atmospheric greenhouse gases could have on global climate is an important issue for many reasons. The diversity of the local consequences in even a small area could be very high. Before policies can be brought forward making optimal use of the expected changes and limiting the adverse affects, it is necessary to explore the regional consequences of global change.

For the simulation of climatical processes, coupled atmosphere-ocean general circulation models (GCMs) are common. The standard procedure for assessing climate change is to run a GCM using the atmospheric CO_2 content of the period before the industrial revolution (1xCO_2 case) and then to run it again under twofold CO_2 content (2xCO_2 case). Due to the relatively low horizontal resolution (a few hundred kilometres) and simplistic parameterisations (atmosphere-surface feedbacks, radiation processes, cloud and precipitation forming, etc.) of these models, the validity of the results for small areas like the Carpathian Basin, is very limited. For practical reasons, the need to convert the large-scale output of GCMs into something more applicable for small-scale research is vital.

The downscaling of GCM data follows three different approaches (Giorgi & Mearns 1991). Empirically speaking, independent of the factor causing global change, similar large-scale climate changes have much the same local consequences. This hypothesis makes it possible to use temporal or spatial analogies (Mika 1992, Rácz 1999). The second approach to downscaling operates with meso-scale numerical modelling. Meso-scale models use GCM outputs as initial and boundary conditions (Giorgi & Marinucci 1992, Marinucci et al. 1995, McGregor 1997). This technique requires a substantial amount of modelling and computer programming and there is at present no satisfactory long-term simulation available to assess extreme conditions. Alternatively, use could be made of stochastic downscaling procedures, particularly as they incorporate elements of both approaches mentioned above. Stochastic downscaling makes use of two key elements: Large-scale atmospheric circulation and an element which links local surface variables and large-scale circulation. For the latter use is made of observed data. Then, this model may be utilised with GCM outputs characterising atmospheric circulation (Bogárdi et al. 1993, Bartholy et al. 1994, Mearns et al. 1999).

The local effects of global climate change have been studied in Hungary since the mid-80s. Mika (1988, 1991, 1992) used an empirical downscaling method to describe climate change scenarios in Hungary. Later, Bartholy et al. (1995, 1998) focused on smaller and more vulnerable regions in Hungary, namely the watershed of Balaton-Sió and the Great Hungarian Plain (Fig. 1) to test the stochastic downscaling technique. Causes and magnitude of climate change, as well as the consequences for hydrology, agriculture, forestry and energy were evaluated (Faragó et al. 1990, 1991). More recently, changes monitored in the Great Hungarian Plain have been associated with the effects of climate change (Mika et al. 1995, Kertész et al. 1999).

The article is divided into four parts: A summary of long-term trend analysis of annual mean temperature and precipitation is followed by a presentation of important empirical downscaling results. In contrast, the results of a stochastic downscaling are discussed. The article closes with a brief summary.

2 Temperature and precipitation trends in Hungary

Hungary is situated at the centre of the Carpathian Basin (Fig. 1). 84% of the country (93 030 km^2) has an altitude less than 200m a.s.l.. At the other end of the scale, only 2% of the country ranges above the 400m mark. The climate is both oceanic, and continental, with slight Mediterranean influences. The mean annual temperature is 10°C. The distribution of temperature reflects latitudinal influence. Maximum values (11 – 11.5°C) are recorded in the southeast, the northern regions are colder with mean annual temperatures around 8 – 9°C. January, with a mean of -1 – -4°C, is the coldest month and a mean of 18 – 22°C is recorded in July.

Mean annual precipitation lies between 600 – 650mm, although the spatial variation is high. Maximum values (800 – 900mm) are recorded in the western and south-western parts of the country; the driest regions are in Hortobágy (below 500mm) (see Fig. 1) and in the southeast. Precipitation underlies a characteristic annual cycle. At the beginning of the summer, rainfall is greatest, with a drier period following in the second part of winter. Due to the Mediterranean influence, a small second precipitation peak occurs in the south-west around October-November. As is the case all over the world, precipitation in Hungary is a highly variable meteorological element. A threefold difference between the wettest and the driest years is possible, and any month may suffer from a lack of precipitation (Okolowicz 1977; Péczely 1981).

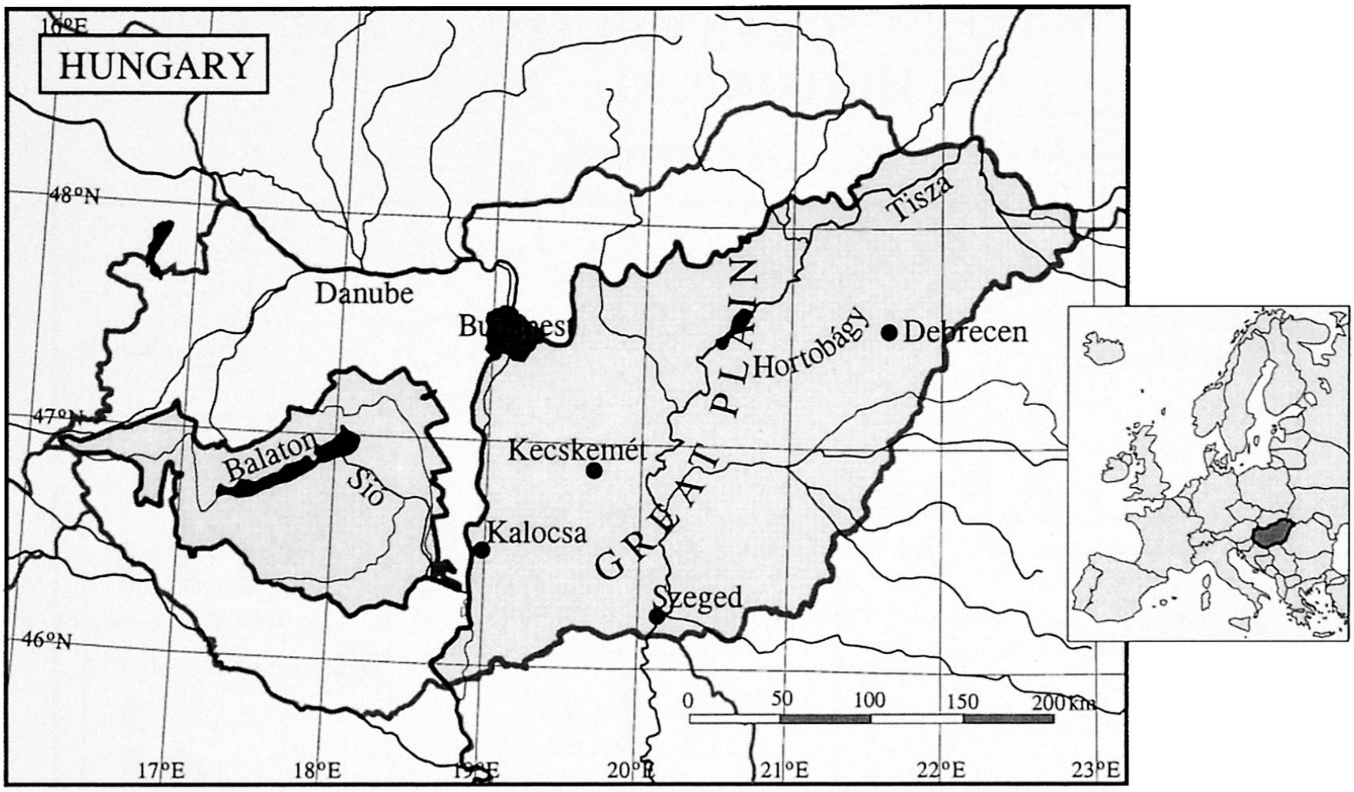

Fig. 1: Two vulnerable regions of Hungary chosen for stochastic downscale modelling
Zwei ausgewählte Regionen von Ungarn für das stochastische downscaling Modell
Deux régions sensible de la Hongrie utilisées pour la modèle de «downscaling» stochastique

MOLNÁR and MIKA (1997) performed a linear trend analysis of temperature and precipitation for 16 locations in Hungary using homogenised time series for the period between 1881 and 1990. For more information about the method, refer to SZENTIMREY (1995, 1996). Interestingly, recordings at each of the stations indicates a general warming (with over 95% statistical significance) with the average temperature rising by 1°C per century. The rise in temperature varies insignificantly and corresponds to other results in Central Europe (BÖHM 1992).

Precipitation on the other hand appears to be decreasing. At 10 of the stations, the values have on average a negative trend of -90mm per 100 years (95% significance). The range varies from -230mm to -27mm per 100 years. Earlier research (KOFLANOVITS-ADÁMY & SZENTIMREY 1986) carried out in the Carpathian Basin for 84 stations offers similar results for the period between 1901 and 1984. BARTHOLY and PONGRÁCZ (1998) emphasise the drift towards aridity in the region. Statistically significant is likewise the increasing number of dry, warm years. For their research, TAR (1992) and MOLNÁR (1996) analysed the frequency of years warmer or colder than average, as well as those years drier or wetter than the annual mean average.

3 Effects of climate change in Hungary based on empirical downscaling methods

Climate change analyses generally need only concentrate on temperature and precipitation, as the performance of other meteorological factors is closely linked. Research on the local influences of changing global climate for Hungary and for the whole Carpathian Basin was carried out by MIKA (1988, 1991, 1992) and MOLNÁR and MIKA (1997) using: (i) a statistical relationship between local meteorological elements and Northern Hemisphere temperature and ocean-continent temperature contrast; (ii) paleoclimatological analogues; (iii) a simple regional energy balance model. Results of the change of regional climate as a function of the change of average hemisphere temperature are summarised in Table 1. As was to be expected, global and local hemisphere temperature change fluctuated to the same degree. However, precipitation shows the opposite reaction. A minor global warming of 0.5 to 1°C generates a considerably drier climate, but in the Northern Hemisphere, a 4°C temperature increase leads to a noticeably more humid local climate. In the course of a moderate global warming, sunshine hours increase by 20%, and an annual dry phase is extended from 1.4 months per year to 2 months per year.

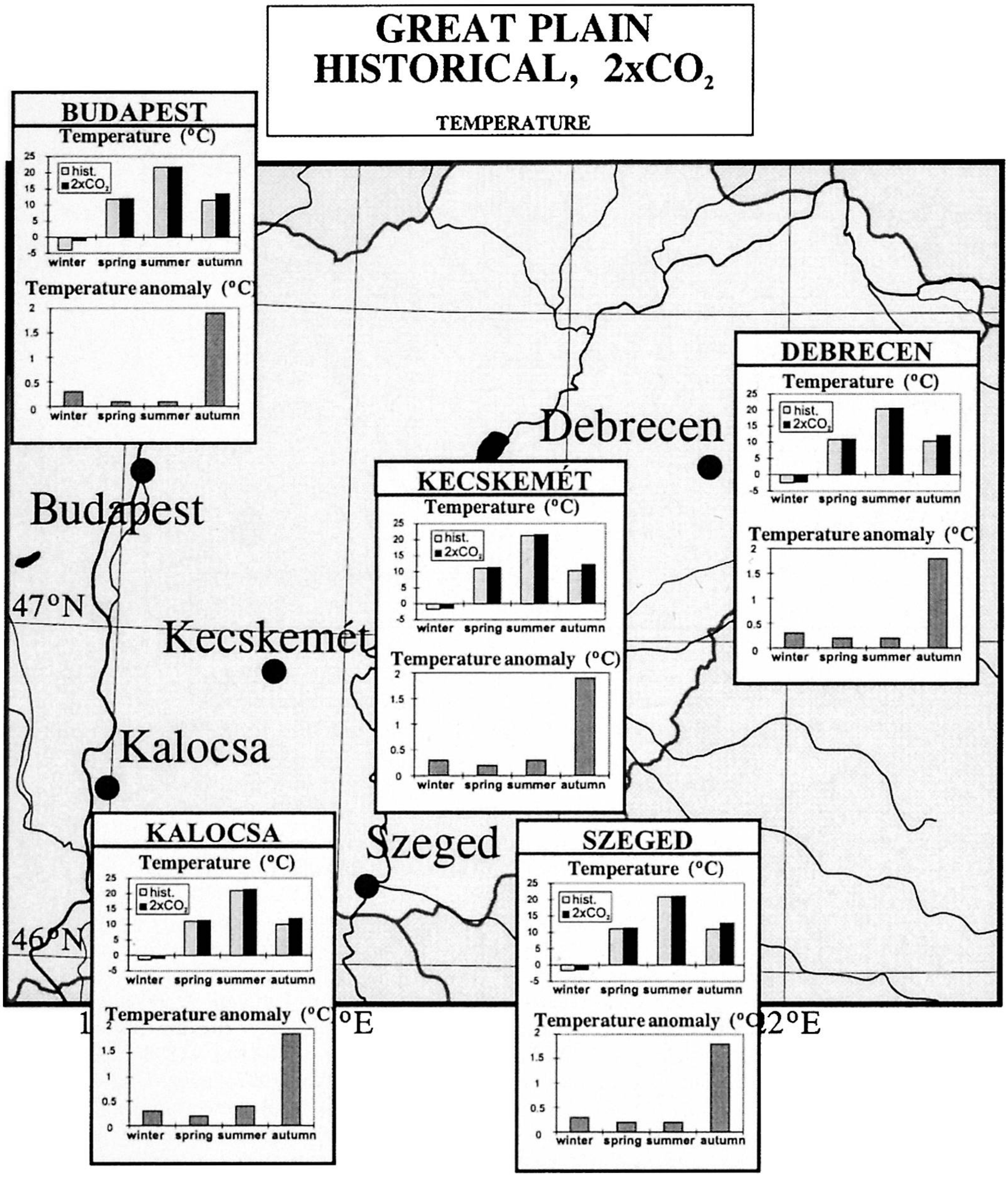

Fig. 2: Temperature changes for selected stations on the Great Hungarian Plain as forecasted by a stochastic downscaling model with twofold atmospheric CO_2 concentration

Erwartete Temperaturänderungen für ausgewählte Stationen im Grossen Ungarischen Tiefland, nachgewiesen von einer stochastischen «downscaling» Technik bei verdoppelter atmosphärischer CO_2-Konzentration

Changements de température prévus pour une sélection de stations dans la Grande Plane Hongroise obtenue par la technique de «downscaling» stochastique, pour un doublement des concentrations atmosphériques de CO_2

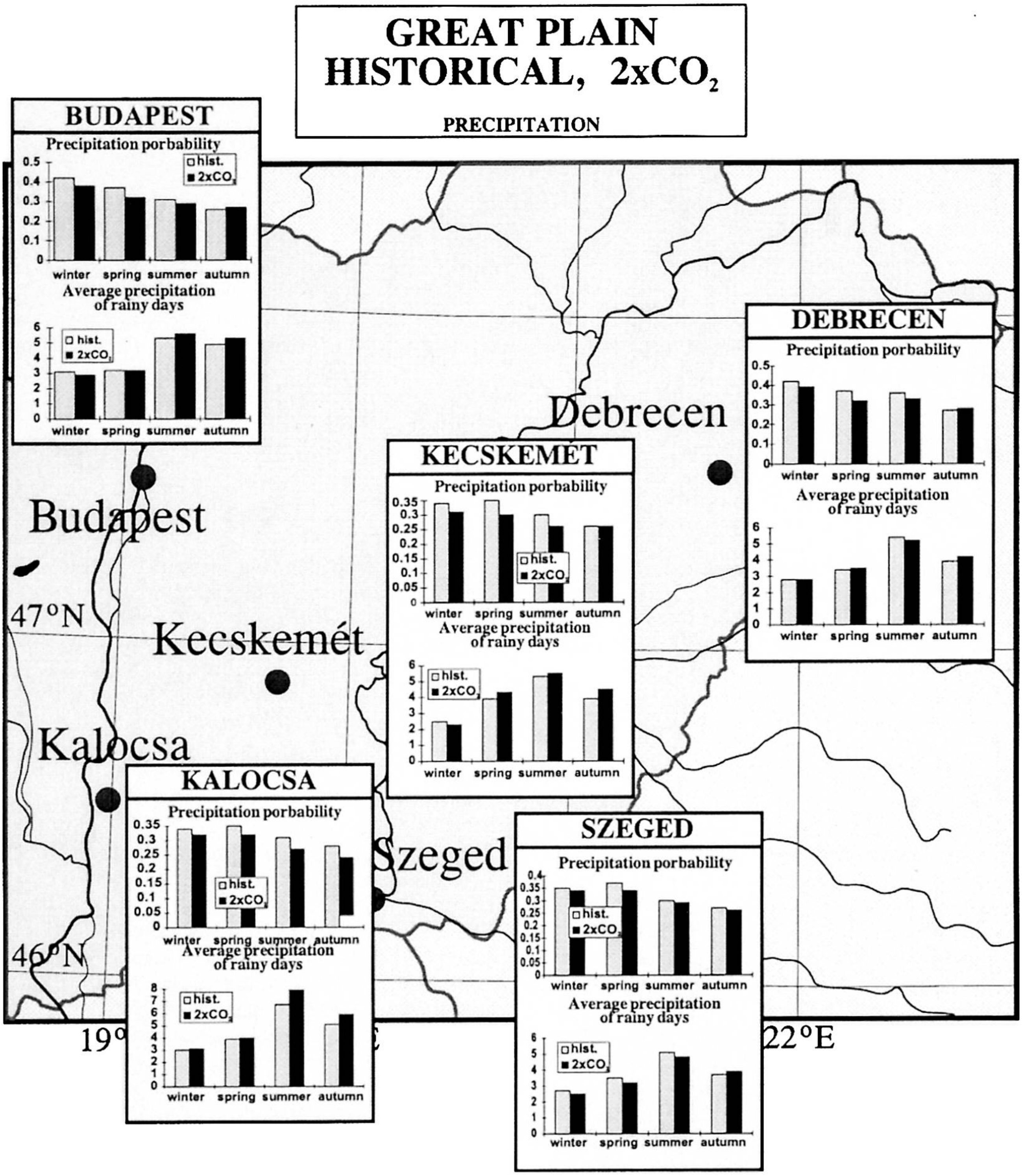

Fig. 3: Precipitation change for selected stations on the Great Hungarian Plain as forecasted by a stochastic down-scaling model with twofold atmospheric CO_2 concentration
Erwartete Änderungen des Niederschlags für ausgewählte Stationen im Grossen Ungarischen Tiefland, nachgewiesen mit einer stochastischen «downscaling» Technik bei verdoppelter atmosphärischer CO_2-Konzentration
Changements de précipitation prévus pour une sélection de stations dans la Grande Plane Hongroise obtenue par la technique de «downscaling» stochastique, pour un doublement des concentrations atmosphériques de CO_2

Hemispheric temperature change [ΔT]	**+0.5 [°C]**	**+1 [°C]**	**+2 [°C]**	**+4 [°C]**
Temperature change for Hungary, *summer*	+0.6 [°C]	+0.8 [°C]	+1.5 [°C]	+3 [°C]
Temperature change for Hungary, *winter*	+0.1 ; +0.5 [°C]	+1 ; +2.5 [°C]	+3 [°C]	+6 [°C]
Temperature change for Hungary, *year*	+0.3 ; +0.6 [°C]	+0.9 ; +1.6 [°C]	+2 ; +2.5 [°C]	+4 ; +5 [°C]
Precipitation change for Hungary, *year*	-30 [mm]	-20 ; -100 [mm]	+ or 0 [mm]	+ 40 ; +400 [mm]
Geographical analogy	within HU; Voyvodina, YU; Zhil-valley, RO; Plovdiv, BG	Varna, BG	Burgas, BG; Yalta, UKR	Firenze, I; Washington, USA

Tab. 1: Relationship between forecasted temperature and precipitation change in Hungary with different levels of hemispheric temperature change after MOLNÁR & MIKA (1997) (Intervals indicate high uncertainty)
Zusammenhang zwischen erwarteter Temperatur- und Niederschlagsänderung in Ungarn mit verschiedenen Stufen von hemisphärischer Temperaturänderung nach MOLNÁR & MIKA *(1997) (Die Intervalle verdeutlichen grosse Unsicherheit)*
Changements de température et de précipitation prévus en Hongrie en cas des différentes changes de la température hémisphérique à MOLNÁR & MIKA *(1997) (Les intervalles indiquent haute incertitude)*

Obviously, long-term changes in temperature and precipitation may cause a number of ecological, agricultural and economical problems. Ecological scenarios include amongst others, drought, a drying out the upper soil horizons and a lowering of the ground water table. Thus, the demand for irrigation increases and more reservoirs have to be built. The probability of the above is underlined by the current situation in the vast lowlands of the Danube and Tisza (Danube-Tisza Interfluve): The ground water table has been sinking here since the mid 1970s (KERTÉSZ et al. 1999).
Crop response can clearly be considered a significant element of climatic and soil milieu change. Simulations of maize and wheat yields indicate a 10 – 20% yield loss. However, it is possible that other factors linked to climatic and soil milieu change will compensate the negative effects on yield: e.g. increasing atmospheric CO_2 concentration, milder winters, and modest denitrification due to a drier climate (BACSI & HUNKÁR 1994, HARNOS 1998, KOVÁCS & DUNKEL 1998). Of further interest is research on the relationship between climate change and possible plant migration MÁTYÁS (1997) and KOVÁCS-LÁNG et al. (1998).

4 Local effects of global climate change in Hungary based on stochastic downscaling modelling

Stochastic downscaling methods make use of the correlation between large-scale atmospheric circulation and hydrometeorological variables. Based on the correlation between observed data and GCM output, future scenarios for hydrometeorological parameter can be estimated using, for example, a $2xCO_2$ climate (BOGÁRDI et al. 1993). The authors developed and applied such a model to two vulnerable regions in the Carpathian Basin (Fig. 1), namely the watershed of Balaton-Sió (BARTHOLY et al. 1995, WEIDINGER et al. 1995) and the Great Hungarian Plain (BARTHOLY & MATYASOVSZKY 1998a). Although not discussed in detail here, the method was also applied to other climatic zones: The dry, continental climate of Nebraska (MATYASOVSZKY et al. 1994, MEARNS et al. 1999), the dry subtropical climte of Arizona (BARTHOLY & DUCKSTEIN 1994), the Mediterranean climate of Greece (MATYASOVSZKY et al. 1995) and the Alpine region of Austria (NACHTNEBEL et al. 1996). Computations were carried out using two different models: An ECHAM (a coupled ocean-atmosphere GCM developed by the Max Planck Institute, Germany (CUBASH et al. 1991), and a GCM of the Canadian Cli-

Hemispheric temperature change [ΔT]	+1.5 [°C]
Temperature change for the Great Hungarian Plain, *summer*	+0.2 ; +0.3 [°C]
Temperature change for the Great Hungarian Plain, *winter*	+0.1; +0.4 [°C]
Temperature change for the Great Hungarian Plain, *year*	~ +0.7 [°C]
Precipitation change for the Great Hungarian Plain, *summer*	-20 ; +5 [mm]
Precipitation change for the Great Hungarian Plain, *winter*	-20 ; -5 [mm]
Precipitation change for the Great Hungarian Plain, *year*	-40 – +10 [mm]
Precipitation change for Lake Balaton-Sió watershed in Hungary, *summer*	-75 ; -35 [mm]
Precipitation change for Lake Balaton-Sió watershed in Hungary, *winter*	-15 ; 0 [mm]

Tab. 2: Temperature and precipitation change in Hungary as forecasted by a stochastic downscaling model with twofold atmospheric CO_2 concentration
Erwartete Niederschlags- und Temperaturänderungen in Ungarn, nachgewiesen mit einer stochastischen «downscaling» Technik bei verdoppelter atmosphärischer CO_2-Konzentration
Changements de température et de précipitation prévus en Hongrie, obtenue par la technique de «downscaling» stochastique, pour un doublement des concentrations atmosphériques de CO_2

mate Centre (CCC). Global warming according to ECHAM is expected to increase by 1.5°C, whereas CCC predicts a 3.5°C global temperature increase (Boer et al. 1984). For the results computed using the ECHAM model, see Table 2.

The spatial variability of temperatures calculated under a $2xCO_2$ climate for the Great Hungarian Plain (Fig. 2) is minimal. The seasonal trend with 0.1 – 0.5°C is positive. Interestingly, the average temperatures in autumn are expected to exceed 1.5°C (Bartholy & Matyasovszky 1998). The expected mean annual temperature change is thus about +0.7°C, a value considerably smaller than the predicted global mean temperature increase of 1.5°C (ECHAM) and corresponding values in Table 1 (after Molnár & Mika 1997).
Because of the spatial-temporal intermittent character of precipitation, its prediction proves to be more complex than that of temperature (Bogárdi et al. 1993). Accordingly, both occurrence and magnitude probability need to be calculated. Furthermore, wet/dry diurnal duration should be considered. Important results of our investigation on the Great Hungarian Plain are: Precipitation frequency decreases and precipitation magnitude during wet periods remains the same or indeed, could increase. Thus, precipitation patterns are expected to fluctuate more in future (Matyasovszky et al. 1994, Matyasovszky et al. 1995, Nachtnebel et al. 1996), On the other hand, precipitation magnitude stays very much the same. Spatial variability is expected to be minimal (Bartholy & Matyasovszky 1998). Changes in precipitation magnitude fluctuate between -10 – +5% in the summer months (Fig. 3), and between -15 – -5% in the winter months. On the whole, annual precipitation change is in the range of 10%.

A more complex analysis was carried out for the watershed Balaton-Sió on the basis of observed data from 28 precipitation stations (Bartholy et al. 1995). Both the frequency and the amount of precipitation on wet days is expected to decrease substantially in summer. The forecast for spatial distribution of precipitation in the winter months is slightly more complicated. Precipitation frequency will definitely decrease, but the amount of wet days will decrease in northern part of the watershed and increase over the southern part. 25 – 35% less precipitation is expected in the summer months; the winter months, with 0 – 10% less precipitation will only be slightly drier than is presently the case.
Because the forecasted precipitation fluctuations for the Great Hungarian Plain were smaller than those calculated for the Balaton-Sió watershed, the development towards a drier climate will probably affect the Great Plain to a lesser degree than the watershed.
A modified version of our stochastic downscaling methodology was also applied for predicting evaporation rates on Lake Balaton under a $2xCO_2$ climate. By adapting pan evaporation readings of surrounding locations, lake evaporation could be modelled (Weidinger et al. 1995). The calculated increase of 3 – 4% in the summer months correlates well with the expected increase in temperature.

5 Summary

The main conclusions of the linear trend analysis for time series of homogenised annual mean temperature and annual precipitation amounts in Hungary are as follows:

- Mean annual temperature is increasing at a rate of 1°C per 100 years (95% significance).
- Mean annual precipitation is decreasing by 90mm every 100 years (95% significance).
- As becomes obvious from the points above, a trend towards aridification has set in.

This tendency will probably be strengthened by the increasing concentration of atmospheric greenhouse gases.

Our stochastic downscaling modelling of two vulnerable climatic regions in Hungary, based on a twofold CO_2 concentration, led to the following conclusions:

- A regional increase of the mean annual temperature by 0.7°C in a prevailing 1.5°C global warming (according to ECHAM calculations) is considerably smaller than previous estimates.
- Anticipated temperature changes are considerably smaller than changes calculated for other regions at the same latitude (Matyasovszky et al. 1994; Matyasovszky et al. 1995, Nachtnebel et al. 1996).
- The frequency of wet days is expected to decrease in future, whereas precipitation magnitude will be increasingly variable.
- The Balaton-Sió watershed is expected to have a noticeably greater precipitation deficit than the Great Hungarian Plain. The scale of our climate change scenarios for precipitation is similar to that used in previous estimations based on empirical downscaling modelling. The results however, highlight the necessity for greater spatial differentiation as the disparity between even small areas can be high.

Acknowledgements
Research leading to this paper was supported by Finance for High Education and Investigation Projects FKFP-0193 and Hungarian Scientific Fund OTKA-T026629, T015707. The authors would like to thank János Mika from the Hungarian Meteorological Service for his helpful comments.

Literature Cited

Bacsi, Zs. & M. Hunkár (1994): Assessment of the impacts of climate change on yields of winter wheat and maize, using crop models. – In: Idöjárás 98: 119-134.

Bartholy, J. & L. Duckstein (1994): Comparing and extending the CCC and MPI GCM outputs from western USA for global change studies. – In: Annales Geophysicae, Supplement II. to Vol. 12, C355.

Bartholy, J., Pálvölgyi, T., Matyasovszky, I. & T. Weidinger (1994): Towards narrowing uncertainties of regional climate change predictions by general circulation models and empirical methods – In: Proc. of XVIIth Conference of the Danube Countries on Hydrological Forecasting and Hydrological Bases of Water Management, Budapest, 5-9 September, 1994: 409-414.

Bartholy, J., Bogárdi, I. & I. Matyasovszky (1995): Effect of climate change on regional precipitation in lake Balaton watershed. – In: Theor. Appl. Climatol. 51: 237-250.

Bartholy, J. & I. Matyasovszky (1988): Effect of climate change on temperature and precipitation in the Carpathian Basin. – In: Dunkel, Z. (Ed.): Climate Change and Consequences. Meteorological Scientific Days '97, November 20-21, 1997, Hungarian Meteorological Service, Budapest, 117-125. (In Hungarian)

Bartholy, J. & R. Pongrácz (1998): The differing trends of the Hungarian precipitation time series, areal and decadal changes of extreme precipitation. – In: Tar, K. & K. Szilágyi (Eds.): Proc. of IIth Conference of Forest and Climate, Sopron, June 4-6, 1997, Debrecen: Kossuth University Press: 62-66. (In Hungarian)

Boer, G.J., McFarlane, N.A. & R. Laprise (1984): The climatology of the Canadian Climate Centre General Circulation Model as obtained from a five-year simulation. – In: Atmos. Ocean 22: 432-437.

Bogárdi, I., Matyasovszky, I., Bárdossy, A. & L. Duckstein (1993): Application of a space-time stochastic model for daily precipitation using atmospheric circulation patterns. – In: J. Geophys. Res. 98 (D9), 16, 653-16, 667.

Böhm, R. (1992): Lufttemperaturschwankungen in Österreich seit 1775. – In: Österreichische Beiträge zu Meteorologie und Geophysik 96.

Brázdil, R. (1992): Reconstruction of the climate of Bohemia and Moravia in the last millennium – problems of data and methodology. – In: Frenzel, B.: European climate reconstructed from documentary data: methods and results. – Stuttgart, Fischer Verlag: 75-86.

Cubash, U., Hasselmann, K., Hock, H., Maier-Reimer, E., Mikolajewicz, U. & B.D. Santer (1991): Time-dependent greenhouse warming computations with a coupled ocean-atmosphere model. – In: Max Planck Inst. Meteorolol., Rep. 67: 1-18.

Faragó, T., Iványi, Zs. & S. Szalai (eds.) (1999): Climate variability and change – I. causes, processes, regional impacts with special emphasis on the socio-economic impacts and the tasks related to the international cooperation. – Hungarian Ministry for Environment and Regional Policy, Hungarian Meteorological Service, Budapest: 1-100. (In Hungarian)

Faragó, T., Iványi, Zs. & S. Szalai (eds.) (1991): Climate variability and change – II. Changes in composition of atmosphere and in the climatic characteristics, detection, modelling, scenarios and impacts of the regional changes. Summary. – Hungarian Ministry for Environment and Regional Policy, Hungarian Meteorological Service, Budapest: 1-31.

Giorgi, F. & L.O. Mearns (1991): Approaches to the simulation of regional climate change: a review. – In:

Reviews of Geophysics 29: 191-216.
KERTÉSZ, Á., LÓCZY, D., MIKA, J., PAPP, S., HUSZÁR, T. & A. SÁNTHA (1999): Studies on the impact of global climate change on some environmental factors in Hungary. – In: Idöjárás 103: 37-65.
KOFLANOVITS-ADÁMY, E. & T. SZENTIMREY (1986): The variations of the precipitation amounts in the Carpathian Basin during the present century. – In: Idöjárás 90: 206-216. (In Hungarian)
KOVÁCS, G. & Z. DUNKEL (1998): Assessment of the impacts of climate change on arable lands of Hungary for the next half century. – In: DUNKEL, Z. (ed.) (1998): Climate Change and Consequences. Meteorological Scientific Days '97, November 20-21, 1997. – = Hungarian Meteorological Service, Budapest: 181-193. (In Hungarian)
KOVÁCS-LÁNG, E., KRÖEL-DULAY, GY., KERTÉSZ, M., MIKA, J., RÉDEI, T., RAJKAI, K., HAHN, I. & S. BARTHA (1998): Change of the gap dynamics of succession in a semiarid gradient for the perennial open sandy steppe. – In: DUNKEL, Z. (ed.) (1998): Climate Change and Consequences. Meteorological Scientific Days '97, November 20-21, 1997. – = Hungarian Meteorological Service, Budapest: 43-54. (In Hungarian)
MARINUCCI, M.R., GIORGI, F., BENISTON, M., WILD, M., TSCHUCK, P., OHMURA, A. & A. BERNASCONI (1995): High resolution simulations of January and July climate over the western alpine region with a nested regional modeling system. – In: Theor. Appl. Climatol. 51: 119-138.
MATYASOVSZKY, I., BOGÁRDI, I. & L. DUCKSTEIN (1994): Comparison of two general circulation models to downscale temperature and precipitation under climate change. – In: Water Resources Research 30: 3437-3448.
MATYASOVSZKY, I., BOGÁRDI, I. & J. GANOULIS (1995): Impact of global climate change on temperature and precipitation in Greece. – In: Appl. Math. Comp. 70: 1-35.
MÁTYÁS, CS. (1997): Effects of environmental change on the productivity of tree populations. – In: MÁTYÁS, CS. (1997): Perspectives of forest genetics and tree breeding in a changing world. – IUFRO World Series 6, Vienna: 109-121.
MCGREGOR, J.L. (1997): Regional climate modelling. – In: Meteorol. Atmos. Phys. 63: 105-117.
MEARNS, L.O., BOGÁRDI, I., MATYASOVSZKY, I. & M. PALECKI (1999): Comparison of climate change scenarios generated from regional climate model experiments and empirical downscaling. Special issue on new developments and applications with the NCAR Regional Climate Model (RegCM). – In: J. Geophys. Res. 104 (D6): 6603-6621.
MIKA, J. (1988): Regional features of global warming in Carpathian Basin. – In: Idöjárás 92: 178-189. (In Hungarian)
MIKA, J. (1991): Predictable impacts of a major global warming in Hungary. – In: Idöjárás 95: 265-278. (In Hungarian)
MIKA, J. (1992): Method of slices to estimate regional features of the global warming at extratropical latitudes. – In: Proc. of 5th Int. Meeting on Statistical Climatology, June 22-26, 1992, Toronto, Canada: 433-436.
MIKA, J., AMBRÓZY, P., BARTHOLY, J., NEMES, CS. & T. PÁLVÖLGYI (1995): Time variability of the climate of the Hungarian plains Alföld. – In: Vízügyi Közlemények, LXXVII 3-4: 261-286. (In Hungarian)
MOLNÁR, K. (1996): Trend of precipitation amount in Hungary. – In: Természet Világa, Special Issue: 66-68. (In Hungarian)
MOLNÁR, K. & J. MIKA (1997): Climate as a changing component of landscape: recent evidence and projections for Hungary. – In: Z. Geomorph. N.F., Suppl.-Bd. 110: 185-195.
NACHTNEBEL, H.P., HEBENSTREIT, K., BOGÁRDI, I. & I. MATYASOVSZKY (1996): Effect of climate change on the hydrology of an alpine watershed. – In: Proc. of Internationales Symposium am 27-28, November 1995 im Europaischen Patentamt in München, Institut für Wasserwesen 56b: 307-331. (In German)
OKOLOWICZ, W. (1977): The climate of Poland Czechoslovakia and Hungary. – In: WALLÉN, C.C. (ed.) (1977): World Survey of Climatology 6, Climates of Central and Southern Europe. – Amsterdam-Oxford-New York: Elsevier: 75-125.
PÉCZELY, GY. (1981): Climatology. – Budapest: Tankönyvkiadó: 1-336. (In Hungarian)
RÁCZ, L. (1999): Climate history of Hungary since 16th century: past, present and future. – = Centre for Regional Studies of Hungarian Academy of Sciences, Pécs, No. 28: 1-160.
SZENTIMREY, T. (1995): General problems of the estimation of inhomogeneities, optimal weighting of the reference stations. – In: Proc. of 6th International Meeting on Statistical Climatology, 19-23 June 1995, Galway, Ireland: 62-63.
SZENTIMREY, T. (1996): Some statistical problems of homogenization: break points detection, weighting of reference series. – In: Proc. of 13th Conference on Probability and Statistics in the Atmospheric Sciences 21-23 February 1996, San Francisco, California: 365-368.
TAR, K. (1992): Change of climate of Túrkeve. – In: Proceedings of Conference of 145 anniversary of birth of Hungarian climatologist Hegyfoky Kabos. Debrecen, Túrkeve: 156-164.
TÓTH, F.L., PETSCHEL-HELD, G. & T. BRUCKNER (1998): Climate change and integrated assessment: The tolerable windows approach. – In: HACKER, J. (ed.) (1998): Goals and Economic Instruments for Achievement of Global Warming Mitigation in Europe. – Dordrecht, The Netherlands: Kluwer.

Weidinger, T., Matyasovszky, I., Bartholy, J. & I. Bogárdi (1995): Climate change impact on daily pan evaporation. – In: Meteorol. Zeitschrift, N.F. 4: 235-245.

Summary: Current Regional Climate Change Studies in Hungary: a Review
After focusing on the changes in Hungarian temperature and precipitation during this century, possible hydrological, agricultural and ecological consequences of a future climate change are described. These results have been obtained using a modified version of empirical downscaling techniques, developed to analyse the local effects of global climate change in a twofold concentration of atmospheric greenhouse gases scenario. In addition, regional changes in temperature and precipitation were examined with the help of the more specific stochastic downscaling method. The climate of Hungary has become warmer and drier over the last century. It is to be expected that an increasing concentration of atmospheric greenhouse gases will enhance the tendency towards aridification.

Zusammenfassung: Aktueller Stand der Forschungen über regionale Klimaänderungen in Ungarn
Im ersten Teil des Artikels werden die Änderungen der ungarischen Temperatur- und Niederschlagsdaten für das zwanzigste Jahrhundert analysiert. Dann werden mögliche hydrologische, landwirtschaftliche und ökologische Konsequenzen einer zukünftigen Klimaänderung zusammengefasst. Diese Resultate wurden mit der Anwendung einer spezifischen Version der sogenannten empirischen «downscaling» Techniken erreicht. Diese Methoden wurden zur Analyse lokaler Effekte der globalen Klimaänderung – verursacht durch verdoppelte Treibhausgaskonzentrationen – entwickelt. Schliesslich werden lokale Temperatur- und Niederschlagsänderungen dargestellt, die mit einer verfeinerten stochastischen downscaling Methode erreicht wurden. Das Klima von Ungarn ist während dieses Jahrhunderts wärmer und trockener geworden . Die mögliche Klimaänderung bei einer Verdopplung der Konzentration der atmosphärischen Treibhausgase verstärkt diese Tendenz.

Résumé : Une résumé des études de la situation actuelle des climatique changements des régions en Hongrie
La première partie de cet article se concentre sur les changements de température et de précipitation pendant le 20e siècle en Hongrie. Ensuite, les conséquences possibles d'un changement de climat futur sur les domaines hydrologique, agricoles et écologique possibles sont récapitulées. Ces résultats ont été obtenu après l'application des techniques de «downscaling» empriques développées pour analyser les effets locaux du changement global de climat en fonction d'un doublement de la concentration des gaz à effet locaux du changement global de climat en fonction d'un doublement de la concentration des gaz à effet de serre. Finalement, l'évolution de la température ainsi que les changements de précipitation obtenus avec une méthode downscaling stochastique plus élaborée, sont présentés. Le climat de la Hongrie a déjà connu un réchauffement et un dessèchement dans ce siècle. Dans un climat influencé par une hausse de la teneur atmosphérique des gaz à effet de serre, cette tendance ira en s'accentuant.

István Matyasovszky, Tamás Weidinger, Judit Bartholy, Zoltán Barcza, Eötvös Loránd University, Department of Meteorology, Pázmány P. sétány 1/A, H-1117 Budapest.
e-mail: Matya@ludens.elte.hu