4.7 EXPECTED REGIONAL VARIATIONS AND CHANGES OF MEAN AND EXTREME CLIMATOLOGY OF EASTERN/CENTRAL EUROPE

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1. INTRODUCTION

IPCC Third Assessment Report suggests that among many regions of the World eastern and central European countries could become highly vulnerable to global warming. Our investigations support these findings, especially, in case of two subregions of the Carpathian Basin: (1) Hungarian Great Plain, (2) watershed of the Lake Balaton. Severe shortage of precipitation occurred in the last few decades in both areas, therefore, ecosystems must face to high risk of environmental change. The Great Plain is the largest agricultural area in Hungary where high variability of floods and droughts cause severe damages in crop yields and human settlements, as well. Although the recent mean precipitation decrease is small and not significant, frequent extreme events (e.g., floods with fast runoff) may result in unstable climate conditions and increased vulnerability of agricultural activity in this region of the country. The largest lake in Western and Central Europe is the Lake Balaton with its unique 3.3 meter depth on average. In the last few years, the mean water level has decreased by 60-80 cm several times for a few months period. The only outflow of the lake, a small creek (called Sió) has been regulated and a sluice system has been built in 1863 in order to control the water runoff from the lake to the river Danube (120 km distance). Nowadays ships cannot use the channel because of the recent low water level, and the sluice system must have been closed for years.

These facts highlight the importance of hydrological and agricultural planning, and encouraged our research. The aim of our investigations is to compare climate change scenarios for these two sensitive regions. Several downscaling techniques have been compared, namely, (1) stochastical downscaling method nested in coupled ocean-atmosphere GCMs, (2) an upwelling diffusion energy balance model combined with GCM outputs and IPCC emission scenarios (Wigley et al., 2000, Hulme et al., 1995, Hulme et al., 2000). The stochastical downscaling method includes large-scale circulation of the atmosphere, and also, it is able to represent the linkage between the local surface variables and large-scale circulation. Seasonal and annual changes in temperature and precipitation have been determined for Hungarian stations in case of the 2xCO_2 climate and compared to historical time series. Furthermore, several IPCC emission scenarios have been compared and GCM outputs have been analyzed in order to project climate conditions (inlcuding daily mean, maximum and minimum temperature, and precipitation) for the 21st century in the Carpathian Basin.

2. HISTORICAL DOCUMENTARY ANALYSIS OF EXTREME CLIMATE EVENTS FOR THE CARPATHIAN BASIN

In historical documents, diaries, letters or other written reports usually extreme events are mentioned and possibly more or less objectively recorded. These historical sources can be used to evaluate the occurrence, duration and geographical location of extreme climatic events of the last millenium until 1900. Antal Réthly, a Hungarian climatologist of the 20th century, made detailed documentary research on the meteorological extremes occurred in the Carpathian Basin. He collected the historical documents related to meteorology into a four-volume-long book, titled "Meteorological events and natural disasters in Hungary" (Réthly, 1962, 1970, 1999). In order to facilitate computational research of these documentary sources a special code system using hierarchical subclasses have been defined and applied to the approximately 15000 collected items and as a result the entire information have been digitized and stored on computer devices for further analysis. The code system distinguishes several types of extreme climate information, including temperature, precipitation and wind-related extreme events, containing 4000, 10000, 1500 extreme information items, respectively.

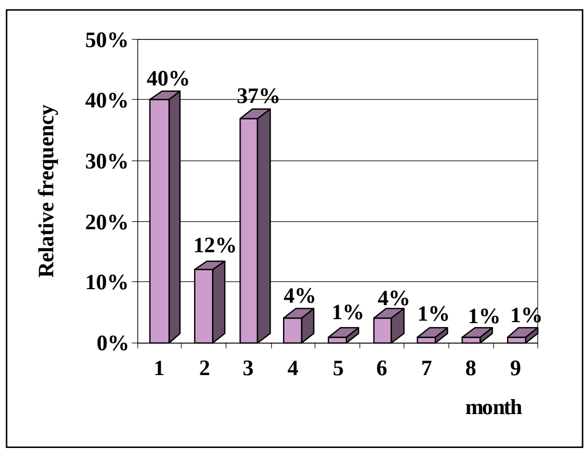

Fig. 1. Frequency of length of severe dry periods (in months)

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The largest portion of the historical database relates to extreme precipitation events, which are classified into 31 groups, e.g., floods, severe droughts, snowstorms, heavy rains, thunderstorms, hails, fogs, extreme wet years, etc. Then, extreme temperature related information is classified into 14 groups, e.g., heat waves, cool summer, severe frost period, extreme cold winter, long winter period, cold years, warm years. Finally, extreme wind information is classified into 15 groups, e.g., hot winds, cold winds, frost winds, strong N/S/E/W winds, extreme strong winds, windstorms, tornado. Both spatial and temporal distribution of extreme climatic conditions has been analyzed and some selected results are presented in this paper.

Fig. 1 presents the distribution of drought events of the last millenium until 1900 mentioned in historical sources. The largest relative frequencies belong to the 1 month and 3 months long dry periods (40% and 37%, respectively). According to the documentary data longer than half-year drought was rare in the Carpathian Basin.

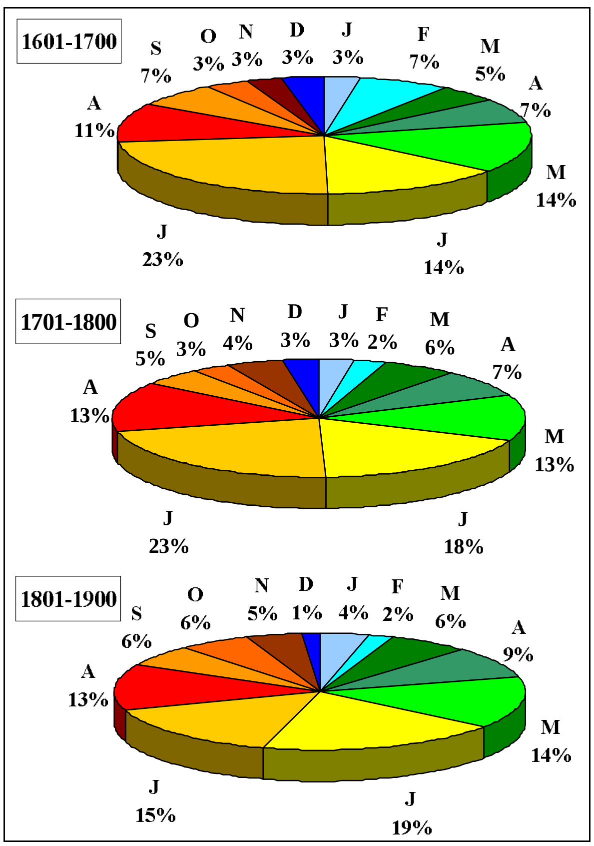

Fig. 2. Annual distributions of thunderstorms (monthly relative frequency in the 17th, 18th and 19th century).

A temporal comparison analysis is shown on Fig. 2, which compares the mean annual distribution of thunderstorms for the 17th, the 18th and the 19th century. The major portion (61-67%) of thunderstorms occur in the summer period (between May and August) when convective processes dominate the weather in the Carpathian region. Monthly relative frequencies of severe storms tend to increase in June and August (from 14% to 19%, and from 11% to 13%, respectively), while significant decreasing tendency can be detected in July (from 23% to 15%). Smaller relative frequencies in other seasons were not changing significantly, except February where relative frequency dropped from 7% to 2% in the 17th and 18th centuries.

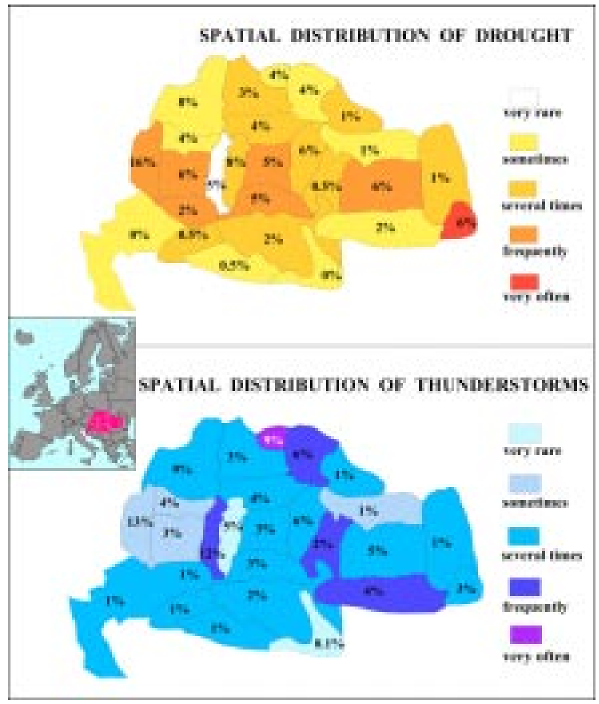

Fig. 3. Distribution of drought and thunderstorm events in the Carpathian Basin

For the spatial analysis of historical data 26 subregions have been defined and separated in the Carpathian Basin based on the historical background and geographical characteristics of the area. In this paper only two examples of spatial distribution of extreme climate events are presented, namely, drought and thunderstorms occurred in the Carpathian Basin during the last millenium until 1900 (Fig. 3). Percentage values indicate the portion of the subregion relative to the total numbers of the particular extreme event in the Carpathian Basin. While shading categories take into account the total number of historical sources from the subregion regardless of the type of extreme events, as well, indicating the relative frequency of droughts and thunderstorms in each subregion.

Finally, temperature index for the Carpathian Basin have been calculated by summing the annual numbers of positive and negative temperature anomalies taking into consideration the intensity of the documented historical data. Plot of the time series suggests that colder than normal climate conditions were documented more times than warmer conditions (Fig. 4). This cold dominance can be explained by more often cold events ("little ice age") or higher sensitivity of the society to decreased temperature values. The temperature index time series for the Carpathian Basin have been compared to the temperature anomalies from the mean value for Central England 1659-1900 (Manley, 1974). The comparison analysis suggests that correlation coefficient between the two time series is 0.33. Despite of the fact that this correlation is quite small (which could be expected because of the large distance of these two regions), more than half of the temperature anomalies shows similar signs (e.g., late 17th century, early 19th century, etc.).

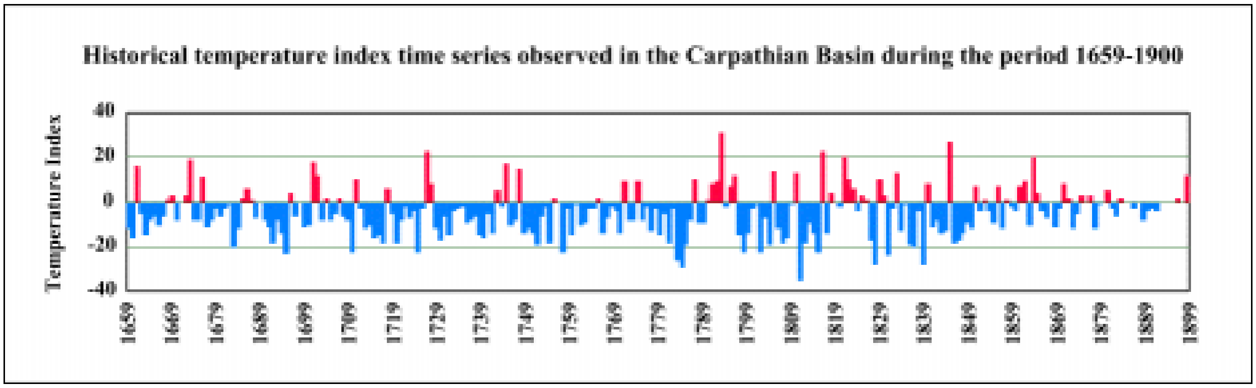

Fig. 4. Temperature Index based on historical documentary sources for the Carpathian Basin (1659-1900)

3. EXTREME CLIMATOLOGICAL ANALYSIS OF THE 20TH CENTURY

In order to analyze the centennial tendencies, extremes and changes of temperature and precipitation for the past century more objective data, namely, regular meteorological measurements are available (Mika et al., 2001). This part of the paper focuses on the climate extremes of the Carpathian Basin for the previous century.

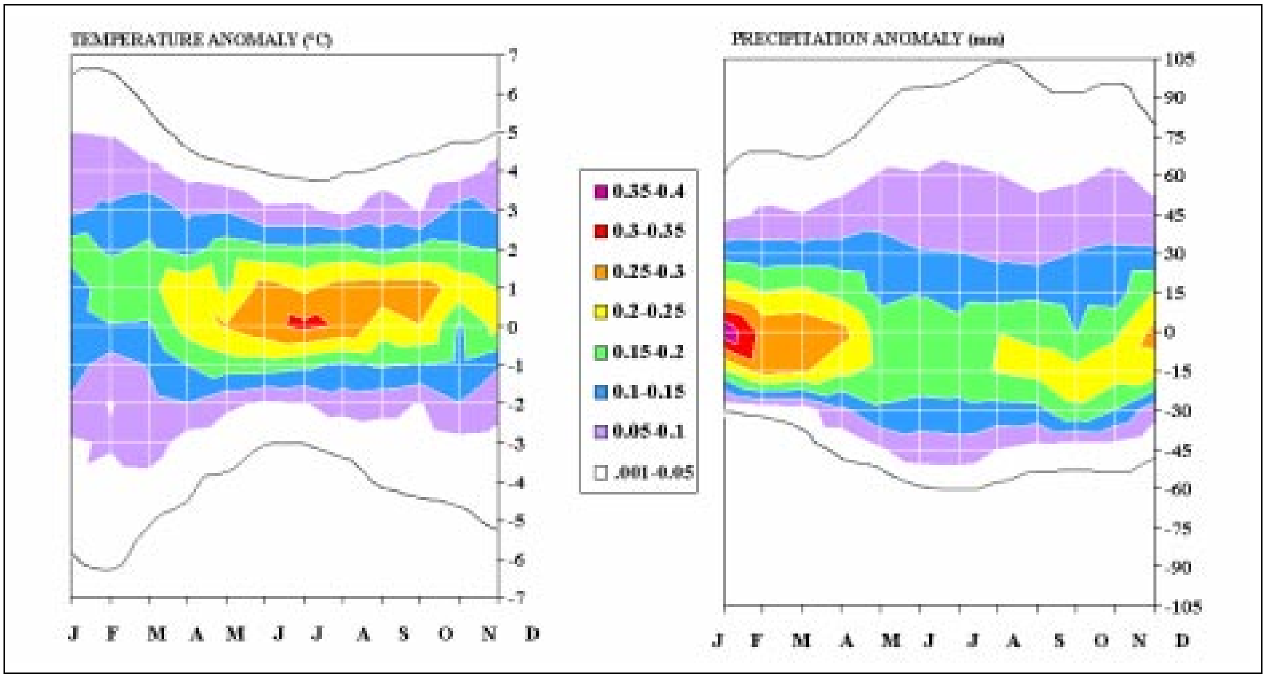

Fig. 5. Annual variation of relative frequencies of monthly temperature and precipitation anomalies observed in 10 Hungarian stations (1901-2000 period).

Figs. 5 and 6 summarize the structures of annual and decadal distribution of monthly temperature and precipitation anomalies in the Carpathian Basin for the 20th century. The annual cycles (Fig. 5) suggest that the largest extremes tend to occur in winter (December-January-February-March) for temperature, and in summer (May-June-July-August) for precipitation. In case of temperature extremes and means slight positive decadal trends are present (Fig. 6 upper panel), and the warming at the end of the century is comparable to the one of the 1941-54 period. Minimum of large precipitation events between 1971-94 (Fig. 6 lower panel) explains the unpreparedness and inability of the local authorities and inhabitants to the several severe flood events in the last few years.

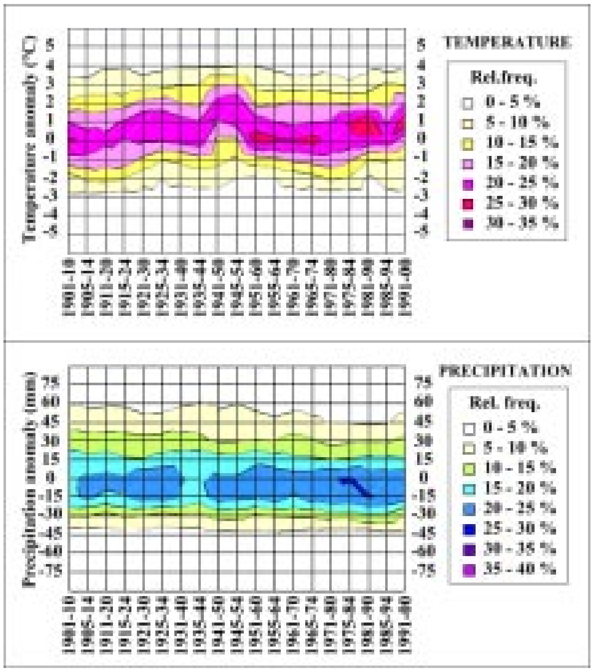

Fig. 6. Changes in decadal distribution of relative frequencies of monthly temperature and precipitation anomalies observed in 10 Hungarian stations (1901-2000 period).

Besides extreme value analysis of precipitation, variability and fluctuation characteristics have been determined. Spatial distributions of several statistical characteristics have been mapped for all seasons (Pongrácz and Bartholy, 2000). Time series have been also analyzed separately as robust and extreme. Distributions of extreme, robust and full time series have been compared (Bartholy and Pongrácz, 1998). Asymptotic approach has been applied to precipitation and temperature time series using Gumbel distribution model. Model parameters have been estimated by method of moments. Return values have been determined for pre-set periods (e.g., 10, 20, 50 years), these thresholds are exceeded once in average during the given period. Probability distribution of extreme daily precipitation for dry and wet regions of the Carpathian Basin have been analyzed (Fig. 7). Duration and intensity of precipitation on several consecutive days, as well, as length of dry periods have been compared. The above-mentioned variables could be important parameters for modeling and forecast of flood and drought.

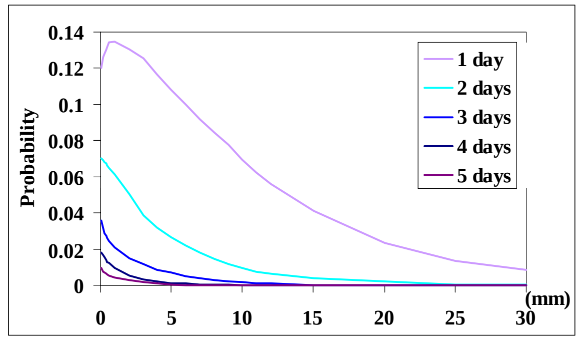

Fig. 7. Precipitation probabilities on several consecutive days (1-5) in the wettest station of Hungary (Keszthely).

4. 2xCO_2 CLIMATE SCENARIOS FOR SENSITIVE REGIONS OF HUNGARY

More detailed investigations have been carried out for two sensitive regions of the Carpathian Basin, namely, the drainage basin of the shallow Lake Balaton and Sió, and the Hungarian Great Plain (Fig. 8). In the present climatic conditions the water balance of these regions tends to be negative, and therefore it is likely that the global change may affect them the most.

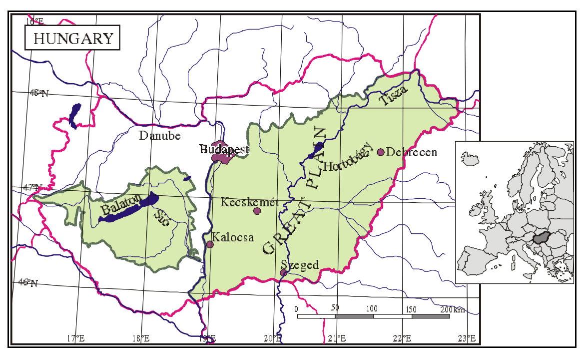

Fig. 8. Geographical location of the sensitive regions in Hungary: Great Plain, Balaton-Sió watershed.

The main goal of the study presented in this paper is to provide estimations for the local effects of the global climate change in Hungary using a stochastical downscaling model.

Stochastic downscaling methods are based on the fact that there exists considerable stochastic relationship between the large-scale atmospheric circulation and the meteorological, hydrological variables. This relationship is estimated from observed data and then is used with large-scale circulation available from GCM output. Thus, an estimation can be obtained for local hydrometeorological parameters under a new, such as $2xCO_2$ climate. (Bogárdi et al., 1993).

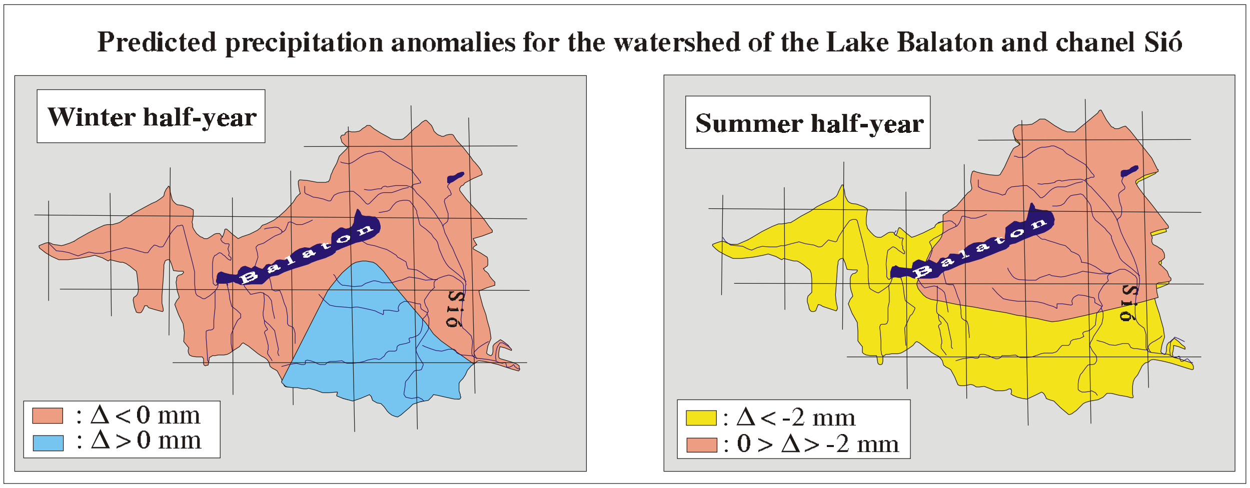

Fig. 9. Stochastical model estimations for daily precipitation anomalies in the watershed of Balaton-Sió on rainy days for $2xCO_2$ climate scenario.

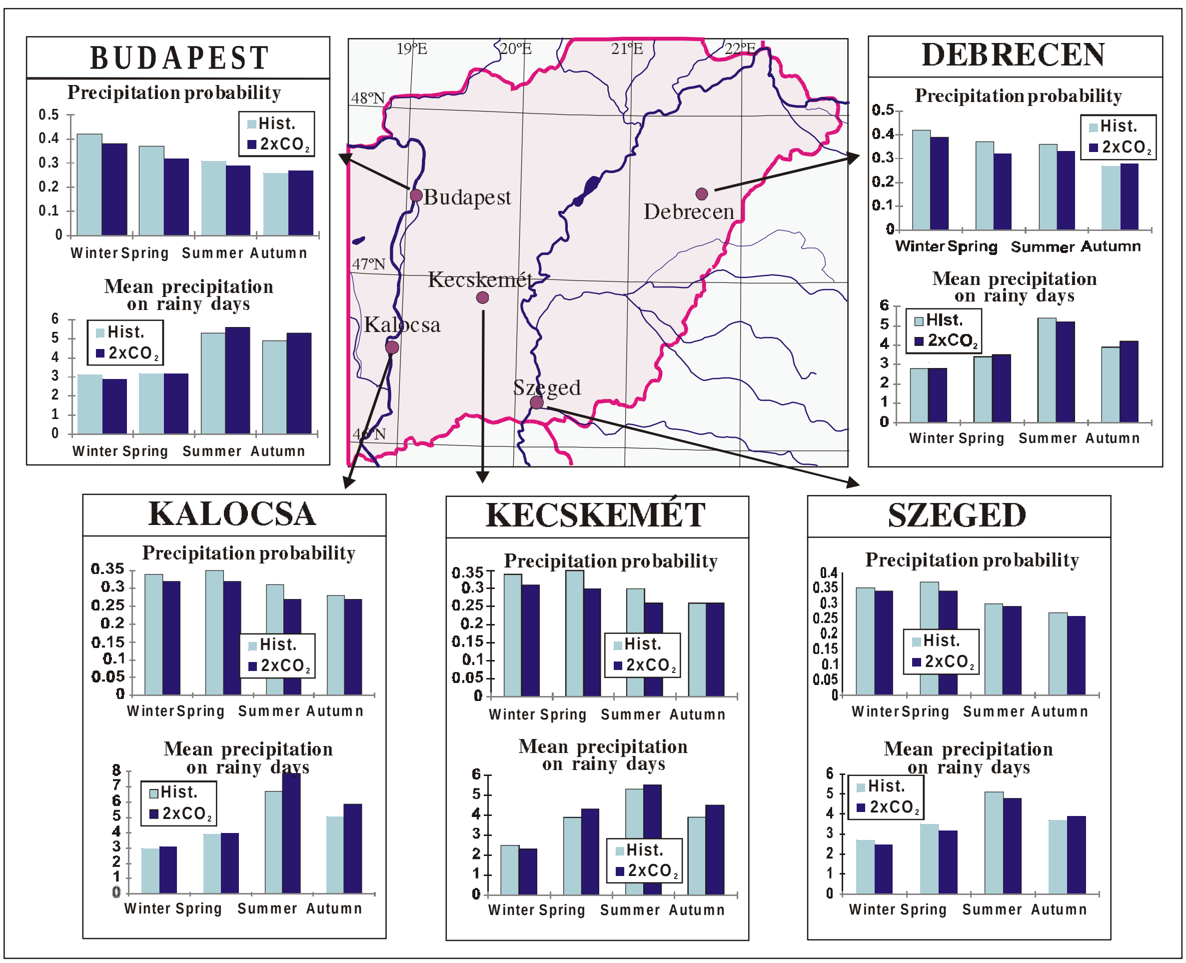

Fig. 10. Regional precipitation scenarios (for $2xCO_2$) by season for the Great Plain of Hungary.

The authors developed and applied such a model to the two sensitive regions of the Carpathian Basin shown on Fig. 8. (Bartholy et al., 1995; Weidinger et al., 1995, Bartholy and Matyasovszky, 1998) and to several other areas, such as to dry continental climate of Nebraska (Matyasovszky et al, 1994; Mearns et al, 1999), dry subtropics of Arizona (Bartholy and Duckstein, 1994), the Mediterranean climate of Greece (Matyasovszky et al, 1995) and to Alpine region in Austria (Nachtnebel et al, 1996). Computations were carried out using ECHAM, a GCM developed by the Max Planck Institute, Germany (Cubash et al., 1991), and a GCM of the Canadian Climate Centre (CCC). ECHAM shows a 1.5°C global warming, while CCC which is not a coupled ocean model predicts 3.5°C global temperature increase (Boer et al., 1984).

Because of the spatial-temporal intermittent character of precipitation, its prediction proves to be more complex than that of temperature. Accordingly, both occurrence and magnitude probability need to be calculated. Furthermore, wet/dry diurnal duration should be considered.

A 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 (Fig. 9). 25-35% less precipitation is expected in the summer months; the winter months, with 0-10% less precipitation will only be slightly dryer than is presently the case.

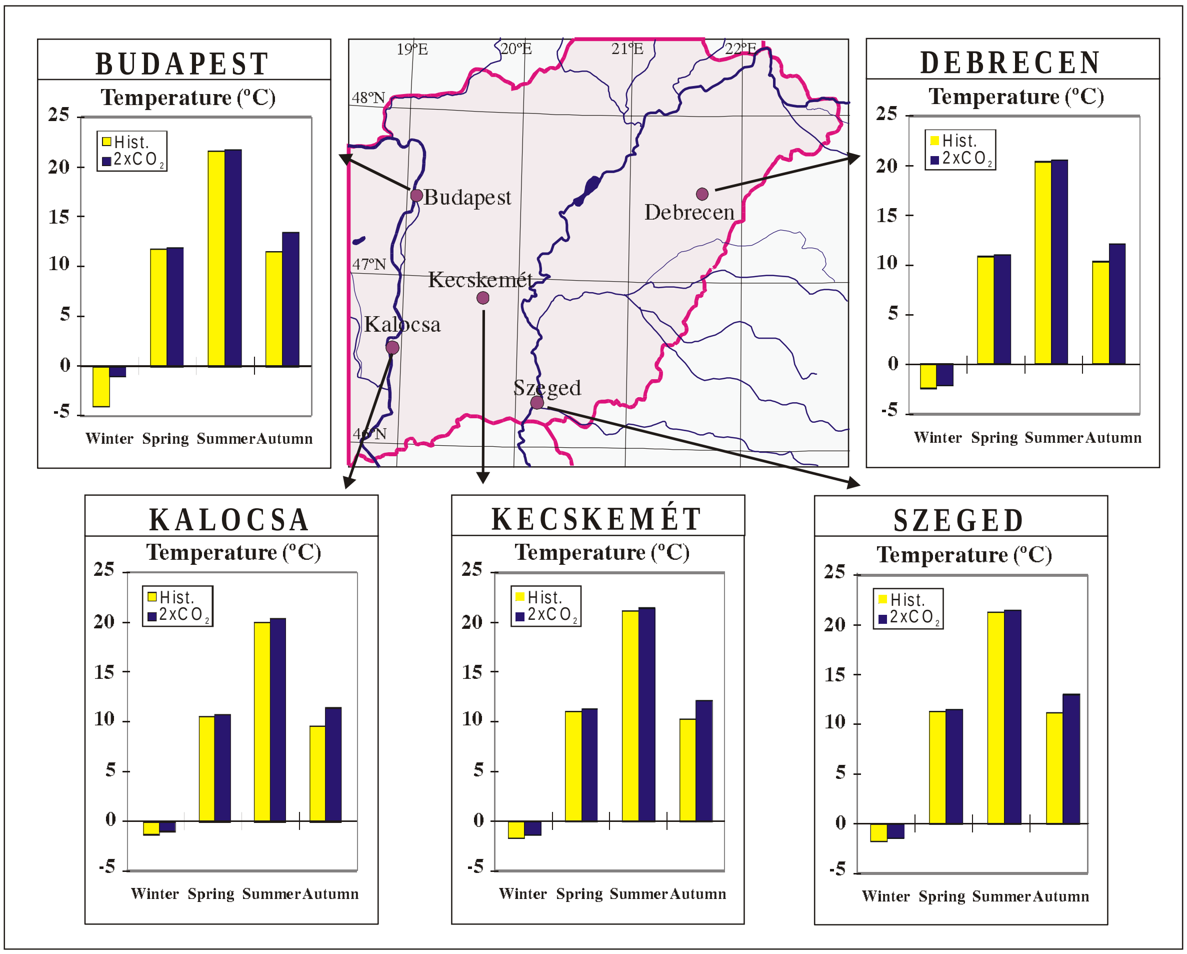

Fig. 11. Regional temperature scenarios (for $2xCO_2$) by season for the Great Plain of Hungary.

Estimations of $2xCO_2$ climate consequences on precipitation and temperature values for the other sensitive region of the country are presented on Figs. 10 and 11, respectively. Important results of our investigation on the Great Plain area of Hungary are: precipitation frequency decreases and precipitation magnitude during wet periods remains the same or indeed, could increase.

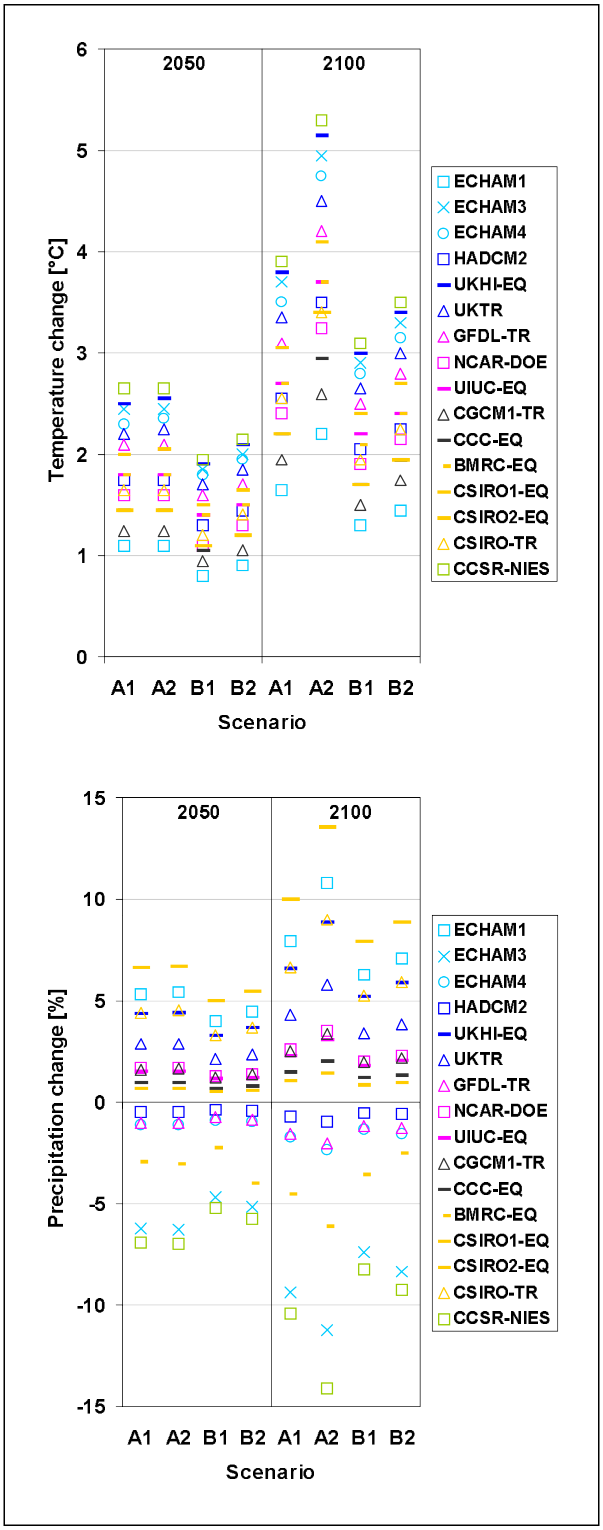

Fig. 12. Summary of the model estimations for annual mean temperature (°C) and precipitation (%) change in Hungary under different climate change scenarios.

Thus, precipitation patterns are expected to fluctuate more in the 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 and Matyasovszky, 1998). Changes in precipitation magnitude fluctuate between -10% and +5% in the summer months (Fig. 10) and between -15% and -5% in the winter months. On the whole annual precipitation change is in the range of 10%.

The spatial variability of temperature calculated under a 2xCO_2 climate for the Great Hungarian Plain (Fig. 11) is minimal. The seasonal trend with 0.1-0.5°C is positive. Interestingly, the average temperature in Autumn are expected to exceed 1.5°C (Bartholy and Matyasovszky, 1998). The expected mean annual temperature change is thus about +0.7°C.

5. PROJECTED CLIMATE CHANGE FOR 2050 AND 2100 IN HUNGARY

In order to generate climate scenarios on local/regional scales for Hungary a relatively simple tool, namely, the MAGICC/SCENGEN package (Wigley et al., 2000, Hulme et al., 1995, Hulme et al., 2000) was applied. This Climate Scenario Generator offers a wide range of model runs from different Global Climate Models (GCMs) that have been evaluated in the IPCC Assessment Reports. The package is based on an upwelling diffusion energy balance model that is combined with GCM outputs and several IPCC emission scenarios. Therefore, a detailed climate change scenario analysis on national/regional scale may serve a key input for further vulnerability and adaptation studies.

For a selected region statistical analysis of a large number of GCM outputs may reduce the high uncertainty of climate prediction. In this paper, 16 GCMs being included in the package are considered. Regional climate conditions are generated for the year 2050 and 2100. Annual and monthly mean temperature and precipitation changes are investigated for Hungary in case of the four main global climate scenarios (A1, A2, B1, B2) evaluated in the IPCC Third Assessment Report.

Upper panel of Fig. 12 presents the summary of the 16 model estimations for the annual mean temperature change by 2050 and 2100. All models and scenarios provide positive temperature tendencies for Hungary. Temperature projections for 2050 range between +0.8°C and +2.8°C, while for 2100 between +1.3°C and +5.2°C. The largest temperature change is estimated using the A2 scenario, especially by 2100. More diverse tendency can be seen for annual mean changes in precipitation for Hungary (lower part of Fig 12). Most of the models predict increasing annual precipitation amount, 13 models out of 16 suggest that annual change will range between -1% and +7% by 2050, while later between -3% and +14% by 2100.

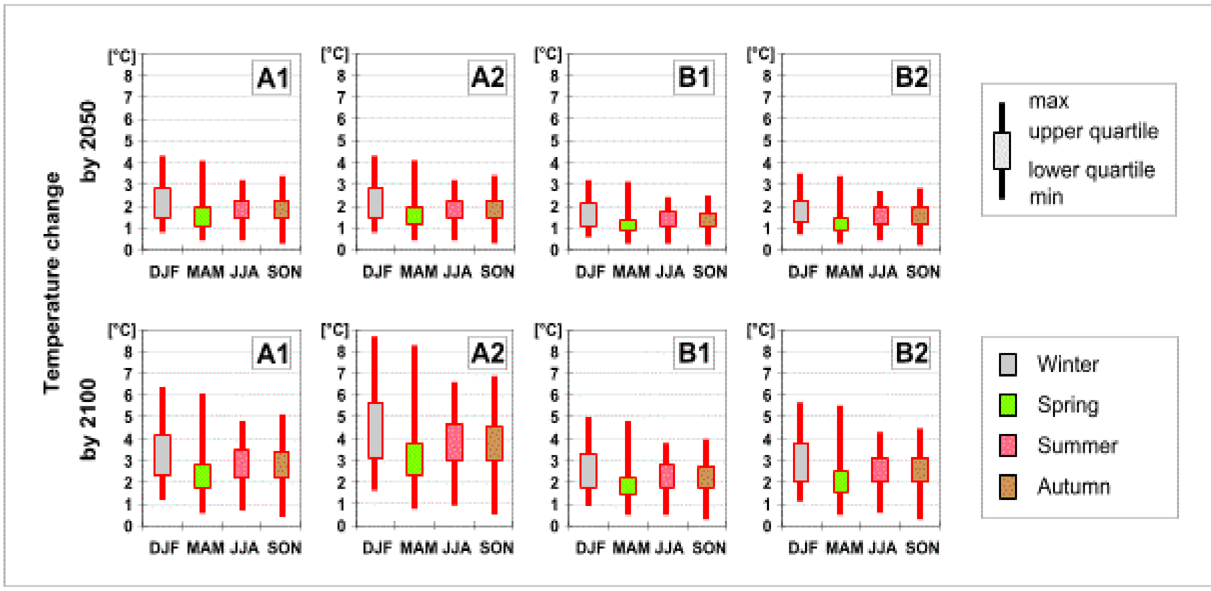

Fig. 13. Comparison of the seasons: model estimations for monthly mean temperature (°C) change in Hungary under different climate change scenarios.

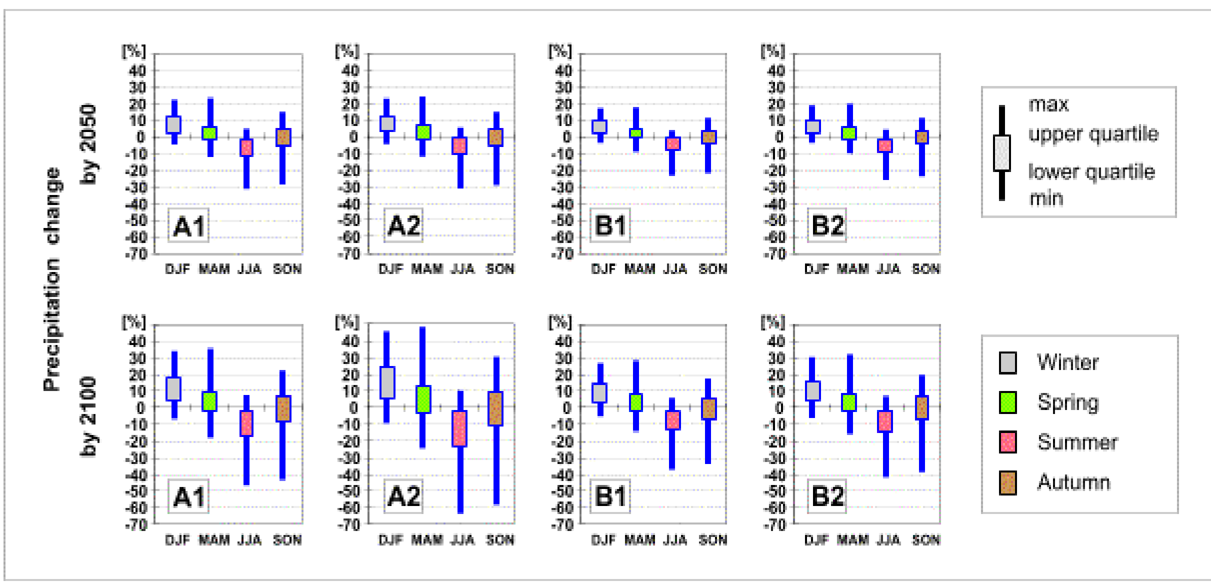

Fig. 14. Comparison of the seasons: model estimations for monthly mean precipitation (%) change in Hungary under different climate change scenarios.

Seasonal comparisons of model estimation for monthly mean temperature and precipitation change are provided on the Whisker-plot diagrams of Figs. 13 and 14, respectively. The largest temperature change will occur in winter and summer, however, the largest uncertainty of projections can be seen also in winter. Annual variation of monthly mean precipitation change exhibits changing signs: increased precipitation is projected for winter and decreased rainfall for the summer months, while small changes in the transient seasons. In case of A2 scenario for the year 2100 very high variability of model outputs (both temperature and precipitation) can be noticed.

Distribution of relative frequencies of the model estimations for monthly precipitation change are presented on Fig. 15. Here, scenarios are not separated. According to the diagrams winter and spring are expected to be wetter than today, while summer and autumn in Hungary are projected to be drier in the 21st century. These changes may result in more frequent flood and drought events.

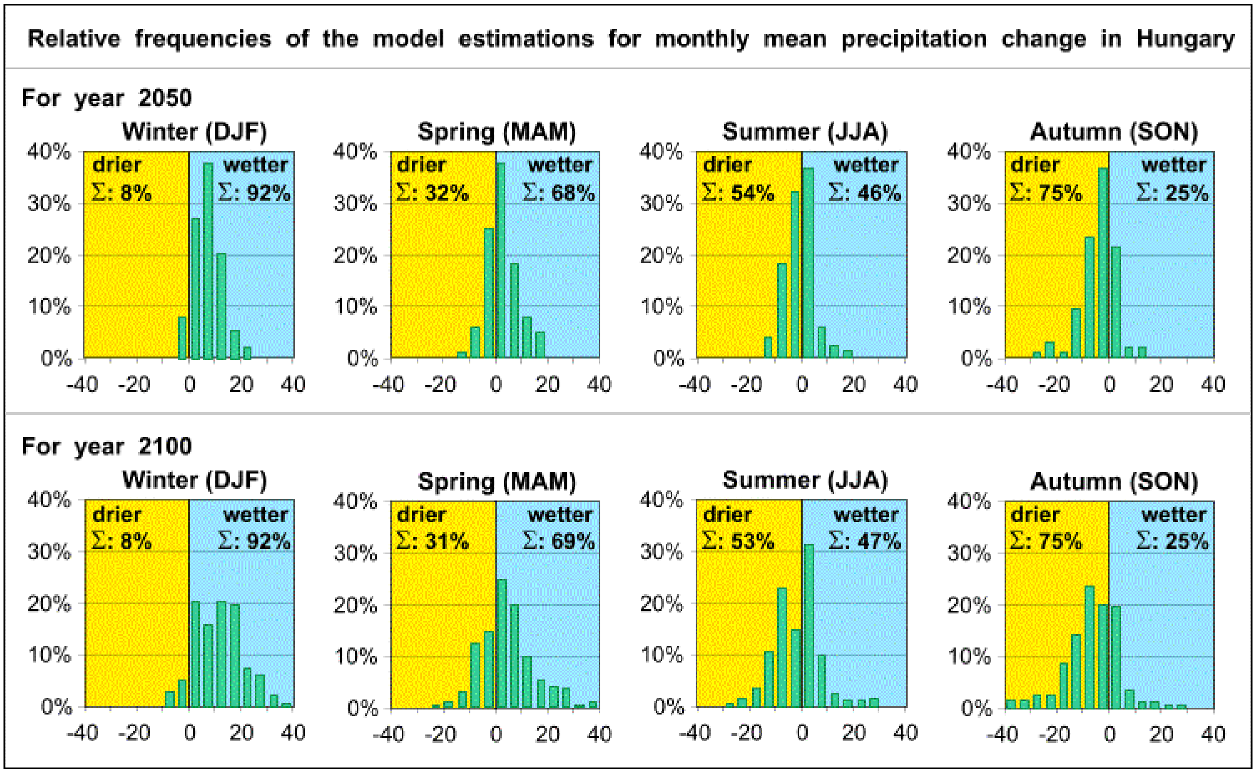

Fig. 15. Seasonal distribution of the model estimations for monthly mean precipitation (%) change in Hungary.

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