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# 20th century variations of the soil moisture content in East-Hungary in connection with global warming

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**Abstract**

Recently, climate change is one of the most current scientific problems. As a result of the change of climatic factors, such regional problems are emphasized by falling of underground water level, decrease of water supply and drying of the upper soil layer. The aim of the study is to detect 20th century variations of the soil moisture content in East-Hungary with statistical analysis of objective time series based on meteorological data. Furthermore, by determining representatively long dry and wet periods, management of agro-ecological problems related to the soil moisture content are supported. Palmer drought severity index time series of five meteorological stations in East-Hungary are analysed in the paper for the growing season between 1901 and 1999. Significant fluctuations of the soil moisture content were detected in the region for the 20th century; moreover, the soil became drier in the recent decades. With the help of the "break-point analysis" decade-long dry and wet periods were defined for the aim of climatic research.


## 1. Introduction

According to the third report of the Intergovernmental panel on Climate Change prepared in January 2001 the global surface temperature in the 20th century exceeded the average of the period 1961–1990 with 0.6 ± 0.2 °C (IPCC, 2001).

In Hungary, temperature time series in the 20th century indicate a warming tendency exceeding the global average with 0.4–0.8 °C. Namely, homogenised temperature time series of three meteorological stations in East-Hungary (Debrecen, Kecskemét and Szeged) show increasing tendencies in the 20th century (Szalai and Szentimrey, 2001). On the other hand, in the 120-year long precipitation data sets of 16 Hungarian stations 40 mm reduction can be observed (Molnár, 1994). On the basis of contemporary comparison of temperature and precipitation time series, an increasing arid character of the climate can be established in East-Hungary (Tar, 1992; Szinell et al., 1998).

The aim of the paper is to analyse tendencies of the soil moisture content in the 20th century and, by determining representatively long dry and wet periods, to support management of agro-ecological problems related to the soil moisture content.

## 2. The selected region and the data

The investigated region is the Hungarian catchment area of the Tisza River, selection of which is motivated by its important role in agricultural yield, strong dependence of repeated inundations and droughts as well as concern on natural protection, too (Horváth, 2002; Makra et al., 2002; Mika et al., 2005). 20th

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century variations of the soil moisture content of the region were analysed on the basis of the Palmer drought severity index (PDSI) time series of five meteorological stations (Miskolc, Nyíregyháza, Debrecen, Kecskemét and Szeged) for the period 1901–1999. Only the growing season of the year was taken into consideration, since soil moisture content plays the most important role in this period in the agricultural output. Not more than every second months were presented in the growing season, considering high autocorrelations of the PDSI (Mika et al., 2005). Even months (April, June, August and October) were chosen for the analysis, because they include August as the driest month considering soil moisture content and June with its extreme precipitation total.

PDSI is a worldwide known and used parameter of agro-climatological analysis (Palmer, 1965; Alley, 1984; Briffa et al., 1994; Scian and Donnari, 1997; Cook et al., 1999), since (1) results can be compared even when using it for regions with different climate and management of water-supplies, (2) it assures decision-makers for measuring abnormal weather phenomena in the given region, (3) with its help actual soil moisture content circumstances can be arranged into historical perspective, (4) it gives possibility for spatial and temporal representation of drought periods. Its disadvantages are as follows: increasing droughts are detected with several months delay and its use is limited in mountainous regions. Their further characteristic is that PDSI gives well usable results only for homogeneous and large regions. PDSI is widely used by the Agricultural Ministry of the USA to determine when allocating special drought grants (Vermes, 2000). PDSI is suitable for detecting spatial and temporal differences of drought periods in Hungary (Bussay and Szinell, 1996; Mika, 1998; Domonkos et al., 2000, 2001; Horváth, 2002; Makra et al., 2002; Mika et al., 2005).

Input parameters required for computing the PDSI index, the calculating procedure consisting of five steps and the formula are published in several professional journals (Palmer, 1965; Alley, 1984; Karl, 1986; Makra et al., 2002). PDSI indicates the severity of the dry and wet periods in such a way that the higher its absolute value, the more severe the dry or wet periods are. Generally, the range of monthly PDSI time series is between $-9$ and $+9$. If the PDSI > $|4|$, this means a severe difference from average circumstances and if the PDSI > $|6|$, then extreme circumstances dominate. These threshold values can change according to geographical regions (Briffa et al., 1994). Originally, Palmer considered the value of $|4|$ as the threshold value of the extremity (Palmer, 1965). Negative (positive) PDSI values indicate dry (wet) periods, while those near zero presume a state near the average.

When calculating the PDSI, it is an important step to choose on the one hand the formula of the potential evapotranspiration and on the other hand the reference plant. For calculating the potential evapotranspiration, Palmer used the Thornthwaite formula in the index (Thornthwaite, 1948). However, the use of the Blaney–Criddle method assured better assessments later (Alley, 1984).

Time series of mean monthly temperatures and monthly precipitation totals are influenced by inhomogeneity owing to the change of observation times and transfer of stations as well as other factors. Homogenised monthly time series were used in the calculations (Szentimrey, 1999).

Besides, meteorological parameters and values of the available water capacity are also required to calculate the index. Uniformly, for each of the five investigated stations water capacity was considered with the value of 150 mm (Makra et al., 2002). This is the low threshold of the water capacity values belonging to different soil types in the examined region of East-Hungary, (Stefanovits, 1975).

On the basis of former results (Mika et al., 2005), high significant correlations both between the homogenised monthly PDSI time series calculated with the Thornthwaite- and Blaney–Criddle methods and between the homogenised and non-homogenised monthly PDSI time series calculated with the Blaney–Criddle method were received. Hence, the PDSI index values were produced with using the *Blaney–Criddle method of calculating evapotranspiration* and *homogenised meteorological time series* of the five meteorological stations in East-Hungary for the period 1901–1999. The selected reference plant is maize, since it is characteristic for the region (Mika et al., 2001) and its quickly increasing leaf surface is similar to that of several other agricultural plants.

## 3. Methods

### *3.1. Significance analysis of linear trends and smoothing of time series*

It was examined whether or not linear trends of the 99-year long PDSI time series of Miskolc, Nyíregyháza, Debrecen, Kecskemét and Szeged for April, June, August and October were significant. The Student's $t$-distribution was considered to be the basis of the significance analysis, which was performed at the 1% probability level and with degree of freedom of $n-2$ ($n$ is the number of the investigated time series).

In order to characterise the data sets, 11-year moving averages and 11-year Gaussian averages of the original index time series were produced. The reason of using Gaussian averages is that moving averages modify wave lengths unequally and sometimes they ascribe extreme values to such years, which have average or slightly below-average values in the given or neighbouring years (WMO, 1986). The used loadings are based on the density function of the standard normal distribution.

### 3.2. Detecting share periods of different averages

In order to detect share periods with significantly higher averages (significantly wetter) or significantly lower averages (significantly drier) than the average of the whole 99-year long time series, a new interpretation of the classic two-sample test is used, developed by Makra et al. (2000, 2002) (Tar et al., 2001).

The basic question of the test is whether or not significant differences can be detected between on the one hand the average of any share period of a given times series and on the other hand that of the whole time series. The Makra-test performes the task for all possible share periods with $n = 3, 4, \dots, N - 1$ element numbers starting from the $1\text{st}, 2\text{nd}, \dots, (N - n)\text{th}$ elements of the time series. Detection of the significant differences also includes information on their duration, onset and end. In order to use the method, normality of the given time series is a sufficient but not necessary condition. Namely, in case of very large $N$ and $n$, considering the central limit theorem, density function of sums of the sample elements (random variables) is nearly normally distributed independently of the distribution of the original sample. Necessary conditions are stationarity of the original distribution, independence of the random variables and they should have standard deviations. In this way, for a sample with high enough element number (for high enough $N$ and $n$) the method can be used even the sample is not normally distributed.

The procedure can produce several such share periods, averages of which differ significantly from that of the whole time series in a given month and station. In our former studies those long enough share samples were detected, which mostly characterised the significant share periods within a given term. Namely, of the received several significant share periods those were retained per stations and months, for which the value of the probe statistics became the highest. After performing the Makra-test, the selected most characteristic significant breaks were generally distinct; however, beginning and ending years of some breaks with different signs slightly overlapped one another. In these cases, some years were omitted from the longer break until the overlapping stopped. The longer break was retained provided the rest of the break remained also significant (Makra et al., 2002). Nevertheless, all share periods with significantly higher or lower averages of that of the whole time series are presented in this study. In this way, with the help of the "break-point analysis", decade-long dry and wet periods are defined for the aim of climatic research.

## 4. Results

### 4.1. Tendencies of PDSI in the 20th century and its connection with time

According to the results of the significance analysis, in trends of the PDSI time series only for three stations of the five (Miskolc, Kecskemét and Szeged) and only for one month of the four (April) were received regression coefficients significant at the 1% probability level. Negative trends in the four months of the five stations indicate clear drying tendency (Table 1).

After using the two filters for the homogenised PDSI data sets, statistical connections of the time series were characterised with the correlation coefficients. Each of the correlations between 0.75 and 0.93 is significant at the 1% probability level. On the basis of the results, slow changes characterised with negative linear trends representing the 20th century decrease of the soil moisture content can be detected both with using the moving averages and Gaussian filters.

The latter smoothing seems to follow the values of the PDSI more exactly than the simple linear regression. For this reason, it is worth to analyse the joint temporal course of the two filters in the 20th century. The smoothed curves are parallely shown for the four months and the two filters, respectively (Fig. 1a and b).

Figures of the 11-year moving averages represent a decreasing tendency in the values of the time series for each station. Definite wet periods can be detected between 1910 and 1925, while the clearest dry periods can be found, except for Debrecen, between 1980 and 1999. Fig. 1 shows results for Szeged.

Curves smoothed with the Gaussian filter also indicate decreasing tendencies in the values of the time series for all the four months of the five stations. In Fig. 1b, for the sake of simplicity, only results for Szeged are presented. Temporal course of the Gaussian filter is similar station by station while its extreme values, with different intensity, can be observed in the same period for each station. When comparing the temporal course of the two filters, it can be established that the Gaussian filter follows the original time series much more precisely and reacts much more sensitively for their changes. In other

Table 1
Regression coefficients of the homogenised PDSI data sets, calculated with the Blaney–Criddle method, 1901–1999, (1/100 year)

| Station | PDSI | | | |
|---|---|---|---|---|
| | April | June | August | October |
| Miskolc | **−2.1** | −1.5 | −1.5 | −1.9 |
| Nyíregyháza | −1.6 | −0.7 | −1.2 | −1.8 |
| Debrecen | −1.6 | −0.7 | −0.7 | −1.7 |
| Kecskemét | **−2.5** | −1.2 | −1.7 | −2.2 |
| Szeged | **−3.1** | −1.7 | −0.9 | −2.0 |

**Bold**: regression coefficients indicating significant trends.

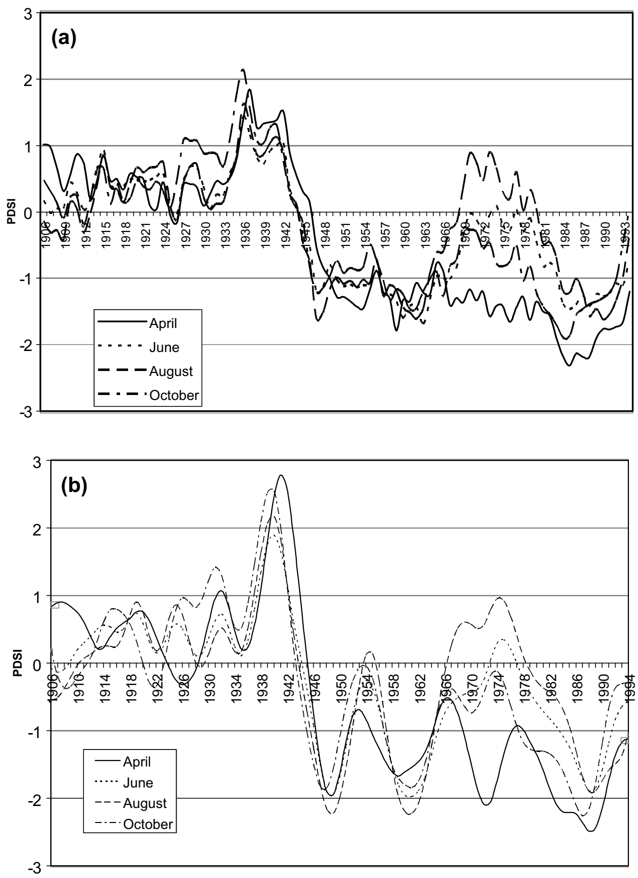


Fig. 1. (a) Moving averages of the homogenised PDSI values calculated with the Blaney–Criddle method, Szeged, 1906–1994. (b) Gaussian averages of the homogenised PDSI values calculated with the Blaney–Criddle method, Szeged, 1906–1994.

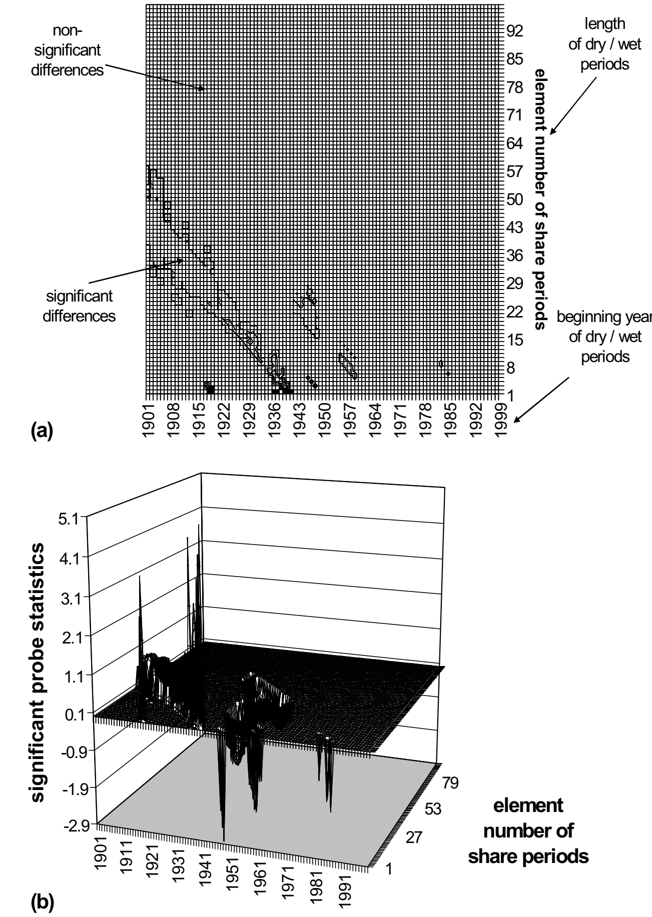


Fig. 2. (a) Those share periods (breaks), averages of which differ significantly from that of the whole homogenised PDSI data set, calculated with the Blaney–Criddle method, Szeged, June, 1901–1999 (two-dimensional representation). (b) Those share periods (breaks), averages of which differ significantly from that of the whole homogenised PDSI data set, calculated with the Blaney–Criddle method, Szeged, June, 1901–1999 (three-dimensional representation).

words, standard deviations of the Gaussian averages are higher than those of moving averages.

### 4.2. Changing and different share periods of PDSI, objective climate-analogies

In this chapter such share periods are planned to show in the homogenised PDSI data sets of the five stations calculated with the Blaney–Criddle method for the period 1901–1999, averages of which are significantly lower (drier) or higher (wetter) compared to the (near-zero) average of the whole data set. To perform this task, the statistical test described in Section 3.2 was used for the data sets of April, June, August and October. Selection of significantly different share periods provides a practical contribution to the historical description of the climate in the 20th century.

In order to illustrate all significant share periods at the 1% probability level, two- and three-dimensional representations were preferred (Fig. 2a and b).

For the two-dimensional figures the horizontal axis shows the time (years), while the vertical axis indicates element number (share periods with 1–98 elements) of the 99-year long (with 99 elements) whole PDSI data set for the period 1901–1999. Quadratic screens include values of probe statistics for all one-element share periods, for all two-, three-,…,97-element share periods and, at last, for the only 98-element share period. Those share periods, averages of which differed not significantly from that of the whole sample were indicated with zero. While for those share periods averages of which differed significantly from that of the whole sample, the values of the probe statistics remained valid. The representation occurs so that the horizontal axis shows the beginning year, while the vertical axis indicates the term of the share periods. For example, on the two-dimensional diagram for Szeged, June the quadratic point belonging to the year 1949 as a horizontal co-ordinate and the value of 16 as a vertical co-ordinate show the share period, which began in the year 1949 and took for 16 years, namely till 1964 (Fig. 2a).

For the three-dimensional figures the horizontal axis ($x$) shows the time, the vertical axis ($y$) indicates the values of the significant probe statistics, while the third axis ($z$) contains element numbers (share periods with 1–98 elements) of the 99-year long (with 99 elements) whole PDSI data set for the period 1901–1999. Quadratic screens include values of probe statistics for all one-element share periods, for all two-, three-,…,97-element share periods and, at last, for the only 98-element share period. Those share periods, averages of which differed not significantly from that of the whole sample were indicated with zero. While for those share periods averages of which differed significantly from that of the whole sample (similarly to the two-dimensional representation), the values of the probe statistics remained valid. The representation was similar to the two-dimensional one, with the exception that differences which proved to be significant in the cut of the beginning year given in the horizontal axis ($x$) and the length of term given in the vertical axis ($y$) were characterised by the distance from the reference-plane (99-year average), too. The difference of the PDSI from the 99-year average was between −1.9 and −0.9 (Fig. 2b).

Fig. 3 illustrates all significant share periods found in the investigated data sets in another way. It contains the following characteristics of all share periods with 1,2,…,98 elements: (a) number of share periods averages of which exceed that of the whole sample significantly, (b) maximum differences of the share periods, (c) number of share periods averages of which are significantly lower than that of the whole sample, (d) minimum differences of the share periods.

Some months and stations have definitely lots of long and important differences, while in some cases difference for only a couple of periods are significant. Maxima of significantly different averages decrease near exponentially with increasing element number of the share period. However, characteristics of this function are not the same at the investigated stations.

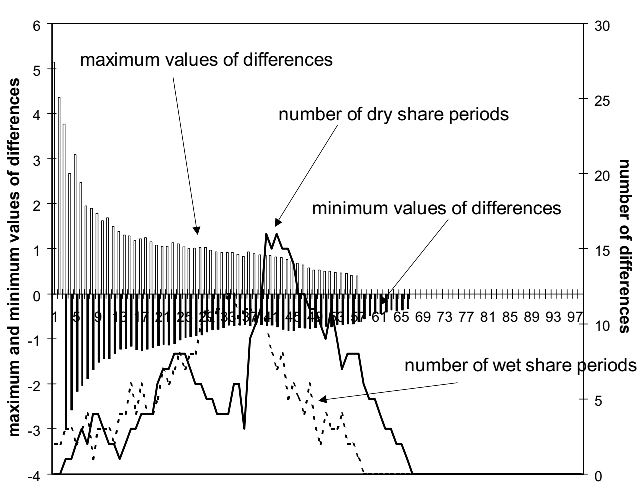


Fig. 3. Those share periods (breaks), averages of which differ significantly from that of the whole homogenised PDSI data set, calculated with the Blaney–Criddle method, Szeged, June, 1901–1999.

Knowledge of any share periods with significantly different averages can be used for climatic research related to soil moisture content.

With the help of the Makra-test significant wet periods were detected in the first part of the 20th century (between 1901 and 1940), while important dry breaks were revealed in the second half of the century. Location of the dry and wet periods in the times series of the 20th century is in agreement with the establishments of the special literature, according to which climate of East-Hungary became drier in the last decades (Molnár and Mika, 1997; Szinell et al., 1998; Horváth et al., 1999; Pongrácz et al., 2000; Makra et al., 2002).

## 5. Conclusion

Results are summarized as follows.

- The PDSI data sets calculating for the even months of the growing season, show significant linear trends in each month and station for the whole period of the 99 year. Namely, the 20th century is characterised by slow drying out. This definite tendency is reflected also in the data sets, smoothed with the moving average and Gaussian filters.
- With the help of the Makra-test all the share periods were determined, averages of which differed significantly from that of the whole 99-year long period. Then, graphic representation made the received share periods more interpretable. These sub-periods were several decade long at the investigated stations and months in most part of the growing season.
- Significant wet periods were detected in the first half of the 20th century, while important dry breaks occurred in the second half of the century.

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## References

Alley, W.M., 1984. The Palmer drought severity index: limitations and assumptions. Journal of Climate and Applied Meteorology 23, 1100–1109.

Briffa, K.R., Jones, P.D., Hulme, M., 1994. Summer moisture variability across Europe, 1892–1991: an analysis based on the Palmer drought severity index. International Journal of Climatology 14, 475–506.

Bussay, A., Szinell, Cs., 1996. Drought continues in Hungary in 1995. Drought Network News, A Newsletter of the International Drought Information Center and the National Drought Mitigation Center 8 (1), 4–6.

Cook, E.R., Meko, D.M., Stahle, D.W., Cleaveland, M.K., 1999. Drought reconstructions for the continental United States. Journal of Climate 12, 1145–1162.

Domonkos, P., Szinell, Cs., Szalai, S., Bihari, Z., Hursán, M., 2000. Meteorological reasons of developing inundations in 1999. Légkör 54 (2), 11–16 (in Hungarian).

Domonkos, P., Szalai, S., Zoboki, J., 2001. Analysis of drought severity using PDSI and SPI indices. Idöjárás 105 (2), 93–107.

Horváth, Sz., Makra, L., Mika, J., 1999. Spatial and temporal variations of the Palmer drought severity index in Southeast Hungary. Acta Climatologica Universitatis Szegediensis 32–33, 29–49.

Horváth, Sz., 2002. Spatial and temporal patterns of soil moisture variations in a sub-catchment of River Tisza. Physics and Chemistry of the Earth 27, 1051–1062.

IPCC, 2001. In: Houghton, J.T., et al. (Eds.), Climate Change 2001. The Scientific Basis. Contribution of WGI to the Third Assessment Report of the Intergovernmental panel on Climate Change Cambridge University Press, p. 881.

Karl, T.R., 1986. The sensitivity of the Palmer drought severity index and Palmer's Z index to their calibration coefficients including potential evapotranspiration. Journal of Climatology and Applied Meteorology 25, 77–86.

Makra, L., Tar, K., Horváth, Sz., 2000. Some statistical characteristics of the wind energy over the Great Hungarian Plain. The International Journal of Ambient Energy 21 (2), 85–96.

Makra, L., Horváth, Sz., Pongrácz, R., Mika, J., 2002. Long term climate deviations: an alternative approach and application on the Palmer drought severity index in Hungary. Physics and Chemistry of the Earth 27, 1063–1071.

Mika, J., 1998. Palmer drought severity index study for Hungary: I. Interpretation, spatial variations and extremes. In: The Water and the Protection of Aquatic Environment in the Central Basin of the Danube, 24–26 September 1998, Cluj-Napoca, Romania, pp. 137–144.

Mika, J., Horváth, Sz., Makra, L., 2001. Impact of documented land use changes on the surface albedo and evapotranspiration in a plain watershed. Physics and Chemistry of the Earth, Part B 26 (7–8), 601–605.

Mika, J., Horváth, Sz., Makra, L., 2005. The Palmer drought severity index (PDSI) as an indicator of soil moisture. Physics and Chemistry of the Earth (in press).

Molnár, K., 1994. Climatological representation of Hungarian landscapes at supposed climatic change. Candidate dissertation. Manuscript (in Hungarian).

Molnár, K., Mika, J., 1997. Climate as a changing component of landscape: Recent evidence and projections for Hungary. Zeitschrift für Geomorfologie 110, 185–195.

Palmer, W.C., 1965. Meteorological Drought. Research Paper, 45, US Weather Bureau, Washington, DC, p. 58.

Pongrácz, R., Bogardi, I., Duckstein, L., 2000. How do weather patterns and ENSO influence extreme hydrology in Hungary? In: Ijjas, I., et al. (Eds.), Proceedings of the International Conference on Water Resources Management in the 21st century with particular reference to Europe. Budapest, pp. 169–176.

Scian, B., Donnari, M., 1997. Retrospective analysis of the Palmer drought severity index in the semi-arid pampas region, Argentina. International Journal of Climatology 17, 313–322.

Stefanovits, P., 1975. Soil science. Mezögazdasági Kiadó, Budapest, pp. 148–150 (in Hungarian).

Szalai, S., Szentimrey, T., 2001. Did the climate of Hungary warm in the 20th century? In: Szász, G., (Ed.) Scientific memorial meeting for the centennial anniversary of birth of Prof. Dr. Sen. Dénes Berényi, 2001, DE—MTA—OMSZ (in Hungarian).

Szentimrey, T., 1999. Multiple Analysis of Series for Homogenization (MASH). In: Proceedings of the Second Seminar for Homogenization of Surface Climatological Data, Budapest, Hungary. WMO, WCDMP, vol. 41, pp. 27–46.

Szinell, Cs., Bussay, A., Szentimrey, T., 1998. Drought tendencies in Hungary. International Journal of Climatology 18, 1479–1491.

Tar, K., 1992. Change of climate at Túrkeve. Scientific memorial meeting for the 145th anniversary of birth of Kabos Hegyfoki. Debrecen-Túrkeve, 8–9 July 1992. pp. 156–164 (in Hungarian).

Tar, K., Makra, L., Horváth, Sz., Kircsi, A., 2001. Temporal change of some statistical characteristics of wind speed over the Great Hungarian Plain. Theoretical and Applied Climatology 69 (1–2), 69–76.

Thornthwaite, C.W., 1948. An approach towards a rational classification of climate. Geographical Reviews 38, 55–94.

Vermes, L. (Ed.), 2000. How to develop a drought mitigation strategy? ICID Guide, Budapest, pp. 25–28 (in Hungarian).

WMO, 1986. Guidelines on the quality control of surface climatological data. WMO Technical Documentation, Geneve, vol. 111, pp. 21–39.