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Application of gridded daily data series for calculation of extreme temperature and precipitation indices in Hungary

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Abstract—The calculation of extreme climate indices defined by several international projects requires homogeneous time series. To this effect, long term daily extreme temperatures and daily precipitation sums were homogenized, quality controlled, and further processed by the method MASH (Multiple Analysis of Series for Homogenization). After homogenization of station observation series, a gridding procedure was performed on the daily observations by the method MISH (Meteorological Interpolation based on Surface Homogenized Data Basis). The idea behind the MISH interpolation scheme stems from the following principles: gridded data can be created (interpolated) at higher quality with respect to certain climate statistical parameters; and these parameters can be modeled by using the long climate data series. In the MISH procedure, the modeling of the statistical parameters for a given location is based on the long term homogenized monthly data of neighboring stations.

In this paper, we present the computations of extreme temperature and precipitation climate indices for the period of 1901–2009 using datasets which were processed by the above homogenization and gridding algorithms. The obtained trends of several extreme indices as well as their spatial distributions are demonstrated on graphs and maps.

Key words: extreme climate indices, data homogenization, data interpolation, climate of Hungary

1. Introduction

The study of climate extremes in a changing climate has come to the fore in recent years. The most common way to detect changes is the analysis of extreme climate indices, which are defined by several international projects (*Alexander et al.*, 2006). Groups, such as the World Meteorological Organization (WMO)

CCI/CLIVAR Expert team on Climate Change Detection and Indices (ETCCDI), the European Climate Assessment (ECA), and the Asia-Pacific Network (APN) have aimed to provide a framework for defining and analyzing the observed climate extremes. Climate index calculations require quality controlled, homogeneous time series, and the analysis of the results requires a consistent approach (*Wijngaard et al.*, 2003). The global and also the regional studies have focused primarily on the analysis of long term daily temperature and precipitation data (*Frich et al*., 2002; *Haylock et al.*, 2008), as these climate variables are the most widely available ones. The majority of long data series is inhomogeneous, and often contains shifts in the mean or in the variance due to non-climatic factors, such as site-relocations, changes in instrumentation or in observing practices. Inhomogeneities can distort the true climatic signal, homogeneity testing is important for climate change studies (*van Engelen et al.*, 2008). Amongst the observation series there are good quality data as well, but sorting them out requires the execution of a homogenization procedure first (*Aguilar et al.*, 2003). Neglecting the inhomogeneous series causes a huge loss of valuable information.

Studying the spatio-temporal changes of extremes can be implemented through the analysis of observations reliable in time and space. The spatial interpolation of extreme indices is a difficult task as the distribution functions of the several derived values are unknown. However, the basic variables, such as temperature and precipitation can be gridded by the knowledge of their statistical properties, thus, higher quality gridded datasets can be constructed for further analysis. The main steps of creating the homogenized, gridded dataset for computation of extreme indices are presented in this paper. The changes of such indices for Hungary from the mid-20th century to present are illustrated and shortly analyzed on graphs and trend maps.

2. *Data and methods*

2.1. Homogenization

The computations implemented in this work are based on long term daily data in the period of 1901–2009. Daily maximum and minimum temperatures of 15 observation stations and daily precipitation sum of 58 precipitation stations were taken into account in the analysis. In the preparation phase, homogenization and quality control of the daily measurements were carried out. The homogenization of data was performed with the procedure MASH (*Szentimrey*, 1999). All the MASH options except the metadata information were used in this paper.

2.2. The main features of MASHv3.02

The MASHv3.02 (*Szentimrey*, 2007) software consists of two parts.

Part 1: Quality control, missing data completion, and homogenization of monthly series:

- Relative homogeneity test procedure.
- Step by step procedure: the role of series (candidate or reference series) changes step by step in the course of the procedure.
- Additive (e.g., temperature) or multiplicative (e.g., precipitation) model can be used depending on the climate elements.
- Providing the homogeneity of the seasonal and annual series as well.
- Metadata (probable dates of break points) can be used automatically.
- Homogenization and quality control (QC) results can be evaluated on the basis of verification tables generated automatically during the procedure.

Part 2: Homogenization of daily series:

- Based on the detected monthly inhomogeneities.
- Including quality control (QC) and missing data completion for daily data. The quality control results can be evaluated by test tables generated automatically during the procedure.

The importance of homogenization is demonstrated in *Fig. 1* which show the annual number of frost days (daily minimum is below zero) for Szeged station using original and the homogenized daily minimum temperatures. Both the magnitude and the sign of the estimated linear trend are different in the two cases.

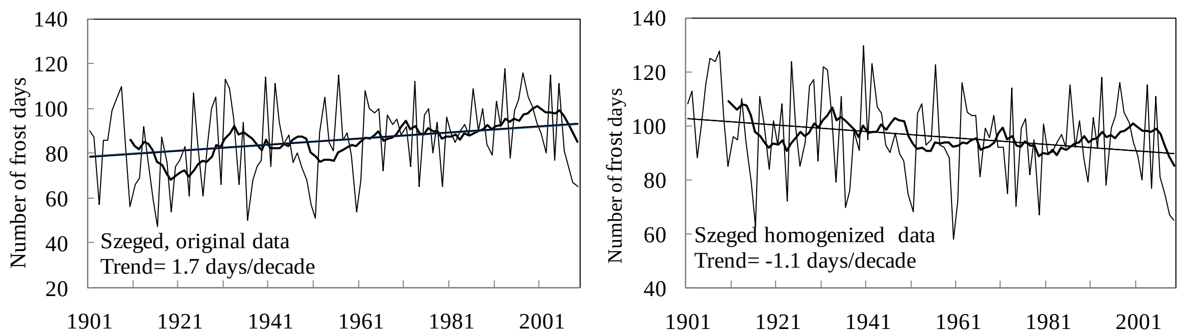

Fig. 1. Annual number of frost days for Szeged station with the fitted linear trend as well as the 10-year moving average in the period of 1901–2009 using the original (left) and homogenized (right) data.

2.3. Gridding

To obtain the high quality, good resolution dataset, a gridding procedure was performed on the homogenized daily series. According to the representativity examinations in the interpolation section, which were performed during this work, the expected interpolation errors may be accepted with using the predictor network of 15 temperatures and 58 precipitation station data series. The MISH interpolation method is a proper choice for this purpose. The MISH procedure was developed at the Hungarian Meteorological Service especially for interpolation of meteorological data (*Szentimrey* and *Bihari*, 2007a). It is based on the principles that the gridded data can be derived (interpolated) at a higher quality if we know certain climate statistical parameters. For example, in the case of normal distribution the means and the covariance structure unambiguously determine the optimal interpolation formula. Long climate data series allow modeling of these statistical parameters. Thus, the modeling for a given location is based on the statistical features of the long term homogenized monthly data of neighboring stations.

2.4. The main features of MISHv1.02

The software MISHv1.02 (*Szentimrey* and *Bihari*, 2007b) consists of two units, the modeling and the interpolation systems. The interpolation system can be operated on the output of the modeling system. The attributes of the MISHv1.02 software can be summarized as follows:

Modeling system for climate statistical parameters in space:

- Based on long homogenized data series and supplementary deterministic model variables, e.g., topography.
- Cross-validation test for interpolation error or representativity.
- Modeling procedure must be executed only once before the interpolation applications!

Interpolation system:

- Additive (e.g., temperature) or multiplicative (e.g., precipitation) model and interpolation formula can be used depending on the climate elements.
- Daily, monthly values and many years' means can be interpolated.
- Few predictors are also sufficient for the interpolation.
- The interpolation error or representativity is modeled too.
- Capability for application of supplementary background information (stochastic variables), e.g., satellite, radar, forecast data.
- Capability for gridding of data series.

Gridding system:

- Interpolation, gridding of monthly or daily station data series for given predictand locations. In case of gridding, the arbitrarily chosen predictand locations are the nodes of a relatively dense grid.

Contrary to geostatistical methods, the values of variograms must be modeled for each interpolating processes (*Szentimrey et al.*, 2007). One of the most important advantages of the MISH is that the modeling part must be executed only once before the gridding of the data on different timescales, such as daily, monthly, seasonal, or other. Additionally, different station networks can be used in the modeling and in the gridding parts. The modeling part of the MISH procedure is executed on a relative dense, $0.5' \times 0.5'$ resolution grid.

In order to calculate extreme indices, the MISH gridding part was performed on homogenized daily observations for a $0.1° \times 0.1°$ grid. The implementation of the MISH gridding procedure resulted in a high quality, homogenized, gridded daily maximum and minimum temperature and daily precipitation datasets with a ~10 km spatial resolution (1104 grid points) in the period of 1901–2009 for Hungary.

3. Climate indices calculations on the gridded dataset

The extreme indices used in this study are based on the CECILIA (Central and Eastern Europe Climate Change Impact and Vulnerability Assessment) project definitions. In the framework of CECILIA project, numerous indices were defined (74 temperature and 55 precipitation indices) on different time scales, i.e., yearly, seasonal and monthly (*Hirschi*, 2008). All of them were implemented for Hungary on homogenized data for observation stations and also for gridded datasets for the whole examined long period. A few selections of the CECILIA extreme indices are presented in this work on yearly scale (*Table 1*).

Table 1. Extreme indices used in this study

Index	**Unit**
Summer days: Tmax > 25 °C	%
Hot days: Tmax ≥ 30 °C	%
Frost days: Tmin < 0 °C	%
Warm nights: Tmin > 20 °C	%
Number of wet days: daily precipitation > 1 mm	days
Percentage of days > 20 mm precipitation	%
Greatest 1-day total rainfall	mm
Greatest 5-day total rainfall	mm
Simple daily intensity: precipitation sum/number of wet days	mm/day
Consecutive dry days: maximum number of consecutive days when the daily precipitation < 1 mm	days

The computational techniques used in the course of index calculations can lead to differences in the results. To obtain comparable results for larger regions, we have to make sure to use the same definition and algorithm. It is particularly important in the case of indices based on percentiles (*Alexander* and *Arblaster*, 2009).

With the help of homogenization, gridding, and extreme index calculation procedures, a high quality, good resolution dataset of the long-term series of indices can be generated and stored. These index datasets can form the basis of further examinations, such as trend estimation and mapping of changes.

4. Graphs and maps based on homogenized gridded data

The course of several temperature and precipitation extreme indices, from the beginning of the 20th century can be followed up in *Figs. 2–4*. Grid point averages represent the countrywide average. The increasing warm temperature extremes coincide with the warming tendencies in the region (*van Engelen*, 2008). The percentage of hot days and that of the warm nights have intensely increased since the early eighties. The presence of more warm nights is also obvious from 1901. The greatest 5-day total rainfall and the days with above 20 mm precipitation show a slight increasing in the last intense warming from eighties. The simple daily intensity index indicates that the rate of the intense rainfall events has increased in summer. The length of the longest dry spell became shorter recently, but considering the whole period, some increase is apparent.

The IPCC Fourth Assessment Report (*IPCC*, 2007) established the features of recent trends of extreme weather events from the late 20th century, in some cases typically after 1960. The trend maps in *Figs. 5–10*, which illustrate the changes of some extreme indices in Hungary, cover the time period 1961–2009 to allow the comparability with other well-known international studies like IPCC. The estimated grid point changes are depicted by linear trend fitting on the corresponding maps. The fitted linear trends were tested on station data and grid point series data as well. In extensive regions of the country, the number of frost days decreased (*Fig. 5*). White areas in *Fig. 5* represent the regions where the changes are not significant at 0.1 probability level. The obvious warming trend is indicated in the percentage of summer days (*Fig. 6*). Beside the point estimation of the slope, confidence intervals were constructed to the estimated trend at different significance levels. *Fig. 7* consists of two maps, according to the bounds of the 0.1 significance confidence interval. The lower bound illustrates the minimum change and the upper bound signifies maximum change occurred in the examined period. Maps of *Figs. 8–10* show the spatial trend of some extreme precipitation climate indices. The number of wet days decreased in Hungary, except for a small region of the country in the northeast (*Fig. 8*). The change in the greatest 1-day total rainfall varies from –15 mm to +10 mm. Regions with growing 1-day precipitation lie mainly to the East from the Danube. The daily precipitation intensity increased in summer. It means that the proportion of the heavy precipitation events in the total rainfall increases over most areas in Hungary

(*Fig. 10*). Regarding the past 50 years the precipitation changes were not significant in extensive regions of the country, according to the applied hypothesis testing.

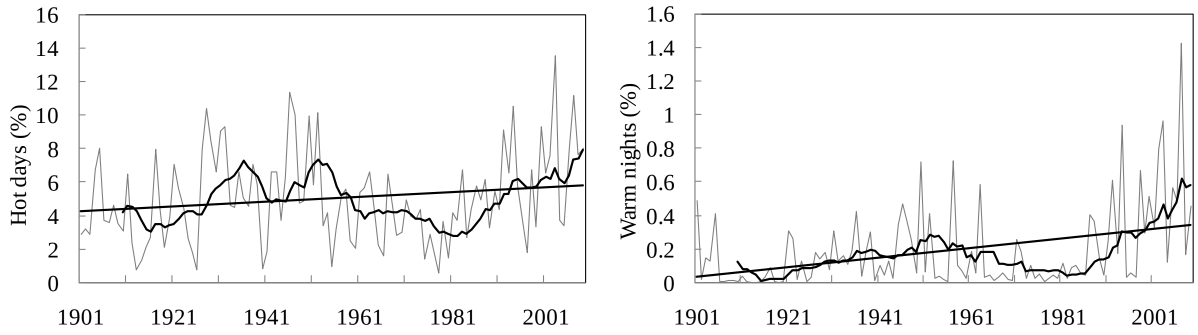

Fig. 2. Grid point average of the yearly percentage of hot days (left) and warm nights (right) with the fitted linear trend as well as the 10-year moving average in the period of 1901–2009 for Hungary.

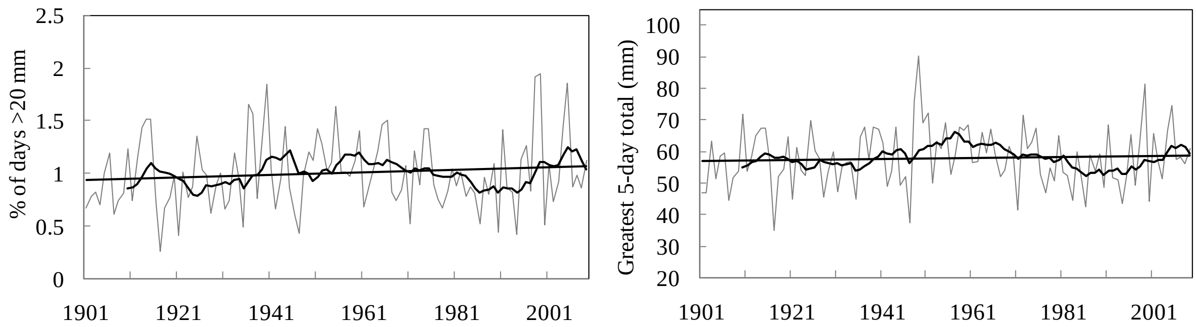

Fig. 3. Grid point average of the yearly percentage of days with above 20 mm (left) and the greatest 5-day precipitation (right) with the fitted linear trend as well as the 10-year moving average in the period of 1901–2009 for Hungary.

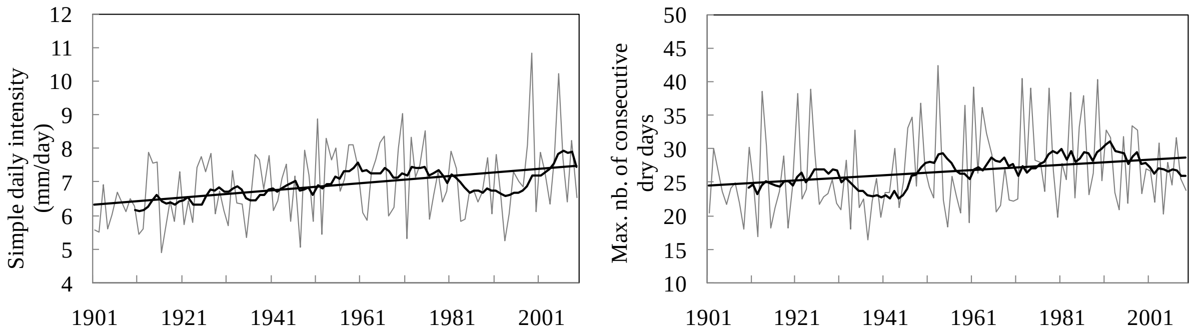

Fig. 4. Grid point average of the daily precipitation intensity index in summer (left) and the maximum number of consecutive dry days (right) with the fitted linear trend as well as the 10-year moving average in the period of 1901–2009 for Hungary.

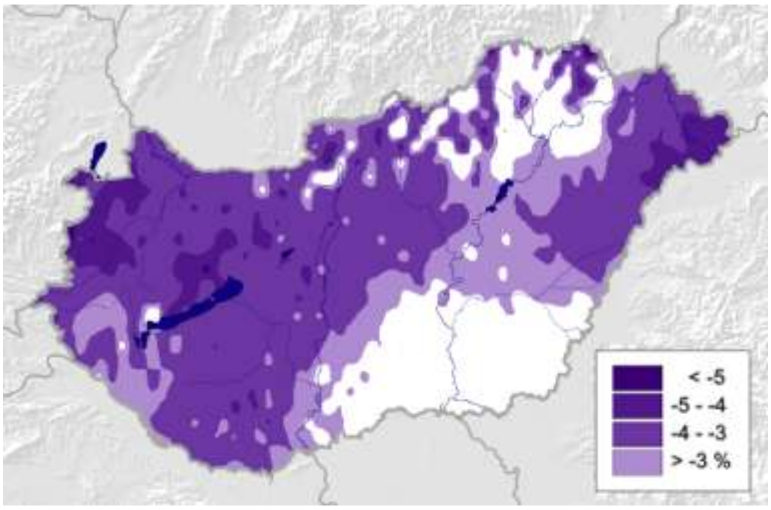

Fig. 5. Change (%) in the number of frost days in the period of 1961–2009. White color indicates no significant change on 0.1 confidence level.

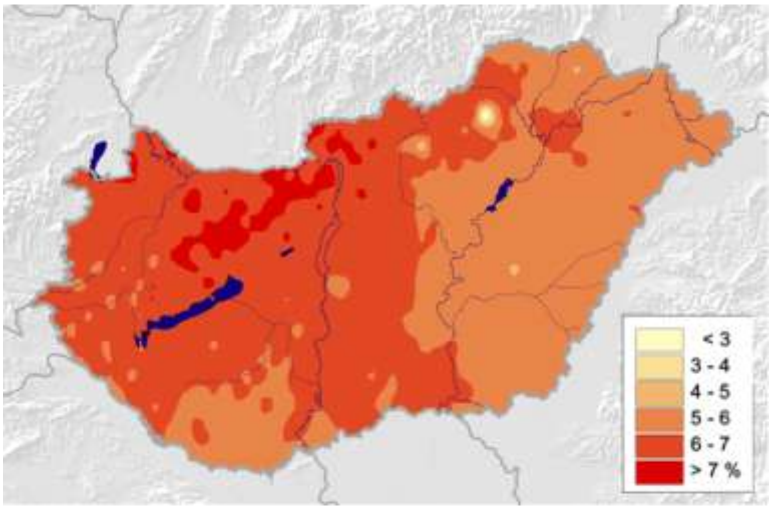

Fig. 6. Change (%) in the number of summer days in the period of 1961–2009.

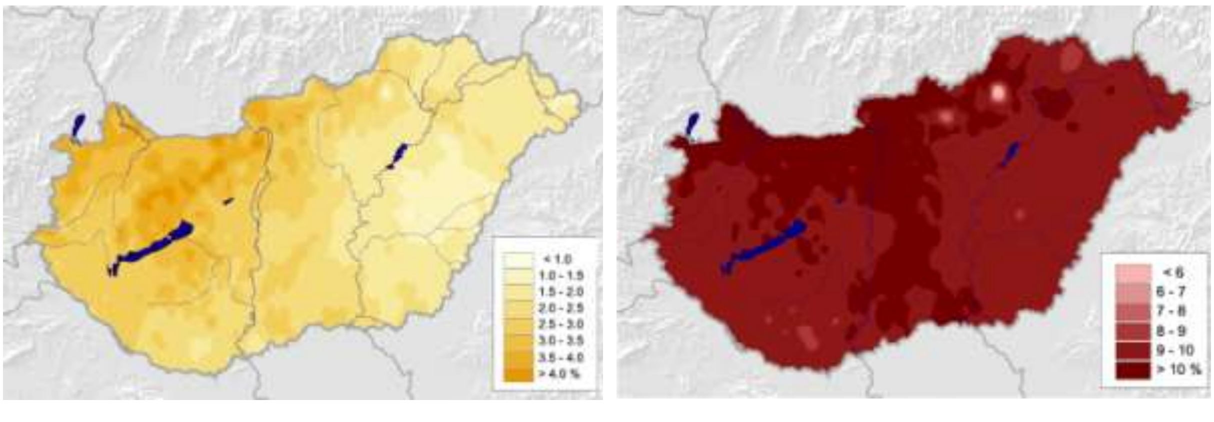

Fig. 7. Change (%) in the minimal (left) and maximal (right) number of summer days according to the 0.1 confidence interval bounds in the period of 1961–2009.

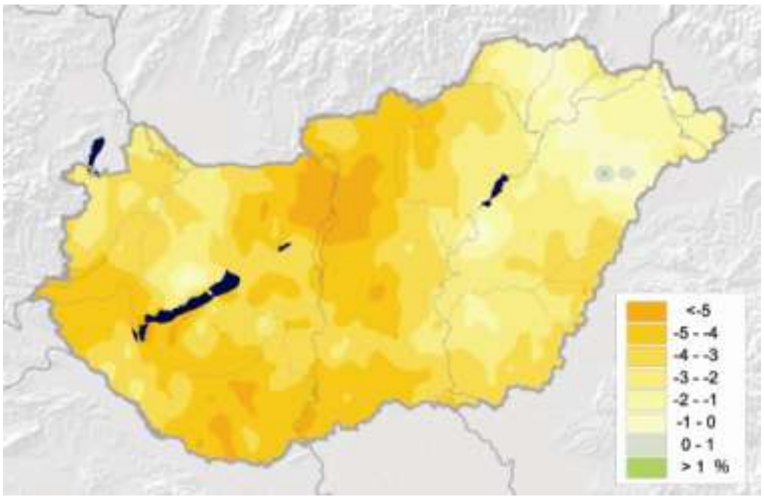

Fig. 8. Change (%) in the number of wet days in the period of 1961–2009.

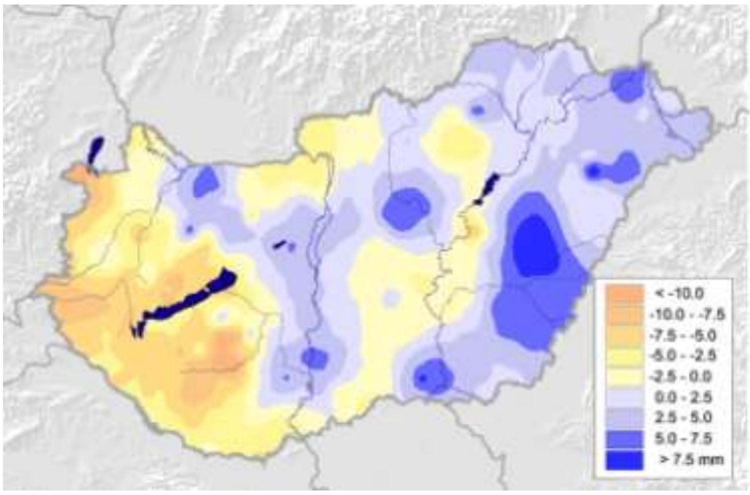

Fig. 9. Change (mm) in the greatest 1-day total rainfall in the period of 1961–2009.

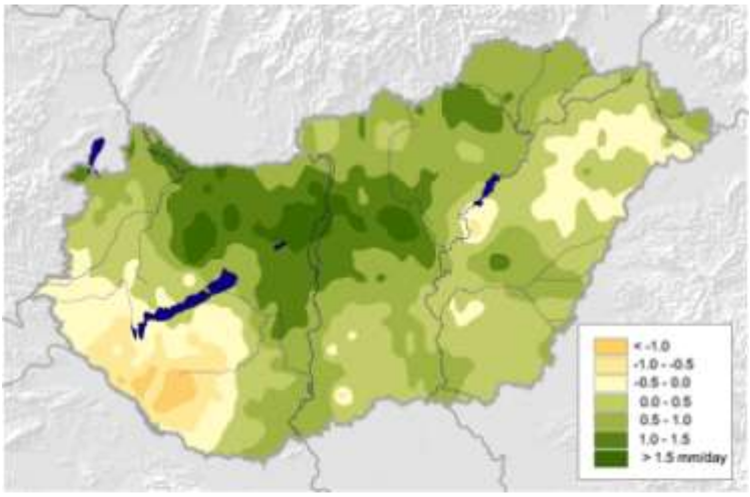

Fig. 10. Change (mm/day) in the summer simple daily precipitation intensity in the period of 1961–2009.

5. *Conclusions*

The preparation of a high quality, homogenized, and gridded daily datasets was presented in this study. Long term daily temperature extremes and precipitation data were quality controlled, homogenized, and gridded in the period of 1901–2009, in order to analyze the extreme climate indices. Instead of the interpolation of extreme indices, the gridding of the basic variables (daily maximum and minimum temperatures and daily precipitation) is recommended, as the probability distributions of the indices are unknown. Time series of the grid point averages for a few selected indices are demonstrated from 1901. The spatial distribution of changes from the mid-20th century is illustrated on trend maps.

The gridded dataset introduced in this work is updated by homogenization and interpolation on the beginning of the new calendar year regularly to serve as an 'as long as possible' time series for climate change studies. The WMO statement on the status of the global climate in 2009 (*WMO*, 2010) underlined that peer reviewed scientific methods for quality control, homogenization, and interpolation to constitute high-quality global climate datasets should be used in the examinations. The created datasets could be relevant contribution to the expected high quality global system of datasets.

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