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Changes of Temperature and Precipitation Extremes following Homogenization

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Abstract – Climate indices to detect changes have been defined in several international projects on climate change. Climate index calculations require at least daily resolution of time series without inhomogeneities, such as transfer of stations, changes in observation practice. In many cases the characteristics of the estimated linear trends, calculated from the original and from the homogenized time series are significantly different. The ECA&D (European Climate Assessment & Dataset) indices and some other special temperature and precipitation indices of own development were applied to the Climate Database of the Hungarian Meteorological Service. Long term daily maximum, minimum and daily mean temperature data series and daily precipitation sums were examined. The climate index calculation processes were tested on original observations and on homogenized daily data for temperature; in the case of precipitation a complementation process was performed to fill in the gaps of missing data. Experiences of comparing the climate index calculation results, based on original and complemented-homogenized data, are reported in this paper. We present the preliminary result of climate index calculations also on gridded (interpolated) daily data.

extreme climate indices / temperature and precipitation trends / data homogenization / climate indices on grid

Kivonat – Hőmérsékleti és csapadék szélsőségek vizsgálata homogenizált adatokon. A klímaváltozás detektálása céljából több nemzetközi, a klímaváltozással foglalkozó programban klímaindexek sorát definiálták. Az éghajlati szélsőségek vizsgálatához, avagy az extrém indexek számításához inhomogenitásoktól (állomás áttelepítések, a mérési időpontok és a mérési módszerek változásai) mentes, jó minőségű napi adatsorok szükségesek. Sok esetben ugyanis jelentősen eltér az eredeti és a homogenizált adatok alapján számolt lineáris trend értéke nemcsak nagyságában, hanem előjelében is. Ez pedig a klímaváltozás tekintetében téves következtetések levonásához vezethet. Az OMSZ klimatológiai adatbázisban történt fejlesztés során megvalósítottuk az ECA&D (European Climate Assessment & Dataset) projektben alkalmazott extrém klímaindexek sorozatát és ezeket kiegészítettük néhány általunk kifejlesztett karakterisztikával. Az extrémumokban fellépő változások nyomon követésére lineáris trendelemzést végeztünk mind az eredeti, mind a homogenizált sorokon, ennek a vizsgálatnak a tapasztalatairól számolunk be ebben a dolgozatban. Bemutatjuk emellett a rácsponti klímaindex számítások előzetes eredményeit is.

klíma szélsőség index / hőmérséklet és csapadék trendek / homogenizálás / rácsponti klímaindex

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1 INTRODUCTION

Determining changes in the behaviour of extreme events is the main topic of several international projects. Extreme climate events can be identified in different ways. One of them is using internationally agreed, predefined indices that is day count exceeding a fixed threshold, percentile threshold, heat wave duration, etc. In the frame of the CCL (Commission for Climatology of WMO)/CLIVAR (Research programme on CLImate VARiability and predictability) (1998) program a range of climate indices were defined to detect probable changes. Such indices were calculated on temperature, precipitation and air pressure data in the ECA&D (European Climate Assessment & Dataset) project.

The ECA&D and some other special temperature and precipitation indices of our own development were applied on the Climate Database of the Hungarian Meteorological Service too. Using uniform methodology allows joining to other international programs.

Climate index calculations require at least daily resolution of time series without inhomogeneities, such as transfer of stations, changes in observation practice. The initiative projects in this field, ECA&D and APN (Asia-Pacific Network), emphasize data quality and data homogeneity.

Characteristics of the estimated linear trends are unambiguously unlike on the different time series. Frequently a decreasing trend is calculated from the original data with interruptions and gaps, while the trend fitted to homogenized data implies an increasing tendency, or reverse.

2 DATA

Extreme temperature index calculations based on daily maximum and daily minimum temperature series from the beginning of the 20th century were performed. The following stations were analysed in the period 1901-2005: Sopron, Szombathely, Mosonmagyaróvár, Keszthely, Siófok, Pécs, Baja, Kecskemét, Kalocsa, Szeged, Túrkeve, Miskolc, Debrecen, Nyíregyháza, Budapest. Implementing the index calculation, the gaps in the observation series and the inhomogeneities caused problems.

The majority of temperature series is exceptionally inhomogeneous *(Figure 1)*, the original data series is biased by break points. Homogenizing of the data series is essential before using them for climate analysis.

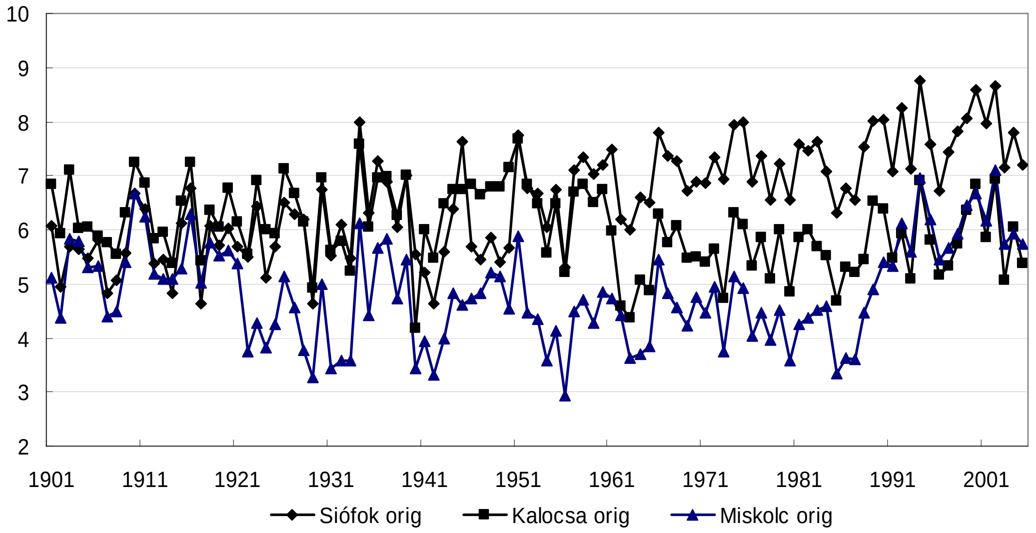

Figure 1. Annual mean of daily minimum temperatures at Siófok, Kalocsa, Miskolc stations, between 1901-2005, original data

Precipitation series are in better condition than temperatures, as turned out on analysing the amounts of daily precipitation. The precipitation indices were calculated for 37 Hungarian stations in the interval 1901-2005. The elaborated rain gauges do not cover the country evenly. The covering of Transdanubia is dense enough, the eastern part of the country is covered sparsely.

3 HOMOGENIZATION

The homogenization of data has been performed with the procedure MASH (Multiple Analysis of Series for Homogenization) (Szentimrey 1999). The original MASH procedure has been developed for homogenization of monthly series. MASH is a relative method and depending on the distribution of the examined meteorological element an additive (e.g. temperature) or a multiplicative (e.g. precipitation) model can be applied. In the software the following subjects were elaborated for monthly data series: comparison of series, break point (change point) and outlier detection, correction of series, automatic usage of metadata, verification for homogenization of daily series, quality control of daily data and complementing missing data.

Extreme climate indices are defined on daily data. The present version of MASHv3.01 (Szentimrey 2006) procedure is suitable for daily temperature elements as normal distribution is assumed and the additive model can be applied.

Daily maximum and minimum temperature series of 15 stations between 1901 and 2005 were homogenized by the MASH method. *Figure 2* shows the annual mean of daily minimum temperatures after homogenization, whereas the original data of the same stations can be seen in *Figure 1*. The obvious break points were eliminated, and the curves are running parallel, as we expected.

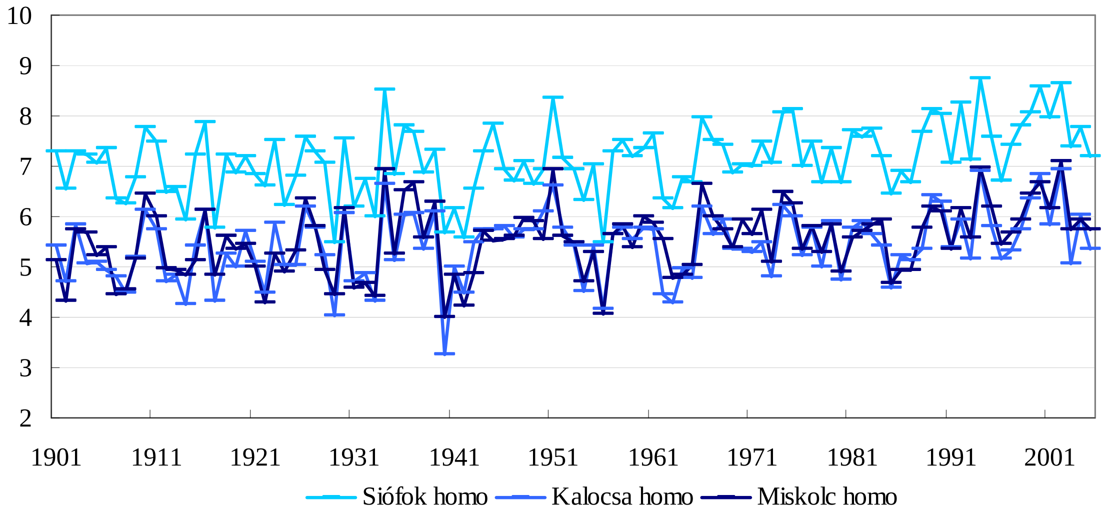

Figure 2. Homogenized annual mean of daily minimum temperatures at Siófok, Kalocsa, and Miskolc stations, between 1901 and 2005

4 CLIMATE INDEX CALCULATION IN THE CLIMATE DATABASE OF THE HUNGARIAN METEOROLOGICAL SERVICE (OMSZ)

The ECA&D indices and some other characteristics (*Table 1, 2, 3*) are built into the climate database of OMSZ. Daily maximum and minimum temperature data series were homogenized and the climate index series based on daily data have been analyzed at 15 stations between 1901 and 2005. The precipitation index calculations were executed on 37 complemented long time daily rainfall series from 1901 to 2005.

Table 1. Extreme hot temperature indices in the climate database of OMSZ

Index/unit	Hot extremes
txx / °C	absolute Tmax
dtx25/day	summer days Tmax > 25 °C
dtx30e/day	hot days Tmax ≥ 30 °C
dtx35e/day	very hot days Tmax ≥ 35 °C
dtn20/day	tropical nights Tmin ≥ 20 °C
ditxgnr/day	heat wave duration index
ditgnr90/day	warm spell days
itxgnr90/day	maximum duration of warm spell
dtgnr90/%	Tavg > 90th percentile of normal period
dtngnr90/%	Tmin > 90th percentile of normal period
dtxgnr90/day	Tmax > 90th

Table 2. Extreme cold temperature indices in the climate database of OMSZ

Index/unit	Cold extremes
tnn/°C	absolute Tmin
dtn0/days	frost days Tmin < 0°C
itn0x/days	maximum number of frost days Tmin < 0°C
dtn0e/days	frost days Tmin ≤ 0°C
t17s/°C	heating degree days
t20s°C	heating degree days
dtx0/day	ice days Tmax < 0°C
dtx0e/day	ice days with Tmax ≤ 0°C
ditnlnr/day	cold wave duration index
ditlnr10/day	cold spell days
itnlnr10/day	maximum duration of cold spell
dtlnr10/day	Tavg < 10th percentile of normal period
dtnlnr10/day	Tmin < 10th percentile of normal period
dtxlnr10/day	Tmax < 10th percentile of normal period

Table 3. Extreme precipitation climate indices in the climate database of OMSZ

Index/unit	Precipitation Extremes
rs/mm	Precipitation sum
dr1/day	Number of wet days
r1a/mm/day	Mean wet-day precipitation
ir0xd/day	Length of longest very dry period R≤1 mm
ir1xd/day	Length of longest dry period R <1 mm
ir1xw/day	Length of longest wet period R ≥ 1 mm
dr5/day	Number of days R ≥ 5 mm
dr10 day	Number of days R≥ 10
dr20/ day	Number of days R≥ 20
rx1/mm	Maximum daily sum
rx5/mm	Maximum sum in 5 day long period
dr75gnr/day	Number of days R> 75% of normal period
pr75gnr/%	Number of days R> 75% of normal period in % of wet days
r75gnr/mm	Precipitation sum of days R> 75% of normal period
~95% 99%	

The ECA&D indices and some other characteristics (*Table 1, 2, 3*) were calculated both on the original and on the homogenized temperature data and on complemented daily precipitation measurements. Year is the base period (one index value is calculated per year) and the period of 1961-1990 is the normal of index calculations.

5 RESULTS

5.1 Temperature tendencies

All built-in climate indices in the climate DataBase can be reached and visualized on homogenized and on original data as well. The time series and the fitted trend of a certain climate index can be constructed in the DataBase. Different stations can be analysed parallel, hereby the regional differences can be shown. In *Table 4.a* and *Table 4.b* the changes of several climate indices in three overlapping periods are summarized.

These tables contain the result of the linear trend fitting. The shade of cells indicate the result of significance test at 95% level (white: no significant trend, dark grey: significant positive trend, light grey: significant negative trend). The changes in a specific time interval are presented on homogenized and on original data. We underline the importance of homogenization because the slope and direction of the fitted trend differs frequently between homogenized and original data.

The number of frost days shows a decreasing tendency the whole last century on homogenized data. From the beginning of the seventies the number of frost days per year is again slightly increasing, amplifying the extremity. The rate of increase in the number of summer days and the number of tropical nights indicates significant warming.

Table 4.a Changes of temperature climate indices on original and homogenized data for different periods

Temperature index	Station	Period					
		1901-2005		1946-2005		1976-2005	
		homogenized	original	homogenized	original	homogenized	original
Change (days) of the number of frost days	Budapest	-7.9	-10.3	-6.1	-6.1	1.9	-1.3
	Debrecen	-5.7	-24.4	-1.7	-0.1	0.5	0.4
	Miskolc	-1.1	*16.4*	-0.7	-13.8	4.1	-22.6
	Mosonmagyaróvár	-10.0	1.6	-11.2	-17.1	-0.6	-5.9
	Szeged	-5.1	*18.0*	3.5	*20.0*	11.8	9.8
	Szombathely	-10.2	7.5	-16.4	-10.5	0.5	-5.5
Change (days) of the number of summer days	Budapest	6.2	2.3	1.6	-6.0	*23.4*	16.2
	Debrecen	*11.8*	-1.0	-0.9	-7.8	*30.8*	*22.9*
	Miskolc	6.2	*27.0*	1.9	-15.3	*32.3*	18.9
	Mosonmagyaróvár	6.9	*16.5*	6.6	10.9	*25.0*	*27.0*
	Szeged	7.8	*13.9*	1.1	0.6	*21.3*	*24.3*
	Szombathely	8.2	*12.2*	6.5	10.1	*27.8*	*32.7*
Change (days) of the number of tropical nights	Budapest	*8.5*	*10.3*	5.7	7.4	*12.2*	*14.6*
	Debrecen	0.9	*1.3*	0.5	0.6	*2.7*	*3.1*
	Miskolc	*1.6*	*2.1*	1.7	*3.5*	3.4	*5.1*
	Mosonmagyaróvár	*1.0*	1.0	*2.1*	*2.0*	*2.3*	*2.2*
	Szeged	0.9	-3.3	0.2	-4.4	*1.9*	*2.0*
	Szombathely	*0.5*	*0.4*	*0.7*	*0.7*	*1.3*	1.1

Table 4.b Changes of temperature climate indices on original and homogenized data for different periods

Temperature index	Station	Period					
		1901-2005		1946-2005		1976-2005	
		homogenized	original	homogenized	original	homogenized	original
Change of the growing season length (days)	Budapest	14.6	*17.2*	*21.0*	*22.3*	28.7	*36.1*
	Debrecen	5.4	10.9	-1.5	4.0	12.3	12.2
	Miskolc	2.4	1.0	-10.1	-8.9	6.3	8.6
	Mosonmagyaróvár	13.0	*17.4*	12.4	19.9	12.5	18.6
	Szeged	0.5	-7.8	-0.6	-8.7	9.4	14.0
	Szombathely	*16.4*	*16.7*	*20.3*	*18.3*	16.5	*30.2*
Change in the number of days with daily maximum > 1961-90 normal (6 day long interval at least)	Budapest	*9.4*	*9.9*	9.5	7.7	*18.4*	*15.8*
	Debrecen	6.3	3.7	1.7	-0.4	*17.2*	*14.0*
	Miskolc	5.6	4.0	3.6	-2.3	*18.2*	*11.9*
	Mosonmagyaróvár	*7.9*	*9.0*	*12.8*	*13.8*	12.0	*16.1*
	Szeged	*10.5*	*8.9*	*12.0*	10.1	*22.4*	*27.2*
	Szombathely	*10.0*	*15.6*	9.1	*17.1*	15.5	*28.6*
Change of the number of days when daily minimum < 10% percentile of 1961-90 normal	Budapest	-19.8	-32.0	-12.0	-13.2	-6.8	-11.7
	Debrecen	-17.7	-44.6	-11.5	-13.4	-6.0	-9.4
	Miskolc	-12.9	-1.2	-15.5	-25.0	21.4	-40.0
	Mosonmagyaróvár	-11.0	-2.5	-15.2	-26.0	-4.4	-9.4
	Szeged	-1.0	*20.4*	-3.0	8.7	2.4	2.4
	Szombathely	-11.9	-1.3	-16.1	-15.8	-4.5	-7.3
Change of the number of days when daily minimum > 90% percentile of 1961-90 normal	Budapest	*25.4*	*30.7*	*22.1*	*21.7*	*33.5*	*38.3*
	Debrecen	*8.4*	*31.1*	8.9	*12.1*	*30.3*	*36.2*
	Miskolc	*20.0*	13.3	4.7	*38.4*	*16.5*	*75.9*
	Mosonmagyaróvár	*17.8*	*10.9*	*19.4*	*31.7*	*22.7*	*31.1*
	Szeged	*22.4*	-18.6	*12.8*	-18.4	*32.5*	*32.1*
	Szombathely	*25.5*	*12.8*	*24.2*	*24.0*	*33.5*	*38.8*

The growing season becomes longer, at some stations significantly. The duration of heat waves has increased significantly in the interval since 1976. The number of cold nights decreased mainly since 1901 and there are fewer cold nights in the last 30 years also, but the changes are significant only for one station.

On the whole we may conclude that the increasing trend in warm climate extremes appears more accentuated from the mid-seventies according to the global temperature tendencies.

5.2 Precipitation tendencies

Correspondingly to the temperature extremes, period changes by stations are presented in *Table 5* for three different overlapping periods. Precipitation is a variable element in time and space alike; the indices derived from daily precipitation sums are variable.

Table 5. Changes in the percentage of days with heavy precipitation for three different periods

Extreme precipitation index	Station	Period		
		1901-2005	1946-2005	1976-2005
Percentage change of days with heavy precipitation (exceeding the 95% percentile of the 1961-90 period)	Baja	-6,2	-2,3	5,3
	Bakonybél	1,4	-3,1	*17,1*
	Bakonyszentkirály	-3,2	0,1	8,9
	Balatonkeresztúr	-6,6	3,2	*11,3*
	Battonya	3,9	6,2	*13,1*
	Beled	-2,5	-3,9	*10,8*
	Budapest	-5,4	-1,5	6,7
	Debrecen	0,4	3,7	0,0
	Gölle	-1,2	-6,2	*20,9*
	Herend	-5,8	-8,6	7,3
	Iharos	-6,6	-3,2	4,1
	Karcsa	1,3	4,7	8,4
	Kemenesszentmárton	1,4	-7,7	*10,5*
	Kerta	-1,4	-6,1	8,8
	Keszthely	-8,0	-7,4	-8,2
	Kunszentmárton	1,9	1,2	6,4
	Kápolnásnyék	-7,4	-0,1	9,0
	Miskolc	0,5	1,1	12,0
	Mosonmagyaróvár	-1,3	-5,7	4,5
	Márianosztra	-3,0	-3,9	5,5
	Nagyvázsony	-1,8	-3,1	5,9
	Nyíregyháza	-2,5	-4,7	5,4
	Pincehely	-3,5	-6,6	*24,1*
	Poroszló	-8,1	-13,7	-12,7
	Pásztó	-2,2	3,7	5,0
	Pécs	2,9	7,7	*14,2*
	Pér	-5,0	2,2	*13,0*
	Ravazd	-7,1	-3,2	*10,9*
	Rinyakovácsi	-4,4	-3,6	4,3
	Siófok	-0,3	-0,3	2,5
	Sopron	-9,8	-6,3	-3,6
	Szeged	-0,3	*8,4*	*14,7*
	Szombathely	-3,8	-2,9	5,3
	Szálka	*12,1*	-0,3	8,6
	Tengelic	2,3	0,5	*14,2*
	Türje	0,6	-3,9	2,4
	Vásárosnamény	*9,0*	4,9	*10,5*

Only the percentage change of days with extremely high daily rainfall is shown in the *Table 5*. That is the percentage of days, when the daily sum exceeds the 95% percentile of the 1961-90 normal period. Considering the whole period until 2005, both increasing and decreasing trends occur. In the last most intense warming period from 1976 the percentage of days with heavy rainfall increased.

5.3 Climate index calculation in grid points

Temperature and precipitation indices calculations were extended to 0.1°× 0.1°gridded (interpolated) daily data too. This resolution matches to 10 km x 10 km approximately. Gridding of homogenized daily data series was carried out by the MISH (Meteorological Interpolation based on Surface Homogenized Data Basis) interpolation procedure (Szentimrey – Bihari 2006). Note that daily observations were interpolated, not the extreme indices, hereby the gridding does not interfere with the fact that the extreme events are local phenomena, interpolation of them is not suggested.

About 1000 grid points cover Hungary; therefore the technical implementation is more complex, than analysing station series. First the index series had to be calculated in every grid point, followed by the linear trend analysis. The preliminary result of climate index calculations is illustrated on gridded (interpolated) daily data (*Figure 3 and Figure 4*).

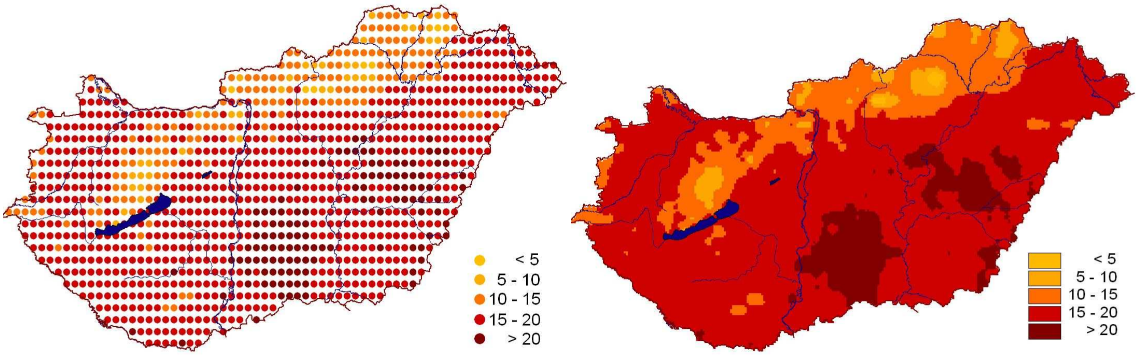

Figure 3. Changes in the number of summer days 1976-2005, in grid points and smoothed

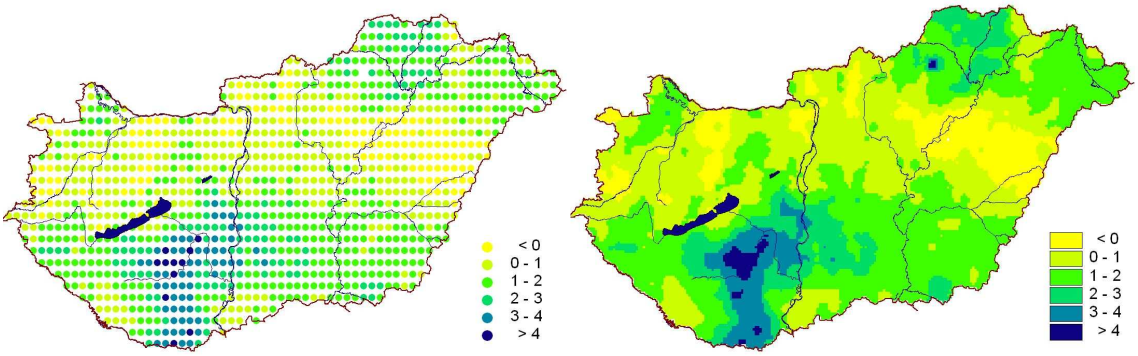

Figure 4. Change in the number of days with precipitation sum >20 mm 1976-2005, in grid points and smoothed

The changes since 1976 in Hungary are substantial, because the warming tendencies came forward parallel to the last most intense global temperature increase In thirty years the number of summer days increased STRONGLY, except in the mountainous area. Especially high values of increase of over 20 days were calculated for the central parts of the Lowlands (Kiskúnság, Nagykúnság) the changes in rain intensity are shown in *Figure 4*. In the South Transdanubian region more days with heavy rain were registered. The other region of increasing rain intensity is the Sajó and Tisza River flood risk triangle.

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