

ASSESSMENT OF THE EFFECT OF HOMOGENIZATION OF BULGARIAN TEMPERATURE SERIES

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Abstract. The effect of homogenization of the seasonal and annual temperature series at 31 stations representative for the lowlands of Bulgaria, is assessed. The data cover the period 1900-2000. The homogeneity adjustments are developed by applying the Standard Normal Homogeneity Test. To assess the effect of homogenization the trends of the adjusted series are compared with the trends of the original ones and, what is more important, the trends in any particular group of stations are compared between themselves. The results show that the regional coherence of the trends of the adjusted series is much higher compared with the raw series, both in magnitude and in sign. In some cases the homogeneity corrections give rise to considerable changes in the patterns of the trends. This confirms the importance of using homogenized data in long-term climatic researches, otherwise there is a risk of obtaining false trends at some stations.

Key words: temperature series, homogeneity test, trend analysis, statistical significance of linear trend, Bulgaria.

Introduction

The investigation of long-term climatic time series aimed at revealing climate variability and change should be based on good quality homogeneous data. A climate series is homogeneous if its variations are caused only by variations in weather and climate (Alisov *et al.*; Conrad and Polak, 1962). Practically, very few climate series, comprising not very long periods of observations, are free of “nonclimatic” changes, caused by such factors as changes of time and location of measurements, of the instrumentation, the averaging method, the environment, etc.

Many tests (parametric and nonparametric) exist and can be used in homogeneity analysis. In Syrakova and Stefanova (2008) the widely used Standard Normal Homogeneity

Test (SNHT) developed by Alexandersson (Alexandersson, 1986; Alexandersson and Moberg, 1997) is used to detect abrupt changes in temperature series on the territory of Bulgaria. The homogeneity adjustments are applied to five sets of temperature series – the four seasonal and the annual mean temperatures at stations, representative for the lowlands of Bulgaria. The aim of the present work is to assess the effect of homogenization on these temperature series. For that purpose, the trend slopes of the series before and after the homogenization are compared.

Data are described in the next section. The methodology and the results are presented in sections 3 and 4, respectively. In the end the conclusions are summed up.

Data

The original data are the monthly mean temperature series at 31 stations distributed over the lowlands of Bulgaria as it is shown in Fig. 1.

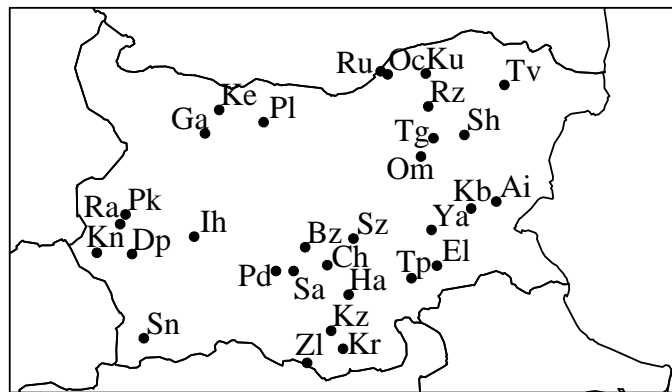


Fig. 1. Spatial distribution of the stations. For the names, see Table 1.

The data are provided by the National Institute of Meteorology and Hydrology. Stations with the longest series of temperature observations, containing the least number of missing data and representative for different parts of the territory (different climatic regions), are chosen. The list of the stations with the abbreviations of the names, used in Fig. 1, geographical position (latitude, longitude, altitude) and periods of observations is given in Table 1 (the arrangement is according to the latitude, from north to south).

Temperature data, covering the entire period of 20th century, are available in very few stations in Bulgaria (7 in the list). In fact, observations at most of them started at the end of 19th century, but in different years, that is why we put the beginning of these series in 1900. A big part of the records began in 1920-1930, but there are stations where temperature observations were started even later – in 1940s and 1950s. Unfortunately, at some stations, observations were interrupted in 1990s.

Table 1. List of the stations. The abbreviations of the names are used in Fig. 1.

Station		Latitude (N)	Longitude (E)	Altitude (m, a.s.l.)	Period (year)	
1.	Russe	(Ru)	43° 51'	25° 57'	37	1928-2000
2.	Obr.chiflik	(Oc)	43° 48'	26° 02'	157	1900-2000
3.	Kubrat	(Ku)	43° 48'	26° 30'	230	1949-1991
4.	Tervel	(Tv)	43° 45'	27° 25'	215	1952-1995
5.	Razgrad	(Rz)	43° 31'	26° 31'	206	1916-2000
6.	Knezha	(Ke)	43° 30'	24° 05'	117	1920-2000
7.	Pleven	(Pl)	43° 24'	24° 36'	156	1900-2000
8.	Gabare	(Ga)	43° 18'	23° 55'	120	1944-1990
9.	Shumen	(Sh)	43° 16'	26° 56'	218	1900-2000
10.	Targovishte	(Tg)	43° 15'	26° 34'	226	1952-2000
11.	Omurtag	(Om)	43° 06'	26° 25'	530	1953-2000
12.	Aitos	(Ai)	42° 42'	27° 16'	90	1925-1995
13.	Karnobat	(Kb)	42° 39'	26° 59'	196	1930-2000
14.	Pernik	(Pk)	42° 36'	23° 02'	694	1947-2000
15.	Radomir	(Ra)	42° 33'	22° 58'	691	1929-1990
16.	Yambol	(Ya)	42° 29'	26° 31'	143	1930-2000
17.	Ihtiman	(Ih)	42° 26'	23° 49'	636	1921-2000
18.	St. Zagora	(Sz)	42° 25'	25° 38'	229	1943-2000
19.	Brezovo	(Bz)	42° 21'	25° 05'	257	1952-1995
20.	Kjustendil	(Kn)	42° 16'	22° 43'	527	1900-2000
21.	Dupnitsa	(Dp)	42° 16'	23° 07'	555	1908-2000
22.	Chirpan	(Ch)	42° 12'	25° 20'	173	1928-2000
23.	Elhovo	(El)	42° 11'	26° 34'	138	1951-2000
24.	Plovdiv	(Pd)	42° 09'	24° 45'	160	1901-2000
25.	Sadovo	(Sa)	42° 09'	24° 57'	155	1900-2000
26.	Topolovgrad	(Tp)	42° 05'	26° 17'	305	1958-2000
27.	Haskovo	(Ha)	41° 57'	25° 34'	230	1900-2000
28.	Kardzhali	(Kz)	41° 39'	25° 22'	331	1930-2000
29.	Sandanski	(Sn)	41° 34'	23° 17'	203	1931-2000
30.	Krumovgrad	(Kr)	41° 30'	25° 30'	231	1953-2000
31.	Zlatograd	(Zl)	41° 22'	25° 06'	430	1933-2000

The time evolution of the number of stations is shown in Fig. 2.

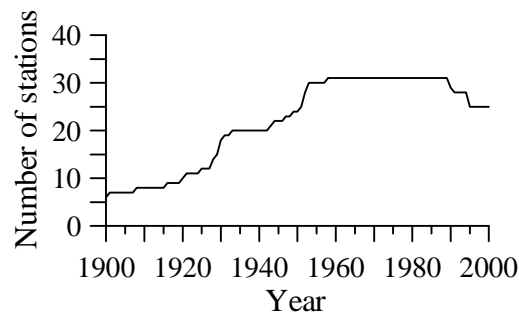


Fig. 2. Time evolution of the number of stations

A preliminary treatment of the data to be prepared for the homogeneity analysis consists in two procedures: removing the outliers and filling in the gaps. Outliers are observations very distant from the mean value that can cause biases in the sample statistics (mean values, standard deviations, etc.) (Trenberth and Paolino, 1980; González-Rouco *et al.*, 2001). In Syrakova and Stefanova (2008) it is assumed that outliers are the values outside the interval $(\bar{t} \pm 3\sigma)$ where \bar{t} is the mean value and σ is the standard deviation of the series. The outliers are substitutes by the threshold values.

The gaps are filled in following the procedure described in Boehm (1992). It is based on the stability of the differences between the series at neighboring highly correlated stations. The missing data are rather few and are dispersed in separate months and years; only one station (Haskovo, Ha) has a period comprising more than two consecutive years with interrupted observations.

After the monthly series are completed, seasonal and annual temperature series are calculated. The four standard climatological seasons are used: winter – December, January, February (DJF); spring – March, April, May (MAM); summer – June, July, August (JJA); autumn – September, October, November (SON). Mean annual temperature corresponds to the period January-December (J-D). The series calculated in this way are called “original” or “raw” data further on.

The SNHT, as other relative homogeneity tests, is based on the coherence of the variations of the climatological series at stations placed in similar climate conditions. That is why, to apply the test, the stations are combined into several groups, which cover regions with similar conditions. The approximate division of the territory is: north-western, north-eastern, western, central, eastern and south-eastern parts of the country. Each group contains 5 to 8 best correlated stations. Some stations are included in more than one neighboring group to assure the quantity of reference stations.

Methods

The SNHT (Alexandersson, 1986; Alexandersson and Moberg, 1997) is performed on the standardized series of differences between the tested series and an appropriate reference series

$$z_i = (d_i - \bar{d}) / \sigma_d, \quad i = 1, \dots, n \quad (1)$$

where \bar{d} is the mean value and σ_d is the standard deviation of the difference series d , i is the time step (i.e. year), n is the length of the period (number of years).

The test statistic is the maximum (T_{\max}) of the values

$$T_m = m\bar{z}_1^2 + (n-m)\bar{z}_2^2, \quad m = 1, \dots, n-1 \quad (2)$$

where \bar{z}_1 and \bar{z}_2 are the mean values of z during the m first and $(n-m)$ last years, respectively.

The reference series are computed on the basis of the relationship between temperatures at the tested and the reference stations, expressed by the respective correlation coefficient. The mean temperatures at different stations are also taken into account. So, the series of differences to be standardized to obtain z_i series is

$$d_i = t_{i0} - \left[\sum_{j=1}^k (t_{ij} - \bar{t}_j + \bar{t}_0) r_j^2 / \sum_{j=1}^k r_j^2 \right], \quad i = 1, \dots, n \quad (3)$$

where t denotes temperature, k is the number of reference stations, each one of them denoted by j , r_j is the correlation coefficient between the tested series and the reference series j , \bar{t}_0 and \bar{t}_j are the sample mean values at the tested station and the reference series j .

If the test statistic T_{\max} is above certain critical value, the null hypothesis that the test series is homogeneous is rejected. A series, identified as inhomogeneous, is corrected by an adjustment factor

$$AF = \bar{d}_1 - \bar{d}_2, \quad (4)$$

added to the data before the break point, where \bar{d}_1 and \bar{d}_2 are the mean values of d_i before and after the break, respectively.

As it is usually difficult to determine in advance which stations are homogeneous, the iterative scheme for gradual improvement of the homogeneity of the data is used (see Hanssen-Bauer and Førland, 1994; Moberg and Alexandersson, 1997; González-Rouco *et al.*, 2001; Tuomenvirta, 2001. Multiple breaks are treated piece-wise (Alexandersson and Moberg, 1997; González-Rouco *et al.*, 2001).

To overcome the problem with different length of the series, the test is applied in

several steps dividing the entire period into several parts according to the changes of the network density (see Fig. 2). First, the test is run over the last 50 years (1950-2000), when data are available at all stations used here. After the corrections are made, a new period (1930-1949) is added for the stations with available data and new corrections are made, if necessary, in years before 1950. In this way the test is gradually performed till the beginning of the longest series.

It is clear that the diminishing number of stations from the end to the beginning of the century necessitates the completion of the groups with available more distant and less correlated stations. So, for the longest period, comprising the whole century, the number of groups (for the initial groups see Part 2: Data), is reduced to two – northern and southern. At that, stations from North Bulgaria are not combined with stations from South Bulgaria, in spite of rather high correlation coefficients between some of them, because this leads to confusing and inconsistency results.

As it is said in the Introduction, in order to assess the impact of adjustments on the temperature series, the trends of the homogenized (adjusted) series are compared with the trends of the original ones and, which is more important, the trends in any particular group are compared between themselves. The stations are combined in the same way as in performing the test. The comparisons should be made only between series spanning over almost one and the same period. That is why they are made for the same time intervals, over which the homogeneity analysis is performed.

The trends are obtained by means of simple linear regression given by the equation

$$y = a + bx \quad (5)$$

In our case, x is time, y is temperature. The constants a and b are determined by the least square method. We expect that the slopes of the regression lines (trend slopes) b of the adjusted series will be in better accordance with each other compared with the slopes of the original series.

The trend slope is statistically significant if the null hypothesis that $b = 0$, i.e. that temperature is constant, can be rejected at certain significance level. To check the null hypothesis, one can compare (see Afifi and Azen, 1982) the residual mean square, representing the deviations of the data points (y_i) from the regression line (i.e. from the fitted values \hat{y}_i)

$$MS_R = \frac{1}{\nu_R} \sum_{i=1}^n (y_i - \hat{y}_i)^2 \quad (6)$$

and the regression sum of squares, representing the deviation of the regression line from the line $y = const = \bar{y}$

$$MS_D = \frac{1}{\nu_D} \sum_{i=1}^n (\hat{y}_i - \bar{y})^2, \quad (7)$$

where ν_R and ν_D are the respective degrees of freedom: $\nu_R = n - 2$, $\nu_D = 1$, n - length of the series. The ratio

$$F = \frac{MS_D}{MS_R} \quad (8)$$

has Fisher distribution with ν_D and ν_R degrees of freedom, i.e. $F(1, n - 2)$. If, at certain significance level α , F is greater than the critical value $F_c(1, n - 2, \alpha)$, the null hypothesis is rejected.

Results

Fig. 3 shows the trends in the raw (left plot) and homogenized (right plot) seasonal and annual series over the period 1951-1995, when observations are available in almost all stations during the entire period. For the graphical representation, the magnitudes of the trend slopes are arranged in groups defined by the limits shown in the legend in Fig. 3. The visual inspection shows that the regional coherence of the trends for the adjusted series is higher compared with the raw ones, both in magnitude and in sign.

In winter, the adjusted trends show positive values in the northern region and are negative in the southern region. The opposite sign of the trend slopes in northern and southern regions can explain the confusing results of the homogeneity analysis when stations from north-eastern and south-eastern regions are combined in one group on the basis of the high correlation coefficient between them. In spring, positive trends are obtained everywhere after the homogenization. In summer, trends become negative almost everywhere, except for a few stations in the western region; the trend slopes in many stations are rather small. In autumn, in contrast to the spring, the trends are negative over the whole area. The annual trends are a result of mutual compensation of the positive and negative seasonal trends. After the homogenization, negative values are obtained at all stations in the southern part of the territory. In the northern part, the trend slope is not well defined, as one can see in Fig. 3 (the last plot) – small positive values prevail, which implies a dominance of the positive winter and spring trends, but in some stations they can not compensate the negative summer and autumn trends.

Convergence of the trend slopes as a result of homogeneity adjustments can be seen in Fig. 4 as well, in which the trend slopes for the period 1930-2000 are represented. The number of stations is reduced to 19, the limits of the groups in which the trendmagnitudes are arranged are the same as in Fig. 3.

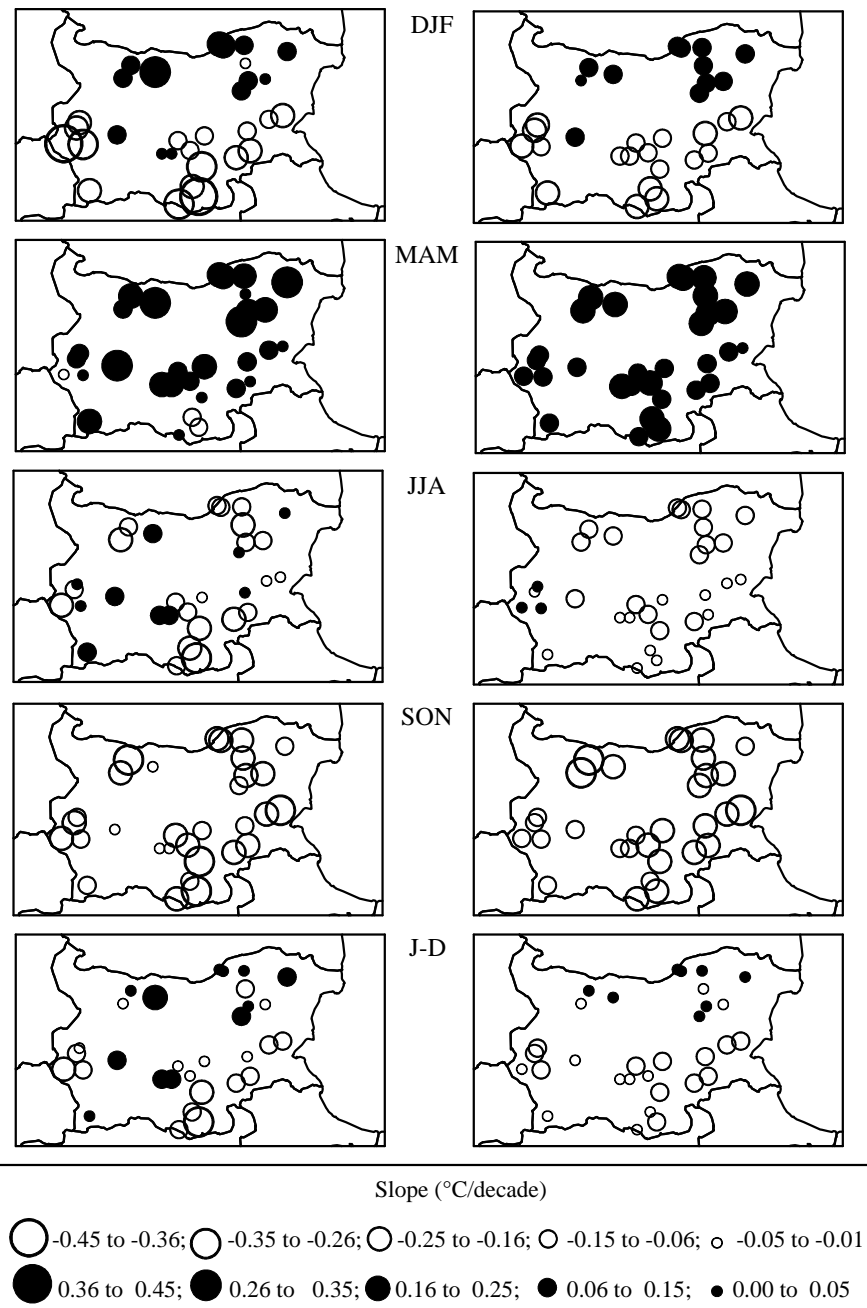


Fig. 3. Trends in the seasonal and annual temperature series over the period 1951-1995. Left – uncorrected, right-homogenized series.

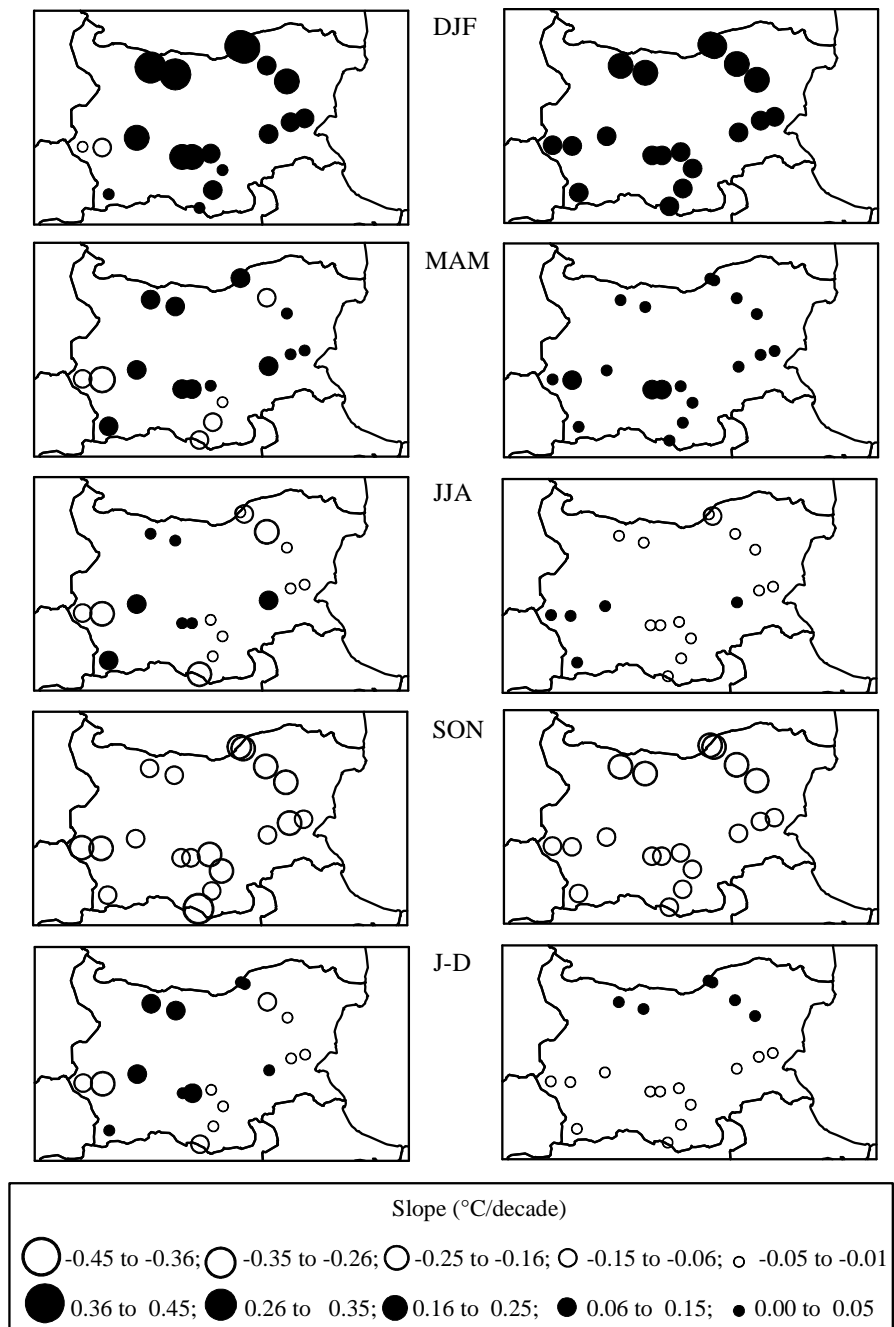


Fig.4. Trends in the seasonal and annual temperature series over the period 1930-1995. Left – uncorrected, right-homogenized series.

The comparison of Fig. 4 with Fig. 3 shows the following features of the adjusted trends. In winter, the trends over the longer period (1930-2000) are positive everywhere, which is not the case over the shorter period (1951-1995). They are greater in North Bulgaria, where they are increased compared to the period 1951-1995. The spring trends are also positive everywhere, but are smaller compared both to the winter ones over the longer period and to the spring trends over the shorter period. The negative summer trends in many stations are also smaller in magnitude compared to the shorter period. The western stations, at which small positive trends are obtained over the period 1930-2000, show higher spatial coherence compared to the shorter period. A station, where an agreement with the surrounding ones is not reached, is Yambol (Ya), in the eastern part of the territory, where the positive trend slope is decreased after the adjustment, but not enough to become negative. The situation with the autumn trends is similar to the shorter period – they are negative everywhere, but with decreased magnitudes at many stations. As it is the case for the winter season, higher magnitudes are obtained at the northern stations. Over the period 1930-2000, the annual trends show small positive values at all available northern stations used here (which is not the case for the period 1951-1995); in the southern area, trends are negative, smaller in magnitude at many stations compared to the shorter period.

The trends obtained for longer periods (1920-2000, 1900-2000) also show a higher spatial coherence of the adjusted series compared to the raw ones, in spite of the reduced number of stations. Compared to the period 1930-2000, the magnitudes of the trend slopes (homogenized series) are almost the same for the period 1920-2000, and are decreased for the period 1900-2000 (except for the annual trends in North Bulgaria). The sign of the winter trends is positive everywhere, in contrast to the shortest period (1951-1995). The spring trends are very small and varying in sign from one period to another – positive over the entire century, which coincides with the periods 1951-1995 and 1930-2000, but negative over the period 1920-2000. The summer trends are also very small, negative over the period 1920-2000, which coincides with the prevailing sign for the shorter periods, but become positive obtained over the entire century. The autumn trends show a decrease with the increase of the period's length, remaining negative over the whole territory. The annual trends are also very small, but the separation of the positive (in North Bulgaria) and negative values (to the south) is well manifested with the positive values at the northern stations being greater over the longest period 1900-2000 compared to all shorter periods.

In Table 2, the number of statistically significant trend slopes, at significance level $\alpha = 0.1$, is given. As one can see, the spring and summer trends of the homogenized series are not significant for any one of the chosen periods. The winter trends reach significance at about 30% and about 70% of the stations over the periods 1930-2000 and 1920-2000, respectively, but are not significant for the shortest and the longest periods. All of the autumn trends are significant over the periods 1920-2000 and 1930-2000, about 40% are significant over the period 1951-1995, but no one is significant for the longest period. Statistically significant annual trends are obtained over the longer periods (1920-2000 and 1900-2000), but while for the period 1920-2000 significance is reached at the southern stations, for the period 1900-2000 it is reached over the northern stations.

Table 2. Number of statistically significant trend slopes at $\alpha=10\%$ significance level in the raw (R) and homogenized (H) series for different time periods. In brackets, the percentage relative to the number of stations (k) in the respective period is given.

Period; number of stations (k)	DJF		MAM		JJA		SON		J-D	
	R	H	R	H	R	H	R	H	R	H
1951-1995 k=31	3 10%	0 0%	7 22%	0 0%	5 16%	0 0%	16 52%	13 42%	9 29%	0 0%
1930-2000 k=19	8 42%	6 31%	2 10%	0 0%	6 31%	0 0%	14 74%	19 100%	8 42%	0 0%
1920-2000 k=11	6 54%	8 73%	3 27%	0 0%	4 36%	0 0%	10 91%	11 100%	5 45%	4 36%
1900-2000 k=7	2 23%	0 0%	1 14%	0 0%	1 14%	0 0%	1 14%	0 0%	2 28%	3 42%

One can get a better idea of the significance of the trends taking into account the confidence levels ($1 - \alpha$). The number of cases with given confidence levels (less than or equal to 0.5, about 0.6, 0.7, 0.8, and equal or greater than 0.9) is represented in Table 3. The following peculiarities can be outlined (the estimates for the homogenized series are given).

Period 1951-1995: In winter, as it is mentioned above (see Table 2), no one trend is statistically significant at $\alpha = 0.1$, i.e. no one trend reaches confidence level 0.9, very few trends reach confidence levels 0.7-0.8, and more than half of the trends have confidence levels less than 0.5, i.e. in these cases ($1 - \alpha \leq 0.5$) the trend slopes can not be distinguished from zero. Stations, at which trends can be revealed with confidence 0.8, are the southernmost ones. Most of the summer (more than 85%) and practically all annual trends have confidence levels less than 0.5, which implies lack of trend. The situation is almost the opposite in spring and especially in autumn. The spring trends have confidence levels 0.7-0.8 at about 80% of the stations (no one being confident at 0.9 level). The autumn trends have confidence levels higher than 0.8 at about 80% of the stations, being higher than 0.9 at about 50% of them.

Periods 1930-2000 and 1920-2000: As one can see in Table 3, the confidence levels of the winter trends increase with the increase of the period's length. In 1930-2000, the confidence levels at all stations are higher than 0.6, being higher than 0.9 at about 1/3 of them; in 1920-2000, they are higher than 0.8 at all stations. In spring, however, in contrast to the period 1951-1995, the confidence levels imply practically lack of trend at all stations. The situation in summer, period 1930-2000, is almost the same (the confidence levels at most stations are less than 0.5), while for the period 1920-2000 the picture is not clear – some trends are confident at 0.7-0.8 level, other do not reach confidence levels higher than 0.5, but there is not well manifested spatial distribution of the confidence level's magnitude. The autumn trends are confident at $1 - \alpha \geq 0.9$ at all stations for both periods. The situation with the annual trends over the period 1930-2000 is similar to the situation with the spring and summer trends – no one station reaches confidence level higher than 0.5. Over the period 1920-2000, however, the confidence levels imply lack of trend at the

stations in North Bulgaria, and trend confident at $1-\alpha \geq 0.8-0.9$ at the stations situated in more southern latitudes.

Table 3. Number of cases with given confidence levels ($1-\alpha$) of the trend slopes for different time periods. In brackets, the percentage relative to the number of stations (k) in the respective period is given. Only homogenized series are considered.

Conf. level ($1-\alpha$)	DJF	MAM	JJA	SON	J-D
1951-1995 (k=31)					
≤ 0.5	16 (51.6%)	3 (9.7%)	27 (87.1%)	1 (3.2%)	30 (96.8%)
0.6	10 (32.3%)	3 (9.7%)	1 (3.2%)	1 (3.2%)	—
0.7	1 (3.2%)	9 (29.0%)	3 (9.7%)	3 (9.7%)	—
0.8	4 (12.9)	16 (51.6%)	—	11 (35.5%)	—
≥ 0.9	—	—	—	15 (48.4%)	1 (3.2%)
1930-2000 (k=19)					
≤ 0.5	—	17 (89.5%)	16 (84.2%)	—	19 (100%)
0.6	7 (36.8%)	—	2 (10.5%)	—	—
0.7	2 (10.5%)	2 (10.5%)	1 (5.3%)	—	—
0.8	3 (15.8%)	—	—	—	—
≥ 0.9	7 (3.8%)	—	—	19 (100%)	—
1920-2000 (k=11)					
≤ 0.5	—	11 (100%)	4 (3.3%)	—	5 (45.5%)
0.6	—	—	1 (9.1%)	—	—
0.7	—	—	3 (27.3%)	—	—
0.8	3 (27.3%)	—	3 (27.3%)	—	2 (18.2%)
≥ 0.9	8 (72.7%)	—	—	11 (100%)	4 (36.3%)
1900-1000 (k=7)					
≤ 0.5	—	1 (14.3%)	4 (57.1%)	7 (100%)	3 (42.9%)
0.6	1 (14.3%)	3 (42.9%)	2 (28.6%)	—	—
0.7	—	1 (14.3%)	1 (14.3%)	—	1 (14.3%)
0.8	6 (85.7%)	2 (28.6%)	—	—	—
≥ 0.9	—	—	—	—	3 (42.9%)

Period 1900-2000: The winter trends are confident at $1-\alpha \approx 0.8$ (except one, which is confident at $1-\alpha \approx 0.6$), but not at $1-\alpha \geq 0.9$. The spring trends are confident at 0.7-0.8 level at the northern stations but the confidence levels decrease to the south reaching values about 0.6 and even less than 0.5. The situation in summer is similar – trends can be revealed with some confidence at the northern stations (the confidence levels being smaller compared to the spring season – about 0.6-0.7) while the stations to the south do not show any trend. In autumn, in contrast to the shorter periods, the confidence levels

show lack of trend at all stations. The spatial distribution of the $(1 - \alpha)$ -values for the annual trends is the opposite compared to the period 1920-2000. As it is mentioned above, significant trends ($1 - \alpha \geq 0.9$) are reached at the northern stations, while the stations to the south show practically lack of trend.

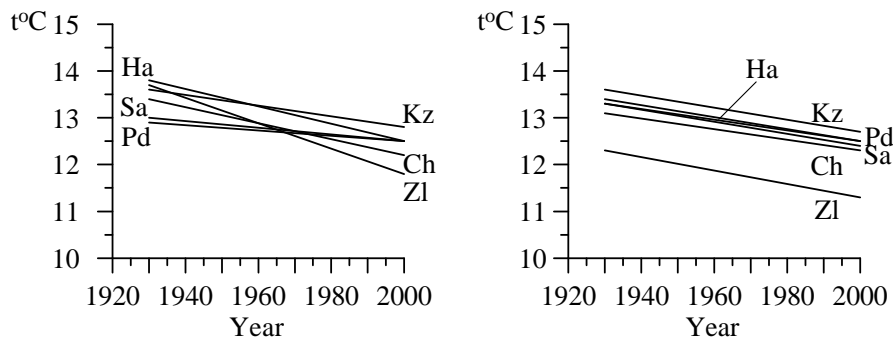


Fig. 5. Trend slopes of the autumn (SON) temperature series, period 1930-2000, for the stations in Central and Southern regions. Left – uncorrected, right-homogenized series.

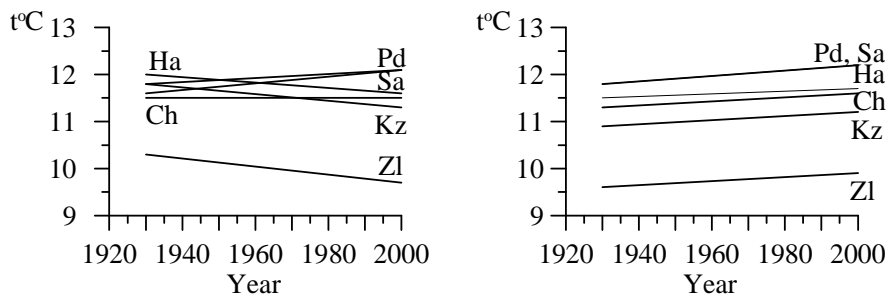


Fig. 6. Trend slopes of the spring (MAM) temperature series, period 1930-2000, for the stations in Central and Southern regions. Left – uncorrected, right-homogenized series.

Figures 5 and 6 illustrate the effect of the homogeneity corrections on the spatial coherence of the trend slopes in a given group of stations. The chosen examples show the trends of the autumn and spring series in the period 1930-2000 at the group of stations situated in the central and central-southern regions. In Fig. 5, the autumn trends are given. All of them are statistically significant at $\alpha = 0.1$ after homogenization, the trends of the raw data at Plovdiv (Pd) and Sadovo (Sa) are not significant ($1 - \alpha \approx 0.5$). As one can see, the trend slopes of the raw series are of the same sign (negative) at all stations, so that the spatial coherence of the adjusted trends results only from changes of the slope magnitudes.

Fig. 6 shows the spring trends. In spite of the different signs of the trend slopes of the raw series, the confidence levels are less than 0.5 only at Chirpan (Ch) and Haskovo (Ha), at other stations they are about 0.8 both for the positive and negative slopes. Homogenization in this case results not only in change of magnitudes but also of the sign of the trend slope at some stations. Though the confidence levels for the adjusted series are less than 0.5 at most stations (only at Plovdiv (Pd) and Sadovo (Sa), where the trend lines coincide, they are about 0.7) a highly coherent spatial behavior arises after homogenization, as one can see in Fig. 6.

Another illustration of the effect of the homogenization is Fig. 7, which shows the summer temperature series from Razgrad (Rz) with the trend lines superimposed. The dashed lines correspond to the original data, the solid lines correspond to the corrected data. The linear fit to the raw data shows a significant ($\alpha < 0.05$) slope of $-0.17^{\circ}\text{C decade}^{-1}$, (which means a decrease of about 1.4°C from the beginning of observations (1916) to 2000), that is reduced to a value of $-0.04^{\circ}\text{C decade}^{-1}$ (or about -0.3°C for the period 1916-2000) for the adjusted data, nonsignificant at $\alpha = 0.1$ (the confidence level $1 - \alpha = 0.6$).

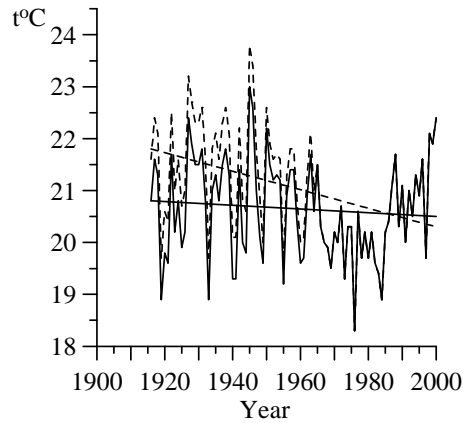


Fig. 7. The raw (dashed line) and homogenized (solid line) temperature series for Razgrad (Rz), summer (JJA), with the trend lines superimposed.

It should be mentioned, that one and the same slope may have different confidence levels ($1 - \alpha$) for different series. For the adjusted spring series in Fig. 6, for example, the confidence level of the slope of $0.05^{\circ}\text{C decade}^{-1}$ at Zlatograd (Zl) is less than 0.5, while the same slope at Sadovo (Sa) is confident at $1 - \alpha \approx 0.7$. This difference is a result of the dependence of the confidence level (or the critical value of the F -statistic (8) at certain significance level α) not only on the deviation of the regression line from the line $y = const$ (i.e. on the magnitude of the slope) but also on the deviation of the data points from the regression line, which is different for different series. This means that a relatively small slope may prove to be significant if the series is relatively stable, while a greater one may prove to be insignificant if the variability of the data is large. The most variable seasonal temperature series are the winter ones (because of the greatest intensity of the atmospheric circulation in this season), the most stable ones are the annual series.

Summary and conclusion

Five sets of temperature series (the four seasonal and the annual mean temperature) at 31 stations, representative for the lowlands of Bulgaria, are checked for inhomogeneities and homogenized, if necessary, applying the Standard Normal Homogeneity Test. Here, the effect of homogenization of these temperature series is assessed. For that purpose, the trend slopes of the adjusted series are compared with the trends of the original ones and, what is more important, the trends in any particular group of

stations are compared between themselves. The stations are combined in groups which cover regions with similar climate conditions.

In accordance with the changes of the network density (Fig. 2), the effect of homogeneity adjustments is assessed over several time periods (1951-1995, 1930-2000, 1920-2000, 1900-2000), as it is done in performing the test. A brief description of the trends over these periods together with the significance/confidence levels of the trend slopes is provided.

The main result of the study is that the adjusted series show much higher spatial coherence compared to the original ones.

At many stations, there is considerable influence of homogeneity corrections on the trends. For some series, not only the magnitude but also the sign of the trend slope is changed. This gives rise to changes of the statistical significance (confidence levels) of the trends. Here, as a rule the number of statistically significant (at $\alpha = 0.1$) trends is decreased after homogenization, being reduced to zero for the spring and autumn series. Only a few changes in the opposite direction occur.

The results obtained here confirm the importance of using homogenized data in long-term climate researches. If nonhomogenized data are used, false (both in magnitude and in sign) temperature trends may be obtained, which are statistically significant in some cases.

Another important result is that combining stations in a group to perform homogeneity analysis one should be very careful. The approach based only on the magnitude of the correlation coefficient may prove to be rather perfunctory. A high correlation coefficient is not a guarantee that the trend slopes of the series are of the same sign. Combining series with opposite time evolution in the process of homogeneity analysis may lead to confusing and inconsistency results. For example, this is the case for the shortest period (1951-2000), especially for the winter and annual series, if stations from South-East Bulgaria are included in the north-eastern group only on the basis of the high correlation coefficients. The results concerning the trends confirm that it is correct to put the stations from North and South Bulgaria into different groups, as it was done in the process of homogeneity analysis.

In the end, we would like to remind the well-known fact that homogenization does not increase the accuracy of the data – it can not be higher than the accuracy of observations. The aim of the adjustments is to put different parts of a series in accordance with each other as if the measurements had not been taken under different conditions.

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Оценка на ефекта от хомогенизацията на температурни редици на територията на България

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Резюме. В работата е направена оценка на резултатите от хомогенизацията на редиците от средните сезонни и годишни температури в 31 станции, представителни за извънпланинската част на България. Данните обхващат периода 1900-2000 г. Хомогенизацията е направена чрез прилагането на т. нар. “стандартен нормален тест за еднородност”. За да се оцени ефектът от хомогенизацията, трендовете на коригираните редици са сравнени с трендовете на оригиналните и, което е по-важно, трендовете във всяка група от станции са сравнени помежду си. В резултат на хомогенизацията се постига много по-добро пространствено съгласуване между трендовете на хомогенизираните редици в сравнение с оригиналните. В някои случаи след хомогенизацията трендовете се променят значително както по големина, така и по знак. Това потвърждава важноста от използването на хомогенизирани данни при дългопериодичните климатични изследвания, в противен случай има опасност от получаването на фалшиви трендове в някои станции.