Hrvatski meteorološki časopis, 38, 3–9, 2003.

UDK: 551.578.1
551.582.3
Izvorni znanstveni rad

INHOMOGENEITIES IN TEMPERATURE TIME SERIES IN CROATIA

Nehomogenosti u temperaturnim vremenskim nizovima u Hrvatskoj

TANJA LIKSO

Meteorological and Hydrological Service
Grič 3, 10000 Zagreb, Croatia
likso@cirus.dhz.hr

Primljeno 10. listopada 2002, u konačnom obliku 2. ožujka 2004.

Abstract: All studies concerning climate variability reveal the necessity of the homogeneity testing of data as the first step in further research. Inhomogeneities caused by station relocation, installation of new instruments, etc. can be the cause of misleading conclusions that do not correspond to real changes. It is quite obvious that data must be tested in order to locate possible inhomogeneities/discontinuities.

This paper describes the homogeneity testing of the mean monthly and annual air temperature in Croatia. Several 50-year temperature time series during the period from 1949 to 1998 were tested using the Standard Normal Homogeneity Test (SNHT). The exact cause of discontinuities was searched from the meta data.

Key words: homogeneity, Standard Normal Homogeneity Test

Sažetak: Sve analize varijabilnosti klime otkrivaju nužnost testiranja homogenosti podataka kao početni korak u daljnjem istraživanju. Nehomogenosti uzrokovane preseljenjem postaje, postavljanjem novih instrumenata itd. mogu dovesti do pogrešnih zaključaka koji ne korespondiraju realnim promjenama. Stoga je logično da se podaci testiraju kako bi se locirale moguće nehomogenosti/diskontinuiteti.

Ovaj rad opisuje testiranje homogenosti srednjih mjesečnih i srednjih godišnjih temperatura zraka u Hrvatskoj. Testirano je nekoliko 50-godišnjih temperaturnih vremenskih nizova u razdoblju 1949–1998. korištenjem Standard Normal Homogeneity Testa (SNHT). Točan uzrok diskontinuiteta istraživan je u meta data.

Ključne riječi: homogenost, test SNHT

1. INTRODUCTION

Homogeneous time series of climatic elements are essential for studies of climatic fluctuations and changes. Inhomogeneities in time series usually occur as a gradual trend, as in the case of urban warming, or as an abrupt discontinuity in the time series. This kind of discontinuities can appear for several reasons: station relocation, instrument changes, change of observer, changes in observing time and changes in the methods used for calculating time averaged values. In practice, it is difficult to preserve the permanence of all observation elements.

This paper describes the causes of inhomogeneities in temperature time series. The SNHT test output reveals the year of the possible break and its size and significance. The exact time and cause of the discontinuities were searched from the station history. However, the SNHT test discovered several breaks at a 97.5% significance level for which no explanation was found in the meta data.

2. METHODOLOGY

Homogeneity testing of the temperature time series was performed by Alexandersson´s SNHT test. The test requires a time series of monthly values from the test station and one or more reference series. The reference series are compared with the test series to estimate the relative homogeneity of the test series. The test series and reference series are obtained from monthly data on a seasonal and annual basis.

As the testing was made on the temperature time series, the differences between test and reference series were considered. The output of this test are the statistical parameters *q*, *z* and *t*. The *q* value may be taken as a deviation of the test series from its mean, compared (subtracted) with the deviation of the reference series constructed from all reference series. When comparing the differences, the *q* value is calculated as the difference between the test deviation and the reference deviations:

$$q_i = y_i - \overline{y} - s_y \frac{\sum_{j=1}^{k} w_j \frac{1}{s_i}\left(x_{ji} - \overline{x_j}\right)}{\sum_{j=1}^{k} w_j} \tag{1}$$

where

i is year/season number, *y* is test series value, *x* is reference series value, *j* is reference series number, *k* is number of reference series, s_y is standard deviation of the test series, s_i is standard deviation of the reference series i, *w* is weight (for example, w = squared correlation coefficient).

The *z* value is the normalized *q* value:

$$z_i = \frac{1}{s_q}\left(q_i - \overline{q}\right) \tag{2}$$

The *t* value is the actual test parameter, and in the case of a single break test the *t* value is calculated by dividing the z series into two separate series, one for $i = 1,\ldots,n$ and the other for $i = n+1,\ldots,n$. The squared means of these two series are summed up for $n = 2,\ldots,n-1$ and the most likely break year is the one in which this sum reaches its maximum. In other words, the break year is the one in which the *z* series can be separated into two different series; one series before the break and the other after the break year. In the case of single break the *t* parameter is calculated according to relation:

$$t = \nu \overline{z}_1^2 + (n - \nu)\,\overline{z}_2^2 \tag{3}$$

where the maximum *t* value is found as *n* runs from 2 to *n*-ν. The break year is the last year of the first series.

In the software programme used for this work five *q* series are constructed; one for each season and one for the whole year. Each series is tested separately. The testing covered the mean monthly and annaul air temperature for 10 stations in the period 1949–1998, where all series were tested at seasonal level (4 tests) and at annual level. Almost all stations pertain to the main meteorological station network (Fig. 1–2).

Regarding the length of the test period, it is advisable to use test periods longer than 10–15 years, i.e. the test and the reference series should overlap for more than 10–15 years. On the other hand, the test period should not be too long because the SNHT test can detect only two breaks or one trend in a period. If a very long time series is tested, it should be divided into shorter overlapping periods, and then tested. In general, the SNHT test is more sensitive at the beginning and at the end of the test period, so breaks and trends should be handled with precaution.

Air temperature is a meteorological element that is sensitive to the distance between test and reference stations, due to its space variability. For this reason, a correct selection of the reference series is very important. The reference stations were selected according to their location, station history and climatic conditions. In other words, the reference stations are relatively near to the test station and they are in a region with the same climatic characteristics as the test station.

3. RESULTS

During homogeneity testing, the temperature time series were divided into shorter periods to detect the years of inhomogeneity. Ten temperature time series consisting of observations during the period 1949–1998 were tested. The results are presented in Table 1. The year of the maximum value of the test parameter, t_{max}, is a break year if t_{max} exceeds the critical value of the parameter *t* at the chosen significance level (Fig. 3–7). Despite the fact that the meta data are frequently incomplete, most breaks are explained by history documents (station relocation and/or change of instrument). There was no explanation for some inhomogeneities in the meta data (Bjelovar, Cri-

Figure 1. The current meteorological station network

Slika 1. Sadašnja mreža meteoroloških postaja

Figure 2. The network of the data sets used

Slika 2. Mreža korištenih setova podataka kvenica and Split-Marjan). Figure 8 shows the difference in mean annual air temperatures for the Karlovac and Zagreb-Maksimir stations. A decrease in mean annual air temperatures after 1992 in Karlovac is the result of the relocation of the station combined with a change of instrument (the instrument type DDR319 was replaced by 918-89 TLOS). In some cases, the decrease in mean annual air temperature after its break year was caused by station relocation (Šibenik) or by relocation plus instrument change (Varaždin and Sisak) (Fig. 11 and Fig. 10). For the Šibenik station the decrease in mean annual air temperature can be explained by the fact that, after its relocation, this station was situated at a higher altitude. The meta data of the Varaždin station provide information about the instrument type (the instrument Schneider 1788/56 was replaced by R. Fuess 89493 after 1971). The meta data of the Sisak station provide information about the station surroundings, which can explain to some extent the decrease in the mean annual air temperature after its break year. In 1956, the meteorological station was relocated to the NW part of Sisak. It is situated on a flat terrain (grassland). The meteorological observing site is about 35–40 m to the north of the building. At the same time, the type of instrument was changed (before 1956 the instrument type R. Fuess 89499 was used, after that year the instrument Schneider 72/56 was used).

On the other hand, the relocation of the Koprivnica station in 1965 led to an increase in the mean annual air temperature after station relocation (Fig. 9). The same effect due to station relocation can be seen for the Rijeka station. On 12 September 1954, the Rijeka station was relocated from Sušak ($\varphi = 45^\circ 20'$, $\lambda = 14^\circ 28'$, $H = 98.7$ m) to Kozala ($\varphi = 45^\circ 20'$, $\lambda = 14^\circ 27'$, $H = 104.3$ m). It is well known that even small changes in the meteorological observing site, tens of meters, for example, can cause a discontinuity. Another explanation for discontinuities are changes in the environment of the meteorological observing site. Unfortunately, the meta data of the Rijeka station did not contain a detailed description of the station environment and it is, therefore, difficult to explain the reason for such a shift in the station temperature level.

Homogeneity testing for the Zagreb-Maksimir station was also performed at both seasonal and annual level. Results reveal that this series is homogeneous for the period 1949–1998 because the maximum value of the test parameter, t_{max}, does not exceed the critical value of parameter t at a 97.5% significance level (Tab. 1).

Table 1. Results of the homogeneity testing of mean annual air temperatures (1949–1998) using the SNHT test. (t_{max}- the maximum t value, t_c- the critical value of parameter t at a significance level of 97.5%)

Tablica 1. Rezultati testiranja homogenosti srednjih godišnjih temperatura zraka (1949–1998) korištenjem testa SNHT. (t_{max}-maksimalna t vrijednost, t_c-kritična vrijednost parametra t na nivou signifikantnosti 97.5%)

Test station	**Reference station(s)**	t_{max}	t_c	**Comparison between t_{max} and t_c**	**Year of inhomogeneity**
Bjelovar	Zgb Grič, Zgb Maksimir	7.66	7.17	$t_{max} > t_c$	1967
Karlovac	Zgb Grič, Zgb Maksimir	25.02	8.56	$t_{max} > t_c$	1992
Koprivnica	Zgb Grič, Zgb Maksimir	15.74	7.88	$t_{max} > t_c$	1965
Sisak	Bjelovar	11.68	7.17	$t_{max} > t_c$	1956
Varaždin	Zgb Maksimir	10.08	7.88	$t_{max} > t_c$	1971
Zgb Maksimir	Zgb Grič	5.23	7.88	$t_{max} < t_c$	
Crikvenica	Rijeka	11.57	7.88	$t_{max} > t_c$	1952
Rijeka	Crikvenica	11.76	9.65	$t_{max} > t_c$	1954
Split-Marjan	Hvar, Lastovo	13.19	7.88	$t_{max} > t_c$	1958
Šibenik	Hvar, Lastovo	12.24	8.39	$t_{max} > t_c$	1954

Table 2. Correlation coefficients between the mean annual air temperatures of the data sets used

Tablica 2. Koeficijenti korelacije srednjih godišnjih temperatura zraka korištenih setova podataka

Stations	Correlation coefficient
Bjelovar, Zagreb-Grič	0.94
Bjelovar, Zagreb-Maksimir	0.95
Karlovac, Zagreb-Grič	0.93
Karlovac, Zagreb-Maksimir	0.91
Koprivnica, Zagreb-Grič	0.94
Koprivnica, Zagreb-Maksimir	0.95
Zagreb-Maksimir, Zagreb-Grič	0.98
Sisak, Bjelovar	0.81
Varaždin, Zagreb-Maksimir	0.96
Crikvenica, Rijeka	0.87
Split-Marjan, Hvar	0.92
Split-Marjan, Lastovo	0.93
Šibenik, Hvar	0.91
Šibenik, Lastovo	0.90

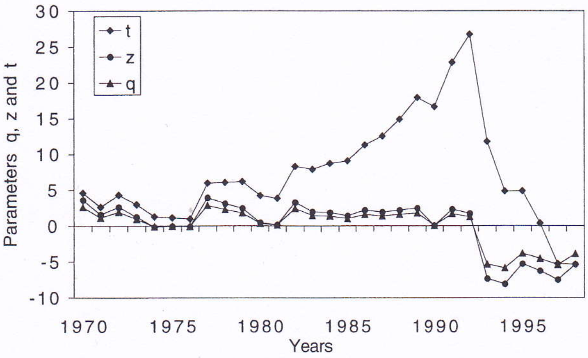

Figure 3. Homogeneity testing of the mean annual air temperature for the period 1970–1998. Test station: Karlovac, reference stations: Zagreb-Grič and Zagreb- Maksimir (t_{max} = 25.02, t_c = 8.56, significance level 97.5%)

Slika 3. Testiranje homogenosti srednjih godišnjih temperatura zraka u razdoblju 1970-1998. Test postaja: Karlovac, referentne postaje: Zagreb-Grič i Zagreb-Maksimir (t_{max} = 25.02, t_c = 8.56, nivo signifikantnosti 97.5%)

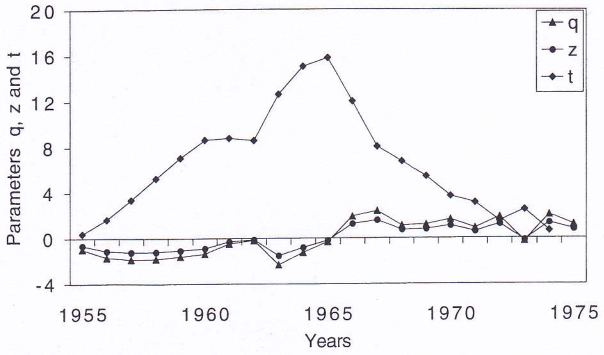

Figure 4. Homogeneity testing of the mean annual air temperature for the period 1955–1975. Test station: Koprivnica, reference stations: Zagreb-Grič and Zagreb- Maksimir (t_{max} = 15.74, t_c = 7.88, significance level 97.5%)

Slika 4. Testiranje homogenosti srednjih godišnjih temperatura zraka u razdoblju 1955–1975. Test postaja: Koprivnica, referentne postaje: Zagreb-Grič i Zagreb- Maksimir (t_{max} = 15.74, t_c = 7.88, nivo signifikantnosti 97.5%)

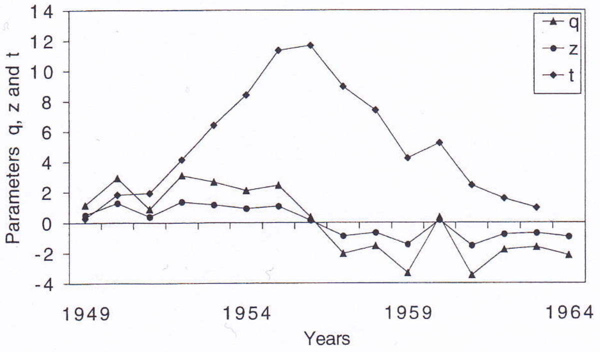

Figure 5. Homogeneity testing of the mean annual air temperature for the period 1949–1964. Test station: Sisak, reference station: Bjelovar (t_{max} = 11.68, t_c = 7.17, significance level 97.5%)

Slika 5. Testiranje homogenosti srednjih godišnjih temperatura zraka u razdoblju 1949–1964. Test postaja: Sisak, referentna postaja: Bjelovar (t_{max} = 11.68, t_c = 7.17, nivo signifikantnosti 97.5%)

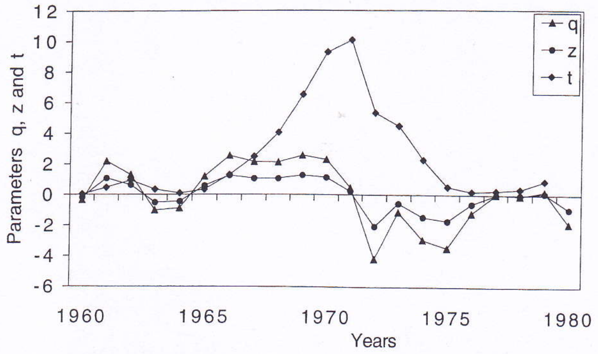

Figure 6. Homogeneity testing of the mean annual air temperature for the period 1960–1980. Test station: Varaždin, reference station: Zagreb-Maksimir (t_{max} = 10.08, t_c = 7.88, significance level 97.5%)

Slika 6. Testiranje homogenosti srednjih godišnjih temperatura zraka u razdoblju 1960–1980. Test postaja: Varaždin, referentna postaja: Zagreb-Maksimir (t_{max} = 10.08, t_c = 7.88, nivo signifikantnosti 97.5%)

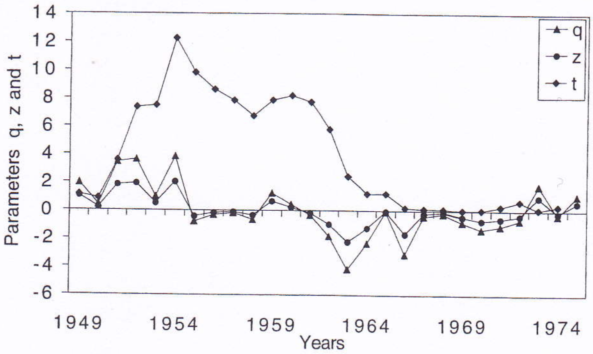

Figure 7. Homogeneity testing of the mean annual air temperature for the period 1949–1975. Test station: Šibenik, reference stations: Hvar and Lastovo (t_{max} = 12.24, t_c = 8.39, significance level 97.5%)

Slika 7. Testiranje homogenosti srednjih godišnjih temperatura zraka za razdoblje 1949–1975. Test postaja: Šibenik, referentne postaje: Hvar i Lastovo (t_{max} = 12.24, t_c = 8.39, nivo signifikantnosti 97.5%)

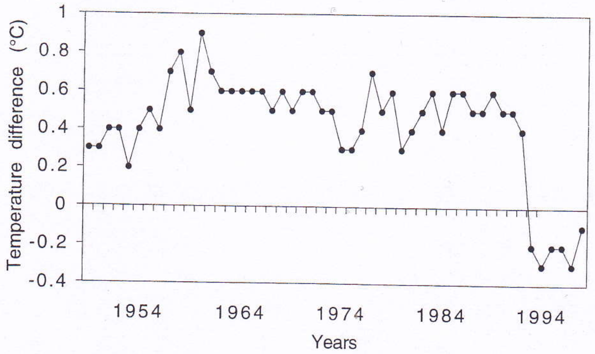

Figure 8. The difference in mean annual air temperatures for the Karlovac and Zagreb-Maksimir stations

Slika 8. Razlika srednjih godišnjih temperatura zraka postaja Karlovac i Zagreb- Maksimir

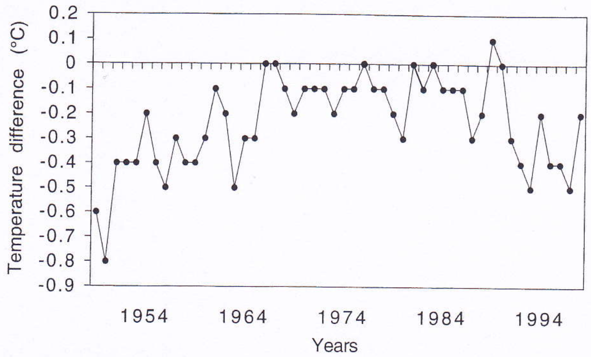

Figure 9. The difference in mean annual air temperatures for the Koprivnica and Zagreb-Maksimir stations

Slika 9. Razlika srednjih godišnjih temperatura zraka postaja Koprivnica i Zagreb- Maksimir

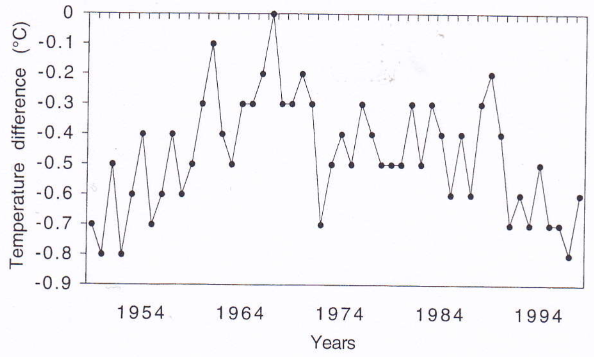

Figure 10. The difference in mean annual air temperatures for the Varaždin and Zagreb- Maksimir stations

Slika 10. Razlika srednjih godišnjih temperatura zraka postaja Varaždin i Zagreb Maksimir

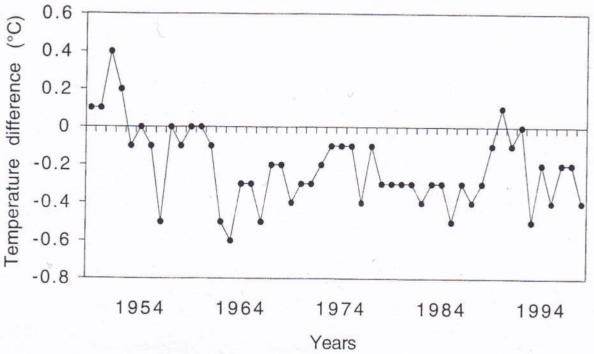

Figure 11. The difference in mean annual air temperatures for the Šibenik and Lastovo stations

Slika 11. Razlika srednjih godišnjih temperatura zraka postaja Šibenik i Lastovo

4. CONCLUSION

The homogeneity of data is very important in climatology, especially in the study of climatic changes. Various factors, such as relocation of station, changes in instruments, observation times and averaging methods introduce inhomogeneities into the data. In practice, the inhomogeneity of a long-term time series is usually a combination of many factors (Heino, 1996).

In this paper, 10 mean annual air temperature time series in Croatia for the period 1949–1998 were tested. The choice of test stations was made on the basis of spatial distribution.

The reference series must be characterised by two properties: they have to be climatologically similar to the test series (high correlation coefficient) and must not have a shift at the same place as the test series. Because of this, reference stations are situated in a region with the same climatic characteristics as the test station itself (Tab. 2). The years of inhomogeneity were found by running the SNHT test and most of these discontinuities were explained by means of meta data. The increase or decrease in the mean annual air temperature was a consequence of station relocation and/or installation of a new instrument. An increase in the mean annual air temperature at the Koprivnica and Rijeka stations was the result of the station relocation. On the other hand, a decrease in the mean annual air temperature was a consequence of either station relocation (Šibenik) or of relocation combined with a change of instrument (Karlovac, Sisak and Varaždin). The results of the SNHT test also reveal that the temperature time series of the Zagreb-Maksimir station is homogeneous for the period 1949–1998.

The meta data containing the description of the environment of the station, its relocation, the type of the instrument and its height are very important because they make possible reliable climatological examinations.

The best way for homogeneity testing is to use statistical tests together with meta data because it is the only way to get reliable conclusions.

REFERENCES

Alexandersson, H., 1984: A Homogeneity Test Based on Ratios and Applied to Precipitation. Department of Meteorology, Uppsala, Report 79, 55 pp.

Alexandersson, H., 1986: A homogeneity test applied to precipitation data. *Int. J. of Climatology*, **6**, 661–675.

Alexandersson, H., 1995: Homogeneity testing, multiple breaks and trends. *Proceedings of the 6th International Meeting on Statistical Climatology*, Galway, Ireland, June 19–23, 1995, 439–441.

Heino, R., 1996: Meta data and their role in homogenization. *Proceedings of the 1st Seminar for Homogenization of Surface Climatological Data*, Budapest, Hungary, October 6–12, 1996, 5–8.

Hadeen, K.D., N.B. Guttman, 1995: Homogeneity of data and the climate record. Instruments and observing methods, Report No. **57**, WMO, 110 pp.

Steffensen, P., 1996: Standard Normal Homogeneity Test for Windows. *DMI Technical report*, No. **96 13**, 35 pp.