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Zakład Klimatologii
UMK w Toruniu

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Homogenisation of seasonal and annual air temperature series from Bydgoszcz and Toruń

Homogenizacja sezonowych i rocznych serii temperatury powietrza z Bydgoszczy i Torunia

INTRODUCTION

For the analysis of climatic change or long-term climatic variation it is essential to use homogeneous data. Conrad and Pollak state that a climate time series is homogeneous if its variations are caused only by variations in weather and climate (Conrad, Pollak 1950). Long series are seldom free of non-climatic irregularities. These usually result from discontinuities caused by station relocations, observation time differences, instrument changes, or as trends caused by changes in the local environment such as urbanisation (Easterling, Peterson 1992; Peterson et al. 1998). In Poland, the analysis of long time series of meteorological data is quite difficult. There are only a few stations with long observations which, due to historical reasons (mainly wars), are often not continuous. Moreover, the observations available are often not homogeneous due to different observational systems and the relocation of stations. At present, homogenised temperature series for the area of Poland are only available for a few stations located in the coastal region of the Baltic Sea (Miętus 1996, 1998), in central (Górski, Marciniak 1992; Lorenc 2000) and in southern Poland (Głowicki 1997; Trepińska 1997).

Many different methods have been developed to identify inhomogeneities and adjust climatic time series. Peterson et al. (1998) give a comprehensive review of such methods. In the present study we have used the Standard Normal Homogeneity Test (Alexandersson 1986, Alexandersson and Moberg 1997) and the multiple regression method (Vincent 1990, 1998). We began our investigation by checking the quality and homogeneity of annual and seasonal air temperature series from Bydgoszcz and annual air temperature series from Toruń.

The main aim of this paper is to obtain homogeneity temperature series from Bydgoszcz and Toruń using the above-mentioned methods.

HISTORY OF STATIONS AND DATA

BYDGOSZCZ

Regular meteorological observations began in Bydgoszcz on 1 January 1848 and have continued till now with two breaks during World War II (Hohendorf 1948). During the first 60 years the places of observations changed quite frequently together with the addresses of observers (1854, 1887, 1897). From 1908 observations were made only at the Agricultural Institute (now the Institute for Land Reclamation and Grassland Farming, Al. Ossolińskich 12). After the breaks during the war, systematic meteorological observations began again in September 1945. In 1946 the location of the station was changed to an open field. Since then the station has been in operation continuously in the same place (φ = 53°08' N, λ = 18°01' E, h = 47 m a.s.l.). For more details see Vizi et al. (in print).

Raw data series of annual and seasonal air temperatures from Bydgoszcz were obtained:

- until 1920 from Smosarski (1923),
- 1921–1937 from Meteorological yearbooks published by the State Meteorological Institute and the State Hydro-Meteorological Institute in Warsaw,
- 1938–1953 from the Institute for Land Reclamation and Grassland Farming,
- 1954–1968 from *Meteorological yearbooks* published by the State Hydro-Meteorological Institute in Warsaw,
- 1969–1990 from the Institute for Land Reclamation and Grassland Farming.

Gaps in the series were filled on the basis of data from nearby stations (Toruń and Poznań) using the method of constant differences. The complete series which was thus obtained for the period 1851–1990 was checked for inhomogeneities.

TORUŃ

The earliest temperature measurements in Toruń were made in 1740 (Parczewski 1948, Rojewski 1965, Marciniak 1990). There are also temperature data for the period 1751–1759. More systematic (twice daily) meteorological observations involving not only air temperature, but also other elements such as precipitation, atmospheric pressure, wind direction and characteristics of the general state of the weather were carried out during the period 1760–1767 (Parczewski 1948). Meteorological measurements were continued in the following years, although of these we now only have incomplete data starting from 1886. However, for the analysis the continuous series of air temperature from 1921 has been used. During the 1930s there were three meteorological stations in Toruń at different locations. At the outbreak of World War II these stations were completely destroyed. Luckily, during the war (20th Feb. 1940–30th Nov. 1944) meteorological observations were carried out in the German station which was situated at the airfield. Data from this period are available at the Archive of the Meteorology and Water Management Institute in Warsaw. After the Germans left the station there was a short break in observations until 30th September 1945. In October 1947 the Soviet Army stationed in Toruń handed over a meteorological station with basic equipment to the State Hydro-Meteorological Institute and from that time observations were made systematically. The station was located in Toruń–Wrzosy (Rzepakowa 19). During the 1970s a significant increase in the number of buildings was observed around the station and therefore the relocation of the station was planned. On 4 December 1981 the station was moved to a new location (Storczykowa 124) situated in an open field ca. 1 km SE from the old one (φ = 53°02' N, λ = 18°35' E, h = 69 m a.s.l.).

The raw data series of annual air temperature from Toruń was obtained:

- 1921–1937 from *Meteorological Yearbooks* published by the State Meteorological Institute and the State Hydro-Meteorological Institute in Warsaw,
- 1938–1953 from the Archive of the State Hydro-Meteorological Institute in Warsaw,
- 1954–1968 from *Meteorological Yearbooks* published by the State Hydro-Meteorological Institute in Warsaw,
- 1969–1972 from the *Statistical Yearbooks* published by the Main Statistical Office,
- 1973–April 1977 from *Meteorological Yearbooks* published by the State Hydro-Meteorological Institute in Warsaw,
- May 1977–1990 from the *Statistical Yearbooks* published by the Main Statistical Office.

Gaps in the series were filled on the basis of data from the Bydgoszcz station using the method of constant differences.

HOMOGENEITY TESTS

The Standard Normal Homogeneity Test (SNHT) was developed by Alexandersson (Alexandersson 1986, Alexandersson and Moberg 1997) and is widely known. It is performed on normalised series of ratios (precipitation) or differences (temperature) between the candidate station values and the reference series. The reference series of a given climatic variable is computed as a weighted average from a few neighbouring stations. In Polish literature more details about the SNHT may be found in Miętus (1996).

The multiple regression method developed by Vincent (1990, 1998) to identify steps and trends in temperature series is less known and up to now has mainly been used for Canadian stations. It is based on the application of four regression models to determine whether the tested series is homogeneous, has a trend, a single step, or trends before and/or after a step. The dependent variable y_i is the temperature at the candidate station at time i and the independent variables x_{ki} are the temperatures at k reference stations at time i. A brief account of this method is presented in Vizi et al. (in print).

RESULTS

Although meteorological observations are available since 1848 for Bydgoszcz, we have chosen the period 1851–1990 for our homogeneity test due to the existing homogeneous reference series for this period. The selected reference stations were Gdańsk and Hel (homogenised by Miętus 1998), Warsaw (homogenised by Lorenc 2000), as well as two stations outside Poland: Berlin and Prague. For Toruń, as was mentioned earlier, a continuous series of data is available from 1921; thus we have analysed the period 1921–1990. As a reference station, in addition to the stations mentioned above, the earlier homogenised temperature series from Bydgoszcz has also been used. The air temperature data were taken from the following sources: Meteorologicka pozorovani w Praze-Klementinum 1976; Groveman, Landsberg 1979; Marciniak, Kożuchowski 1990; Miętus 1998. There are some more long temperature series from stations in Poland and other neighbouring countries but we did not use them because they either have long breaks or the coefficients of correlation with the Bydgoszcz and Toruń series are too low. The correlation coefficients between the annual and seasonal mean temperatures of the selected reference stations and the candidate stations (Bydgoszcz and Toruń) are very high (Table 1).

Table 1. Correlation coefficients between the annual and seasonal mean temperatures of the selected reference stations and the candidate stations (Bydgoszcz and Toruń)
Współczynniki korelacji średniej rocznej i sezonowej temperatury powietrza między stacjami referencyjnymi i badanymi stacjami (Bydgoszcz i Toruń)

Station	Correlation coefficient						
	1851–1990					1921–1990	
	Bydgoszcz					Bydgoszcz	Toruń
	DJF (XII–II)	MAM (III–V)	JJA (VI–VIII)	SON (IX–XI)	Year	Year	
Hel	0.971	0.944	0.759	0.917	0.920	0.929	0.951
Gdańsk	0.939	0.919	0.790	0.891	0.869	0.917	0.868
Bydgoszcz	1.000	1.000	1.000	1.000	1.000	1.000	0.964
Berlin	0.963	0.888	0.772	0.849	0.851	0.929	0.900
Warsaw	0.968	0.927	0.850	0.921	0.918	0.899	0.956
Prague	0.909	0.897	0.712	0.871	0.861	0.857	0.886

BYDGOSZCZ

Both methods applied to check the quality of the temperature data in Bydgoszcz have shown that the series is not homogeneous. The detected change points discovered by the SNHT method were found for the years 1886/1887 (T_{max} = 22.3; $q_2 - q_1$ = 0.3°C) and 1970/1971 (T_{max} = 57.7; $q_2 - q_1$ = 0.5°C). For more details see Vizi et al. (in print).

In the case of the multiple regression method, Model 1 was first fitted to the same temperature series. The obtained residuals clearly indicate inhomogeneities at the beginning and end of the series (see Fig. 4 in Vizi et al., in print). After the application of the other models, we have obtained the following shifts: 1886/1887 (0.4°C), and 1970/1971 (0.5°C).

According to Vizi et al. (in print), the most probable reason for the inhomogeneity detected in 1886/1887 is the relocation of the station. The second large inhomogeneity in 1970/1971 is connected with the changes in observational hours (from 7 a.m., 1 p.m. and 9 p.m. LT to 1 a.m., 7 a.m., 1 p.m. and 7 p.m. CET) and the calculation of the daily mean temperatures. We did not take into account the small shift detected in 1939/1940, but we suppose that it can be related to the errors in the process of filling the missing data.

The homogeneity of the seasonal series of air temperature was only checked for Bydgoszcz using the SNHT method. For the Toruń station the work is still not finished. Thus, the results will be presented in our next paper. Analysis

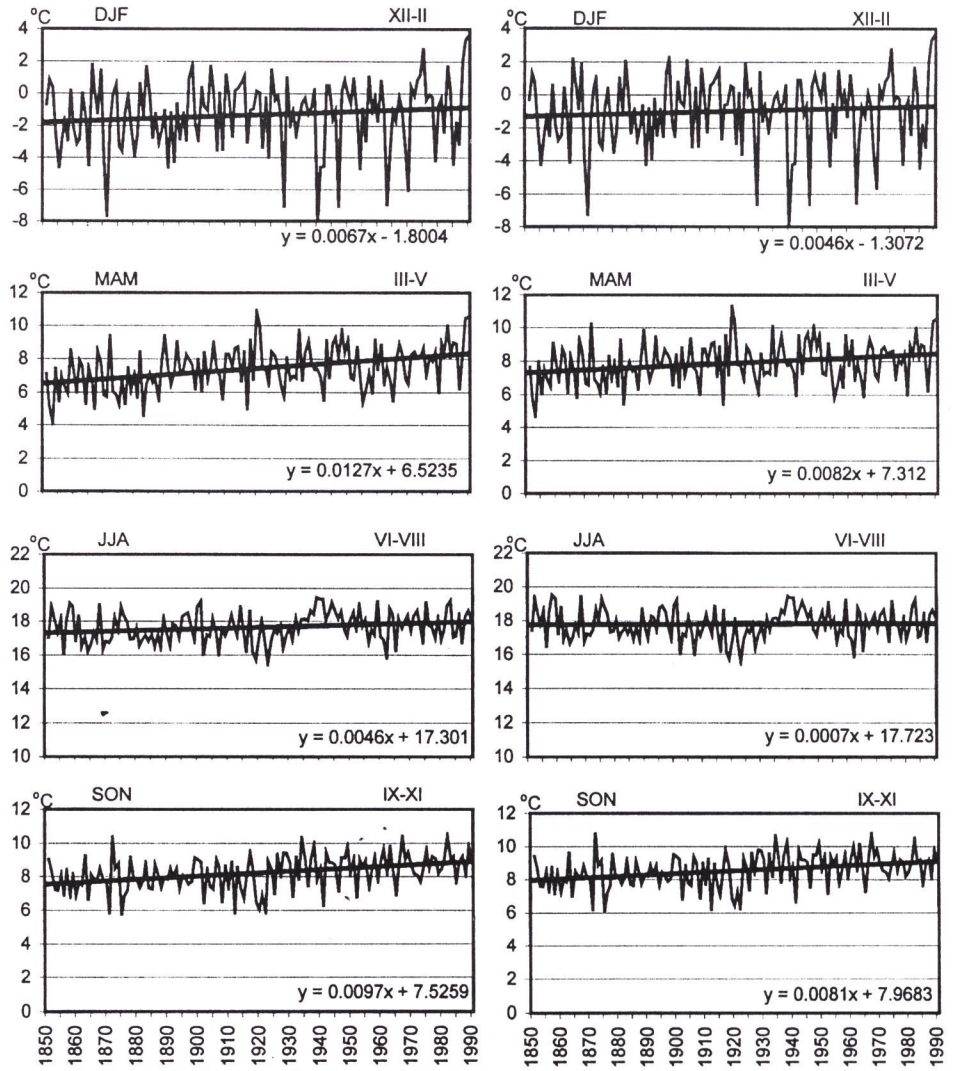

Fig. 1. Long-term seasonal courses of mean air temperatures in Bydgoszcz before (left panel) and after (right panel) homogenisation for the period 1851–1990
Średnie wieloletnie przebiegi sezonowych temperatur powietrza w Bydgoszczy przed (lewy panel) i po (prawy panel) homogenizacji w okresie 1851–1990

for the Bydgoszcz station has shown that all seasonal series are inhomogeneous. Most of them contain one break in the homogeneity (except the spring series which reveals three breaks). The years of the occurrence of these inhomogeneities are different in each season and are also different in comparison with the annual series (Table 2). However, it is worth adding that the timing of the inhomogeneities in all of the series is roughly similar; the inhomogeneities in the series occurred mostly at the end of the 19th century (spring and summer) or in the 1970s (winter, spring and autumn; see Table 2). Reasons for the detected inhomogeneities in the seasonal series have not yet been established. The courses of seasonal air temperatures in Bydgoszcz before and after homogenisation are presented in Fig. 1. They reveal that after homogenisation, the observed warming in the study period is lower than in the not adjusted (original) series. A similar result has also been obtained for the annual series (see Vizi et al., in print).

Table 2. Years of break points, test values (T_{max}) and temperature corrections ($q_2 - q_1$) applied to the mean seasonal temperatures from Bydgoszcz
Lata zerwania, wartości testowe (T_{max}) i wprowadzone poprawki ($q_2 - q_1$) do średnich sezonowych temperatur z Bydgoszczy

Season	Year	T_{max}	$q_2 - q_1$
DJF (XII–II)	1970/71	12.39	0.4
MAM (III–V)	1888/89	37.66	0.41
	1974/75	27.07	0.42
	1860/61	9.61	-0.28
JJA (VI–VIII)	1896/97	29.69	0.42
SON (IX–XI)	1974/75	23.82	0.37

TORUŃ

Using the same reference stations and the homogenised data from Bydgoszcz we have applied the SNHT for annual air temperature series from Toruń. Figure 2 shows the courses of the annual air temperature, Q-series and T-series before and after homogenisation. The detected change points are 1946/1947 (T_{max} = 17,14, $q_2 - q_1$ = -0.2°C) and 1976/1977 (T_{max} = 11.4, $q_2 - q_1$ = 0.19°C).

Fitting Model 1 of the multiple regression method to the data we found a strong autocorrelation in the residuals and this means that the series is not homogeneous. Successively applying the other models we detected a shift in 1946/1947 (-0.14°C) and in 1977/1978 (0.16°C).

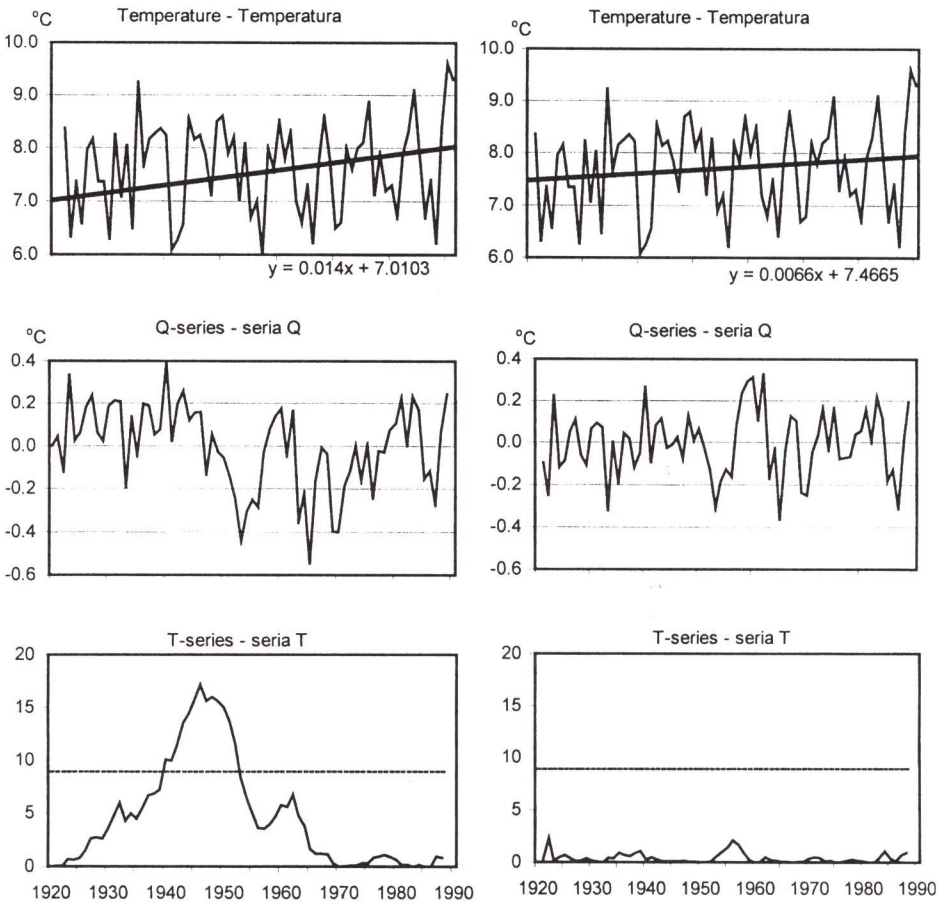

Fig. 2. Courses of annual mean air temperature, of differences between the candidate series and the reference series (Q-series), and of test values (T-series with 90% critical level) for Toruń before (left panel) and after (right panel) homogenisation for the period 1921–1990
Przebiegi średniej rocznej temperatury powietrza, różnic między badaną stacją a stacjami referencyjnymi (seria Q) oraz wartości testowych (seria T z 90% poziomem krytycznym) w Toruniu przed (lewy panel) i po (prawy panel) homogenizacji w okresie 1921–1990

The inhomogeneity detected in 1946/1947 is most probably caused by the relocation of the station. The second one may be connected with the rising cover of the area around the station by buildings in the 1970s.

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STRESZCZENIE

Celem niniejszego artykułu jest przedstawienie wyników prac dotyczących homogenizacji serii średnich sezonowych i rocznych temperatur powietrza z Bydgoszczy (1851–1990) oraz średnich rocznych temperatur powietrza z Torunia (1921–1990).

Serie temperatury powietrza z Bydgoszczy i z Torunia zostały zhomogenizowane przy użyciu testów opartych na metodach statystyki przestrzennej (test Alexanderssona oraz test opracowany przez Vincent). Do sprawdzenia jednorodności badanej serii danych potrzebne jest porównanie jej z ciągami danych z innych stacji (tzw. referencyjnych) należących do tego samego regionu klimatycznego i charakteryzujących się jednocześnie wysoką korelacją z badaną stacją. W zbiorze tych stacji powinny znaleźć się jednak także stacje zagraniczne, gdyż ich obecność pozwala wyeliminować wpływ zmian wprowadzonych jednocześnie na obszarze danego kraju, np. zmian metod obliczania średnich wartości lub zmian używanych instrumentów.

Do homogenizacji serii temperatury z Bydgoszczy zostały wykorzystane serie temperatury z Gdańska, Helu, Warszawy, Berlina i Pragi. W przypadku Torunia wykorzystano oprócz wyżej wymienionych stacji także wcześniej zhomogenizowaną serię z Bydgoszczy.

1. Jednoczesne zastosowanie dwóch różnych testów dało podobne wyniki odnośnie do miejsc zerwania jednorodności badanych serii termicznych z Bydgoszczy i z Torunia. Takie podejście badawcze powiększa wiarygodność uzyskanych wyników.

2. Pierwsze zerwanie jednorodności w serii rocznej temperatury z Bydgoszczy rzędu 0,4°C stwierdzono od 1887 r. Jego przyczyną była prawdopodobnie zmiana lokalizacji stacji. Ponownie jednorodność analizowanej serii została zerwana od 1971 r., co należy wiązać ze zmianą godzin wykonywania obserwacji meteorologicznych oraz jednoczesną zmianą obliczania średnich dobowych wielkości. Wartość wprowadzonej poprawki wyniosła 0,5°C.

3. Seria z Torunia wykazała, podobnie jak seria bydgoska, dwa miejsca zerwania jednorodności, które wystąpiły jednak w innych latach, a mianowicie od r. 1947 (poprawka -0,2°C) i od 1977 r. (0,2°C). W pierwszym przypadku niejednorodność serii wywołana została przeniesieniem stacji meteorologicznej, a w drugim najprawdopodobniej była związana z rosnącą zabudową wokół stacji, głównie w latach siedemdziesiątych.