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Urban heat island bias in Italian air temperature series

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Summary. — A new data-set of Italian monthly minimum and maximum temperature series for the period 1865-1996 has recently been set up and analysed for trend within the project "*Reconstruction of the climate of the past in the Mediterranean area*" of the National Research Council (CNR). The project allowed the completion and updating of the Ufficio Centrale di Ecologia Agraria (UCEA) secular series data-set that was set up in the '70s. Although the data were tested for homogeneity and sometimes homogenised, the presence of some urban series may cause urban heat islands to partially affect the observed trends. In this framework the aim of this paper is the analysis of the effects of this possible bias in the period 1951-1996 in regional average series calculated for two different geographic areas: Northern and Central-Southern Italy. The analysis is performed comparing Northern and Central-Southern seasonal average temperature anomalies calculated using the UCEA-CNR data-set with the same series calculated using the Italian Air Force data-set that includes only rural and airport stations.

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1. – Introduction

The urban heat island is probably the most serious source of systematic errors so far identified in climatological measurements [1]. Urban bias in surface air temperature, a principal effect of the urban heat island, is believed to persist in all the most widely used global land surface data sets. Therefore, estimating the magnitude of urban bias is important for the detection and monitoring of possible long-term trends associated with increasing concentrations of atmospheric greenhouse gases.

On global or hemispheric scales, the contribution of the heat island is not considered to have caused any major distortion of average temperature changes [2]. On smaller spatial scales (regional), however, data inhomogeneities caused by urbanisation are undoubtedly important in some regions, especially the United States [3]. Corrections for urban development in this area have been estimated by Karl *et al.* [4] and they have been applied in subsequent analyses [5]. On a global or hemispheric scale the contribution of the heat island can be considered small also for monthly means of minimum and maximum daily temperatures as the differences between the trends calculated including or excluding urban stations are of the order of 0.1 °C/100 years [6].

In this context the aim of this paper is the analysis of urban heat island bias in regional average series calculated for two different Italian areas: the continental (Northern Italy, hereinafter N) and the peninsular and insular (Central and Southern Italy, hereinafter S) parts of the country. These series have recently been used to estimate the Italian temperature trend in the period 1865-1996 [7-9]. The analysis is performed for the period 1951-1996 for which a large data-set of rural and airport stations is available from Italian Air Force (Aeronautica Militare, hereinafter AM).

2. – Data and methods

For our analysis we used two different data-sets: the former was set up in a project funded by the Italian National Research Council (CNR), the latter is the AM one (fig. 1). The CNR data-set is mainly an updated and completed version of the Ufficio Centrale di Ecologia Agraria (UCEA) one that was set up in the '70s in the framework of a project of reconstruction and digitisation of Italian meteorological series. The project supported the digitisation of daily minimum and maximum temperatures for 27 secular series [10]. As the UCEA daily minimum and maximum temperatures data-set had a lot of gaps, extensive work of data digitisation has recently been performed by the authors within the project "*Reconstruction of the climate of the past in the Mediterranean area*". In this project a number of monthly means of daily minimum and maximum temperatures were recovered from Italian meteorological year books in order to complete and to update the UCEA series.

At present the CNR data-set consists of 27 secular series, 15 in N and 12 in S. As the project is still going on, it is in continuous evolution and new series may be added in the near future. The AM data-set is larger, consisting of 73 series, 26 in N and 47 in S. The data have daily resolution but they cover only the period 1951-1996.

The CNR data set was completed and homogenised both for monthly mean temperatures (hereinafter T) [7, 8] and for monthly means of daily minimum and maximum temperatures (hereinafter $T_{\min}$ and $T_{\max}$) [9].

The AM data-set was not corrected but only tested for homogeneity and completeness. Moreover some tests were used in order to eliminate suspicious daily values from the calculation of monthly means and if a series had too many suspicious values it was eliminated from the data set.

Both the CNR and the AM series were transformed into anomalies and averaged over N and S in order to obtain regional series for the two areas. Seasonal and yearly anomalies and their 5 year running means were then calculated for $T_{\min}$ and $T_{\max}$. Moreover, yearly and seasonal differences between CNR and AM series both for $T_{\min}$ and $T_{\max}$ (hereinafter $DT_{\min}$ and $DT_{\max}$) were calculated in the two regions.

N and S seasonal and yearly $DT_{\min}$ and $DT_{\max}$ series were analysed with the Mann-Kendall non-parametric test, as described in Sneyers [11] to look for a trend. The slopes of the linear trends were calculated by least squares fitting.

The Mann-Kendall test was also used for a progressive analysis of the $DT_{\min}$ and $DT_{\max}$ series, as already done in Maugeri and Nanni [8] and described in Sneyers [11].

In order to verify if the trend in the urban temperature bias in the period 1951-1996 can be quantified also at a local level, a direct comparison between urban and rural data

Fig. 1. – Map of the AM (▲) and CNR (●) stations.

has been performed for some specific cities. This study showed that, even if urban and rural temperatures result generally highly correlated both at seasonal and yearly level, the signal in their differences often seems to be smaller than the noise produced by inhomogeneities in the data. An example of this situation is displayed in fig. 2 where Milan urban temperatures (Brera) are shown together with a rural temperature series calculated averaging the data of 6 airports surrounding Milan (Novara-Cameri, Milano-Malpensa, Bergamo-Orio al Serio, Milano-Linate, Piacenza and Brescia-Ghedi). The case study of Milan is particularly interesting as the history of the observations is well known [12] and so it is possible to explain many features of the differences between the urban and the rural data (*e.g.*, the very difficult period 1964-1968 and the

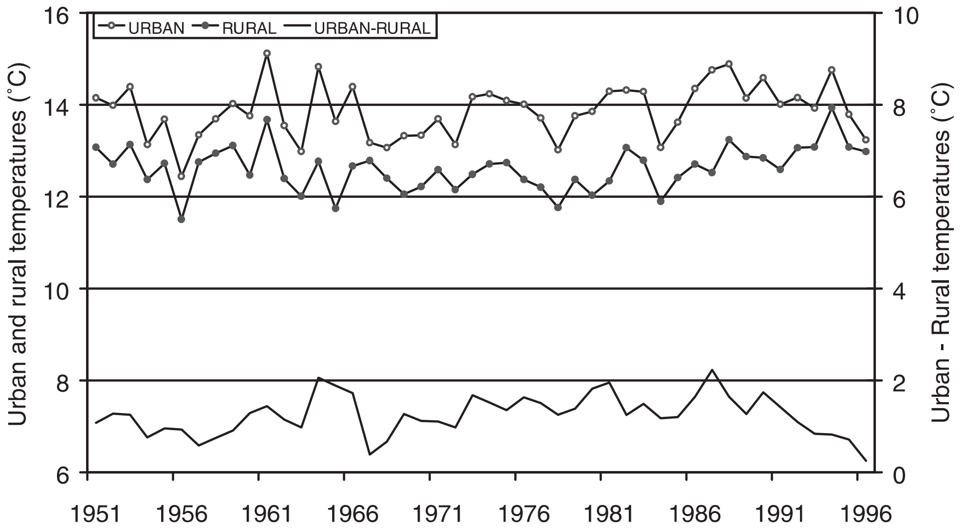

Fig. 2. – Comparison between urban (Brera) and rural temperatures for Milan.

change points in 1972 and in 1990) on the light of changes in observation location and methods. The problem of the signal-to-noise ratio can be solved only using homogenised data [13]. But homogenisation has to be performed using the data of the surrounding stations and so the procedure makes the homogenised data more representative of the regional scale than of the local one [14].

So we concluded that our data allow the quantification of the trend in the urban temperature bias only at a regional scale.

3. – Results and discussion

CNR and AM series have a highly correlated behaviour in all the seasons and in the year both for T_{min} and T_{max} with seasonal correlation coefficients ranging from 0.96 to 0.98 in N and from 0.94 to 0.98 in S. Yearly correlation coefficients are only slightly lower, ranging from 0.95 to 0.97 in N and from 0.93 to 0.95 in S. No relevant differences are evident between T_{min} and T_{max} coefficients and also for T the values are very similar. Figure 3 gives evidence of the correlation between the two data-sets, showing yearly anomalies of CNR T *vs.* AM T both for N (correlation coefficient: 0.97) and S (correlation coefficient: 0.96).

Figure 4, where yearly and seasonal DT_{min} and DT_{max} for N are represented, displays that in Northern Italy there is a positive trend in the differences between CNR and AM T_{min}, whereas for T_{max} the trend is not so evident. Figure 5 shows the same series for Central-Southern Italy where the trend is neither evident for T_{min} nor for T_{max}. The application of the Mann-Kendall test and of linear least squares fitting to DT_{min} and DT_{max} series allows a more detailed trend analysis (table I). Considering a 95% confidence level, significant trends are present only in N: they are positive in winter, spring and autumn for T_{min} and in winter for T_{max} and negative in summer for T_{max}. All the positive trends have a confidence $> 99\%$, whereas the

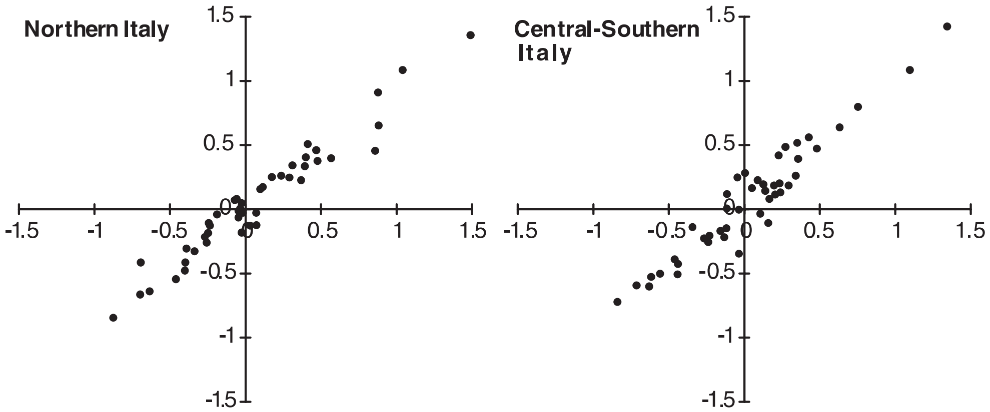

Fig. 3. – Yearly CNR T anomalies *vs.* yearly AM T anomalies (period 1951-1996) for Northern and Central-Southern Italy.

negative one has a confidence > 95%. On a yearly basis, DT_{min} presents a significant (confidence > 99%) trend only in N.

The slope of N yearly DT_{min} is 0.7 °C/100 years, that correspond to an increase in the difference between CNR and AM minimum temperatures of around 0.3 °C in the period 1951-1996. The increase is mainly due to the winter season that shows an increase of around 0.5 °C.

A more detailed analysis of the behaviour of yearly N DT_{min} can be obtained with the progressive application of the Mann-Kendall test. The result is shown in fig. 6 that gives the graphical representation of the direct (u_i) and backward (u_i') curves for this series. The figure gives evidence that the u_i curve begins to grow around 1975, then it intersects the u_i' curve in 1980 and begins to have a significant value in 1982. Moreover the figure shows that u_i and u_i' intersect only once. On this basis, a yearly N DT_{min} positive trend can be assumed to start around 1980.

Considering mean temperature and averaging N and S results, the urban heat island bias of the CNR data-set in the period 1951-1996 can be estimated to be around 0.1 °C. Therefore the influence of urbanisation seems to be slightly higher (around 0.2 °C/100 years) than in global climatological data-sets (around 0.1 °C/100 years) [6]. Also for the CNR series, however, the urban heat island bias in the period 1951-1996 is rather small in comparison with the temperature trend. In fact the trend of the annual mean temperature averaged on all Italy has a slope of about 0.5 °C that corresponds to 1 °C/100 years.

It is not easy to extend the evaluation of CNR series urban heat island bias in the past as the AM data-set begins in 1951 and no other computer readable data-sets of rural stations are available at present time for Italy. It is, however, worth noticing that in the period 1865-1996, both in N and in S, the daily temperature range (*i.e.* the difference between T_{max} and T_{min}, hereinafter DTR), that in the presence of an increasing urban temperature bias should decrease, seems to be completely independent of urban development. In fact, Brunetti *et al.* [9] showed that: i) both in N and in S T_{max} shows a stronger trend than T_{min}, causing a decrease of the DTR in the period 1865-1996, ii) the behaviour of the DTR series seems to depend mainly on the cloud cover with higher values in the dry periods and lower ones in the wet ones.

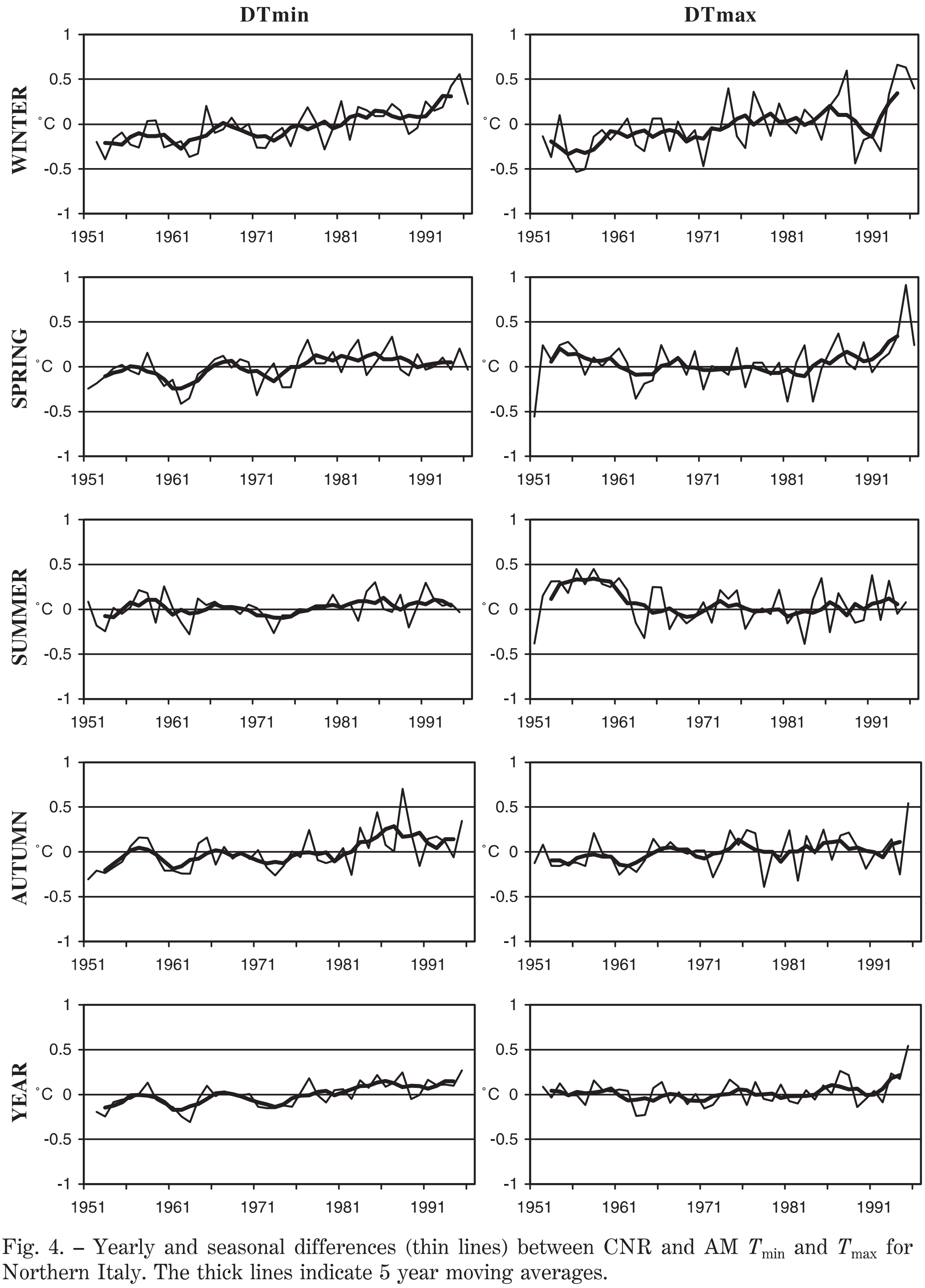

Fig. 4. – Yearly and seasonal differences (thin lines) between CNR and AM T_{min} and T_{max} for Northern Italy. The thick lines indicate 5 year moving averages.

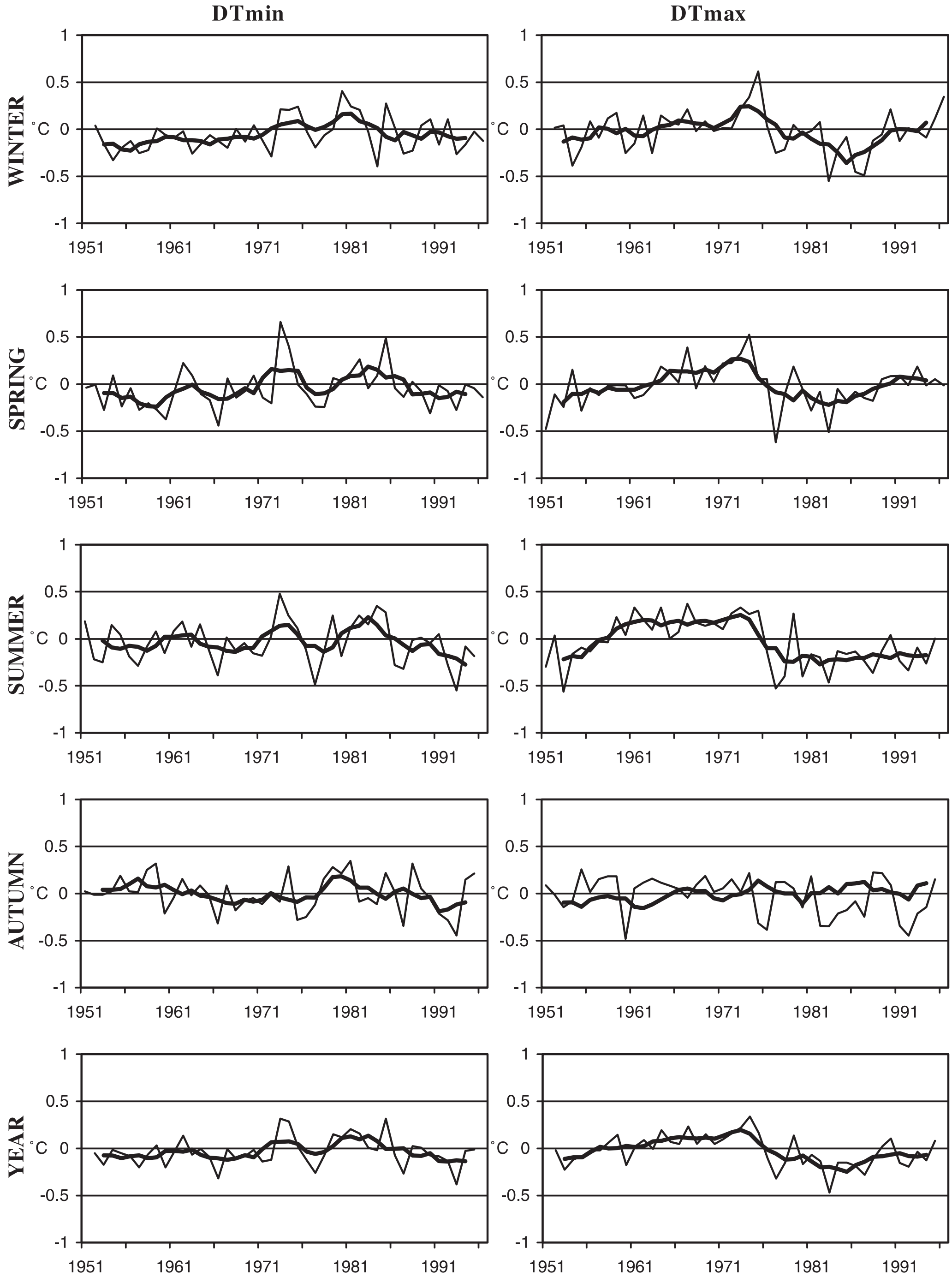

Fig. 5. – Yearly and seasonal differences (thin lines) between CNR and AM T_{min} and T_{max} for Central-Southern Italy. The thick lines indicate 5 year moving averages.

TABLE I. – *Yearly and seasonal* DT_{min} *and* DT_{max} *trends for* N *and* S *defined by: linear regression coefficient* (b), *associated error* (σ_b), *associated linear correlation coefficient* (r) *and Mann-Kendall test value* (u).

		DT_{min}			DT_{max}		
		$b \pm \sigma_b$ (°C/100 y)	r	u	$b \pm \sigma_b$ (°C/100 y)	r	u
North	Winter	1.1 ± 0.2	0.68	4.3**	1.2 ± 0.3	0.52	3.0**
	Spring	0.5 ± 0.2	0.42	2.6**	0.4 ± 0.3	0.24	0.2
	Summer	0.2 ± 0.2	0.20	1.2	− 0.4 ± 0.3	0.24	− 2.1*
	Autumn	0.8 ± 0.2	0.48	2.7**	0.4 ± 0.2	0.30	1.9
	Year	0.7 ± 0.1	0.62	4.3**	0.3 ± 0.2	0.27	1.1
South	Winter	0.3 ± 0.2	0.21	1.5	− 0.1 ± 0.3	0.05	− 0.9
	Spring	0.2 ± 0.2	0.15	1.0	0.1 ± 0.2	0.08	0.7
	Summer	− 0.1 ± 0.3	0.06	0.1	− 0.5 ± 0.3	0.27	− 1.8
	Autumn	− 0.2 ± 0.2	0.12	− 0.9	− 0.5 ± 0.2	0.31	− 1.6
	Year	0.1 ± 0.2	0.09	0.5	− 0.3 ± 0.2	0.26	− 1.2

* Significance level greater than 95%.
** Significance level greater than 99%.

Therefore the behaviour of the DTR should exclude any major influence of urbanisation in N and S CNR regional average series in all the period 1865-1996.

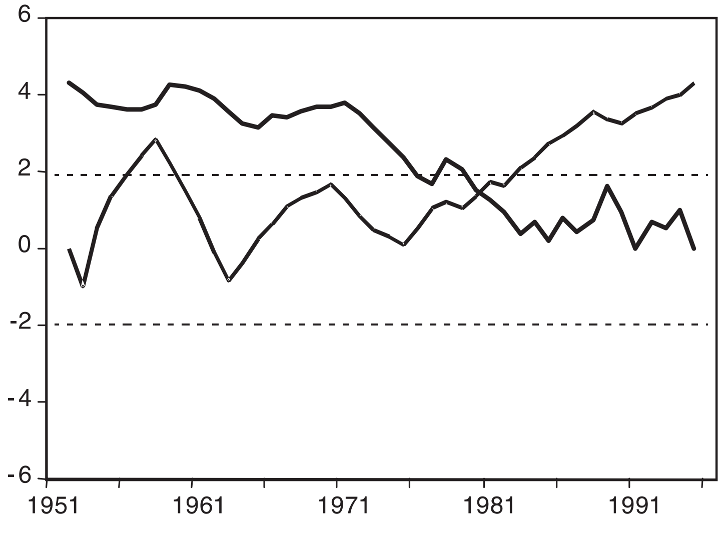

Fig. 6. – Progressive values of u_i (thick line) and u_i' (thin line) for N yearly DT_{min}. The straight lines indicate a confidence level of 95%.

4. – Conclusions

Comparison with AM rural and airport station data shows that the CNR secular series data-set that has recently been used to estimate the Italian temperature trend in the period 1865-1996 [7-9] could have a significant heat urban bias in the period 1951-1996. The effect seems to be present only in Northern Italy, especially in winter, and seems to concern mainly minimum temperature.

Considering mean annual temperature and averaging the results of Northern and Central-Southern Italy, the bias of the CNR data-set can be estimated to be around 0.1 °C in the 46 year period. Even if slightly higher than for the global climatological data-set [6], also for the CNR series the bias seems rather low in comparison to the observed temperature trend.

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