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URBAN INFLUENCES ON SOUTH AFRICAN TEMPERATURE TRENDS

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ABSTRACT

Temperature trends are examined for a variety of locations in South Africa. The long-term mean annual temperature record (1885–1993) shows warming over the past century, with much of the warming occurring in the most recent three decades. However, our analyses show that half or more of this recent warming may be related to urban growth, and not to any widespread regional temperature increase. Maximum and minimum temperatures for the period 1960–1990 reveal a statistically significant decrease in the diurnal temperature range in large urban areas, but no change in the non-urban network. This assessment of the urban effects on temperature trends in South Africa may contribute to our understanding of apparent climate changes occurring in the Southern Hemisphere during the period of historical records.

KEY WORDS: South Africa; temperature trends; urban effects.

INTRODUCTION

Interest in identifying a temperature response to the known build-up of anthropogenic greenhouse gases has stimulated research on historical climate records from around the world. Most of this research has focused on the mid-latitudes of the Northern Hemisphere, where most high-quality, long-term temperature records can be found. Over the past century, these Northern Hemisphere locations generally have warmed by approximately 0·5°C, with much of the warming occurring in the low-sun seasons and at night (Folland *et al.*, 1990, 1992). Many studies have been conducted showing that urban growth has played a role in producing these patterns found in the historical climate records (see Jones *et al.*, 1990; Balling, 1992).

When compared with the Northern Hemispheric land areas, climate records are relatively sparse throughout much of the Southern Hemisphere. One notable exception is the availability of climate records for stations in South Africa, where some larger cities have mean temperature data extending more than a century and many smaller towns have digitized maximum and minimum temperature records available from 1960 onward. The purpose of this paper is to examine these records to determine (i) trends in mean temperature in South Africa over the past century, (ii) trends in the mean, maximum, and minimum temperatures over the past 30 years, and (iii) the potential role of urbanization in generating temperature trends in the South African records. The results of our investigation should add to the growing body of knowledge on climate changes that have occurred in the Southern Hemisphere over the past century.

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DATA

The following temperature data bases are used in this investigation.

(i) Jones (1994) has generated a new time series of historical temperature data that are available for 5° latitude by 5° longitude grid-cells throughout the world. Four of these cells comprise most of South Africa and have records extending from the 1880s to the near present. Jones (1994) used 15 stations from South Africa in constructing these time series, including the data from the relatively large cities of Pretoria, Johannesburg, Kimberly, Durban, Cape Town, and Port Elizabeth.

(ii) Maximum and minimum temperature data were kindly supplied to us by the Weather Bureau of the Republic of South Africa for the period 1960–1990. These records include data from five very large metropolitan areas and 19 stations from non-urban locations (Figure 1; Table I). These 19 stations have three-letter locational codes (du Toit, 1988) indicating agriculture, irrigation, lighthouse, or prison locations. The small percentage of missing months in these data (1·9 per cent) have been replaced by interpolation from adjoining months; there are 1·0 per cent missing data from the five large metropolitan areas over this same time period.

(iii) For comparative purposes, we examine the 12-station South African diurnal temperature range data of Karl *et al.*, (1993) over this 1960–1990 period. In commenting on the potential influence of urban growth on these data, Karl *et al.* (1993, p. 1014) state that the data from South Africa include some stations from urban areas, but countrywide decreases of the diurnal temperature range are not overwhelmed by these stations. Although Karl *et al.* (1993) do not specify which 12 stations were used from South Africa, we suspect that substantial overlap occurs between the three data sets described in this section.

MEAN TEMPERATURE TRENDS

A plot of the new Jones (1994) annual temperature data from four grid-cells in South Africa reveals a cooling from 1885 to 1915, a warming from 1915 to 1945, a slight cooling from 1945 to 1970, and rapid warming from 1970

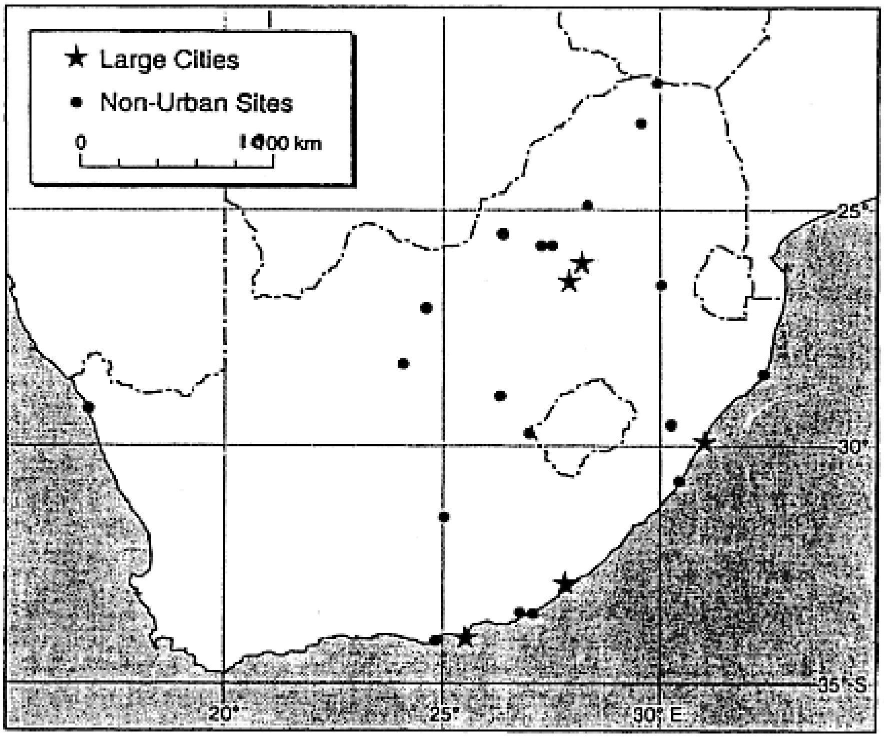

Figure 1. Map of South Africa showing Jones' grid cells, five large cities, and 19 non-urban stations

Table 1. Description of South African station

Station		Latitude (°-′S)	longitude (°-′E)	Elevation (m)	ΔT (°C/decade^{-1})
Non-Urban sites:	Cape St.Francis	34-12	24-50	7	0.073
	Bathurst	33-31	26-49	259	0.091
	Great Fish Point	33-32	27-06	73	0.020
	Grootfontein II	31-29	25-02	1270	0.018
	Port Shepstone	30-44	30-27	17	0.155
	Wepener	29-44	27-02	1438	0.142
	Cedara	29-32	30-17	1076	0.142
	Port Nolloth	29-14	16-52	4	0.299
	Glen College	28-57	26-20	1304	0.053
	Koopmansfontein II	28-12	24-04	1341	0.023
	Cape St. Lucia	28-30	32-24	107	0.195
	Armoedsvlakte	26-57	24-38	1234	0.050
	Nooitgedacht	26-31	29-58	1694	0.148
	Rustenburg	25-43	27-18	1157	0.325
	Buffelspoort II	25-45	27-29	1230	− 0.106
	Marico	25-30	26-21	1078	0.081
	Warmbad-Towoomba	24-54	28-20	1143	− 0.071
	Mara	23-09	29-34	894	0.016
	Macuville	22-16	29-54	522	0.074
Large cities:	Vereeniging	26-28	28-00	1704	0.234
	East London	33-02	27-50	125	0.082
	Port Elizabeth	33-59	25-36	60	0.291
	Durban	29-58	30-57	8	0.346
	Johannesburg	26-12	28-06	1753	0.240

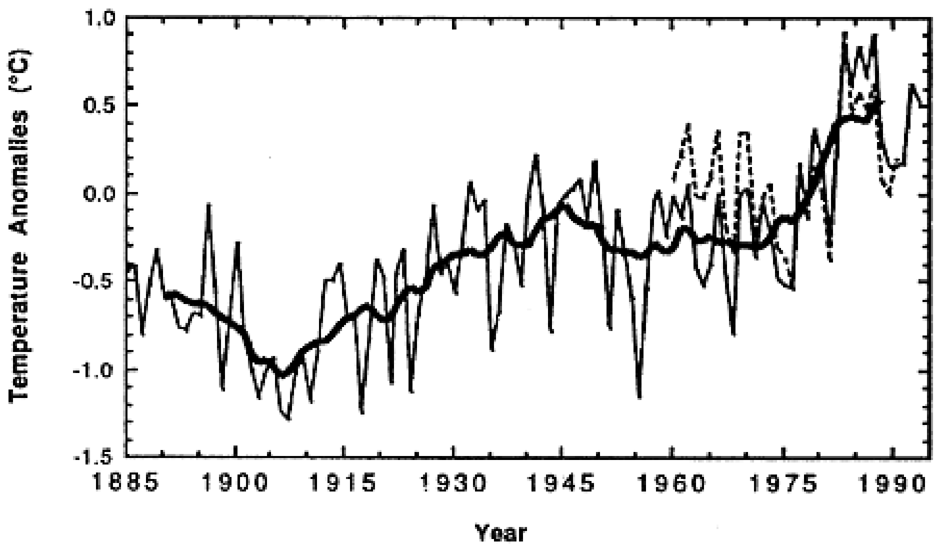

Figure 2. Jones (1994) South African temperature anomalies 1885-1993, with 10-year smoothed values. Also, the dashed line represents 1960–1990 temperature anomalies of the 19 non-urban sites

onward (Figure 2). The temperature anomalies show a very warm period extending from 1983 to 1987, when the values averaged +0·77°C above the mean for the 1961–1990 base period. Over the entire 109-year period of record, South African mean temperature appears to have increased linearly by 1·13°C; these data have a first-order autocorrelation of +0·71. Although South Africa covers only 0·24 per cent of the Earth's surface, this statistically significant warming in an area of the Southern Hemisphere with long-term records is broadly consistent with the expected warming given the build-up of greenhouse gases. However, the question remains whether this warming is widespread throughout South Africa or simply an artifact of urban growth. This question becomes even more interesting when considering that Mühlenbruch-Tegen (1992) analysed temperature data from 18 urban and non-urban stations in South Africa over the period 1940–1989 and found little evidence for changes in mean temperatures.

To address the issue of possible urban contamination in the South African temperature time series, we examine the 1960–1990 temperature data from both the five large metropolitan stations and the 19 non-urban stations. We find that over this 1960–1990 period, the Jones (1994) temperature data warmed at a rate of +0·31°C decade^{-1} or +0·90°C overall (Figure 3). Obviously, a substantial part of the warming of the past century in the Jones (1994) South African temperature record has occurred in this recent period. The warming in the five large cities averaged 0·24°C decade^{-1}, and the trend in the difference between the two temperature time series is statistically significant. Even when we gridded the data from the large cities to more evenly represent South Africa, we continued to find that the Jones (1994) data warmed faster than the warming established for the largest cities in South Africa. It is possible that temperature data from surrounding countries incorporated into the Jones (1994) calculations may be responsible for this difference.

To further explore the nature of temperature variations in the South African data, we focused our attention on the mean temperatures from the 19 non-urban stations. We began our analyses by examining each time series for homogeneity using the von Neumann ratio as a test of randomness against unspecified alternatives (Mitchell *et al.*, 1966). Using groups or pairs of near-neighbour stations, we developed composite time series of mean annual temperatures. We subtracted the data from each station in the cluster from the group mean, and we tested the time series of temperature differences for randomness. A high level of homogeneity should produce a random pattern in the differences whereas station inhomogeneities should generate non-random signals in the time series of differences. Sixteen stations passed this test, but Port Shepstone, Wepener, and Warmbad-Towoomba appeared to have some type of inhomogeneity with respect to surrounding stations. Accordingly, we conducted our analysis with and without these stations contributing to composite, countrywide temperature time series.

The warming rate for the 19 non-urban centres was a statistically insignificant 0·09° decade^{-1} over the 1960–1990 period; including or deleting the three stations with potential homogeneity problems had no significant effect on this result. The correlation between the Jones data and the 19 station non-urban temperatures is +0·84, and the anomalous warm period from 1983 to 1987 appears in both records (Figure 2). However, the disparate trends in

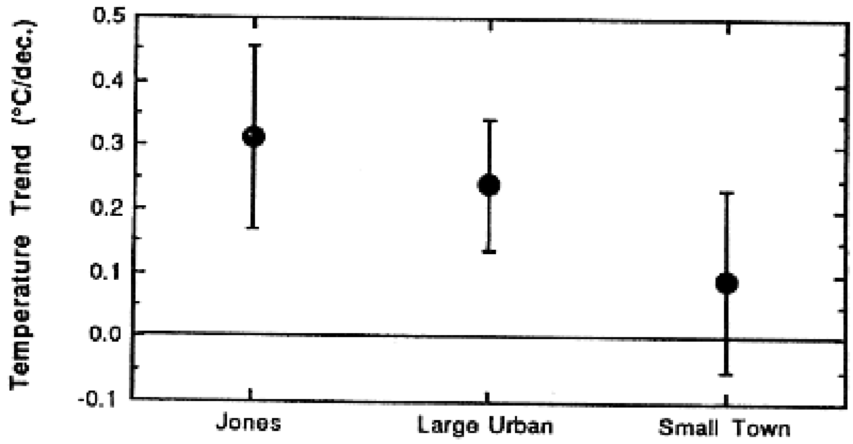

Figure 3. Plot of 1960–1990 mean temperature trends for various South African data sets along with 0·95 confidence levels

temperature (+0·09° decade^{-1} verses +0·31°C decade^{-1}) suggest that urbanization has influenced the Jones (1994) records for South Africa over the 1960–1990 period of apparent rapid warming.

We recognized that our network of non-urban stations is concentrated in the eastern half of South Africa. Therefore, we interpolated the temperature data to a 2·5° latitude by 2·5° longitude grid established for the country. The interpolation procedure allowed the westernmost station, Port Nolloth, to more strongly impact the composite temperature time series. Despite the fact that Port Nolloth had a relatively large rate of warming (+0·30° decade^{-1}), the gridding procedure did not change any of the fundamental results; the gridded temperature data showed a warming of 0·11°C decade^{-1}.

DIURNAL TEMPERATURE RANGE

Scientists have found a decrease in the diurnal temperature range in many parts of the world, although a few exceptions have been found where the range has actually increased (see Karl *et al.*, 1993). Mühlenbruch-Tegen (1992) found that during the period 1940–1989, South African maximum temperatures had decreased generally whereas minimum temperatures had increased; this pattern was most pronounced during the spring season, but was reversed in the autumn period. In their comprehensive survey of diurnal temperature range patterns, Karl *et al.* (1993) found a slight increase in maximum temperatures, a significant increase in minimum temperatures, and a corresponding decrease in the diurnal temperature range in South Africa for the period 1951–1991. We have reanalysed these data for the large cities and small towns and found the following for the 1960–1990 period:

(i) Maximum temperatures increased about the same across South Africa regardless of the size or location of the station. The rate of increase in maximum temperatures was +0·11°C decade^{-1} at the small towns and +0·12°C decade^{-1} at the largest city locations. These increases were not statistically significant.

(ii) Minimum temperatures showed a pronounced urban influence. At the non-urban stations, minimum temperatures increased at a statistically insignificant rate of +0·07°C decade^{-1}; gridding the station data or eliminating the three stations with potential homogeneity problems did not alter this result. However, minimum temperatures increased at +0·34°C decade^{-1} at the five large towns, and the trend is statistically significant.

(iii) The trend in selected diurnal temperature range time series for the period 1960–1990 is presented in Figure 4. The data from the five large towns show a clear decrease in the diurnal temperature rate, whereas the remaining two data sets show no statistically significant trends.

DISCUSSION AND CONCLUSIONS

Our results have shown that South Africa has warmed over the past century, and according to the new Jones (1994) temperature data, South Africa may have warmed by over 1°C. However, we have found that much of this warming

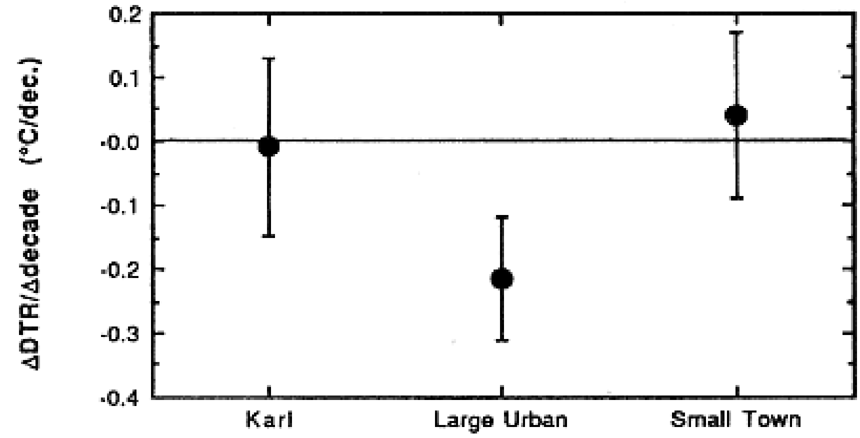

Figure 4. Plot of 1960–1990 mean temperature ~~trends~~ range for various South African data sets along with 0·.95 confidence levels

occurred over the most recent three decades, and during this period, urban growth appears to have contaminated the records. In contrast to data from urban areas, we find that the 19 non-urban sites in South Africa have not warmed significantly during this recent period. The lack of overall warming in the country is consistent with the results presented by Mühlenbruch-Tegen (1992). The diurnal temperature range was decreasing in the urban settings, but not at the rural locations.

The analysis of historical records from the Southern Hemisphere are particularly important with respect to the greenhouse issue. Owing to the sparsity of records for this half of the planet and due to the generally low levels of aerosol sulphates which can counteract greenhouse warming (Jones *et al.*, 1994; Taylor and Penner, 1994), the areas with long-term climate data in the Southern Hemisphere should receive special attention. In this regard, we hope that our assessment of urban contamination of South African records contributes to our understanding of climate changes during the time of historical climate records. Our analyses show that the warming apparent in the new Jones (1994) data probably is inflated by urban effects; in addition, we could not find any decrease in diurnal temperature range in the rural temperature data.

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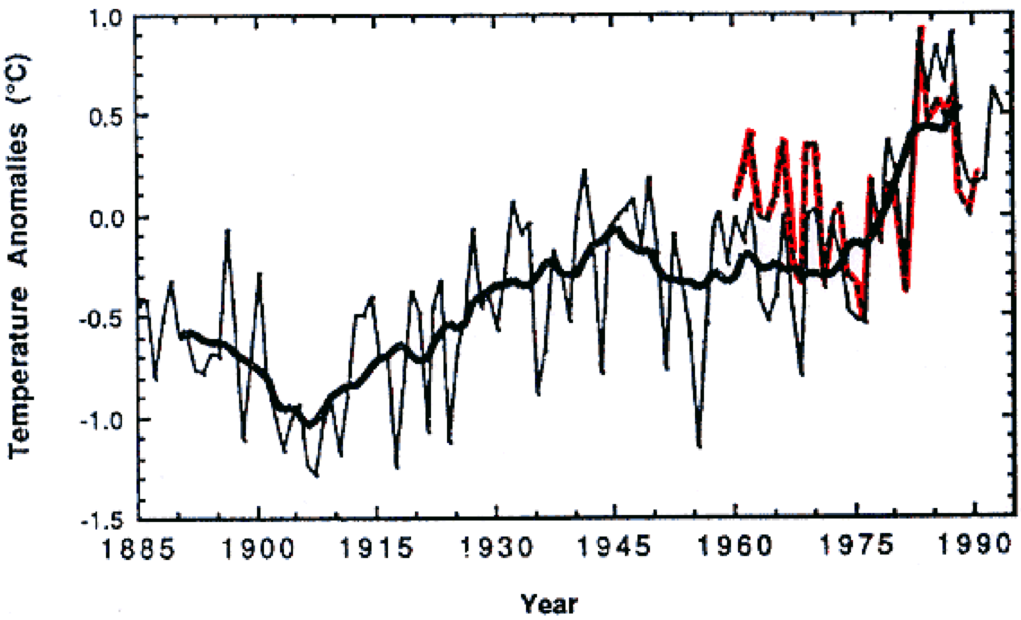

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