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Surface Temperature Variation over Zimbabwe Between 1897 and 1993

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With 17 Figures

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Summary

The surface temperature variation over Zimbabwe, and, Harare and Bulawayo between 1933 and 1993, and, 1897 and 1993 respectively, is investigated. For the national average two significant warm phases are identified, with a net warming of +0.3 to +0.5 °C since 1933. Warming occurs in maximum temperature, whereas the mean national temperature cools. The effect of the rainfall pattern on temperature is also investigated. If warming phases coincide with drought years and the warming is confined to the rainy months only, then reduced cloudiness could be an important factor in explaining some of the warming. The first warm phase occurs during the mid-1930s to late 1940 and the second major warm phase occurred from the early 1980s onwards. For Harare, with temperature records starting before 1900, a major warming phase occurred between about 1910 and late 1920. The effect of drought on the national temperature record is evident through a strong negative association between maximum temperature anomalies and rainfall anomalies. A number of possible causes of the observed changes are discussed. The effects of urbanisation and industrialisation on temperature trends over Harare and Bulawayo are quite conspicuous. The question that remains difficult to answer is whether the observed warming trend is a result of inherent climate variability, enhanced greenhouse effect or a combination of many factors.

1. Introduction

Climatic change, whether due to natural forcing mechanisms or anthropogenic greenhouse induced, raises major conflicts and dilemmas for developing countries (Bolin et al., 1986; Kelly and Hulme, 1992). The need to balance short term development objectives and the mitigation of existing social, economic and environmental problems against the requirement for long-term climatic and environmental security are major dilemmas facing developing countries such as Zimbabwe. Quantifying what we know about past climates is becoming increasingly important for climate change and adaptation studies across the globe. The recent increase in global mean temperatures and other events, such as the American and African droughts during the 1980s and 1990s generated a lot of research interest about global warming and climate change among meteorologists (Matarira, 1990; World Meteorological Organization (WMO), 1995).

Studies aimed at finding evidence of global warming, the magnitude, the causes, links with rainfall patterns, possible impacts and establishing future scenarios have been carried out for various parts of the world (Bolin et al., 1986; Schönwiese et al. 1990; Pittock and Salinger, 1991; Tucker, 1991; Tyson, 1991; Coops, 1992; Kelly and Hulme, 1992; Koleva and Iotova, 1992). On the climate change issue, three features of the climate are critical: atmospheric carbon dioxide (CO_2), temperature and rainfall. The possibility that global warming resulting from an enhanced "greenhouse effect" might be accompanied by changes in rainfall is of concern in Zimbabwe. Agriculture, and the general economic performance of Zimbabwe, are highly dependent on rainfall. Changes in the rainfall pattern could therefore affect the country's food security position and development path considerably. The Intergovernmental Panel on Climate Change (IPCC) has set a mean global temperature increases beyond 1 °C as the minimum threshold beyond which rapid, unpredictable and non-linear climatic responses capable of extensively damaging the ecosystem may occur [United Nations Environment Programme (UNEP), 1993].

Based on land and marine measurements, the global average surface temperature has shown an upward trend since about the late nineteenth century until 1940s followed by cooling until the mid-1960s (Angell and Korshover, 1977, 1978; Jones and Kelly, 1983; Bolin et al., 1986). Since then, the whole globe appears to have entered a warming phase. During the last 100 years, periods of greatest warming have been 1920 to 1940 and the 1980s (UK Dept. of Environment and Met. Office, 1989). For selected site in southern Africa, Kelly and Hulme (1992) found greatest temperature rises during the period 1910–1940 and the 1980s which is in close agreement with the global pattern. Taking a global average, the 1980s was the warmest decade on record and had many notable weather anomalies across the globe (WMO, 1992), leading to a lot of speculation and debate about possible greenhouse induced climate change. Using 13 European stations, Coops (1992) found largest increases in temperature around 1910 in winter and about 1930 in summer. Taking a global average based on 63 well spaced radiosonde stations, Angell and Korshover (1977) found a cooling of about 0.3 °C over much of the globe between 1958 and 1965–1968 and slight variations thereafter. The question that remains difficult to answer at this stage is whether this warming trend is a result of inherent climate variability, enhancement of the greenhouse effect or a combination of many factors. It is thought that a gradual rise of atmospheric carbon dioxide (CO_2) concentration will have a trend-effect on the surface temperature superimposed upon the natural variability evident in most temperature time series (Coops, 1992). Some authors have associated the natural variability to sun spot cycles, whereas volcanic eruptions have been associated to tropospheric cooling (Angell and Korshover, 1978; Coops, 1992). The difficult in ascertaining the causes of the observed warming creates considerable problems in trying to project the future temperature trends from the current observations and also isolating greenhouse related warming from warming due to other factors. However, there is a lot to learn from past temperature variability, for this represents the backdrop against which future impacts can be inferred.

This study seeks to establish the nature of surface temperature variation Zimbabwe has experienced during the period 1897 to 1993 and also to find out if there is any relationship with rainfall variability over the country during the same period. A series of droughts affected southern Africa from 1980 onwards, and it is also during the same period that the greatest warming has occurred (WMO, 1995). It is therefore hypothesised that reduced could coverage could explain some of the observed warming. This hypothesis justifies isolating and investigating the relationship between the temperature and rainfall anomalies during Zimbabwe's rainy season (October to April). Instead of using the mean temperature, daytime (maximum) and night-time (minimum) temperatures are used to investigate the temperature trends. A warming trend at night would imply reduced radiation cooling or increased opacity of the atmosphere to longwave radiation which can be attributed to an increase in the concentration of "greenhouse" gases and other pollutants in the atmosphere, whereas warming during the day could be associated with increased insolation due to less cloud coverage, change in surface albedo or some other factors.

Many climate change studies have had a marked reliance on simple measures of temperature variations. Often, only the mean annual temperature variation and hemispheric averages based on a few stations have been used for the studies (Jones and Kelly, 1983). The representativeness of the selected stations of the area under study has in some cases not been considered. Besides annual and hemispheric temperature variations, investigations of variations at seasonal timescales and at country level should yield detail

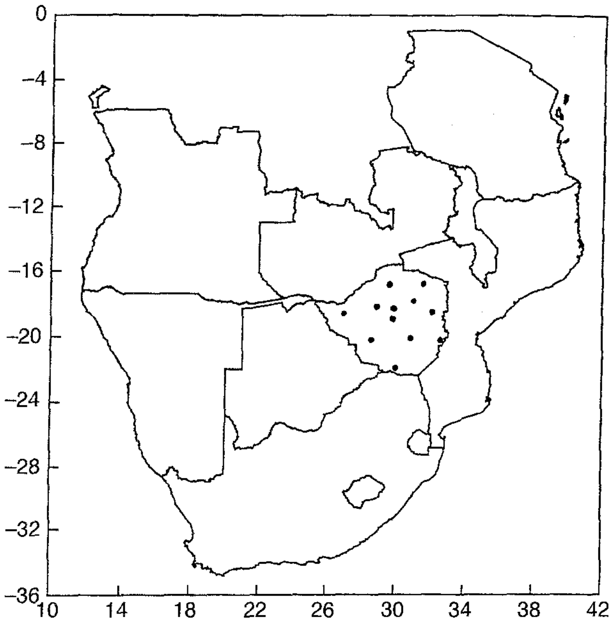

Fig. 1. Geographical location of Zimbabwe and the stations used in the study

that will aid understanding of the causes of climate changes. This further justifies the study of surface temperature variations over Zimbabwe for different seasons. Figure 1 shows the geographical location of Zimbabwe and the spatial distribution of the stations used in the study.

2. Data and Methods

Reliable temperature data sets in southern Africa are sparse. For Zimbabwe, the longest temperature records available date as far back as 1897 for two stations; Harare and Bulawayo. For the whole country, reliable temperature records date back to July 1923 when grass thatched thermometer shelters were replaced by the conventional Stevenson's screen. The effect of the thatched shelter on the measured temperature is not known. To avoid mixing records measured under two different instrument shelters, monthly mean temperature data for the period 1933 to 1993 from the 12 stations listed in Table 1 were used to determine the national mean temperature. All the 12 stations had complete temperature and rainfall records over the period 1933 to 1993. Normalized point rainfall data from 1900 to 1993 was averaged to give a national mean which was used to investigate the longterm rainfall pattern. These datasets were from the Zimbabwe Meteorological Department's archives and had been subjected to the range quality check technique as well as other World Meteorological Organisation (WMO) recommended techniques before archiving.

To minimise the effects due to, inter alia, changes in observers, instrument deterioration, instrument calibration inconsistencies and site modifications, national average temperatures derived from the entire period over which records are available were used and only those sites that have not undergone major changes in instrument exposure were selected. Jones and Kelly (1983) used a similar approach to avoid or reduce effects due to station height, aspect and observing times in determining average gridded temperature

Table 1. *Stations Used in the Study*

Station	Latitude	Longitude	Altitude (m)	Period for temperature	Period for rainfall
Beitbridge	22°13′S	30°00′E	457	1933–1993	1901–1993
Bulawayo	20°09′S	28°37′E	1343	1897–1993	1897–1993
Chipinge	20°12′S	32°37′E	1131	1933–1993	1900–1993
Gokwe	18°13′S	28°56′E	1282	1933–1993	1900–1993
Harare	17°50′S	31°01′E	1471	1897–1993	1892–1993
Hwange	18°38′S	27°00′E	1079	1933–1993	1928–1993
Kadoma	18°19′S	29°53′E	1149	1931–1993	1925–1993
Karoi	16°50′S	29°37′E	1343	1933–1993	1908–1993
Kwekwe	18°56′S	29°50′E	1213	1933–1993	1901–1993
Masvingo	20°04′S	30°52′E	1094	1908–1993	1898–1993
Mt. Darwin	16°47′S	31°35′E	965	1933–1993	1900–1993
Rusape	18°32′S	32°08′E	1430	1933–1993	1918–1993

data. Harare and Bulawayo temperature records from 1897 to 1993 were used to investigate the effects of urbanization and industrialization on temperature patterns. Mean monthly data have been averaged to yield averages for the seasons December to February (DJF), January to March (JFM for rainfall only), March to May (MAM), June to August (JJA), September to November (SON), October to April (O–A) and May to September (M–S). To avoid splitting the rainfall season, the meteorological calendar in southern Africa starts from July and ends in June of the following calendar year. The rainy season is from October to April of the following calendar year and the dry season spans the months May through September in the same calendar year.

Simple linear trend analysis was used to investigate the existence of trends in both the rainfall and temperature times series.

3. Results

3.1 *National Temperature and Rainfall Variation*

The national mean minimum and maximum surface temperature variation over Zimbabwe during the period 1933 to 1933 for the seasons December to February (DJF), March to May (MAM), June to August (JJA), September to November (SON), October to April (O–A) and January toDecember (annual) are shown in Figs. 2–7. The bars represent temperature departures from the longterm mean, the smoothed curve shows the 5 year running mean, whereas the straight line shows the trend in the series. Trend lines are plotted only for those time series where a statistically significant trend exists. The national rainfall anomaly time series for the seasons DJF, JFM and October to April are shown in Figs. 8–10. As in Figs. 2–7, the bars show the normalized national rainfall anomaly index (RAI), the smoothed curve is the 5 year running mean and the straight line represents the trend. The rainfall anomaly time series covers the period 1900 to 1992. Figures 2–7 can be used to identify warm phases and trends in the temperature series, whereas Figs. 8–10 can be used to identify periods of drought and also trends in the southern summer rains over Zimbabwe. Trends in either the temperature or rainfall time series are indicated by a negative or positive gradient in the straight line. The five year

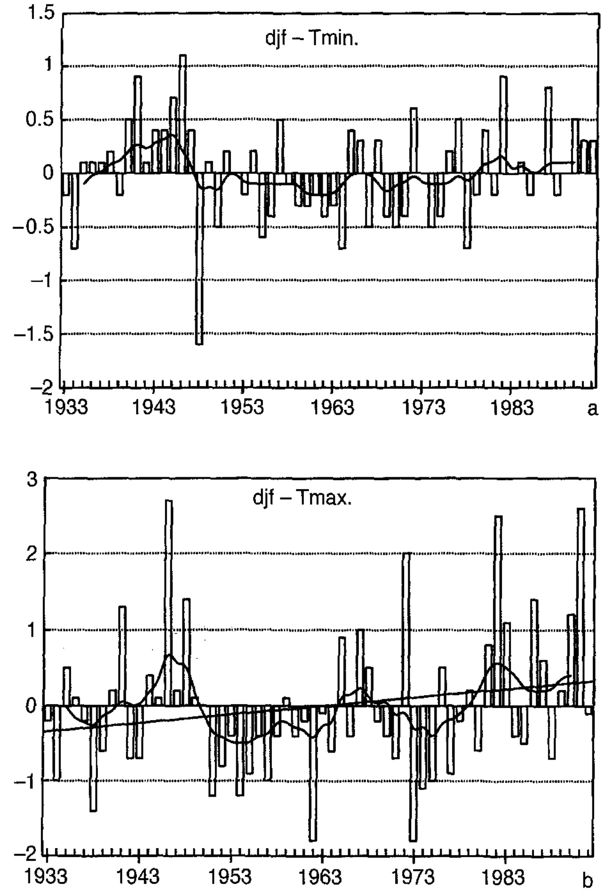

Fig. 2. National average minimum (a) and maximum (b) temperature anomaly variation (C) for the December- January-February (DJF) season over Zimbabwe during the period 1933 to 1993. Bars indicate the temperature departure from the 1933–1993 mean, the smoothed curve is the 5 year running mean and the straight line shows the trend

running mean has been plotted in Figs. 2–10 to facilitate better visualization of the trends and also to indicate the cyclical tendency inherent in the temperature and rainfall patterns over Zimbabwe.

There is no evidence of a warming trend in the minimum temperatures at national level for any of the seasons presented in Figs. 2–7. Minimum temperature trends during JJA, SON, October to April and January to December indicate a cooling trend, whereas the remainder of the seasons show no trend at all. Except for the SON season where no trend is evident for maximum temperatures at national level, the rest of the seasons in Figs. 2–7 show a warming trend, the biggest warming being during the JJA season (Fig. 4). The gradient of the linear trend is 0.8 °C from 1933 to 1993 for the JJA

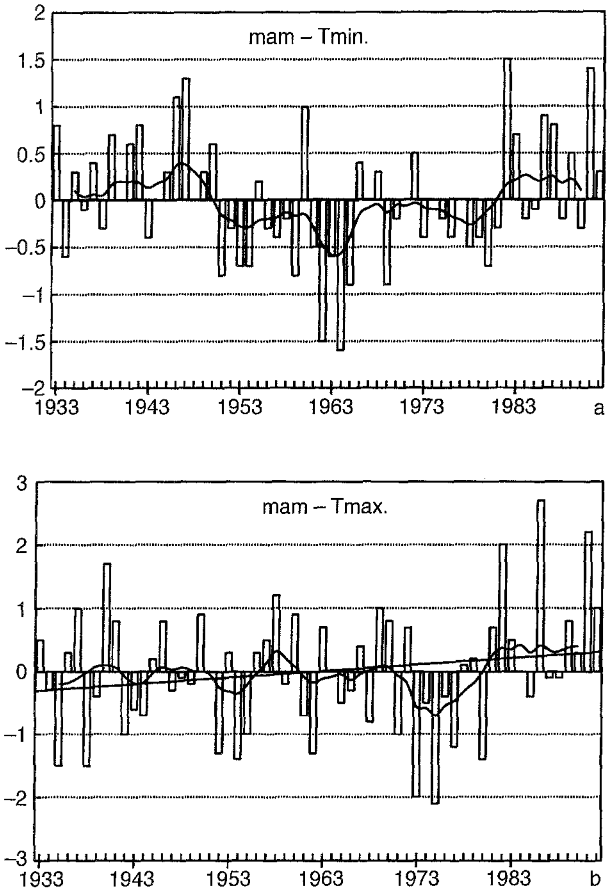

Fig. 3. As in Fig. 2 for the March-April-March (MAM) season

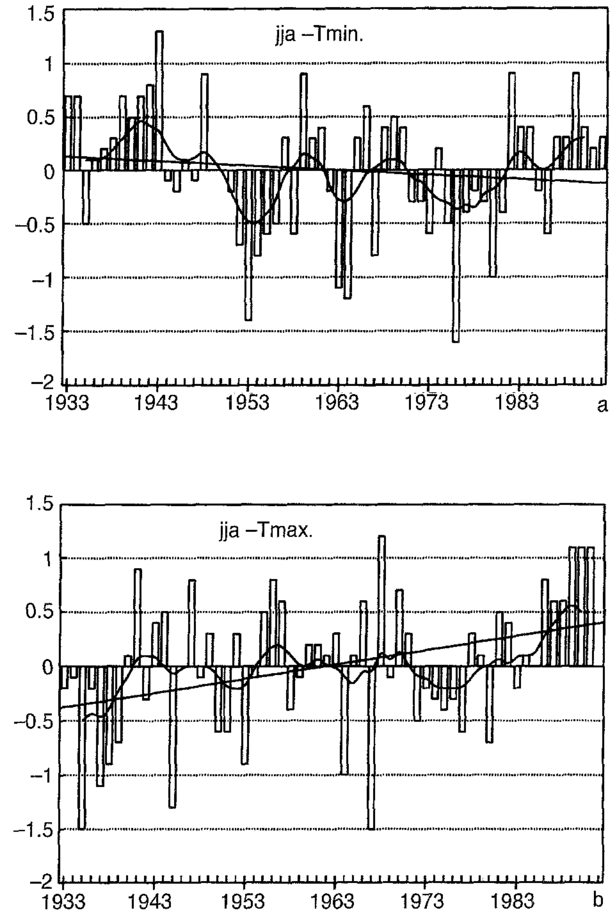

Fig. 4. As in Fig. 2 for the June-July-August (JJA) cool dry season

season and for the other seasons with a warming trend, the trends have ranged from +0.4 to +0.6 °C over the 1933 to 1993 period. The cooling trend in the mean night-time temperature ranged from −0.1 to −0.2 °C between 1933 and 1993. Despite the cooling trend in the night-time temperatures, both the minimum and maximum temperature time series show the existence of two distinct anomalously warm phases, the first being from mid-1930s to late 1940s and the second major warm phase being from about 1980 onwards (Figs. 6–7). The warm phase during the mid-1930s to late 1940s is less consistent in the maximum than in the minimum temperature time series. A long cool phase separates the two warm phases. The two anomalously warm phases were warmer by about +0.3 to +0.5 °C, whereas the cool phase was cooler by about −0.2 to −0.3 °C.

Figures 8–10 show the national average rainfall pattern in Zimbabwe from 1900 to 1993, for the seasons DJF, JFM and October to April respectively. All the three seasons show a downward trend in rainfall from 1900 to 1993. From 1900 to 1993, the Zimbabwe national average rainfall has declined by about 10% during the October to April rainy season. This magnitude of change represents about 0.4 standard deviations. During the DJF and JFM seasons the rainfall has declined by 10 and 16% respectively. Hulme (1992) reports a similar magnitude of percentage change in the austral summer (DJF) daily rainfall rates over parts of Zimbabwe between 1931–1960 and 1961–1990. Figure 11a,b show a scatterplot of national average standardized rainfall departure from normal versus minimum and maximum temperature anomalies from 1933 to 1993. A strong negative association exists between maximum temperature anomalies and rainfall anomalies (Fig. 11b) during the rainy season over Zimbabwe (correlation coefficient = −0.822, $n = 60$). For

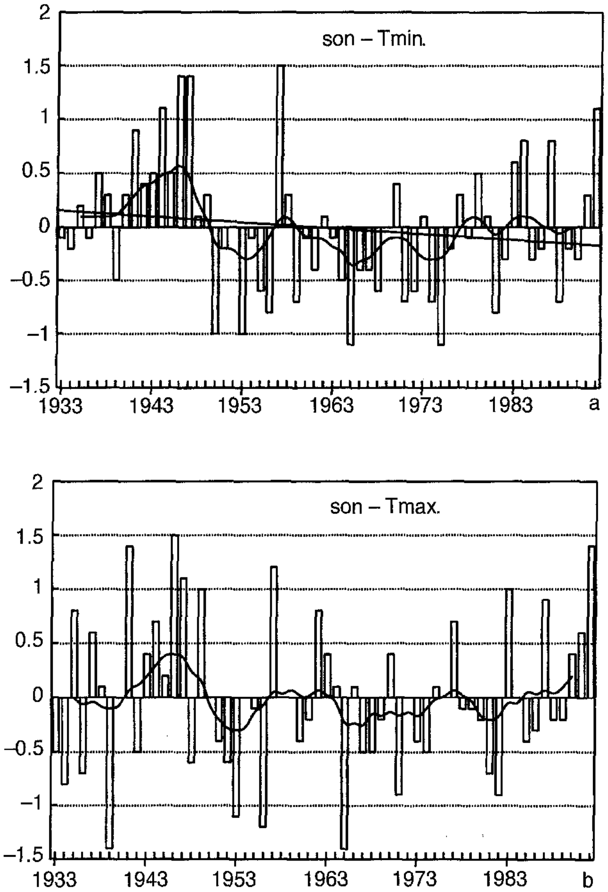

Fig. 5. As in Fig. 2 for the September-October-November (SON) season

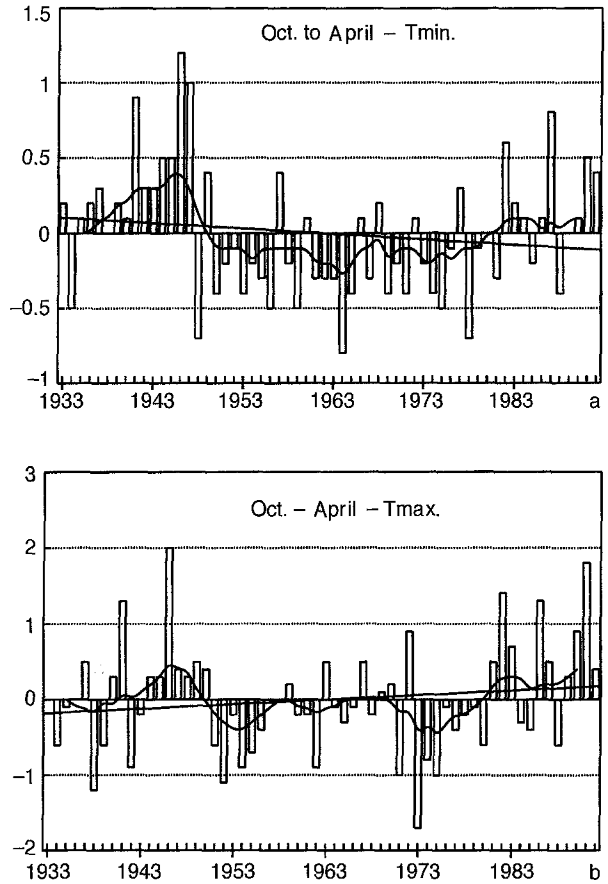

Fig. 6. As in Fig. 2 for the October to April rainy season

minimum temperature anomalies, no distinct association exists (Fig. 11a). This finding tends to support the hypothesis that the warming in maximum temperature observed over Zimbabwe from 1933 to 1993 could be related to less cloud coverage and consequently increased insolation. However, the existence of a warming trend in the JJA season (Fig. 4) which is a dry season, implies that reduced cloudiness alone cannot fully explain the observed upward trend in daytime temperatures.

3.2 Surface Temperature Variation over Harare

Two stations with the longest temperature record Harare and Bulawayo were analysed in more detail. Harare and Bulawayo were chosen because they are the largest cities in Zimbabwe and are the two main centres of industrialisation and urbanisation in the country with a population of more than 2 million people between them. The effects of urbanisation and resultant increase in atmospheric pollution should be more evident when temperature records from major cities are analyzed. Because the results for the two stations were very identical, only Harare is presented here. The mean minimum and maximum temperature anomalies for Harare for the seasons DJF, MAM, JJA, SON, October to April and January to December are shown in Figs. 12–17. As in Figs. 2–7 the bars show the temperature deviation from the longterm mean, the smoothed curve is the 5 year running mean and the straight line shows the trend in the times series for the seasons where a significant trend exists.

There is evidence of warming over Harare both in the minimum and maximum temperatures for all seasons in Figs. 12–17. The trend in minimum temperature over Harare has been as much as +1.2°C during the JJA season, and +0.8 to +1.0 °C in the other seasons from 1897 to 1993.

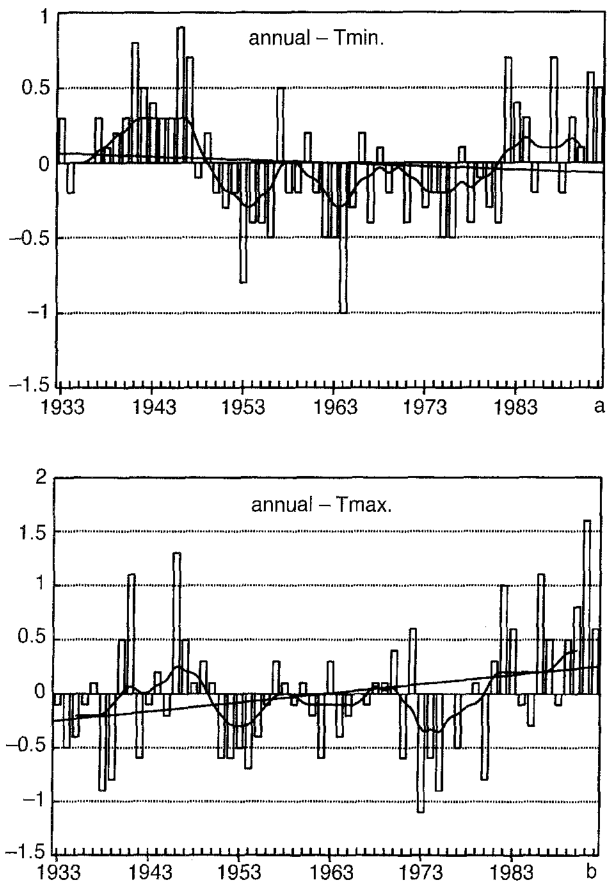

Fig. 7. As in Fig. 2 for the calendar year (January to December)

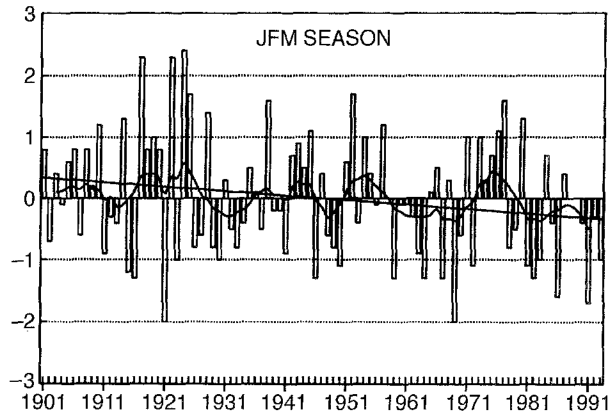

Fig. 9. As in Fig. 8. For the January-February-March (JFM) season

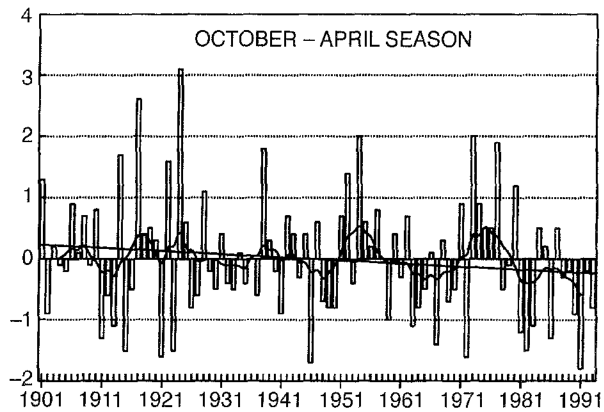

Fig. 10. As in Fig. 8 for the October to April rainy season

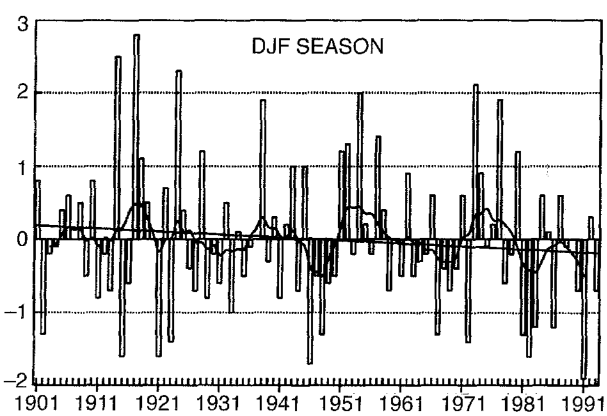

Fig. 8. The variation in normalized rainfall anomalies during the DJF season over Zimbabwe for the period 1900 to 1993. Bars indicate the normalized rainfall anomaly for the season, the smoothed curve is the five year running mean and the straight line shows the trend

During the same period, the trend in maximum temperature has been about +0.1 to +0.8 °C. The largest trends in daytime temperatures were during the MAM and JJA season with +0.8 and +0.7 °C increments, respectively. In a similar study for Rome, Colacino and Rovelli (1983), as cited in Kumar and Hingane (1988), found that the increasing trend in urban temperatures was more conspicuous in the minimum temperatures rather than in the maximum temperatures, a conclusion similar to the findings in this study. Two major warm phases are evident in the maximum temperature time series for all seasons (Figs. 12–17). The first major warm phase was during the period 1910 to about 1924, whereas the second major warm phase is from about 1980 onwards. The first warm phase occurred in the maximum temperature time series only, whereas a significant cool period occurred in the minimum

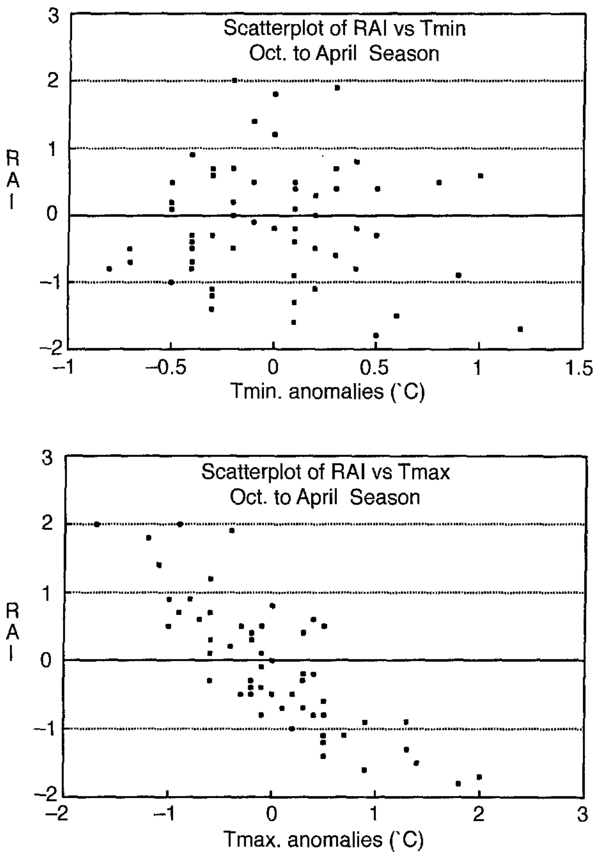

Fig. 11. Scatterplot of the October to April rainy season national average Rainfall Anomaly Indices (RAI) versus minimum (a) and maximum (b) temperature anomalies over Zimbabwe. A strong negative linear association exists between rainfall anomalies and daytime (maximum) temperature anomalies

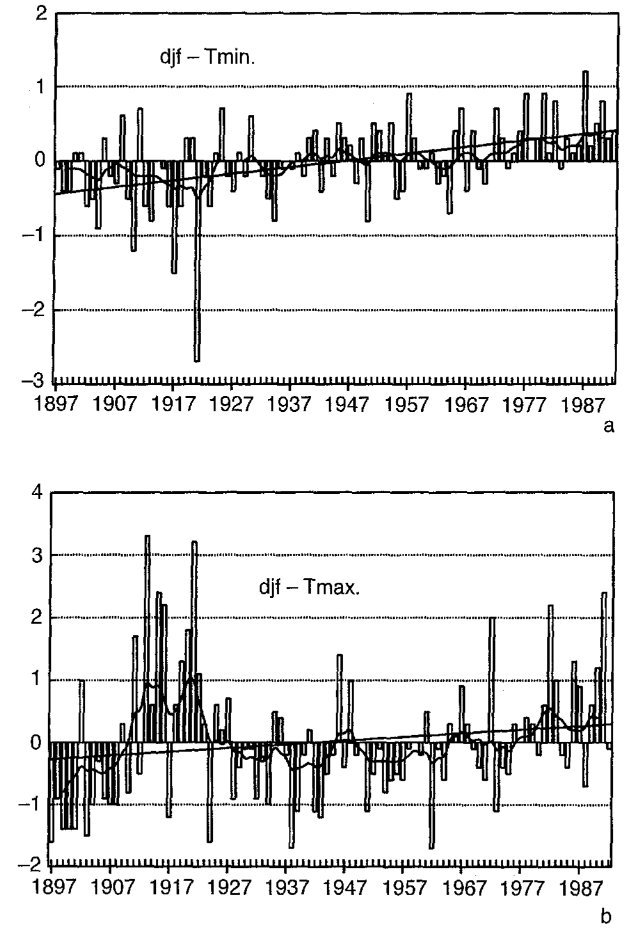

Fig. 12. Minimum (a) and maximum (b) temperature anomaly (°C) variation for the December-January-February (DJF) season over Harare during the period 1897 to 1993. Bars indicate the temperature departure from the 1897–1993 mean, the smoothed curve is the 5 year running mean and the straight line shows the trend

temperature series. However, the warming phase of the 1980s onwards exists in both the minimum and maximum temperature time series.

For Harare, the 1930 to late 1940 warm phase depicted in the national average does not manifest itself in the maximum temperatures, but does exist albeit weakly in the minimum temperature series during the MAM, JJA, SON, October to April and the January to December seasons. The warming trend over Harare has been greatest at night, which is consistent with findings for major cities from elsewhere (Kellog, 1977; Angell and Korshover, 1978; Kumar and Hingane, 1988). The warming trend could be largely attributed to the urban heat island effect.

4. Discussion and Conclusions

The results presented here tend to agree with results from earlier studies of temperature and rainfall trends over Zimbabwe. Hulme (1992) found that summer rainfall over parts of Zimbabwe declined by about 10% between 1931 and 1990, and Kelly and Hulme (1992) found two major warm phases in the temperature series for Harare. This study shows a warming trend in both the maximum and minimum temperatures over Harare since record keeping begun, with two well pronounced anomalously warm phases. At national level, maximum temperatures show a warming trend during all seasons studied, whereas minimum temperatures

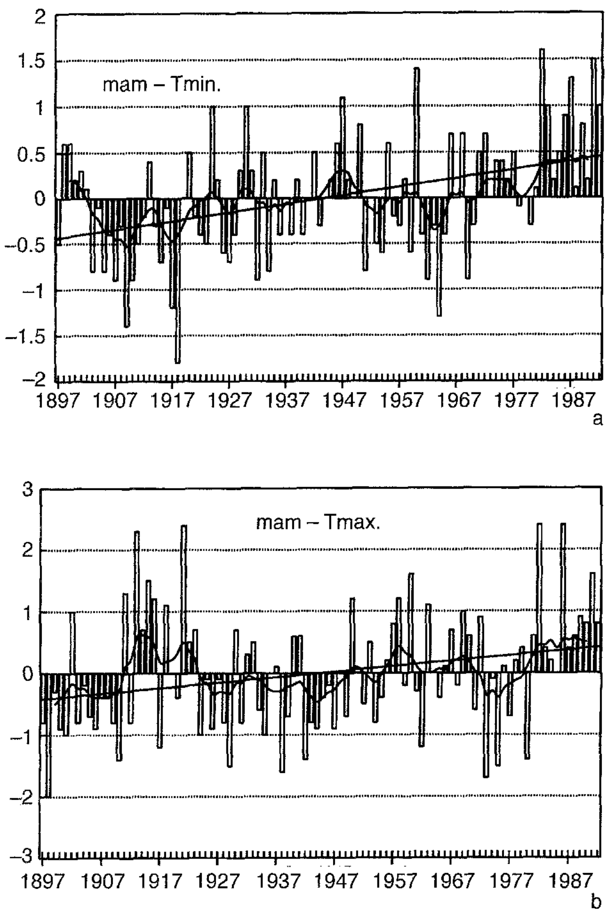

Fig. 13. As in Fig. 12 for the March-April-May (MAM) season

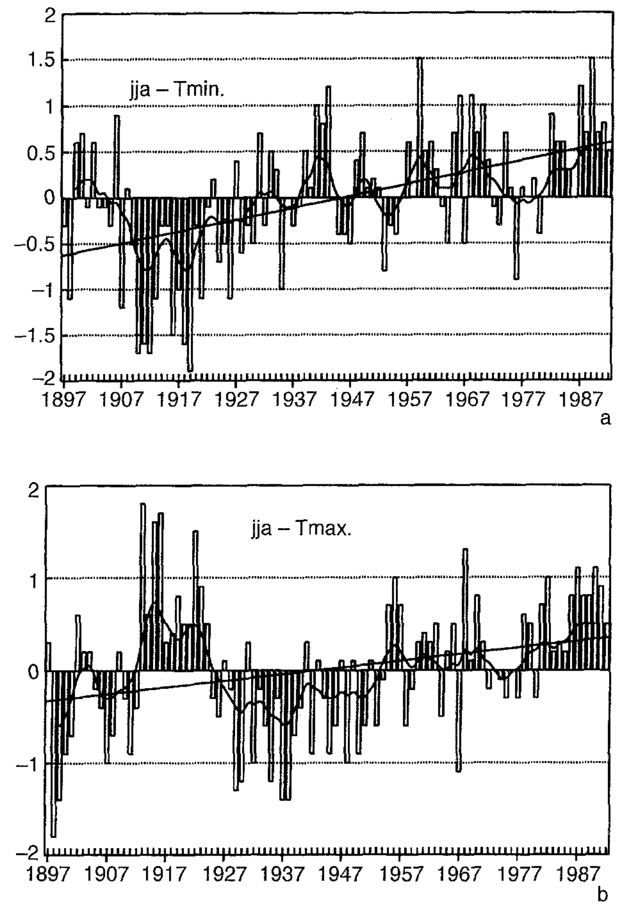

Fig. 14. As in Fig. 12 for the June-July-August (JJA) cool dry season

either show no trend or have been on a cooling trend.

What explanations can be offered for the temperature and rainfall trends identified in this study. Hulme (1992) proposed three possible broad categories to explain rainfall changes observed over Africa between 1931–1960 and 1961–1990. The three categories are mainly: land cover changes, changes in the global ocean circulation and associated sea-surface temperature (SST) patterns and the changing composition of the atmosphere. Comprehensive studies on the association between rainfall anomalies over southern Africa, the El Niño/Southern Oscillation (ENSO) phenomenon and sea surface temperature anomalies in the central equatorial- and southwest Indian ocean have been carried out by Lindesay (1988), Mason (1992), Rocha (1992), Mason and Lindesay (1993) and Jury (1994). A significant number of severe droughts over much of southern Africa tend to be associated with ENSO events. The association is strongest over the southeastern section of southern Africa (Ropelewski and Halpert 1987; Lindesay, 1988) and has led to the development of operational seasonal rainfall forecasting schemes for those areas (Matarira and Unganai, 1994). Over the last 60 years, the ENSO remained in a generally low phase for 3 consecutive seasons or more, during the periods 1939–1941, 1981–1988 and 1990–1994. During all these periods, Zimbabwe was generally less cloudy as indicated by the poor rainfall pattern and the major warming phases also occurred around these periods. Changes in the pattern of global atmospheric circulation and SST anomalies can therefore offer a reasonable explanation for the changes in rainfall and the major warm phases observed over Zimbabwe. It has also been hypothesised that

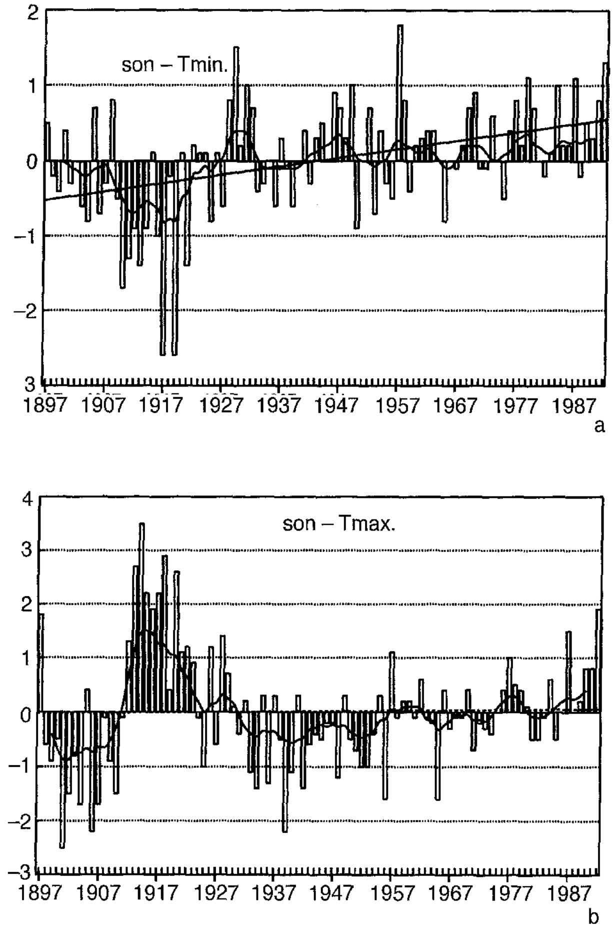

Fig. 15. As in Fig. 12 for the September-October-November (SON) season

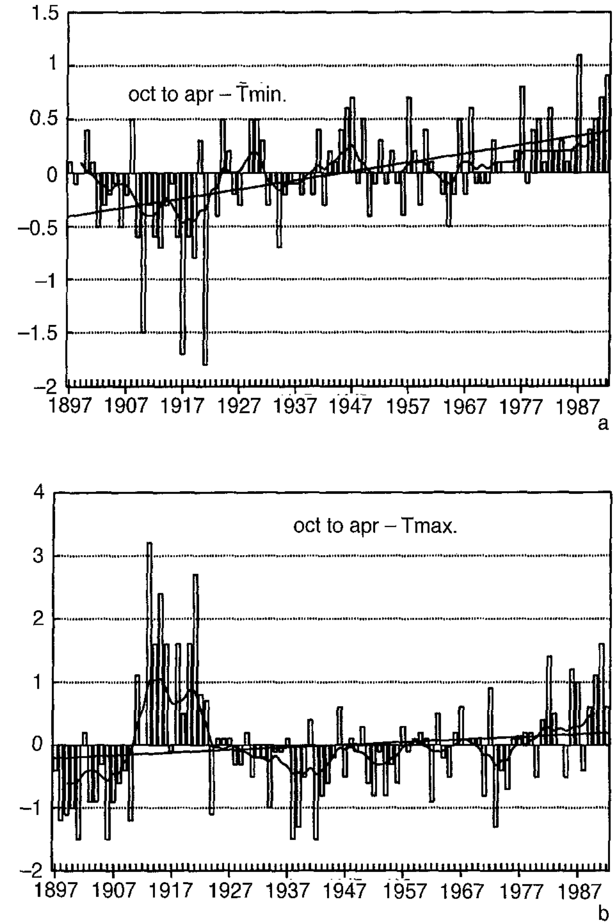

Fig. 16. As in Fig. 12 for the October to April rainy season

changes to the sea ice extent temperatures around the Antarctic can cause changes to the mean Southern Hemisphere atmospheric circulation and to the ocean currents, both of which strongly influence the climate of the other Southern hemisphere continents (Budd, 1991).

Another possible explanation of the observed temperature trends over Zimbabwe concerns the changing composition of the global atmosphere. Evidence of global warming induced by greenhouse gases remains inconclusive. Wigley and Jones (1981) have examined the question of detecting a carbon dioxide induced climate change and found that the signals to be expected as a result of CO_2 are similar to climate variations which occurred earlier in the century which could not be attributed to CO_2. The national average minimum temperature for Zimbabwe show a downward trend, which is the opposite of what would be expected under greenhouse induced warming. The warming trend in national mean maximum temperature suggest a case for reduced cloudiness. Trends in the temperature series for Harare however, suggest warming enhanced by local changes in atmospheric composition. The upward trend in the night-time temperatures over Harare strongly suggests increased opacity of the atmosphere to longwave radiation. Continuous addition of gaseous and particulate pollutants and waste heat in the urban and industrial atmospheric environment are strong candidates in explaining the observed rise in the night-time temperatures over Harare. However, it is difficult to quantify the warming that can be attributed to each possible causal factor. According to Kumar and Hingane (1988), due to the high energy consumption and friction in cities, large amounts of heat are stored in the walls of buildings, streets,

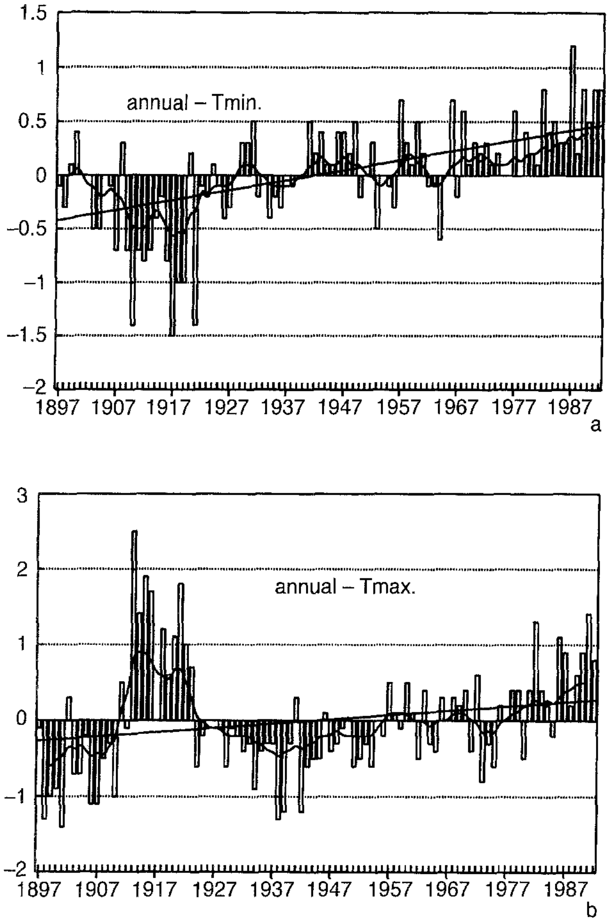

Fig. 17. As in Fig. 12 for the calendar year (January to December)

etc., which gets released during the night, thereby making nights warmer. This finding shows that, if a large number of highly industrialised centres are included in local scale temperature studies, the urban effect might be so strong as to influence the average trend. In an assessment of urbanization effects in time series of surface air temperature over land, Jones et al. (1990) concluded that for hemispheric data sets, the influence of urbanization on the warming observed on a century time scale is quite small.

Deforestation is also a possible factor in trying to explain the observed temperature trends in Zimbabwe. Wild-fires, overgrazing and fuelwood collection have contributed significantly to deforestation in Zimbabwe over the years. About 80% of Zimbabwe's population of 10.5 million people depend on natural forests for fuelwood, heating and construction materials. Zimbabwe is estimated to be undergoing deforestation at a rate of about 900 km^2 per year (SARDC, 1994). Frequent droughts have significantly reduced the ability of most of the vegetation to regenerate. Once bare soil is exposed to direct radiation, there are marked changes in the heat balance, the soil becoming much hotter during the day and colder at night. The upward trend in Zimbabwe's day-time temperatures and downward trend in night-time temperatures appear to be partly explained by this deforestation factor.

Global circulation model (GCM) experiments suggest that if greenhouse gas emissions continue at current rates, the earth's surface temperature will rise by 2 to 4.5 °C within the next 80 to 100 years (Pittock and Salinger, 1991). As a result of the warmer oceans and a warmer land, the rainfall in much of the tropical countries of the Southern Hemisphere is projected to rise by 10 to 15% as moisture flux from the oceans increase and winds strengthen (Mobbed, 1989; Tucker, 1991; Pearman, 1991). The evidence for the increase in the global concentration of the greenhouse gases is concrete and irrefutable and there can be no doubt that an increase in the infrared (longwave radiation) opacity of the atmosphere, without any change in the incoming solar radiation, must lead to a net warming of the earth's surface (Bolin et al., 1986; Pearman, 1991). However, the pattern of the temperature and rainfall trends observed over Zimbabwe between 1933 and 1993 does not seem to bear much resemblance to the patterns from GCM greenhouse experiments. The night-time temperatures, which are expected to show the greenhouse effect signal most, have been cooling on a national average, whereas the day-time temperatures have been rising, most probably due to reduced cloudiness and the effect of land surface changes. The difference in the observed temperature and rainfall pattern to the GCM generated scenarios is not surprising. Most of the GCMs have not adequately represented the Southern Hemisphere climate (Tucker, 1991). The role of oceans on the climate has not been modelled and obviously not all known human and natural factors known to affect climate have been included in the models (Pearman, 1991; Tucker, 1991; Hulme, 1992).

The results presented here do not suggest the existence of enhanced greenhouse warming over Zimbabwe. The upward trend in the annual average maximum temperatures between 1933 and 1993 appears to be linked to reduced cloudiness particularly in the last fifteen years and possibly land surface changes that have been taking place mainly due to deforestation. However, the results for Harare clearly indicate the changes in the local atmospheric environment brought about by industrialisation and urbanisation, leading to an increase in night time temperatures.

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