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Aspects of monitoring local/regional climate change in a tropical region

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RESUMEN

La evaluación de la magnitud del cambio climático a escala regional en los trópicos, es una tarea necesaria en vista de que los modelos de circulación general no predicen cambios a dicha escala.

En el presente trabajo se examina el efecto de la urbanización en las series de temperatura en centros urbanos del centro de México durante el período 1921-80. Los resultados señalan que el calentamiento del aire urbano por el efecto de la isla de calor es evidente en grandes ciudades de rápido crecimiento poblacional como León y la Cd. de México. En aquellas poblaciones con menos de 50,000 habitantes, los cambios de temperatura semejan a los reportados a escala global, es decir, calentamiento antes de los años cuarentas y enfriamiento después de los sesentas/setentas. La escasa información disponible para la década de los ochenta no permite constatar el calentamiento observado en otras latitudes.

ABSTRACT

It has been claimed that air temperature (averaged over all latitudes) has increased by about 0.5°C during the last 100 years. Since models are not able to simulate regional variations, it is of interest to explore temperature trends, especially in tropical areas where the climate change signal is likely to be smaller than at higher latitudes and therefore, more difficult to be distinguished from natural variability. Using mean annual minimum temperatures, an attempt is made to examine climatic change in a tropical region over the past half century. The following are the main findings from this analysis. Urban warming is evident in stations located in tropical cities with rapidly growing populations like Leon and Mexico City. Temperature records from smaller cities (less than 50,000 inh.) tend to duplicate the global temperature changes (warming before the 1940's and cooling in the 1960-1970's). For rural stations, however, no appreciable warming trend is evident in the 1980's.

1. Introduction

Studies of the greenhouse effect agree that resulting changes will differ among regions. While temperature changes (by year 2040) in the high/mid-latitudes in the Northern Hemisphere could be two times greater than globally averaged annual values, those in the tropics will probably be somewhat smaller (0.5 - 6°C) (WCP, 1988).

Results from current general circulation models (GCM) do not allow any detail at the regional scale. Assessments of the magnitude of climate change are necessary at this scale. A concensus prevails that the potential bias of the urban effect on global data sets has not been definitly assessed.

Despite careful use of basic station data for assessment of hemispheric temperature trend in the recent past (Jones *et al.*, 1986; Jones and Wigley, 1986), other researchers have argued that a portion of the 0.5 °C warming found over a century may be related to urbanization (Wood, 1988; Kukla *et al.*, 1986).

Karl *et al.* (1988) have shown that an urbanization influence could be detected in many records, with urban bias being a non-linear function of population. In comparing the gridded and the historical records for the contiguous U. S., these authors found an urban warming of approximately 0.1°C over the period 1901-1984. In assessing the urban bias in their Northern Hemisphere temperature data, Jones *et al.* (1989) have concluded that this effect should not be larger than 0.1°C over the 20th century. They argue that this bias is about one fourth of the global land-based temperature increase of 0.4°C over the same period of time. However, Hansen and Lebedeff (1987) in assessing global trends had found an urban bias effect over the U. S. between 0.3–0.4°C over the 20th century, which is larger than the overall trend in the U. S. They point out that the U. S. is the only large area of the globe where the magnitude of the bias has been thoroughly studied.

Even though some authors (Jones *et al.*, 1986) suggest that it is unlikely that the remaining unsampled areas in developing countries in the tropics could significantly increase the overall urban bias above 0.05°C during the 20th century, it would be advisable that detailed studies of the impact of urbanization on the long-term temperature trends be undertaken, especially in developing countries where large-scale urbanization has recently occurred.

In this paper an attempt is made to examine aspects of the magnitude of the overall urban bias for cities of different sizes located in a tropical wet/dry climate.

2. The data

Monthly/annual temperature records from the National Meteorological Service were used for stations located in inland valleys (latitude: 19-24 N.) in tropical Mexico (Fig. 1). Few long-term temperature records are available for Mexico. Most of the long-term records begin in the 1920's. There were, to our knowledge, no station moves or changes of time of observation of the stations used.

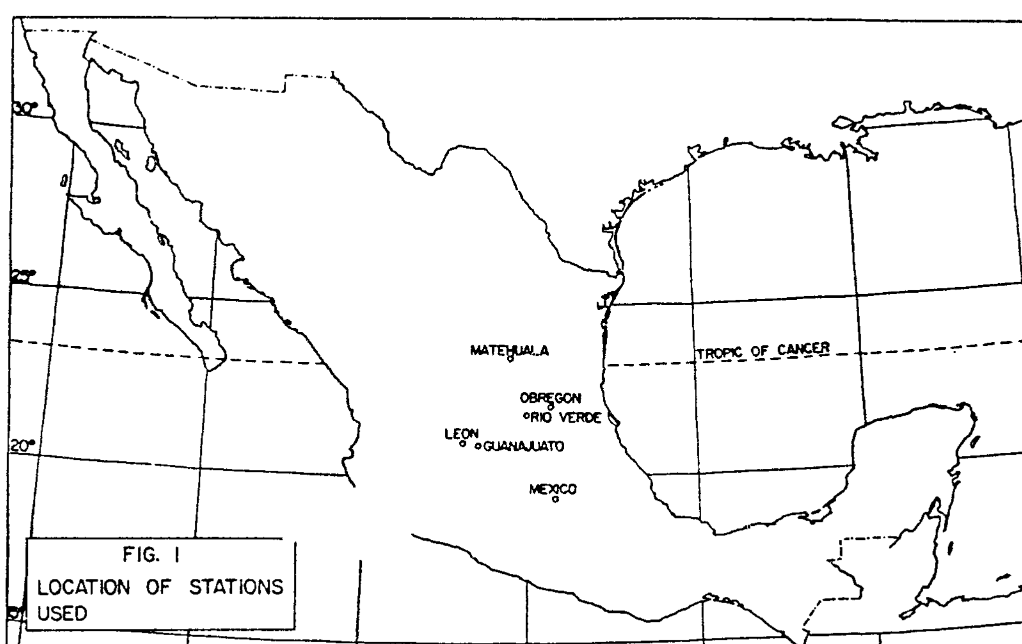

FIG. I
LOCATION OF STATIONS USED

3. The urban effect on air temperature

The urban heat island is a well documented physical phenomenon in mid-latitude cities (Landsberg, 1981; Oke, 1982), as well as in some large tropical urban areas (Sani, 1986; Padmanabhamurty, 1986; Jáuregui, 1986). The instantaneous and mean (monthly) urban/rural thermal contrasts have been quantified in different regions of the globe, but, as noted by Karl *et al.* (1988) these results are difficult to link to seasonal and annual mean temperatures. The urban effect on temperature has been found to be a predominantly night-time phenomenon, especially pronounced at sunrise in the tropics. Since thermal contrasts are minimal (or even reversed) at noon the overall result is a reduction of the temperature range (Karl *et al.*, 1988). The urban/rural temperature contrasts occur during calm clear nights associated with intense radiational cooling. In the tropics and near the coast, the prevailingly high humidity levels (and land/sea breezes) reduce the possibility of formation of intense heat islands. Such is the case of large metropolis like Rio de Janeiro (Figueiredo, 1986) and Bombay (Padmanabhamurty, 1986). Large urban/rural temperature contrasts are more likely to be found in those large cities located in interior valleys like Delhi (Padmanabhamurty, 1986) or in elevated basins like Mexico City. Even in these cases, the urban effect on temperature is well developed only during the dry season (Jáuregui, 1986).

4. Results

ESTIMATION OF MAXIMUM HOURLY/MONTHLY/ANNUAL URBAN BIAS IN A TROPICAL REGION

A) Hourly

Table 1 shows the mean urban/airport temperature contrasts on an hourly basis for Mexico City for a month (January) when urban warming is marked. The mean instantaneous magnitude of the urban effect amounts to 0.76°C.

Table 1. Mean hourly variation of temperature difference of urban/airport tempearutre difference (°C) for January 1979 in Mexico city (Adapted from Jáuregui, 1986)

hr.	2	4	6	8	10	12	14	16	18	20	22	24	Month
delta	2.0	2.8	2.7	0.4	0.7	-1.4	-1.2	-0.5	0.6	0.6	1.2	1.3	0.76

B) Month/year

Table 2 shows the variation of urban/suburban temperature contrast for the year 1979 for two large tropical cities, Mexico City (pop. 14 million) and Guadalajara (pop. 2.4 million), both at latitude 20°N. The urban heat island is more marked (2 to 3°C) during the dry season, when the suburban site is under an intense surface inversion at sunrise due to unresticted nocturnal cooling under clear skies at both cities in central Mexico. Abundant insolation, followed by turbulent mixing brings about a larger morning heating rate in the rural surroundings, resulting in a marked cool island at midday. The net effect over the year is 0.5 °C for Mexico City and 0.43 °C for Guadalajara.

Table 2. Average T_{max}, T_{min} monthly variation of urban/airport temperature difference (°C), delta t = t at Tacubaya minus t at Airport in Mexico City (a) and Guadalajara (b) delta t = t at Rayon Station minus t at (suburban) Experiencia Station (see Jáuregui *et al.*, 1992).

	J	F	M	A	M	J	J	A	S	O	N	D	YR
a)													
T_{max}	-0.8	-0.6	-1.2	-0.2	-0.8	0.2	0.1	0.2	-0.3	-0.7	-0.3	-0.9	
T_{min}	3.8	3.0	3.1	2.2	2.1	0.1	-0.2	-0.7	-0.2	2.5	2.2	2.7	
avg.	1.5	1.2	0.0	1.0	0.6	0.5	-0.1	-0.3	-0.3	0.9	0.9	0.9	0.5
b)													
T_{max}	-1.4	-1.4	-1.5	-2.2	-1.2	-0.9	-0.7	-0.9	-1.4	-12.	-1.1	-1.5	
T_{min}	3.6	3.8	3.2	3.1	1.6	1.5	0.2	0.9	1.1	1.9	2.9	2.1	
avg.	1.1	1.2	0.8	0.5	0.2	0.3	-0.3	0.0	-0.2	0.4	0.9	0.3	0.4

LONG-TERM TEMPERATURE RECORDS FOR THE ESTIMATION OF OVERALL URBAN WARMING: LARGE CITIES

Long-term surface temperature records are of particular importance in the detection of climatic impact due to increasing greenhouse gases. A serious problem is to separate the influence of the urban heat island from the regional climate signal. In this section we examine urban/rural temperature series to look for overall urban warming trends in tropical Mexico.

A) Mean annual temperature

There is an overall warming trend in the mean annual temperature for large urban agglomerations in Mexico. This is the case for Mexico City, where the temperature increase has been of the order of 1.5°C over the period 1901-1989 (Fig. 2). As also shown in Table 3, the rate of increase has been uneven over the period. It may be mainly the result of the urbanization

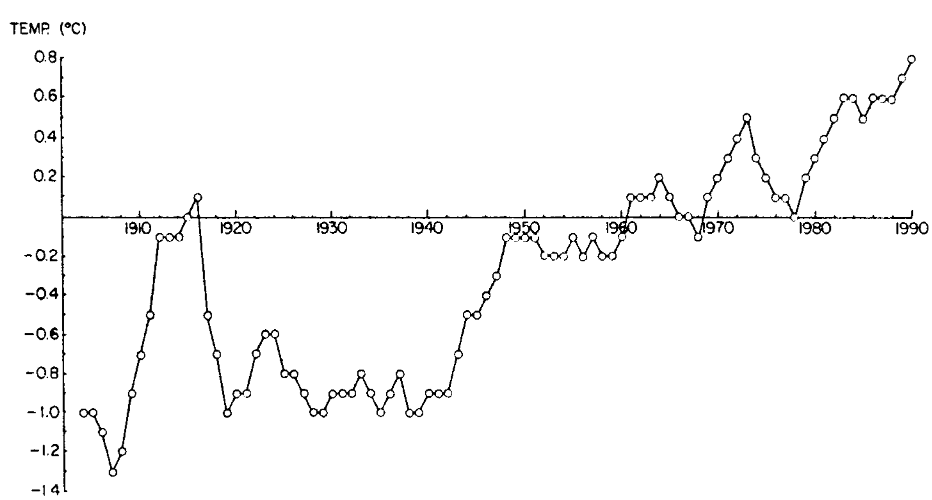

FIG. 2 FIVE-YEAR ANNUAL RUNNING MEAN TEMPERATURE FOR TACUBAYA OBSERVATORY IN MEXICO CITY, PERIOD 1900-1990. REFERENCE PERIOD 1951-1970.

Table 3. Decadal mean annual temperature variation for Mexico City (lat.: 19.9°C)

Decade	Mean annual Temp.(°C)	Delta t/decade
1901-1910	14.7	-
1911-1920	15.7	0.4
1921-1930	14.9	-0.2
1931-1940	14.7	-0.2
1941-1950	15.3	0.5
1951-1960	15.5	0.2
1961-1970	15.8	0.3
1971-1980	15.9	0.1
1981-1989	16.1	0.2
		0.016°C/yr

process, which evidently has not been uniform over the period (the Observatory located then in a semi rural site in the town of Tacubaya about 6 km West of Mexico City, is now part of the city). The curve in Figure 2 resembles in general the global temperature pattern observed for the Northern Hemisphere: the cooling during the 1920-1930 period reported by Jones *et al.* (1986), and the warming during the 1940's and since about 1975 mentioned in the literature (Houghton, 1991).

B) $T_{\max}$, $T_{\min}$:

Several studies have indicated that in the mid-latitudes, the minimum temperature is more strongly affected by urbanization than the maximum temperature (Landsberg, 1981; Hage, 1982). Other mid-latitude work on instantaneous urban/rural thermal contrasts suggest that urban effects during the daytime (T_{max}) are small or even give rise to a cool island development (Oke, 1982). In the previous section we have seen that, as would be expected, similar results are obtained for the tropical city, except perhaps that:

a. the heat island is less marked in the tropics,

b. the cool island seems to be more developed.

If these characteristics are representative for tropical urban areas, then:

a. the urbanization bias would be more difficult to be detected in annual temperature series because of the averaging process.

b. The urban effect would result in a reduction of the daily temperature range, since daytime urban effects would remain either small or perhaps even decrease with time by the absorption effect of pollutants.

The reduction in the daily temperature range has been noted by Karl *et al.* (1984) for mid-latitude series.

Figure 3 shows that, in agreement with the mid-latitude experience, while minimum temperatures have steadily increased, midday temperatures have remained appreciably unchanged

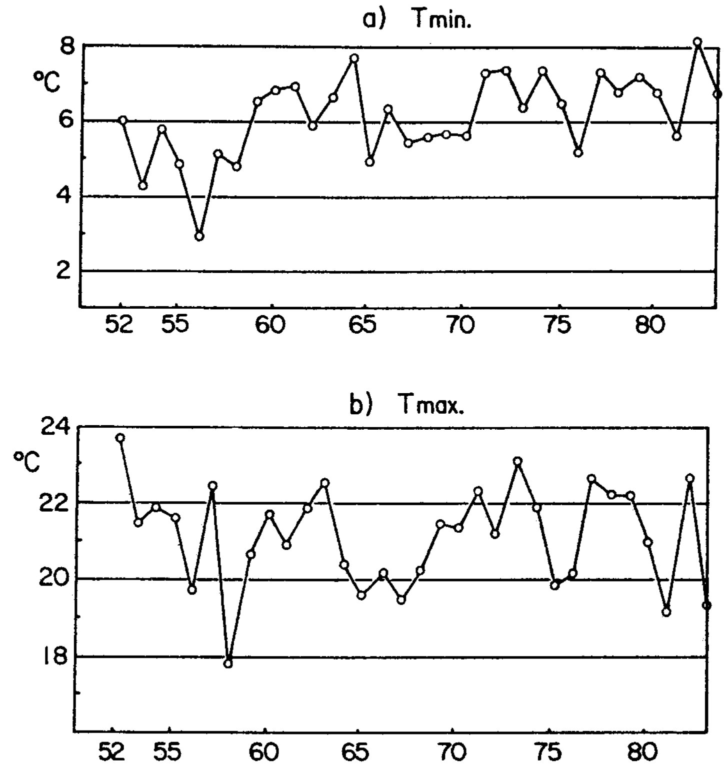

FIG. 3 MEAN ANNUAL MAX/MIN TEMPERATURE VARIATION FOR MEXICO CITY PERIOD 1952–82.

in Mexico City (Tacubaya Observatory) during the period 1952-1983 at a time when the city experienced phenomenal growth.

As Karl *et al.* (1986) have suggested, the decreasing temperature range that they have observed for the U. S. over recent decades is perhaps a signal consistent with increase of greenhouse gases, or that it may corroborate evidence for the impact of changes in tropospheric aerosol composition. From Table 4 it is readily apparent that the mean annual temperature range for Mexico City has steadily decreased, by about 0.12°C/yr during the 1952-83 period.

Table 4. **five year averages of the mean annual temperature range (°C) ($T_{max} - T_{min}$) for Mexico City (Tacubaya observatory)**

1952-1956	17.4
1957-1961	14.8
1962-1966	14.9
1963-1971	15.2
1972-1976	15.7
1977-1981	14.9
1982-1983	13.8

THE ANNUAL MINIMUM TEMPERATURE TREND IN MEDIUM/SMALL TOWNS IN MEXICO

Since urban bias is likely to be more evident at the time of the minimum temperature, we have chosen the annual minimum temperature series in order to track global climate changes in a tropical region on a time scale of decades. As mentioned by Wood (1990), decadal data can help determine if global warming is consistent with changes projected by major climate models.

We have selected stations located in small urban centers (less than 50,000 inh. in 1980) with low rates of population growth during the 1940-80 period (Fig. 4). For comparison, the medium size town of Leon, which has experienced a phenomenal growth, was also selected.

The rural stations show both the warming during the 1940's and the cooling during the 1960's/1970's largely evident at the global scale (Houghton, 1991) and for the rural U. S. data (Karl *et al.*, 1988). Unfortunately, recent temperature data for the stations shown in Figure 4 could not be obtained. The economic crisis that plagued the country during the last decade was the origin of a decline in the quality and continuity of climatological series in general. Therefore, it is difficult to determine with certainty the temperature trend that occurred in the region during the 1980's. The scant and discontinuous data available for the last decade for the same group of stations shows no evidence of a warming trend (Table 5).

These results are in agreement with temperature trends found by Cayan and Douglas (1984) for S. W. United States rural sites. The non-urban sites they examined were completely lacking a warming trend for minimum temperature.

	POP. (THOUS.) 1940	POP. (THOUS.) 1980	LAT. °N	ΔT(°C) 1921-80	ALTITUDE (m)
1. GUANAJUTO	23	49	21	0	2037
2. OBREGON	10	20	21	-1.3	1239
3. MATEHUALA	16	39	23.5	-1.9	1581
4. RIO VERDE	8	23	22	-0.1	991
5. LEON	130	724	21	2.0	1809

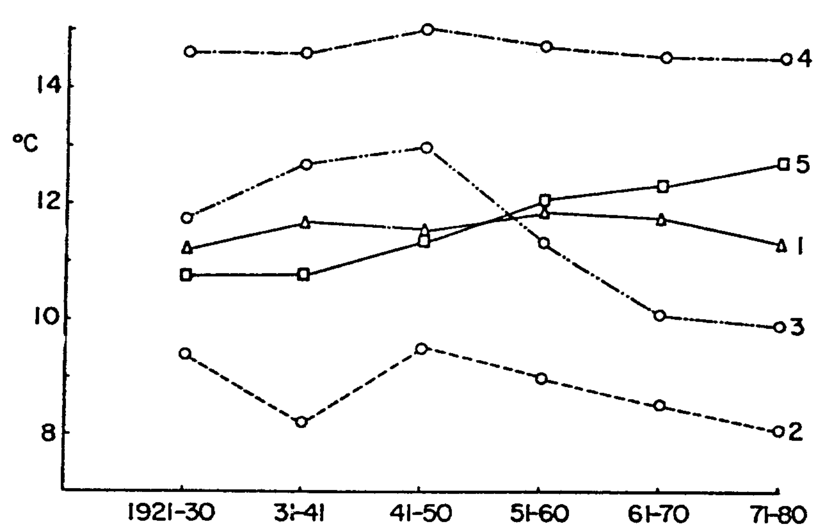

FIG. 4 TEN-YEAR MEAN ANNUAL MIN. TEMP. TREND AT SEVERAL STATIONS IN CENTRAL MEXICO 1921-80.

Table 5. Decadal variation of annual T_{min} in medium/small inland towns in tropical Mexico.

Decade	City Lat Pop. Approx Thous.	1 21 40	2 21 8	3 23 15	4 21.3 10	5 21 800
1921-1930		11.3	9.4	11.8	14.6	10.7
1931-1940		11.7	9.4	12.7	14.6	10.8
1941-1950		11.6	9.5	13.4	15.0	11.4
1951-1960		11.9	9.0	11.3	14.7	12.0
1961-1970		11.8	8.5	10.1	14.5	12.3
1971-1980		11.3	8.1	9.9	14.5	12.7
		11.2 (81-90)			14.5 (81-88)	

1. Guanajuato
2. Obregón
3. Matehuala
4. Río Verde
5. León

As expected, the curve for the medium sized city of Leon shows a continuous temperature increase of 0.033°C/yr over the 60-year period (Fig. 4).

5. Concluding remarks

Importance was given at the Second World Climate Conference to the early detection of the greenhouse effect. It is therefore essential that detailed studies of the impact of urbanization on long-term temperature series in tropical regions be undertaken soon. There is a need to develop rurally-based land-surface temperature trends in tropical countries.

Urban warming, as observed in mid-latitude cities, cannot be generalized to urban areas in the tropics. As Jones *et al.* (1989) suggest, more work is required to substantiate the generalizations that have been made in order to extrapolate results from the United States to tropical areas.

In conclusion, from the analysis of temperature data series examined in this paper, it may be stated that:

a. The urban warming bias is evident for medium/large (inland) cities located in a tropical region.

b. Even though the heat island phenomenon may be detected on a daily/monthly basis in small towns in the tropics, this effect is not always reflected in annual temperature trends.

c. Rural temperature data available for central Mexico seem to confirm the cooling trend of the 1960's and 1970's observed in mid-latitudes. However, the scant data examined for the 1980's do not confirm the recent warming documented for temperature climates.

In order to assess the magnitude of the urban bias in the long-term temperature records in the tropics, it is necessary to undertake comprehensive comparison for urban/rural stations where large-scale urbanization is occurring. This is a difficult task to accomplish, since long-term temperature records are rarely available in developing countries.

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