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Local wind and air pollution interaction in the Mexico basin

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RESUMEN

Los componentes del régimen termotopográfico del viento en la cuenca de la ciudad de México son examinados en su interacción con la circulación centrípeta, inducida por la isla de calor. El régimen de viento resultante es tal, que el flujo superficial convergente sobre la ciudad es predominante, principalmente durante la noche y temprano en la mañana.

La convergencia del flujo superficial de aire hacia la ciudad, a pesar de ser debilitado por turbulencia y vientos de valle, es aun evidente en los mapas de vientos resultantes observados durante el día, en una red de 9 estaciones. La posición del máximo de las isolíneas de SO_2 es casi coincidente con la posición que corresponde a la isla de calor.

Se concluye que, para el periodo examinado los vientos locales generados térmicamente en la Ciudad de México, tienden a restringir la ventilación del aire contaminado cerca de la superficie.

ABSTRACT

Components of the thermotopographic wind regime in the Mexico City basin are examined in their interaction with the heat island induced centripetal circulation. The resulting wind regime is such that convergent surface flow over the city is predominant mainly during the night and early morning.

The low-level convergence of air flow into the city, although weakened by turbulence and up-slope valley winds is still evident on daytime mean maps of resultant winds from a network of 9 stations. The position of the maximum SO_2 isolines is almost coincident with the corresponding position of the heat island.

It is concluded that, for the period examined, the local thermally generated winds in Mexico City tend to restrict the ventilation of the polluted air near the surface.

1. Introduction

Located in an elevated basin (2250 m) in Central Mexico, Mexico City's urban atmosphere is known to suffer high levels or air pollution. In this study an empirical analysis of the role of local winds (thermotopographycally developed) in air pollution dispersion shall be attempted with the purpose of assessing which components of the local air flow regime contribute to the pollution problems in the city. In addition, the part played by the heat-island induced centripetal circulation is examined as a contributing factor in reducing ventilation in the urban area.

2. The data

Hourly air quality and meteorological data corresponding to a network of 9 stations in the urban area (Fig. 1) are used for a period of 20 days (7 - 28 February, 1986). Radio sonde data (from airport) for 6 am are utilized in order to estimate the frequency of surface inversions.

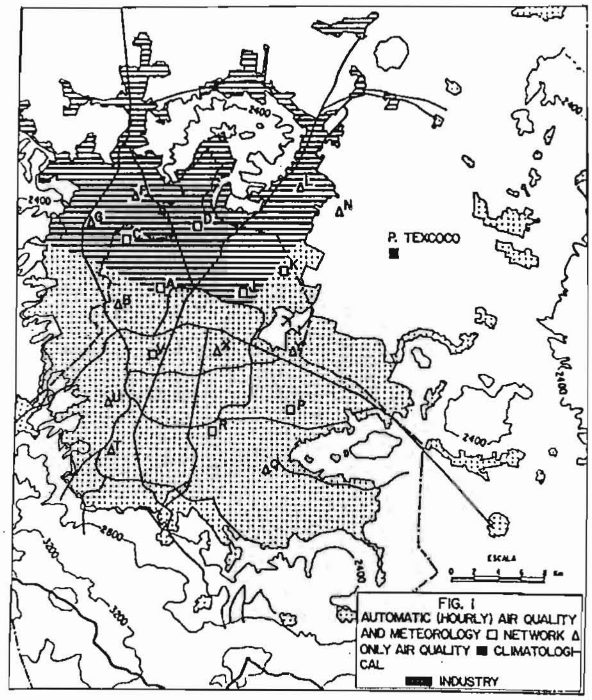

FIG. 1
AUTOMATIC (HOURLY) AIR QUALITY AND METEOROLOGY □ NETWORK Δ ONLY AIR QUALITY ■ CLIMATOLOGICAL

3. Wind systems

a) Synoptic winds

Located in the Tropics (lat. 19^{o}N), the basin of Mexico is a broad (100 km from N-S and 50 km E-W) flat land surrounded by mountains with mean heights of 600-800 m above the valley floor. The city is located in the SW corner of the basin where the mountain tops are highest including the 5000 m -snow-capped volcanoes to the East. Two wind regimes are clearly discernible:

a) The westerly current prevalent from Novembre to April which is characterized by anticyclonic flow and mostly cloudless skies.

b) The moist Trade current associated with the rainy season from May to October.

Westerly winds are usually stronger and not infrequently internal gravity waves are developed in the gradient wind. These gravity waves produced by upwind air flow over the Serranía de las Cruces to the west of the city are often made visible by stationary lenticular clouds observed during this time over the basin. It is difficult to establish in what measure they might contribute to flushing or scouring of cold air out of the basin at night or early morning has suggested by Pielke (1985).

b) The trade wind current

These trubulent winds are generally weaker and, due to its higher moisture content, radiational cooling at night is less effective in generating stable density gradients in the air basin as shall be examined later.

The seasonal shift in latitude of these major circulation systems determines the distribution of precipitation (and moisture) in the Mexico basin.

4. The local winds

As stated by Sturman (1987), mountain and valleys winds represent thermally developed air flow along the valley axis in the down-valley and the upvalley directions respectively. However, in the case of our study the so-called valley of Mexico is a closed flat, level basin with no natural drainage of run-off water. Frequent flooding of the ancient city which was built (on an island) in the midst of Lake Texcoco resulted in the excavation of a canal through the northern end of the basin during colonial times.

Components of the thermotopographic regime

As in other latitudes, the nocturnal air drainage is best developed in the Mexico basin on calm nights with clear skies which are often observed during the cool season. Therefore, in this paper we shall refer only to local wind circulation typical of this season. During the wet period higher moisture content and night turbulence, proper to the trade wind current, dampens nocturnal radiational cooling and surface-based inversions (6 am) are less frequently established in the basin (Fig. 2).

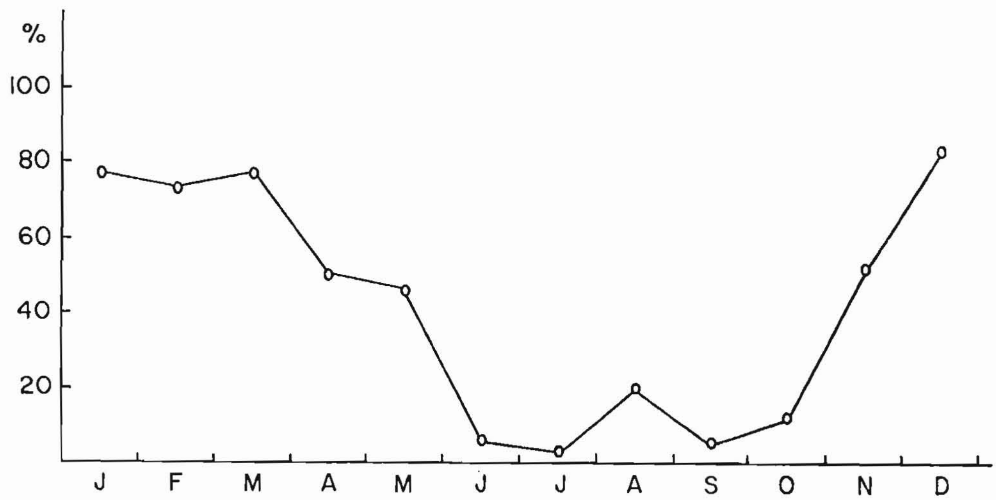

FIG. 2. FREQUENCY OF SURFACE INVERSIONS IN MEXICO CITY IN 1981. UNITS ARE PERCENT OF OBSERVATIONS AT THE AIRPORT HAVING SURFACE INVERSIONS.

We shall examine the three stage diurnal wind regime in the basin, as suggested by Banta and Cotton (1981):

a) The nocturnal phase dominated by stable stratification.

b) The morning phase of up slope wind regime.

c) The afternoon phase dominated by prevailing synoptic winds which eliminate the local flow due to increased downward transfer of momentum during maximum convection.

a). The nocturnal phase

The slope flow resulting from surface cooling from the mountains to the West starts moving, first slowly over vegetated surface as the piedmont, later over city structures and finally over the basin floor east of the airport where it meets its counterpart arriving from the slopes to the East. At this point of confluence in the center of the basin (east of the city) the drainage air begins to stagnate and increase in depth (Fig. 3).

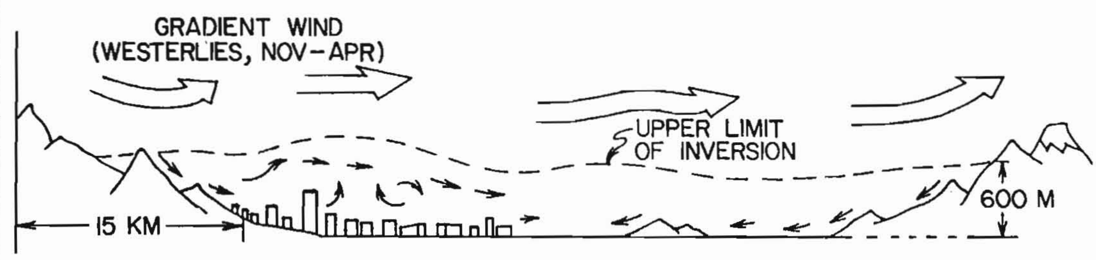

FIG. 3. SCHEMATIC ILLUSTRATION OF DRAINAGE AIR FLOW OVER THE MEXICO BASIN.

Some evidence for the deceleration of this down slope flow could be provided by Figure 4 which shows the frequency of calms at two locations; one at the piedmont (Tacubaya Observatory) at the west edge of the city and the other at the airport in the center of the basin, where in January the frequency of calms during the night period is (except at 6 am) higher than at the piedmont (especially from 10 pm to 4 am).

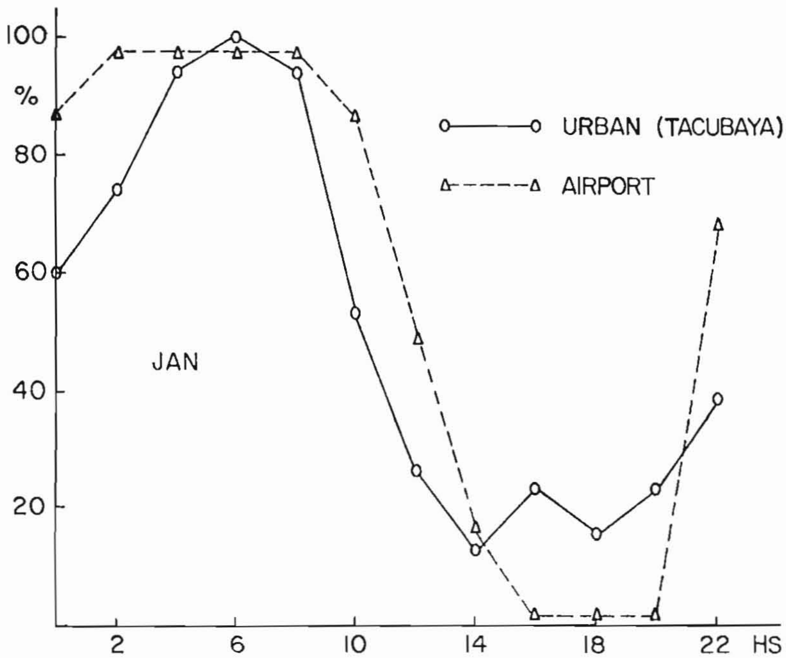

FIG. 4. FREQUENCY OF CALMS AT URBAN AND SUBURBAN SITES IN MEXICO CITY, 1980.

During this time, and as soon as the nocturnal downslope winds reach the piedmont they are, first reinforced by the heat island (Fig. 5) induced centripetal winds from the western edge to the center of the city where they start decelerating (due to the opposing heat island horizontal temperature gradient and the flow originating on the western slopes of the mountains to the East) until they come to a virtual standstill. This is illustrated in Figure 6, where westerly resultant wind vectors are shown on stations located on the western half of the city. These resultant winds were computed for the period 8 pm to 7 am during February 7 to 28, 1986. On the eastern suburbs on the other hand, resultant winds show a slight but definite easterly component (station N) in response to the heat island induced circulation or the air is almost calm (station Y).

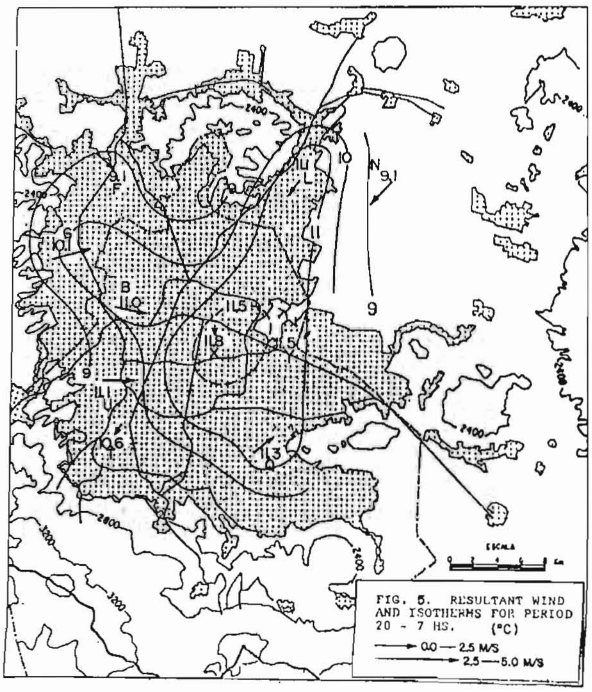

FIG. 5. RESULTANT WIND AND ISOTHERMS FOR PERIOD 20 - 7 HS. (°C)
0.0 — 2.5 M/S
2.5 — 5.0 M/S

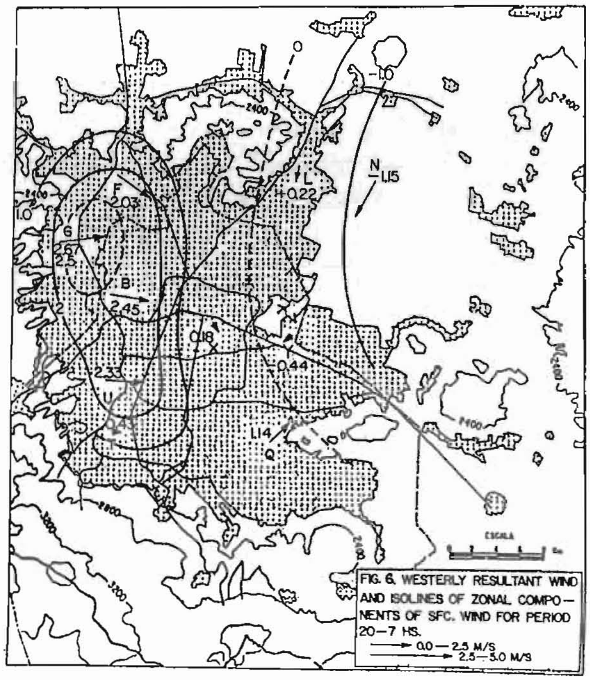

FIG. 6. WESTERLY RESULTANT WIND AND ISOLINES OF ZONAL COMPONENTS OF SFC. WIND FOR PERIOD 20—7 HS.
0.0 — 2.5 M/S
2.5 — 5.0 M/S

The East-West (or zonal) surface wind components of the nocturnal period (8 pm to 7 am) are also shown in Figure 6. As is noted, the high values (up to 2.5 m/s) of the westerly wind occupy the western half of the urban area and the zero line, indicating a change of sign (and direction) to easterly flow, lies almost on the eastern edge of the urban area. Also, the values of the easterly component of the winds are only less than half the intensity of the westerly components. But still, these easterly winds constitute evidence of the response to the thermal gradient established by the heat island phenomenon to the West.

The mean position of the maximun temperature contrast between urban and suburban areas in the city is coincident with the zero line position of the zonal component of the surface winds, as may be seen in Figure 5.

b) The morning phase on the western slope

After sunrise the eastern side (of the N-S oriented mountains to west of the city) begins to be heated by the sun and upslope winds (from the east) tend to develop against both the heat-island induced local westerly flow and the gradient wind (from the west). At this time the city receives more solar radiation than the surrounding country through building surfaces facing the sun. Perhaps this fact explains in part the permanece of the heat-island phenomenon, at least during the first hours of the morning.

The result is that, even when considering the whole sun-light period (from 8 am to 7 pm) which includes the afternoon hours, the upslope winds are not able to get established over the western half of the urban area. This may be appreciated in Figure 7, where the resultant wind vectors have been plotted. Here, despite the presence of more turbulent air, a weak centripetal circulation is able to persist in response to the heat-island thermal gradient observed during the daylight period (Fig. 8).

On the same Figure 7 the values for the east-west components have been plotted. Here, the absolute values of the westerly components on the west side of the city have decreased considerably with respect to the night period, whereas over the eastern half of the urban area the easterly components show comparatively high values, again as a response to the urban/rural thermal contrast.

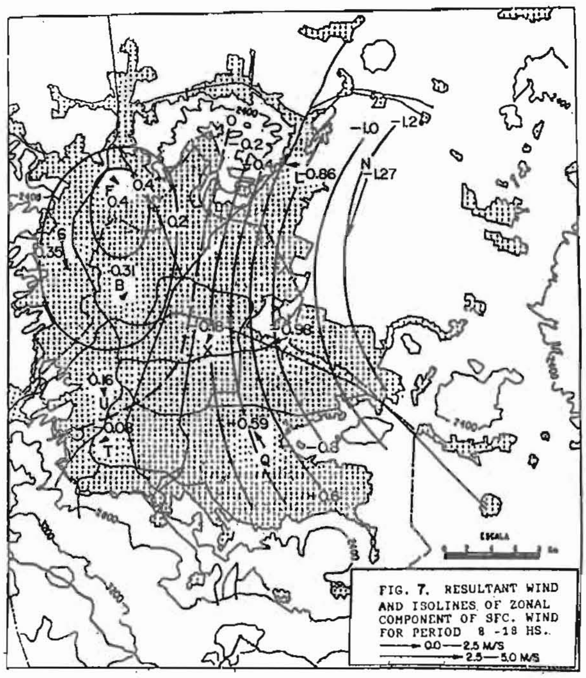

FIG. 7. RESULTANT WIND AND ISOLINES OF ZONAL COMPONENT OF SFC. WIND FOR PERIOD 8 -18 HS.
0.0—2.5 M/S
2.5—5.0 M/S

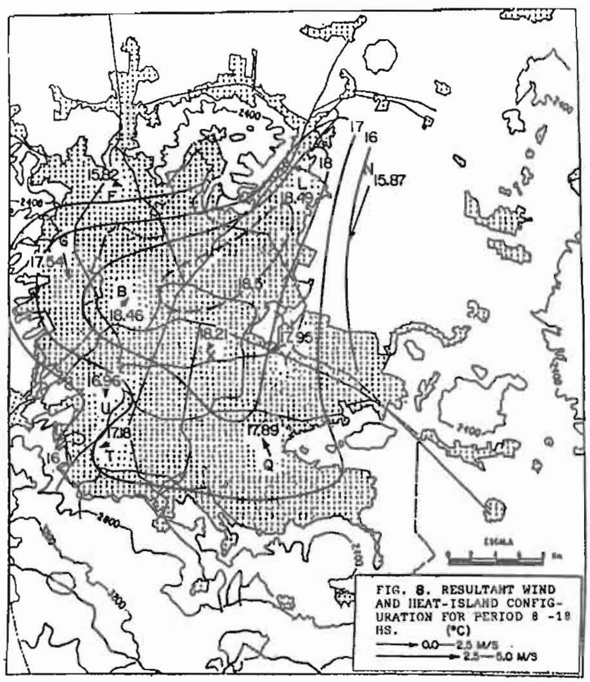

FIG. 8. RESULTANT WIND AND HEAT-ISLAND CONFIGURATION FOR PERIOD 8 -18 HS. (°C)
0.0—2.5 M/S
2.5—5.0 M/S

The above results suggest that during the second half of the day and over the urban area, the gradient winds (from the West) during the period examined were not able to mix down to the surface of the urban area and eliminate the heat-island induced circulation and subsequent coupling of the near surface and upper-level winds, At other times however, when ourbreaks of turbulent polar air sweep over the basin, the local scale urban circulation is totally eliminated by vertical turbulent mixing transporting momentum from the strong winds aloft all the way down to the surface of the urban area.

c) The afternoon phase

Over the flat center of the basin and away from the urban influence, erosion of the nocturnal cold pool during the morning and subsequent surfacing of the upper-level winds seems to take place. This is illustrated by surface wind data from a station (Plan Texcoco) located about 10 km to the NE of the airport on the dry bed of Lake Texcoco (Fig. 1). Here, at the end of the night a stable layer is formed next to the ground resulting from night-time radiational cooling and from cool air drainage from the mountain slopes (distant some 12 km) to the East and South; thus, this nocturnal wind exhibits a predominantly easterly component (SSE), as may be seen in Table 1.

	1-6hs	11-16hs	18-24hs
East	74	21	70
West	20	74	24
Other Dir.	6	4	6
Avg. wind (m/s)	1.6	5.0	3.0

Table 1. Frequency (%) of surface wind zonal components (hourly values) for station Plan Texcoco, on the center of the Mexico basin for 1-15 March 1982 and for three periods during the day.

After sunrise, with the heating of the surface of the plain by the sun, the stable layer is gradually eroded by turbulent mixing from its bottom upwards, until convective coupling with the gradient of regional wind is accomplished in the afternoon. As a result we show during this period a predominantly westerly component (from NNW mainly), as shown in Table 1. As it would be expected, these gradient winds were stronger and more turbulent (Table 1).

5. The local winds and air pollution

It is well known that meteorology and topography play a dominant role in the development of serious air pollution problems. In the case of the Mexico City urban area, the complex mountain-valley terrain coupled with the heat-island induced wind system do not permit a simple description of pollutant dispersion and transport. The type of local wind circulation described in the previous section tends to produce a peak concentration of pollution over the area of confluence of the surface air flow (which, as it was shown, is also coincident with the heat-island maximum) concentration at some distance to the east of the center of convergence on the eastern suburbs. This may be appreciated in Figures 9 and 10 which show the mean SO_2 isoline concentrations for the day and night period respectively. Also, the position of the maximum SO_2 isolines is almost coincident with the corresponding position of the heat island and to some extent not too far from the main emission sources in the northern sector of the city (Fig. 1). the eastward displacement of SO_2 peak observed during the night period (Fig. 10) could perhaps be explained by the corresponding larger values of the nocturnal westerly components of the surface drainage wind, relative to the easterly components of the converging air flow. Even though the centripetal circulation is difficult to detect during the daylight period, the mean highest buildup of SO_2 tends to persist however on the eastern suburbs (Fig. 9).

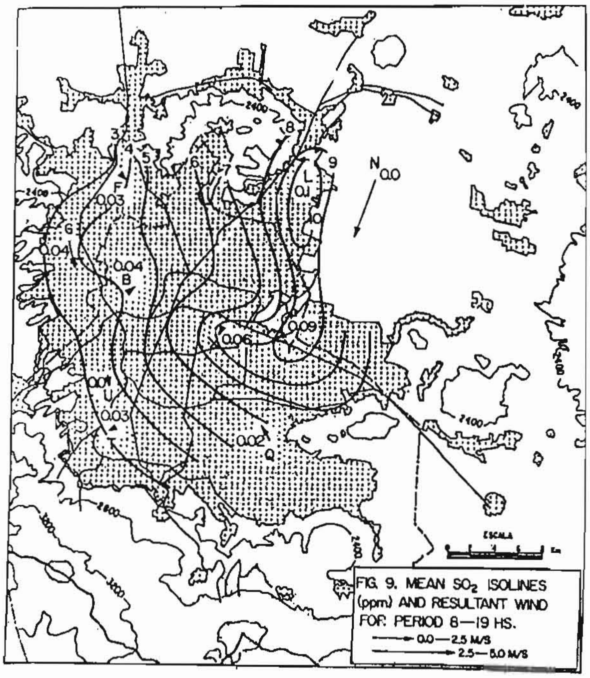

FIG. 9. MEAN SO_2 ISOLINES (ppm) AND RESULTANT WIND FOR PERIOD 8—19 HS.
0.0—2.5 M/S
2.5—5.0 M/S

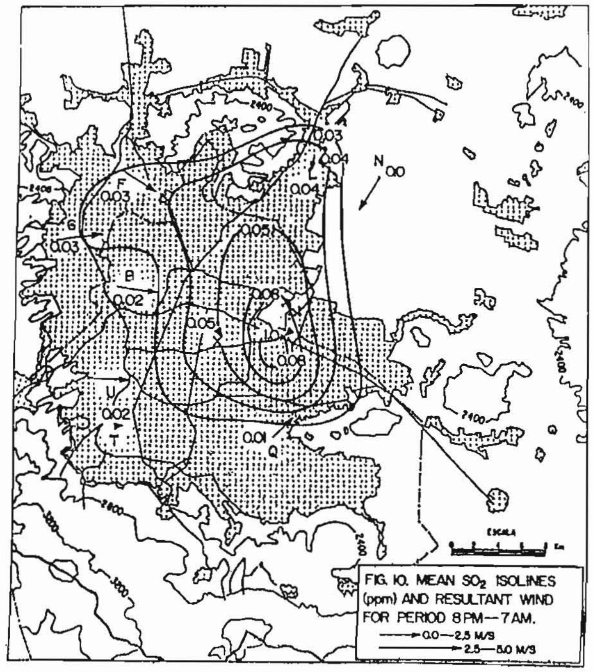

FIG. 10. MEAN SO_2 ISOLINES (ppm) AND RESULTANT WIND FOR PERIOD 8 PM—7 AM.
0.0—2.5 M/S
2.5—5.0 M/S

6. Diurnal variation of surface divergence

Resultant wind fields displayed in Figures 6 and 8 reveal an area of horizontal convergence which seems to be related to the heat-island center (shown on the same Figure). Since topographic and heat-island induced winds are superimposed on the mean gradient wind in order to compute the resultant winds, vector differences between the wind at each station and the network resultant (mean) wind were performed following the procedure suggested by Shreffler (1978). In order to estimate the diurnal variation of surface wind inflow, hourly values of surface divergence were computed for the area of the triangle formed by anemometric stations L, U, Q which includes the area where the heat-island center is located. The result is shown in Figure 11 where it is apparent that convergent flow prevailed not only during the night period, but was also present during most of the daylight hours, when it would be expected that turbulent mixing would tend to weaken the heat-island induced flow.

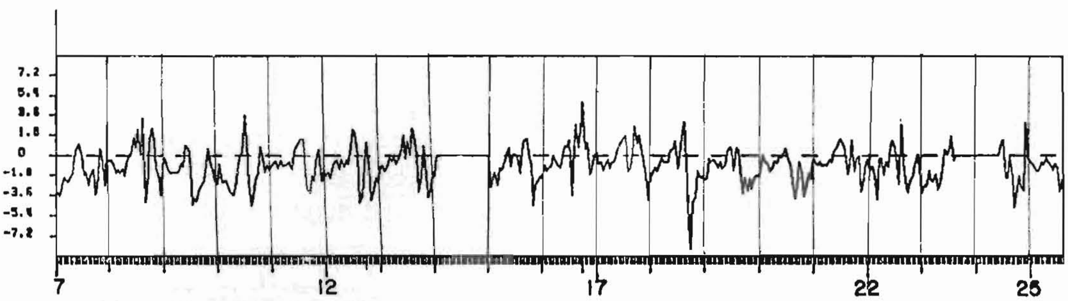

FIG. 11. HOURLY VARIATION OF SURFACE WIND DIVERGENCE OVER THE AREA ENCLOSED BY STATIONS L, U, Q FOR PERIOD 7 - 25 FEBRUARY 1986. ($\times 10^{-4}$ s^{-1})

From the above results it seems plausible to conclude that (as shown in Fig. 11) heat-island induced convergent flow was more prevalent at night, since it was reinforced by drainage winds from the mountains to the West. During the day, with similar heat-island intensity, convergence of flow was evident only during those hours when convective instability helped producing such circulation, since (as suggested by Shreffler, 1978) vertical motions may be initiated with a relatively small input of thermal energy from the urban surface.

7. Concluding remarks

It has to be admitted that even in ideal conditions (weak regional wind, clear skies) the urban surface wind pattern is rarely simple. The forcing mechanism for this wind circulation, (the heat island) is seldom monolitic, as has been illustrated for mid-latitude cities (Chandler, 1965) as well as for a tropical urban area (Jáuregui, 1973; 1986). Also, the arrangement of hill slopes and level plain in the Mexico basin has an influence on local wind development. These slope winds (caused by topography) are superimposed on the heat-island induced centripetal circulation (or rural wind). The resulting local wind regime is such that convergent surface flow over the city prevails mainly during the night and early morning. Another factor that has been suggested to be responsible in part for this convergent flow is the ground friction caused by the presence of the urban structures (Riehl and Herkhof, 1972). According to these authors this so-called 'stovepipe efect' for the city of Denver is primarily caused by friction. The low-level convergence of air flow into the city, although weakened by turbulence and by upslope valley winds is still evident in the daytime mean maps of resultant wind. During the forenoon hours, as the mixing layer increases in depth the outflow counter current begins to grow in importance resulting in a more effective removal mechanism for the outward transport of pollutants aloft (stovepipe effect). Part of this bouyant pollution is able to be carried away from the basin by the gradient wind current aloft. During the night period the slope winds reinforce the western branch of the rural winds displacing the center of convergence to the eastern suburbs, where the peak values of SO_2 are also found as a result of the converging surface winds. From the foregoing it may be concluded that the local thermally generated winds in Mexico City tend to maintain the polluted air near the surface within the limits of the urban area, especially during the night and morning period. When this happens high pollution levels may occur because of shallow nocturnal mixing depth.

Acknowledgements

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REFERENCE

Banta, R. and R. Cotton, 1981. An analysis of the structure of local wind systems in a broad mountain basin. *J. Appl. Meteorology,* **20**, 1255-66.

Chandler, T., 1965. The climate of London. London, Hutchinson.

Jáuregui, E., 1973. The urban climate of Mexico City. *Erdkunde,* **28,** (**4**), 298-307.

Jáuregui, E., 1986. The urban climate of Mexico City, in Proceedings of WMO Tech. Conference, T. R. OKE, (ed) WMO No. 652, 63-86, Geneva.

Pielke, R. A., 1985. The use of mesoscale numerical models to assess wind distribution and Boundary-Layer structure in complex terrain. *Boundary-Layer Meteor.* **31**, 217-32.

Shreffler, J., 1978. Detection of centripetal heat-island circulations from tower data in St. Louis. *Boundary-Layer Meteor.* **15**, 229-242.

Sturman, A., 1987. Thermal influences of airflow in mountainous terrain. *Progress in Physical Geogr.* 11 (2), 183-206.

Riehl, H. and F. Herkhof, 1972. Some aspects of Denver air pollution meteorology. *J. Appl. Meteor.*, **11**, 1040-1046