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Time and space variations of sulfur dioxide concentrations in the metropolitan area of Mexico City

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RESUMEN

Se analizan las variaciones espaciales y temporales del bióxido de azufre (SO_2) en la atmósfera de la Zona Metropolitana de la Ciudad de México (ZMCM) para varios períodos de 1986 a 1989. Se utilizan mediciones horarias registradas por la red de monitoreo gubernamental (SEDUE) y por la estación de monitoreo del Centro de Ciencias de la Atmósfera, UNAM. El análisis cubre los siguientes aspectos: variaciones espaciales y temporales de SO_2 en base anual, estacional, mensual, semanal y horaria. Se incluye un análisis y discusión de la tendencia invernal del SO_2 en la zona Sur de la ZMCM.

El análisis anual señala que las mayores concentraciones se presentan al norte de la ZMCM, donde se localiza la zona industrial, disminuyendo la concentración del SO_2 en la dirección del viento dominante (hacia el Sur). La norma primaria de calidad del aire de la EPA para SO_2 de 30 ppb (promedio anual) es rebasada en la mayor parte de la ZMCM. Los meses invernales presentan el mayor problema en toda el área urbana. El ciclo semanal indica que en los días laborables los niveles de SO_2 son significativamente mayores comparados con los presentes en los días de descanso conforme a la cercanía a la zona industrial. El ciclo diurno señala que la concentración pico de SO_2 varía en tiempo y distancia de las fuentes emisoras en la ZMCM.

La tendencia de concentración del SO_2 en el campus de la Universidad de México (zona semiurbana) indica que el problema es creciente desde 1986, en contra de lo que previamente han señalado diversos organismos públicos en México.

PALABRAS CLAVE: Bióxido de azufre, contaminación atmosférica, calidad del aire urbano, Ciudad de México.

ABSTRACT

SO_2 concentration measurements in the Metropolitan Zone of Mexico City (MZMC) over the period from 1986 through 1989 are analyzed. Mean hourly measurements recorded by the governmental monitoring network (SEDUE) and by the Centro de Ciencias de la Atmósfera monitoring station were used. The survey covers annual, seasonal, monthly, weekly and diurnal variations. An analysis and discussion of the trend of SO_2 in the south of the MZMC for 1986-1989 is also included.

The highest SO_2 concentrations occur in the northern area of the Mexico City where the industrial zone is located. Concentrations decrease toward the South of the city following the prevailing wind direction. The EPA air quality standard of 30 ppb annual average is exceeded for most of the MZMC. During the winter months the SO_2 problem is worse. The weekly cycle shows that normal weekday concentrations are significantly higher than weekends and holidays near the industrial zone. The diurnal cycle of SO_2 concentration is strong. The morning peak varies in time with distance from the main industrial area.

The winter trend of SO_2 since 1986 in a suburban area (University Campus) shows that the SO_2 problem is large and growing, despite soothing official statements.

KEY WORDS: Sulfur dioxide, air pollution, urban air quality, Mexico City.

INTRODUCTION

The Metropolitan Zone of Mexico City (MZMC) is located near the southwest corner of a basin at 2 240 m above sea level (Fig. 1). It has an estimated population of 19 million inhabitants and contains close to 3 million cars and 21% of the industries in Mexico.

The wind (Fig. 2) is predominantly from the north-northwest (Bravo *et al.*, 1988). However, local thermally generated winds tend to keep the polluted air near the surface within the limits of the urban area, especially during the night and morning period (Peña, 1986; Jáuregui, 1988). When this happens, high pollution levels occur because of shallow nocturnal mixing depth. The MZMC is known to have high levels of air pollution (SEDUE, 1986; Bravo, 1987; CONADE, 1988; Bravo *et al.*, 1989; Jáuregui, 1988). The northern sector of the MZMC has a high population density. It contains many industrial plants and has the highest sulfur dioxide (SO_2) concentrations of the Metropolitan area (SEDUE, 1986; Bravo, 1987).

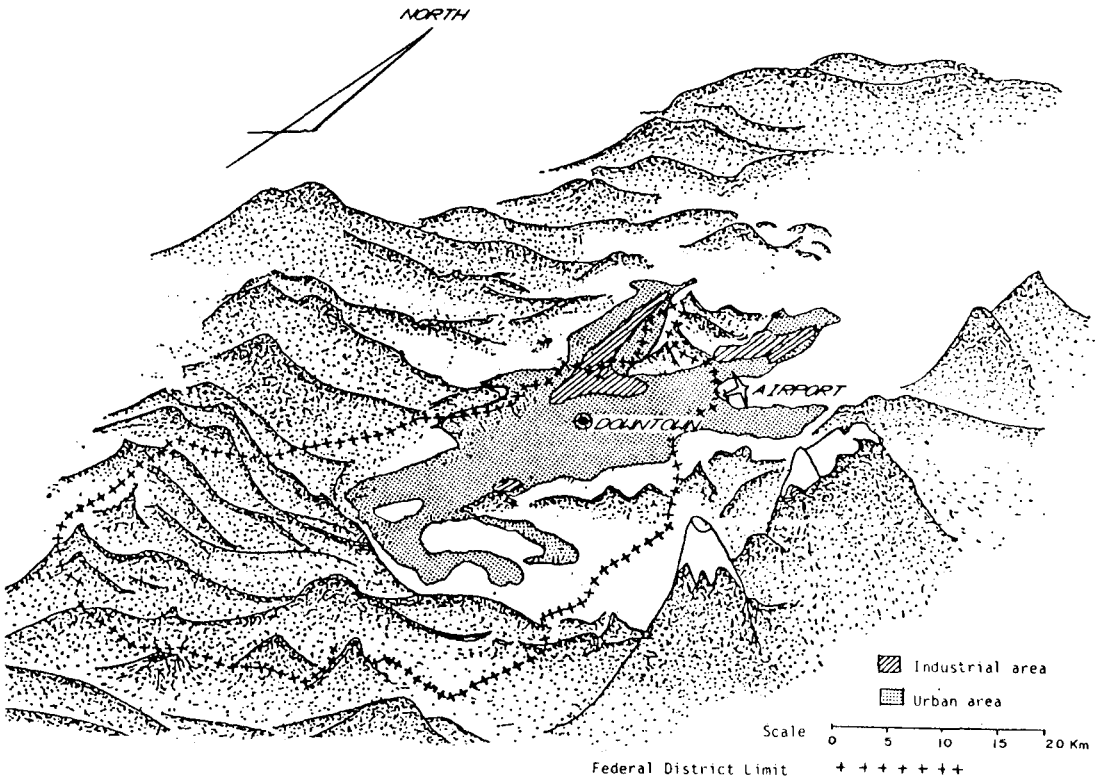

Fig. 1. The Metropolitan Area of Mexico City and the Mexico Basin, showing location of most heavy industry.

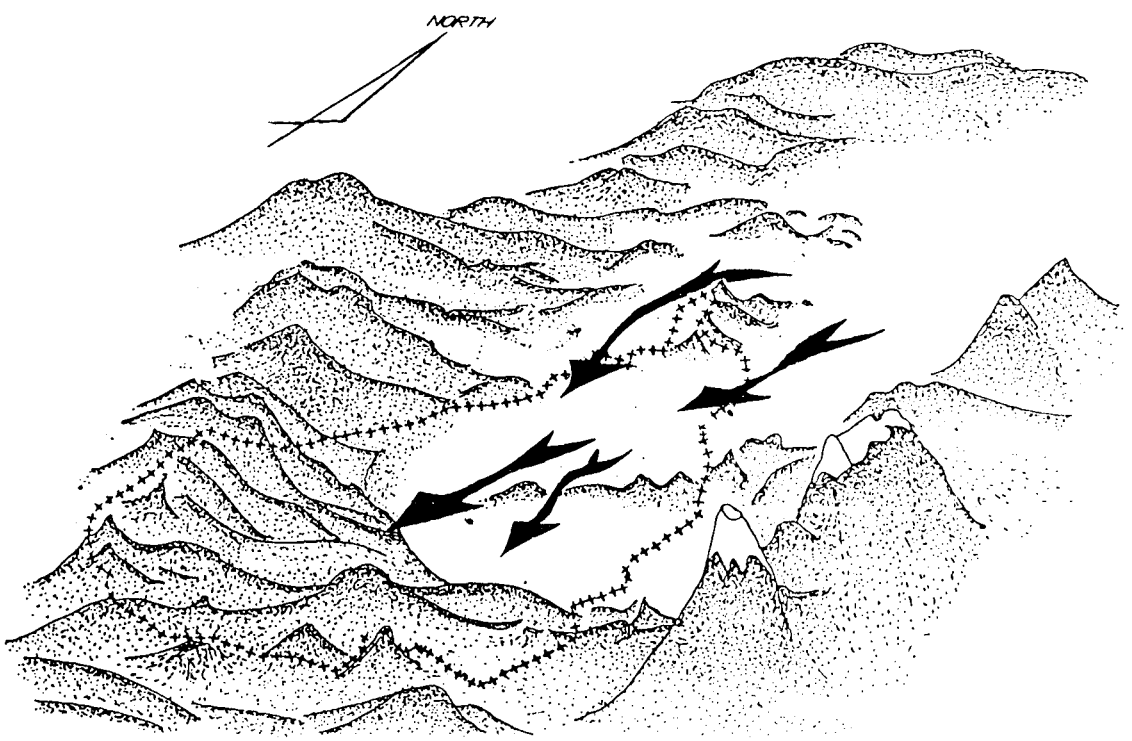

Fig. 2. Air mass transport by prevalent diurnal surface winds in the Metropolitan Area of Mexico City.

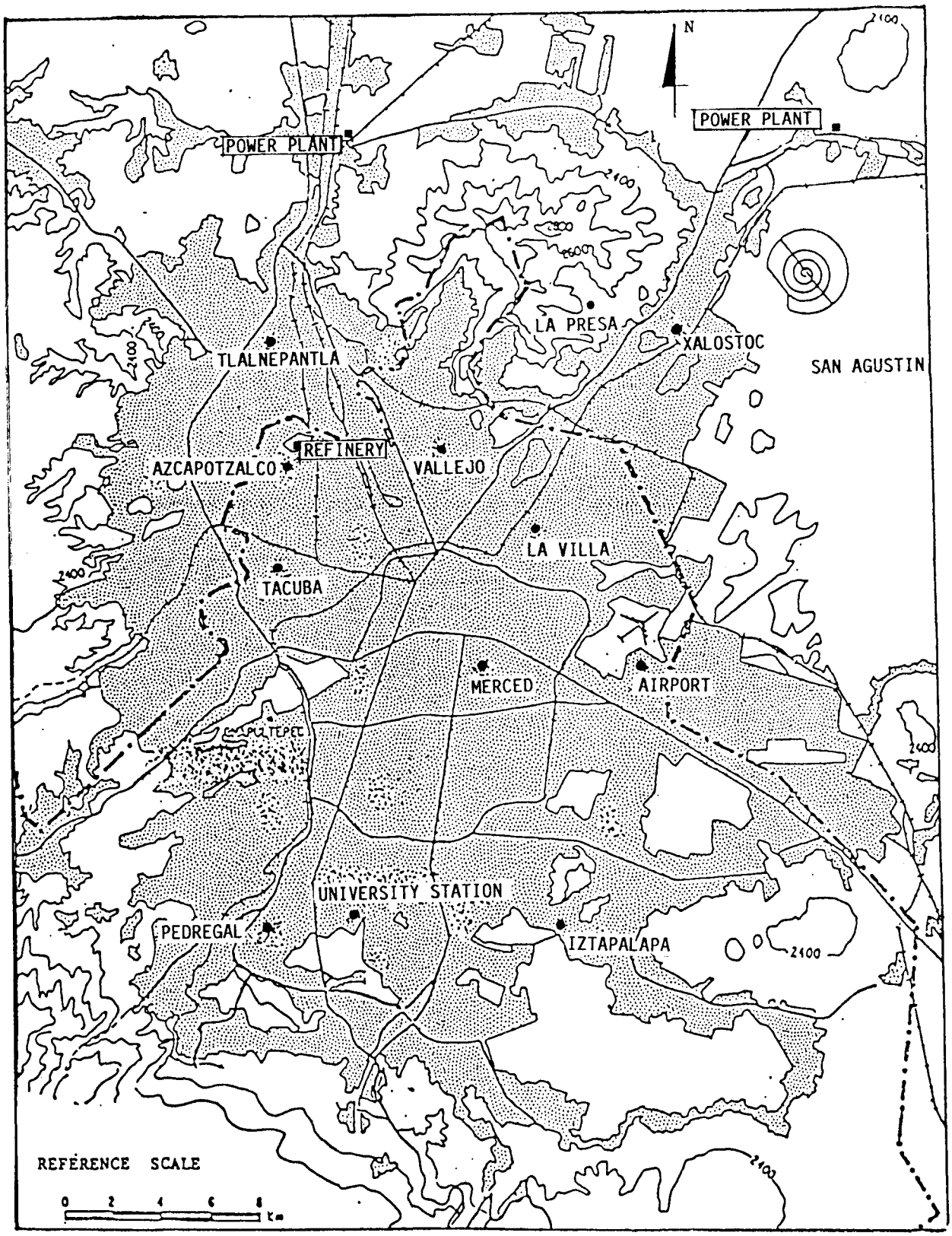

Fig. 3. Localization of the SO_2 monitoring stations, and some major sulfur dioxide sources in the Metropolitan Area of Mexico City.

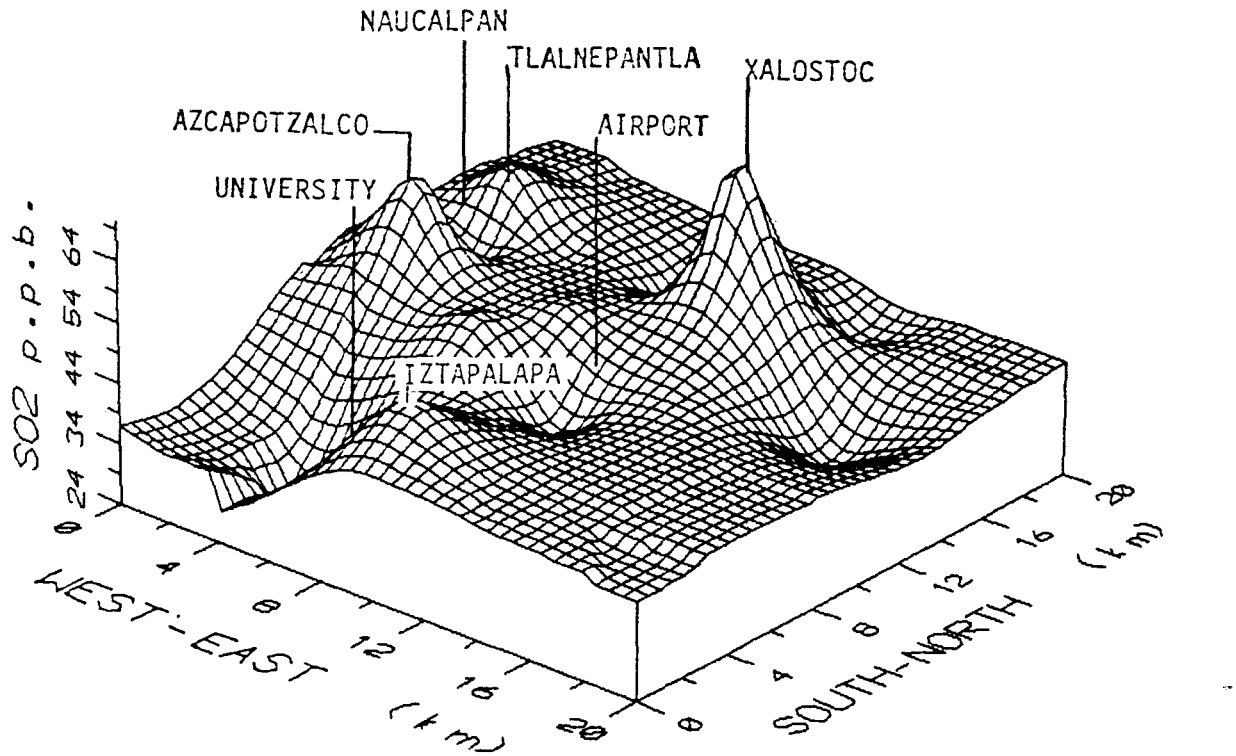

Fig. 4. Three dimensional plot of yearly average sulfur dioxide concentrations in the Metropolitan Area of Mexico City (1988).

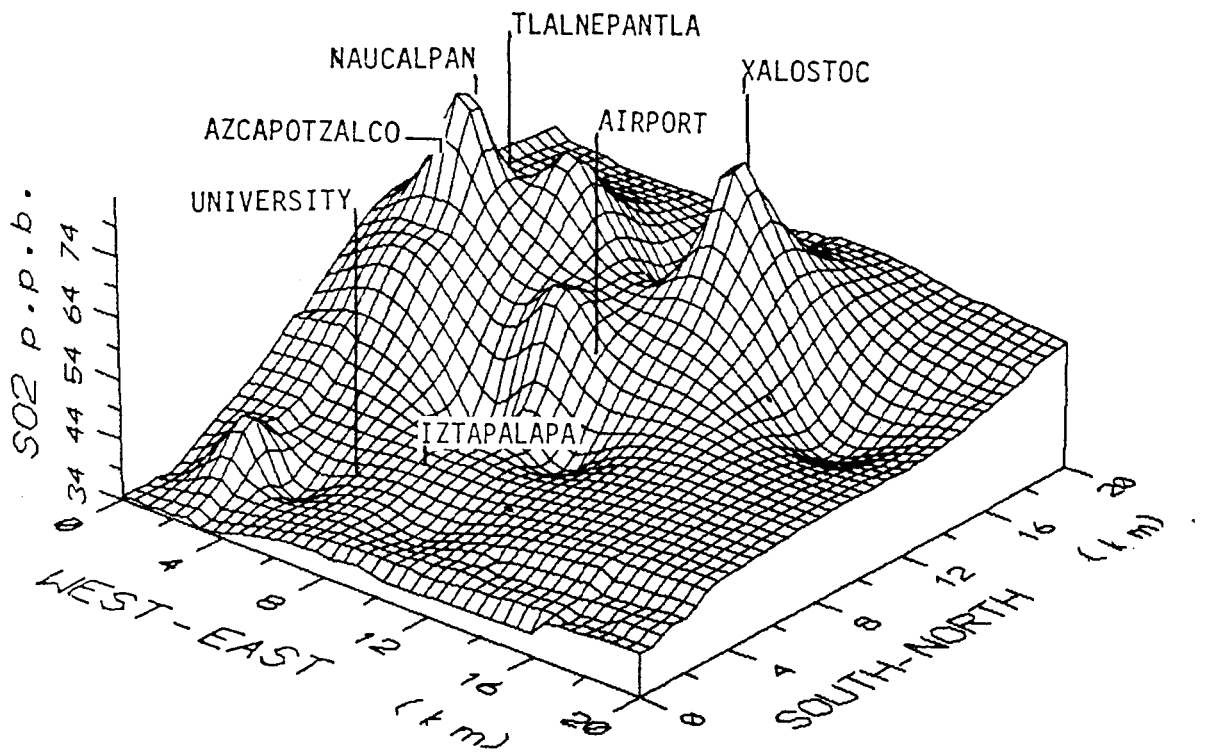

Fig. 5. December average sulfur dioxide concentrations in the Metropolitan Area of Mexico City (1987).

The use of heavy bunker oil and diesel oil with relatively high sulfur content (3.5% weight and 0.4% weight respectively) in industrial plants and power plants is responsible for much of the SO_2 emissions. High levels of SO_2 have been observed in the last twenty years in the North of the City (Bravo, 1960; Bravo y Magaña, 1979; Jáuregui *et al.*, 1981; Bravo, 1987).

In 1986 the federal government acted to control the SO_2 problem in MZMC (Diario Oficial de la Federación, 1986). Following this regulation, the Mexican Petroleum Company (PEMEX) reduced the use of fuel-oil in different industrial activities, including the refinery of Azcapotzalco and the " Valle de México" power plant, using natural gas instead (CONADE, 1987). PEMEX stated that this should diminish the SO_2 concentrations observed in Mexico City during previous years (SEDUE, 1989).

At the end of 1988, the federal government published a report stating that the SO_2 concentration was controlled and diminishing (CONADE, 1987).

This paper provides data on the spatial and temporal distribution of SO_2 in the atmosphere, especially downwind of the industrial sector in the Metropolitan area, following the 1986 regulation.

METHODOLOGY

Mean hourly SO_2 measurements were taken over a one year period at twelve monitoring stations of the government network (SEDUE), and over a three year period at the Centro de Ciencias de la Atmósfera (University Station). Figure 3 shows the location of these stations. The SEDUE network employs Thermoelectron Model 43 fluorescent SO_2 analyzers. The University station uses a Monitor Labs Model 8850 fluorescent SO_2 analyzer. Calibration of all instuments was done according to EPA-standards (EPA, 1985). Meteorological data were obtained from the SEDUE network and the University station.

The hourly SO_2 data were sorted by year, season, month, week and hour. Spatial distribution analysis was by interpolation (EPA, 1977a).

The University station was chosen as representative for urban SO_2 levels according to the site selection criteria of EPA (1977b; Zeldin and Meisel, 1978; EPA, 1987). An increasing trend of SO_2 concentration was established at the 95% significance level.

RESULTS

The annual mean distribution of SO_2 concentrations (December, 1987 through November 1988) on the MZMC is shown in Figure 4, following McCready (1987). Concentrations are highest near the industrial area of Xalostoc and the industrial corridor of Tlalnepantla-Naucalpan-Azcapotzalco.

Most of the urban area exceeds the maximum SO_2 concentration value of 30 ppb. of the U.S. primary air quality standard. The small peak at Iztapalapa is attributed to a small industrial area located there. Otherwise the SO_2 levels are close to tolerable in the southern residential area.

The southward decrease persists throughout the year, but the concentration gradient becomes steeper during the winter months when SO_2 values are higher. Figure 5 shows the December 1987 mean distribution of SO_2 concentrations in the MZMC. Values increase everywhere as compared with the yearly averages (Fig. 4), but most dramatically in the northern industrial districts.

The mean annual concentration of SO_2 is plotted in Figure 6 as a semi-log function of distance from the power stations in the Northern area. The line of best fit is described by the equation:

$$X = 4.28e^{-0.0107x}$$

where: X = SO_2 concentration (ppb); x = distance from a base line going through the two power plants shown in Figure 3.

The December 1987 concentration data are also plotted following the same procedure (Fig. 7). The line in Figure 7 is described by the equation:

$$X = 4.51e^{-0.0509x}$$

The last four figures confirm that the industrial area is the principal source of the SO_2 in the air of the MZMC. The diurnal geographic distribution is shown in Figures 8, 9, 10 and 11. The diagrams were constructed using monthly mean three-hour periods (3-6 a.m.; 9-12 a.m.; 3-6 p.m. and 9-12 p.m.) for December 1987.

The period of 3 to 6 a.m. shows some nighttime industrial activity and SO_2 accumulation near Naucalpan and Tlalnepantla. The period of 9 to 12 a.m. shows an increase in SO_2 everywhere from the industrial areas toward the South of the City. The period of 3 to 6 p.m. shows SO_2 moving over the MZMC with some eastward displacement. This displacement has been partly explained by Jáuregui (1988) as a meteorological effect produced by surface air flow and a heat-island gradient in the urban area. The mixing-height inversion is well developed at this time; the SO_2 levels are low even compared with the 3 to 6 a.m. levels. The periods of 9 to 12 p.m. shows SO_2 accumulations near La Villa and the downtown area toward the East. There is a slight displacement of SO_2 concentrations from the South to the Central part of the City.

From the above data it appears that SO_2 emissions are almost exclusively point-source oriented.

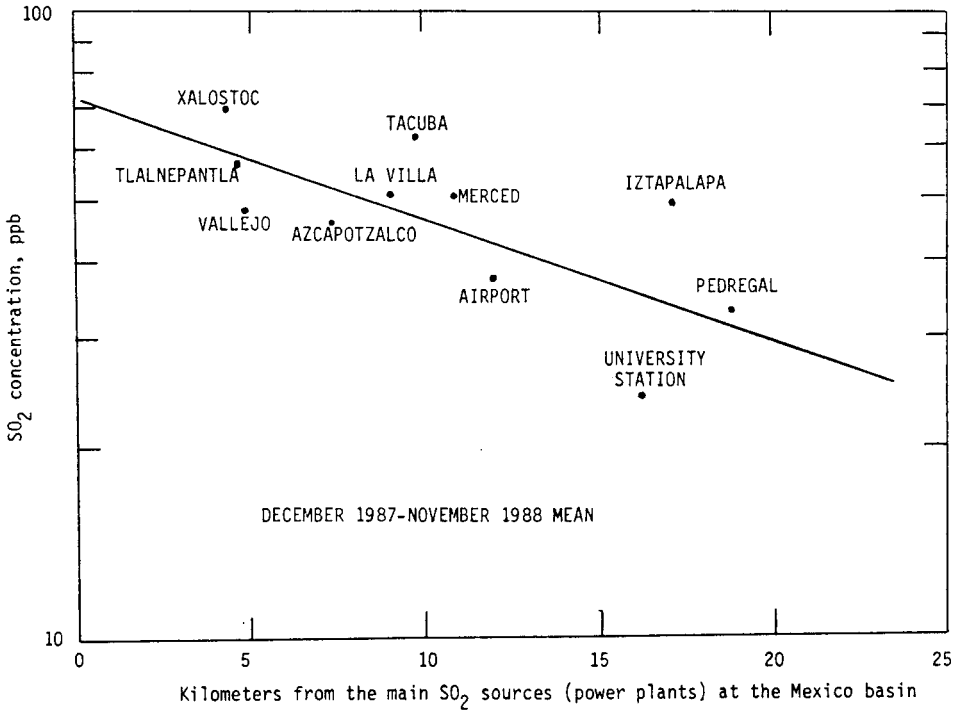

Fig. 6. Change of mean annual sulfur dioxide concentration with distance from power plants in the North of the Metropolitan Area of Mexico City (1987-1988).

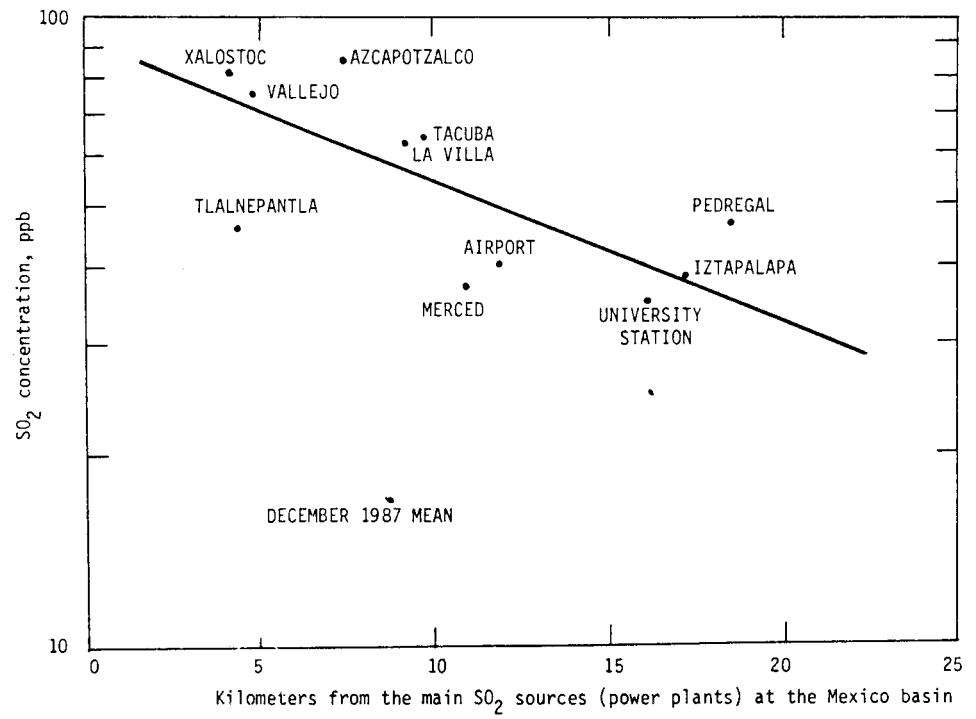

Fig. 7. Change of mean monthly sulfur dioxide concentration with distance from power plants in the North of the Metropolitan Area of Mexico City (December, 1987).

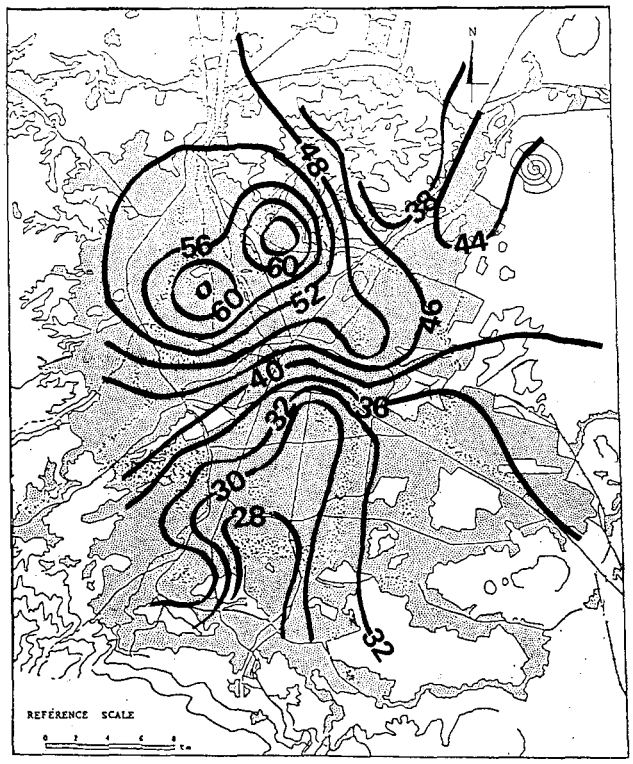

Fig. 8. Spatial SO_2 distribution in the MZMC for the period 3 to 6 a.m. during December 1987.

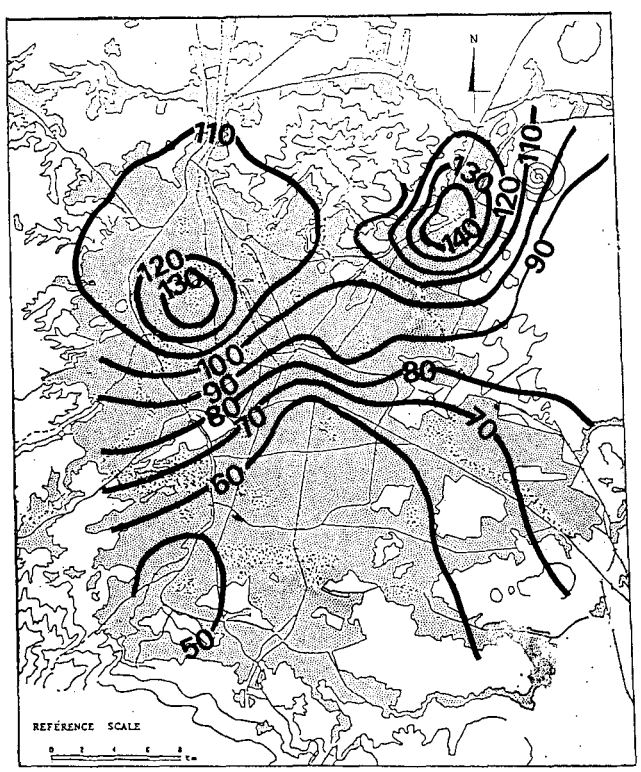

Fig. 9. Spatial SO_2 distribution in the MZMC for the period 9 to 12 a.m. during December 1987.

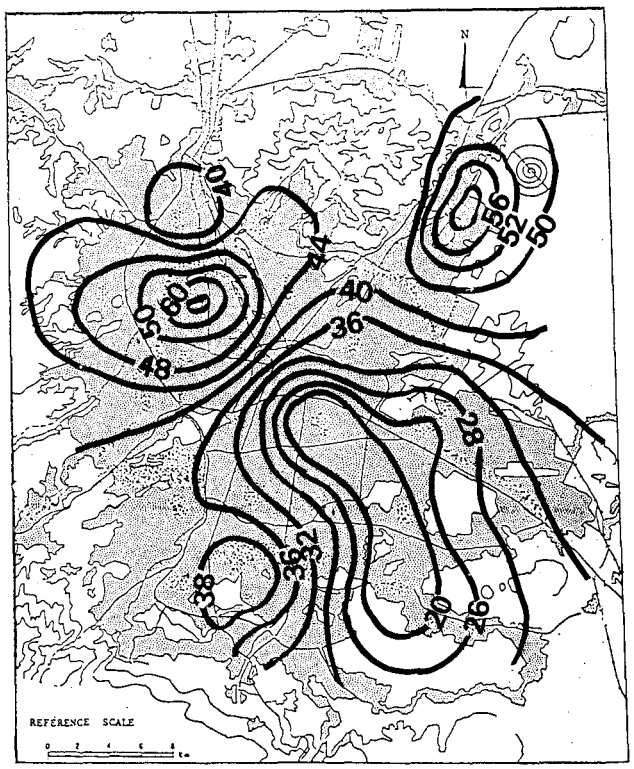

Fig. 10. Spatial SO_2 distribution in the MZMC for the periods 3 to 6 p.m. during December 1987.

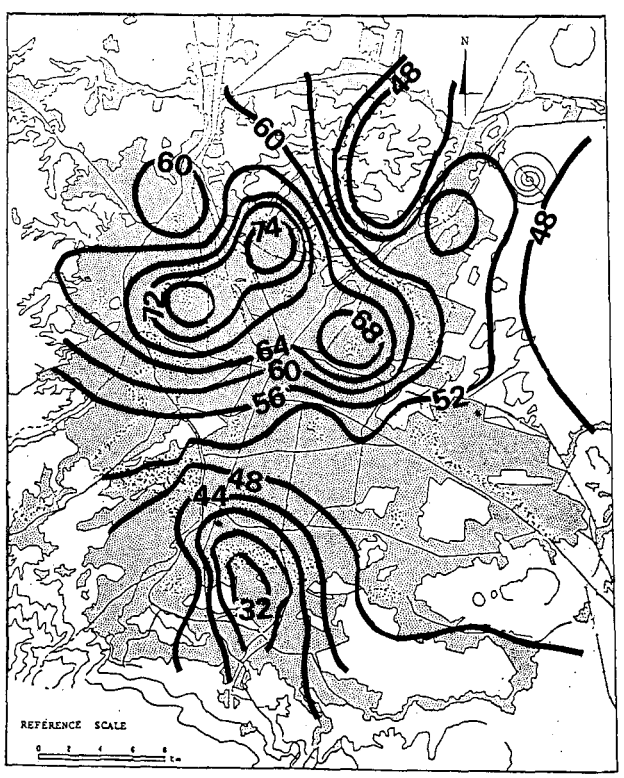

Fig. 11. Spatial SO_2 distribution in the MZMC for the period 9 to 12 p.m. during December 1987.

Table 1

Quarterly average SO_2 concentrations for different monitoring stations in the Metropolitan Zone of Mexico City (1987-1988).

Monitoring Station	Winter	Spring	Summer	Fall
		SO_2 ppb.		
Airport	40.3	34.3	35.0	40.6
Azcapotzalco	69.0	39.6	33.3	41.6
Iztapalapa	49.3	53.3	37.3	63.3
La Presa	41.0	32.3	20.0	37.6
La Villa	57.0	53.0	38.6	54.6
Merced	44.3	42.3	52.3	67.3
Pedregal	50.3	34.6	23.6	25.0
San Agustín	36.3	29.3	30.0	77.0
Tacuba	63.6	53.3	61.6	67.6
Tlalnepantla	65.3	51.0	54.3	60.6
Univ. station	31.6	22.6	17.3	25.0
Vallejo	69.6	47.3	29.0	35.0
Xalostoc	80.0	83.6	56.0	67.6

Annual variation

Monthly average concentrations at all monitoring stations show a clear annual cycle with maxima in fall or winter and minima in the summer months. Typical curves are illustrated in Figure 12 for Tlalnepantla (industrial area) and University station (suburban downwind area). Table 1 shows the quarterly average SO_2 concentrations for the monitoring stations during 1987-1988.

Weekly and diurnal variation

The SO_2 concentration data for December 1987 were analyzed to determine if weekend concentrations differed from weekdays. Weekday and weekend means are shown in Figure 13 for Tlalnepantla and University stations. Normal working days are significantly higher in SO_2 than non-working days. The influence of the industrial activity for

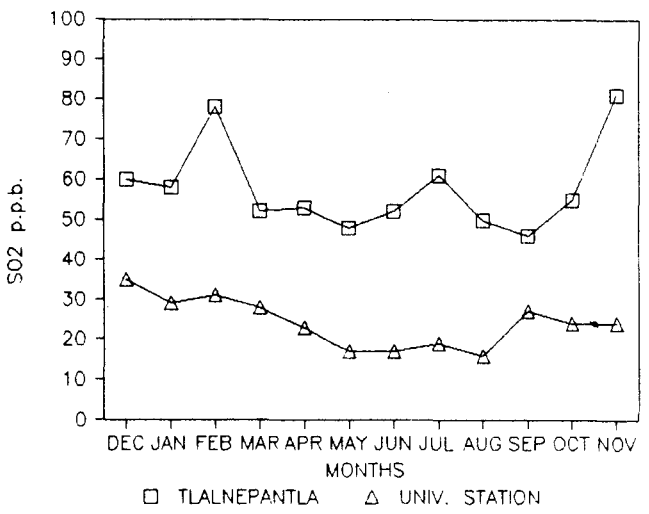

Fig. 12. Annual cycle of sulfur dioxide concentrations at Tlalnepantla and University station from monthly means.

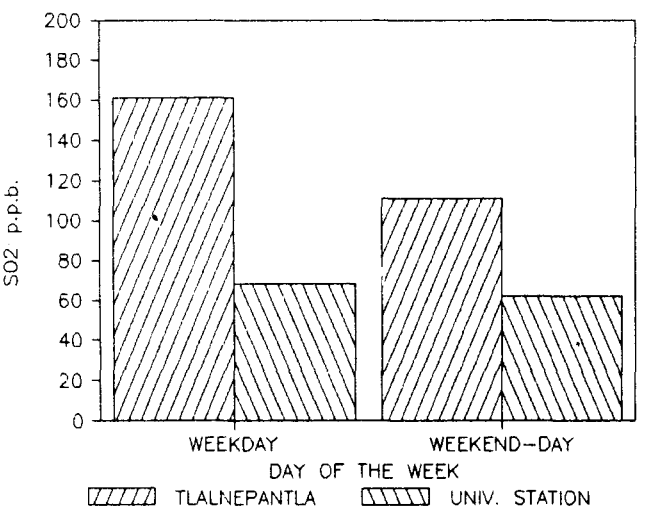

Fig. 13. Weekday and weekend day average sulfur dioxide concentrations at Tlalnepantla and University station during December 1987.

Tlalnepantla is clear, since many industries shut down over the weekend thus resulting in a reduction of SO_2 emissions.

The University station does not show any significant day-of-the-week effect.

The diurnal cycle of SO_2 concentration is also more marked in the industrial zone. Stations show morning peaks and afternoon or evening minima. The morning SO_2 peak occurs between 9 to 13 hrs. local time, depending on the location of the urban area. Figures 14 and 15 show mean hourly SO_2 concentrations at Tlalnepantla and University station for weekdays and weekends during December 1987.

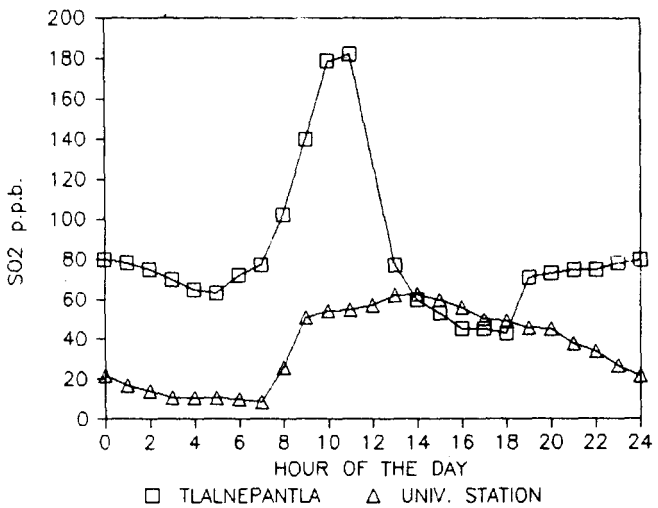

Fig. 14. Weekday mean hourly SO_2 concentrations at Tlalnepantla and University station during December 1987.

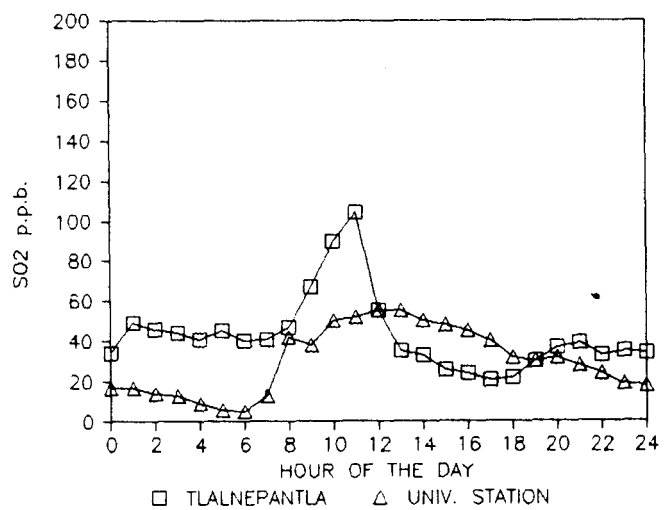

Fig. 15. Weekend mean hourly SO_2 concentrations at Tlalnepantla and University station during December 1987.

Trends since 1986

From a statistical point of view, the data of the University station are more consistent than the other stations due to the small difference between weekdays and weekends (Spiegel, 1961). Figure 16 shows ninety-five percent confidence intervals of SO_2 concentration for quarterly data (Dec.-Jan.-Feb.) according to a procedure suggested by EPA (EPA, 1987). These confidence intervals are used to compare periods since 1986. From Figure 13 it is clear that SO_2 concentrations are increasing with time. The upward trend is statistically significant, because no two confidence intervals overlap. This rise reflects a general increase in SO_2 concentration throughout the Mexico City Metropolitan Area after 1986.

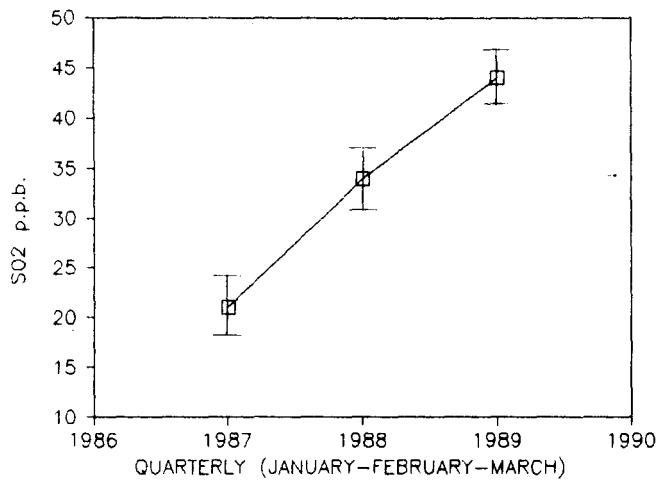

Fig. 16. Sulfur dioxide air quality trend (95% confidence intervals) at the University station for the months of December through February since 1986.

CONCLUSIONS

The annual averages of sulfur dioxide concentrations suggest that sources are located in the North sector of the urban zone, coinciding with the location of the industrial area. Concentrations of SO_2 decrease from North to South following the wind regime. All stations show a marked annual cycle with peak concentrations in the winter season.

The diurnal SO_2 cycle reflects the industrial activity and local winds with a maximum in the morning hours and a minimum during afternoon.

The difference between concentrations of SO_2 on weekdays and weekends suggests that industrial activity is largely responsible for SO_2 pollution in the MZMC.

An increasing trend through the years (1987-1989) is found at the University station. This upward trend suggests

two possibilities. Either the strategy of heavy fuel oil substitution by natural gas has failed, or it has not been implemented.

Compliance with environmental commitments is essential to the preservation of adequate health standards for the population of Mexico City.

ACKNOWLEDGMENTS

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