Atmósfera 20(4), 329-339 (2007)

On the usefulness of atmospheric measurements for air quality evaluation in the context of recent urban meteorology findings in México City

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Received June 13, 2006; accepted January 18, 2007

RESUMEN

En muchas ciudades la herramienta principal en la evaluación de las políticas para el control de la contaminación es la información de calidad del aire proveniente de las redes locales de mediciones. Sin embargo, en el contexto de una meteorología compleja y el uso de suelo de la Ciudad de México, el carácter puntual y la carencia de detalle en la química de los datos pueden conferir una información conflictiva o sesgada. La aproximación al problema pudiera no tener bases sólidas. No es sino hasta que el esfuerzo de medición se complementa con una modelación detallada de la meteorología y la calidad del aire que puede asegurarse el adecuado uso de la información de mediciones. Con el fin de comprobar lo anterior, se hizo una estimación de la utilidad de las mediciones de calidad del aire de una manera sencilla a través de la construcción de gráficas tridimensionales que llamamos "isopletas de ozono" usadas para relacionar las mediciones de óxidos de nitrógeno (NO_x), compuestos orgánicos volátiles (COV) y máximos de ozono (O_3) para tres sitios de la Ciudad de México. El ejercicio consiste en interpretar el transporte de la contaminación atmosférica en el Valle de México utilizando solamente los datos medidos y nuestras isopletas junto con sus correspondientes datos de rosas de los vientos. Esta interpretación -la basada en la información de mediciones únicamente- está sujeta a influencias locales y se compara con resultados recientes de modelación que muestran que cuando los datos medidos se usan en conjunción con la modelación de la calidad del aire, se puede obtener una mejor comprensión del problema de la contaminación atmosférica. Una estrategia correcta para estudiar el problema de la contaminación del aire, especialmente en el caso de la Ciudad de México donde meteorología y uso de suelo complejos están presentes, debe ser aquella en la que ambos componentes, modelación y medición, se persigan con igual vigor.

ABSTRACT

In many cities, the main tool used to assess pollution abatement policies is the air quality information obtained from local monitoring network. However, in the context of a complex meteorology and land use such as those prevailing in México City, the point-wise character and lack of detailed chemistry of this information may confer conflictive or biased information. The approach to understand the problem could be not based on solid ground. It is not until the measurement effort is complemented with detailed meteorological and air quality modeling that proper use of the information can be assured. In order to provide an example of this assertion, the usefulness of measured air quality data is gauged in a simplified manner, constructing three dimensional graphs containing local emission concentrations of nitrogen oxides (NO_x), volatile organic compounds (VOC) and maximum ozone (O_3) concentrations, that we call "ozone isopleths", for three sites in México City. Together with corresponding wind rose data, an interpretation of the air pollution transport in the Valley of México using only measured data is attempted. This interpretation, based on measured information subject to local influences, is compared with recent air quality modeling results showing that when measured data is used in conjunction with air quality modeling a better interpretation of air pollution problem can be obtained. A correct strategy to study the air quality problem, especially in the case of México City where complex meteorology and land use is present, should be that both endeavors, measuring and modeling, are pursued with equal vigor.

Keywords: Air quality modeling, air quality measurements, meteorology, México City, urban air quality.

1. Introduction

Measurements of atmospheric pollutants are an expensive but indispensable undertaking if the air quality of a region or city is to be evaluated. The importance of documenting the concentrations of primary and secondary criterion gases with their diurnal changes, and of building the corresponding data bases to gain an historical perspective of their evolution cannot be understated and play a prominent role in the basic information of modern urban societies.

In México City the official automatic air quality monitoring network (SIMAT for its acronym in Spanish) has 36 stations that make continuous measurements of ozone (O_3), sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), particles smaller than 10 micrometers (PM_{10}), particles smaller than 2.5 micrometers ($PM_{2.5}$) and sulfhidric acid (H_2S). The information provided by this network is used to prepare the Metropolitan Air Quality Index (IMECA) that allows for the implementation of the Environmental Contingency Program (SMA, 2006).

In many cities, this type of information is the main tool used to assess pollution abatement policies (Gramsch *et al*., 2006; Broday and Broday, 2006; Chen *et al*., 2006). However, in the context of a complex meteorology and land use such as those prevailing in México City, its point-wise character and its lack of detailed chemistry may confer conflictive or biased information. Decisions taken based on this information could be counterproductive or ineffective. It is not until the measurement effort is supplemented with detailed meteorological and air quality modeling that proper use of the information can be assured.

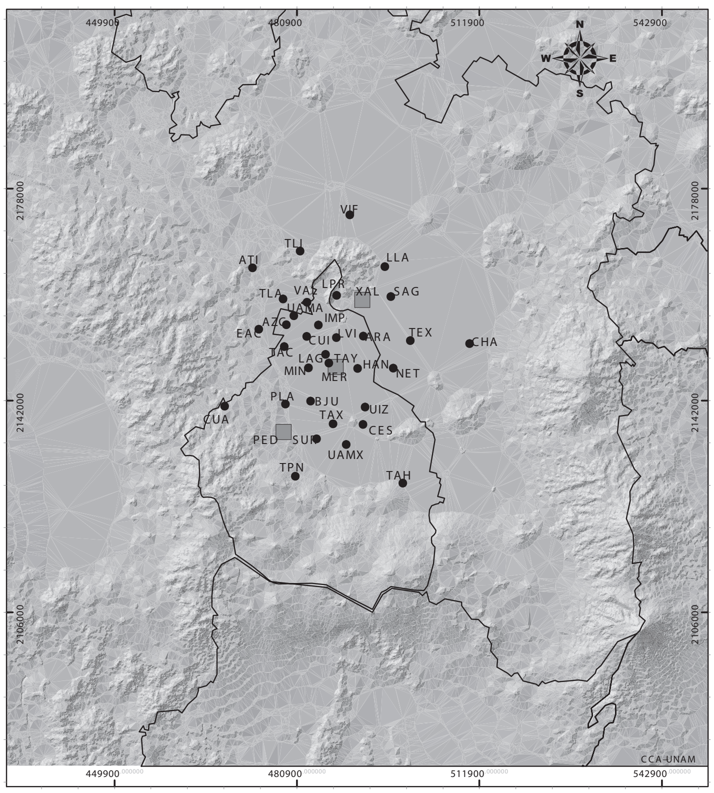
To provide an example of this, we first obtain simplified the dimensional graphs relating the recorded local concentrations of organic compounds (VOC), of nitrogen oxides (NO_x) and maximum ozone (O_3) that we call "ozone isopleths" at three sites in México City, where measured information is available for March and November from 1995 to 2001. We emphasize that these ozone isopleths are merely a graphic aid to interpret the measured information and are not used to predict ozone concentrations based on VOC and NO_x measurements.

Secondly, the graphic information rendered by the ozone isopleths is supplemented with wind roses for the same time period at each site, and an interpretation combining these data and previous published work on the behavior of local meteorology and air quality is attempted. This interpretation is then reevaluated by comparing it with recent air quality and meteorological modeling results found by different researchers for the Valley of México.

2. Ozone isopleths and wind roses

As a tool for the analysis of the NO_x, VOC and ozone measurements we have chosen the use of three dimensional graphs reminiscent of the so called ozone isopleths. The purpose is to capture the most important features of the local NO_x, VOC and ozone measurements in a graphic way.

The selected sites for this study are the SIMAT stations Xalostoc, La Merced and Pedregal. In Figure 1 their location is shown.



ARA Aragón
ATI Atizapán
AZC Azcapotzalco
BJU B. Juárez
CES Cerro Estrella
CHA Chapingo
CUA Cuajimalpa
NET Nezahualcoyotl
TAC Tacuba
TAH Tlahuac
TAX Taxqueña
TAY Tacubaya
TEX Texcoco
TLA Tlalnepantla
TLO Tultitlán
TPN Tlalpan
UAMA UAM Azcapot.
UAMX UAM Xoch.
UIZ UAM Iztapalapa
VAL Vallejo
VIF Villa Flores
XAL Xalostoc
LAG Lagunilla
LLA Los Laureles
LPR La Presa
LVI La Villa
MER Merced
MIN Insurgentes
IMP Inst. Petróleo
PED Pedregal
CUI Cuitlahuac
EAC Ecatepec
HAN Hangares
PLA Plateros
SAG Sn. Agustín
SUR Sta. Úrsula

Fig. 1. México City Automatic Atmospheric Monitoring Network. Small gray boxes show the location of Xalostoc, La Merced and Pedregal stations used for this work.

The information used to construct ozone isopleths for these sites is shown in Figure 2a, b and c. Data on VOC corresponds to March and November and was recorded by the Mexican Petroleum Institute from 1995 to 2001 (Arriaga-Colina *et al*., 2004). Corresponding data on NO_x and O_3 was obtained from the local air quality monitoring stations of SIMAT.

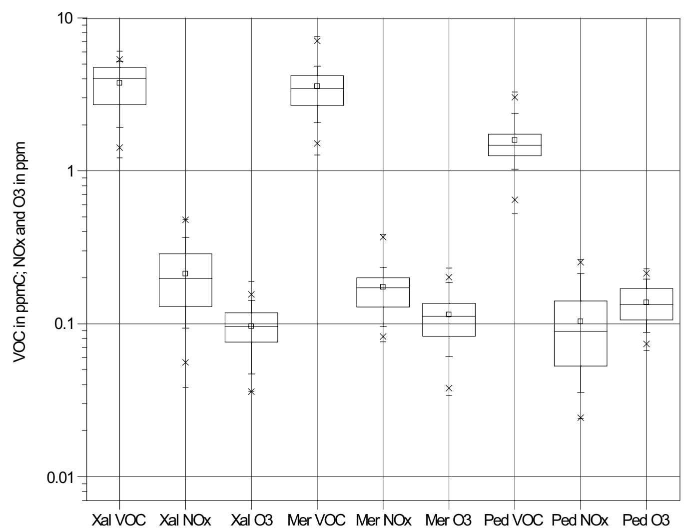


Fig. 2. VOC, NO_x, and maximum concentrations of O_3 for Xalostoc, (Xal), Merced (Mer), and Pedregal (Ped) from 1995 to 2001.

In the literature, ozone isopleths are graphical displays of a series of simulations used for box models (US EPA, 1977, 1978) to calculate plots of maximum ozone yields as a function of (VOC) and (NO_x) mixtures (Carter *et al*., 1982) that were used extensively in past decades to estimate the effects of reducing ozone precursors (Wolff *et al*., 1967; Carter *et al*., 1982; Shafer and Seinfeld, 1986; Kelly and Gunst, 1990; Tonnesen and Jeffries, 1994; Winner *et al*, 1995).

Isopleths allowed researchers to predict in a qualitative form ozone production as a function of its precursors, VOC and NO_x. Here they are not constructed as a predictive tool but rather as a three dimensional graphical device to relate local VOC, NO_x and ozone maximum measurements, as will be described and shown shortly.

To construct our ozone isopleths we proceed as follows: as done in EKMA box model (US EPA, 1977, 1978), in order to capture fresh emissions only the average of morning concentrations measurements from 6:00 to 9:00 LT of NO_x and VOC are used. To form the isopleths the maximum O_3 concentration for that day was considered. In a two dimensional plot of VOC versus NO_x, points with the same ozone concentration are lined together to get the isopleths.

Wind roses for years 1995 to 2001 for Xalostoc are shown in Figure 3. The historical meteorological data for March and November from 1995 to 2001 suggest that winds between 2 to 5 ms^{-1} come from the northeast in November with the presence of other wind directions components.

Wind data for La Merced is shown in Figure 4. Winds come mainly from the east with important components from the west and small components from the north. Wind magnitude never exceeds 2 ms^{-1}.

Wind roses for Pedregal for March and November 1995-2001 are shown in Figure 5. The dominant wind direction is from the southwest, but also small components from north and northeast are present.

The corresponding ozone isopleths for the three selected sites are shown in Figures 6 to 8.

3. Data analysis

The information at each of the three sites provided by our ozone isopleths and wind roses is now examined. This exercise provides important clues about how measurements are locally influenced.

In broad terms, ozone isopleths for Xalostoc show relatively low O_3 concentrations but high VOC and substantial NO_x concentrations.

The corresponding wind roses indicate that Xalostoc is mainly upwind, since its location is in the northeast of México City and dominant winds are from the northeast. It should be mentioned that this site may be influenced by nearby car painting facilities.

La Merced monitoring station is located on the roof of a Public Health Services center (one level above ground) in a mixed urban area, in which low income residential and commercial land use coexist along with some primary schools, sports fields and parks with temporary vegetation. It is located on a main avenue with traffic circulation in both directions with dense vehicular traffic. Two hundred meters southeast of the monitoring station a police shooting range is located.

Meteorology of this area is composed of winds coming mainly from the east and on a smaller scale from the west during March and November 1995-2001, 0600 to 0900 LT. Wind magnitudes never exceed 5 ms^{-1}. VOC levels in La Merced are very high, reaching almost 7 ppm from 0600 to 0900. Also, NO_x levels reach 0.4 ppm. Ozone levels are as high as 0.2 ppm.

Pedregal monitoring station is at floor level in a primary school backyard, east of the classrooms. This station is surrounded by an urban area consisting mainly of high income residential homes with green areas. The surrounding streets show low vehicular traffic consisting mainly of new private cars and local school buses.

A brief look into the wind rose for March and November, 1995 to 2001, shows a prevailing contribution from southeast. Wind speed is mainly less than 2 ms^{-1} although velocities of up to 2 ms^{-1} can sometimes be found.

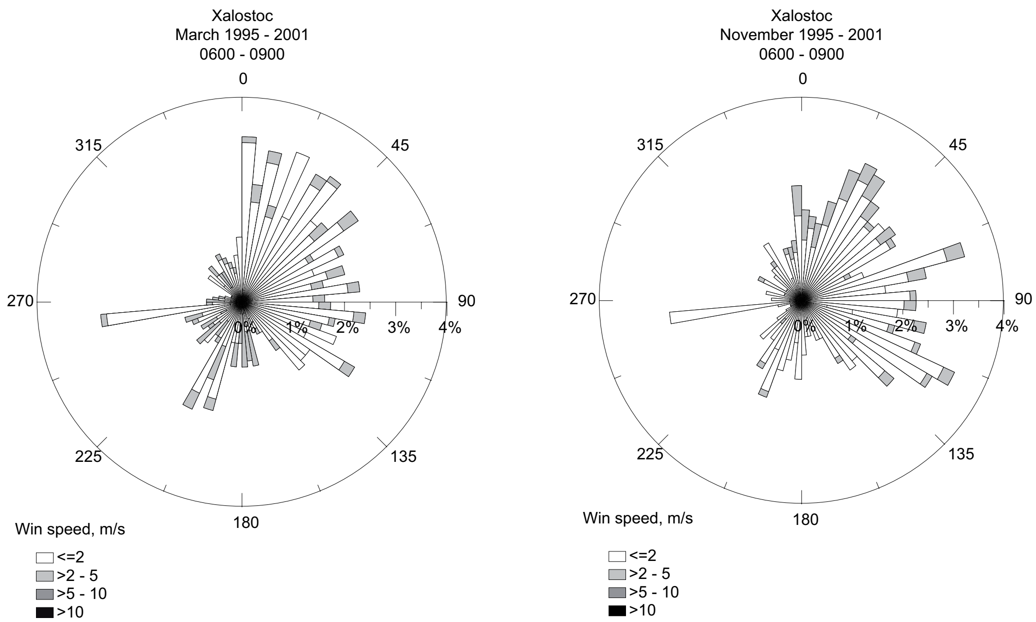


Fig. 3. Xalostoc wind roses for March and November 1995-2001.

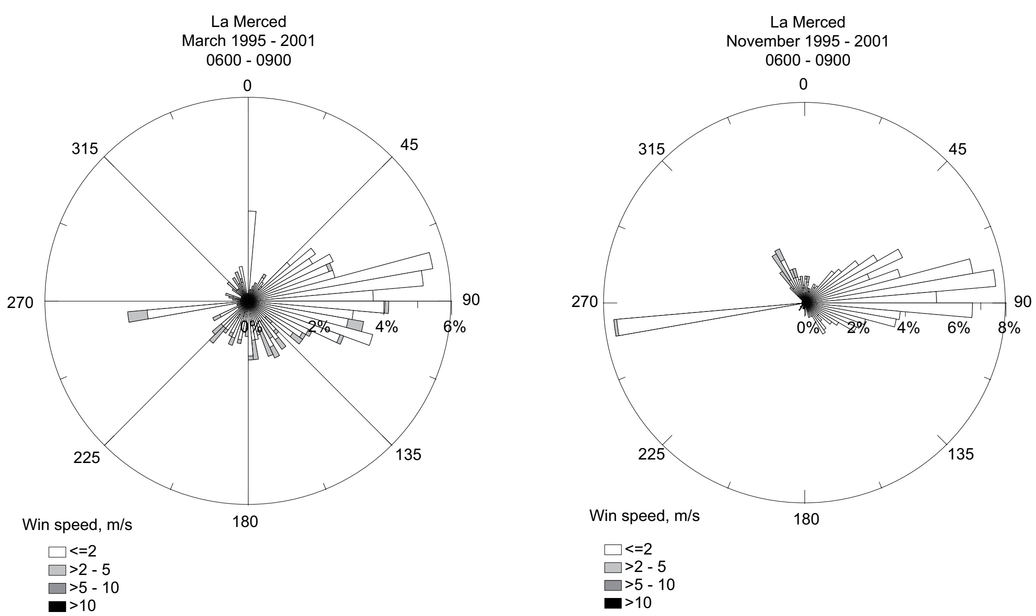


Fig. 4. La Merced wind roses for March and November 1995-2001.

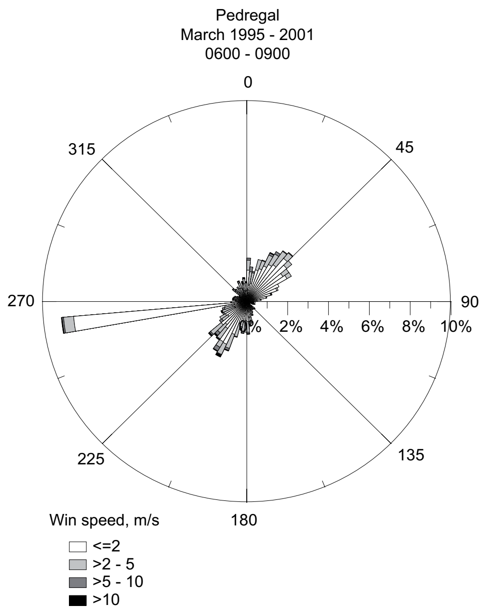


Fig. 5. Pedregal wind roses for March and November 1995-2001.

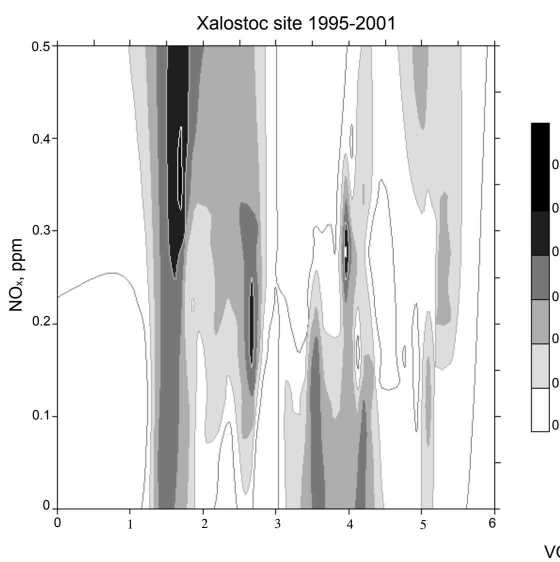


Fig. 6. Ozone isopleths for Xalostoc site, 0600 to 0900 measurements from 1995-2001.

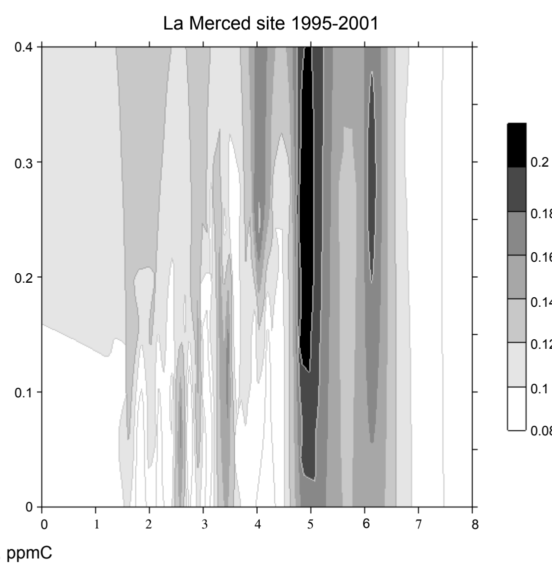


Fig. 7. Ozone isopleths for La Merced site, 0600 to 0900 measurements from 1995-2001.

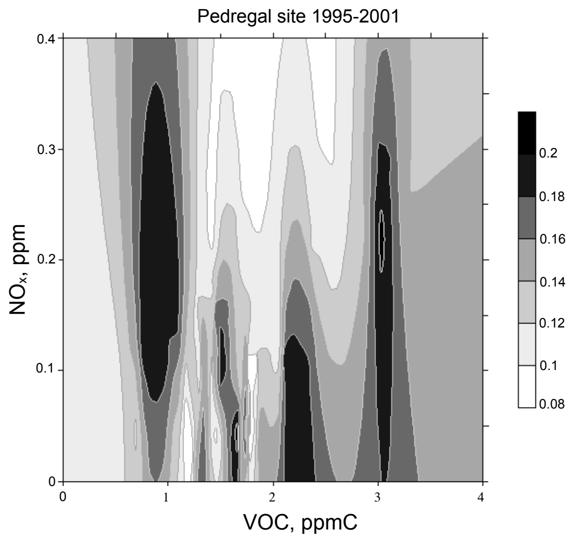


Fig. 8. Ozone isopleths for Pedregal site, 0600 to 0900 measurements from 1995-2001.

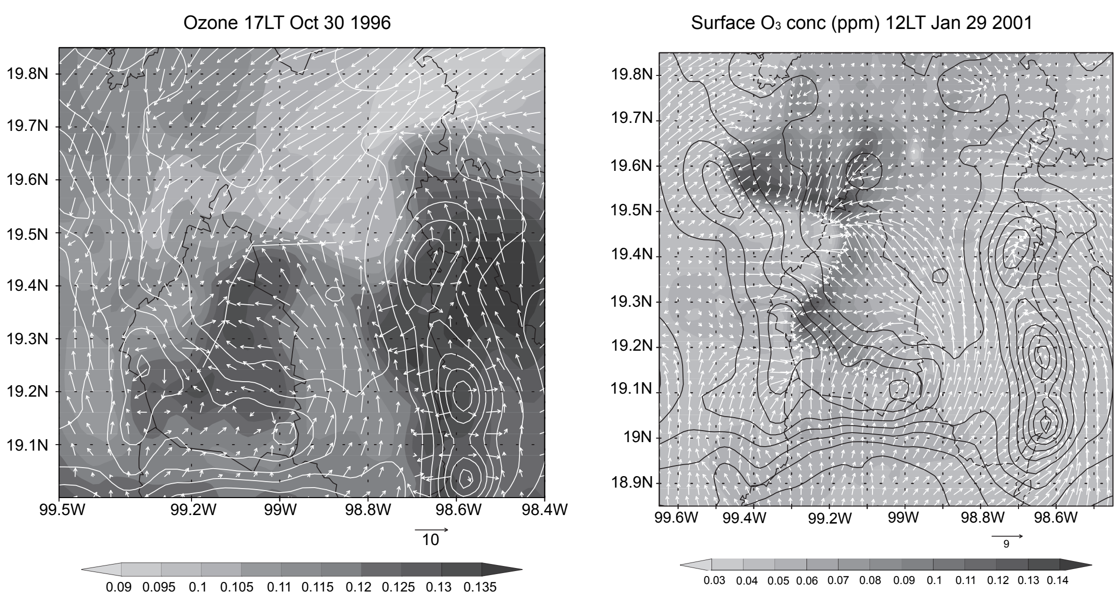


Fig. 9. In a) Surface wind fields in ms^{-1} and ozone mixing ratios in ppm, for October 30, 1996, 17:00 LT. The white lines signal the position of a confluence. Highest ozone mixing ratios accumulate around the confluence line in the north and southwest of México City. In b), the same information but for January 29, 2001, 13:00 LT. Highest ozone mixing ratios accumulate around the confluence line. (From Jazcilevich, 2005).

Pedregal isopleth shows, as La Merced and Xalostoc, high levels of volatile organic compounds but not higher than 4 ppmC. Nitrogen oxides levels range up to 0.3 ppm. Ozone levels are as high as 0.15 ppm.

4. Discussion

Through a cursory examination of the ozone isopleths shown in Figure 6 to 8 two facts are evident:

1) The important differences in the isopleths shape and the concentration values for NO_x, VOC and O_3 at each site underscore the local nature of air quality measurements.
2) VOC concentration values are very high. Predictive isopleths found in Wolff *et al*. (1967), Carter *et al*. (1982), Shafer and Seinfeld (1986), Kelly and Gunst (1990), Tonnesen and Jeffries (1994) and Winner *et al*. (1995) do not contemplate this VOC values. This suggests that O_3 concentrations should be much higher than what was actually measured. An explanation for this could be that although the atmosphere in México City is highly reactive, VOC measurements include a large proportion of low-reactive compounds for O_3 formation such as propane and n-butane widely used in México City (Arriaga *et al*., 1996).

Using the information provided by the ozone isopleths and wind roses we may attempt further conclusions. The geographical locations of the three selected sites form a diagonal line passing over México City. At first glance, and as pointed out in Williams *et al*. (1995), wind roses show that this diagonal may be a general pattern for the wind direction: dominant winds from the northeast traveling over the city towards Pedregal passing over La Merced.

This conclusion is reinforced from the following observations: 1) Xalostoc is an "emitter" since it shows the lowest O_3 concentrations even though the VOC are high and the NO_x concentrations are substantial; 2) in La Merced all compounds have high concentration since it receives the emissions coming from the northeast; and, 3) in Pedregal, which is surrounded by residential traffic, no industries and therefore relatively low emissions, high O_3 concentration are reported conferring to this site a "receptor" character.

Does this last set of conclusions hold when confronted with recent air quality modeling studies such as Jazcilevich *et al*. (2005) and DeFoy *et al*. (2005), showing the presence of more complex surface wind meteorology and therefore more complex transport processes? Figures 8a and b show the presence of confluence lines over México City formed during peak concentration hours. This phenomenon occurs typically when high pressure systems dominate central México. During November and early March these systems are common. Also see, Klaus *et al*. (1999).

Only after this modeling information is considered, another picture emerges on the nature of the three selected sites. Pedregal is no longer receptor, and La Merced is now a possible place for a confluence to be present. Furthermore, the existence of southwest components for the Pedregal wind roses shown in Figure 5 and the spread of wind direction components for La Merced, shown in Figure 4, cannot be ignored and actually strengthen the notion of the existence of surface confluences.

5. Conclusions

Our purpose has been to provide an example how insight and a proper interpretation of measured data are obtained only when meteorological and air quality modeling information is introduced detailing the behavior of local air mass fluxes and the corresponding pollutants transport.

Expensive measurements campaigns in México City have been carried out in recent times such as MARI (IMP and LANL, 1994), IMADA (Edgerton *et al*., 1998), and more recently, the MILAGRO project (Centro Molina para la Energía y el Ambiente *et al*., 2006). Certainly valuable detailed information on the chemical composition of the atmosphere in México City will be obtained clarifying or explaining important issues on the local photochemistry. Nevertheless, as we exemplified here in a simplified form, in order to put this measured data in a proper perspective it has to be accompanied by a similar modeling effort increasing its resolution, improving the emissions inventories and photochemical mechanisms.

The best way to reveal the shortcomings of each endeavor such as the point-wise character of measurements and the possible lack of fidelity of air quality models is to carry them out as a unified scientific effort. Only then we can gauge their usefulness and their potential to become powerful tools to analyze and study the air quality problems and solutions in México City.

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