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Recent Trend in Ozone Levels in the Metropolitan zone of Mexico City

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Abstract. Ozone concentration in the atmosphere of Mexico City is analyzed for the period 2000-2006, finding an average reduction of 24%, in spite of not meeting the norm of 110 ppb in more than 42% of the days in Pedregal. The maximum ozone levels in the last three years were 250 ppb well above the norm of 110 ppb. The number of vehicles registered in the Federal District has increased in the period by an average of 35%. Notwithstanding the increase in vehicular fleet, improvement of air quality is ascribed to the replacement of old cars by more efficient and less contaminating new cars. To decrease even more the ozone concentration, it is suggested to decrease further the Reid Vapor Pressure of gasoline to 7.0 psia to reduce the evaporation of light olefins.
Keywords: Ozone, replacement of old cars by new ones, daily emission

Resumen. Se analiza la concentración de ozono en la atmósfera de la Zona Metropolitana de la Ciudad de México durante el período 2000-2006, encontrando una reducción promedio de 24%, a pesar de que no se cumple con la norma de 110 ppb en más de 42% de los días en la estación de Pedregal. El máximo nivel de ozono en los últimos tres años fue de 250 ppb, arriba de la norma de 110 ppb. El número de vehículos registrados en el Distrito Federal tuvo un incremento promedio en el periodo de 35%. A pesar del incremento vehicular, la mejoría en la calidad del aire se adscribe al remplazo de vehículos viejos contaminantes por más eficientes y menos contaminantes vehículos. Para disminuir aún más los niveles de ozono se propone reducir la presión Reid de la gasolina a 7 psia, lo cual reduciría la evaporación de las olefinas ligeras.
Palabras clave: Ozono, remplazo de vehículos viejos por nuevos, emisión promedio diaria.

Introduction

Garfias and Díaz [1] analyzed the trend in ozone levels from 1986 to 2000, finding that the worst year was 1991, when a peak of 404 ppb was reached**.** Since then, ozone levels were substantially decreased to a maximum of 282 ppb in 2000. However, as in 2000 the ozone concentration did not decreased as consistently as previously, it was feared that the increment in the vehicular fleet and its consequent increase in vehicular emissions would deteriorate air quality in the Valley of Mexico. To study data, they found that the universe made by the following five stations: Tlalnepantla, Xalostoc, Merced, Pedregal and Cerro de la Estrella, when ozone data was grouped yearly can be studied statistically. They concluded that the year with the highest ozone level and the higher standard deviation was 1991, year which was taken as reference thereafter to make comparisons on the efficiency of the municipal programs to reduce ozone levels. Furthermore, they observed an average reduction in the ozone levels of 34.4% on the group of the five stations in 1999 among the percentiles 5 and 95% with respect to 1991, reduction that increases as the percentile is smaller. They also found that in the years of the ninety decade of last century, the maximum daily ozone concentration was reduced year by year, with the exception of 2000. Comparing the ozone levels of 2000 with respect to 1999, there was a reduction in the lower percentiles but not in the higher ones. In 1991 only 22.7% of the measurements complied with the norm in the five stations, while in 1999 the satisfactory maximum daily ozone measurements raised to 55%, and consequently it was affirmed that the program to control ozone was successful and met the goal set then.

The present study is a continuation of the previuos one and it encompasses data from 2000 to 2006 for the five stations described previously

The five meteorological stations considered have the following geographical coordinates:

Tlalnepantla:	19° 31’ 42.229” Lat. N.	99° 12’ 15.233” W. Long.
Xalostoc	19° 31’ 39.893” Lat. N.	99° 04’ 35.201” W. Long.
Merced	19° 25’ 27.792” Lat. N.	99° 07’ 09.397” W. Long.
Pedregal	19° 19’ 29.045” Lat. N.	99° 12’ 13.377” W. Long.
C. de la Est.	19° 20’ 09.184” Lat. N.	99° 04’ 28.829” W. Long.

The figure 1 shows de meteorological stations relative position (All the stations are located at 99° West Longitude and 19° North Latitude. The longitude as well as the latitude in the figure are in minutes of degree and the horizontal axis is with negative numbers because West longitude increases towards the left):

The distance between meteorological stations in kilometers appears in the table 1:

Recent trend

The registry of ozone data in the five stations could be considered reliable for comparison purposes, as there is sufficient data, close to the 1825 days in normal years and 1830 in a leap year. The numbers of registered days in the period are given in Table 2.

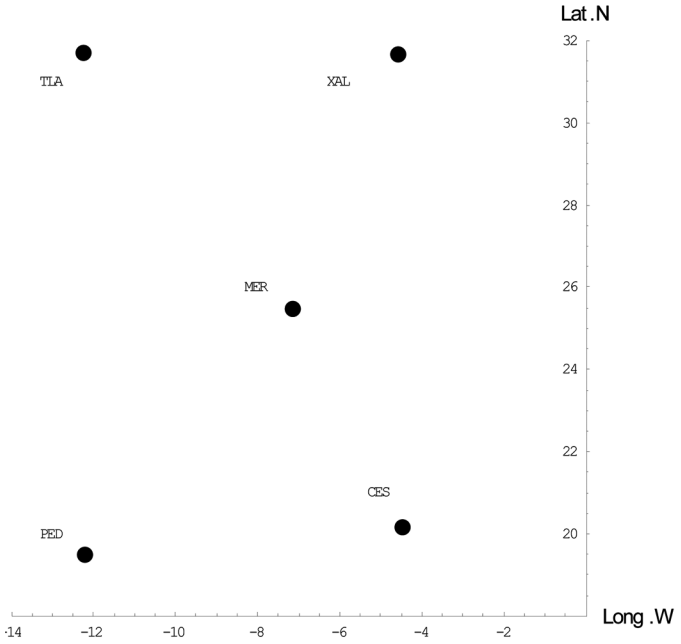


Fig. 1

Table I. Distance between meteorological stations (kilometers).

	CES*	Merced	Pedregal	Tlalnepantla	Xalostoc
CES*	0	5.946	7.771	13.923	11.512
Merced	5.946	0	7.837	8.058	6.713
Pedregal	7.771	7.837	0	12.220	14.375
Tlalnepantla	13.923	8.058	12.220	0	7.667
Xalostoc	11.512	6.713	14.375	7.667	0

* Cerro de la Estrella.

Table 2. Number of days in the period 2000-2006 producing ozone data.

Year	Days registered
2000	1801
2001	1822
2002	1805
2003	1809
2004	1819
2005	1795
2006	1815

The media evolution of the daily maximum ozone levels in the group of five stations is illustrated in Figure 2.

In Figure 2 it can be appreciated that the media trend decreases in the whole period, but the decrease is more acute in the first part of the period (2000-2001) than in the final portion (2005-2006). The percentage of days in the 5 stations, in which the norm 110ppb is exceeded, is another important factor to be analyzed. This is illustrated in Figure 3.

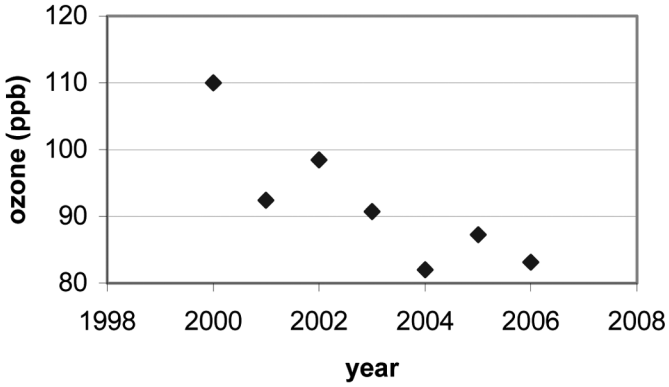


Fig. 2. Yearly mediam of maximum daily ozone.

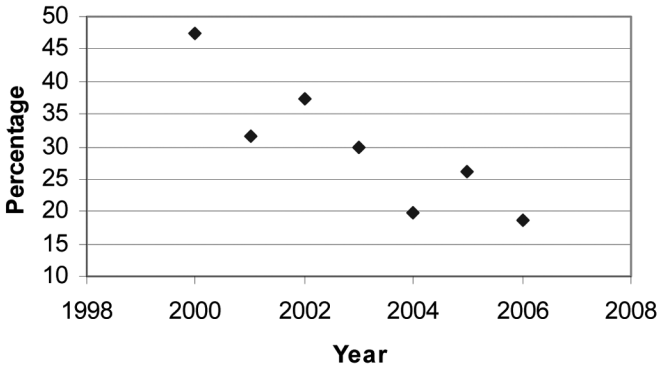


Fig. 3. Porcentage of days exceeding norm.

The maximum daily ozone per year is illustrated in Figure 4. It can be appreciated that the maximum daily ozone lies around a figure of 225 in the last portion of the graph regardless of year.

The hourly ozone data for the 5 stations depict the ozone concentration in the Valley of Mexico is summarized in Table 3.

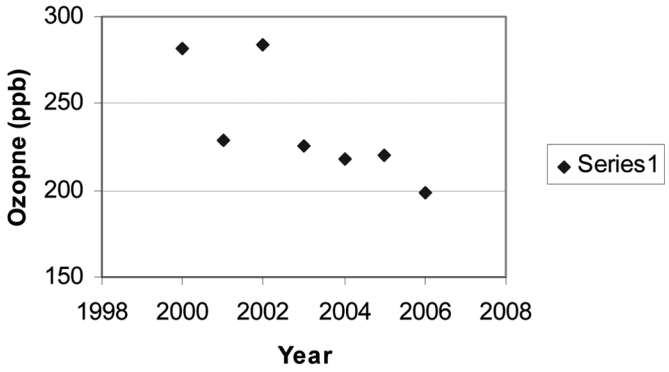


Fig. 4. Maximum daily ozone in the 5 stations.

Table 3. Ozone concentration (ppb) in the Valley of Mexico (5 stations).

percentile	2000	2001	2002	2003	2004	2005	2006	Reduction 2000-2006 (%)
10	51	41	44	44	38	39	40	21.6
20	69	56	61	58	51	53	53	23.2
30	83	68	73	68	63	66	65	21.7
40	97	79	85	80	72	76	73	24.7
50	108	90	97	88	80	86	83	23.2
60	120	101	108	99	89	96	90	25.0
70	132	113	120	110	98	105	99	25.0
80	148	127	133	123	110	119	109	26,4
90	169	147	153	140	129	136	127	24.9
							Average = 24.0	

From the data shown in Table 3, it can be concluded that:

- The average ozone reduction in the period 2000-2006 was 24%, which compares favorable and continues the observed trend in 1991-1999 that showed a reduction of 34.4%.
- In the period 1991-1999 the decrease in the ozone concentration was higher in the lower percentiles than in the higher ones. The opposite took place in the period 2000-2006, where the higher ozone reductions took place in the higher percentiles.

With respect to each station, the percentage of days exceeding the ozone norm is shown in Table 4.

Pedregal is the station in which the norm was more often exceeded, as in 2006 the norm was not met in more than 42% of the days. On the other hand, Xalostoc was the station with the lowest number of days in which the norm was not complied with, as only less than 6% of the days did not meet the norm in 2006.

From inspection of Figures 3 and Table 3 it can be concluded that the highest ozone concentration in the period was registered in 2000, followed by 2002.

The distribution of the maximum daily ozone levels for the five stations, from the 10% percentile to the 90% is given in Table 3.

Conclusions and Recommendations

It can be concluded that:

- Ozone levels have been decreasing along the period 2000-2006, but still very often the norm is exceeded, mainly at the Pedregal Station, where they amounted to 42% of the registered days.
- The worst ozone levels were found in the year 2002 within the period 2000-2006.
- Air quality improved as the years pass, the improvement is more notorius in the higher percentiles than in the lower ones.

Vehicular Fleet

The trend in ozone levels can not be discussed without considering the number of vehicles circulating in the Metropolitan Zone of Mexico City. In Table 5, it is summarized the number of vehicles registered every two years by the Government of the Federal District.

From Table 5 it can be concluded that:

- Except pick'ups all other type of vehicles have increased in number in the period 2000-2006 by an average of 35%.As ozone is mainly affected by gaso-

Table 4. Yearly percentage of days per station in which the ozone norm is exceeded.

	2000	2001	2002	2003	2004	2005	2006
Cerro Est.	35.9	29.7	28.2	27.9	17.3	21.5	11.2
Merced	58.6	45.7	42.1	32.5	21.3	30.4	22.5
Pedregal	73.4	41.6	67.7	51.5	34.1	48.3	42.2
Tlalnepantla	35.0	26.6	27.1	22.1	15.9	14.1	12.0
Xalostoc	33.6	14.4	20.8	15.5	10.1	14.6	5.7

Table 5. Vehicular Fleet circulating in the Metropolitan Area of Mexico City.

Type	1994	1996	1998	2000	2002	2004	2006
private car	1,969.277	1,947,464	2,147,448	2,364,031	2,722,080	2,967,893	3,275,567
taxi	69,745	92,222	96,639	109,792	112,452	118,634	155,126
combi	20,963	20,963	20,820	19,825	19,700	19,485	31,418
microbus	32,346	32,346	31,590	31,949	30,757	33,051	32,419
Pick up	153,916	146.748	148,896	145,846	151,218	128,281	105,761
< 3 ton	48,172	49,189	50,572	53,607	61,494	62,543	64,613
Tract bus	49,667	53,333	51,017	62,886	75,575	83,034	86,324
bus	23,561	23,829	22,884	24,896	30.656	32,565	41,198
>3 ton	52,730	51,934	51,584	52,804	56,744	57,913	61,368
motorcycle	37,667	54,408	73,869	96,703	102,499	127,454	173,372
Total	2,458,944	2,472,436	2,697,317	2,964,339	3,363,175	3,630,853	4,027,166

Source: Secretaría del Medio Ambiente del GDF.

Table 6. Gasoline consumption in the Metropolitan Area of Mexico City (millions of liters per day).

	2000	2001	2002	2003	2004	2005	2006
PEMEX Magna	16.4	16.4	16.1	16.0	16.2	16.6	18.1
PEMEX Premium	1.75	2.0	2.4	2.7	2.8	2.7	2.9
Total	18.2	18.4	18.5	18.7	19.0	19.3	21.0

Source: Petróleos Mexicanos

line driven vehicles, it is convenient to analyze the consumption of gasoline in the period, information which is given in Table 6.

- In Table 6, it can be appreciated a yearly increase in gasoline consumption, which amounts to 15.7% in the period. The higher quality gasoline, the PEMEX Premium had an increase of 64% in the period, which is indicative of the preference shown by the owners of new cars, to use PEMEX Premium.
- The ozone reduction is slightly higher in the higher percentiles. As the regions showing higher ozone levels are where the most affluent society resides, it could be inferred that the rate of car replacement for most modern and less contaminating vehicles is higher in wealthy regions than in lesser ones.
- As the volume of gasoline used in the Valley of Mexico of 20 millions of liters a day is high, it is advisable to improve gasoline quality by reducing the Reid Pressure to 7 psig, in order to decrease the gasoline lost by evaporation richer in olefins (2).
- Another factor that is required to analyze to reach firm conclusions is the temperature profile in the five stations aforementioned, as ozone formation is also temperature dependant. Unfortunately there is not a full registry of the temperature profile in the 5 stations that represent the Metropolitan Area of Mexico City.

The relation between temperature and ozone concentration is a very strong one. The following plot shows de hourly concentration of ozone and temperature normalized for the first six days of 1999 in the Pedregal metereological station. (the normalization of both: ozone and temperature was done substracting the mean value form the series and dividing by the standard deviation of the corresponding series. The mean of the ozone is 0.05388 ppm and the mean of the temperature 16.322°C. The standard deviation for the already substracted series are 0.05236 and 5.411 for ozone and temperaure respectively).

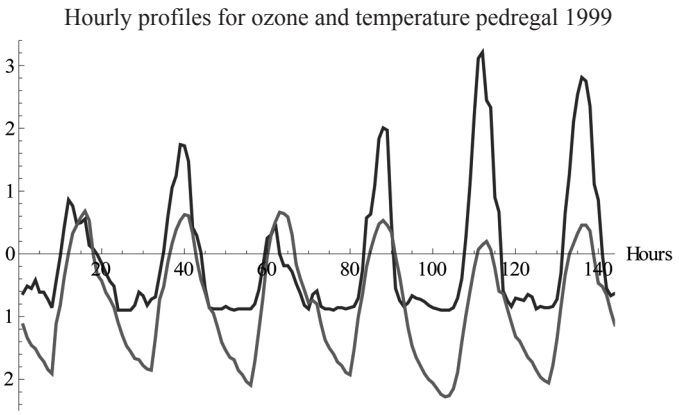


Fig. 5. Hourly profiles of ozone and temperature for six days

The most sharp peaks correspond to de ozone plot. A better relationship between de temperature and ozono behavior is obtained considering the mean values along the year. The next plot (Figure 6) shows the hourly average of temperature and ozone normalized (normalization was acomplished as in the previous plot. The means are 0.0363 ppm and 16.74°C for ozone and temperature respectively. The standard deviations are 0.02928 ppm and 4.68°C for ozone and temperature respectively) for the full year of 2005 in Pedregal meteorological station. The sharpest peak is for ozone

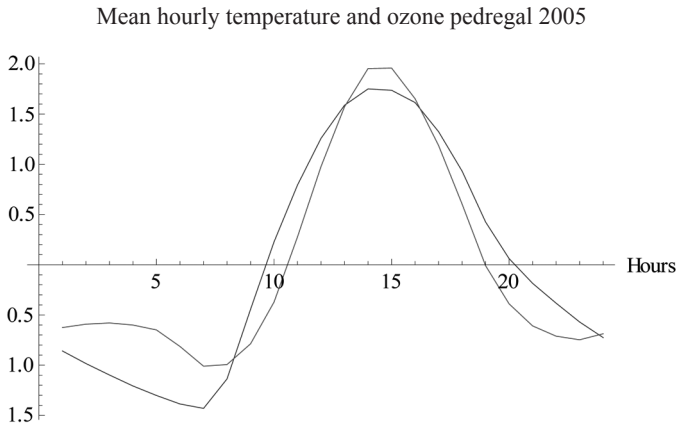


Fig. 6.

the same plot for the temperature and ozone for 2004 is the following (means of temperature and ozone are:16.05°C and 0.0308 ppm. The standard deviations are 4.18°C and 0.0264 ppm):

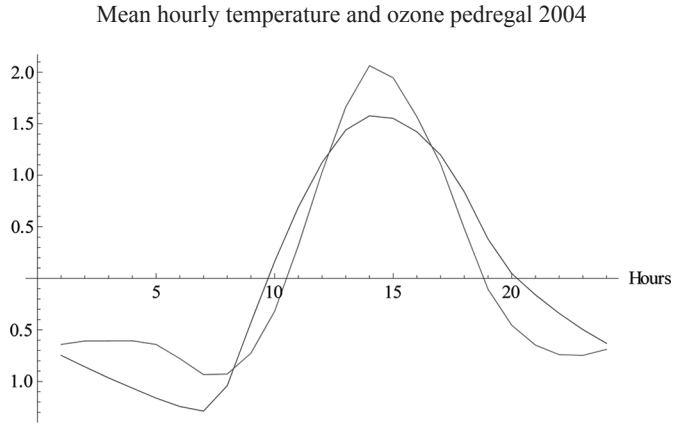


Fig. 7.

The plot comparing the normalized hourly temperatures for 2004 and 2005 for the same meteorological stations is:

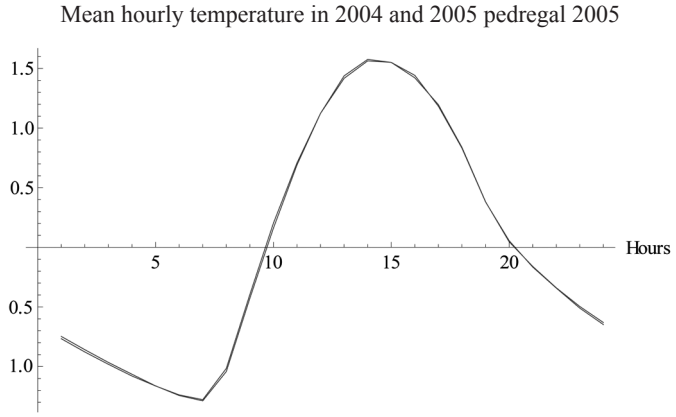


Fig. 8.

Both curves are almost identical.

Similarly the plots of mean yearly hourly for ozone for 2004 and 2005 given in the next figure almost coincide, which means that temperature was not a factor for air quality improvement.

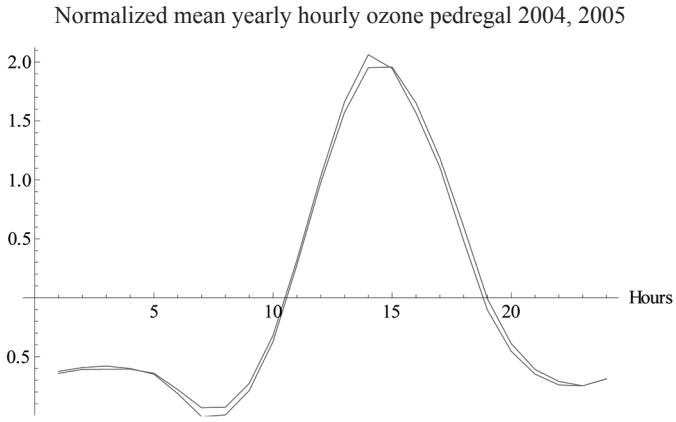


Fig. 9.

- It is recommended to have more reliable statistics as to the number of cars circulating in Mexico City, as the owners of old cars seem to maintain its registration even if they posses and only use the newly acquired cars.
- It can be concluded that the rate of change of old cars by new ones and less contaminating ones, has decreased the ozone levels in Mexico City. However, the problem still subsists in the area close to the Pedregal Station, where the norm is exceeded 42% of days.
- There is no doubt that as far as ozone is concerned, air quality in the Valley of Mexico has improved considerably. In order to better understand the reason for the improvement, it is convenient to consider jointly

the evolution of the vehicular fleet and gasoline consumption. If it is assumed that the whole set of private cars, taxis, combis, pick ups and motorcycles consume gasoline and if it is supposed that the distance traveled by the gasoline powered vehicles is constant in time, this is, that not withstanding the year, the total distance run by the vehicular fleet is the same, then it is possible to calculate an average figure for the liters per day consumed per vehicle for the years 2000, 2002, 2004 and 2006. The figures arrived at, are given in Table 7. The figures obtained are 6.64 for 2000; 5.96 for 2002; 5.64 for 2004; and 5.61 for 2006. It should be said that not necessarily the vehicles registered are those that circulate, as the owner of a new car shows preference to drive the new car rather than the older car. However, both cars are registered.

Table 7. Average gasoline consumption per day for the vehicular fleet in the Valley of Mexico

	2000	2002	2004	2006
Vehicles	2,736,197	3,107,949	3,361,747	3,741,244
Total daily gasoline consumption ($l \cdot 10^{-3}$)	18,157	18,523	18,952	21,003
Daily vehicular consumption (l/day)	6.64	5.96	5.64	5.61

- One would expect that the higher number of cars circulating would require an incremental volume of gasoline consumption. However, in spite of an increment in time on the number of units comprising the vehicular fleet, the gasoline consumption per unit has decreased, which indicates that there has been an increase in the efficiency of the vehicular fleet, by the incorporation of new models. An increase in efficiency means that the vehicles are less contaminating, disregarding the type of gasoline consumed. The relative volume increase in Premium over Magna would involve lesser emission of particles, as Premium has lower sulfur content than Magna, but as regards as the ozone precursors there should not be much difference between both fuels.

The relative volume increase in the demand of Premium over Magna confirms that there has been a car renewal, circulating now newer and more efficient cars than the older inefficient ones.

It seems to be that the increase trend in efficiency is approximating to a minimum and is not expected to a further spectacular increase in efficiency, as the figure reached in 2004 of 5.64 is close to 5.61 of 2006, unless a new policy is implemented to favor 4 cylinder cars over 6 or 8 cylinders ones.

On the other hand, in a survey conducted by one of the authors (3) it was found that the average daily consumption by a taxi was 18 liters. The taxi fleet in 2000 was 109 972 vehicles, which gives a total daily consumption of nearly 2 million liters, which is approximately 11% of total. If in top of that it is added the gasoline used by combis and buses, it is realized the importance that must be given to the Inspection and Maintenance Programs for the sector of public transportation.

Recently, some discussion has arisen upon the convenience to install the program to avoid vehicle circulation on Saturdays to improve air quality in Mexico City. We have no solid arguments to favor or oppose such a program, but from the ozone viewpoint, it is convenient to look at the average ozone levels during the different days of the week, to see if a lower ozone level on Saturday brings down an ozone level on another day.

In Table 7, the average ozone levels for the different days of the week are shown for the stations of Pedregal, Merced and Tlalnepantla for 2006.

In the following graphs the data in Table 7 are illustrated as follows:.

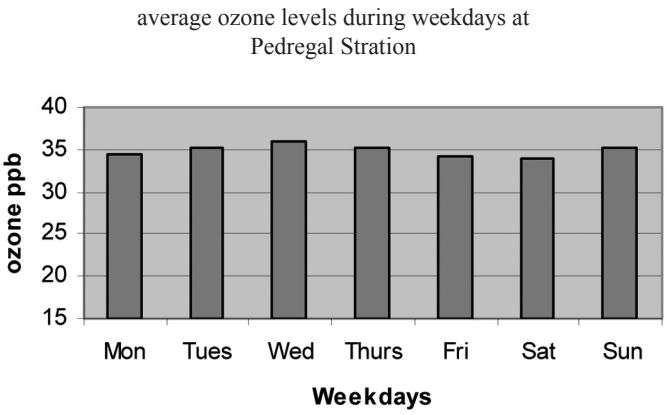
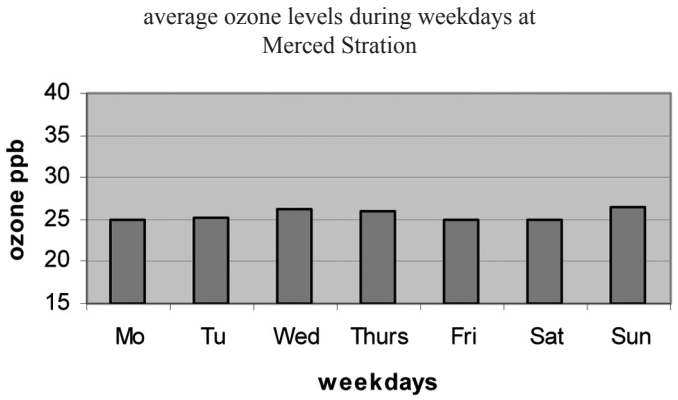
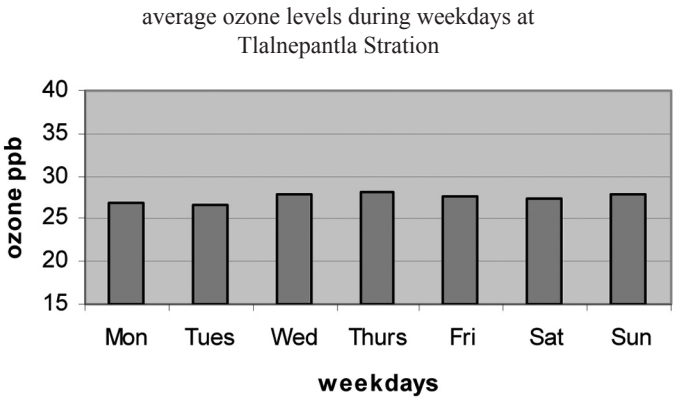


Table 7. Average ozone levels (ppb) for different days of week in Mexico City in 2006

Station	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Pedregal	34.373	35.313	35.866	35.305	34.279	33.978	35.162
Merced	24.995	25.333	26.236	25.862	24.989	24.839	26.406
Tlalnepantla	26.918	26.572	27.826	28.010	27.556	27.472	27.963





As expected, in general the worst ozone level is at Pedregal, with an average of 35 ppb. It is also seen that in general the worst ozone day on average is on Wednesday, and the lowest ozone level occurs on Saturday, and the low Saturday level does not reflect on the Sunday level, as in one station (Merced), the average ozone level is even the worst during the whole week. It must be said, that temperature is the factor that has most influence on ozone formation, so an analysis of temperature profiles among the weekdays would give a better idea as to the improvement on air quality by curtailing car circulation on Saturdays.

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