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Ozone weekend effect analysis in México City

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RESUMEN

Usando técnicas de modelado de la calidad del aire se presenta un análisis del episodio de contaminación atmosférica del fin de semana del 14 al 15 abril de 2007. Se muestra que las emisiones de la Zona Metropolitana de Toluca influyen en la calidad del aire de la ciudad de México, lo que explica este evento y no el debido al "efecto fin de semana". Haciendo uso de este escenario se muestra que la aplicación de la política de reducción de la circulación de automóviles durante ese fin de semana no hubiera podido disminuir las concentraciones de ozono sobre la Ciudad de México. La mejora en la calidad del aire de la Ciudad de México requiere la aplicación de medidas integrales a escala regional.

ABSTRACT

An analysis of the weekend air pollution episode of April 14-15, 2007 is presented using air quality modeling techniques. It is shown that the emissions of Toluca Metropolitan Area west of México City influencing the air quality of the city is a better explanation of the air pollution event on that weekend than the existence of a "weekend effect". It is also shown that the enforcement of traffic rules curbing car circulation during that weekend would not have resulted in ozone concentration reductions over México City. The improvement in air quality in México City requires the implementation of comprehensive measurements at the regional scale.

Keywords: México City, air quality modeling, ozone weekend effect.

1. Introduction

Surface ozone production in urban areas is caused by a non-linear process interaction of its precursors, nitrogen oxides (NO_X), volatile organic compounds (VOC), and light (Seinfeld and Pandis, 1998). Ozone concentration levels are influenced by mixing height variations, temperature and wind speed. Furthermore, emissions of highly reactive biogenic compounds produced by surrounding forest (Guenther *et al*., 1993; Simpson *et al*., 1995) may interact with the urban anthropogenic emissions.

Due to a non-linear relationship between precursors and ozone production it is possible in some cases that a reduction in precursors may not result in lower ozone levels. For example, in some cities during weekends when service, industrial, and traffic emissions are lower, there are comparable or even higher ozone concentrations than on workdays. The ozone weekend effect (OWE) indicates that the observed concentration on weekends is higher than that on workdays. The OWE combined with change of emission inventories of ozone precursors might imply whether O_3 formation was NO_X or VOC control-limited (Altshuler *et al.*, 1995). It is generally accepted that a VOC control-limited region is one where the concentration of ozone depends on the amount of VOC in the atmosphere. In these regions, ozone increases with increasing VOC and decreases with increasing NO_X. Reductions in VOC will only be effective in reducing ozone if VOC sensitive chemistry predominates. On the other hand, a NOx control-limited region is one where the concentration of ozone depends on the amount of NO_X in the atmosphere. In the NO_X control-limited regime, ozone increases with increasing NO_X and shows relatively little change in response to increased VOC emissions. Reductions in NO_X emissions will be effective only if NO_X sensitive chemistry predominates and may actually increase ozone in VOC control-limited regions. The OWE phenomenon has been studied in cities like Barcelona (Jiménez *et al.,* 2005), Phoenix, Arizona (Atkinson-Palombo *et al.,* 2006) and in southern California (Marr-Linsey and Robert*,* 2002; Qin et *al*., 2004; Gao and Niemeier, 2007). Researchers have shown that the OWE is stronger in urban areas than in rural areas (Marr-Linsey and Robert*,* 2002; Atkinson-Palombo *et al.,* 2006).

From 1990 to 2006 ozone concentration in México City (MC) during weekends has been in general lower than or similar than weekdays in spite of the weekend reductions in ozone precursors (Torres-Jardón, 2004; Muñoz-Cruz *et al*., 2007). An exception occurred on the weekend of April 14 to 15, 2007, when maximum ozone concentrations were significantly higher than the previous weekdays. Some policy-makers claim that this occurrence is the beginning of a weekend pattern caused by local traffic emissions.

Recent studies on the O_3-NO_X-VOC sensitivity in México City have suggested that peak ozone in MC is sensitive to reductions of VOC emissions (Torres-Jardón, 2004; Lei *et al.*, 2006). Therefore, a reduction in NO_X emissions will result in an increase in ozone, but will result in a decrease in O_3 only if NO_X control-limited conditions predominate.

There are six proposed hypotheses that explain the weekend effect (Jiménez *et al.,* 2005; CARB, 2003):

1. NO_X reduction: in areas that are "VOC-limited" more ozone is formed on weekends because decrease in NO_X emissions increase the VOC/NO_X ratio that can generate more ozone.
2. NO_X timing: peak emissions of NO_X are shifted to a different hour of day. This shift in the timing of NO_X emissions may induce a more efficient O_3 formation on weekends than on weekdays.
3. Carryover at ground level: this hypothesis assumes that light duty vehicle (LDV) traffic is higher with correspondingly lower heavy duty vehicle (HDT) on Friday and Saturday evenings, leading to overnight carryover of pollutants with higher VOC/NO_X ratios that can generate more O_3 on weekends than on weekdays. Carryover aloft: ozone-forming compounds aloft can descend and mix with surface fresh emission in a way more conducive to produce extra surface O_3 levels on weekends than on weekdays.
4. Increased weekend emissions: more ozone is formed on weekends because an increment of VOC and NO_X emissions from weekend activities i.e. lawn mowing, recreational cooking, etc.
5. Aerosols and UV radiation: increase in ozone can be related to an increment in radiation due to lower aerosol concentrations in the early morning and mid-day on weekends.

6. Ozone inhibition: variation in the traffic composition and activity can cause a change in emissions of NO during early morning: Lower NO concentrations decrease the titration of ozone, increasing the initial and peak ozone levels.

Ground-level ozone measurements are the consequence of a combination of factors that involve: local production of ozone (and its precursors), local transportation of ozone, long- and medium-range transportation of ozone. In this study we will analyze the April 14 to 15, 2007 weekend episode in México City and show that a plausible explanation for its occurrence was the transport of partially photochemically-aged plumes coming from neighboring Toluca Metropolitan Area, an industrial city west of México City (see Fig. 1).

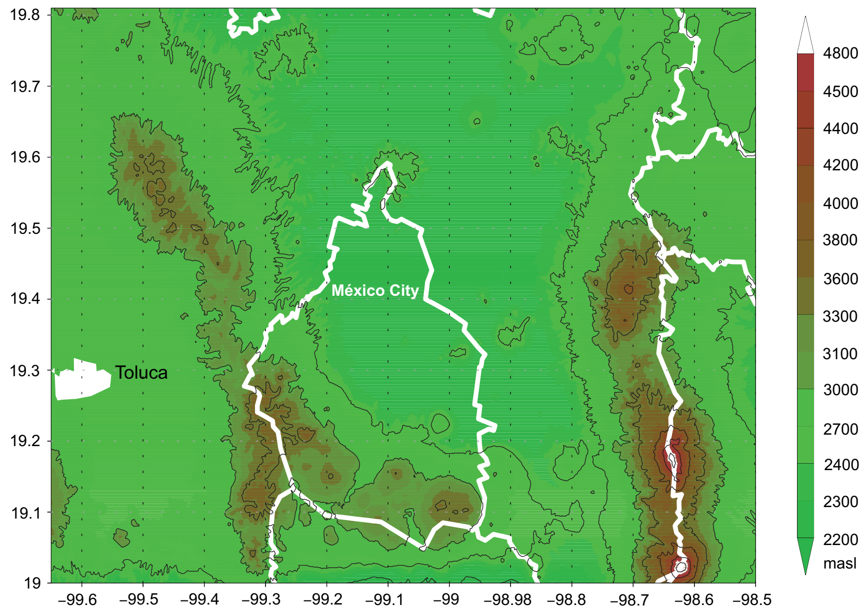

Fig. 1. Topography in the studied region (meters above sea level, masl) the elevation rage is from 2200 to 4800 masl. México City is surrounded by mountain ranges at east, south and west side, towards west is located Toluca city urban area in gray. Political boundaries are showed in white.

2. Methodology

First, air quality data from the local network were analyzed to identify and quantify the ozone levels during the weekend episode of April 14-15, 2007.

The actual emissions inventory for modeling purposes considers week-day emission (García-Reynoso, 2002); however this pattern is not representative for weekend and holidays therefore a weekend emissions inventory is created in order to model the weekend days using the Multiscale Climate Chemistry Model (MCCM). A set of statistical metrics is used to evaluate the performance of the model results. Finally a "what if" scenario analysis was conducted in order to test the effects of an emission control policy on Saturdays consisting of a reduction of allowed car circulation.

2.1 Air quality measurement analysis

An analysis of measured concentrations from the air quality monitoring network (SIMAT, 2007) was performed, considering 21 stations for ozone, 25 for CO, and 19 for NO and NO_2, in order to identify the weekend effect during April 14-15 in 2007 for those pollutants. The data set covers the period from January 1 to September 30, 2007. The weekend to workday ratio of hourly average concentration as defined in Eq. 1 was used in order to identify the magnitude of the weekend effect. The considered ratios were the following:

$$r_{wed,\,i} = \frac{\overline{[\chi]}_{wed,\,i}}{\overline{[\chi]}_{w,\,i}} \tag{1}$$

where $r_{wed,\,i}$ is the ratio for weekend day *wed* (Saturday or Sunday) at hour *i*, $\overline{[\chi]}_{wed,\,i}$ is the averaged concentration over all the stations of the compound χ (CO, NO_2, NO_X, O_3) for the weekend day *wed* at hour *i* and $\overline{[\chi]}_{w,\,i}$ is the same as previous one but for the workday *w* (Monday to Friday). The *r* is computed for every possible combination of weekend day over workday. Additionally a specific ratio was used to compare the April 14 -15 concentrations with the average Saturday and Sunday ratios.

2.2 Emissions inventory

According to the México City's annual emissions inventory for 2006, 99.3% of CO, 81.9% of NO_X, 34.1% of VOC, 48.1% of SO_2, 61.9% of $PM_{2.5}$, 22.8% of PM_{10} and 21.8% of NH_3 are emitted by mobile sources (SMA, 2008), this inventory does not account for weekly variations. Based on the ratios of week and weekend days of CO and NO_X concentrations it is possible to identify the vehicular emission variations. Considering that mobile (line) sources are the largest generators of CO and NO_X and because there is no information available to correct area (household, economic activities, airport, etc.) and point (industry) sources, the correction in emissions will be applied only for mobile sources. With these ratios a correction coefficient factor was generated to obtain an emission inventory for weekend days. The following equation was used:

$$E_{wknd,\,i} = E_{a,\,i} + E_{p,\,i} + r_i \;\; E_{m,\,i} \tag{2}$$

where $E_{wknd,\,i}$ is the corrected emission for a weekend day, $E_{a,\,i}$ is area emission, $E_{p,i}$ is point emissions, $E_{m,\,i}$ is mobile emissions (line) and r_i is the weekend/workday day ratio for CO at hour *i*.

The modeling domain covers a larger area than the México City's emissions inventory and includes the cities of Toluca, Pachuca and Cuernavaca. To include emissions from surrounding cities in the emissions inventory for the modeling domain, estimates were made based on population density for the year 2000. Grid cells from the México City's emissions inventory were mapped onto the other cities' grid cells taking into account that those grid cells have similar population density. This new emission inventory does not consider point sources in those urban areas and most certainly will underestimate emissions from those cities.

2.3 Multiscale climate chemistry model

MCCM was used to model the photochemistry in the region (Jazcilevich *et al.,* 2003a, 2003b, 2003c, 2005, 2007; García-R. *et al.,* 2000 and García-Reynoso, 2002). It includes modules for meteorology, biogenic emissions, photolysis, radiation, and deposition, among others. The meteorology module of MCCM is based on the PSU/NCAR mesoscale model (MM5) (Grell *et al*., 1994). An advantage of MCCM is that the meteorological model is directly coupled with the chemistry-transport model and a photolysis module. The biogenic emissions module is coupled with the radiation and RADM2 photochemistry modules (Stockwell *et al*., 1995). A deposition module is coupled with higher order closure turbulence parameterization. For a detailed description of MCCM see Grell (2000).

National Centers for Environmental Prediction (NCEP) meteorology data was used in order to generate the initial and boundary conditions of the meteorological field for MCCM. The data contains Global Final Analyses (FNL) on 1.0 × 1.0 degree grids covering the entire globe every six hours. These were operationally prepared by NCEP. The nest strategy and parameterizations used were the same as Jazcilevich *et al.* (2007).

To evaluate the performance of the model for each station, a set of standard statistical measures can be computed (Willmot, 1981; Lu *et al.,* 1997; EPA, 2008). These measures are: standard deviation of predicted and observed values, the root mean square difference (RMSD), systematic root mean square difference (RMSDs), unsystematic root mean square difference (RMSDu), normalized gross error (E_{ng}), normalized bias (nb), index of agreement (d), and normalized mean bias (NMB).

2.4 What if? scenario

A policy to control emissions from mobile sources is considered here to test its impact. It consists of reducing the number of car emissions by 20% from 10:00 to 18:00 h (all hours are in local time).

For this purpose, two computational experiments were performed. The first one uses the modified weekend emissions inventory as explained above. The second one uses this emissions inventory but considers a 20% reduction of mobile emissions from 10:00-18:00 h on Saturday. In the latter case it may be possible to even have lower emissions due to an increase in the average speed in the streets but at the moment there is no way to estimate this effect.

3. Results

The average concentration of measured ozone over all the México City monitoring stations from April 10 to 17 is shown in Figure 2. Peak ozone concentrations during the weekend of 14-15 are above 140 ppb in contrast with the workday peaks that are below 100 ppb. That behavior could be representative of an OWE.

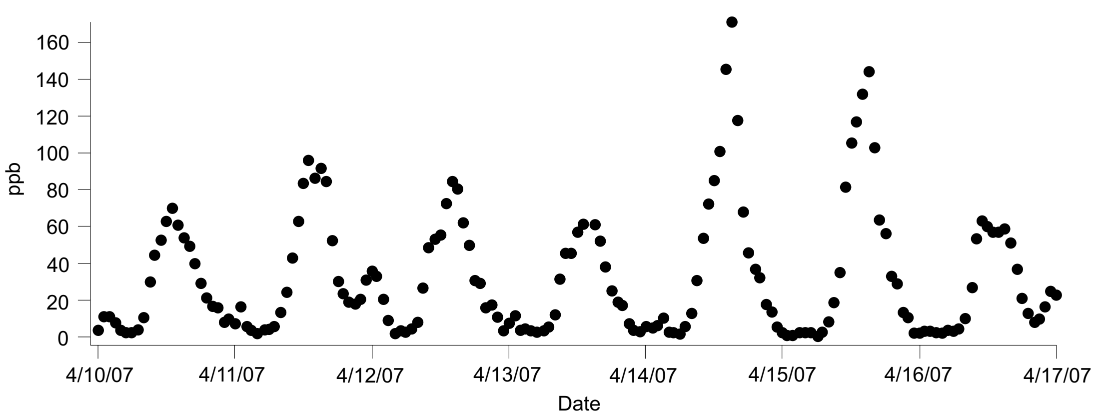

Fig. 2 Hourly measured ozone mixing ratios averaged for all MC stations from April 10 to 17, 2007.

However, this was an unusual ozone peak during a weekend. Ozone data analysis for 2007 showed that average Saturday's concentrations was in general 0.06% higher than workdays. For Sundays the average was 9.7% (on Sunday there is less traffic activity during morning hours, 6 to 10, inducing an increase in ozone due to less titration by NO) confirming previous analyses that showed no difference between week and weekend days (Torres-Jardón, 2004; Muñoz-Cruz *et al*., 2007). However, in the specific case of Saturday April 14 the O_3 concentrations were 71% higher than the average workdays. For Sunday 15 the levels were 57% higher.

A comparison of average weekend/workday ratios and ratios of April 14-15 to average workday concentrations are presented in Figure 3. Hourly ozone ratios for the studied weekend episode (circles) have larger values than the ratios obtained using the averaged weekend day/workday values (boxes).

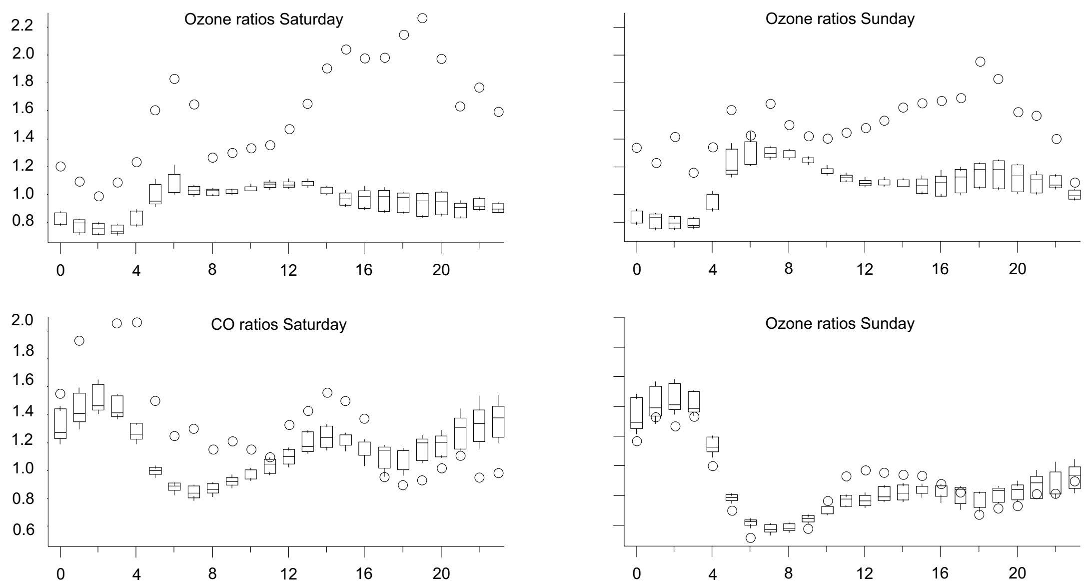

Fig. 3 Average ozone and CO concentration ratios vs. time of the day for Saturday and Sunday. Boxplot represent average weekend day/week day, circles are ratio for Sat 14 or Sun 15 over workday average. Axis x shows the hour of the day and axis y is ratio. Line in boxes is the mean, upper part of the box is the 75th percentile and bottom the 25th percentile, upper limit of the line is 90th percentil and the lower is 10th percentile.

Analyzed in isolation from ozone ratios box plots, the hypothesis of lack of ozone titration in the case of the studied weekend (April 14-15) would be valid for both days since lower NO emissions could have induced higher ozone concentrations.

The CO ratios are greater than 1.0 from 01:00 to 07:00 h on Saturday 14. Because CO concentrations depend mainly in vehicular sources, it is possible to consider that intense weekend nighttime activity could induce concentrations up to 2 times larger than any other day of the week. However for Sunday 15 the CO ratios are similar to the average Sundays in 2007.

Radiosonde measurements taken on April 14 show no lower mixing height during the early morning. Lower mixing layer would explain an increase in ground concentrations (Fig. 4).

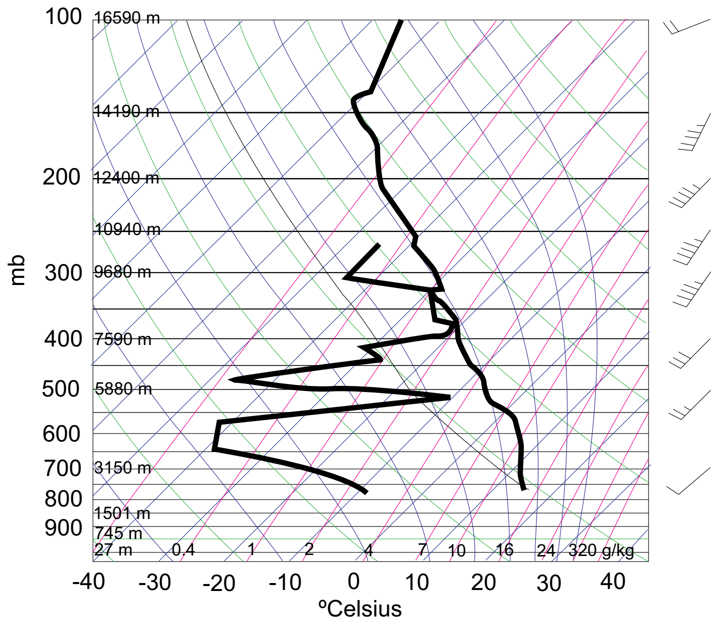

Fig. 4. Radiosonde from México City international Airport (6:00, April 2007). Plot shows vertical dew point profile (left) and temperature profile (right). Temperature line does not show any inversion layer from surface up to 600 mb (Source: University of Wyoming).

In order to consider the meteorological effects on the ambient concentrations of ozone, the MCCM model was used. A set of runs was made using the standard emission inventory, the weekend emission inventory, and new policy emissions inventory with 20% emission reductions.

The standard emissions inventory is the same described by García-Reynoso (2002) and Tie *et al.* (2006). The modified CO emissions inventory using the ratios for Saturday is 14% larger during the early morning hours than workday average and for Sunday is 20% lower than workdays. Additionally the emissions inventory includes data of the Toluca valley.

3.1 Simulations

MCCM was used to model from April 12, 18:00 to April 16, 00:00 h. The results for temperatures and wind speeds are shown in Figures 5 and 6.

The measured wind speed average (10:00 to 15:00 h) for Friday was 3.7 m/s ($\sigma = 2.29$ m/s), Saturday 1.7 m/s ($\sigma = 0.79$) and Sunday 1.6 m/s ($\sigma = 0.90$). The average wind speed for April was 2.0 m/s ($\sigma = 1.42$). Figure 7 shows a box plot of wind during April 10 to 17 it is possible to observe that the wind intensity during Friday is larger than during the weekend, but the winds during the weekend were similar to Wednesday 11. Ventilation defined as the product of the boundary layer height with the wind speed at the first layer of the model was used (Pielke *et al.,* 1991) in order to compare and evaluate the days in the studied period. The ventilation is considered favorable for values larger than 6000 m^2/s. This was the case for Friday April 13 and Saturday 14 (Fig. 8), which indicates that Friday was a well-ventilated day and induce lower ozone concentrations, also this induces less pollutants available from Friday to Saturday. But in spite of favorable ventilation in Saturday the ozone concentrations were higher than Sunday (Fig. 2) when the ventilation was poor and with the lowest winds of the weekend.

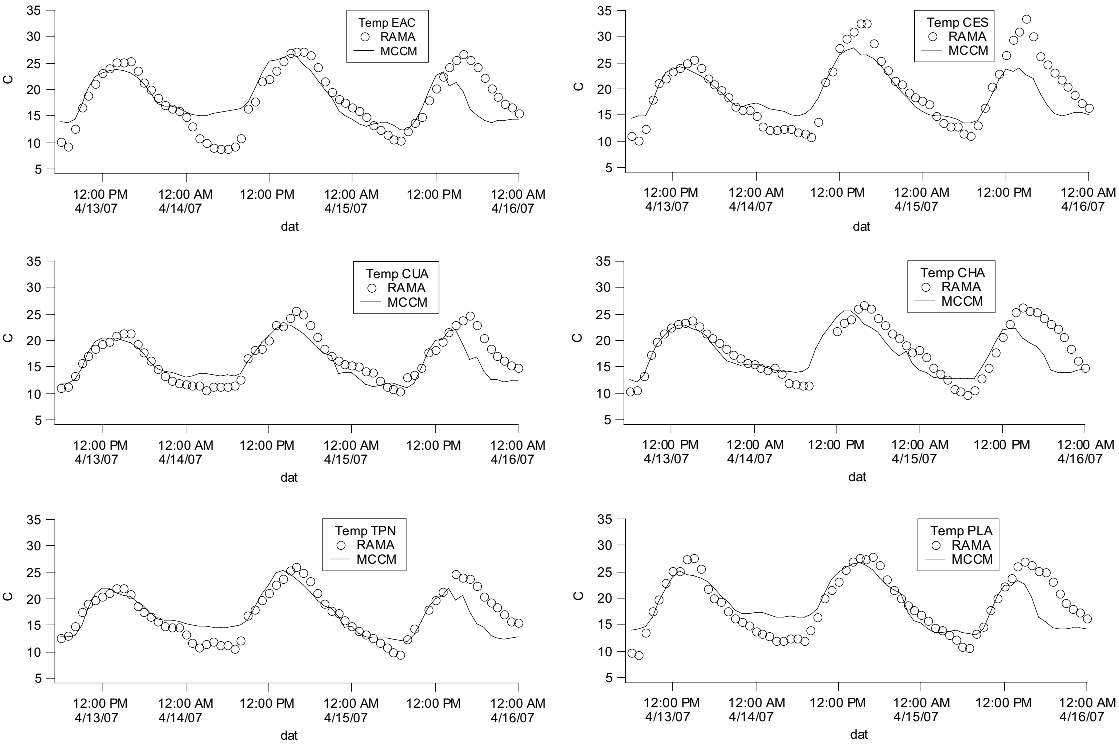

Fig. 5. Measured (circles) and modeled (line) temperature for selected stations (April 13 to 15) for the automatic air quality monitoring network (RAMA) and MCCM results.

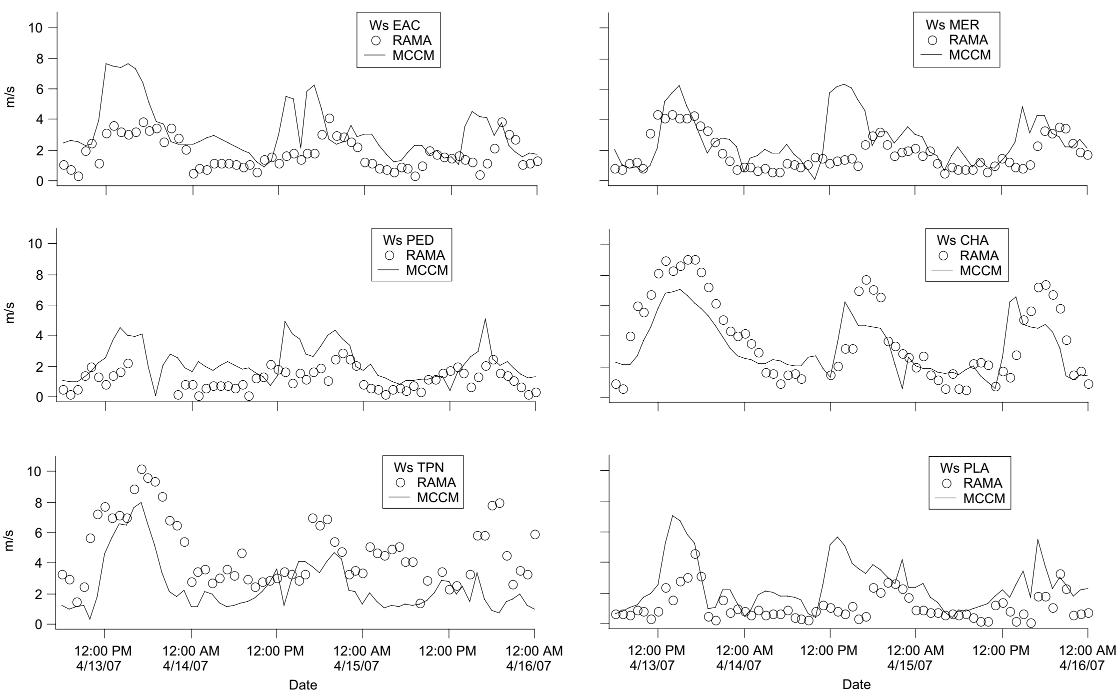

Fig. 6. Measured (circles) and modeled (line) wind speed for selected stations (April 13 to 15).

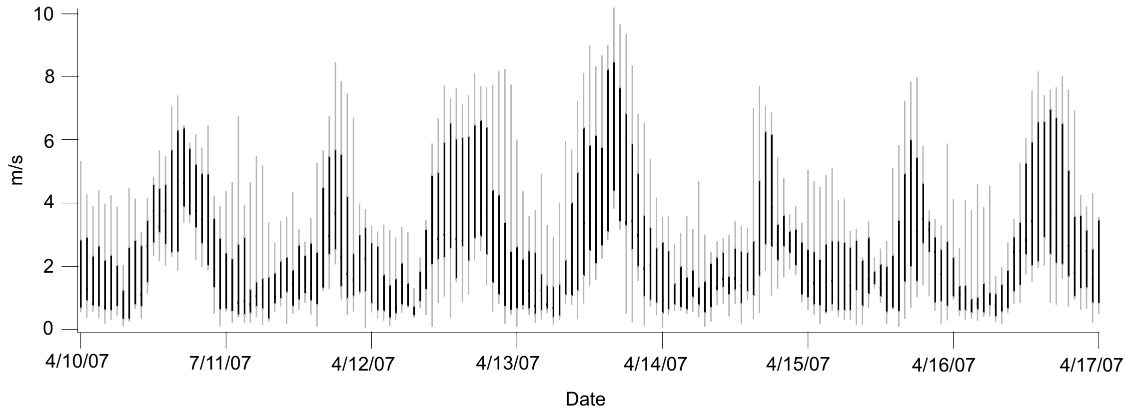

Fig. 7. Box plot of wind speed measured values from April 10 to 17. On Friday 13 there were the highest winds of the week, Saturday 14 and Sunday 15 have similar winds that Wednesday 11.

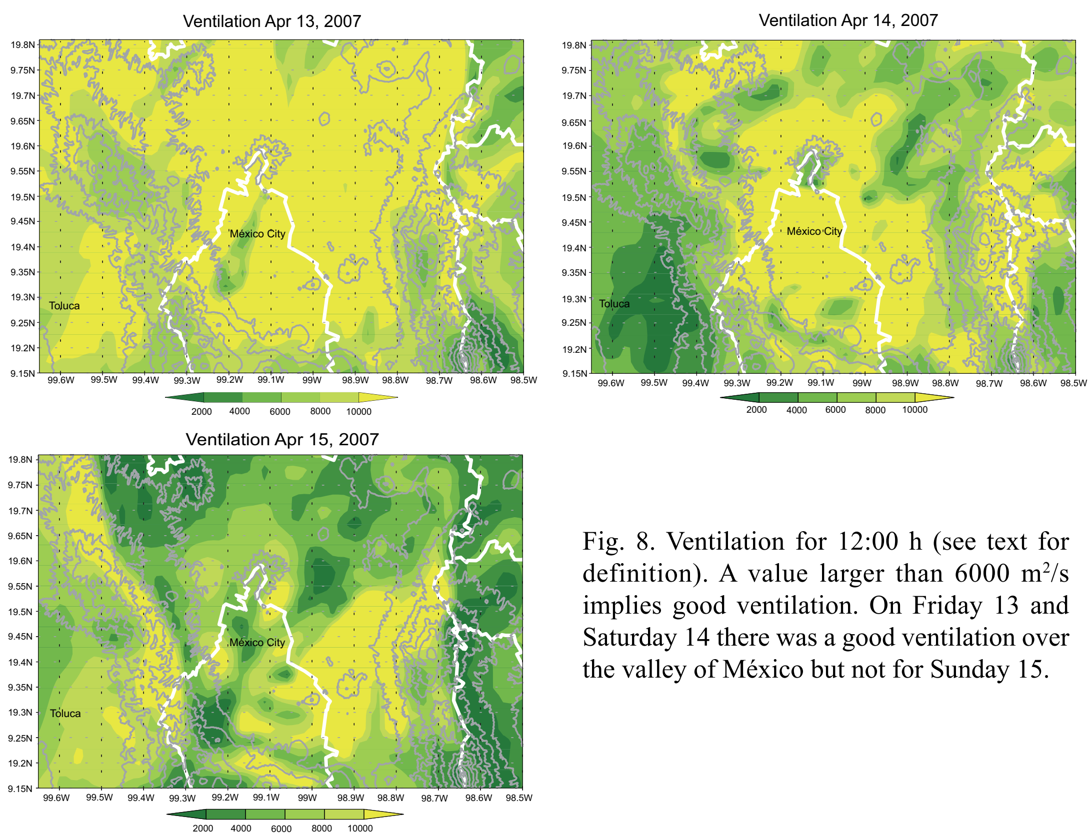

Fig. 8. Ventilation for 12:00 h (see text for definition). A value larger than 6000 m^2/s implies good ventilation. On Friday 13 and Saturday 14 there was a good ventilation over the valley of México but not for Sunday 15.

3.2 Was the episode of April 14 and 15 a case of a weekend effect?

Backward trajectories indicated that emission from Toluca to the west of México City impacted the air quality of México City. Figure 9 (left) shows ozone simulation results with an emissions inventory not including Toluca valley. Figure 9 shows the effect if emissions of the valley of Toluca are included.

A comparison between measured and simulated O_3 values with and without the Toluca emissions for selected stations is shown in Figure 10.

Thanks to the inclusion of the Toluca emissions it was possible for the model to reach the measured peak concentrations of ozone during Saturday and Sunday.

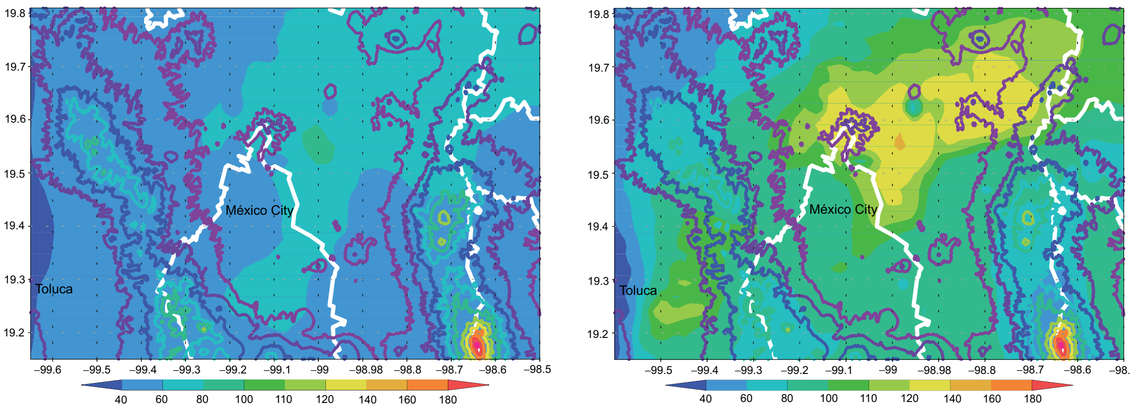

Fig. 9. Average ozone concentrations in ppb from 10:00 to 17:00 h on April 14. Left, original emissions inventory (without Toluca emissions); right, expanded emissions inventory (including Toluca emissions). The inclusion of Toluca emissions inventory induces an increment up to 50 ppb over the average México City ozone levels.

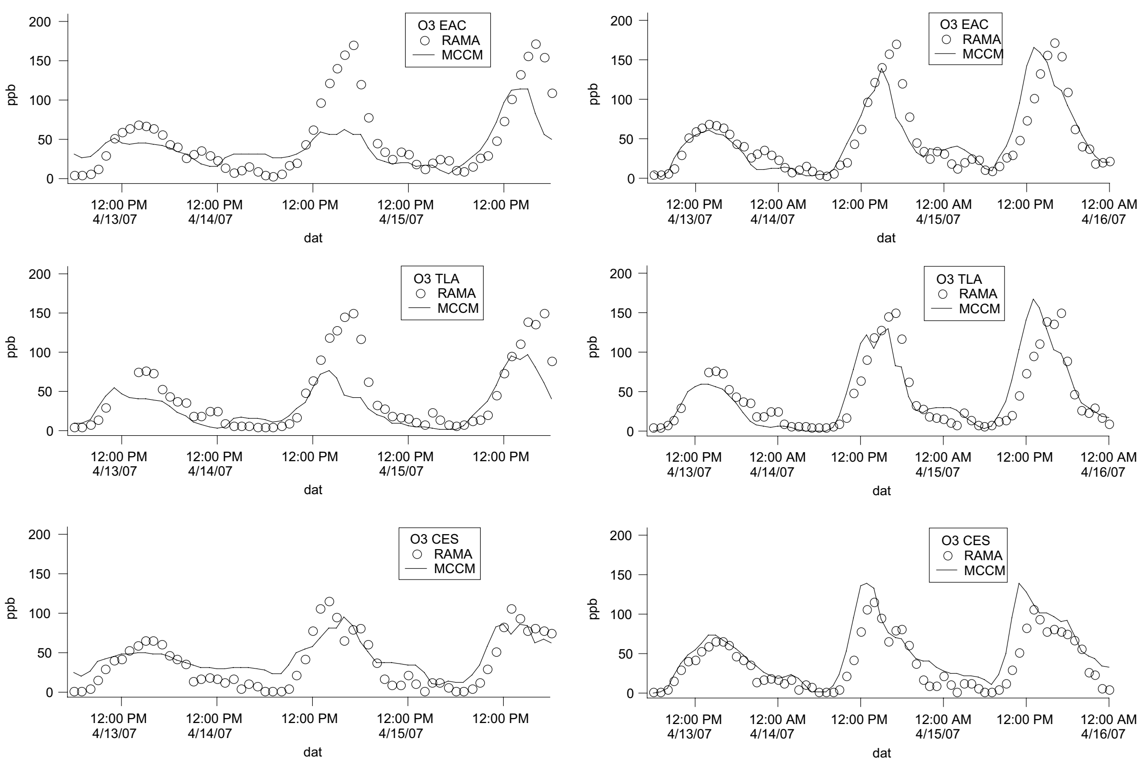

Fig. 10. Ozone measured (circles) and modeled (line) for selected stations (April 13 to 15). Modeled values. Left original emission inventory; right, include the emission of the valley of Toluca.

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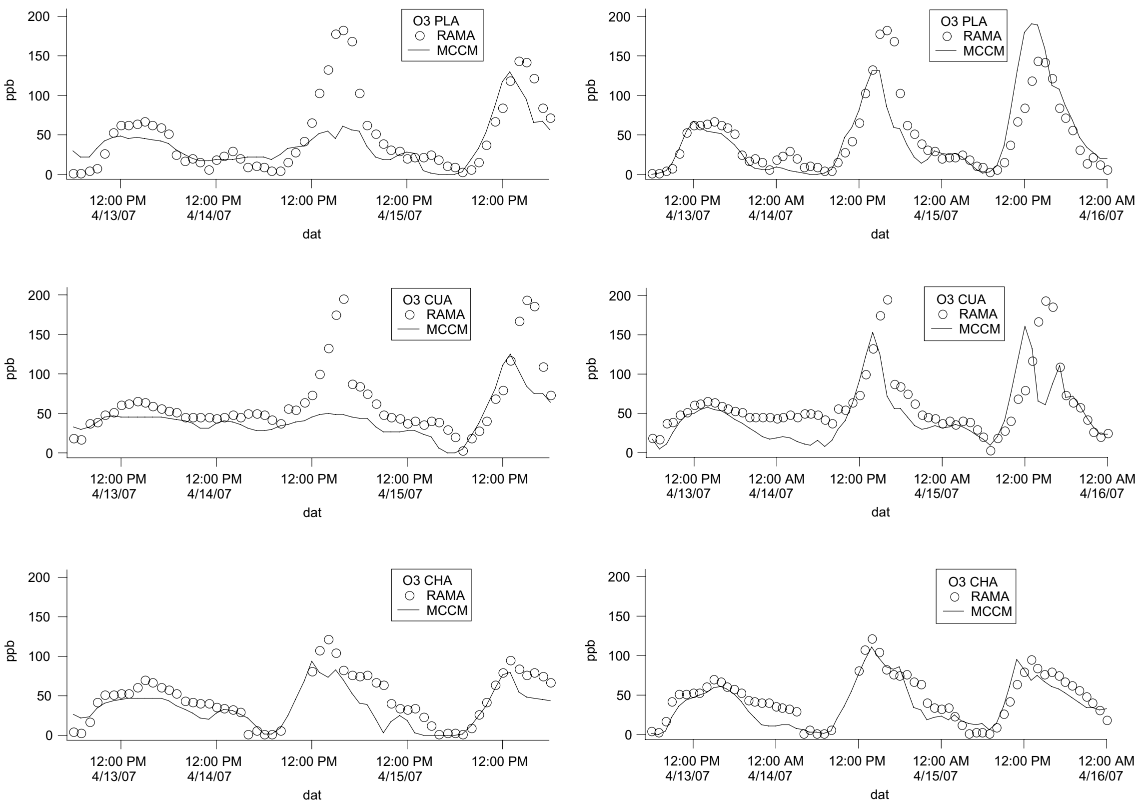

Fig. 10. Continued.

3.3 Statistics

Comparison of air pollutants considers the weekend emission inventory that includes modified mobile and surrounding cities emissions. In this study, an analysis of the root-mean-square difference (RMSD), the RMSD systematic (RMSDs), RMSD unsystematic (RMSDu), and the index of agreement (d) has been used. The values of RMSDs correspond to systematical differences between model and observations (systematical bias of computations), while values of RMSDu stand for unsystematical differences between model and observations. The total differences are shown in RMSD. The index of agreement (d) is a measure of the degree of accord between model and observations. The possible range of the value is 0-1, where the latter value suggests perfect agreement. The N_{ge} and nb are used to assess the model performance for meteorological variables and trace species concentrations. The previous measures are computed for each station. The NMB is 4.4% for the weekend studied and considers 1115 observations. Tables I, II, III and IV show the statistical metrics used in order to compare data in actual versus predicted values for temperature, wind speed and air pollution compounds.

As mentioned, the inclusion of the Toluca valley emissions not only improves the performance of our model but also explain the ozone peaks reached during that weekend.

3.4 "What if?" scenario results

The emissions coming from Toluca valley explain the ozone peaks for April 14. In this section an analysis of the influence on ozone peaks by the reduction in vehicular activity (as proposed by the policy makers in México City) is presented.

Table I. Index of agreement, standard deviation observed (σ_0) and predicted (σ_p) values, root mean square deviation systematic (RMSDs), unsystematic (RMSDu) and total (RMSD), normalized gross error (Eng) and normalized bias (nb) for temperature for selected stations.

Station	Index	σ_0	σ_p	RMSDs	RMSDu	RMSD	Eng	nb
CES	0.88	6.39	4.11	2.97	2.06	3.61	0.15	0.00
CHA	0.88	4.98	3.87	2.08	2.22	3.04	0.13	–0.03
CUA	0.90	4.30	3.61	1.44	1.93	2.41	0.11	–0.03
EAC	0.86	5.56	4.17	2.33	2.63	3.51	0.18	0.05
PLA	0.88	5.45	4.17	2.08	2.45	3.22	0.15	0.03
TLA	0.87	5.37	4.38	2.01	2.69	3.36	0.14	0.00
TPN	0.89	4.46	3.71	1.47	2.15	2.60	0.12	0.01

Table II. Index of agreement, standard deviation observed (σ_0) and predicted (σ_p) values, root mean square deviation systematic (RMSDs), unsystematic (RMSDu) and total (RMSD), normalized gross error (Eng) and normalized bias (nb) for wind speed for selected stations

Station	Index	σ_0	σ_p	$RMSD_S$	$RMSD_U$	RMSD	Eng	nb
CHA	0.83	2.66	1.81	1.39	1.16	1.81	0.57	0.17
EAC	0.54	1.01	1.74	1.37	1.51	2.03	1.33	1.25
MER	0.59	1.12	1.59	0.92	1.44	1.71	0.93	0.76
PED	0.51	0.69	1.11	1.04	0.98	1.43	2.69	2.62
PLA	0.56	0.91	1.58	1.35	1.28	1.86	2.26	2.22
SAG	0.61	1.31	1.23	1.06	1.13	1.55	1.18	1.03
TLA	0.37	1.07	1.68	1.33	1.67	2.14	1.41	1.20
TPN	0.63	2.12	1.76	2.44	1.41	2.82	0.47	–0.44
XAL	0.71	1.48	1.64	0.66	1.41	1.55	0.56	0.12

Table III. Index of agreement, standard deviation observed (σ_0) and predicted (σ_p) values, root mean square deviation systematic (RMSDs), unsystematic (RMSDu) and total (RMSD), normalized gross error (Eng) and normalized bias (nb) for carbon monoxide for selected stations.

Station	Index	σ_0	σ_p	RMSDs	RMSDu	RMSD	Eng	nb
PED	0.89	0.56	0.63	0.22	0.33	0.40	0.32	0.25
SUR	0.88	0.70	0.57	0.29	0.32	0.44	0.42	0.32
TLA	0.84	0.87	0.56	0.43	0.34	0.55	0.27	0.09
TAX	0.83	0.90	0.67	0.41	0.45	0.61	0.33	0.10
PLA	0.82	0.72	0.75	0.57	0.36	0.67	1.04	1.02
UIZ	0.81	0.56	0.42	0.31	0.29	0.43	0.54	0.45
LAG	0.80	0.77	1.13	0.49	0.68	0.84	0.41	0.36
EAC	0.80	0.64	0.44	0.34	0.31	0.46	0.35	0.20
SAG	0.69	0.66	0.48	0.57	0.35	0.67	0.39	–0.31
XAL	0.65	1.07	0.46	0.80	0.37	0.87	0.59	0.35

Table IV. Index of agreement, standard deviation observed (σ_0) and predicted (σ_p) values, root mean square deviation systematic (RMSDs), unsystematic (RMSDu) and total (RMSD), normalized gross error (Eng) and normalized bias (nb) for ozone for selected stations.

Station	Index	σ_0	σ_p	RMSDs	RMSDu	RMSD	Eng	nb
AZC	0.91	0.05	0.04	0.01	0.02	0.03	0.66	0.12
CES	0.90	0.03	0.04	0.01	0.02	0.02	1.25	1.16
CHA	0.93	0.03	0.03	0.01	0.01	0.01	0.68	0.20
CUA	0.75	0.04	0.04	0.02	0.03	0.04	0.37	–0.19
EAC	0.92	0.05	0.04	0.01	0.02	0.02	0.40	0.12
LAG	0.91	0.04	0.04	0.01	0.02	0.02	1.09	0.62
MER	0.91	0.04	0.04	0.01	0.02	0.02	1.13	0.86
PED	0.87	0.05	0.05	0.02	0.03	0.03	0.43	–0.27
PLA	0.90	0.05	0.05	0.01	0.03	0.03	0.48	0.00
SAG	0.84	0.03	0.04	0.02	0.02	0.03	1.37	1.36
SUR	0.94	0.04	0.05	0.00	0.02	0.02	0.37	0.04
TAH	0.91	0.02	0.03	0.01	0.01	0.01	0.34	0.02
TAX	0.88	0.04	0.04	0.01	0.03	0.03	0.67	0.29
TLA	0.92	0.04	0.04	0.01	0.02	0.02	0.57	0.07
TPN	0.83	0.03	0.04	0.01	0.03	0.03	0.45	–0.22
UIZ	0.94	0.04	0.04	0.01	0.02	0.02	0.71	0.51
XAL	0.92	0.04	0.04	0.01	0.02	0.02	0.74	0.46

A vehicular emissions scenario with 20% lower emissions from 10:00 to 18:00 h was compared with the scenario without reductions. The results show that the ozone concentration over the city would increase up to 6%. A concentration decrease of up to 3% will be present downwind outside the city. This situation is shown in Figure 11.

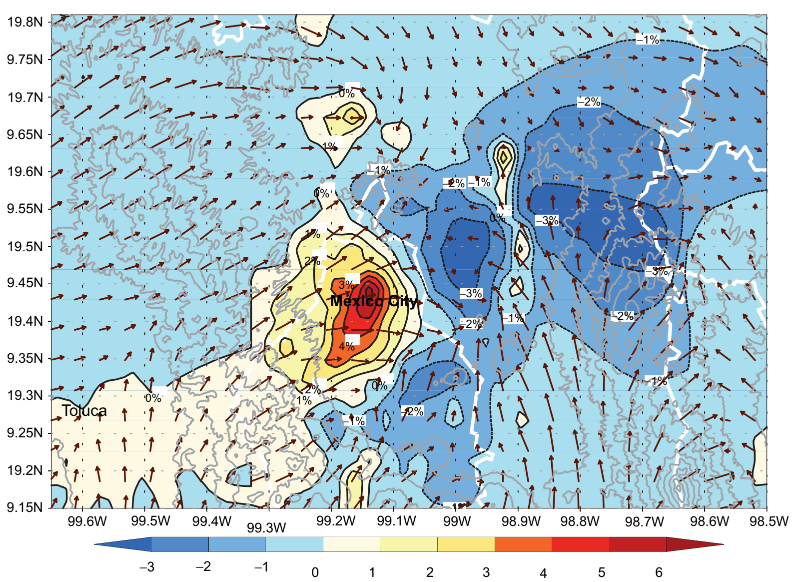

Fig. 11. Variations in percentage of modeled ozone average levels from 10:00 to 18:00 h after applying the proposed new policy of reducing traffic by 20%. Positive values represent an increment and negative values a decrement.

4. Discussion

The analysis of air quality measurement shows that weekend of April 14 to 15 had larger pollutant concentrations than other weekends.

Analysis of wind speed showed that there was good ventilation during Friday and Saturday but not for Sunday. The highest winds measured during the period were on Friday having as a result lower ozone concentrations; on Saturday there was a good ventilation and winds higher than Sunday but with the higher ozone concentration values; finally, on Sunday the winds were lower and with reduced ventilation, however ozone concentrations values were lower than Saturday. An explanation of Saturday episode is that pollutants measured in México City were not from the city because good ventilation transports pollutants outside of the City, but the new arriving air parcels contains pollutants. As shown in Figures 6 and 9, obtained using MCCM, it is clear that the air pollution episode in the valley of Mexico was severely influenced by emissions originated in the valley of Toluca. Volatile organic compounds and NO_X emissions originated there were transported over the Sierra Las Cruces, interacting with highly reactive biogenic emissions injecting ozone and fresh precursors in the metropolitan area of México City and the northern surrounding areas. This explanation is based on regional modeling and provides a clear cause and effect. The air pollution statistical data and the occurrence of the April 13 to 15 episode can now be easily understood.

By enforcing the vehicle circulation reduction policy of 20%, a reduction of NO may be induced due to the increment in the average speed and lower traffic congestions, but even by reaching a 20% emission reductions, an increase of ozone concentrations by 6% could be obtained in some areas of México City, therefore this emission reduction should not be applied only in México City but also in surrounding cities like Toluca, and the measures also have to consider VOC reductions.

Additional work has to be done in order to identify if composition variations in emissions are also important for other weekends.

In the Sunday case, unfavorable ventilation, carryover of pollutants from early morning and the low levels of titration of ozone during the day may induce high levels of ozone.

The control of ozone in México City has to be considered from a regional point of view in order to obtain local and regional benefits. For example, it is important to analyze how often the air quality of México City is influenced by other outside sources like Toluca, Popocatépetl volcano and Tula.

5. Conclusion

An analysis of CO measurements shows that there are changes in the emissions profile during weekends, but there is no clear evidence of a weekend effect occurring during 2007.

Ozone analysis of the data showed that during Saturday April 14, the concentrations were 71% larger than average workday and for the following Sunday 15 the ozone levels were 57% larger.

Friday 13 was the windiest day of the week, Saturday have larger winds than Sunday, the weekend winds were similar to other days like Wednesday 11, but ozone concentrations on weekend were larger than Wednesday. The ventilation was higher during Saturday 14 than in Sunday but lower than Friday in the México Valley. The large values of ozone were the result of the influence over the city of reactive species coming from area sources in Toluca and Cuernavaca, not necessarily by a weekend effect. This was shown using MCCM.

With the expansion of the emissions inventory used in MCCM incorporating outside sources it was possible to reproduce the peak during the weekend of April 14-15.

The emission reduction policy tested for this weekend episode reducing 20% car emissions may produce higher ozone concentrations in some areas. The effects of those reductions are seen outside the city but not inside, where emissions from, neighbor city for this specific weekend have a large impact.

Specifically the control policy consisting in reducing car emissions tested here will not reduce air pollution but also may be counterproductive, since higher ozone concentrations may be created in some areas. As far as our air quality modeling capabilities allow, we can say that mobile sources are not the main cause for the air pollution episodes presented here.

This work casts doubt on that the air pollution episodes that have attracted the attention of environmental authorities in México City is really caused by a weekend effect due to traffic.

A better explanation is that the event was caused by the pollution transport between surrounding valleys. This also provides a sounder hypothesis for air pollution abatement strategies.

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