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Short communication

Comparison between weekend and weekday ozone concentration in large cities in France

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Abstract

This paper examines ozone data from five large French cities (Marseilles, Lyon, Paris, Strasbourg and Toulouse) in spring and summer over a three-year period to study the possible influence of local primary pollutant emissions. In these cities the level of traffic emission varies according to the day of the week. There is a decrease of about 25% in traffic emissions between non-consecutive Tuesdays and Sundays. Traffic emissions on Fridays are about 40% more than on non-consecutive Sundays whereas they seem to be similar for non-consecutive Tuesdays and Thursdays. Despite this variation in traffic emissions between Fridays and Sundays, 85% of daily ozone maxima are identical for all days compared; in 15% of cases, percentiles of daily ozone maxima vary by about 20% at the most. This difference is observed for the highest values of daily ozone maxima that we can find both in rural and urban sites. Marseilles is the most pollution-sensitive city; every site of this area is concerned, which gives a regional origin to ozone variability. In the less-populated Toulouse area, differences between ozone on Fridays and Sundays are less significant. Our results show the importance of advection phenomena of ozone. It calls into question strategies of local reductions in traffic during ozone episodes. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Ozone episodes; Traffic emissions; Trend analysis; Regional scale; Chemical non-linearity

1. Introduction

Densely populated and industrialized areas are sources of primary pollutants. Ozone precursors such as nitrogen oxides, hydrocarbons and CO are emitted from various sources. These chemical compounds are found in car emissions, in various emissions from chimneys in industrialized sites or from boiler room or heating systems. Assessing which of these sources are predominant in the process of ozone formation seems to be very difficult as, on the one hand, fields of precursor emissions are not known in much detail and, on the other, ozone concentration is the result of phenomena of different scales: it depends upon photochemical production via its precursors, upon horizontal transport on a regional and synoptic scale, upon vertical transport from the stratosphere and finally upon sinks such as surface deposition and photochemical destruction by NO. Nevertheless, various studies on local NO_x and hydrocarbon reduction strategies have been made; they tend to show that in some cases this reduction would be likely to cause an increase in ozone concentrations. This is the case for Montreal (McKendry, 1993) and also for the northeast US for several large urban areas (Possiel and Cox, 1993). Cities seem to be a sink for ozone (McKendry, 1993). On a regional scale, net O_3 production efficiency, defined as the net number of O_3 molecules produced per molecule of NO_x consumed, is three times higher in the western United States than in the east because of lower NO_x concentrations in the west. Reducing NO_x emissions in the western United States is thus far more effective for decreasing O_3 production on a per molecule basis than reducing NO_x emissions in the east (Jacob et al., 1993). Furthermore, there is a little difference in peak ozone

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concentration between weekday and weekend despite the weekday to weekend differences in the pattern of pollutant emission over the New York Metropolitan Area (Rao et al., 1991). Cleveland and McRae (1978) found that there was no weekend reduction of ozone in New York and New Jersey, but that there was one in Connecticut and Massachussetts. In Detroit, regional transport and upwind NO_x emissions have a significant impact on peak O_3 (Sillman and Samson, 1993). Besides, Vanderstraeten et al. (1996) wrote that momentary traffic regulations during summertime in Belgium – as radical as reducing traffic to a normal weekend regime – would result in an increase of ozone concentration on the next day almost all over the country. In Switzerland, "in case of favorable meteorology, the amount of peak ozone reduction (10–15%) is considerable, but much smaller than emission reductions (20–50%)" (Brönniman and Neu, 1997). In cities of Milan and Varenna (Italy), the highest ozone values occur at the weekend (Vecchi and Valli, 1999). So, would the implementation of local reduction strategies for NO_x and HC in France, such as the reduction of traffic levels during an ozone episode, be effective? In order to know the impact of traffic emissions on variations in daily ozone concentration maxima in France, we have compared data for daily ozone maxima between the weekend and weekdays as a relative assessment of traffic in cities has been established between these different days.

2. Ozone and carbon monoxide data and sites measurements

The ozone data analyzed in this study consists of daily maximum ozone concentrations at different sites in large cities of France (Paris, Strasbourg, Lyon, Marseilles and Toulouse) (cf. Fig. 1). The time periods studied are from 1 April to 30 September for the years 1994–1996. Ozone data was obtained from AASQA (Air Quality Survey Registered Association in French) situated in each of the above-mentioned cities. There are several types of sites according to their location (i.e. Street (S), Urban (U), Rural (R), Mountain (M), Others (O)). In this study, we have considered all types of sites in order to understand better the influence of emissions of ozone precursors from cars on a large scale. In some cities, during the years studied, survey networks have been improved and so, measurement sites have been added. We have used the 4 sites in Marseilles over the three time periods. Over the time period of 1994 we used 4 in Lyon, 14 in Paris, 7 in Strasbourg and 3 in Toulouse; over the time period of 1995, 4 in Lyon, 15 in Paris, 7 in Strasbourg and 4 in Toulouse, and over the time period of 1996, 6 in Lyon, 16 in Paris, 11 in Strasbourg and 4 in Toulouse. Table 1 gives information about the type of measurement sites. Ozone concentration was measured by using Environment S.A UV absorption analysers. The data in $\mu g\,m^{-3}$ represents the hourly mean value obtained from measurements taken over 1 h. Table 2 gives some information about the quantity of data considered for the study of each city. The measurement errors in the hourly concentration are about 10% (Vecchi and Valli, 1999). The value we have employed in this study is the daily maximum of ozone as it stands for the value of the well-mixed boundary layer. This avoids large differences between two sites on the same day, in the same city, that we could have found if we had taken the daily mean for each site. For a given region, high correlation were found between the daily ozone maxima distributions of each site over periods studied; which means that, whatever type of site we consider (S, U, R or M), its daily ozone maxima distribution varies in the same way as another site in the region (Pont and Fontan, 2000b). Over one region, day-by-day variations of daily ozone maxima between different sites are similar, which enables us to combine daily ozone maxima distributions from many sites of a region into one sample. Comparing daily samples that combine different types of sites of one region enables us to avoid comparisons between mean seasonal levels as each specific mean seasonal level corresponding to a type of site is included in both compared distributions of percentiles.



Fig. 1. Map of the air pollution monitoring networks of Paris, Strasbourg, Lyon, Marseilles and Toulouse.

In addition, some information for each day of the week about traffic levels was given by DDE (The French administration's Direction Départementale de l'Equipement) in the Marseilles and Toulouse areas. Friday shows the highest traffic level of the week whereas on Sunday traffic levels show a reduction of about 40% in comparison with Friday, and about 25% in comparison with Tuesdays. Tuesday and Thursday seem to have the same level of traffic. These trends in traffic levels are

Table 1
Type of sites according with studied city and year. (S: street; U: urban; R: rural; M: mountain; O: others)

	Type of sites	Marseilles	Strasbourg	Toulouse	Lyon	Paris
	S	—	1	—	1	—
	U	2	5	3	2	9
1994	R	1	1	—	1	3
	M	1	—	—	—	—
	O	—	—	—	—	3
	S	—	1	—	1	—
	U	2	5	3	2	9
1995	R	1	1	1	1	3
	M	1	—	—	—	—
	O	—	—	—	—	3
	S	—	—	—	1	—
	U	2	5	3	2	10
1996	R	1	1	1	1	3
	M	1	5	—	—	—
	O	—	—	—	2	3

Table 2
Information by city

	Number of measurements[a]	One percent[b]
Strasbourg	490	4.90
Lyon	359	3.59
Paris	1130	11.30
Marseilles	253	2.53
Toulouse	240	2.40

[a]Number of daily maxima of ozone data for one day considered over studied period.
[b]Number of data concerned by one percentile.

revealed by similar differences in CO concentrations between these days. All the cities under study are densely populated and their traffic density depends, among other things, upon daily "home-work" migrations. Because of this, the relative variations in traffic levels for different days in the week are similar from one area to another. Friday is the day of the week that shows characteristic traffic behavior with an intense early work to home migration plus weekend migration for leaving the city. Friday has been considered in this study and compared to Sunday as we want to study the ozone patterns between two days that show the largest difference in pollutants and ozone precursor emissions due to traffic intensity.

To assess this 40% reduction in the traffic levels on Sundays in comparison with Fridays, we have plotted the daily mean variation of CO on every Friday and Sunday over the three years of the study in Marseilles (see Fig. 2). We think CO is a good tracer for traffic levels. Fig. 2 shows the high difference between the mean diurnal variation of the concentration of CO on Sundays and that on Fridays. Thus, we can expect that all other emissions from traffic decrease, as much as CO does, between Fridays and Sundays. In Switzerland, the total amount of reduction on Sundays is 35–50% (NO_x) and 17–35% (VOC) of Friday levels (Brönnimann and Neu, 1997). Fig. 2 also shows that there is no such difference between mean diurnal cycles of ozone on Fridays and those on Sundays.

Moreover, we consider the daily mean from 5 a.m. to 8 p.m. for each Friday and each Sunday over the summer period for 1994–1996. These data were collected at the 4 Marseilles sites for CO measurement. These sites are of S (dense traffic) type. CO was not measured in rural sites as the concentrations were too low. We obtain a distribution of daily means for Fridays and Sundays. To plot these distributions, we use the method of quantile–quantile plots (explained in Section 3). Fig. 3 shows that all values on Sundays decrease by about 40% in comparison with Friday values; indeed, the equation of the straight line in Fig. 3 is $y = 0.578x$. Thus, owing to this analysis of CO data in Marseilles, the estimated reduction of traffic levels is in harmony with the decrease of primary emissions due to traffic. We obtain the same type of curve by comparing CO concentrations between Sundays and one day of the week; the difference between these two days is about 25%. Similar variations have also been observed in other cities studied.

3. Method of analysis

To estimate the influence of traffic levels, we have compared, on the one hand, distributions of daily ozone maxima on every Tuesday and every Thursday, and on

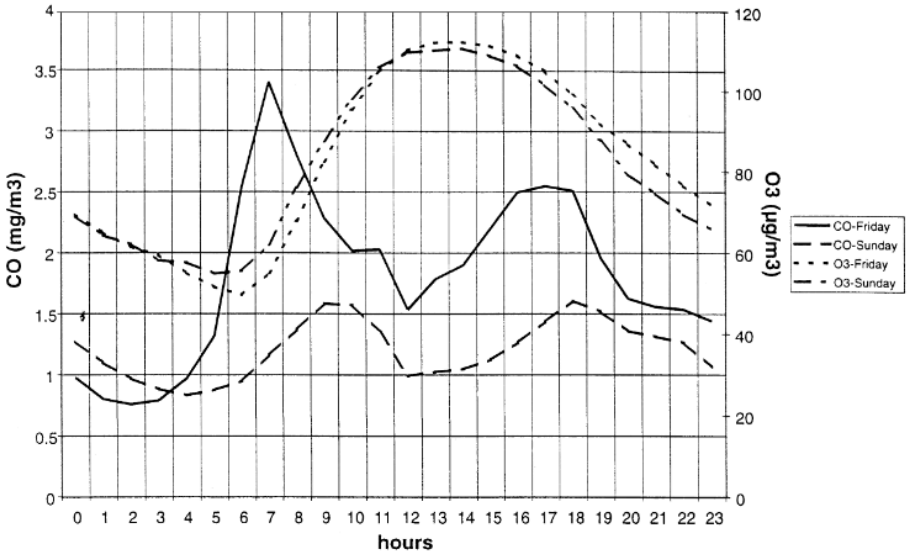


Fig. 2. Mean diurnal cycles of CO and O_3 in Marseilles on Fridays and Sundays from 1994 to 1996, April–September.

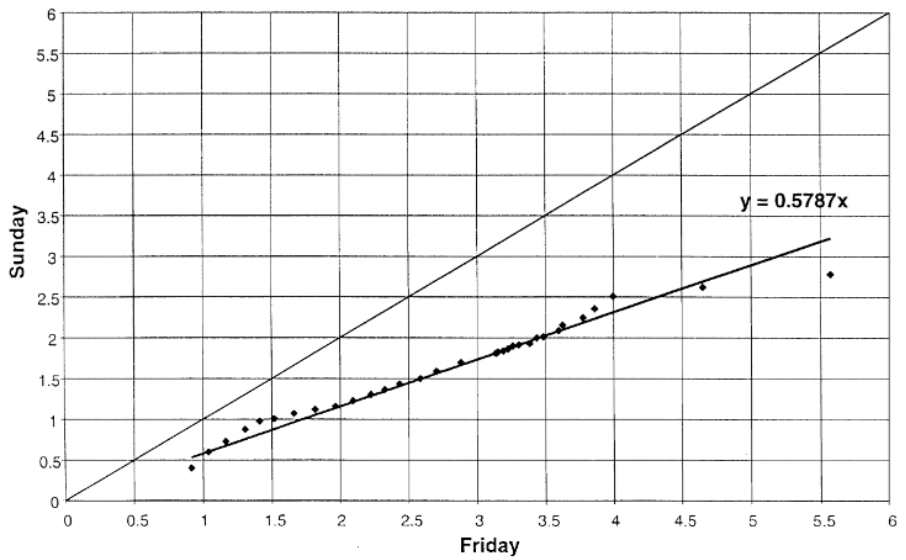


Fig. 3. Quantile–quantile points of daytime (5 a.m.–8 p.m.) mean CO ($mg\,m^{-3}$) at four sites in Marseilles during the summer period of 1994–1996. Each point: Sunday percentiles against Friday percentiles. Thin line: $Y = X$, thick line: $y = 0.5787x$.

the other, distributions of daily ozone maxima on every Friday and every Sunday over the period studied. Thus, we have used the method of quantile–quantile plots. The pth percentile (quantile) of a set of data is a value such that p percent of the data is less than or equal to the value. Percentiles of one set of data (Friday, for example) are plotted against the corresponding percentiles of the other set of data (Sunday, for example). As both sets have the same amount of data, we are able to plot the largest concentration of one set against the largest concentration of the other and so on, down to the lowest value of both sets. If both distributions of daily ozone maxima are nearly the same, the points plotted will be close to the line $Y = X$, and d (difference between co-ordinates of one plot) close to zero. Lines standing for a difference of 20% from $Y = X$ are also plotted. We calculated percentiles 5×5

from the 5th percentile to the 85th percentile and 1×1 from the 85th percentile to the 100th percentile, to better appreciate variations in high ozone concentrations.

The *U*-test has also been applied to each day-to-day comparative study; this test is independent of the distribution (normal or not). It enables us to compare the general tendency between the two whole distributions considered, with a confidence interval of 99%.

4. Results and discussion

Globally, each figure reveals the same tendency (see Figs. 4 and 5). Actually, distributions of percentiles of daily ozone maxima do not differ in a striking way between Sunday and Friday nor between Tuesday and Thursday. The *U*-test gives the following result for every city studied: with a confidence interval of 99%, we can say that there is no difference in the general tendency of Tuesday and Thursday distributions. We also find this result for Friday and Sunday distributions.

Tuesday percentiles versus Thursday percentiles have been plotted as there is no difference in traffic levels for these two days (a study of CO concentrations shows this result). The only difference between these two days is the possible occurrence of different types of weather and thus, the occurrence of different dynamic and meteorological parameters, which leads to different types of transport, advection and photochemical production of ozone. Drawing on data from these two distributions means that we consider enough days of data to include similar meteorological situations in the two distributions considered. Deviations from line $Y = X$ in extreme cases (1% of "Tuesday–Thursday" distributions; cf. Fig. 4) are often due to the occurrence of different meteorological situations. Nevertheless, the meteorological variability can be supposed the same for the two days considered. As number of days of studied data are equal whatever day of the week studied, so we can consider, in the same way, the same hypothesis for Sundays and Fridays. Thus, we examine enough pairs of non-consecutive Friday–Sundays or non-consecutive Thursday–Tuesdays over 1994–1996 to suppose that the probability that we meet similar meteorological situations whatever day of the week we consider over the period studied is the same.

The points plotted for percentiles are often close to the line $Y = X$. They rarely go beyond the $\pm$ 20% lines (see the two points outside the $\pm$ 20% lines in Figs. 5(a)). These results mean that there are no large differences between daily ozone maxima concentrations on Sundays and those on Fridays whereas traffic levels between these two days decrease by about 40%. Indeed, there is no difference between 85% of the percentile values and 15% of the percentile values of the two considered distributions differ at the most by 20%, which represents less than the reduction in the CO concentrations. We can also notice that daily ozone maxima levels are similar for Sundays and Tuesdays (or Thursdays) in all the cities studied.

In the following discussion, we will go deeper into an analysis of these results by considering, city-by-city, gaps to the tendencies mentioned above.

4.1. Marseilles

By analyzing Fig. 4(a), we can see $|d|$ is low. Traffic levels and traffic emissions are identical between these two days. Thus, meteorological variations do not seem to modify variations in ozone between these two days. It may be that meteorological situations are nearly identical between Thursday and Tuesday distributions.

Fig. 5(a) shows higher levels of ozone on Fridays than on Sundays. By analyzing the highest values among ozone data, we notice that high levels of ozone occur on the same days at the different sites of measurements (some of them are separated by about 100 km). This reveals the regional character of the ozone pollution, sustained by a high correlation found between daily ozone maxima distributions from these sites during the period studied (Pont and Fontan, 2000b). On the other hand, the highest value for daily ozone maxima, which occurs on Friday (276 $\mu g\,m^{-3}$ on 1 July 1994), reveals the measurement of an urban plume whereas the other sites of measurements on the same day give high, but lower, values for daily ozone maxima of about 190 $\mu g\,m^{-3}$. At this same measurement site, we also found this phenomenon on 30 June 1995 with a daily ozone maxima value of 201 $\mu g\,m^{-3}$. This means that local ozone production from urban plumes adds to ozone pollution coming from larger scales.

As explained below, the probability that we meet similar meteorological situations whatever day of the week we consider over the period studied is the same. So, by comparing Fig. 4(a), where only different meteorological occurrences between these two days could lead to the points plotted deviating from the line $Y = X$, and Fig. 5(a), where either traffic emissions or meteorological occurrences could make points deviate from the line $Y = X$, we reach the conclusion that Marseilles would seem to be a city where the variation in traffic levels, both, in the city and at a regional scale, between Sundays and Fridays has an influence on regional variations in the daily ozone maxima.

4.2. Strasbourg

Fig. 4(b) shows eight points (i.e. 8% of the data) that deviate from the line $Y = X$, which may be due to the occurrence of different meteorological situations that generate different situations of ozone transport and different photochemical production.

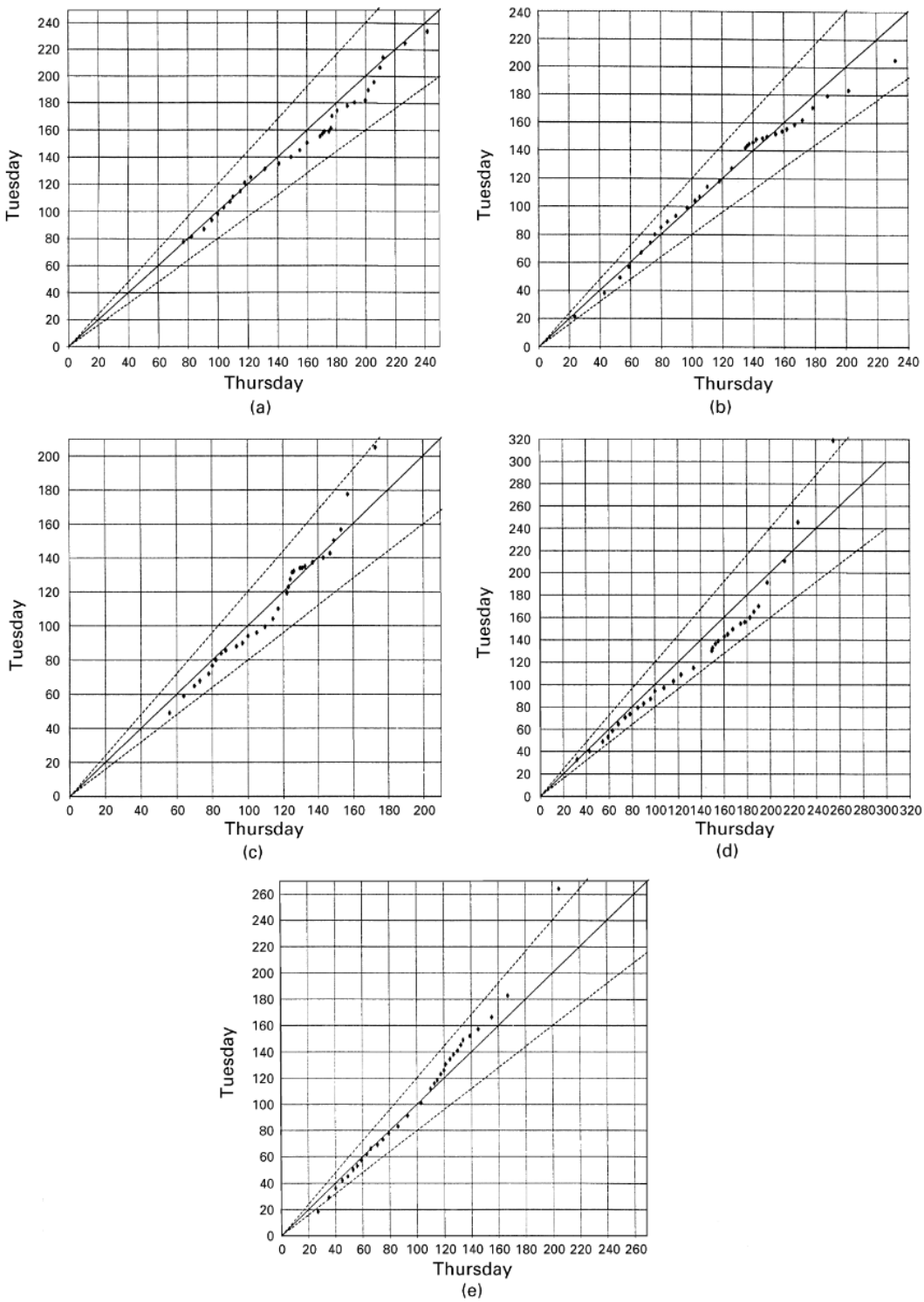


Fig. 4. Quantile–quantile points of daily maxima of ozone ($\mu g\,m^{-3}$) during the summer period of ozone in 1994–1996 in: (a) Marseilles, (b) Strasbourg, (c) Toulouse, (d) Lyon, (e) Paris. Each point: Tuesday percentiles against Thursday percentiles. Straight black line $Y = X$; dotted lines $\pm 20\%$.

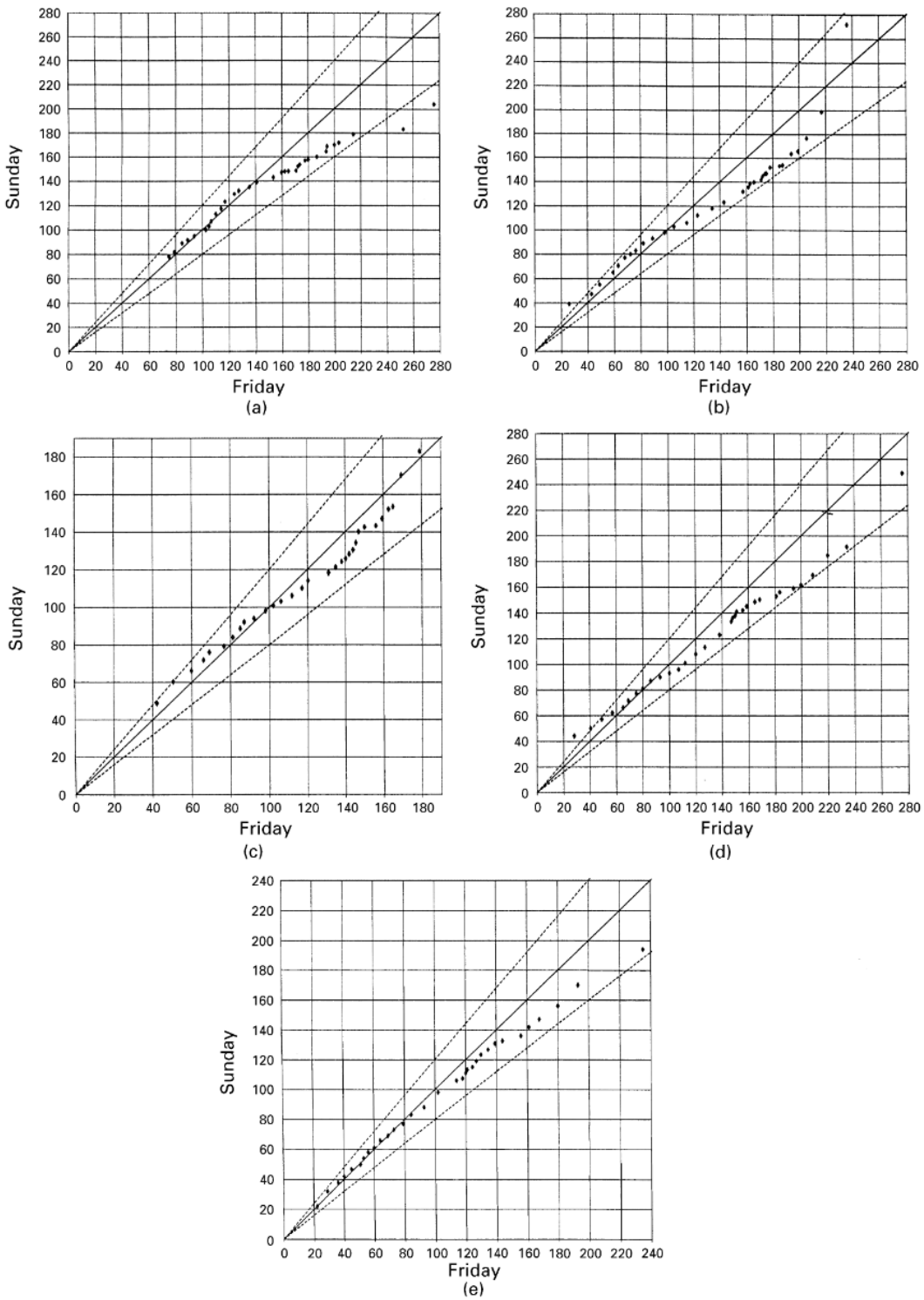


Fig. 5. Quantile–quantile points of daily maxima of ozone ($\mu g\,m^{-3}$) during the summer period of ozone in 1994–1996 in: (a) Marseilles, (b) Strasbourg, (c) Toulouse, (d) Lyon, (e) Paris. Each point: Sunday percentiles against Friday percentiles. Straight black line $Y = X$; dotted lines $\pm 20\%$.

As we can see in Fig. 5(b), the linear tendency is appreciable between Sunday percentiles and Friday percentiles. No points deviate beyond $\pm 20\%$ from the line $Y = X$. From the 55th percentile to the 99th percentile, it seems that levels of ozone are higher on Friday than on Sunday. Only the 100th percentile is higher on Sunday than on Friday. In fact, this deviation is only due to the highest value ($272\,\mu g\,m^{-3}$) of the distribution of daily ozone maxima on Sunday; this high concentration of ozone occurs only at one site (16001, an urban site in Schiltigheim, a suburb of Strasbourg) out of all the sites used. Nevertheless, on this day (8 May 1994) all the devices (R and M included) in the area measured a high level of ozone; moreover, the U and S devices read high values too (between 190 and $210\,\mu g\,m^{-3}$). We can therefore assume that this high concentration of ozone on 8 May 1994 in site 16001 is the result of pollution from a regional origin coupled with pollution due to local conditions. In view of these graphs, we can say that a decrease of 40% in traffic levels on Sundays seems to have a limited influence on the variation of ozone concentration as ozone concentrations on Fridays are slightly higher than ozone concentrations on Sundays. Thus, in Strasbourg traffic emissions at local scale are not the main cause of pollution by ozone.

4.3. Toulouse

In Fig. 4(c), there are only two points with a statistically significant deviation from the line $Y = X$. The occurrence of different meteorological situations may cause these deviations. Fig. 5(c) reveals an important linear tendency. High values for ozone concentration occur just as well on Fridays as on Sundays whereas traffic levels remain about 40% higher on Fridays than on Sundays. Statistically speaking, variations in traffic levels of about 40% in the Toulouse area between Fridays and Sundays have little significant influence on variations in the daily ozone maxima.

Advection may play a large role in the formation of episodes of ozone over Toulouse, to which the local contribution of traffic emissions is added in lesser proportion and influence.

4.4. Lyon

In Fig. 4(d), only the 100th percentile shows a deviation that is greatly higher than the limit value of the $\pm 20\%$ lines. 1% stands for about three values (3.59 exactly, see Table 2) of daily ozone maxima. Four high values of daily ozone maxima occur in two identical urban sites of measurement on Tuesday 28 June 1994 and Tuesday 27 June 1995. We can suppose these high values are due, respectively, to the influence of an urban plume as other sites of measurements do not show high values for ozone on the first day and to pollution from a regional scale as all the sites of measurement show a high level of ozone on the second day.

Fig. 5(d) shows that percentile values on Fridays seem to be higher than those on Sundays, but they never exceed the dotted lines of $\pm 20\%$. Even if the traffic level is 40% higher on Fridays than on Sundays, it does not make the ozone concentration on Friday vary in a striking way.

Globally, we can say that a reduction of the traffic levels of about 40% does not imply an equal decrease in daily ozone maxima because of a chemical non-linearity and a proportion of O_3 that is advected from larger scales.

4.5. Paris

The trend found for the four previous cities can also be noted in Figs. 4(e) and 5(e). Fig. 4(e) shows that only the difference d of the percentile 100 values is large and exceeds 20%. According to the U-test, these two distributions remain identical. Traffic emissions are identical between these two days. Ozone concentrations vary along with the different occurrence of meteorological situations between these two days, and thus, along with different types of advection.

For the "Friday–Sunday" graph, the difference d progressively increases from the 95th to the maximum. Nevertheless, it never exceeds the line of 20%. The 100th percentile represents about 11 values of the daily ozone maxima. Two thirds of these high values occurred at different sites on two days (8 April 1994 and 30 June 1995). This implies that during these days there was a high regional level of ozone over Paris. Moreover, the fact that the deviation is not only the result of one value in one site indicates that these high values cannot be only of a local origin. On 30 June 1995, the ozone pollution must have been advected within the widespread anticyclonic air mass, as in summer the more the air mass stagnates the greater the daily ozone maximum becomes (Pont and Fontan, 2000a).

In Paris, traffic levels on Fridays are also about 40% higher than traffic levels on Sundays. We can say that the similar variation in NO_x and HC sources does not make ozone concentration vary in any striking way.

5. Conclusion

A comparative study of variations in daily ozone maxima between different days of the week in big French cities over the summer periods of 1994–1996 indicates a difference, at the most, of 20% between the highest values of ozone concentrations measured on weekdays and during the weekend, whereas traffic levels vary by more than 40%, especially between Fridays and Sundays. Fig. 2 reveals an important decrease in the CO concentrations between Sundays and Fridays in Marseilles, which lets us suppose a similar decrease in all traffic emissions. All the

cities studied know similar variations in primary pollutant concentrations. About 85% of ozone values in each city studied showed little difference between Fridays and Sundays, while all CO values are concerned by the 40% decrease. Only about 15% of ozone values, but the highest values, seem to be influenced by the variations in traffic emissions. It reveals the chemical non-linearity of ozone (Liu et al., 1987; Brönniman and Neu, 1997) and overall an important background level of ozone which is advected over these urbanized areas, to which is added the local production. Only the city of Marseilles shows a more significant decrease in its concentrations of ozone when traffic levels are lower. But we should remember that the points concerned by this trend stand for only 2% of the data, that is to say for 1.3 Fridays out of all the Fridays of the three spring–summer periods. This study highlights the predominant role of advection in the origin of ozone pollution. Moreover, not only have we seen that a decrease of 40% of the traffic intensity in cities does not have a striking impact on ozone levels, as we compared Fridays and Sundays percentiles distributions, but also we can notice that daily ozone maxima levels on Sundays are as great as (and sometimes greater than) those on Tuesdays and Thursdays. Pryor and Steyn (1995) had also found that typically at sites throughout the region, summertime O_3 concentrations were higher during weekends. On a regional scale, differences between primary pollutant concentrations are difficult to study, as concentrations are low out of urban areas and the sensitivity of measurements devices used in monitoring networks is not enough to properly bring out these differences.

Thus, this study would seem to suggest that strategies of local reduction in traffic levels during episodes of ozone pollution are insufficient at the scale of the town and its suburbs, to lead to significant effects. Sudden high reductions in emissions, which start when ozone concentrations are already high, won't be successful (Vogel et al., 1996). A greater reduction in traffic levels higher than that between Fridays and Sundays, at a scale larger than the scale of a town and its suburbs, would certainly have a more significant effect, if it's applied before the ozone values are already high.

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