Identification of joint targets for traffic and ozone in Bilbao (Spain)

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Abstract

In urban environments, the measured levels of ozone are the result of the interaction between emissions of precursors (VOC’s and NOx mainly) and meteorological effects. In this work, time series of daily values of ozone measured at three locations in Bilbao (Spain) have been built. Then, after removing meteorological effects, ozone and traffic data have been analyzed jointly. The goal was to identify traffic situations and link them to ozone levels in the area of Bilbao. Analysis of these long-term fractions of ozone has made possible the identification of two long-term traffic targets for the whole area, associated with different profiles of ozone forming capability. The first one favours low ozone forming capability, and is associated with a situation of fluent traffic. The second one shows high ozone forming capability and represents congestion.

Keywords: Bilbao; congestion; KZ filter; ozone precursor emissions; traffic; urban air pollution.

1 Introduction

Many urban areas of the world [1] have air quality problems, mainly due to photochemical smog (O3, NOX, VOC’s...), being traffic the most important factor [2] involved in its formation. Bilbao, a city of half a million people in North Central Spain is one such city where traffic is the most important contributor to the formation of smog.

Since 1977, the regional government of the Basque Country rules an air pollution and meteorological network in the area of Bilbao. Besides, the local municipality of Bilbao operates a traffic network with 140 control points spread throughout the central area of the city.
Ozone is not emitted directly into the atmosphere but it is produced by the interaction of meteorological effects and precursor emissions (NO\textsubscript{x} and VOC’s) [3, 4]. To assess and detect changes in ozone precursor emissions, several works [5,6,7,8,9,10,11] have proposed various methodologies in order to remove the impact of meteorological effects from measured ozone time series.

Among these methodologies, it is worth mentioning the technique originally developed by Zurbenko and Rao which includes the use of the Kolmogorov-Zurbenko (KZ) low-pass filter [12,13,14,15,16]. This technique allows filtering out the effects of meteorology in measured ozone time series and detect long-term changes in ozone precursor emissions. The use of the KZ filter makes possible to analyze separately the apportions of the different periodicities embedded in a given time series.

In this paper, the methodology by Zurbenko and Rao has been applied to the time series of ozone for three locations inside the Bilbao area. The objective was to remove the effects of high and medium frequencies (periodicities below 1.7 years) from the original time series. In the case of ozone, it is known [12,13,14,15,16] that, after the application of the above mentioned technique, the remaining fraction is devoid of meteorological influences and only represents the long-term changes in ozone forming capability due to changes in precursor emissions. This fraction of ozone includes the effects of periodicities above 1.7 years and is known as the long-term fraction. Since the whole approach was based on comparable time scales for ozone and traffic, the KZ filter was also used to extract the long-term trends of traffic due to periodicities above 1.7 years.

The objectives for this work were two:

i) to find for the area of Bilbao a relationship between ozone and traffic

ii) to identify traffic situations that may result in low ozone precursor emissions.

2 Database

The data used for this study were simultaneously obtained between 1993 and 1996 from the two networks operating in the area (Fig. 1). The one ruled by the Basque Government was used to collect air pollution and meteorological readings, while that operated by the local municipality was used to collect traffic information. Hourly records of ozone were measured at three stations (Elorrieta, Mazarredo, and Txurdinaga), which are within 4 to 5 km of each other in and near central Bilbao city. Daily ozone averages were calculated from these readings and logarithms of the daily ozone means were computed.

Hourly records of meteorological measurements were collected at Sondika and Feria (at sea level) and Banderas, 200 metres above sea level. The height difference allows detection of thermal inversions. The meteorological variables collected were, daily maximum thermal contrast and daily temperature means at Feria and Banderas; wind speed, absolute humidity, and dew point temperature at Feria. Pressure and radiation were measured only in Sondika (Fig. 1).
The traffic network has 140 measuring points beneath the roads of central Bilbao city that every 10 minutes measures
i) number of vehicles passing above the sensor (NV), and
ii) the occupation percentage (OP, a variable representing the fraction of time the area of the road above the sensor is occupied by a vehicle).

Figure 1: Location of sensors. The traffic network spreads throughout the grey zone.

The combination of number of vehicles and occupation percentage gives an idea of the level of congestion. For this work, daily means of those two variables were computed at each of the 140 measuring points. A preliminary analysis of the long-term fractions of number of vehicles and occupation percentage at those 140 points showed no significant difference among them. Therefore, it was decided to use the averages of the 140 sensors for those two variables. Using all the above corresponding to years 1993, 1994, 1995, and 1996 allowed the building of time series with 1461 cases of traffic variables, meteorological parameters, and ozone at the three locations (Elorrieta, Mazarredo, and Txurdinaga).

3 Methodology

Measured ozone levels are the result of the interaction between precursor emissions (NOx and VOC’s) and radiation. The actual levels of precursors and also the ratio between NOx and VOC’s yields a typical ozone forming capability for the area whose interaction with radiation originates measured ozone levels. To estimate the evolution of this ozone forming capability due to precursor emissions and relate it with its major source (traffic) two different approaches were considered.

Due to the strong masking effects of meteorological variables, if ozone measured inmission data were to be used it was necessary to separate
i) the fraction that was due to a ozone forming capability originated by emissions and

ii) the fraction owing to meteorological effects, (radiation).

The reason is that only the fraction of the ozone signal attributable to emissions could be expected to be related to traffic.

To address this problem, the technique developed by Rao and Zurbenko [12,13,14,15,16,17] allows extracting from an ozone time series the fraction attributable to emissions of precursors. Their works have shown that embedded in the time series built with logarithms of daily maxima of ozone recorded at a given location, three independent component can be distinguished:

1. Short-term component - $O_{3WT}(t)$. Includes the effects of periodicities equal or smaller than 1 month. It is very close to being white-noise.

2. Seasonal component -SEASONO$_{3KZ}(t)$. Originated by seasonal-meteorological changes. Includes the apportion of periodicities between 1 month and 1.7 years.

3. Long-term component (noted as $\tau_{KZ m=365, p=3}(t)$ from now on) attributable only to long-term changes in the ozone forming capability due to emission of precursors. This fraction is originated by the apportion of periodicities above 1.7 years.

This methodology was applied to the ozone inmission levels measured at three locations in Bilbao to obtain the only fraction which is known to be due only to emissions: $\tau_{KZ m=365, p=3}(t)$. Since a lot of bibliography about this technique and its applications is available [12,13,14,15,16,17] it will not be explained here in detail. As usual, it was applied in three steps to finally obtain $\tau_{KZ m=365, p=3}(t)$ for the three locations in Bilbao. At each of the three locations, the three fractions $O_{3WT}(t)$, SEASONO$_{3KZ}(t)$ and $\tau_{KZ m=365, p=3}(t)$ were uncorrelated. Meterological effects were removed from the seasonal-meteorological fraction SEASONO$_{3KZ}(t)$ by multiple linear regression (MLR) using meteorological data.

Since the long-term fraction $\tau_{KZ m=365, p=3}(t)$ only includes the effects of periodicities above 1.7 years comparison with traffic had to be performed on similar time scales. For this reason, the fractions of NV$(t)$ and OP$(t)$ corresponding to the effects of periodicities above 1.7 years (NV$_{KZ m=365, p=3}(t)$ and OP$_{KZ m=365, p=3}(t)$) were also obtained for further comparison with $\tau_{KZ m=365, p=3}(t)$.

4 Results and discussion

Levels of $\tau_{KZ m=365, p=3}(t)$ above the median have been classified as “high values” while those below the median have been considered to be “low values”. Graphical representation of raw data show no difference between high and low values. However, analysis of the long-term fractions of the variables NV$_{KZ m=365, p=3}(t)$ and OP$_{KZ m=365, p=3}(t)$ when selected values (high or low) of $\tau_{KZ m=365, p=3}(t)$ take place, allows identification of two traffic regimes. These two traffic
regimes are defined by the particular combinations of $NV_{KZ, m=365, p=3} (t)$ and $OPKZ_{m=365, p=3} (t)$ and can be grouped into two zones of the long-term NV-OP diagram (Fig. 3).

![Figure 2: a. Low values of ozone. Raw data. b. High values of ozone. Raw data.](image)

![Figure 3: Long-term fractions of traffic and ozone.](image)

The zone I (486 cases out of 1096; Fig. 3) represents an optimum long-term traffic target associated to low values of the long-term fraction of ozone forming capability ($\tau_{KZ, m=365, p=3} (t)$ values below 50th percentile) which are common to the three analyzed locations (Elorrieta, Mazarredo and Txurdinaga). This optimum traffic target (Fig. 3) takes place with $NV_{KZ, m=365, p=3} (t)$ values in the range 415.8-420 and $OPKZ_{m=365, p=3} (t)$ between 6.1 and 6.4.

A second regime (labelled as zone II in figure 4 and with 224 cases out of 1095) can be detected. This second regime is associated with high values of $\tau_{KZ, m=365, p=3} (t)$ (those above the median) and takes place (Fig. 3) with values of $NV_{KZ, m=365, p=3} (t)$ ranging from 405 to 412 and $OPKZ_{m=365, p=3} (t)$ from 6.3 to 6.6.
Finally, there are 385 cases out of 1095 which do not fall into zone I or zone II because for the same long-term traffic regimes, the $\tau_{KZ m=365, p=3} (t)$ values are not high or low simultaneously at the three locations studied.

These results show that

i) traffic is the main explanatory factor for $\tau_{KZ m=365, p=3} (t)$. The long-term fractions of traffic can explain between 91 and 99% of the variability of the long-term fractions of ozone at three locations in the area of Bilbao.

ii) two major long-term traffic targets for Bilbao can be identified. One of them favours high values of $\tau_{KZ m=365, p=3} (t)$ while the other is associated to low values for the three locations of Bilbao where ozone is measured. The regime that favours high values of $\tau_{KZ m=365, p=3} (t)$ (zone II) has fewer cars and higher occupation percentage, than in the case of low $\tau_{KZ m=365, p=3}$ (zone I). In zone I, the long-term fractions of traffic represent a situation of fluent traffic, while in zone II traffic congestion. This suggests that traffic jamming is the major factor behind high ozone precursor emission levels.

iii) other traffic regimes which in the 1993-1996 period represent the third part of the cases, result in different values of $\tau_{KZ m=365, p=3} (t)$ for each of the three ozone sensors.

If measured inmission data are used, analysis of raw data of ozone and traffic do not show any clear pattern and analysis must be performed on the only fraction attributable to precursor emissions and its corresponding time scale. This fraction is $\tau_{KZ m=365, p=3} (t)$ and only includes the effects of periodicities above 1.7 years. Several emission inventories for the area of Bilbao have shown that since late 80’s, traffic is the main source of precursor emissions: NOx (85-90% of total emissions) and VOC’s (70-75% of total emissions). If instead of using traffic variables (NV and OP) as surrogate of emissions, these had been calculated directly, the appropriate way would have been to use the emission factors (USEPA or CORINAIR) which need quite an accurate knowledge of the movements of vehicles (km-driven and vehicle number to mention a few). Such an accurate information could not be obtained directly from the measuring network. If a more accurate knowledge on the movements of vehicles were available, emission factors -along with an EKMA model- would be applicable and a deeper analysis could be performed on all time scales. However, the long-term changes obtained as shown before or from emission factors are expected to be the same.

The disadvantage of the present approach is that the long-term fractions of traffic variables represent only a small fraction (roughly 1%) of the overall variability and taking action on such a small fraction may be difficult. The whole approach has been done under the assumption that Bilbao’s vehicle fleet is related roughly to one single profile of emissions. This is not exact during a too long period of time since the characteristics of Bilbao’s vehicle fleet and also the associated emissions profile, change in time. This is why the coefficients obtained cannot be used beyond the studied period and, in that sense, the equations obtained represent diagnostic models that cannot be used for prognostic purposes.
However, the explanatory factor behind the identified zones is different degrees of traffic congestion. In zone I where low values of $\tau_{KZ, m=365, p=3} (t)$ take place, the long-term fractions of NV of OP represent a situation of fluent traffic (more cars passing with low occupation percentage). In zone II, with high levels of $\tau_{KZ, m=365, p=3} (t)$ the values of NV and OP indicate a situation of heavy traffic or congestion (fewer cars passing and high occupation percentage). This means that the results are in agreement with common knowledge and though the coefficients cannot be used to describe the exact relationship linking long-term traffic and ozone beyond the four years studied, the results can inspire future policies.

5 Conclusions

A joint analysis of the long-term fractions of ozone and traffic confirms that traffic is the main driving force to explain the long-term changes of ozone precursors in the area of Bilbao $\tau_{KZ, m=365, p=3} (t)$. $\tau_{KZ, m=365, p=3} (t)$ has been obtained from measured data of ozone at three locations in the area of Bilbao using the widely used methodology developed by Zurbenko and Rao. The long-term fractions of traffic can explain between 91 and 99% of the long-term fractions of ozone at the three locations studied [17], [18]. This suggests that in Bilbao, ozone and traffic should be managed jointly. If there were other important sources involved in the creation of the ozone forming capability, an approach like this one would not be possible.

A graphical and mathematical analysis of the results makes it possible to identify two long-term traffic targets, one associated with low values and the other one with high values of $\tau_{KZ, m=365, p=3} (t)$. The one with low values of $\tau_{KZ, m=365, p=3} (t)$ (below the median) at the three studied locations is associated with a long-term traffic regime related to a situation that could be described as fluent traffic. The second zone shows high values (above the median) of $\tau_{KZ, m=365, p=3} (t)$ at the three studied locations and the long-term traffic target associated, can be defined as traffic jamming or congestion.

Though the coefficients obtained are valid only for the studied period (1993-1996), the two zones identified are expected to be valid for other periods since they represent a relevant factor known to be involved in ozone precursor emissions: traffic congestion. Therefore, in other periods the identified traffic targets will also be associated to high (Zone II) or low (Zone I) values of $\tau_{KZ, m=365, p=3} (t)$ at the three sensors.

6 Recommendation and outlook

The results show that traffic and ozone should be managed jointly. However, the practical implementation of actions aiming to reach the targets of traffic associated with low ozone values (ZONE I) may be difficult for two reasons:

1. NV and OP are average values of traffic variables measured at 140 different sensors over throughout the area of Bilbao. All the results have been obtained for the long-term fractions of traffic averages computed
with the typical dispersion or spatial variability among the 140 measuring points corresponding to the 1993-1996 period. Adopting measures that, though acting on the averages of NV and OP, may result in a variation of the typical variability among the 140 measuring points, might not lead to the expected results. Therefore, implementation of measures on transport policy applicable to the whole area intended to shift the averages of NV and OP towards the traffic targets identified in this work may be a difficult task if significant changes in the spatial variability of NV and OP are involved.

2. Zone I and II are not very far from each other in the long-term NV-OP diagram and since the long-term fractions of traffic only represent 1% of the overall variability of the original variables, taking action on this fractions to reach a traffic target or shift from one zone to another may be difficult.

However, a more general approach aiming to reduce overall congestion may be useful to reduce ozone problems. The results shown in this paper are useful only if ozone precursor emissions are mainly due to traffic, like in the case of Bilbao. If other important source of ozone precursors existed this methodology could not be applied, because traffic variables (NV and OP) could not be used as a surrogate of precursor emissions. In that case, it would be necessary to include the information on the rest of emissions not associated to traffic. In fact, this scenario will take place in Bilbao and surroundings –the so called Great Bilbao– in a few years since up to 4 Combined Cycle power plants which will be fed with gas, are intended in the area. The number of Mw-h expected will be enough to provide the Basque Country with electricity for all uses. Their Environmental Impact Assessment Studies have already been made public and the overall emissions of NOx are expected to grow in the area by 20-25% due to this fact. In that situation, the long-term trends of ozone attributable to changes in precursor emissions should also incorporate information on the emissions from the power generation plants.

Apart from the evolution that traffic may experiment (number of vehicles by type or age, type of gasoline, future developments in catalytic converters……) this is the only factor expected to change dramatically in the future overall amount of NOx and VOC emissions in the area. These Combined Cycle power plants are designed to operate about 8000 hours/year at peak power, which means that their emission profile is expected to be fairly constant along the whole year. If that were the case, their apportion to the overall emissions, would represent a constant value that when added to the traffic-related emissions, perhaps would make it possible to perform a study like the one shown here for the period 1993-1996 in which ozone precursor emissions are mainly due to traffic.

Most likely, in the forthcoming years, emissions from the power plants, along with those from traffic, will also play a crucial role in defining the profile of the NOx-VOC mix that results in the ozone forming capability due to emissions in the area.
The long-term fractions of the traffic variables (NV and OP) only represent a very small fraction (1%) of their overall variability, which may make difficult to achieve a practical implementation of the optimum traffic target for a minimum value of the ozone precursor emissions. If a more detailed knowledge of the movements of the vehicles circulating in Bilbao were available, emissions from traffic could be estimated directly using emission factors. The total amount of NOx, VOC’s and their ratio would yield a daily ozone forming capability due only to emissions from traffic. Comparison of these values with NV(t) and OP(t) daily values would make possible an analysis on all time scales and not only on the long-term fractions. Since the studied area is rather small, an approach like this would yield an average value for Bilbao, and it would not be possible to analyze separately the evolution at the three different locations studied.

The results obtained for the long-term fractions using inmission data are in agreement with common knowledge and congestion is expected to be also the major factor to explain high ozone forming capability due to emissions at all time scales.

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References


