SUMMER OZONE CYCLES IN THE LISBON METROPOLITAN AREA AND ITS RELATION TO SOME METEOROLOGICAL VARIABLES

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Abstract. The aim of this work is to study the tropospheric ozone concentrations and daily peak cycles in the Lisbon Metropolitan Area (LMA) during the summer season (June, July and August, JJA) covering the 4-yr study period 2002-2005. The results show that all the stations have the same pattern: a minimum in the early morning followed by an increase at 1000 UTC reaching to a peak at 1300-1400 UTC, dropped again to minimum values 1800 UTC but with different concentrations due to regional and local wind circulations and complex dynamic interactions. We identified in Lisbon city the ozone “weekend effect”. Finally, we studied an episode of very high levels of tropospheric ozone and related daily ozone concentrations with some meteorological variables.

Keywords: tropospheric ozone, daily peak cycles Lisbon Metropolitan Area, summer, weekend effect, meteorological variables.

Introduction

Tropospheric ozone is one of the air pollutants of major concern in Europe. It is produced by complex photochemical processes involving NO_x and VOC components. In fact, with climate change scenarios the amounts of this pollutant in the atmosphere will rise, especially in summer (Meleux *et al.* 2007; EEA, 2007). The highest concentrations of ozone result from specific meteorological conditions, specifically low wind ventilation and cloudiness and higher temperature, radiation and insolation, which promote the accumulation of ozone precursors and their photochemical formation. On local and regional scale, the ozone concentrations depend on the great number of variables than can be aggregated as orographic, meteorological and precursor sources (Castell *et al.* 2008a) leading to a complex mosaic of ozone concentration. In the Mediterranean environment, during summer season, ozone reach highest levels and contribute to air degradation, especially in urban areas, exceeding frequently the limits imposed by European Community which can generate coercive effects on human health and ecosystems (e.g. Castell and Mantilla 2002; Klump *et al.* 2006).

The aim of this paper is to study the dynamic of daily ozone peaks occurrence and their weekly dynamic in the Lisbon Metropolitan Area (LMA) in the summer months, June, July and August (JJA) throughout the 4-yr study period 2002-2005. This work is divided in three main issues. In the first we analyse the summer ozone diurnal cycles, the ozone peak behaviour and the weekly cycle; in the second, we study an episode when very high levels of tropospheric ozone occurred; and in the third we relate daily ozone peaks occurrence to some meteorological variables.

Data and Methodology

The ozone dataset used in this study is from the Environmental Portuguese Agency, validated and available at http://www.qualar.org. To this study we selected 7 monitoring stations distributed in the LMA, named Loures, Alfragide and Reboleria, located inland of the metropolitan area, Entrecampos in the city centre, and Beato, Restelo and Paio Pires next to the Tagus River (Figure 1). We selected these stations network because their spatial distribution covers a great part of the LMA area, and allows us to know the effects of the major wind and estu-

arine breezes fluxes on the ozone or the ozone precursor transport.

The LMA has over 2 500 000 inhabitants, about 25% of the Portuguese population and receives on average 150 000 vehicles per day. However, during the period in analysis, the traffic circulation is lower due the vacation or closure period of many industries, especially in August. To relate the ozone dynamic to meteorological variables, we selected the station of Lisboa/Geofisico, located at 38º43'N, and 09º09ºW at 77 m a.s.l. (above sea level) (Figure 1) and available in http://eca.knmi.nl/ (accessed in January, 2009) (Klein Tank *et al.* 2002).

The methodology applied in data treatment is original from Castell *et al.* (2008a) and is based on hourly averages for the summer months, JJA, between 2002 and 2005. We selected this period of study because in this season the high temperatures and insolation increase the risk of high ozone concentration and can overcome the ozone threshold of protection to the population health and vegetation defined by the European Directive 2008/50/CE (Pryor and Steyn 1995; Meleux *et al.* 2007; Castell *et al.* 2008a).

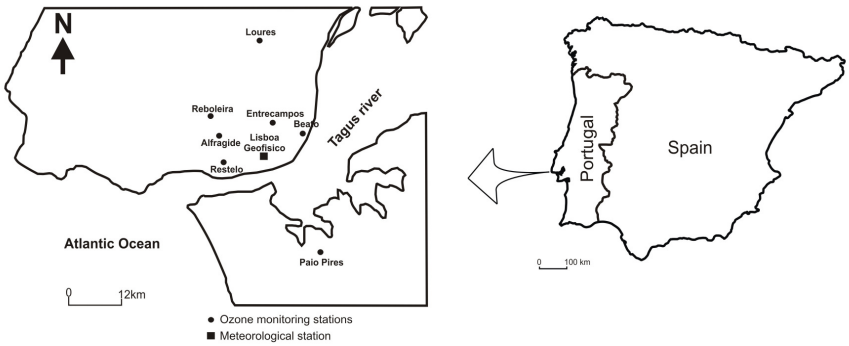

Fig. 1. Location of the stations in the Lisbon Metropolitan Area (LMA)

Analyses and discussion of the results

Daily and weekly cycles.

The results of average ozone diurnal cycles for summer months are plotted in Figure 2, and are linked with hourly ozone maximum distribution as observed Castell *et al*. (2008a) (Figure 3).

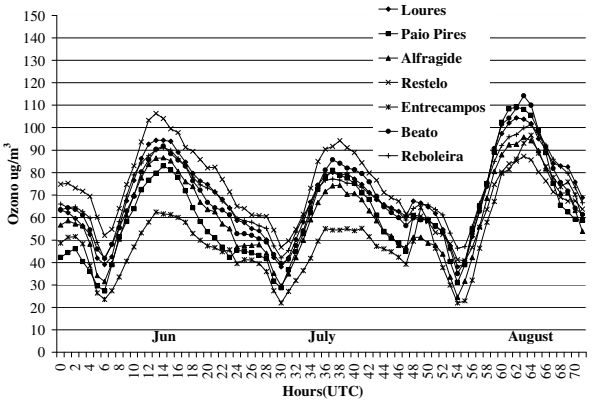

Fig. 2. Mean daily averages of the ozone diurnal cycle for JJA between 2002 and 2005 at 7 stations located in Lisbon metropolitan Area

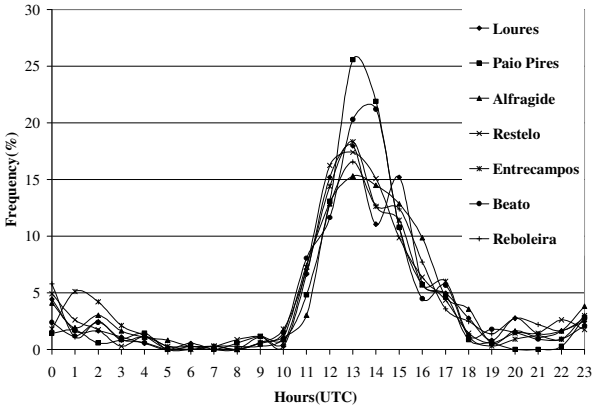

Fig. 3. Weekly distribution of ozone concentrations in JJA between 2002–2005

They are characterized by very low concentrations during the first hours of the day, with a minimum during the early morning, due to the emissions of NOx in rush hours traffic, that destroy the ozone which remained along the night. At 1000 UTC with the increase of solar radiation, we identified a rise in ozone production. Due the heating of land surface, the nocturnal inverse layer is broken, leading to the formation of a mix layer, and from

this moment, optimal conditions for photochemical processes produce greater increases in ozone accumulation. After the breaking of the inversion layer and the generation of the mixing layer, the ozone may stay in the upper layers, falling to lower levels during the firs hours of the morning (daylight) (Millan *et al.* 2002; Adame *et al*. 2008). After the peak in ozone concentrations between 1300-1500 UTC reduced levels are founded at 1800 UTC, probably due to the decrease of radiation, temperature and, the photochemical mechanisms are reduced and the concentrations of ozone in the atmosphere diminish. Furthermore, in the late afternoon the traffic emissions increase and the emissions of NOx are higher leading to more efficient ozone depletion. However, little variations in ozone concentration are observed. The atmosphere becomes more stable and the inversion layer is favoured. This decreasing trend at night is especially abrupt in summer because ozone formation is more intense throughout the daylight, hence creating higher levels of destruction that can take place over a large number of hours (Adame *et al*. 2008). In spite of the similar pattern in daily cycles observed in all study cases, differences occurred in the values reached in each station. The influence of synoptic scale winds and mesoscale breezes plays an important role redistributing the ozone concentrations, especially in coastal areas (Mukammal *et al.* 1982).

During June and July, the coastal stations of Restelo and Beato (Figure 1), which are located in the SW and SE of LMA respectively, present during daytime higher levels of ozone concentration. This behaviour can be explained by the complex local wind circulations. According to Alcoforado and Lopes (2003), in the afternoon, in 52% of the cases, the wind blows from N and NW due the presence of a high pressure over the Atlantic and a thermal low in the Iberian Peninsula, creating a strong pressure gradient. This behaviour can explain us why the southern stations present higher levels of ozone concentration, due to ozone or ozone precursors transport. In August, this gradient is stronger due major thermal difference and the *Nortada* wind is more dominant (Alcoforado *et al.* 1998) and this fact can explain the higher ozone concentrations in Paio Pires. Nevertheless, we also observed that Loures (N station) reaches in all summer months substantial ozone concentrations, which can be related to complex ozone concentration dynamics. The wind/breeze system in Lisbon is closely related to the Tagus estuary.

Figure 4 shows the mean weekly ozone for the months of JJA, and we observed a maximum in all stations in Tuesday (with the exception of Loures) followed by a decline in Wednesday and a rise towards the weekend, when major ozone peaks concentration were achieved. This rise is particularly evident in Entrecampos station that showed a high frequency in the weekend. In the others stations, this pattern is not so evident and it is identified also a decline in peak ozone frequency at weekend in Alfragide and Reboleira station and in Sunday in Beato station. Overall, we observed in the some stations a peak of frequency in weekend days, especially in Sunday (Entrecampos and Restelo). This "weekend effect" was also observed in other cities in several studies (Lobron 1975; Pryor and Steyn 1995; Brönniman and Neu 1997) and was linked to large reductions of hydrocarbons and nitrogen oxide emissions on weekends.

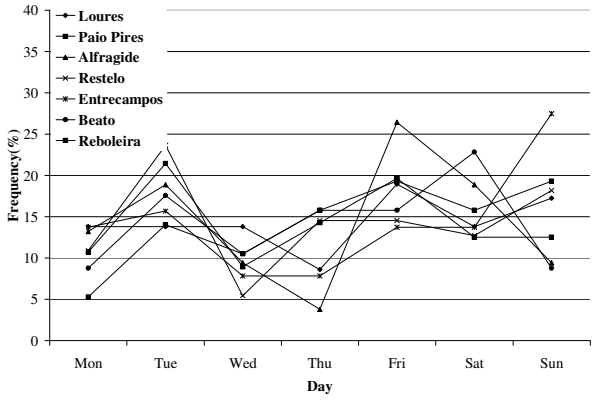

Fig. 4. Weekly distribution of ozone concentrations in JJA between 2002–2005

The episode of August 1, 2003.

On 1st August 2003 in the LMA ozone concentration levels reach extreme high values due to the particular meteorological conditions. That day was very warm and Lisboa/Geofisico station recorded 25.9ºC as the minimum temperature, 33.8ºC of average temperature and 41.8ºC of maximum temperature. In summer 2003, especially between the end of July and middle of August, extreme high temperatures and tropospheric ozone levels were registered in the Iberian Peninsula (Trigo *et al.* 2006; Castell *et al.* 2008b). The hourly values reached in each station are plotted in the Figure 5. The ozone concentration levels start to rise abruptly between 0800 and 0900 UTC, achieving extreme concentrations (>180 $\mu g/m^3$) between 1200 and 1700 UTC and decreasing thereafter, but gradually. The higher concentrations were observed in Paio Pires (4 hours with concentration higher than >180 $\mu g/m^3$) and in Restelo, Beato and Reboleira (3 hours with concentration higher than >180 $\mu g/m^3$). It is documented in some stu-

dies that synoptic patterns are related to high ozone concentrations (Hegarty *et al.* 2007; Ainslie and Steyn 2007) and the 1st August 2003 episode was characterized by the presence of a blocking anticyclone over Central Europe and a thermal low in the SW of the Iberian Peninsula (Figure 6). During that day there was a blocking anticyclone characterized by a weekly synoptic forcing with low gradient over Lisbon metropolitan area and hot and dry air blow from the interior of Iberian Peninsula. These synoptic patterns are characterized by high radiation and temperatures, and low cloudiness and relative humidity, leading to the occurrence of dry and hot weather.

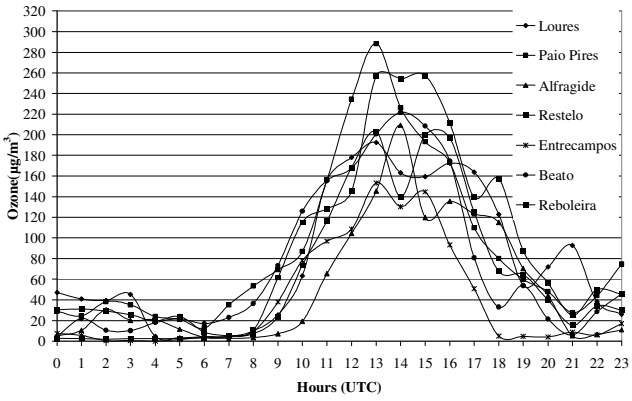

Fig. 5. Distribution of ozone values on August 1, 2003 in the stations in study

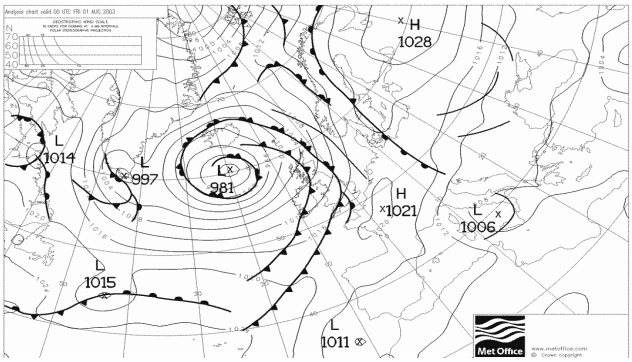

Fig. 6. Surface synoptic chart on August 1, 2003

Relation between meteorological variables and peak ozone.

Meteorological variables play a key role in the formation and depletion of ozone in the atmosphere. High concentrations of tropospheric ozone are associated with high radiation, temperature and low wind conditions, relative humidity, insolation and precipitation (Silman 2000).

In this item we relate some meteorological variables to the daily peak ozone observed in the station of Entrecampos, located in the city centre. The relation between maximum temperature and the daily peak ozone is plotted in the Figure 7a and we detected a high significant relationship (0.61, $p<0.001$). Ozone concentrations rise with the temperature and the results obtained showed that high concentrations of ozone are related to high temperatures.

The Figure 7b represents the relation between daily sunshine duration and daily peak ozone, and we observed lower correlations but significant (0.18, $p<0.05$) as Cox and Chu (1996) identified.

Clear skies are associated with high ozone concentrations because of the high radiation. Hence, as we expected, a significant correlation between cloudiness and daily peak ozone was found in Entrecampos station (-0.34, $p<0.001$) (Figure 7c).

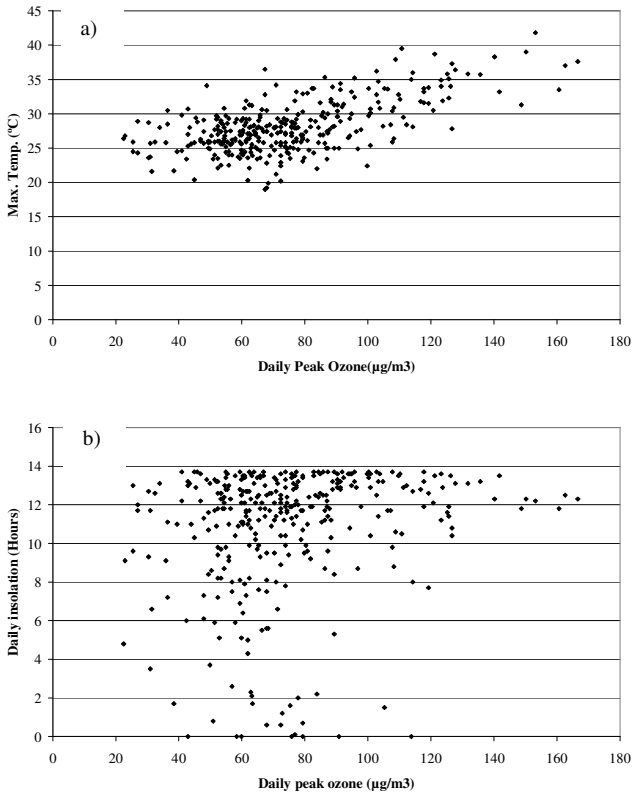

Fig. 7. a) Relation between summer daily peak ozone and maximum temperature in Entrecampos station (2002–2005). b) Relation between summer daily peak ozone and daily sunshine duration in Entrecampos station (2002–2005). c) Relation between summer daily peak ozone and cloudiness in Entrecampos station (2002–2005)

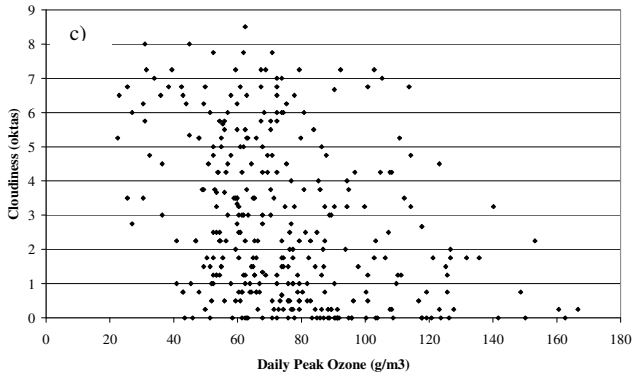

Fig. 7. (Continuation)

Conclusions

1. Diurnal ozone cycles in the Lisbon Metropolitan Area show a minimum in the early morning followed by a rise at 1000 UTC a peak at 1300-1400 UTC, and a decrease again at 1800 UTC around minimum values.

2. We identified the "weekend effect" in the frequency of ozone peak concentration in the majority of the stations and might be related to the lower anthropogenic emissions, especially NOx, leading to a reduced ozone titration.

3. According to the exceptional episode of 1st August 2003, high concentrations of ozone in Lisbon, which surpass the threshold imposed by the European Directive, are related to the presence of a blocking anticyclone and low gradient, generating a eastern circulation, that blow hot and dry winds from the interior of the Iberian Peninsula.

4. The meteorological variables explain the pattern of the peak ozone values during the summer. However, anthropogenic emissions might have an important influence too.

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VASAROS OZONO KONCENTRACIJŲ CIKLAI LISABONOS DIDMIESČIO TERITORIJOJE IR JŲ SĄVEIKA SU METEOROLOGINĖMIS SĄLYGOMIS

Paulo Pereira, Cesar Azorin-Molina, Nuria Castell-Balaguer, Arturo Sanchez-Lorenzo, Joan A. Lopez-Bustins.

Santrauka

Šio darbo tikslas yra ištirti troposferos ozono koncentracijas ir didžiausius dienos ciklus Lisabonos didmiesčio teritorijoje (LDT) vasaros sezono metu (birželis, liepa ir rugpjūtis, BLR) keturių metų laikotarpiu (2002-2005). Rezultatai rodo, kad visos stotys, turi tą patį bruožą: mažiausias koncentracijas ankstų rytą (apie 1000 UTC), pasiekiant iki 1300-1400 UTC ir vėl sumažėjant iki mažiausios, apie 1800 UTC, tačiau koncentracijos yra skirtingos atsižvelgiant į regioninio ir vietos vėjo cirkuliaciją bei sudėtingas dinamikos sąveikas. Darbe nustatytas ozonui būdingas "savaitgalio efektas" Lisabonos mieste. Be to, darbe tirtas labai didelės troposferos ozono koncentracijos ir ozono koncentracijos sąveika su meteorologinėmis sąlygomis dienos metu.