TWO CASE-STUDIES OF BOUNDARY LAYER DEVELOPMENT EFFECT ON THE GROUND LEVEL OZONE CONCENTARTION OVER AN URBAN AREA

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ABSTRACT

Some results obtained during two campaigns (summer 2004 and autumn 2005) of observation of the planetary boundary layer dynamics over the urban area of the Sofia city are presented. An EARLINET scanning aerosol lidar, an ozone analyzer and a ground meteorological station were used during the observations. Particularly, the mixing layer development and the residual layer destruction along with the relevant variations in the ground level ozone concentration followed during the convective boundary layer formation in two situations (in a clear sunny summer day and in the case of a partial solar eclipse with max phase 0.557) are presented and considered.

1. INTRODUCTION

The air quality (including the ozone concentration) over an urban area is determined by the pollution sources and by the atmospheric boundary layer (ABL) structure which depends mainly on the terrain orography, the vertical profile of the temperature and the wind quarter; in other words, it is determined by the distribution of the local pollution sources and by the processes of vertical mixing and advection [1, 2]; the influences of the latter two vary considerably in space and time. Consequently, the parameters determining the air quality are also different, e.g. the heights to which the pollutants (including ozone) spread to, the time of their retaining over the area, etc. The methods and techniques involved in relevant investigations could also be different, so as to correspond to the goal of the particular study, e.g. they could depend on (i) the pollutants nature, (ii) the heights which they to be studied to within the ABL, (iii) the apparatus used, e.g. the aim is to record the vertical profile of the studied parameter, to perform in-situ measurements or to carry out remote sensing [7].

This work reports two different case-studies of processes in the ABL which influence the ground level ozone concentration. The first one follows (using the aerosol as a tracer) the behaviour of the residual layer (RL) during the stable boundary layer (SBL) destruction and convective boundary layer (CBL) formation during a clear sunny summer day (23.06.2004) and the corresponding effect on the ground level ozone concentration. The second one examines the variation in the ground level ozone concentration during the partial solar eclipse on 03.10.2005 (starting at 10:09 and ending at 13:52 LST) from 09:00 till 14:30 LST.

The present study aimed also at following the variations in the aerosol optical characteristics over the area during the ABL formation. An attempt is made of estimating which processes (photochemical ones, those of vertical mixing or advection ones) mainly determine the ground level ozone concentration during the day over the urban area. For the purpose results obtained in a clear sunny day and during a partial solar eclipse (i.e. reduced sun heating) are juxtaposed and considered. An aerosol lidar and an ozone analyzer were used to implement this task.

Many researches engaged in similar investigations. Lalas et al. [1] studied the horizontal and vertical distribution/spreading of ozone in the case of breeze circulation presence in the Athens region performing point measurements and recording the vertical profiles (using balloons) of its concentration. Accompanying meteorological measurements were performed by conventional means and using a sodar for wind velocity determination up to heights of about 1000 m. Beyrich et al. [2] carried out similar investigations also using a sodar and recording the ozone concentration profile in a mountain valley.

2. APPARATUS

We applied well known techniques for processing of the lidar and ozone analyzer data.

The main parameters of the two devices are:

Specifications of the lidar (developed in the Institute of Electronics): **transmitter** – a standard Nd-YAG laser (operational wavelength 532 nm, pulse duration and energy 15–20 ns and 10–15 mJ, repetition rate 12.5 Hz; **receiving antenna** – a Cassegrainian telescope (main mirror diameter 150 mm, equivalent focal length 2250 mm); **photodetector** – a PMT aligned with an interference filter (1 nm FWHM); **data acquisition and processing set** – a 10 bit 20 MHz ADC and a PC [4].

Surface ozone concentration was measured by using an ozone analyser. ***Specification of the ozone analyser:*** model 3-02P1 (Russia) employing the chemi-luminescent method of O_3 detection, sensitivity 2 $\mu g/m^3$, response time <1 sec [5].

3. RESULTS AND DISCUSSION

3.1. Lidar data

In this work some experimental results obtained during two lidar observational campaigns (summer 2004 and autumn 2005) performed in the Sofia city (42°39′ N, 23°23′E, 591 m ASL), Bulgaria are presented.

In Fig. 1 height-time indicators (HTIs) obtained on 23.06.2004 during the development of the ABL from SBL to CBL are shown. In the first two images the layered SBL structure is well pronounced; two aerosol layers could clearly be seen up to a height of about H=200 m followed by RL up to about H=650-700 m. The destruction of the SBL formed during the night starts after 07:30 LST. In the image obtained at 08:30 LST the beginning of new ML formation could be clearly distinguished. At 10:30 LST the ML reached height of about H=500 m and the destruction of the RL started. The height of ML rose up to H=800 m till 11:30 and up to H=1200-1300 m till 13:00 LST.

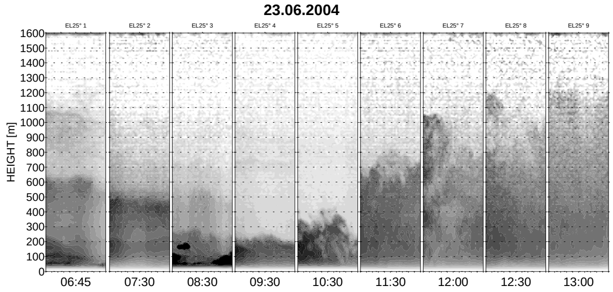

Fig. 1. Height-time indicators obtained on 23.06.2004.

Fig. 2 presents HTIs obtained on 03.10.2005 during the partial (55.7 %) solar eclipse; in the beginning they were recorded at 30 minutes intervals whereas during the eclipse (from 11:09 till 13:52 LST) – every 15 minutes. In the first four images one can see the presence of haze at heights of about 200-300 m which is clearing away around 10:30 and the new ML formation starts; its height is about H=200 m. The solar eclipse started after 30-40 min and the ML development slowed up; its height of about 200 m remained till 11:30.

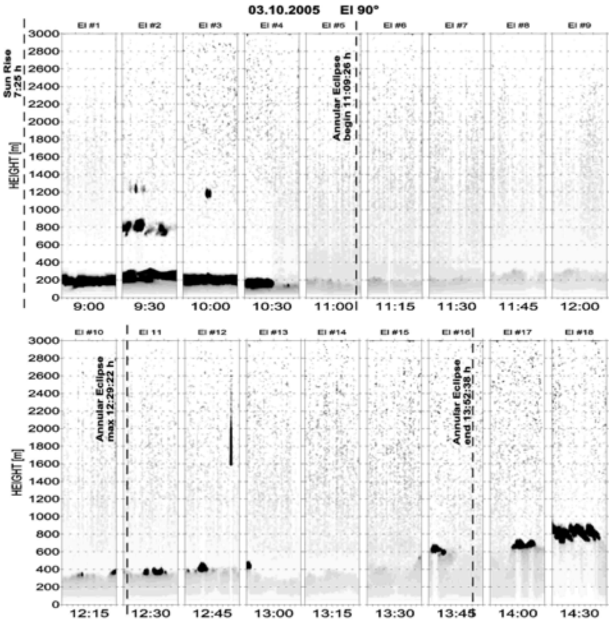

Fig. 2. Height-time indicators obtained on 03.10.2005.

A slight increase of the ML height is observed around 11:45 and during the eclipse maximum (around 12:30) it reaches H=400 m. The ML height decrease (starting at around 13:00) down to about H=300 m then increasing again up to H=400 m at 13:30, at the end of the eclipse (around 13:45) it is H=600 m; the height of about H=800 m was reached at 14:30 which is characteristic of this season in the area of observation. At the upper boundary of the ML a clouds formation is observed (Fig. 2).

3.2. Ozone concentration data

The importance a coupled system of chemical and meteorological processes to be treated in order the spatial and temporal variations of the concentrations of ozone and other oxidants in the troposphere to be understood along with the corresponding causes is being increasingly recognized in the scientific community dealing with the atmosphere. In this connection we consider here two different sets of data which reveal two different kinds of processes affecting the ground level ozone concentration in an urban area situated in a mountain valley.

In Fig. 3 data about the ground level ozone concentration measurements obtained on 23.06.2004 (a clear sunny day with a slight cloudiness before sunrise) are shown. The ozone concentration was about c=10 $\mu g/m^3$ at 08:30 gradually increasing up to about 23 $\mu g/m^3$ at 10:30, that increase becomes more abrupt between 11:00 and 11:30 then reverting to the gradual increase reaching a concentration of about 70 $\mu g/m^3$ at 14:00 LST.

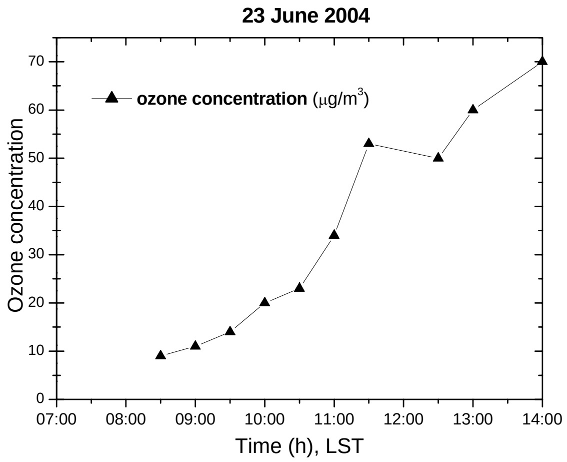

Fig. 3. Variation in the ozone concentration; 23.06.2004.

In Fig. 4 analogous graph shows the variation of the ground level ozone concentration with time after sunrise but obtained during the partial solar eclipse. One can see that the ozone concentration is <10 μg/m^3 till 10:00 LST (which is common in the case of SBL in the area), increases up to 17 μg/m^3 around 11:00 (shortly before the partial eclipse beginning). The ozone concentration varies negligibly at the beginning of the eclipse reaching values of about 20 μg/m^3. After the eclipse maximum it increases up to c=38 μg/m^3 at 14:00 (before the end of the event) reaching the maximum value of c=49 μg/m^3 around 15:00 LST. The ozone concentration then decreases down to about c=32 μg/m^3 at 18:00 LST which value is characteristic of a developed CBL over the area during this season.

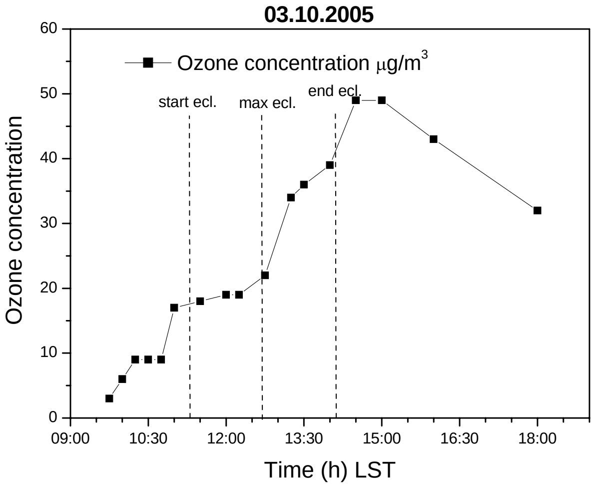

Fig. 4. Variation in the ozone concentration; 03.10.2005.

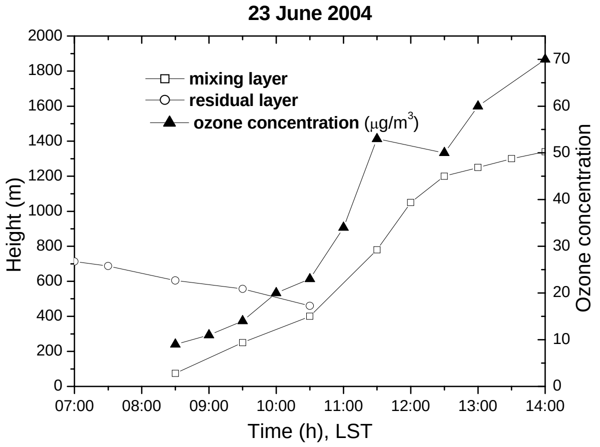

Fig. 5. Variations in the mixing and the residual layers height and in the ozone concentration on 23.06.2004.

In Fig. 5 the variations in the heights of the ML and RL on 23.06.2004 determined from lidar data according to the gradient method [3] are shown. Such type of graphs gives possibility the time of the RL destruction and the height of the ML to be better determined. The changes in the ground level ozone concentration during the same time period are also depicted (Fig. 5).

It is shown in our previous works [5] that the RL (where ozone is accumulated during the previous day) is being destroyed as well from below (by the new ML forming) as from above (as an effect of the local mountain-valley circulation). During the RL destruction an increase of the ground level ozone concentration is observed around 10:30-11:30 LST which could be explained by "mixing from above", i.e. by the so-called entrainment process. Such a process was observed also by other authors [6].

In Fig. 6 the variations in the heights of the SBL and ML on 03.10.2005 determined from lidar data are presented. The changes in the ground level ozone concentration during the same time period are shown too. One can definitely see that the ground level ozone concentration is low while the SBL is covered by haze (Fig. 2). After the haze clearing (around 10:30 LST) the earth surface (and the atmosphere above it) is being more heated by the sun but the energy for new ML

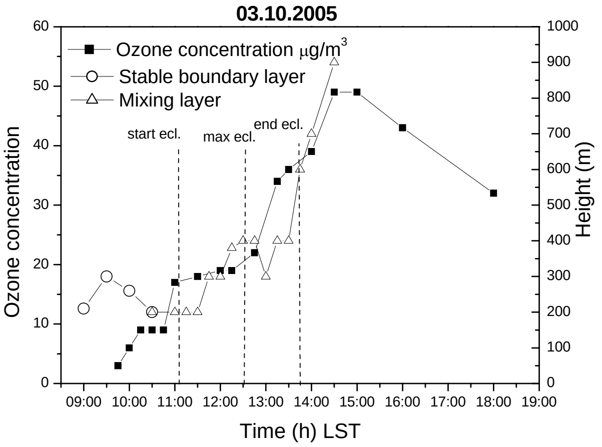

Fig. 6. Variations in the mixing and the residual layers height and in the ozone concentration on 03.10.2005.

formation is still not enough. At the nearly same time (after 10:45) the ground level ozone concentration increases, after the beginning of the eclipse it practically does not change till the eclipse maximum (at 12:29, max phase 0.557). The ozone concentration then increases nevertheless that the ML height does not increase, i.e. there is not intensive mixing (the ML height even decreases around 13:00). The ozone concentration increase continues up to a value of $c=38\ \mu g/m^3$ at the eclipse end (around 14:00) reaching the maximum of $c=49\ \mu g/m^3$ around 15:00. The ground level ozone concentration data obtained in this case show that fast photochemical processes take place which leads to generation of additional amount of ozone. At the same time the ML formation processes are inerter so the ML height remains almost constant, which grounds the suggestion that the increase of the ground level ozone concentration is due mainly to fast photochemical reactions/processes even in the case of lower sun radiation owing to the partial solar eclipse. It could be considered that the rest two processes contributing to the ground level ozone concentration increase (namely, the mixing from above and the advection) play a negligible role in this case.

In conclusion it should be noted that the obtained results are in a good correspondence with the conceptual models currently used in the field of the air quality over an urban area situated in a mountain valley [4].

The influence of the meteorological factors on the ground level ozone concentration could be summarized as follows:

i. The increase of the ML height observed in the case of eclipse is due to the inertness of its development; firstly, the earth surface is being heated by the sun then it, in turn, heats the adjacent air mass nevertheless the eclipse maximum takes place at that time. The same effect is being observed after the eclipse maximum, namely, the ML height decreases notwithstanding the increased solar radiation. In these two cases the processes within the ML do not affect significantly the ground level ozone concentration.

ii. In the same time it should be noted that the ground level ozone concentration is, to a certain extent, also a consequence of the accumulation of precursors such as NO and NO_x generated by the road traffic at those hours.

iii. The ground level ozone concentration decreases or increases depending on the solar activity; in the case of a haze presence (in the beginning of the observation) the destruction of the ozone (by the nitrogen derivatives) prevails whereas in the case of photochemical processes prevailing the ozone concentration increases.

REFERENCES

1. Lalas P., et al., An experimental study of the horizontal and vertical distribution of ozone over Athens, *Atmospheric Environment,* Vol. 21/12, 2681-2693, 1987.

2. Beyrich Fr., et al. Comparative analysis of sodar and ozone profile measurements in a complex structured boundary layer and implications for mixing height estimation, *Boundary-Layer Meteorology,* Vol. 81, 1-9, 1996.

3. Menut L, et al., Urban boundary layer height determination from lidar measurements over the Paris area, *Applied Optics,* Vol. 36, 357-375, 1999.

4. Kolev I., et. al., Lidar observation of the nocturnal boundary layer formation over Sofia, Bulgaria, *Atmospheric Environment*, Vol. 34, 3223–3235, 2000.

5. Kolev N., et al., Aerosol lidar and in situ ozone observations of the planetary boundary layer over Bulgaria during the solar eclipse of 11 August 1999, *International Journal of remote Sensing,* Vol. 26, No. 16, 3567-3584, 2005.

6. Fast J.D. and Zhong Z.Y., Meteorological factors associated with inhomogeneous ozone concentrations within the Mexico city basin, *J. Geoohys. Res.*, Vol. 103, 18927-18946, 1998.

7. Takamura T., et al., Tropospheric aerosol optical properties derived from lidar, sunphotometer and optical particle counter measurements, *Applied Optics*, Vol. 33, 7132-7140, 1994.