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Lidar study of the dynamics of aerosol type pollution in the lower troposphere over urban area

Zdzisław Błaszczak[a], Marek Hałas[a], Józef Grabowski[b], Alexandros Papayannis[c]
[a] Physics Department, A. Mickiewicz University, Umultowska 85, 61-614, Poznań, Poland
[b] Institute of Physics, University of Technology, Nieszawska 13A, 60-965, Poznań, Poland
[c] Physics Department, National Technical University of Athens, Greece

ABSTRACT

This paper presents results of a study of aerosol pollution distribution and dynamics measured by lidar observations over the city of Athens. The seasonal dynamics of vertical changes in the backscattering coefficient, extinction coefficient and lidar ratio for lower troposphere has been determined.

Keywords: aerosols, light scattering, lidar

1. INTRODUCTION

The studies of the atmosphere have been conducted to clarify the character of phenomena taking place in it and also to be able to predict the processes expected to occur in future. The studies are conducted by many methods of which of great interest are optical ones, in particular those using lasers (of pulse and continuous work) arranged in a lidar system with the optical and detection parts [1 - 3]. The lidar systems permit a high accuracy determination of the type and size of air pollution clouds, including marine aerosols of low concentration and observation of their space-time dynamics.

The paper reports results obtained during the measurement sessions in 2000 at the Faculty of Physics, Athens Polytechnics, Lidar Laboratory. The results have been processed by the method based on the general iteration method known also as the Klett general recurrence method described in [4]. The recurrence of the lidar data starts from the points farthest from the earth surface (at an altitude of ~10 kilometres) where the presence of aerosols can be disregarded. The values of the extinction coefficient α and backscattering coefficient β determined for a single point from this range permit the calculation of the values of β_{aer} and α_{aer} and their lidar ratio lr_{aer} for aerosols in the lower troposphere.

2. EXPERIMENT

The experimental system was working with the laser beam of an Nd: YAG laser made by Continuum, and its second (532nm) and third (355nm) harmonics, Fig. 1. The beams were emitted coaxially to the axis of the receiving Newton type telescope of the diameter of 26 cm. The scattered light coming back to the receiving system was focused on the optical waveguide and sent to the detection system. The detection system was composed of a set of filters separating the wavelengths 355nm and 532nm, directed to the multichannel photomultipliers made by Hamamatsu. The electric signal was amplified and converted into the digital form recorded in a PC unit hard disc. The laser generated pulses of 10 Hz frequency, a few nanoseconds duration and energy of an order of 0.4 J. The single signals recorded by detectors in a period of 6 minutes in a one series of measurements were composed of a few thousands of records. The time distance of the measuring points dependent on the time of recording by the detection system was on average 50 ns, which gives the resolution of 7.5 metre. High initial energy of the laser beam permitted recording of the presence of pollution at up to 10 kilometres. However, taking into account the fact that the signal from higher altitudes was weak, the range of up to 5 or 6 km was taken into regard.

The results are presented in Figs. 2a and 2b as the plots of the β_{aer} coefficient and the lidar ratio lr_{aer} as a function of altitude, in selected time ranges. The altitude considered was of up to 3000 – 4000 metres, because for higher altitudes the intensity of the signal reaching the detector rapidly decreased and the noise increased. The plots reveal two maximums marking the limits of the temperature inversion and testifying to the presence of the bordering layer of inversion indicating the specific winds. If the bordering layer occurs at an altitude below 2000 metres, the winds blow from the sea, and if it occurs above 2000 metres, the winds blow from the land. The winds are responsible for the appearance of a certain type of aerosol. The wind from the sea (south or south-west wind) brings the marine-city aerosol. For Athens it is not purely marine aerosol because to the south of the city there is a dense urban area and Piraeus emitting enough pollution to change the characteristics of the pure marine aerosol. The winds from the land bring typical city aerosol of fine mesh size.

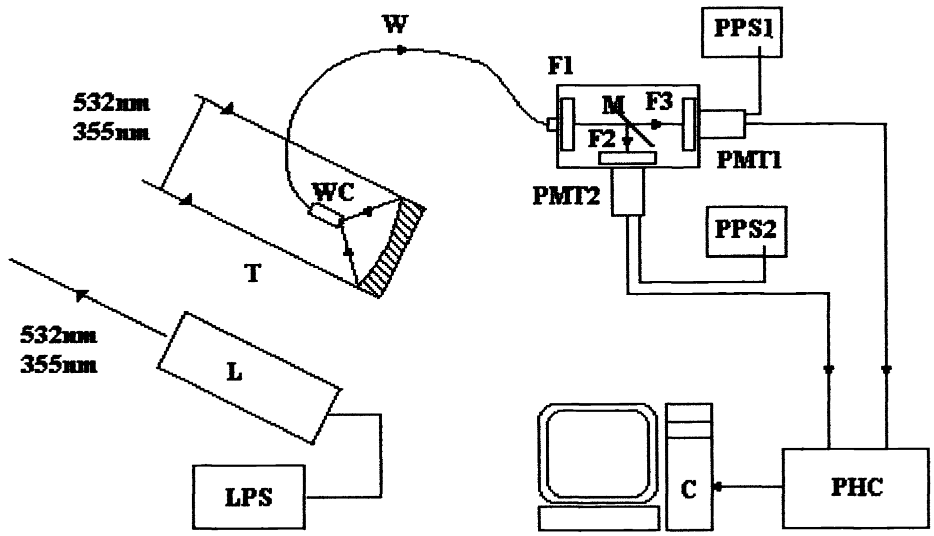

Fig.1. The experimental lidar system designed and constructed at the Faculty of Physics, the Athens Polytechnics, (T - telescope, WC – light waveguide connection, W –light waveguide, F1, F2 and F3 – narrow band interference filters, PMT1 and PMT2 – photomultipliers, PPS1 and PPS2 – photomultiplier power supply systems, PHC –photon counter, C - PC unit, L – Nd:YAG laser, LPS –laser power supply)

The measurements performed on August 25th, indicate a significant effect of the continental wind. The plot obtained shows two clear maximums of inversion: one at an altitude ~2000 metres, while the other at an altitude of ~ 4000 metres. The plots presented in Fig. 2a indicate a gradual increase in the concentration of pollution as the value of β_{aer} increases from 2 to 3 times. As follows from the same figure, the two inversion peaks grow at a rate of about 2.5 metre per minute. The plots also illustrate great dynamics of the aerosol grain size distribution, Fig. 2b) as the lidar ratio change from 0.08 to 0.03 at an altitude of 2000 metres. These data also mean that the contribution of greater size particles increases with time. We can also conclude that the contribution of greater size particles increases more at lower altitudes than at higher ones.

Fig. 3a presents the data collected during the measuring session on the 3rd of November. On this day the dominant wind blew from the continent and it was responsible for the convection of the inversion layer at a rate of 11 m/minute. The concentration of aerosol pollution was significantly increasing as the value of β_{aer} increased 2.5 times in a relatively short period of time (about 40 minutes). Also the thickness of the pollution layer increased from 1000 to 1500 metres.

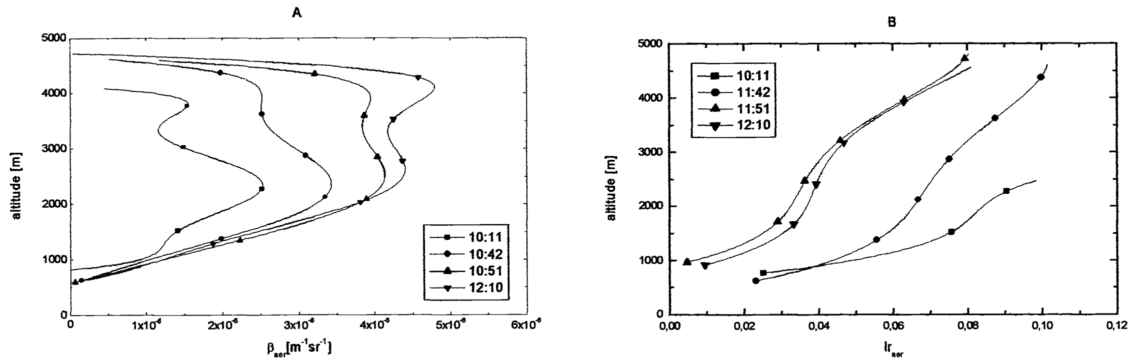

Fig.2. The backscattering coefficient β_{aer} and the lidar ratio lr_{aer} for aerosols as a function of altitude, on August 25th, late in the morning ($\Delta\beta_{aer} \approx 10\%$, $\Delta lr_{aer} \approx 10\%$)

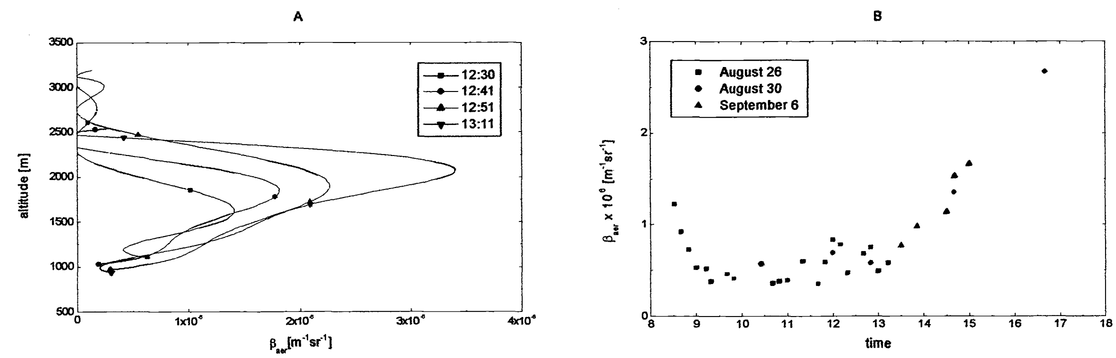

Fig.3. The backscattering coefficient β_{aer} for aerosol as a function of altitude: A – on Nov. 3rd, in the afternoon, B – as a function of the time of day on August 26th, 30th, and Sept. 6th, ($\Delta\beta_{aer} \approx 10\%$)

3. CONCLUSIONS

Measurements were also made to detect day changes in the concentration of aerosol pollution. The results obtained on three days of close weather conditions are presented in Fig. 3b. In the morning the concentration of aerosol pollution was very high because of the radiation inversion. The ground was cooled and the near ground layers remained cool, although the traffic was already intense and emission of hot exhaust gases was high. The layer of highly concentrated pollution occurred at a small height over the ground and was observed as photochemical smog. As a consequence of solar radiation activity the ground and near-ground layers of air heat up during the day leading to stop the inversion of temperature and the photochemical smog.

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