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Near Surface Aerosol Lidar Mapping of Sofia Area. On the Synergy with City Sensor Networks

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Abstract

Experimental results obtained during the implementation of a Contract, financed by Sofia Municipality for Aerosol Lidar Mapping of urban and industrial Sofia-capital areas are presented. The basic goals were to get experimental estimates of different basic parameters of a perspective lidar monitoring system for the remote scanning from a single position over the entire Sofia area. We obtained lidar maps of good quality for radial operational distances above 25 km from the Lidar Station, covering the entire urban and the surroundings, including Vitosha and Stara Planina mountain regions. Considering lidar maps as high resolution aerosol sensor networks we analyzed a novel high resolution air monitoring system based on three sensor networks: lidar aerosol network and city sensor and meteo networks.

Key words: lidar mapping, near surface atmosphere, lidar aerosol network, city sensor networks, synergy of networks.

Introduction

Near-surface atmospheric measurements over urban and industrial areas are of great importance due to the strong and direct impact of fine pollution particles on the human health. We conducted by lidar scanning a large set of zones in horizontal and vertical directions using lidar systems developed at the Institute of Electronics (IE), Bulgarian Academy of Sciences (BAS). Some parts of experimental results are presented in this work. An additional information can be found in [1, 2].

Sofia Lidar Station

Lidar mapping experiments were performed with the 3 Lidar systems (Fig. 1a, b, c), operating in the EARLINET Sofia Lidar Station of the IE-BAS Laser Radars Laboratory. The scanning lidar in Fig.1a, based on Cu vapor laser is emitting simultaneously 2 waves on 510.6 nm and 578.2 nm at a repetition of frequencies as 5-8 kHz. This lidar is scanning approximately the half hemisphere. It was used for probing toward the Sofia City Center (West) and the Stara Planina Mountain (Nord).

The next scanning Nd:YAG lidar in Fig.1b is emitting 3-waves on 532 nm and 1064 nm and 607 nm (Raman channel). It was directed to Vitosha Mountain (South) to scan the near mountain atmosphere and its surrounding zones. The third lidar in Fig. 1c is a three wavelengths laser (510.6 nm (green), 578.2 nm (yellow) and 627.8 nm) based on our novel combined Cu & Au vapors, for probing the open atmosphere in vertical direction above 15 km. It is used under EARLINET & ACTRIS programs: Saharan and volcano dusts, dusts from fires, etc. This set of 3 lidars can provide very informative lidar measurements by an obtaining lidar maps of very good quality.

Fig.1a. Cu-vapor lidar.

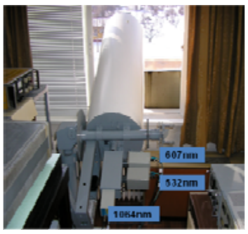

Fig.1b. Nd:YAG lidar.

Fig. 1c. Cu–Au vapor lidar.

Lidar mapping of the near surface aerosol field

Lidar maps present 2-dimensional images of the aerosol field distribution in radial coordinates (ρ, θ), ρ is the distance from the lidar and θ is the radial angle. The aerosol field can be described in the general case by the two-dimensional distribution of the mass concentration $m_{aer}(\rho,\theta)$ of aerosol particles in the resolution volume of coordinates (ρ,θ). The first step of this procedure is the mapping of the so-called aerosol back-scattering coefficient $\beta_{aer}(\rho,\theta)$. Then the mass concentration is calculated by the expression $m_{aer}(\rho,\theta)=C_{calib}\beta_{aer}(\rho,\theta)$, where the coefficient C_{calib} can be determined experimentally. It is evident that Lidar maps can be also considered as some virtual aerosol sensor networks of closely distributed very large number of single aerosol sensor cells of dimensions, determined by the spatial resolution $\delta\sigma_{lid}$ of lidar maps. The last is easily calculated by the product $\delta\sigma_{lid} \sim \delta\rho\delta\varsigma$ of the lidar radial resolution $\delta\rho \sim 30m$ and the angular resolution $\delta\varsigma = \rho\delta\theta$, where ρ is the distance from the lidar. It is important to note here the aerosol concentrations, measured within each resolution cell are independen**t** and thus, the number N_{aer} of single aerosol sensors is defined by the expression $N_{aer} \sim \Sigma_{lmap} / \delta\sigma_{lid} >> 1$ (Σ_{lmap} is the total lidar map area).

Some experimental results

Here we will present a small part of experimental results, obtained during the 7-months period of the contract with the Sofia Municipality. As a first step we determined the maximum operational distances ρ_{max} by the scanning lidar systems. The plot in Fig. 2a presents a sector lidar map toward the Vitosha mountain acquired by a Nd:YAG lidar on 1.064µ, where ρ_{max} >20km. For the scanning Cr-vapor lidar in Fig. 1a ρ_{max} > 27 km was measured. Thus, the lidars of Sofia Lidar Station are capable to provide lidar maps of good quality, covering many times the Sofia Municipality territory. The next Fig. 2b is presenting a lidar map in vertical direction to demonstrate the height of the very polluted near surface atmosphere to heights of 700-800 m above the city. This zone is playing an important role in atmospheric processes from external pollution sources, etc.

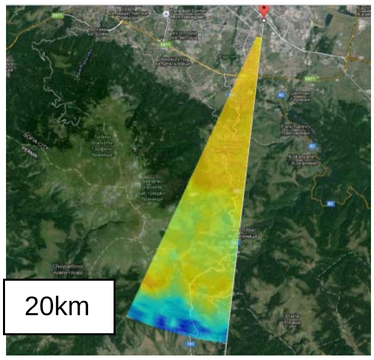

Fig. 2a. Maximum mapping distance.

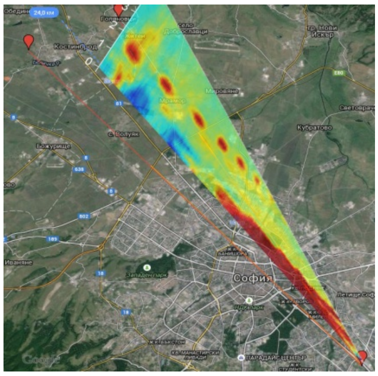

Fig. 2b. Lidar mapping of near surface polluted atmospheric layer.

In Fig. 3a to Fig. 3d we present four (4) successfully scanned lidar images of the same area through 30 min toward the city centre. The areas of intensive traffic near the Lidar station are seen as more polluted in dark brown to light blue, while the city areas at about 9.5 km are more clean (in dark blue). Analyzing the 4 images as a whole one can see the relatively fast temporal dynamics of near surface pollutions. The decrease of traffic intensity is correlating with the decreasing the traffic pollution over the zones near the Lidar station, while the atmosphere above the distant areas are seen more clean (wider dark blue zones).

Fig. 3a. First 30 min scan.

Figs. 3b. Second 30 min scan.

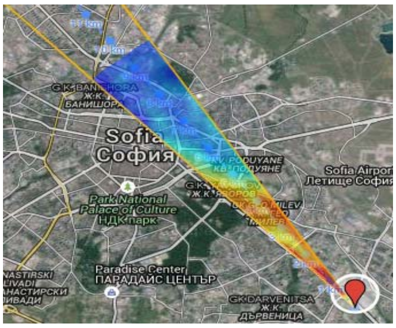

Fig. 3c. Third 30 min scan.

Fig. 3d. Fourth 30 min scan.

Successive LIDAR MAPs toward the City Center acquired every 30 minutes.

On the Synergy of lidar mapping with city atmospheric sensors

As well known the typical existing air monitoring systems contain the following basic structural components: 1) ground-based city sensor network of limited number of aerosol, gaseous, biological, etc. sensors; 2) network of meteorological sensors; 3) information system, containing computer models, data processing modules as well as blocks for visualization and estimations with outputs to blocks for development of recommendations to the competent authorities. The synergy approach is realized here by the computer models of the information system. The use of low number of sensors by the both ground-based networks over the large urban areas imposes serious limitations on the information capabilities of the monitoring systems. These problems could be solved by additional sensor networks of quite higher space resolution, working together with the existing city sensors networks. In the view of above results, the created by lidar mapping aerosol sensor network is just a promising technology to improve the information quality of monitoring systems.

Now, using the concept for lidar maps as aerosol sensor networks, situated within the near surface atmosphere above the city structure area we can present the basic idea for the creation of a modern lidar mapping based air-quality monitoring system, given schematically in the next Fig. 4.

As seen in Fig. 4 it contains in general same modules, typical for the existing Air-quality systems: the city sensor (2) and the meteorological networks (3), together with their information system (4), providing the data processing and recommendations. The main new module is the Aerosol network (1) of high spatial and temporal resolution, based on the lidar mapping here analyzed. Thus, we have now three fully independent sensors networks. Such of approach provides a lot of advantages at the development of novel monitoring systems. The synergy of these networks is provided by improved computer models. The novel information here is extracted through the correlations between the aerosol lidar maps and the city ground based structure. Lidar maps just contain the information about the near surface dynamics of air masses, driven by the surface winds, but affected by the city structures. We have to note also the lidar aerosol network here could be considered also as some virtual network in the sense that it exists during the laser action only. It disappears after the switching off the laser system.

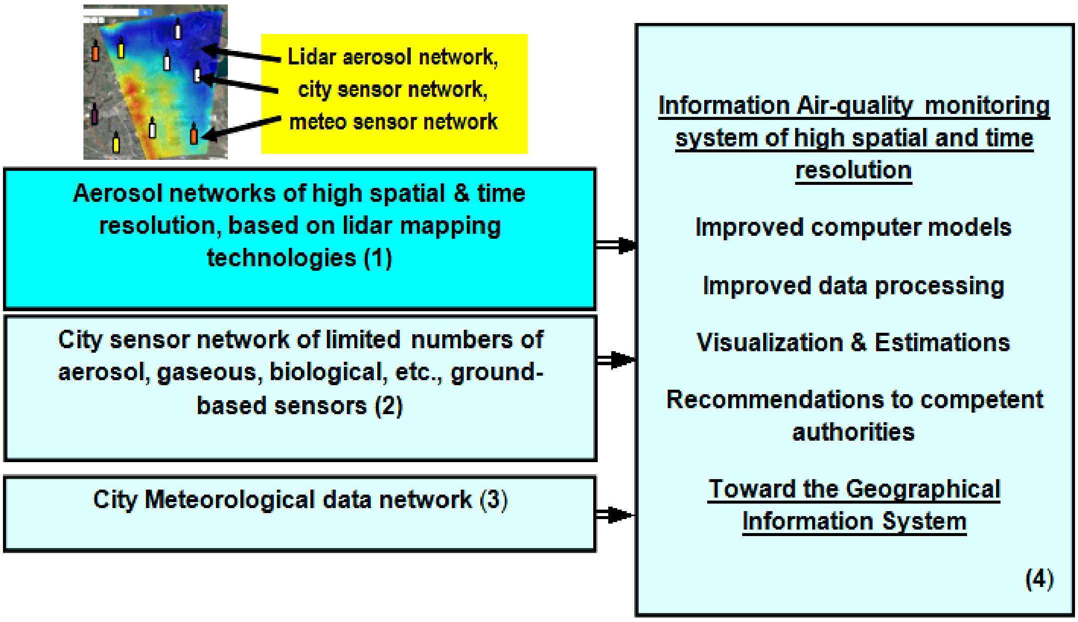

Fig. 4 Block-schematic of the novel Air-quality monitoring system of high spatial & temporal resolutions, based on incorporating of lidar mapping technologies.

Conclusions

A large lidar mapping experiment using 3 scanning lidars was performed over Sofia urban area. We obtained a large set of good quality lidar maps, overlapping them on the geographical maps and analyzing the aerosol field dynamics. The operational radial ranges exceed 25 km for both the lidars. We also analyzed also the concept for lidar maps as a continuous set of high resolution independent sensors, creating an aerosol sensor network. On this basis we considered the problem of synergy of three fully independent sensors networks as components of a modern high resolution city monitoring system.

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