OPTICAL PROPERTIES OF ANTHROPOGENIC AEROSOLS OVER THESSALONIKI, GREECE DURING SCOUT-O_3 CAMPAIGN

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ABSTRACT

We present the optical properties of anthropogenic aerosols over Thessaloniki, Greece during 24th and 25th of June 2006. Aerosol optical depth is significant high of the order of 0.8 – 0.9 at 550 nm, while Ångström exponent ranges from 1.2 to 2.0. Backscatter coefficient indicates large aerosol load inside boundary layer. There was almost no advection of air-masses from outside Europe within the planetary boundary layer, while FLEXPART model simulations indicate that Thessaloniki was slightly influenced in the free troposphere by the advection of pollution from North America.

1. INTRODUCTION

Aerosols play an important role in the atmospheric budget [1]. Depending on the aerosol type, they can absorb or scatter the incoming and outgoing radiation, warming or cooling the atmosphere and, depending on their size and composition, they can act as condensation nuclei, modifying cloud physical and radiative properties [2].

A lot of effort has been made in the past to measure the horizontal, vertical, and temporal distribution of the aerosol particles on a global scale to acquire the optical properties of different aerosol types. Passive remote sensing instruments aboard satellites or ground based sun-photometers cannot derive the vertical layering of aerosols which is very important for e.g. the indirect effect. Vertically resolved lidar measurements therefore are an indispensable tool to study the vertical structure of the aerosol field and its temporal development. Unfortunately, single ground-based lidar observations cannot detect the horizontal variability of the aerosol field, and lidars aboard aircraft cannot perform process studies or long-term measurement series.

The sun-photometer measurements used in many studies pertain to the entire integrated vertical column. Column-only measurements can cause biased estimates of aerosol properties in situations with inhomogeneous aerosols. More recently, many additional high quality case studies charactering vertically resolved aerosol optical properties of specific aerosol types world-wide have been made with ground-based Raman lidars [3].

The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite was launched in April 2006. It carries the first satellite-borne lidar instrument CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization) which provides highly vertically resolved aerosol profiles on the global scale. CALIOP is a simple backscatter lidar. Profiles of the extinction-to-backscatter (lidar) ratio are needed to derive profiles of extinction coefficients which are one key parameter for the assessment of the aerosol effect on climate. An improper assumption of the lidar ratio results in large uncertainties of the extinction profiles.

In contrast to simple backscatter lidars like CALIOP, Thessaloniki lidar system (Thelisys) can retrieve extinction and backscatter profiles directly and independently of each other. The particle extinction-to-backscatter (lidar) ratio allows for a rough separation among different aerosol types. Multi-wavelength Raman lidars are used for a more detailed differentiation of aerosol types and for the retrieval of microphysical aerosol parameters.

An aerosol campaign was held from July 14 to July 25, 2006, at Thessaloniki, Greece, as part of the integrated project SCOUT-O_3 (Stratospheric-Climate Links with Emphasis on the Upper Troposphere and Lower Stratosphere) inclouding ground-based and air-borne measurements. In this paper we present measurements with Thelisys, CALIPSO, MODIS and AERONET on July 24th and 25th, 2006, together with trajectory analysis obtained with HYSPLIT. We use this case study to illustrate the potential of such a combined data set to study the optical properties of aerosols.

2. INSTRUMENTATION AND DATA

2.1 Thessaloniki lidar system

The data presented in this study were acquired with Thelisys. Thelisys is a lidar system located at the Laboratory of Atmospheric Physics (LAP) (40.5° N, 22.9° E, 50 m above sea level) in Aristotle University of Thessaloniki (AUTH) and is a 355/532 nm Raman/elastic lidar system operational since May 2000 in the framework of the European Aerosol Research Lidar Network (EARLINET) [4].

Typical statistical errors due to noise in signal detection are below 10% in the PBL for backscatter and extinction coefficients at 355 nm. In the free troposphere, typical backscatter coefficient errors at 355 nm are below 30% for values higher than 0.25 $Mm^{-1}sr^{-1}$. For extinction coefficient at 355 nm, errors are below 30% in the free troposphere for values higher than about 8 Mm^{-1}.

2.2 Sunphotometer

The sunphotometric observations reported in this paper were performed by a CIMEL sun-sky radiometer, which is part of the Aerosol Robotic Network (AERONET) Global Network (http://aeronet.gsfc.nasa.gov). The instrument is located on the roof of the Laboratory Atmospheric Physics. The technical specifications of the instrument and AERONET data products are given in detail in [5].

2.3 Satellite measurements

The Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) mission (http://smsc.cnes.fr/ CALIPSO/), is an Earth Science observation mission that launched on 28 April 2006 and flies in nominal orbital altitude of 705 km and an inclination of 98 degrees as part of a constellation of Earth-observing satellites known as the “A-train”. CALIOP is an elastically backscatter lidar operating at 532 and 1064 nm, equipped with a depolarization channel at 532 nm, that provides high-resolution vertical profiles of aerosols and clouds [6].

The Moderate Resolution Imaging Spectro-Radiometer (MODIS) aerosol 5-min level-2 swaths (collection5) were retrieved through NASA’s Earth Observing System Data Gateway. Aerosol optical depth values at 550 nm were extracted with an uncertainty of ±0.05±0.15*AOD over land [7].

2.4 Model

The Langrangian particle dispersion model FLEXPART [8] provides profiles of the footprint emission sensitivity for different gas species as well as profiles of the source contribution of the different continents to the pollution above a measurement site.

The Dust Regional Atmospheric Model (DREAM) is used in this study to confirm that no aerosol originated from Saharan are observed during the period under study.

The NOAA HYSPLIT model [9] was used to assess the transport pattern and to explain the advection of air masses over Thessaloniki. Four-days back-trajectories were calculated for arrival height of 500, 1500, 2500, 3500, 6000 and 7000 m.

3. RESULTS

We use a period in July 2006 as a case study to illustrate the potential of a combined data set of CALIPSO, AERONET, MODIS, Thelisys and modeling results.

The European synoptic condition from July 23-25, 2006, was dominated by a stagnant high pressure situation and low wind speeds. European pollution remained close to the sources. There was almost no advection of air-masses from outside Europe within the planetary boundary layer [10]. Results of the DREAM model show that Thessaloniki was not influenced by the advection of dust from Africa. FLEXPART model simulations indicate that Thessaloniki was slightly influenced in the free troposphere by the advection of pollution from North America.

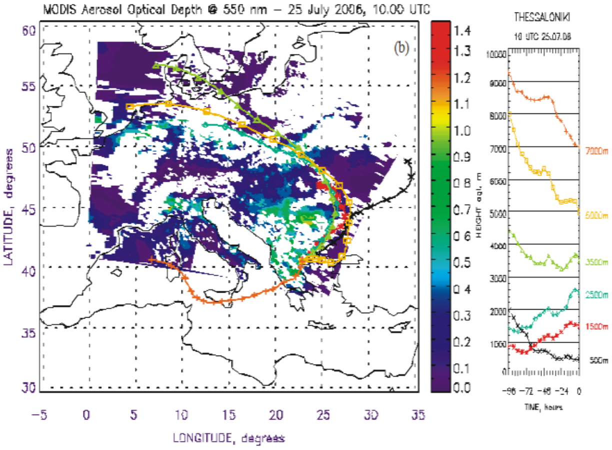

Figure 1. Spatial distribution of aerosol optical depth obtained at 550 nm by the MODIS sensor at 25 July 2006, 10:00 UTC. Four-days back trajectories have been over plotted for arrival height of 0.5, 1.5, 2.5, 3.5, 6.0 and 7 km.

In Figure 1 we present the satellite aerosol data from MODIS space-borne instruments. The aerosol optical depths at 550 nm are plotted over Greece, taken by MODIS/Terra aerosol 5-min level-2 swaths (collection 5) at 10:00 UTC. Aerosol optical depth values are significant high of the order of 0.8 – 0.9 at 550 nm.

Four-day backtrajectories are superimposed in Figure 1 for arrival height of 500, 1500, 2500, 3500, 6000 and 7000 m over Thessaloniki. The trajectories indicated that the air masses were circulating for four days over Europe where (as already mentioned) significant aerosol load is observed. Mixing ratio of carbon monoxide for 24th of July (not shown here) indicates that a slight contribution of the aerosol load may be attributed to aerosols advected from North America to the free troposphere.

To characterize the aerosol properties over Thessaloniki during 24th and 25th of July 2006, ground-based sunphotometric and combined backscatter/Raman lidar measurements are used in this study. From the direct CIMEL sunphotometric measurements over Thessaloniki, the aerosol optical depth at selected spectral channels is derived, following the well-known Beer-Bouguer-Langley law. The Ångström exponent is derived according to the Ångström power law, using the 440 and 870 nm channels. The data are processed within the AERONET version 2 direct Sun algorithm, which is described in detail in the AERONET web page. In Figure 2 we present the temporal evolution of the aerosol optical depth and the Ångström exponent over Thessaloniki AERONET site.

Figure 2 indicates that the aerosol optical depth increases significantly on July 24th. The highest aerosol optical depth is registered on July 25th on 08:35 with a value of 1.08 (500 nm), while the next day the aerosol optical depth remain significant high.

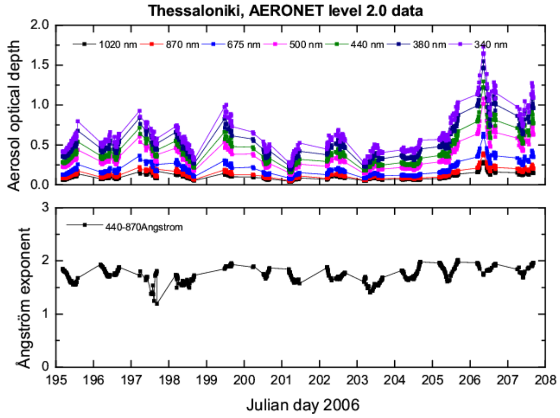

Figure 2. Aerosol optical depth at 1020, 870, 675, 500, 440, 380 and 340 nm (upper panel) and the Ångström exponent between 440 and 870 nm (lower panel) during SCOUT-O_3 campaign.

In Figure 2 we can also observe the time series of the Ångström exponent, which ranges from 1.2 to 2.0 during the period of SCOUT-O_3 campaign. No significant change is observed on 24th, 25th and 26th of July comparing with the previous days. This indicates that during the period under study the size of the particles did not face significant change.

The temporal evolution of backscatter coefficient during 24th of July is presented in Figure 3. Backscatter coefficient at 532 nm were retrieved in time steps of 30 min. The signature of a strong particle layer about 500 m deep is evident at 09:00 UTC. The increase of optical depth observed by CIMEL can be explained by the high values of backscatter coefficient observed at 1km around 09:00 UTC. Maximum backscatter coefficient at 532 nm is observed later on 11:15 UTC at 1700 altitude range.

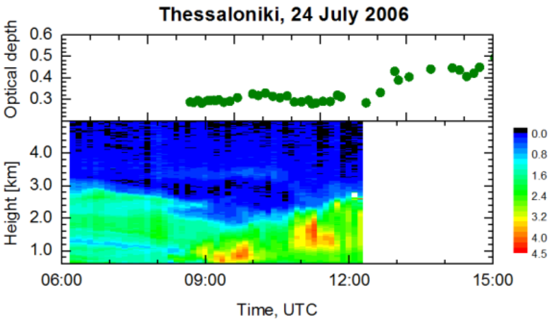

Figure 3. Temporal evolution of backscatter coefficient at 532 nm (low panel) and the corresponding aerosol optical depth at 532 nm (upper panel) on 24th of July 2006.

The columnar optical depth at 500 nm from CIMEL sun-photometric measurements are also presented in the upper panel. The sudden increase of optical depth may be attributed mainly to aerosols that are circulating over Europe inside the planetary boundary layer. As FLEXPART model simulations shows (not shown here) Thessaloniki was also slightly influenced in the free troposphere by the advection of pollution from North America.

CALIPSO overpasses above Thessaloniki in the morning of 25th July. Additionally we take into account 3 closest overpasses on 24th (one during nighttime and two during daytime) to examine the spatial distribution of aerosols. The selected orbits of CALIPSO are shown in Figure 4.

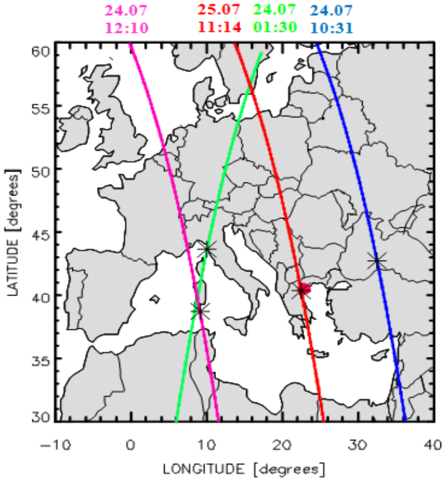

Figure 4. Flight orbits of CALIPSO selected on24th and 25th of July. Red dot corresponds to Thessaloniki lidar station. Black asterisks corresponds to minimum distance between the station and the overpass for each of the flights.

For each of these overpasses we include the backscatter coefficient, depolarization ratio at 532 nm as well as the vertical feature mask using level 2 version 3.01 profile product from CALIPSO. We screen our data for clouds and stratospheric features using Atmospheric Volume description (AVD). Cloud Aerosol Discrimination (CAD) score, which reflects our confidence that the feature under consideration is either an aerosol or a cloud, is used. In this study we screen out features with CAD score greater than -80. CALIPSO extinction Quality Control (QC) flags are also used. We use solutions where the lidar ratio is unchanged during the extinction retrieval (extinction QC = 0) or if the retrieval is constrained (extinction QC = 1).

Backscatter coefficient at 532 nm, depolarization ratio at 532 nm and vertical feature mask for the four overflights are presented in Figure 5. During the night of 24th of July (01:30 UTC, green) backscatter coefficient indicates large aerosol load in the first km, with relatively low depolarization ratio. In the morning of 24th of July (12:10 UTC, magenta) the layer seems to be present only in the first 300m, while two hours earlier (10:31 UTC, blue) no significant aerosol load is observed. This can be explained taking into account that the air masses were advected from the West where the aerosol optical depth is larger (Figure 1).

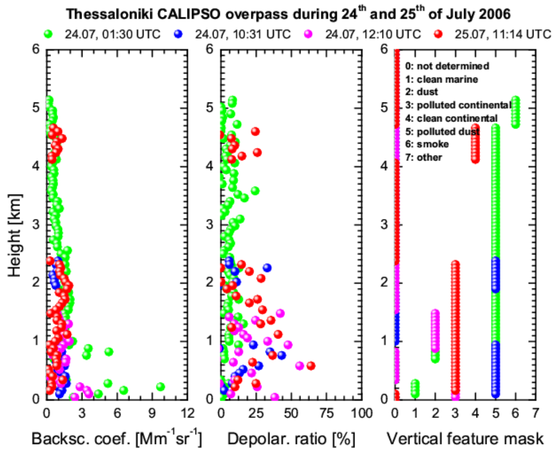

Figure 5. Profiles of backscatter coefficients, depolarization ratio and vertical feature mask for the four overpass of CALIPSO.

4. CONCLUSIONS

We examined the optical properties of anthropogenic aerosols over Thessaloniki, Greece during 24th and 25th of June 2006. During this period large optical depth was observed which was attributed to anthropogenic aerosols originated both from Europe and North America. This study highlights the potential of combined data set to study the horizontal, vertical and temporal evolution of optical properties of aerosols.

ACKNOWLEDGMENTS

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