Saharan dust observations over Thessaloniki using backscatter/Raman lidar and BSC/DREAM model

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ABSTRACT

In this study we present a multiyear study of Saharan dust intrusions over Thessaloniki. Observations were performed at Thessaloniki with a combined Raman/elastic lidar system from January 2001 to December 2006 in the framework of European Aerosol Research Lidar Network (EARLINET). In the referred period we collected a dataset of 33 Raman lidar observations when Saharan dust was present in the free troposphere over Greece. To identify the origin of the observed aerosol layer we have used 4-day back air mass trajectories using the NOAA HYSPLIT-4 model at several altitudes. Firstly, we identify the base and the top of the desert dust layers. After the boundaries of the dust layers are identified, we calculate the mean optical properties and vertically integrated optical properties within the layers. In the second part of the study an attempt to validate Dust Regional Atmospheric Modeling (DREAM) simulations is made in terms of aerosol extinction profiles. Comparisons of modeled and measured aerosol extinction coefficients over Thessaloniki show that the Saharan dust layers are well captured by the DREAM simulations in several cases while we demonstrate cases where measured geometrical as well as the optical characteristics of dust are underestimated by the model.

1. INTRODUCTION

Mineral dust is an important component of the atmospheric aerosol loading. Mineral dust accounts for about 75% of the global aerosol mass load and 25% of the global aerosol optical depth [1]. The African continent, especially its northern part, the Saudi Arabian regions, as well as the Asian continent are the main sources of dust around the world [2]. The Mediterranean area is strongly affected by the presence of desert dust due its proximity to North Africa. Limitations on the description of the dust cycle are mainly related to the lack of enough dense and regular measurements.

Lidar is the only technique that provides high resolution vertical profiling of aerosols. The European Aerosol Research Lidar NETwork (EARLINET) was established in 2000 to characterize the horizontal, vertical and temporal distribution of aerosols on a European scale [3]. Aerosol measurements over Greece have started on May 2000 within the frame of EARLINET. Basic optical properties of dust particles over Greece in the Eastern Mediterranean region have been given on the basis of case studies [4,5]. In addition, the optical and geometrical properties of Saharan dust particles were studied on a statistical basis in Greece [6,7].

Several operational dust forecasting models have been developed so far. These models include parameterizations for dust uplift, dust transport and dust deposition and provide forecasting diagnostics such as aerosol optical depth, dust load, dust surface concentration, as well as vertical profiles of dust concentration [8,9]. These models have been validated across case studies and can provide good forecast of dust events several hours ahead.

2. METHODOLOGY

2.1 Instrument

The data presented in this study were acquired with a lidar system located at the Laboratory of Atmospheric Physics (LAP) (40.5^o N, 22.9^o E, 50 m above sea level) in Aristotle University of Thessaloniki (AUTH) from 2001 to 2006. LAP-AUTH lidar system is a 355 nm Raman/elastic lidar system operational since May 2000. The LAP-AUTH lidar is based on the second and third harmonic frequency of a compact, pulsed Nd:YAG laser, which emits pulses of 300 and 120 mJ at 532 nm and 355 nm, respectively, with a 10 Hz repetition rate [4,5,7]. Elastically backscatter signals at both 355 and 532 nm and N_2 Raman shifted signal at 387 nm are collected with a Newtonian telescope of 500mm diameter with 0.7–3 mrad adjustable field-of-view. Three Hamamatsu R7400P-06 photomultipliers are used to detect the lidar signals at 532, 355 and 387 nm with 15m height resolution and 2 min time resolution.

2.2 The BSC/DREAM dust model

DREAM [8] is a regional model designed to simulate and/or predict the atmospheric cycle of mineral dust aerosol. The Barcelona Supercomputing Center maintains dust forecast operations with DREAM and conducts modelling research and developments for short-term prediction. During model integration, calculation of the surface dust injection fluxes is made over the model grid points declared as deserts. Once injected into the air, dust aerosol is driven by the atmospheric model variables: by turbulent parameters in the early stage of the process when dust is lifted from the ground to the upper levels; by model winds in the later phases of the process when dust travels away from the sources; finally, by thermodynamic processes (atmospheric water phase changes producing clouds, rain and dust wet scavenging) of the atmospheric model and land cover features which provide wet and dry deposition of dust over the Earth surface.

One of the key components of the dust model is the treatment of the source terms in the concentration con-

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tinuity equation. Failure to adequately simulate/predict the production phase of the dust cycle leads to wrong representation of all other dust processes in the model. Therefore, special attention is made to properly parameterize dust production phase. The dust emission parameterization in the model is controlled mainly by the following factors: type of soil, type of vegetation cover, soil moisture content, and surface atmospheric turbulence. In the model, grid points acting as desert dust sources are specified using arid and semiarid categories of the global USGS 1-km vegetation data-set. Another data participating in dust production calculations is the FAO 4-km global soil texture data set from which particle size parameters are evaluated. The main general features of the last version of the model [9] used in this study are: Dust production scheme with introduced viscous sub-layer, 8 particle size bin distribution, soil wetness effects on dust production, dry deposition and below cloud scavenging, horizontal and vertical advection, turbulent and lateral diffusion represented as for other scalars in the Eta/NCEP model and dust radiative feedbacks on meteorology [9].

2.3 Case studies

In the following two examples of Saharan dust are presented. A typical example of Saharan dust forecasted by the BSC/DREAM model on 15 July 2002 (fig.1). That day was a cloud-free day with high mean aerosol load of 0.126 g/m^2 of dust particles transported from the Western Saharan region to Greece.

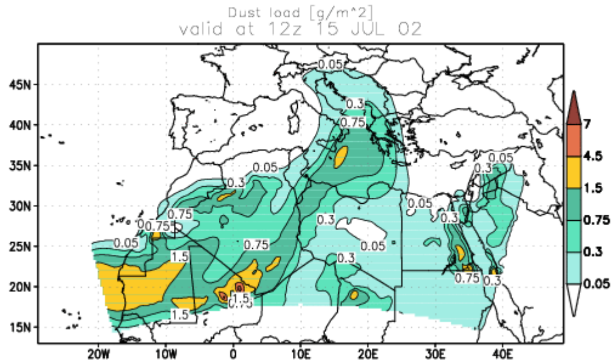

Figure 1. Dust load *over South Europe, on 15 July 2002, estimated with the DREAM model*

During this Saharan dust event Raman/lidar measurement was performed. Vertical profiles of extinction coefficient at 355nm, backscatter coefficient at 355 and 532 nm, Angstrom exponent related to backscatter between 355 and 532 nm, as well as lidar ratio at 355nm are presented in Figure 1. Profiles are plotted for the complete overlap height region of LAP's lidar.

To determine the geometrical properties of dust aerosol layers we have used the vertical profile of backscatter coefficient at 532 nm. The base of the dust aerosol layer corresponds to the lowest point of a strong increase in the aerosol backscatter profile over the retrieved PBL height. On the other hand the top of the desert dust layer is located at the local minimum of aerosol backscatter coefficient. Knowing the base and the top of the dust layer we can easily calculate the geometrical thickness as well as the geometrical center of mass of the dust layer.

Backscatter profiles on 15 July 2002 show a well defined dust layer between 3.5 and 6 km altitude range. This aerosol layer was quite stable during the period of measurements. As we can see this layer is characterized by larger values of lidar ratio and lower Angstrom exponent which strongly indicate the presence of Saharan dust at these height levels. There is also a second layer with lower particle content directly below the first layer between 2.2 and 3.5 km.

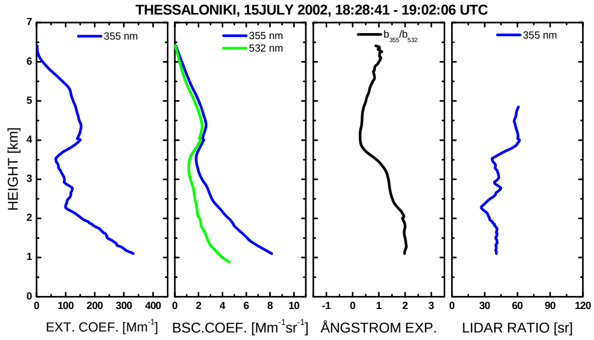

Figure 2. Extinction, backscatter, Angstrom exponent related to backscatter and lidar ratio profiles measured in the dust free-troposphere aerosol layer at Thessaloniki on 15 July 2002, between 18:28 and 19:02 UTC.

In Figure 3 we compare modeled vertical profile of extinction at 550nm at 18:00 UTC with Raman lidar-derived vertical profile of extinction at 532 nm for 15 july 2002. To calculate the extinction coefficient at 532 nm from extinction at 355nm we have used the Angstrom exponent related to backscatter between 355 and 532 nm.

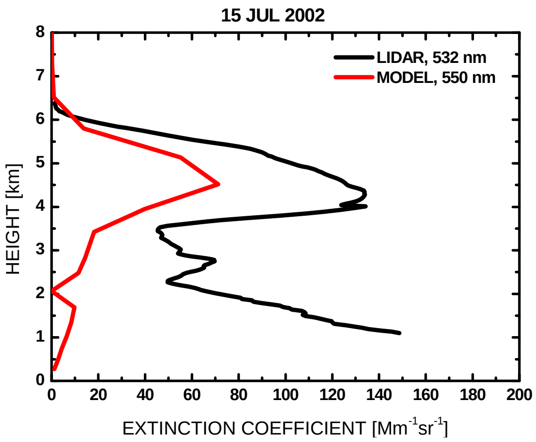

Figure 3. *Comparison of extinction coefficient profile simulated by BSC-DREAM at 550 nm (only for dust) and observed by Raman lidar measurements at 532 nm over Thessaloniki, on 15 July 2002.*

The geometrical characteristics of the desert dust from model predictions are in very good agreement with the measurement. Concerning the values of extinction we should keep in mind that the model shows only the dust profile and not the actual aerosol profile which also contains aerosols emitted from other sources and thus an absolute comparison is not possible. The model predictions show almost half of the extinction for heights above 3 km.

Another example of Saharan dust forecasted by the BSC/DREAM model on 12 September 2005 is presented in Figure 4.

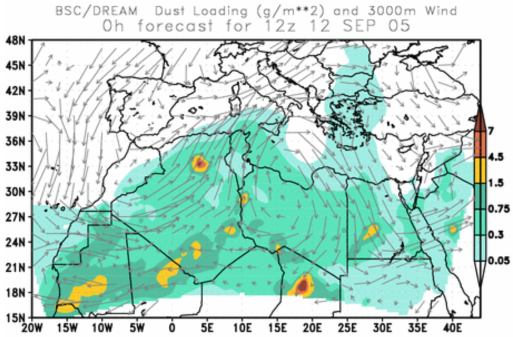

Figure 4. Dust load *over South Europe, on 12 September 2005, estimated with the DREAM model.*

Vertical profiles of extinction (355 nm) and backscatter (355 & 532 nm) coefficients as well as angstrom exponent and lidar ratio (355nm) on 12 September 2005 are presented in Figure 5. A well defined dust layer between 1.94 and 4.6 km altitude range is observed from both backscatter and extinction coefficients.

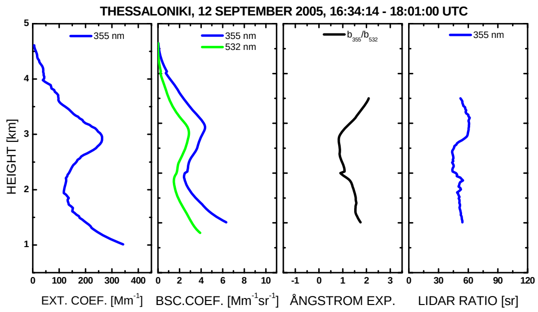

Figure 5. Extinction, backscatter, Angstrom exponent related to backscatter and lidar ratio profiles measured in the dust free-troposphere aerosol layer at Thessaloniki on 12 September 2005, between 16:34 and 18:01 UTC.

In Figure 6 we present the vertical profile of extinction at 550nm at 18:00 UTC as calculated by DREAM model with Raman lidar-derived vertical profile of extinction at 532 nm for 15 july 2002.

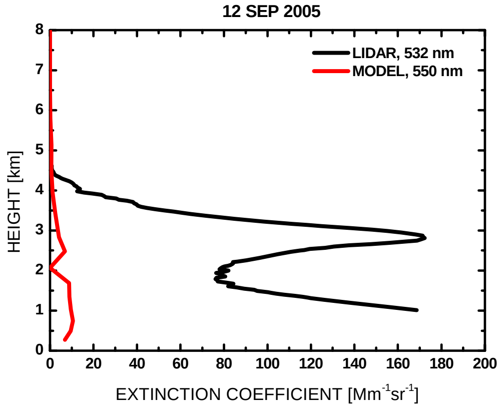

Figure 6. *Comparison of extinction coefficient profile simulated by BSC-DREAM at 550 nm (only for dust) and observed by Raman lidar measurements at 532 nm over Thessaloniki, on 12 September 2005.*

Based on the backtrajectories the observed layer is due to dust aerosols, however the modeled vertical profile of extinction at 550 nm is negligible with aerosol optical depth of 0.022. The measured (total) aerosol optical depth at 532 nm is 0.45. The optical characteristics of the dust layer observed on the two measurements are similar. For the almost the same geometrical depth of layer, 2.76 km and 2.67 km for 15/07/02 and 12/09/05, the optical depth at 355 nm is being calculated at 0.28 and 0.34 respectively, while mean lidar ratio values are 57 and 52 sr. The main difference in the optical characteristics of the two examples is the values of Angstrom exponent. Thus, for the case of 15/07/02 mean Angstrom exponent is 0.6 while for 12/07/05 mean Angstrom exponent is 1.2, indicating smaller particles.

3. RESULTS AND DISCUSSION

Following the above mentioned methodology, we calculated the base and top heights for each Saharan dust profile for our selected cases. Table 1 shows the mean, median, minimum and maximum values of desert dust altitude range parameters (base, top, thickness, geometrical center), as retrieved from aerosol extinction profiles at 355 nm for Raman/lidar measurements and at 550 nm for DREAM model calculations.

Table 1. Height distribution of the mean, minimum and maximum values of desert dust altitude range parameters (base, top, thickness, geometrical center) from lidar Raman measurements and BSC/DREAM model.

	Mean [km]		**Median [km]**		**Min [km]**		**Max [km]**	
	RAMAN	**DREAM**	**RAMAN**	**DREAM**	**RAMAN**	**DREAM**	**RAMAN**	**DREAM**
Base	2.5 ± 0.9	1.7 ±1.4	2.3	2.1	1.1	0.3	5.5	5.8
Top	4.2 ± 1.5	5.2 ± 3.1	3.9	5.4	1.9	2.0	8.9	13.5
Thickness	1.8 ± 0.9	3.6 ± 2.1	1.4	3.4	0.7	0.8	3.9	8.7
G. Center	3.4 ± 1.2	3.4 ± 2.1	3.4	3.8	1.5	1.1	7.2	9.3

From Table 1 we can see that multiple aerosol dust layers of variable thickness (0.7 – 3.9 km for Raman/lidar measurements and 0.8 – 8.7 km for DREAM model) were observed. The mean geometrical center of dust layers is located at 3.4 km, for both measurements and model calculations. The top of the dust layer ranged from 1.9 to 8.9 km, with a mean value of the order of 4.2 km for Raman lidar measurements. On the other hand, the top of the dust layer range from 2.0 to 13.5 km with a mean value of 5.2 km for DREAM model calculations. This result possible indicates the weakness of Raman/lidar to measure in large height range. Moreover, the base of the dust layer is measured between 1.1 and 5.5 km with a mean value of 2.5 km using the Raman lidar, while it is being estimated from 0.3 to 5.8 km with a mean value of 1.7 km from model calculations. These values reveal the difficulty to estimate the base of dust layer if this layer is inside the boundary layer from Raman/lidar measurement. However, the geometrical boundaries of the dust layer is not well identified in separately cases the mean geometrical characteristics of Saharan dust over Thessaloniki estimated by DREAM model is within the standard deviation of the Raman/lidar measurements.

To further investigate we have calculated the aerosol optical depth of each layer from Raman/lidar measurements (at 355 nm) and BSC/DREAM model (at 532n nm). Most of the desert aerosol layers have optical depth lower than 0.05 both from Raman/lidar measurements and model predictions. However, DREAM model fails to estimate larger optical depths, as in case of 12 September of 2005, possible because of the smaller particles.

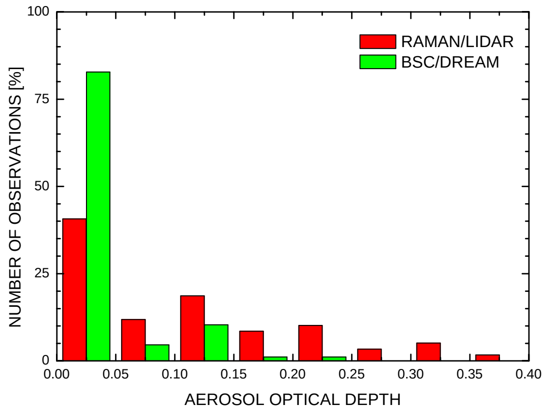

Figure 1 *Histogram of aerosol optical depth of dust layers with a Raman lidar and BSC/Dream model from 2001 to 2006.*

4. CONCLUSIONS

The main aim of this work is to present a statistical analysis on the geometrical properties of Saharan dust vertical distribution over Thessaloniki, Greece, for a six year period (2001-2006) using backscatter/Raman lidar measurements and BSC/DREAM model calculations. Multiple aerosol dust layers of variable thickness were observed. The mean geometrical center of dust layers is located at 3.4 km, for both measurements and model calculations. Mean geometrical characteristics of Saharan dust over Thessaloniki estimated by DREAM model are within the standard deviation of the Raman/lidar measurements. Moreover, most of the desert aerosol layers have optical depth lower than 0.05 both from Raman/lidar measurements and model predictions, while the work reveals the weakness of BSC/DREAM model to estimate large optical depths.

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