CHARACTERISTICS OF BIOMASS BURNING AEROSOLS OVER SE EUROPE DETERMINED FROM LIDAR AND SUNPHOTOMETRIC MEASUREMENTS

Dimitris Balis(1), Vassilis Amiridis(1), Elina Giannakaki(1), Stylianos Kazadzis(1), Antti Arola(2) and Alexandros Papayannis(3)

(1) Laboratory of Atmospheric Physics, Aristotle University of Thessaloniki, 54124, Thessaloniki, Greece, e-mail:balis@auth.gr
(2) Finish Meteorological Institute, Helsinki, Finland, e-mail:Antti.Arola@fmi.fi
(3) National Techical University of Athens, Greece, e-mail: apdlidar@central.ntua.gr

ABSTRACT

The influence of biomass burning smoke on the aerosol loading in the free troposphere over Thessaloniki, Greece is discussed in this paper. Ten selected cases during 2001-2005 are presented, when very high aerosol optical depth values were observed, with the synergy of different remote sensing instruments. The data collected allowed the characterization of the optical properties of the biomass burning aerosols in this region, where limited information has so far been available. Four-day back trajectories indicated that air masses were advected from regions where strong forest fires occurred. In order to investigate the optical properties of biomass burning aerosols, we used a two-wavelength lidar system that combines Raman and elastic-backscatter observations in addition to Brewer spectrophotometer UV irradiance measurements and aerosol optical depth estimates. The retrieval of single scattering albedo employed the Brewer global irradiance measurements and radiative transfer model calculations. The Raman lidar measurements showed that for smoke aerosols the lidar ratios varied in the range of 45-90sr depending on the age of the smoke, while the estimated single scattering albedo was 0.96±0.02.

1. INTRODUCTION

Aerosols from biomass burning activities have been identified as a significant radiative forcing agent [1]. A considerable body of research using in situ measurement techniques has been published on the optical properties of smoke. This includes the analysis of laboratory burns [2] and intensive field campaigns involving large-scale forest fires in the North America [3], as well as over Brazil [4,5] and over Africa [6]. Remote-sensing techniques included ground-based sun photometry [7], quantitative inversions of satellite imaginary for smoke optical properties [8] and ground-based and airborne lidars [9,10].
Lidar measurements of particle optical properties with high spatial and temporal resolution give detailed information on the occurrence, extent and development of aerosol structures. The determination of the extinction-to-backscatter ratio (the so-called lidar ratio) profile is possible using the Raman-lidar technique for the independent determination of the particle extinction and backscatter vertical profiles [10]. Such observations are rare in the case of air masses rich in biomass burning smoke.

2. INSTRUMENTATION AND METHODS

At the Laboratory of Atmospheric Physics (LAP) (40.5^0N, 22.9^0E, 50 m asl) a 355nm Raman lidar is used to perform continuous measurements of suspended aerosols particles in the Planetary Boundary Layer (PBL) and the lower free troposphere [12]. It is based on the second and third harmonic frequency of a compact, pulsed Nd:YAG laser, which emits pulses of 300 and 120 mJ output energy at 532 nm and 355 nm, respectively, with a 10 Hz repetition rate. The optical receiver is a 500 mm diameter telescope (1-3 mrad adjustable field-of-view). At a system level the LAP lidar was successfully intercompared with the other EARLINET groups showing on the average an agreement of better than 5% for height above 2 km [13]. The lidar-data handling procedures that we are using in LAP for the application of Fernald-Klett and Raman retrieval methods were successfully tested by 2 algorithm intercomparisons that took place during EARLINET [14,15] and include error estimates.

Two UV spectrophotometers (one single and one double monochromator) are also operating continuously at Thessaloniki station and monitoring the whole UV solar spectrum with a 0.5 nm spectral resolution. In addition, measurements of global total, UV-A and UV-B radiation, direct and diffuse erythemal irradiance are being performed. Routine measurements of the O_3 and SO_2 total columns have also been used as input to radiative transfer model calculations. From the UV sunphotometric measurements it is possible to derive the aerosol optical depth and the Angstroem coefficient in the UV spectral region. The single scattering albedo (ssa) can also be estimated using the Brewer global irradiance measurements and radiative transfer (RT) modeling tools. For this purpose we used LibRadtran 0.99 package and UVSPEC DISORT version. For the estimation of ssa, we adopted a look-up table (LUT) approach, in which the values global irradiance at 350 nm were tabulated as a function of the variable input parameters (solar zenith angle and AOD) [16].

3. RESULTS AND DISCUSSION

Regular aerosol extinction and backscatter measurements using a UV Raman lidar have been performed from January 2001 to December 2005 at Thessaloniki, Greece, in the framework of the European Aerosol Research Lidar Network (EARLINET). Profiles of the aerosol extinction coefficient, backscatter coefficient, and extinction-to-backscatter ratio (so-called 'lidar ratio') were acquired under nighttime conditions. Trajectory analysis shows that for ten days of our lidar measurements air masses were advected over Thessaloniki from regions with fire activity. 4-day back trajectories were computed for the days of interest, using the Hybrid Single-Particle Lagrangian Integrated Trajectory HYSPLIT) model [17], which uses the meteorological data produced by the National Weather Service ETA model to compute advection and dispersion of air parcels. For each trajectory, the positions of fires were superimposed (source: ATSR World Fire Atlas, http://dup.esrin.esa.it/ionia/wfa/index.asp).
In Fig.1 and Fig. 2 we present two of the ten cases where air masses from regions with fire activity were advected over Thessaloniki. In the upper panel of each figure we present the 4-day back-trajectory analysis along with the position of fires, while in the lower panels we present the corresponding lidar profiles for each day. In Fig.1 we present a case (22 August 2002) where the back-trajectory analysis indicates possible advection of smoke from forest fires in Portugal in the free troposphere over Thessaloniki, at 3.5km. The backscatter profile measured on that day shows that an aerosol layer is present at approximately 3.5km. The lidar ratio profile for that day is almost constant also for the height range 3-3.6km with an average value of 47±1 sr. The vertical variability of this optical parameter suggest aerosol content above 3km is of different type from that in lower altitudes and implies different microphysical properties below and above 3km. This is also confirmed by the trajectory analysis where one can see the difference in the origin of the air masses over Thessaloniki below and above 3km height.

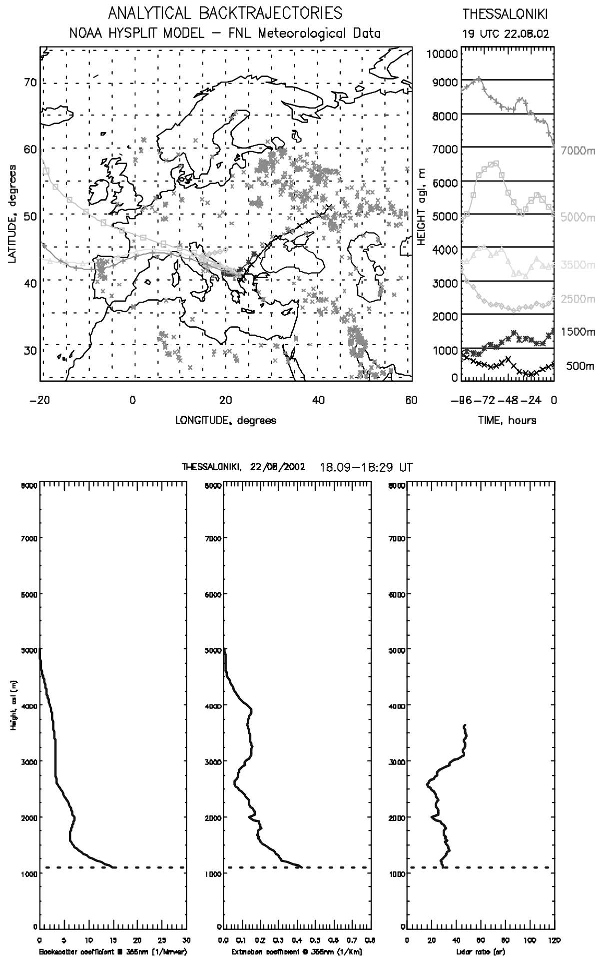

Fig. 1. Four-day back-trajectories and location of fires (crosses) from ATSR World Fire Atlas (European Space Agency – ESA/ESRIN) (Upper panel). Backscatter (bottom left), Extinction (bottom middle) and lidar ratio (bottom right) profiles at 355nm measured in the biomass burning free-troposphere aerosol layer at Thessaloniki on 22 August 2002, between 18:09 and 18:29 UTC (Lower panel).

In Fig.2 we present a case (1 August 2005) where the back-trajectory analysis indicates possible advection of smoke from the northern coast of the Black Sea, where intensive biomass burning activities took place in early August 2005. Satellite imaginary data from MODIS and ATSR fire atlas detected several fires in late July and early August 2005 that are probably related to the harvest. Farmers are burning the crop stubble off recently harvested fields in anticipation of the next sowing. Free tropospheric contribution of biomass burning aerosols is clearly shown in the lidar profiles. The backscatter profile measured on that day shows that an aerosol layer is present in the height range 2-3km. The lidar ratio profile for that day is almost constant also for the height range 1.5-3.0km with an average value of 89±7 sr.

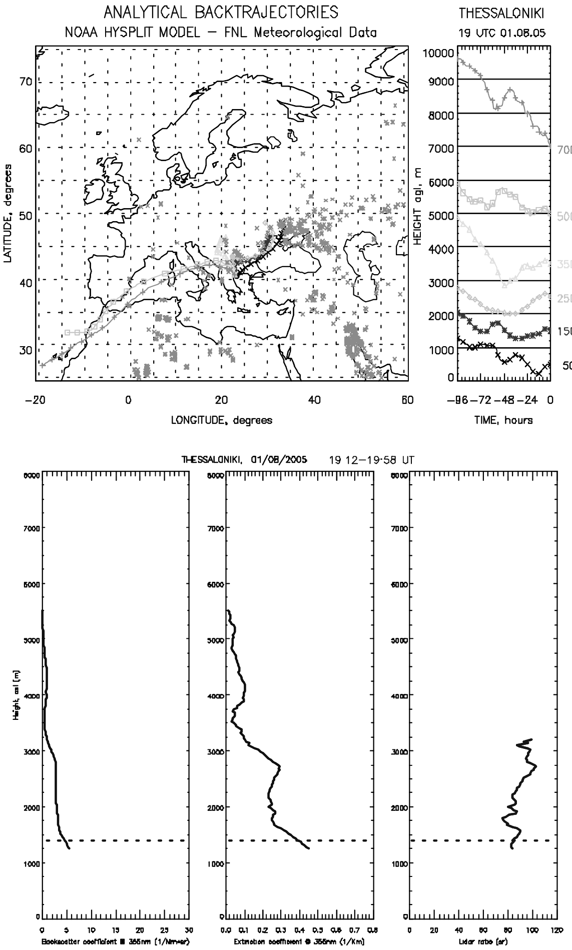

Fig. 2. Same as Fig.1 but for 1 August 2005, between 19:12 and 19:58 UTC (Lower panel).

In Fig. 3 we present all the lidar ratio profiles over Thessaloniki for the ten days of our lidar measurements where air masses were advected over the station from regions with fire activity. The lidar ratio values that according to the trajectory analysis refer to smoke aerosols are lying in the range between 45-90sr. These differences can be attributed to different source characteristics and to the fact that the regions studied here are located in variable distances from Thessaloniki which affects the optical characteristics of the observed smoke aerosols due to different aging processes.

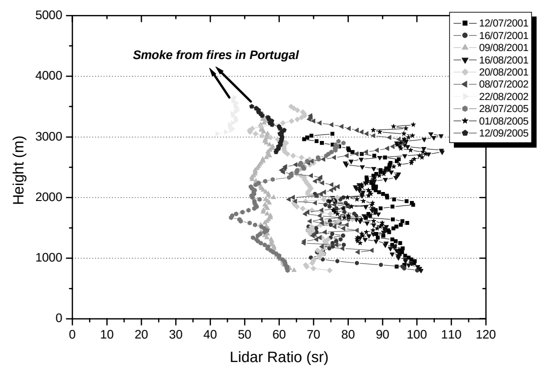

Fig. 3. Lidar ratio profiles for the ten days of our Raman lidar measurements where air masses were advected over Thessaloniki from regions with fire activity

In Table 1 we present a summary of all the estimated optical characteristics of smoke aerosols for the ten days of our lidar measurements where air masses were advected over Thessaloniki from regions with fire activity.

Table 1: Estimated optical characteristics of smoke aerosols over Thessaloniki.

Date	Main Source Region	Mean lidar ratio	Single Scattering Albedo
12 Jul 01	RAD*	89.2	-
16 Jul 01	RAD*	75.4	0.96
09 Aug 01	RAD*	57.7	0.91
16 Aug 01	RAD*	90.3	0.95
20 Aug 01	RAD*	67.3	0.95
08 Jul 01	RAD*	75.4	0.99
22 Aug 01	Portugal	46.7	-
28 Jul 05	RAD*	59.4	0.98
01 Aug 05	RAD*	89.5	0.95
12 Sep 05	Portugal	59.5	0.96

* *Russia's agricultural district*

4. SUMMARY AND CONCLUSIONS

In this paper, we have described two of total ten selected cases during 2001-2005, when air masses were advected over Thessaloniki from regions with fire activity. For the ten days of possible smoke influence on the aerosol load over Thessaloniki we have presented the corresponding lidar ratio profiles. Lidar ratios in the range of 45-90sr were observed for smoke aerosols, while the single scattering albedos estimated from the conjunction of UV irradiance measurements and radiative modelling tools was 0.96±0.02. The knowledge of the optical properties of biomass burning aerosol in this region is very important for climatic studies, taking also into account an increasing trend of forest fires during the last decade mostly due to extended dry summers. It was found that the optical characteristics of biomass burning aerosol were variable and this behaviour can be attributed to different source characteristics and to the fact that the regions studied here are located in variable distances from Thessaloniki which affects the optical characteristics of the observed smoke aerosols due to different aging processes.

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