VARIABILITY OF MIXING AEROSOLS OVER A S-E MEDITERRANEAN SITE

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ABSTRACT

Cyrpus is located to the South Eastern Mediterranean and thus is strongly affected by both, Saharan and Saudi Arabian deserts. At the end of September 2011, a strong dust storm from Saudi Arabian desert occurred over Eastern Mediterranean. The dust plume was recorded by MODIS satellite sensors on the 28th, 29th and 30th of September 2011. Additionally, during that period fire sources in eastern and central Turkey generated smoke plumes, transported Southwestern reaching Mediterranean region. In this study the variability or the mixing aerosols during an intense dust event has been examined in terms of backscatter coefficient and particle depolarization vertical profiles in visible spectral range. Lidar measurements performed at Cyprus EARLINET station, located in Lemesos in the premises of the Cyprus University of Technology, are used in combination with the AERONET sun-photometer measurements. Indeed, such data are used for the vertical separation of the different aerosol types.

1. INTRODUCTION

Mineral (desert) dust and biomass burning smoke are major components of the atmospheric aerosol system [1,2].

In Mediterranean region dust layers and smoke plumes usually during summer or early autumn are combined showing a complex vertical layering. The lidar observations presented here were performed in a seaside lidar station located in Eastern Mediterranean region during autumn 2011. Several remote sensing techniques have been developed to separate the aerosol profiles of particle backscattering and extinction related to the fine-mode aerosol (biomass burning smoke, urban haze) and the coarse mode fraction (sea salt, desert dust). In this study the authors used the 532-nm particle depolarization ratio to separate dust and smoke contribution to the 532-nm backscatter coefficient following the procedure proposed by [3].

2. INSTRUMENTATION

2.1 EARLINET lidar station

Cyprus University of Technology (CUT) -LIDAR system is located in Lemesos, Cyprus (34.675ºN, 33.043ºE, 10m above sea level) and performs daily measurements during the overpass of MODIS sensor since 2010.

The System is based on a Nd-YAG laser with pulse energies around 25 and 56 mJ at 1064 and 532 nm, respectively and has a repetition rate of 20 Hz. An achromatic beam expander reduces the divergence to less than 0.15 mrad. Elastically backscatter signals at two wavelengths (532nm, 1064nm) are collected with a Newtonian telescope with primary mirror diameter of 200 mm and an overall focal length of 1000 mm. The, lidar covers the whole range starting at the full overlap of the lidar (170 m) up to tropopause level. So far, three channels are detected, one for the wavelength 1064 nm and two for 532 nm. The two polarization components at 532nm are separated in the receiver by means of polarizing beamsplitter cubes (PBC). The CUT depolarization lidar operates at 532nm and it is possible to rotate the detection box included the polarization beamsplitter cube according to authors [4] in order to calibrate the instrument. Finally, a photomultiplier (Hamamatsu) is used for the detection of Visible (Vis), while an APD is used for the detection of Infrared (IR). In case of 532nm a transient recorder (Licel) that combines a powerful A/D converter (12 Bit at 20 MHz) with a 250 MHz fast photon counting system is used, while the 1064nm is acquired only in analog mode. The raw signal is recorded with a spatial and time resolution of 7.5 m and 60s respectively. Since 2011, CUT lidar station is a member of the European Aerosol Lidar Research Network (EARLINET) [5].

2.2 AERONET station

The sun-photometer observations used in this paper were performed by a CIMEL sun-sky radiometer, which is part of the AERONET Global Network (http://aeronet.gsfc.nasa.gov). CIMEL allows the measurements of the direct solar irradiance and sky radiance at wavelengths; 340, 380, 440, 500, 670, 870, 1020 and 1640 nm. The technical specifications of the instrument are given in detail by [6].

The instrument is located on the roof of the building of the Department of Civil Engineering and Geomatics of Cyprus University of Technology (CUT) (34ºN, 33º E, elevation: 20 m). The CUT_TEPAK AERONET station is located at the old town of Lemesos, 500 m from the sea. The sunphotometric station is operated since April 2010 by the Laboratory of Remote Sensing.

3. METHODOLOGY

For the vertical separation of backscatter profiles to different aerosol types we follow the procedure proposed by [3]. The volume depolarization ratio given in Equation 1 is used for the separation:

$$\delta_{\lambda,v} = \frac{\beta^{\perp}_{\lambda,m} + \beta^{\perp}_{\lambda,p}}{\beta^{//}_{\lambda,m} + \beta^{//}_{\lambda,p}} \tag{1}$$

where, $\beta^{\perp}_{\lambda,m}$, $\beta^{\perp}_{\lambda,p}$, $\beta^{//}_{\lambda,m}$, $\beta^{//}_{\lambda,p}$ are the parallel (//) and cross-polarized ($\perp$) components of the molecular (*m*) and the particle (*p*) backscatter coefficient, respectively. Taking into account the molecular ($\delta_{\lambda,m}$) and the particles depolarization ratio ($\delta_{\lambda,p}$), after conversions the volume and the particle depolarization ratio are given from equations (2) and (3), respectively

$$\delta_{\lambda,v} = \frac{\beta_{\lambda,m}\delta_{\lambda,m}(1+\delta_{\lambda,p}) + \beta_{\lambda,p}\delta_{\lambda,p}(1+\delta_{\lambda,m})}{\beta_{\lambda,m}(1+\delta_{\lambda,p}) + \beta_{\lambda,p}(1+\delta_{\lambda,m})} \tag{2}$$

$$\delta_{\lambda,p} = \frac{\beta_{\lambda,m}(\delta_{\lambda,v} - \delta_{\lambda,m}) + \beta_{\lambda,p}\delta_{\lambda,v}(1+\delta_{\lambda,m})}{\beta_{\lambda,m}(\delta_{\lambda,m} - \delta_{\lambda,v}) + \beta_{\lambda,p}(1+\delta_{\lambda,m})} \tag{3}$$

where, $\beta_{\lambda,m}$ and $\beta_{\lambda,p}$, are the molecular and the particle backscatter coefficient, respectively. The same approach can be used for the separation of mineral dust and smoke contributions. After the replacement of the volume, particle and molecular optical properties with the particles (*T*), type1 (*t1*) and type2 (*t2*) aerosols, respectively and starting from

$$\delta_{\lambda,T} = \frac{\beta^{\perp}_{\lambda,\mathrm{T}}}{\beta^{//}_{\lambda,\mathrm{T}}} \tag{4}$$

finally, the particle depolarization ratio in terms of 2 pure types of aerosols is obtained according to the following equation:

$$\delta_{\lambda,T} = \frac{\beta_{\lambda,t2}\delta_{\lambda,t2}(1+\delta_{\lambda,t1}) + \beta_{\lambda,t1}\delta_{\lambda,t1}(1+\delta_{\lambda,t2})}{\beta_{\lambda,t2}(1+\delta_{\lambda,t1}) + \beta_{\lambda,t1}(1+\delta_{\lambda,t2})} \tag{5}$$

The backscatter coefficient of the pure aerosol type is given as follows:

$$\beta_{\lambda,t1} = \beta_{\lambda,\mathrm{T}} \frac{(\delta_{\lambda,\mathrm{T}} - \delta_{\lambda,t2})(1+\delta_{\lambda,t1})}{(\delta_{\lambda,\tau 1} - \delta_{\lambda,t2})(1+\delta_{\lambda,\mathrm{T}})} \tag{6}$$

where, $\beta_{\lambda,\mathrm{T}}, \beta_{\lambda,t1}, \beta_{\lambda,t2}$ are the measured backscatter coefficient as well as the retrieved after separation of the two aerosol type respectively. The total particle depolarization as retrieved by the lidar measurements is given as $\delta_{\lambda,T}$ and finally, $\delta_{\lambda,t1}$ and $\delta_{\lambda,t2}$ represent the mean values of the pure components, given from literature.

4. RESULTS AND DISCUSSION

During the last days of September 2011, a strong dust storm over Saudi Arabian desert transfer a high load of mineral dust over Eastern Mediterranean. The dust plume was recorded by MODIS satellite sensors on 28, 29 and 30 of September. Additionally, fire activity was observed by MODIS satellite in Eastern Turkey during on September 2011. The smoke aerosols from eastern and central Turkey were transported to Southwest reaching Mediterranean Sea. These fire sources (red spots) are indicated in the MODIS satellite image (http://rapidfire.sci.gsfc.nasa.gov/firemaps) of Eastern Europe within the period 18 to 27 September 2011.

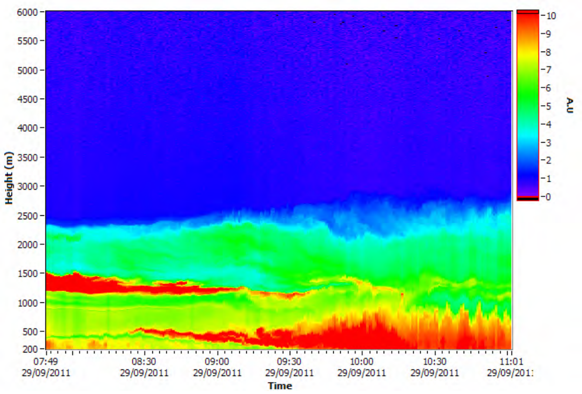

Figure 1: Complex stratification of dust and smoke observed with CUT lidar system over Lemesos, Cyprus, on 29 September 2011. Range-corrected 532-nm signal (arbitrary units) with 7.5-m vertical and 60-s temporal resolution.

Complex aerosol layering was observed over Lemesos, Cyprus on September 29, 2011. Figure 1 provides an overview of the situation on 29 September 2011 based on the aerosol lidar observations at 532 nm. From the RCS time series given in Figure 1, the shallow boundary layer is up to 500 m in the morning hours reaching 1.0km height on noon hours. A distinct layer was observed between 07:00 and 09:30 UTC from 1.2-1.5km. The lofted aerosol layer above 1.5 km height up to 2.5km (Figure 1) was indicated during the measurements time period. After 09:00 UTC the lofted aerosol layer became stronger and descended to the height ranges below 1.5 km. Finally between 10:15 and 11:00 a well mixing aerosol layer extends at the height range between 1 and 2.7 km observed by the CUT lidar. The possible origin and sources of the observed aerosol layers above Lemesos site can be concluded if one combines satellite images and air mass back-trajectories analysis. [4]

In Figure 2 the dust storm occurred on September 29, 2011 as observed by MODIS sensors on board on TERRA and AQUA satellites is given. From the satellite images shown that the dust episode was stronger during the TERRA overpass (08:30 UTC). During AQUA overpass (10:30 UTC) the dust plume moved to the East showing lower dust concentrations above Cyprus lidar station.

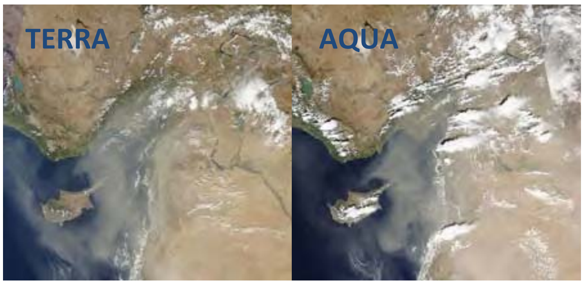

Figure 2: MODIS sensor images of the Eastern Mediterranean on September 29, 2011 during TERRA overpass time (08:30 UTC) (left panel) and AQUA (11:00 UTC) (right panel)

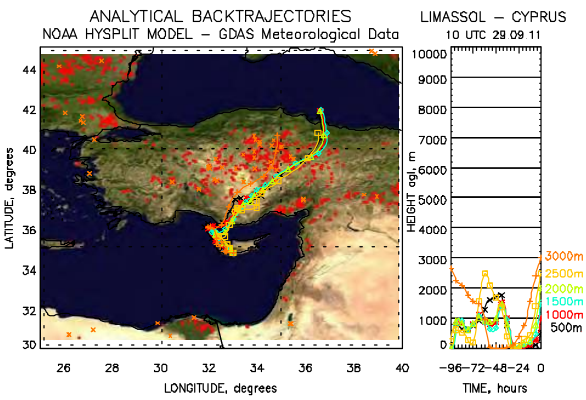

Figure 3. Four-day HYSPLIT back-ward trajectories ending at Lemesos on 29 September 2011, 10:00 UTC. The underlying image is a MODIS 10-day fire map that shows all locations of fires (red spots) detected during the period between 17 and 28 September.

Figure 3 provides additional information about the possible origin and the observed aerosol sources over Lemesos. HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) [7] backward trajectories at 500 to 3500 m height indicate aerosols transported from areas with fire activity over Eastern Turkey. Backward trajectories at heights from ground up to 3 km arrived within the aerosol layer observed during the measurements period. All these trajectories crossed areas with biomass burning about 1-3 days before the arrival over Lemesos as can be shown by the MODIS satellite observations of fires within the period from 18 to 27 September 2011 (http://rapidfire.sci.gsfc.nasa.gov/firemaps) underlying to the air mass back-trajectories analysis.

Additionally, the desert plume reached the Lemesos site one day before (according to MODIS observations). As a result, the aerosol layers observed on the specific day are expected to consist of a mixture of mineral dust and smoke particles.

Figure 4 shows profiles of the dust and smoke backscatter coefficient. The separation procedure described in section 3 is applied for dust and biomass burning smoke particles. Four sets of measurements were used with one-hour time averaging period between 08:00 and 11:00 UTC on September 29, 2011 as shown in Figure 4. For the backscatter coefficient calculations, a lidar ratio value of 50sr, representative for dust and smoke mixtures (according to SAMUM foundings) has been used. The particle depolarization ratio required for the separation between dust and smoke particles is computed from the measured volume depolarization ratio. The equations given in methodology proposed by [3] were used for the case of dust and smoke aerosol types. For pure dust and smoke particle depolarization values of 0.32 and 0.05 are used, respectively taking into account representative values from the literature.

Between 08:00 and 09:00 UTC (panels 1 & 2) an almost pure dust layer from the Saudi Arabian desert is identified between 1.2 and 1.6 km; inside the lofted layer (1.7-2.5 km) low contribution of smoke aerosols is retrieved. Later on that day (10:00 and 11:00 UTC) the mixing of the dust and smoke particles increased and extended from the ground up to 2.7 km. The contribution of the smoke aerosols to the total particle backscatter coefficient was during morning hours of the order of 18% and close to the local noon reached the values of 50% at the height range 1.5-2.7km.

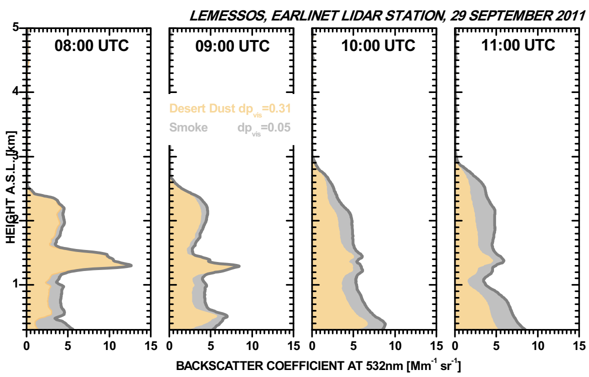

Figure 4. Separation of dust (orange) and smoke (grey) particle backscatter coefficients at 532 nm for the four one hour averaging datasets on 29 September 2011.

From the sun-photometer measurements, a slightly increase of the aerosol optical depth was recorded during the measurements having a mean daily value of 0.53 for visible and 0.31 for infrared wavelength. In conjunction to the relative small variability of AOD values, the spectral dependence represents high variability (not shown here, but available in http://aeronet.gsfc.nasa.gov/cgibin/type_one_station_opera_v2_new?site=CUTTEPAK&nachal=2&level=3&place_code=10). Additionally, the volume size distribution retrieved from the sunphotometer measurements on 29 September 2011 at 07: 40 and 12: 40 UTC represents clearly the variability of aerosol mixing during the day in terms of fine/coarse mixture. The AERONET size distribution given in Figure 5 (top) retrieved from the measurements at 07:40 clearly shows a bi-modal size distribution of particles having diameters around 0.2 μm (small particles) and around 3 μm (large particles). The strong bi-modal size distribution given in Figure 5 (bottom) is retrieved from the AERONET measurements during noon in the same day. The fine mode represents particles with diameters around 0.2 μm and the coarse mode represents particles around 5 μm diameter. In any case, the columnar size distribution of particles on 29 September 2011 during morning hours gives a large predominance of the large particles (centered around 2.5 μm) versus the smaller ones (centered around 0.15 μm), indicating the presence of dust aerosols. Later on the contribution of fine mode aerosols increased, indicating the presence of rather fine particles as smoke.

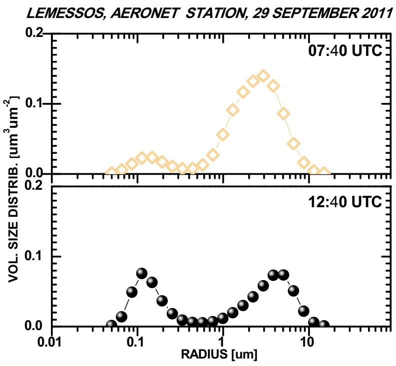

Figure 5. Volume size distribution from AERONET retrievals on 29 September 2011, in the morning (top) and in the noon (bottom)

5. CONCLUSIONS

In this paper a case with complex aerosol structure during daytime lidar measurements is used in order to study the variability of the aerosol mixing within troposheric layers over Lemesos, Cyprus. The optical aerosol properties retrieved from lidar such as the backscatter coefficient and the particle depolarization at 532nm on 29 September 2011 are used for the vertical separation of the backscatter coefficient of two aerosol component. During September 2011, dust storms from Saudi Arabian desert as well smoke plumes from fire activity in Eastern Turkey were transferring over Eastern Mediterranean. The complex aerosol layers observed during the morning hours was examined in terms of 1 hour averaging time. Between 08:00 and 11:00 UTC the contribution of dust aerosols to the total backscatter coefficient decreased form 85% to 50%. The increasing of smoke particles around noon observations can be adittionally confirmed from the volume size distribution retrievals of AERONET sunphotometer measurements.

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