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Retrieval of the optical properties of tropospheric aerosols over Athens, Greece combining a 6-wavelength Raman-lidar and the CALIPSO VIS-NIR lidar system: Case-study analysis of a Saharan dust intrusion over the Eastern Mediterranean

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The National Technical University of Athens (NTUA) 6-wavelength (355, 387, 407, 532, 607 and 1064 nm) Raman lidar system has been used to derive the aerosol optical properties (e.g. the lidar ratio, the aerosol backscatter and extinction profile) and the water vapour mixing ratios over Athens, Greece during the CALIPSO space lidar overpasses over our area at 355, 532 and 1064 nm. These data have been analyzed for the case of a Saharan dust intrusion over the Eastern Mediterranean, occurred on January 26, 2007, using concurrent aerosol optical depth (AOD) data at 550 nm from the Moderate Resolution Imaging Spectroradiometer (MODIS) and forecasted data from the Dust Regional Atmospheric Modeling (DREAM) model.

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1. Introduction

Tropospheric aerosols arise from both natural (windborne dust, sea spray, forest fires and volcanic eruptions, etc.) and anthropogenic sources (combustion of fossil fuels, car traffic and biomass burning activities, etc.). As a consequence their composition is highly variable (Andreae and Crutzen, 1997). Aerosols of desert origin constitute about 40% of aerosol mass yearly injected into the troposphere.

It is well established that the atmospheric aerosols have large influence on earth's radiation budget, depending on their chemical composition (IPCC, 2007). Recent estimations on the possible impact of aerosols (both direct and indirect effects) on the radiative forcing (cooling effect) in a global average are of the same order of magnitude as the CO_2 effect (warming effect). However, high uncertainties still exist concerning the indirect and direct effects, which are connected with the aerosol influence on climate (IPCC, 2007).

Despite their importance in atmospheric physics, significant gaps in the scientific knowledge about aerosols still exist, concerning their concentration, shape, size distribution and refractive index (IPCC, 2007). This is especially true for the vertical distribution of the aerosol properties in the atmosphere, mainly during dust outbreaks, which is highly variable in space and time and is of essential relevance to understanding aerosol effects on climate.

In this paper the National Technical University of Athens (NTUA) 6-wavelength Raman lidar system has been used to derive the aerosol optical properties (e.g. the lidar ratio, the aerosol backscatter and extinction profile) and the water vapour mixing ratios over Athens, Greece during the CALIPSO space lidar overpasses over our area at 355, 532 and 1064 nm. These data have been analyzed for the case of a Saharan dust intrusion over the Eastern Mediterranean, occurred on January 26, 2007, using concurrent Moderate Resolution Imaging Spectroradiometer (MODIS) aerosol optical depth (AOD) data and forecasted AOD data at 550 nm from the Dust REgional Atmospheric Modeling (DREAM) model (Nickovic et al., 2001).

2. Instrumentation and methodology

2.1 The NTUA 6-wavelength Raman lidar system

The compact 6-wavelength NTUA Raman lidar system is based on a pulsed Nd:YAG laser emitting simultaneously at 355 nm, 532 nm and 1064 nm. The respective emitted output energies per pulse are 75 mJ, 130 mJ and 140 mJ, with a 10 Hz repetition rate. The optical receiver is a Cassegrainian reflecting telescope with a primary mirror of 300 mm diameter and of focal length f=600 mm, directly coupled, through an optical fiber, to the lidar signal multi-channel detection box. The elastically backscattered lidar signals (at 355, 532 and 1064 nm), as well as those generated by Raman scattering by atmospheric N_2 and H_20 (at 387, 607 and 407 nm, respectively) are simultaneously recorded by photomultipliers (PMTs) and avalanche photodiode systems (APD), after the spectral separation of the returned lidar signals.

2.2 The CALIPSO Space lidar

The CALIPSO space lidar was launched by NASA on June 2006. CALIPSO science objectives include: observationally-based estimates of direct and indirect aerosol radiative forcing, improvement of the characterization of surface longwave radiative fluxes and atmospheric heating rates and model parameterizations of cloud-climate feedbacks.

The CALIPSO payload consists of the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP), a two-wavelength polarization sensitive lidar, the Infrared Imaging Radiometer (IIR), which has three channels in the thermal infrared, and the Wide Field Camera (WFC) with a single channel at 650 nm. CALIOP is an elastically backscattered lidar operating at 532 and 1064 nm, equipped with a depolarization channel at 532 nm. The lasers operate at 20.16 Hz and are Q-switched to provide a pulse length of about 20 ns. Each laser generates nominally 220 mJ per pulse at 1064 nm, which is frequency-doubled to produce about 110 mJ of pulse energy at each of the two wavelengths (Hostetler et al., 2001).

2.3 Retrieval of aerosol optical properties by NTUA and CALIPSO lidars

The CALIPSO lidar data (level 1 data) were used to derive the aerosol backscatter coefficient profiles over our area in the visible (VIS) and near-infrared (NIR) wavelengths (532 and 1064 nm, respectively), due to the non-availability of Raman channels on board CALIPSO. For this reason the standard Klett retrieval method was used (Klett, 1981).

The six detected lidar signals of the NTUA system were used to derive the aerosol backscatter (at 355, 532 and 1064 nm) and the extinction (at 355 and 532 nm) coefficient profiles over Athens, using the standard Raman technique (Ansmann et al., 1990), except for the 1064 nm signal where the Klett retrieval method was applied (Klett, 1981).

3. Retrieved aerosol properties and water vapour mixing ratios over Athens during a CALIPSO overpass

The aerosol optical properties were retrieved by using the Klett algorithm, as discussed earlier in Section 2.3. The water vapour profile, in mixing ratio units (g/kg), is determined by inverting the ratio of the lidar signals corresponding to the 355 nm-Raman shifted laser beam that is backscattered by H_2O (at 407 nm) and N_2 atmospheric molecules (at 387 nm). This ratio is proportional to the water vapour concentration, since the molecular N_2 can be assumed to have constant mixing ratio within the altitude range of measurements. In order to retrieve the water vapour in mixing ratio units, it is necessary to estimate a profile of a constant K(z), depending on the instrumental characteristics, by comparison with an independently measured water vapour mixing ratio profile (e.g. by a radiosonde). The detailed inversion procedure has been previously described by Whiteman (2003).

4. Case-study analysis of a Saharan dust intrusion over the Eastern Mediterranean region

In this section we present a case study of a dust intrusion from the Saharan region to the European continent. Such kind of intrusions are quite common from early spring to later summer periods, according to systematic lidar observations performed in the Eastern Mediterranean region (Papayannis et al., 2005).

The case of the January 26, 2007 is an interesting one since it was an intense dust transport event which covered the whole Mediterranean region and was very well followed by concurrent satellite lidar (CALIPSO) and other spectral sensors (MODIS), ground-based lidars (EARLINET-ASOS) and sun-photometer networks (AERONET).

The CALIPSO overpasses on January 26, 2007 over the European continent are shown in Fig. 1.

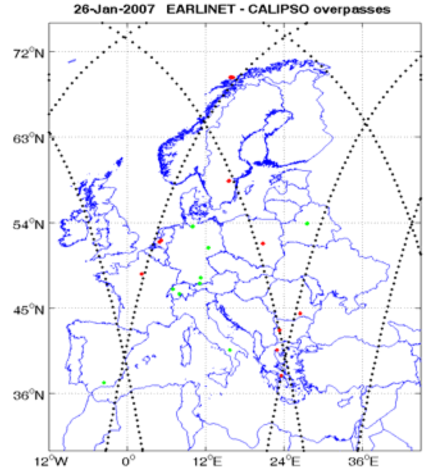

Fig. 1. The CALIPSO overpasses on January 26, 2007 over the European continent.

Fig. 2 presents an example of the retrieved aerosol backscatter profiles retrieved by the Raman (at 355 and 532 nm) and Klett (at 1064 nm) techniques, during the CALIPSO overpass (shown in Fig. 1) on Januray 26, 2007 over our site (at a distance of the order of 20-30 km).

Fig. 3 presents an intercomparison between the water vapour mixing ratio profile obtained by the NTUA lidar and that obtained by radiosonde operated by the Hellenic Meteorological Service (HMS) at the “Hellinikon” site, located some 20 km from our site. The mean difference between the two profiles stays well below 10% at all heights.

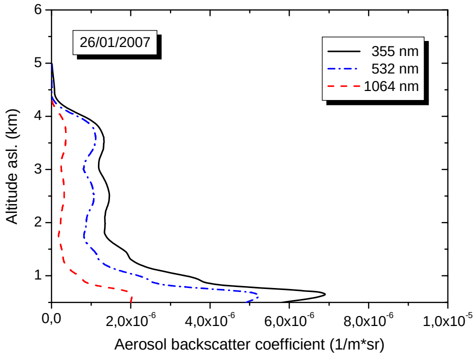

Fig. 2. Example of the retrieved aerosol backscatter profiles retrieved by the Raman and Klett techniques (at 355, 532 and 1064 nm), during the CALIPSO overpass (26/01/2007).

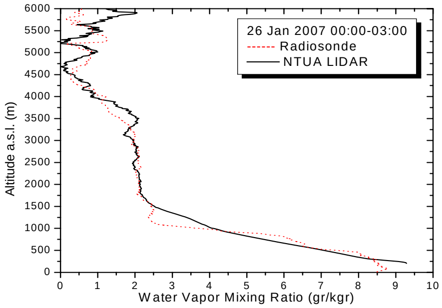

Fig. 3. Intercomparison between the water vapour mixing ratio profile obtained by the NTUA lidar and that obtained by radiosonde operated by HMS at the “Hellinikon” site (26/01/2007).

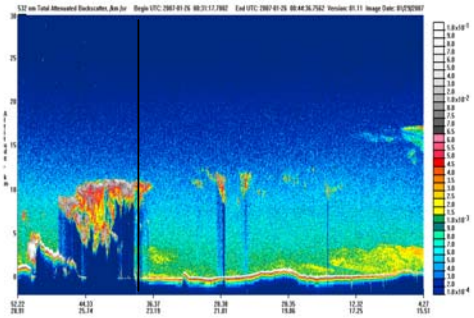

*Fig. 4. Temporal evolution of the total attenuated backscatter aerosol profiles obtained at 532 nm (in 1/km*sr) during the CALIPSO overpass between 00:31:17 and 00:44:36 UTC on 26/01/2007 (the black line shows the position of the Athens station).*

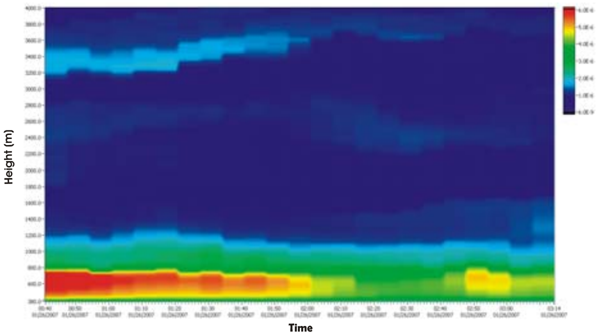

*Fig. 5. Temporal evolution of the aerosol backscatter profiles obtained by the NTUA lidar at 532 nm (in 1/m*sr) over Athens on 26/01/2007, between 00:40 and 03:14 UTC.*

Fig. 4 shows the temporal evolution of the total attenuated backscatter aerosol profiles obtained at 532 nm (in 1/km*sr) during the CALIPSO overpass between 00:31:17 and 00:44:36 UTC. The black line shows the position of the Athens station. The respective temporal evolution of the aerosol backscatter profiles obtained at 532 nm (in 1/m*sr) over Athens is shown in Fig. 5 (between 00:40 and 03:14 UTC). The dust layer, visible between 3.2-4 km asl. (Figs. 2, 4 and 5), has originated from the Saharan dust region according to air mass back-trajectory analysis and forecast modelling from the DREAM model (not shown). The AOD values from MODIS/DREAM (at 550 nm) over Athens were 0.5. The Planetary Boundary Layer (PBL) that day was estimated to be at 750 m above sea level (a.s.l.) which corresponds very well to that also retrieved by the CALISPO lidar data (Figs. 4 and 5). Cloud layers are visible between 5 and 10 km height (Fig. 4). Fig. 4 shows the good spatial coverage of the CALIPSO lidar system and its ability to follow with a high temporal and spatial resolution such dust transport events from the African to the European continent.

5. Conclusions

The methodology of the retrieval of the optical properties of tropospheric aerosols over Athens, Greece combining a 6-wavelength Raman-lidar and the CALIPSO VIS-NIR lidar system was presented. A successful follow-up of a Saharan dust intrusion event in the Eastern Mediterranean region was also shown based on the synergy of ground-based and space-borne (NTUA and CALIPSO) lidar data and AOD data from space sensors (MODIS) and dust forecast models (DREAM).

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