VALIDATION OF CALIPSO NIGHTTIME AEROSOL PRODUCTS USING AIRBORNE LIDAR AND IN-SITU OBSERVATIONS

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ABSTRACT

In this paper, the evaluation of CALIPSO nighttime extinction retrievals with collocated/coincident airborne lidar and in situ measurements is presented for the 9th of September 2011 over Greece. Specially oriented research flights were carried out in Greece on September 2011 with the Facility for Airborne Atmospheric Measurements (FAAM) BAe-146 research aircraft in the framework of the ACEMED campaign. The comparison between CALIOP and airborne lidar extinction coefficient vertical distributions reveal a good agreement. CALIOP agrees also with in situ airborne extinction retrievals for dry aerosol layers, however humidity corrections are needed. The aerosol type classification scheme of CALIPSO shows good performance over land.

1. INTRODUCTION

The Cloud Aerosol LIdar with Orthogonal Polarization (CALIOP), on board the CALIPSO platform, is a three-channel elastic backscatter lidar optimized for aerosol and cloud profiling. CALIOP measures high-resolution profiles of the attenuated backscatter by aerosols and clouds at visible (532 nm) and near-infrared (1064 nm) wavelengths along with depolarized backscatter in the visible channel [1]. These data are distributed as part of the level 1 CALIOP products. The level 2 CALIOP products are derived from the level 1 observations using a succession of algorithms that are described in detail in a CALIPSO-dedicated special issue of the Journal of Atmospheric and Oceanic Technology [e.g. 1]. The level 2 retrieval algorithm is composed of a feature detection scheme, a module that classifies features according to layer type (e.g., cloud vs. aerosol) and sub-type, and, finally, an extinction retrieval algorithm that estimates the aerosol backscatter, the extinction coefficient profile and total column aerosol optical depth (AOD) for an assumed lidar ratio for each detected aerosol layer. The aerosol classification scheme is presented in detail in [2]. Level 1 attenuated backscatter profiles have been shown to yield reasonable agreement with ground-based [e.g. 3; 4] and airborne [e.g. 5] measurements. Nonetheless, there are significant uncertainties associated with the version 2 CALIOP aerosol extinction and backscatter retrievals.

In order to assess the accuracy of CALIPSO's aerosol classification scheme and level 2 retrievals, the National Observatory of Athens (NOA) organized an airborne experimental campaign over Greece on September 2011. The campaign, called "ACEMED - Evaluation of CALIPSO's aerosol classification scheme over Eastern Mediterranean", was supported by the European Facility for Airborne Research (EUFAR - http://www.eufar.net/) through the provision of flight award on FAAM-BAe146 aircraft (http://www.faam.ac.uk/). In this study, we assess the consistency of CALIPSO level 2 products and comparative airborne lidar and in-situ observations during one CALIPSO under-flight over Thessaloniki on 9th of September 2011.

2. AIRBORNE INSTRUMENTATION

The UK research aircraft FAAM-BAe146 performed two CALIPSO under-flights over Greece in the frame of the ACEMED campaign. The aerosol scattering and absorption coefficients were obtained in-situ by using a three-wavelength integrating nephelometer (TSI 3563; 450, 550, and 700 nm) and a Radiance Research Particle Soot Absorption Photometer (PSAP, 567 nm) respectively. The aerosol size distributions were measured by using a Passive Cavity Aerosol Spectrometer Probe 100-X (PCASP) and a Scanning Mobility Particle Sizer (SMPS). Size resolved chemical composition was acquired by using an Aerosol Mass Spectrometer (AMS). Moreover, a Leosphere ALS450 backscatter lidar operating at 355 nm and featuring a depolarization channel was additionally mounted on FAAM-Bae146 in a nadir-viewing geometry [6].

3. RESULTS AND DISCUSSION

In this paper we concentrate on the CALIPSO under-flight performed on 9th of September 2011 over Thessaloniki. The flight pattern is superimposed to the CALIPSO overpass in Figure 1. Colored circles denote the airborne lidar profiles used in our study. Some measurements were excluded due to aircraft's off-nadir inclination or cloud presence.

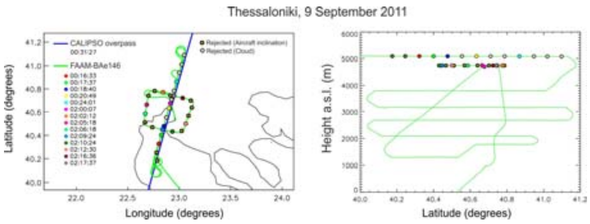

Figure 1. FAAM-Bae146 flight and CALIPSO overpass (top) and flight altitudes (bottom) on 9th of September 2011 over Thessaloniki

The CALIPSO attenuated backscatter coefficients at 532 nm and the simultaneous airborne range-corrected lidar signals at 355 nm are shown in Figure 2. Measurements contaminated with the cloud (visible with red color in Figure 2), were removed from both lidar datasets.

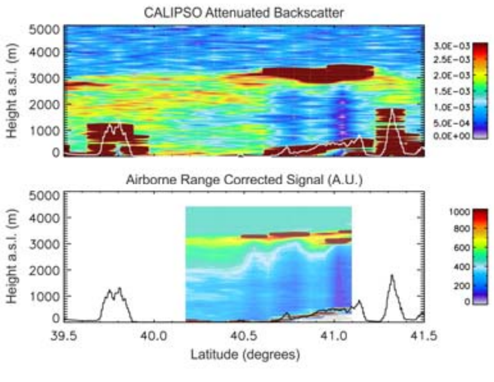

Figure 2. CALIPSO attenuated backscatter coefficient at 532 nm (top) and airborne range-corrected lidar signals at 355 nm (bottom)

CALIPSO aerosol classification scheme [2] derived a number of aerosol types during the flight, shown in Figure 3.

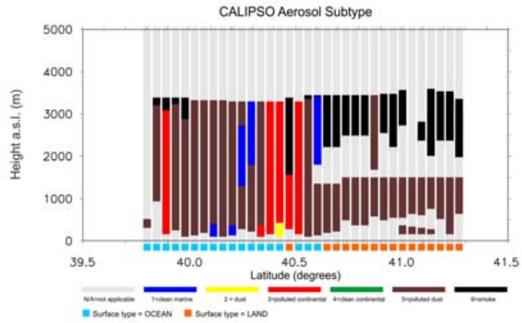

Figure 3. CALIPSO aerosol type classification

The aerosol type classification algorithm [2], differs for Land or Ocean surface types, which are denoted with light blue and orange colors in Figure 3. According to this classification, a smoke layer between 2.5 and 3.2 km is present over Thessaloniki but only over land. The presence of smoke is indicated also by model simulations presented in Figure 4.

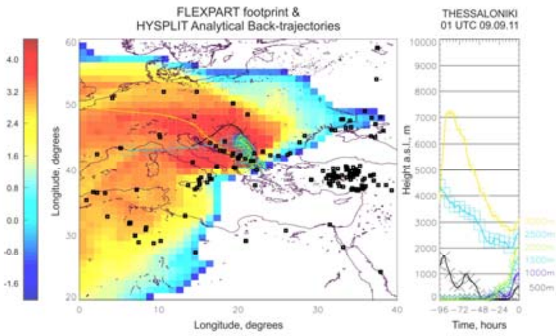

Figure 4. FLEXPART footprint for air-masses arriving at Thessaloniki at 01.00 UTC on 9 September 2011, HYSPLIT back-trajectories and hot spots derived by MODIS

The FLEXPART footprint in Figure 4 shows the air-masses which traveled and arrived at Thessaloniki at 1 UTC on 9 September 2011. The colors represent the logarithm of the integrated residence time in a grid box in seconds for 10-day integration time. The footprint map shows that the air-masses over Thessaloniki were advected from Northern Western directions, being mainly influenced by pollution in Balkans. The black squares represent the active fire hot spots detected by MODIS. 4-day back-trajectories derived with the HYSPLIT model indicate the advection of smoke over Thessaloniki at 3 km, while for lower altitudes the aerosol load is influenced by local sources in Balkans. FLEXPART simulations indicate advection from the Saharan desert however our measurements did no show indications of dust presence, and this has been validated also by BSC-DREAM dust model simulations (not shown here).

AMS measurements at different flight altitudes showed different aerosol composition for the lower (below 1500 m) and free-tropospheric region, which is consistent with the difference on the origin of the air masses revealed by the trajectory analysis.

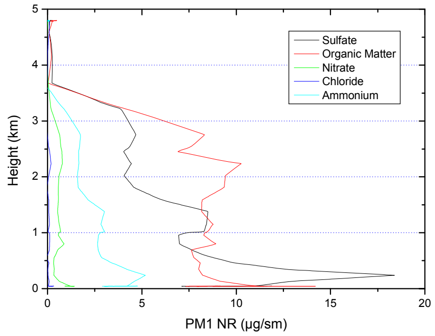

Figure 5. AMS retrievals of the chemical composition

Figure 5 shows the organic matter enhancement in the free-troposphere. It is likely that the organic component denoted by AMS is due to the advection of smoke from NW. The layer richer in organic matter as indicated by AMS is consistent with the elevated smoke layer retrieved by CALIPSO classification scheme (Figure 3) and with trajectory simulations (Figure 4). Indications for smoke presence come also from the measurement of the size of the particles, namely the size distributions (not shown here) and the Angstroem exponent profiles (Figure 6 - left). Moreover, single scattering albedo retrievals from the combination of nephelometer and PSAP measurements show the increase of absorption in the free troposphere, which is typical for smoke particles (Figure 6 - right).

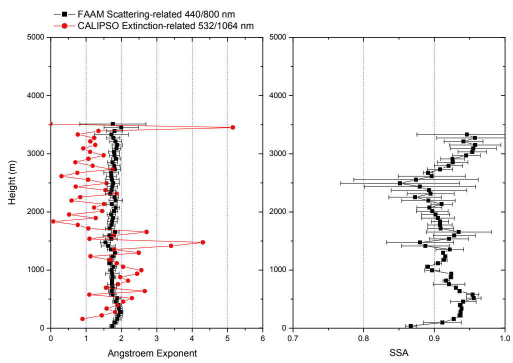

Figure 6. Angstroem exponent from CALIPSO (532/1064 nm) and nephelometer (440/800 nm) (left) and single scattering albedo profile at 550 nm (right)

In Figure 6 (left), the CALIPSO retrieved extinction-related Angstroem exponent is presented (red line) along with the nephelometer retrievals of the scattering-related Angstroem exponent. While the nephelometer shows the lack of vertical distribution on this parameter, CALIPSO reveals lower Angstroem coefficients in the free troposphere. The difference is attributed, first, to the absorption that is not taken into account to in-situ retrievals, second, to the lack of relative humidity (RH) corrections for the nephelometer data so they'll refer to ambient conditions and third to the different lidar ratios used by CALIPSO for the extinction inversion.

Direct comparisons of extinction profiles from in-situ measurements with CALIPSO retrievals shown in Figure 7 depict once again the need for RH correction of in-situ data. The in-situ retrievals clearly underestimate CALIPSO (left). The relative difference between these collocated measurements increase with RH in the free troposphere (Figure 8 - right).

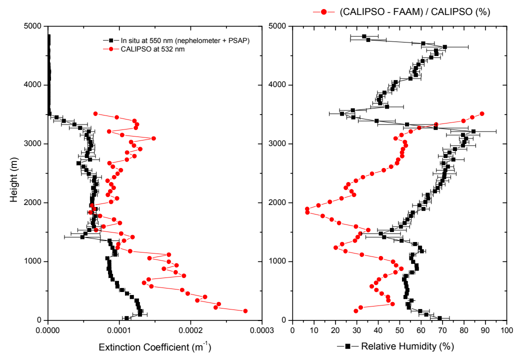

Figure 7. Extinction coefficient from airborne in-situ measurements versus CALIPSO retrieval (left). Comparison of the relative extinction difference with relative humidity (right).

In Figure 8, the airborne lidar retrieval is compared with CALIPSO extinction. Measurements were taken with a vertical resolution of 1.5 m and an integration time of 2 s, but vertical smoothing with a running average and additional integration were applied during the post processing in order to reduce the signal-to-noise ratio. Each vertical profile thus has a vertical resolution of 45 m and an integration time of 1 min; as the aircraft travels at a ground speed of 120–180 m/s (typical at an altitude of 6–10,000 m), the latter translates into a 7–11 km footprint. Moreover, 14 vertical profiles corresponding to the area of interest have been further integrated together, after removal of profiles affected by cloud formation and off-nadir pointing (see Figure 1). This further integration is justified as all data indicate a homogeneous aerosol distribution in the atmosphere over Thessaloniki during the flight. Full overlap of the receiver field of view with the emitted beam is achieved at a range of 300 m, and only data beyond this point will be considered here. The lidar equation is solved with two boundary conditions for the extinction: in the upper aerosol-free region, and at approximately 1000 m (this second reference being within the aerosol layer, it is determined using the in-situ data, since no lower aerosol-free region is available). The lidar ratio is then determined via an iterative approach, using as a criterion the consistency of the far and near end retrievals [see, e.g., 6].

The lidar ratio at 355 nm determined in this manner was found to have a mean of 60 sr. The 355 nm extinction retrieval has been converted to 532 nm using an effective value for the Angstroem exponent equal to 1.5. This value is consistent with late-afternoon AERONET retrievals over Thessaloniki. CALIPSO's mean Angstroem exponent retrieved by the 532 and 1064 nm extinction retrievals was found of the same order. The comparison of CALIPSO and airborne lidar extinction profiles at 532 is shown in Figure 8.

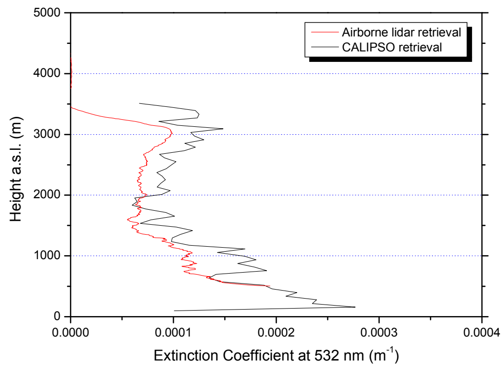

Figure 8. Extinction coefficient at 532 nm from CALIOP and airborne lidar

Figure 8 shows a first good agreement between airborne and CALIPSO lidar retrievals. An extinction underestimation is possible regarding the airborne lidar retrieval, since is the boundary assumption at 1000 m has been taken from in-situ measurements. These measurements refer to dry conditions and should be corrected for RH to refer to ambient conditions.

4. CONCLUSIONS

CALIPSO shows a good performance when compared with airborne lidar and in-situ retrievals in terms of aerosol typing, but also quantitative results. Future work on this study includes the correction of in-situ retrievals (in terms of size distributions and refractive indexes) using the ISORROPIA-II thermodynamic model [7], based on AMS chemical compositions and measured quantities. Mie scattering calculations are expected to reveal intensive aerosol optical properties for direct comparison with CALIPSO retrievals (e.g. the lidar ratio).

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