AEROSOL DISTRIBUTION OVER MUNICH USING CALIPSO LEVEL 2 DATA AND COMPARISON WITH MODIS, AERONET AND MULIS DATA

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ABSTRACT

The dataset of the backscatter lidar CALIOP onboard the satellite CALIPSO is most valuable, because it is at present the best source of information for the global, vertical resolved distribution of aerosols. Using the CALIOP level 2 data several aerosol related parameters can be investigated as e.g. the average PBL height, the occurrence of aerosol types, or the extent of elevated layers.

The Meteorological Institute Munich (MIM) operating the ground based Raman lidar MULIS and an AERONET Sunphotometer is well suited to review the information content and the limitations of the dataset. A comparison of the aerosol optical depth with the independent datasets of AERONET and MODIS shows significantly smaller values of the CALIPSO dataset. Thorough studies of CALIPSO data and first comparisons with MULIS suggest that one reason for this discrepancy is that CALIPSO fails to detect optical thin layers. Also, the distinction of ground near layers from the strong surface return can lead to a loss of aerosol information. The use of a too small lidar ratio would cause too low extinction coefficients for optical thin and medium aerosol layers and as a consequence underestimate the AOD.

1. INTRODUCTION

Aerosols are a very important component of the atmosphere due to their influence on the radiative budget by direct interaction with the radiation and indirectly by modification of cloud properties [1]. The knowledge about this influence is at the moment insufficient, because the spatial and temporal distribution of aerosols in the troposphere and stratosphere is highly variable. Additionally, the influence depends strongly on the microphysical properties of the aerosols, e.g. of their shape and their chemical composition, for which reason aerosols are often divided into different types as dust or biomass burning.

To study the aerosol distribution on continental and global scale, many projects were established during the last years, e.g. networks of ground based instruments as the Aerosol Robotic Network (AERONET) [2] or the European Aerosol Research Lidar Network (EARLINET) [3]. Especially for global sampling several space missions were developed (e.g. the Moderate Resolution Imaging Spectroradiometer MODIS [4], or MISR). At the moment, the best source of global range resolved aerosol information is the backscatter Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) aboard the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO). It was launched as part of the A-Train of NASA in April 2006 and offers a unique possibility to get vertical resolved optical properties of aerosols and clouds [5]. As the lidar is detecting backscattered light at two wavelengths (532 nm and 1064 nm) and is additionally measuring the depolarization at 532 nm, it is possible to distinguish between six different aerosol types. But the lidar also has limitations when very low signal-to-noise ratios prevent a quantitative retrieval or a definite discrimination between aerosols and clouds. Therefore, validation with independent datasets is needed.

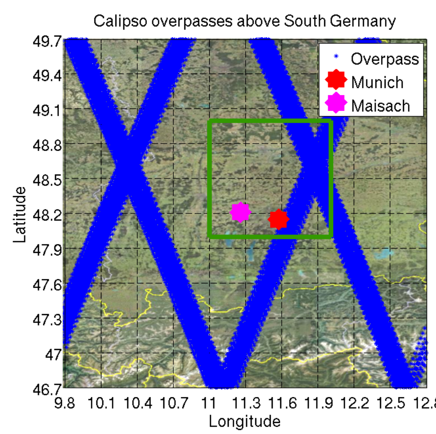

Figure 1. Overview over the region 46.7°-49.7°N and 9.8°-12.8°E around Maisach/Munich: each blue star shows one 5-km-profile of CALIPSO footprint. The green rectangle shows the 1°x1° region of the used MODIS monthly average.

In this study the aerosol optical depth (AOD) of the CALIPSO dataset is compared to that of the spaceborne spectroradiometer MODIS and the ground based CIMEL Sun photometer of AERONET. In a case study an extinction profile of the multi-wavelength lidar MULIS of the MIM [6] is compared with the corresponding CALIPSO profile to show the potential of the CALIPSO lidar.

2. USED DATASETS

In this study we use the data from the years 2007 to 2010 of the region ± 1.5° (henceforward referred as 'Munich region') around MULIS in Maisach, Germany, located 25 km north-west of Munich. Figure 1 shows the footprints of the CALIPSO overpasses in this time period (blue), the red and the magenta colored stars mark the location of MULIS in Maisach and the CIMEL in Munich. The green rectangle shows the 1°x1° region of the used MODIS monthly average.

2.1 CALIPSO

NASA delivers several products based on CALIPSO data (Level 2 products, Version 3.01), all in relation to a horizontal resolution of 5 km. One CALIPSO overpass track over the Munich region can include up to 68 5-km-profiles. Within the above mentioned time period 350 overpasses of CALIPSO can be considered. The general overview over the measurement conditions is given by the vertical feature mask (VFM). Vertically integrated parameters, e.g., the optical thickness of layers ('layer data'), as well as vertically resolved data, e.g., profiles of extinction coefficients, are given separately for clouds and aerosols.

The layer data have to be used very carefully, because the aerosol information refers to varying resolutions up to 80 km. To get 5 km resolved data, we used the VFM to locate the aerosol layers, and the profile data to calculate the optical depth of each layer. Clouds in the 5-km-profile can bias the aerosol statistics, so all profiles containing clouds were removed, as well as all aerosol data with medium or low classification quality (CAD score > -70).

2.2 MODIS

The MODIS onboard of the NASA satellites Terra (since 1999) and Aqua (since 2004) is viewing the entire Earth's surface every one to two days. One of its atmospheric products is the AOD for three wavelengths: 470 nm, 550 nm, and 660 nm. The dataset for comparison is based on the Collection 5.1 data of the Terra satellite. Used are the 48 Level 3 monthly mean AODs (M3 data) for the years 2007 to 2010. The Level 3 data have a resolution of 1°x1°.

2.3 AERONET

The Cimel Sun photometer of the AERONET network is located at the MIM in the center of Munich. From 2007 to 2010 it provides AOD at seven wavelength including 532 nm which makes a direct comparison with CALIPSO possible. Here, we use the level 2.0 AOD data because of their strict quality assurance.

2.4 MULIS

The Raman lidar MULIS located at Maisach allows to retrieve aerosol extinction coefficients at 532 nm and 355 nm and backscatter coefficient profiles at 1064 nm, 532 nm and 355 nm. Furthermore, the particle linear depolarization ratio at 532 nm can be retrieved. So a suite of optical parameters is available for the validation of CALIPSO. A special advantage of MULIS is that the distance of full overlap is at about 250 m. As a consequence, it is possible to assess the accuracy of CALIPSO profiles especially in the lowermost boundary layer. Validation measurements of MULIS started in July 2006 and are performed, whenever the satellite overpass is nearer than 100 km.

3. AEROSOL DISTRIBUTION OVER MUNICH REGION BASED ON CALIPSO DATA

From the CALIPSO overpasses over the Munich region different aerosol related issues were studied: Figure 2 shows the spatial variation of the AOD at 532 nm. The white boxes are areas not covered by CALIPSO overpasses (see Fig. 1). Except for two boxes, the spatial variation of the AOD is small, the values are between 0.03 and 0.15.

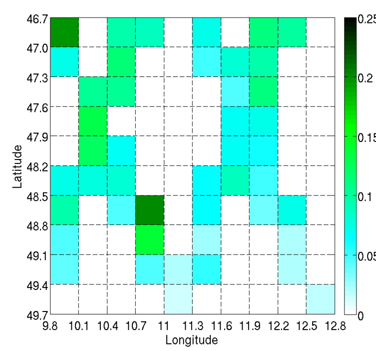

Figure 2. Aerosol optical depth at 532 nm derived from the CALIPSO aerosol data for the region shown in Fig. 1. The white boxes mark areas not covered by CALIPSO.

To study the properties of the planetary boundary layer (PBL) and elevated layers (EL), the aerosol data was divided into two classes: all aerosol layers with their base below a height of 0.5 km above the surface are classified as boundary layer, other aerosol layers are considered as elevated. This leads to 772 cases when the PBL was resolved and 265 cases of EL with mean optical depths of 0.09 and 0.06, respectively.

Based on the set of CALIPSO measurements together with auxiliary data, NASA identifies six aerosol types: 'clean marine', 'dust', 'polluted continental', 'clean continental', 'polluted dust' and 'smoke/biomass burning'.

The occurrence of these aerosol types over the Munich region can be seen in Figure 3, separately for PBL and EL. The upper pie plot shows the relative frequency of the different types, whereas in the lower plot the corresponding optical depth is shown. The most frequently detected type in the PBL is 'smoke/biomass burning', whereas for the ELs 'polluted dust' dominates. The occurrence of 'dust' is larger in EL than in the PBL. But considering the optical depths and the nearly same geometric depth of the dust layers (not shown here), the little amount of dust in the PBL has clearly higher aerosol concentrations then the huge amount in the EL.

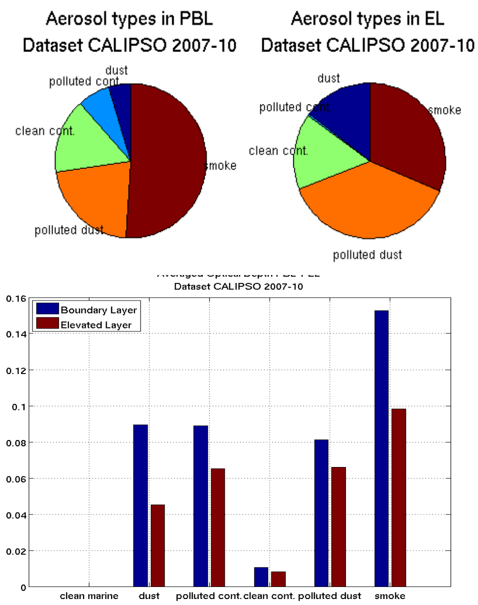

Figure 3. Aerosol types detected by CALIPSO over the Munich region, separately shown for near-ground (PBL) and elevated (EL) layers. The upper pie plot shows the relative frequency of the different types (left PBL, right EL). In the lower plot the corresponding optical depth is shown (blue for PBL, red for EL).

According to the CALIPSO classification, 'smoke' and 'polluted dust' aerosols are the most common aerosols over Munich. 'Dust' and 'polluted continental' are observed less frequently but their optical depth is comparably large.

4. COMPARISON OF DATASETS

To estimate the quality of the CALIPSO products, we discuss two independent datasets (MODIS and CIMEL radiometer) of the same time period. For a better comparison especially with the MODIS data, only the part of the CALIPSO data included in the MODIS rectangle (Fig. 1) is used.

4.1 Comparison with monthly averages of MODIS and CIMEL

The spaceborne and ground based radiometers provide only columnar values such as the AOD, and the AOD-related Angström exponent. These quantities are compared with the CALIPSO dataset. In Figure 4 the inter-annual variation of the AOD of the 'green' channels (532 nm + 550 nm) can be seen. The shape of all three curves is consistent, with 'minima' in the years 2008 and 2010. However the CALIPSO AOD values are significantly lower compared to MODIS and CIMEL. The mean values over four years show a very good agreement between MODIS and CIMEL (0.15 ± 0.07 and 0.16 ± 0.05), whereas the CALIPSO values have smaller values (0.08 ± 0.04). The underestimate of the AOD appears also in monthly and seasonal data (not shown here).

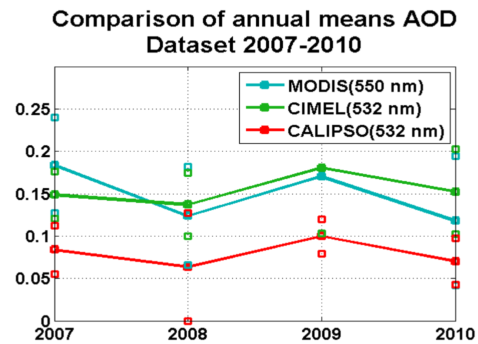

Figure 4. Yearly averaged AOD and standard deviation of CALIPSO and CIMEL (for 532 nm) and of MODIS (for 550 nm). The MODIS and CIMEL data agree very well with each other, the CALIPSO AOD is significantly smaller.

To identify the reasons for the underestimate of the AOD, a direct comparison of co-located and coincident lidar profiles is required and discussed in more detail in section 4.2. Note, that 'co-location' is understood as a distance between 30 and 90 km. A possible reason for the finding is that optically thin layers are below the detection limit of CALIPSO or cannot be resolved by the detection algorithm HERA. Also, the distinction of ground near layers from the strong surface return can lead to a loss of aerosol information. As seen in the CALIPSO data, often the lowermost layer has its base more than 0.2 km above the surface. Since the atmosphere has normally the highest aerosol amount close to the surface, the missing 200 m can lead to an underestimate of the AOD.

Furthermore, the application of a too small lidar ratio would cause too low extinction coefficients for optical thin and medium aerosol layers and consequently an underestimate the AOD. For CALIPSO, the estimation of the lidar ratio is done by the aerosol classification into the six types. The values for the lidar ratio of 532 nm are between 20 and 70 sr. A wrong classification can therefore lead to a wrong AOD. With the Raman lidar MULIS we are able to directly measure lidar ratios: a comparison with the lidar ratios used in the CALIPSO retrieval is still ongoing.

4.2 Case Studies with MULIS data

The direct comparison of CALIPSO and MULIS measurements can be used to investigate to which extent thin aerosol layers can be detected. In 37 out of 206 overpasses with cloud free profiles, the level 2 data of CALIPSO do not detect aerosols at all. One example (not shown here) is the overpass of the 3 September 2009 at 12:20 UTC: MULIS detected aerosol layers up to 4 km with an AOD at 532 nm of 0.14 which is very consistent with the CIMEL radiometer measurement at 12:14 UTC of AOD = 0.16. However, in the CALIPSO data no aerosol was detected (AOD = 0) although cloud free conditions facilitates the retrieval.

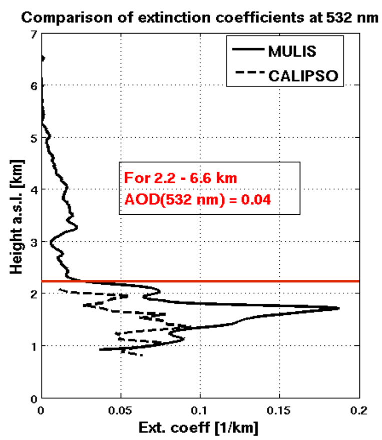

Figure 5. Extinction profiles of MULIS (line) and CALIPSO (dotted) for the overpass of 29 July 2008, ~ 01:35 UTC: the upper thin aerosol layer (3-5 km) with an optical depth of 0.04 was not detected by CALIPSO.

Figure 5 shows another example why the AOD derived from CALIPSO can be lower compared to other data sets. At stable night-time conditions, MULIS detected aerosol layers up to 5 km, whereas the CALIPSO profile only found aerosols up to 2.2 km. The optical depth of these elevated layers is 0.04. CALIPSO has missed this layer: although its vertical extent is approximately 3 km, however, the extinction coefficient is very small. Especially with low signal-to-noise ratio the detection of such layers is difficult. The profiles below 2 km show a similar structure with three sublayers with a small vertical displacement. The MULIS extinction coefficient is about 2 times larger, but this has possibly its reason in the horizontal distance. Over the three hours of the MULIS measurement we see a decrease of the extinction of the lower layer, while the elevated layer remains stable in time.

5. SUMMARY

The satellite lidar CALIPSO offers a good opportunity to get aerosol information on global scale. Especially the vertically resolved information about the aerosol types and the occurrence of elevated layers is unique. A special advantage in comparison to passive radiometers is, that it is possible to get aerosol information also at night-time. But there are limitations in the data due to problems with the detection of thin layers. Comparisons with MODIS and CIMEL data show significant smaller AOD values, whereas a case study with the ground based lidar MULIS confirms, that optical thin layers are missed, even if their vertical extent is large. Thus, CALIPSO seems to give a lower limit of the aerosol 'conditions' of the Munich region. In this work, only two MULIS measurements were considered. But there are four years of validation measurements for a day-to-day comparison with MULIS, the CIMEL radiometer and MODIS, which will be used to study in more detail the aerosol detection of the CALIPSO data.

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REFERENCES

1. Solomon S. et al., 2007: Climate Change 2007: The Physical Science Basis, in *IPCC 2007, Cambridge University Press*, Cambridge, United Kingdom and New York, NY, USA.

2. Holben B. N. et al., 1998: AERONET–A federated instrument network and data archive for aerosol characterization, *Remote Sens. Environ.*, **66**, pp. 1–16.

3. Bösenberg J., V. Matthias, 2003: EARLINET: A European Aerosol Research Lidar Network to Establish an Aerosol Climatology, *MPI-Report* **No. 348**, Max-Planck-Instiut für Meteorologie, Hamburg.

4. Kaufman Y. J. and Tanré D., 1998: Algorithm for remote sensing of tropospheric aerosol from MODIS, *MODIS ATBD Product ID: MOD04*, 1-85 pp.

5. Winker D.M. et al., 2009: Overview of the CALIPSO Mission and CALIOP Data Processing Algorithms, *J. Atmos. Oceanic Technol*., **26**, pp. 2310-2323.

6. Freudenthaler V. et al., 2009: Depolarization-ratio profiling at several wavelengths in pure Saharan dust during SAMUM 2006, *Tellus, Ser. B*, **61**, pp. 165-179.