Vertically resolved observations of aerosols over Portugal with CALIPSO

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ABSTRACT

For this work profiles of backscatter and extinction coefficients from the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) on board of the CALIPSO satellite were investigated. Observations of the boundary layer as well as the free troposphere over four sites in Portugal (Vila Real, Cabo da Roca, Évora and Faro) were analysed with regard to aerosols in the period from 2006 to 2008. HYSPLIT-trajectories were used for the classification of aerosol layers regarding their origin. Most of the investigated aerosol layers (56%) came from or were transported over the Atlantic Ocean. About 18% of the layers came from the European continent and 12% from the Saharan desert. The remaining 14% could not be assigned to any of those source regions. Considering the different observation sites, a seasonal cycle in layer top height and layer depth could be found with higher values of both, top height and depth, in summer. Aerosols from the Atlantic and from Europe primarily were observed in the boundary layer. Layers from the Saharan desert and layers of unknown origin could also be observed at higher altitudes. The analysis of layer mean extinction coefficients and layer mean backscatter coefficients as well as profiles of extinction and backscatter coefficients regarding the source regions results in no distinct differences.

1. INTRODUCTION

Uncertainties of aerosol properties and their distribution in the atmosphere affect the investigation of their impact on radiation processes. Hence the climatic effect of aerosols cannot be determined with a satisfying accuracy yet[1].

The space-borne lidar CALIOP (Cloud-Aerosol LIdar with Orthogonal Polarization) [2] aboard the CALIPSO-satellite (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) enables horizontally and vertically resolved observations of the global aerosol distribution as well as the measurement of optical aerosol properties. Aerosol layers over different sites in Portugal measured by CALIOP were investigated regarding their origin by means of HYSPLIT back-trajectories [3]. Portugal is appropriate for the observation of relatively pure aerosol types, as desert dust from the Sahara or anthropogenic induced aerosol from the European continent because of the small distance to the source regions as well as the relatively low emissions from local aerosol sources.

2. INSTRUMENTATION AND METHODOLOGY

CALIPSO was launched in April 2006 with CALIOP aboard. Measurements of the atmosphere from space are done since June 2006. Profiles of extinction and backscatter coefficients are captured and from those, different layer properties are automatically derived. Some properties are for example layer base and top height, the integrated attenuated backscatter at 532 nm with the associated uncertainty as well as the minimum, maximum and mean value of the 532 nm attenuated total backscatter computed between layer base and top, and a feature classification. The applied algorithms are described by the authors in [4]. For this work the backscatter and extinction coefficients at 532 nm from June 2006 to September 2008 were analysed.

Through NASA Langley Atmospheric Sciences Data Center [5] preliminary data products are available. It is recommended in the CALIPSO Quality Statements [6] not to use them as standalone products. Therefore no total values of the backscatter and extinction coefficients were analysed. Instead the profiles and layer mean values were only compared qualitatively depending on the origin of the detected aerosols and the observation site respectively.

HYSPLIT back-trajectories were analysed for the determination of the source regions. For each detected aerosol layer, three 7-day back-trajectories were started over the observation site within the height range, the aerosol layer was detected. With those trajectories aerosol layers from the Saharan desert, the Atlantic, Europe and North America could be found. As the American aerosol moved over and hence was influenced by the Atlantic, those layers were assigned to the source region Atlantic. Some layers could not be assigned to one of the mentioned source regions and therefore were classified as of unknown origin.

For this study aerosol layers observed over four sites in Portugal (see figure 1) were investigated in order to find differences in the aerosol distribution between coastal and inland regions as well as between the southern and northern part of the country. Those sites were Vila Real (41.3º N, 7.92º W), situated in the mountainous northern part of Portugal about 460 m asl, Cabo da Roca (38.78º N, 9.5º W), the westernmost point of the European continent about 140 m asl, Évora (38.57º N, 7.92º W), another inland-site in central Portugal about 260 m asl and Faro (37.05º N, 7.92º W), on the southern coast about 6 m asl.

CALIPSO overpasses were defined as ground tracks within 40 km distance from the above mentioned sites

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Figure 1. *Map of Western Europe showing Portugal (blue) as well as the four observation sites Vila Real, Cabo da Roca, Évora and Faro.*

and occurred every 16 days. Only data from those overpasses was investigated for this work.

3. RESULTS

In total 125 aerosol layers were observed from June 2006 to September 2008. In Figure 2 the vertical extents of the detected layers for each observation site are shown. In Vila Real only 25 and hence least layers were recorded (see also table 1). Vila Real is situated in a mountainous region in northern Portugal and hence is more frequently affected by optical dense clouds and precipitation than the other sites. Aerosol layers below such clouds cannot be observed by CALIOP, which is an explanation for the low number of observed layers. Besides tropospheric aerosol layers, some very high stratospheric structures were found. Their origin was not further analysed and the source regions are unknown.

At the coastal site Cabo da Roca 34 layers could be detected. Relatively low layers were observed there, as can be seen in the second plot in figure 2. The maximum layer top lies below 5 km. No aerosol was detected above that height. This might be due to a shallow marine boundary layer and the prevailing wind from westerly directions, which means from the ocean. Convective processes over the sea are not that effective in lifting up air masses than they are over land.

Some of the 31 layers detected over Évora, especially those observed in winter, were relatively thin (500 m or less) as well. However, some layers with comparatively larger depths occurred over Évora in summer probably as a result of stronger convective activity and of free tropospheric layers, which could hardly be found at Cabo da Roca. Aerosol layers above Évora had a maximum top height of about 7 km.

Aerosol layers above Faro were relatively thick with an average of 2 km and a maximum of 5 km. In total 35 layers could be detected over Faro. As at Vila Real, some stratospheric structures were found there and were handled in the same way. Layers detected above Faro, were thicker than those observed at the other

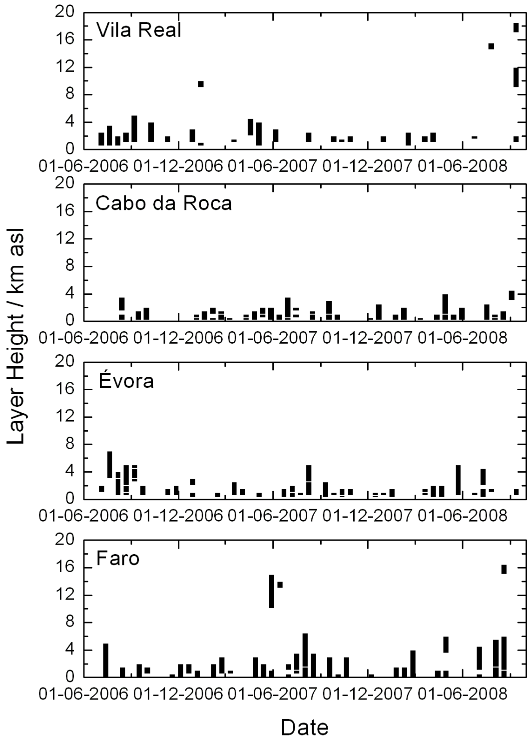

Figure 2. *Vertical extents of the detected aerosol layers for Vila Real, Cabo da Roca, Évora and Faro.*

sites and the layer tops are higher, although it is, as Cabo da Roca a coastal site. This might be due to the lower latitude and warmer water as well as the East-West alignment of the southern coast of Portugal.

Each of the four plots in figure 2 shows a seasonal cycle. In summer the top heights of the observed layers as well as the layer depths were higher than in winter. This feature is less distinct for Vila Real due to the relatively small amount of layers and for Cabo da Roca because of generally low layer tops observed over that site.

In table 1 the numbers of layers detected at the four sites and assigned to the four source regions are listed. Most layers (56%) originated or were transported over the Atlantic Ocean. This meets expectations owing to the prevailing wind pattern in Portugal. About 18% of the observed layers came from the European continent and 12% from the Saharan desert. The number of layers originating from the African continent is surprisingly low. However more remarkable is the low

Table 1. *Number of aerosol layers observed over Vila Real, Cabo da Roca, Évora and Faro assigned to Atlantic, Europe, Sahara and unknown.*

	Vila Real	Cabo da Roca	Évora	Faro	total
Atlantic	10	25	13	21	70
Europe	7	3	7	5	22
Sahara	4	3	6	2	15
unknown	4	3	5	7	18
total	25	34	31	35	125

number of layers from the Saharan desert observed above Faro, the southernmost station, compared to the number of such layers detected over the other sites. An explanation for that could be found in the data processing of CALIPSO. The cloud and aerosol discrimination algorithm described by the authors in [4] favours the identification of a feature as cloud, if the classification is ambiguous [7]. Besides, the authors in [8] found some aerosol types misclassified more often than others. Dense desert dust is one of those types. Another reason for few dust layers could be the frequency of dust events and CALIPSO overpasses. About one to four dust outbreaks per month can be observed over southern Portugal with duration of less than 5 days. Those outbreaks are more frequent in summer. Then, desert dust occurs in about 10% of the time according to the authors in [9], who analysed data from Évora from June to September of the years 2002 and 2003. However CALIPSO overpasses the same point of the earth’s surface every 16 days. Furthermore those overpasses only last few seconds. Consequently there are gaps of nearly 16 days in the observation of one single site, enough time for dust outbreaks to remain undetected by CALIPSO.

Table 1 also shows similarities of both inland sites as well as of the coastal sites respectively. The numbers of layers from the different sources detected over Vila Real and Évora are comparable, whereas more layers from the Atlantic but fewer from Europe could be observed at both coastal sites.

Figure 3 shows the distributions of layer top heights and layer depths of layers from the four above mentioned source regions as box plots. The median of the layer depths of layers from the Atlantic Ocean was smallest with about 1 km. Layers with the highest depths (median about 2 km) were found likely to originate from Sahara or from unknown sources. The median of the layer depths of layers originated in Europe was about 1.5 km.

Aerosol layers assigned to Europe and Atlantic primarily were boundary layers, as relatively low layer tops indicate. Top heights of layers from the Saharan desert are clearly higher. These are deep boundary layers as well as free tropospheric layers. The highest layers were of unknown origin. The detected stratospheric features were assigned to this class as mentioned above. Their influence on the distribution is obvious.

The box plots in figure 4 show the distributions of the mean extinction and backscatter coefficients of the aerosol layers from the different source regions at 532 nm respectively. The median of the layer mean extinction coefficients is about the same for layers from the source regions Atlantic and Europe. For layers from Sahara the median is slightly lower. In those three distributions the mean values are higher than the medians. This indicates few layers with relatively high and many layers with relatively low mean extinction coefficients. For layers with unknown origin the mean value is lower than the median, which implies few layers with exceptionally small mean extinction coefficients. However, the median of this distribution itself is higher compared to those of the other distributions. Again it should be mentioned that the total numbers of extinction and backscatter coefficients were calculated from preliminary data. Only differences and similarities should be regarded.

The lower plot of figure 4 shows the distributions of the layer mean backscatter coefficients. In all four distributions the relation between mean value and median is the same as for the extinction coefficients. The median is lowest for layers from Europe and from the Saharan desert and highest for layers assigned to the source region Atlantic. The median of the distribution of 'unknown' layers lies in between.

Besides layer mean values, profiles of the extinction and backscatter coefficients were analysed. Clusters of those profiles for Atlantic, Europe, Sahara and unknown as well as for Vila Real, Cabo da Roca, Évora and Faro show only slight differences and therefore are not presented here.

The small differences in the distributions shown in figure 4 and in the profile clusters (not presented) can be due to the variety of possible source regions of layers assigned to Atlantic or unknown. Furthermore trajectories only give information on the transport path, but not on aerosol uptake and transformation along them. So clean air could be transported from the so-called source regions and affected by local sources instead. The small differences also may be due to the algorithms used for the classification of the layer type (clouds or aerosol), which are applied before data uploading by CALIPSO and which are described by the authors in [4].

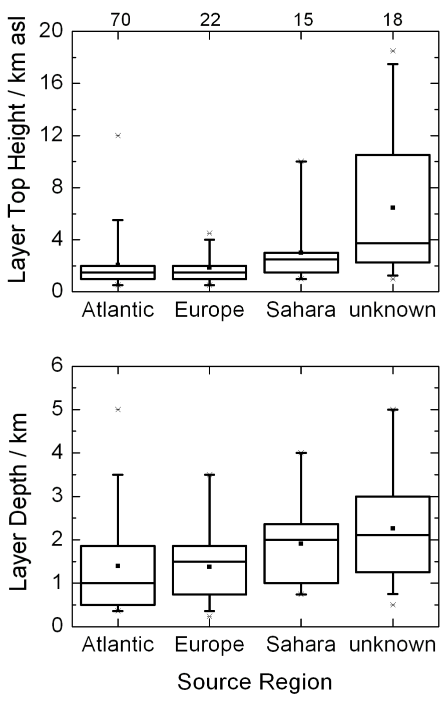

Figure 3: *Distributions of layer top heights (upper plot) and layer depths (lower plot) for the source regions Atlantic, Europe, Sahara and unknown as box plots. The boxes are 75 percentile and 25 percentile, the horizontal line is the median, 95 and 5 percentiles are shown as error bars, mean values as squares and maxima and minima as crosses. On top of the upper plot the number of layers in the respective distribution is shown.*

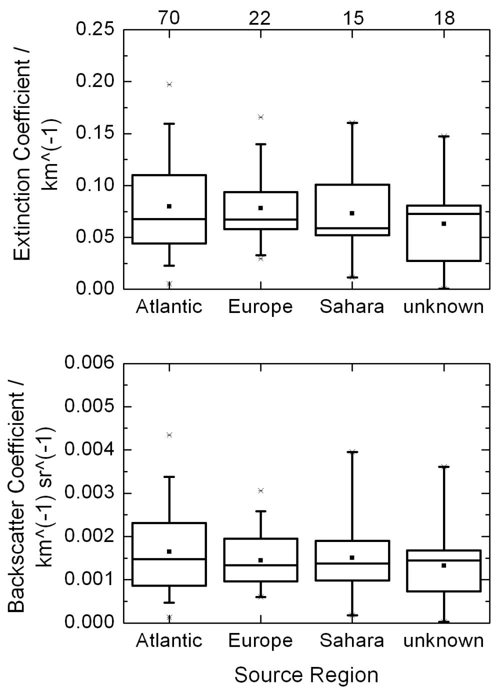

Figure 4: *Distributions of the layer mean extinction (upper plot) and backscatter (lower plot) coefficients at 532 nm respectively for the source regions Atlantic, Europe, Sahara and unknown.*

4. SUMMARY AND CONCLUSIONS

Geometrical properties of 125 free tropospheric aerosol layers and boundary layers were determined from CALIPSO data for four sites in Portugal in the time period from June 2006 to September 2008. Fewest layers were observed above Vila Real. Most of the detected aerosol layers were assigned to the source Atlantic. The seasonal cycle of layer top height and layer depth could be found for all four observation sites, although, some differences were discovered. For example the influence of the Atlantic Ocean on aerosol layers observed over Cabo da Roca manifested in relatively small layer heights and depths. Whereas layers detected above Faro, also a coastal site, were thicker and thus the layer tops were higher. Layers with comparatively low top height came from Europe and the Atlantic. They are primarily boundary layers. Furthermore, the layer mean extinction and backscatter coefficients were examined. The characterisation of aerosol layers from different sources regarding those optical properties results in distributions with similar mean and median values. Also clusters of vertical profiles of extinction and backscatter coefficients per source region as well as per observation site (not presented) did not show particular characteristics.

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REFERENCES

[1] IPCC-Report, Climate Change 2007 - Synthesis Report, 2007: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf.

[2] Winker, D. M., W. H. Hunt and M. J. McGill, 2007: Initial performance assessment of CALIOP, *Geophysical Research Letters*, **34**, doi:10.1029/2007GL030135.

[3] Draxler, R. R. and G. D. Rolph, 2003: HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) Model access via NOAA ARL READY Website (http://www.arl.noaa.gov/ready/hysplit4.html), NOAA Air Resources Laboratory, Silver Spring, MD.

[4] Vaughan, M., S. Young, D. Winker, K. Powell, A. Omar, Z. Liu, Y. Hu and C. Hostetler, 2004. Fully automated analysis of space-based lidar data: an overview of the CALIPSO retrieval algorithms and data products, *Proceedings of SPIE*, **5575**, doi:10.1117/12.572024.

[5] Atmospheric Sciences Data Center, CALIPSO Data Sets, 2009: http://eosweb.larc.nasa.gov/PRODOCS/calipso/table_calipso.html.

[6] CALIPSO Quality Statements: Lidar Level 2 Cloud and Aerosol Profile Products Version Releases: 2.01, 2.02, 2009: http://eosweb.larc.nasa.gov/PRODOCS/calipso/Quality_Summaries/CALIOP_L2ProfileProducts_2.01.html

[7] Winker, D., B. Getzewich and M. Vaughan, 2008: Evaluation and Applications of Cloud Climatologies from CALIOP, http://www-calipso.larc.nasa.gov/resources/pdfs/conf_pap/Winker_ILRC24.pdf

[8] Liu, Z., M. Vaughan, D. Winker, C. Kittaka, B. Getzewich, R. Kuehn, A. Omar, K. Powell, C. Trepte and C. Hostetler, 2009: The CALIPSO Lidar Cloud and Aerosol Discrimination: Version 2 Algorithm and Initial Assessment of Performance, *Journal of Atmospheric and Oceanic Technology*, **26**, doi:10.1175/2009JTECHA1229.1.

[9] Elias, T., A. M. Silva, N. Belo, S. Pereira, P. Formenti, G. Helas and F. Wagner, 2006: Aerosol extinction in a remote continental region of the Iberian Peninsula during summer, *Journal of Geophysical Research*, **111**, doi:10.1029/2005JD006610.