VERTICAL DISTRIBUTION OF AEROSOLS OVER THE GREATER MEDITERRANEAN BASIN USING CALIOP OBSERVATIONS

V. Pappas[1], N. Hatzianastassiou[1]

[1] *Laboratory of Meteorology, Physics Department, University of Ioannina, Greece, vpappas@cc.uoi.gr*

ABSTRACT

Vertically resolved data from Level 3 Version 3 CALIOP database are used to assess the vertical distribution of aerosols over the greater Mediterranean basin (9.5˚W to 38.5˚E and from 29.5˚N to 46.5˚N). Extinction coefficient measurements at 532 nm from 4 years (December 2006 to November 2010) are analysed and provided at the high resolution of 60 meters. The latitudinal variation reveals a south-to-north gradient of the highest altitude of aerosols that is 6 km in summer. The pattern is mixed in the longitudinal variation presenting high boundary and surface layer values in the western, central and eastern parts of the basin varying with season. The seasonal pattern of aerosol optical depth (AOD) values is in general agreement with other studies, indicating higher values in the dry than wet season of the year. However, there are also some differences like the smaller spatial and seasonal variations of AOD and relatively high autumn AOD.

1. INTRODUCTION

Clouds and aerosols are among the primary determinants of the Earth-atmosphere climate system [1]. Aerosols have a well-known direct effect on radiation, which is to absorb and/or scatter it. Depending on the type of aerosols, some of them are highly absorbing, i.e. aerosols from biomass burning smoke, while others are more scattering, i.e. desert dust. The relative position of aerosol and clouds has a different impact on the radiation field. Especially, in the case that aerosols are located above clouds, they are able to heat the planet depending on cloud cover below them [2]. This shows the importance of inferring the relative position of aerosols and clouds. Most of the current aerosol retrieval algorithms are restricted to cloud-free scenes in order to avoid cloud contamination in their results. This however, reduces our ability to monitor aerosol properties at a global scale —there are areas where low-level clouds are persistent— and limits the possibilities of adding important information on the aerosol-cloud interaction. Recent advances in Earth observation from space have greatly enhanced our ability to detect clouds and aerosols throughout the globe. CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation) along with CLOUDSAT have been designed in order to provide an in-depth knowledge of the vertical distribution of clouds and aerosols. This study uses aerosol vertical distribution data, as these are retrieved from CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarisation) lidar onboard CALIPSO. The main objective is to present an analysis of the aerosol vertical distribution over the greater Mediterranean basin (28°N-46°N, 12.5°W-37.5°E). The new knowledge that comes out of this study is an original three-dimensional view of aerosol layers over the Mediterranean basin on a mean monthly and seasonal basis. Mediterranean basin is a very important study area in terms of aerosols, since there is frequent transport of aerosols from Sahara desert [3] throughout the whole basin, affecting even the northern parts of Central Europe.

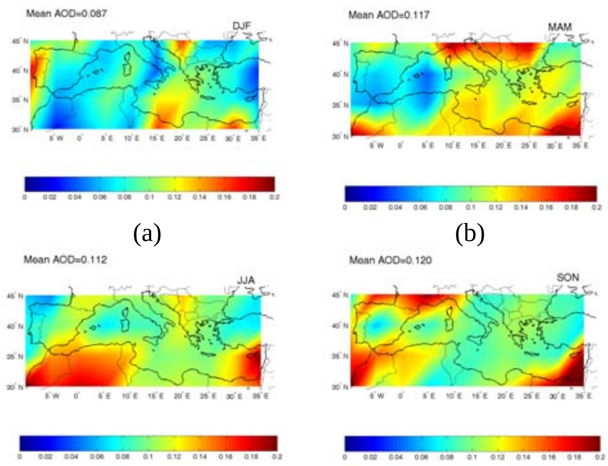
Our study is structured in the following way: section 2 presents all significant capabilities and limitations of CALIOP data, section 3 presents the spatial and temporal variability of extinction coefficient and aerosol optical depth (AOD) over our area of study, and section 4 has conclusions and discussion for further work.

2. CALIOP DATA

CALIOP data have justifiably been used by an increasing number of scientists. Some of them have used Level 1 data, like in [4] and [5], while some others have used Level 2 data, like in [6] and [7] or both datasets, like in [8]. For our study we have used a new product (Level 3) that has become available only recently (December 2011). The lidar Level 3 aerosol data product reports monthly mean profiles of aerosol optical properties on a uniform spatial grid (2˚x5˚ latitude-longitude). The data used here account for 4 years, from December 2006 to November 2010. Level 3 parameters are derived from Level 2 aerosol profile product and are quality screened prior to averaging into monthly files. More information on the specific quality control filters applied for deriving the Level 3 CALIOP data can be found on the relevant website (http://eosweb.larc.nasa.gov/PRODOCS/calipso/Quality_Summaries/CALIOP_L3AProProducts_1-00.html).

3. RESULTS

Figure 1 shows the seasonal variability of columnar aerosol optical depth (AOD) at 532 nm, as a vertical integral of the extinction coefficients from all layers, from the surface up to 12 km. Larger regional mean values appear during spring (0.117), summer (0.112) and autumn (0.120) and smaller in winter (0.087). The CALIOP AOD seasonality is in relatively good agreement although the maximum values are quite lower compared to the study in [9] using other satellite data, namely MODIS (Moderate Resolution Imaging Spectroradiometer). The seasonal plots reveal a transportation path that moves from season to season. For instance, during spring (Fig. 1b), dust is transported from Africa (Sahara desert) to the north mainly over the central and eastern Mediterranean basin. In summer, (Fig. 1c), this path moves westwards and transport occurs over the western Mediterranean basin with high AOD values up the northern coast of Morocco and Spain. Winter is the season with the lower AOD values, which remain smaller than 0.1 in widespread parts of the basin. High AOD values appear in autumn over continental parts of the basin, mainly in the western and eastern North Africa and west Europe, These values should be attributed either to anthropogenic sources or to biomass burning. Nevertheless, some geographical patterns in autumn, namely the large AODs over Morocco and Algeria, seem to be different than those reported by other studies based on MODIS data (e.g. [9] and [10]). Also, our CALIOP results do not exhibit some known patterns like the large AOD values over the Anatolian plateau (Minor Asia). Differences between CALIOP and other data are possibly due to the fact that the few passes of CALIPSO per month (16-day orbit) from a site, could justifiably mean that the maps shown are rather representative of the CALIPSO overpass days than a real climatology of the area.



(a) (b) (c) (d)

Figure 1. CALIOP Level 3 Aerosol Optical Depth for all-sky cases at 532 nm for: a) winter, b) spring, c) summer and d) autumn.

The average vertical distribution of extinction coefficient, averaged over the study region, varies for each season (Fig. 2). The largest values of extinction coefficient per layer —note that each layer is of geometrical thickness of around 60 m— are found within the first 1 kilometer from surface and gradually decrease with height. Winter has the smoothest vertical gradient and the minimum vertical uplift due to decreased convection. Opposite to winter and autumn, the aerosol layer is mostly elevated in summer, with spring following due to expanded boundary layer. The maximum altitude, where non-negligible extinction due to aerosol has been detected is 6.2 km, although there are also non-negative values at the altitude of 9 km, but only for summer.

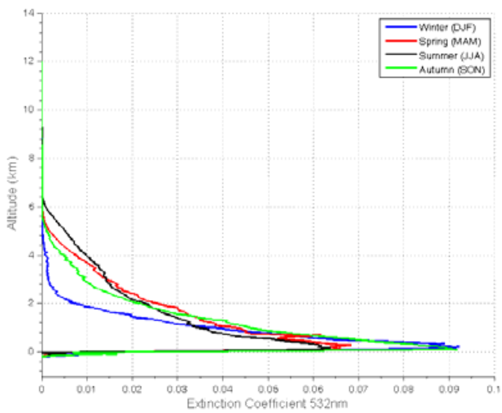


Figure 2. Vertical distribution of Extinction Coefficient per layer (~600 m each) for Mediterranean for each season.

The longitudinal, averaged over all latitudes, variation of vertical aerosol distribution over the Mediterranean basin per season is given in Figure 3. Boundary layer and aerosols within it are lifted higher up during spring and summer, reaching altitudes of about 5 and 6 km in spring and summer, respectively. On the other hand, winter aerosols are mostly confined up to the level of 2.5 km, in agreement to the shallower boundary layer due to decreased convection.

In terms of geographical distribution, the far-left edge of the plot (from about 15°W to 5°W), including northwestern Africa (Atlas Mountain) and the Iberian peninsula, exhibits increased aerosol presence in the lowest 1 km throughout the year. The other band that presents large values of extinction coefficient is the eastern Mediterranean, mostly between 25°E and 35°E, including northeastern Africa, the Anatolian peninsula and Middle East. According to the existing literature, e.g. based on MODIS measurements, it is known that the above areas, i.e. both western and eastern Mediterranean, have large aerosol loads from spring through autumn.

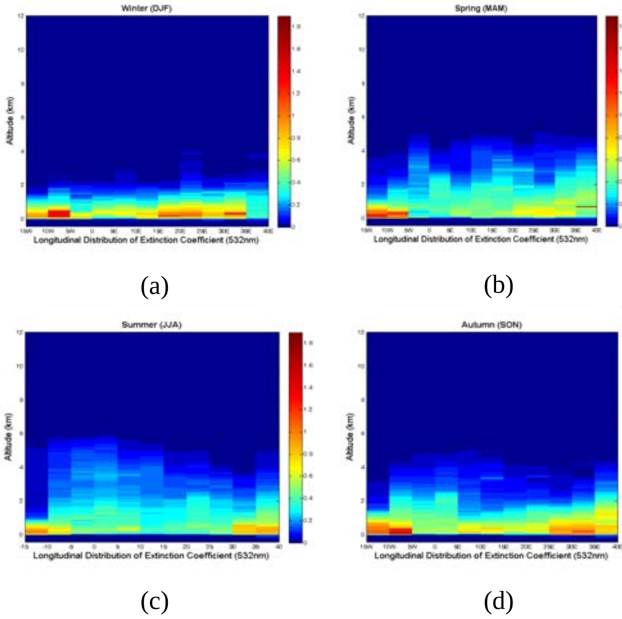


Figure 3. Longitudinal distribution of Extinction Coefficient at 532 nm for a) winter, b) spring, c) summer and d) autumn. Each longitude-height bin equals the sum of extinction coefficient for all latitudes considered. The color scale is the same for all plots.

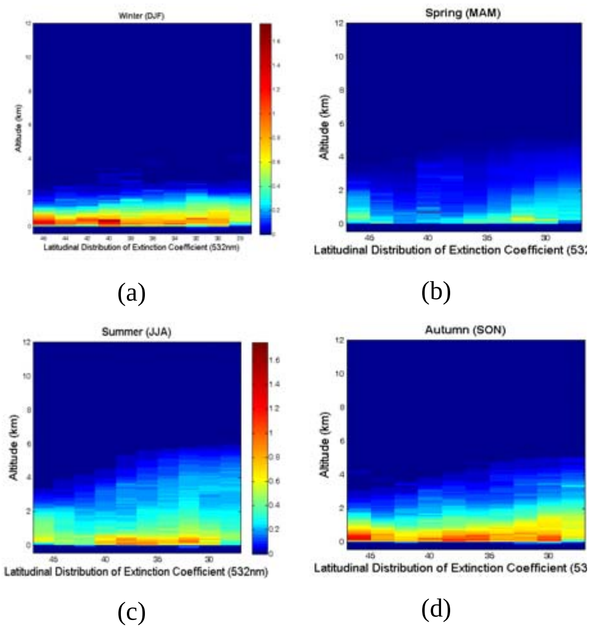


Figure 4. Latitudinal distribution of Extinction Coefficient at 532 nm for a) winter, b) spring, c) summer and d) autumn. Each latitude-height bin equals the sum of extinction coefficient for all longitudes considered. The color scale is the same for all plots.

Over the Mediterranean region, a latitudinal (zonal), i.e. averaged over all longitudes, variation of aerosol extinction (or AOD) is expected to show a south-to-north gradient, mostly due to dust transport from Sahara northwards. Such a gradient, especially in terms of vertical uplift, is evident in all seasons, but mostly during summer, spring and autumn (Figs. 4c, b, d). In the south of our region aerosols are lifted higher up, leading to smaller values of extinction coefficient in the lowest layers, as opposed to the north of the region, where a shallower boundary layer leads to increased values of extinction coefficient. In summer (Fig. 4c), the majority of aerosols is lifted higher than all other seasons, in agreement with both figures 2 and 3.

4. CONCLUSIONS

The aim of this study has been to add knowledge on the vertical distribution of aerosols and clouds over the entire Mediterranean region. As CALIOP has narrow swath and a 16-day orbit period, there are issues as to how representative its retrievals are. Analysis of CALIOP data has shown that aerosols are lifted higher primarily during summer and secondarily in spring and autumn, due to expanded heated boundary layer and increased convection. Winter and autumn have the largest values of extinction coefficient in the lowest atmospheric levels, namely the first kilometer from surface. The latitudinal distribution of extinction coefficient reveals a south-to-north gradient of the highest altitude that aerosols can reach, mainly in spring, summer and autumn. Regardless of their vertical distribution, the values of regionally and vertically summed CALIOP aerosol optical depths do not show a significant difference between the dry (spring-summer) and the wet (autumn-winter) seasons, as documented based on MODIS data [9] although CALIOP regional mean AOD indicates a similar seasonal cycle. The AOD differences with other databases, namely MODIS certainly deserve to be further investigated, and might be related to the limited spatial coverage of the region by CALIOP data. The most heavily loaded region of Mediterranean, though, seems to be South-East Mediterranean, where high values of AOD are present throughout the year. Part of the subsequent work for this study is the investigation of the vertical distribution for distinct aerosol types, based on available relevant information from CALIOP, mostly dust, which is the dominant aerosol type in the region. Also, inclusion of further CALIOP data from increasingly available observations will be essential for improving the representativeness of the results of this study, especially in terms of spatial coverage.

ACKNOWLEDGMENTS

The authors thank CALIPSO Science Team for their efforts in making data products publicly available. CALIOP data were obtained from the NASA Langley Research Center Atmospheric Science Data Center.

REFERENCES

1. Intergovernmental Panel on Climate Change (IPCC), 2007: Climate Change 2007: The Physical Science Basis. Summary for Policymakers. Paris, February 2007.

2. Remer A. L., 2009: Atmospheric science: Smoke above clouds, *Nature Geoscience* **2**, 167 - 168, doi:10.1038/ngeo456.

3. Gkikas A., N. Hatzianastassiou, A. Mihalopoulos, 2009: Aerosol events in the broader Mediterranean basin based on 7-year (2000-2007) MODIS C005 data. *Ann. Geophys.*, **27**, 3509-3522.

4. Vuolo M. R., H. Chepfer, L. Menut, G. Cesana, 2009: Comparison of mineral dust layers vertical structures modeled with CHIMERE-DUST and observed with the CALIOP lidar, *J. Geophys. Res.-Atmospheres*, **114**, 14.

5. Mamouri R. E., V. Amiridis, A. Papayannis, E. Giannakaki, G. Tsaknakis, S. Balis, 2009: Validation of CALIPSO space-borne-derived attenuated backscatter coefficient profiles using a ground-based lidar in Athens, Greece, *Atmos. Meas. Tech.*, **2**, 513-522.

6. Devasthale A., M. A. Thomas, 2011: A global survey of aerosol-liquid water cloud overlap based on four years of CALIPSO-CALIOP data, *Atmos. Chem. Phys.*, **11**, 1143-1154.

7. Yu H., M. Chin, D. M. Winker, A. H. Omar, Z. Liu, C. Kittaka, T. Diehl, 2010: Global view of aerosol vertical distributions from CALIPSO lidar measurements and GOCART simulations: Regional and seasonal variations, *J. Geophys. Res.*, **115**, D00H30, doi:10.1029/2009JD013364.

8. Jordan N.S., R. M. Hoff, J. T. Bacmeister, 2010: Validation of Goddard Earth Observing System-version 5 MERRA planetary boundary layer heights using CALIPSO, *J. Geophys. Res.*, **115**, D24218.

9. Papadimas C., N. Hatzianastassiou, N. Mihalopoulos, X. Querol, I. M. Vardavas, 2008: Spatial and temporal variability in aerosol properties over the Mediterranean basin based on 6-year (2000-2006) MODIS data, *J. Geophys. Res.*, **113**, D11205, 5, doi:10.1029/2007JD009189.

10. Hatzianastassiou N., A. Gkikas, N. Mihalopoulos, O. Torres, B. D. Katsoulis, 2009: Natural versus anthropogenic aerosols in the eastern Mediterranean basin derived from multiyear TOMS and MODIS satellite data, *J. Geophys. Res.*, **114**, D24202, doi:10.1029/2009JD011982.