

This discussion paper is/has been under review for the journal Atmospheric Measurement Techniques (AMT). Please refer to the corresponding final paper in AMT if available.

Airborne sunphotometer PLASMA: concept, measurements, comparison of aerosol extinction vertical profile with lidar

Y. Karol^{1,2}, D. Tanré¹, P. Goloub¹, C. Vervaeke¹, J. Y. Balois¹, L. Blarel¹, T. Podvin¹, A. Mortier¹, and A. Chaikovsky²

¹Laboratoire d'Optique Atmosphérique (LOA), UMR8518, CNRS – Université des Sciences et Technologies de Lille, 59655 Villeneuve d'Ascq, France

²B. I. Stepanov Institute of Physics National Academy of Sciences of Belarus, 68, Nezavisimosti av., 220072 Minsk, Belarus

Received: 1 August 2012 – Accepted: 29 August 2012 – Published: 19 September 2012

Correspondence to: Y. Karol (yana.karol@ed.univ-lille1.fr)

Published by Copernicus Publications on behalf of the European Geosciences Union.

AMTD

5, 6813–6834, 2012

**Airborne
sunphotometer
PLASMA**

Y. Karol et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Abstract

A 15-channel airborne sun tracking photometer has been developed. The instrument provides aerosol optical depths over a wide spectral range (0.34–2.25 μm) with an accuracy of ΔAOD from 0.005 to 0.01. Doing measurements at different altitudes allow us to derive the aerosol extinction vertical profile. Thanks to the wide spectral range of the instrument, information on the aerosol size distribution along the vertical is also available.

1 Introduction

Atmospheric aerosols play a role in the earth radiative budget (see, for example, Hansen et al., 1997; Ramanathan et al., 2001 or Kaufman et al., 2002). Due to their interaction with solar and thermal radiation, aerosols first cool the atmosphere-surface system (aerosol direct effect) and by absorbing sunlight in the atmosphere, they further cool the surface but warm the atmosphere and change the temperature and humidity profiles (semi-direct effect). They also impact the cloud properties by acting as cloud condensation nuclei and ice nuclei (indirect effects). Thus, it is important to measure the 3-D distribution of aerosol properties at local and global scales. There are several satellite sensors (imagers or scanners) that provide a 2-D distribution but the vertical aerosol repartition is poorly sampled. Satellite missions that include lidars such as CALIPSO (Winker et al., 2010) are useful tools for measuring vertical profiles of aerosols on the satellite track, however, Mie lidar have limitation in quantitative measurement because the lidar equation cannot be solved without an assumption on aerosol optical characteristics or some additional constraint such as independent optical depth measurement, for example, with a sunphotometer.

An airborne sun-tracking photometer named PLASMA (that stands for Photomètre Léger Aéroporté pour la Surveillance des Masses d'Air) has been developed. Aerosol optical depths (AOD) within several wavelengths are derived from measurements of the

AMTD

5, 6813–6834, 2012

Airborne sunphotometer PLASMA

Y. Karol et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Airborne sunphotometer PLASMA

Y. Karol et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



extinction of solar radiation by molecular and aerosol scattering and absorption processes. The spectral dependence of AOD (that is expressed by the classical Ångström exponent when two wavelengths are considered) gives information on the aerosol size distribution when the spectral range is large enough (King et al., 1978). Of course, flying at different altitudes provides the corresponding vertical profiles of both quantities.

Algorithmically, the use of photometer is quite simple since there is no assumption regarding aerosol properties and type. With an airborne version like PLASMA, we can easily sample different locations within few minutes, which is valuable for validating AOD derived from satellite sensors like MODIS (Remer et al., 2005), MISR (Kahn et al., 2010) or PARASOL (Tanré et al., 2011). It can also be used to validate extinction vertical profiles obtained by ground-based or space-borne lidars such as CALIOP on CALIPSO (Winker et al., 2010).

If recent similar airborne projects were successfully realized (Matsumoto et al., 1987; Schmid et al., 2003; Asseng et al., 2004). The main advantages of PLASMA are its larger spectral range compared to AATS-14 (from 0.354 to 2.139 μm) and FUBIS-ASA (from 0.3 to 1.7 μm), its smallness and lightness which allow to easily settle it on several vehicles or small airplanes. In this paper we first present technical characteristics, calibration and evolution of the instrument. Then, preliminary results of ground-based, airborne and car measurements are discussed, comparison with lidar profile is finally provided.

2 Description of the instrument

The head of PLASMA contains two parallel optical channels. One for visible and near-infrared ranges (0.343 μm , 0.380 μm , 0.441 μm , 0.499 μm , 0.553 μm , 0.677 μm , 0.869 μm , 0.94 μm , 1.23 μm) and the second for middle infrared (1.14 μm , 1.24 μm , 1.60 μm , 1.646 μm , 2.25 μm), both with a field of view of 1.5 degrees; and a four-quadrant detector for tracking the sun with a FOV of 6 degrees. The head can move in elevation (0–90°) and azimuth (0–360°), and rotation in azimuth can be continuous

thanks to a ring power connector. Hereinafter, we will limit our study to the channels that are in atmospheric windows (Fig. 2).

At start up, the software uses a GPS (on the ground) or a navigation system (on the plane) to locate the sun within the sky then the instrument follows the Sun by using a four-quadrant detector. If GPS can be usually disconnected in flight, it is again needed when there is a shadow or cloud and a turn at the same time since PLASMA cannot longer track the Sun in these conditions. Stepper motors are used to rotate the filter wheels and DC motors are used for tracking the Sun.

The instrument is operated with a PC, which also records the data. The software provides the data file which includes: digital count for the visible and middle infrared channels and data such as latitude, longitude and altitude, speed and other characteristics of aircraft movement given by GPS or navigation system connected.

The currents from the SI visible detectors and the INGAS infrared one are digitized by mean of a delta-sigma ADC. PLASMA is not temperature sensitive in 0–45 °C; the level of noise is less than 0.1 % of numerical count for each channel. The absolute value of noise does not depend from the level of signal but becomes significant when the signal is low, for very turbid atmosphere.

3 Theoretical background

AOD is not directly measured, but is derived from measurements of the atmospheric spectral transmission. Due to Bouguer-Lambert-Beer law the sun irradiance $E(\lambda, z)$ at wavelength λ at an altitude z above sea level is (Bohren and Huffman, 1998):

$$E(\lambda, z) = t_g(\lambda, z)E_0(\lambda)e^{-\tau(\lambda, z)m} \quad (1)$$

where $E_0(\lambda)$ is the extraterrestrial sun irradiance; $t_g(\lambda, z)$ is the gaseous transmission; m is the airmass proportional to $1/\cos(\theta_s)$ when refraction is neglected; θ_s is the solar zenith angle; $\tau(\lambda, z)$ is the total optical depth of the atmosphere that is the sum of

Airborne sunphotometer PLASMA

Y. Karol et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



aerosol extinction and molecular (Rayleigh) scattering optical depths:

$$\tau(\lambda, z) = \tau_{\text{ext}}^a(\lambda, z) + \tau_{\text{ext}}^m(\lambda, z) \quad (2)$$

As numerical count ($\text{DN}(\lambda, z)$) of photometer is proportional to sun irradiance $E(\lambda, z)$ one can write:

$$\text{DN}(\lambda, z) = t_g(\lambda, z) \text{DN}_0(\lambda) e^{-\tau(\lambda, z) / \cos(\theta_s)} \quad (3)$$

PLASMA measures $\text{DN}(\lambda, z)$ and from Eqs. (3) and (2) after gaseous absorption correction we can, in case of spherical or randomly oriented particles, obtain aerosol extinction optical depth:

$$\tau_{\text{ext}}^a(\lambda, z) = \frac{1}{m} [\ln(\text{DN}(\lambda) / t_g(\lambda, z)) - \ln(\text{DN}_0(\lambda))] - \tau_{\text{ext}}^m(\lambda, z) \quad (4)$$

To calculate gaseous absorption, i.e. absorption by oxygen, ozone, water vapor and other gases, we use calculations of standard 5S procedure for middle-latitude summer atmospheric model (Tanré et al., 1990).

Molecular scattering optical depth at the altitude z is:

$$\tau_{\text{ext}}^m(\lambda, z) = \tau_{\text{ext}}^m(\lambda, z_0) \frac{P(z)}{P(z_0)} \quad (5)$$

As pressure measurements are not included by this time in PLASMA instrument, we use equation $P(z) = P(z_0) \exp(-z/8.5)$, z is measured in km.

The aerosol extinction coefficient is the altitude derivative of AOD:

$$\sigma_{\text{ext}}^a = \frac{d\tau_{\text{ext}}^a}{dz} \quad (6)$$

We can compare aerosol extinction coefficient derived by PLASMA and lidar and thus validate lidar retrieval procedure.

Ångström exponent α that provides additional information on the particle size (Schuster et al., 2006) can be found from the equation:

$$\tau(\lambda) = \tau(\lambda_0) \left(\frac{\lambda}{\lambda_0} \right)^{-\alpha} \quad (7)$$

Another capability of airborne sunphotometer with wide spectral range is to retrieve size distribution of aerosol particles $n(r, z)$ through solving the equation (King et al., 1978):

$$\tau_{\text{ext}}^m(\lambda, z) = \int_z^\infty dz' \int_{r_{\text{min}}}^{r_{\text{max}}} \pi r^2 Q_{\text{ext}}(m(\lambda), \frac{2\pi r}{\lambda}) n(r, z') dr \quad (8)$$

where r is particle radius; $n(r, z)$ is particle's size distribution; $m(\lambda)$ is complex refractive index; Q_{ext} is extinction efficiency factor. Equation (8) assumes that the aerosol type does not depend on the altitude.

4 Evolution of the instrument, calibration and ground-based measurements

For PLASMA calibration we used Langley method and intercalibration with master sunphotometer CIMEL CE-318 that is used in Aerosol Robotic Network (AERONET) (Holben et al., 1998).

The procedure of Langley calibration (Schmid and Wehrli, 1995) consists in installing the instrument in a place with low optical depth, usually in high altitude site, where measurements are held during the whole day. Following Eq. (3) $\ln(\text{DN}(\lambda)/t_g(\lambda, z)) = \ln(\text{DN}_0(\lambda)) - \tau(\lambda, z)m$; the dependence $\ln(\text{DN}(\lambda))$ from m is linear with the intercept equal to $\ln(\text{DN}_0(\lambda))$. $\text{DN}_0(\lambda)$ can be found with a high accuracy for $m < 5$ when the atmosphere is stable. The method of Langley calibration is more accurate and covers all channels, but this requires sending the instrument in an appropriate place that involves additional costs.

Intercalibration can be done with near-simultaneous measurements of sun irradiance by PLASMA and CIMEL sunphotometers in one place. DN_0 can be found from the relation:

$$\frac{DN_0^{\text{PLASMA}}(\lambda)}{DN_0^{\text{CIMEL}}(\lambda)} = \frac{DN^{\text{PLASMA}}(\lambda)}{DN^{\text{CIMEL}}(\lambda)} \quad (9)$$

The accuracy of AOD depends on the accuracy of calibration coefficients. The error of only 1 % in calibration coefficient leads to inaccuracy up to $\Delta AOD \approx 0.01$. Nevertheless, even with wrong AOD profile it is possible to get the right value of aerosol extinction coefficient. This approximation is quite reasonable when the measurements are held during a short period of time (see Eq. 4). Usually the flight last around 30 min, in this period the airmass changed slightly and we can assume that the value of AOD shifted by a constant within the accuracy of the instrument. Since the extinction coefficient is a high derivative of AOD, its shift for a constant does not affect the value of AOD.

The first calibration campaign after the instrument was built and preliminarily characterized was organized at Izaña (28.3° N 16.5° W Elevation: 2391.0 m) Atmospheric Observatory (October 2009) and some additional in Carpentras (44.1° N 5.1° E Elevation: 100.0 m) in March 2009.

The calibration coefficients calculated with Izaña and Carpentras data in 2009 were applied to all data collected in Lille (50.6° N 3.1° E Elevation: 60.0 m) until March 2010 to obtain aerosol optical depth (AOD). The comparison with CIMEL at common wavelengths (0.34 μm , 0.38 μm , 0.44 μm , 0.67 μm , 0.86 μm , 1.20 μm , 1.64 μm) showed the agreement between these two instruments with an accuracy ΔAOD from 0.01 to 0.02.

Since the mechanical part of PLASMA was modified in the end of 2009, a new calibration campaign was organized at Izaña in March 2010. Several measurements were then performed in LOA to sample different atmospheric conditions during 12 days in April–June 2010. At the same time PLASMA data were integrated into LOA internal tools developed for AERONET instruments to facilitate analysis. After modification of

Airborne sunphotometer PLASMA

Y. Karol et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Airborne sunphotometer PLASMA

Y. Karol et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



PLASMA mechanical part better agreement with CIMEL master instrument was obtained with $\Delta\text{AOD} = 0.01$. Then a new field campaign was carried out in January 2011 at Izaña to perform again absolute calibration of the instrument using the Langley method. The objective was to obtain a PLASMA calibration as accurate as AERONET reference instruments ($0.005 < \Delta\text{AOD} < 0.01$). Calibration coefficients obtained were used for all data processing until March 2011.

Final improvements of the instrument were performed in March 2011. Attenuation filters were removed because of their degradation, electronic changes were done to increase the signal to noise ratio, new motor was installed and at last PLASMA software was updated. The final version of the instrument was intercalibrated with CIMEL master sunphotometer in Lille on 18 of April 2011. Since April 2011 over 20 days of measurements were performed in Lille and 2 days in Beijing (40.0°N 116.4°E Elevation: 92.0 m). Now the difference of AOD retrieved by PLASMA and CIMEL master instrument is less than 0.005 for all channels except $0.34\text{ }\mu\text{m}$ channel for which the gaseous transmission correction specifics lead to increasing of inaccuracy of AOD when the airmass $m > 2$ (see Fig. 3).

Currently, we analyze only those wavelengths that could be compared with CIMEL instruments. Of course, PLASMA covers a larger spectral range with a $2.25\text{ }\mu\text{m}$ channel that is very important for AOD inversion. Nevertheless at this stage we do not consider this wavelength since we cannot validate calibration coefficient with any other instrument.

5 Airborne measurements

As reported in Sect. 4, several flights were performed in Lille: two technical flights in 2009, 6 flights in 2010 and 3 flights in 2011. We provide hereinafter results for flights performed since October 2010 only.

Figure 4 shows profiles of 4 flights in 2010–2011. The first column presents the vertical profile of AOD at different wavelengths; the second is the profile of extinction

coefficient; the third column is the comparison of extinction at 0.553 μm with the one retrieved from lidar measurements at 0.532 μm . The extinction profile retrieved from lidar measurements is quite consistent with what we get from measurements of PLASMA. Altitudes below 500 m could not be observed by lidar, there is an algorithm to obtain the profiles of extinction coefficient which can be validated by direct PLASMA measurements.

To get extinction profile we decided to remove all noisy data due to the presence of clouds and then to average over 10 measurements. It means that we assume that the state of the atmosphere was stable over 30–60 s, along 50–100 m in vertical direction and 2–4 km in horizontal direction. The best agreement between aerosol extinction coefficient profiles retrieved from PLASMA and lidar data was observed 15 October 2011 when the atmosphere was enough stable as seen from AOD profile.

For other days, there are differences that can be explained by time and space variability of aerosol and clouds. On 29 September 2011 clouds were present in the vicinity and the turbidity was somewhat high; as a result the data present more noise and a 50 % difference of extinction coefficient at an altitude around 400 m is observed. Discrepancies can also result from spatial variability of the aerosol field; distance between both instruments was around 10 km when the airplane was on the ground, and more than 50 km when the plane was at the altitude 3000 m. Moreover, PLASMA measurements were carried out during around 20 min and are compared to the nearest in time lidar profile ($\Delta t \approx 15$ min). Despite this difference we can say that the profiles are consistent at least in terms of layers position.

6 Car measurements

In addition to airborne measurements it is also possible to install PLASMA on the roof of a car in order to obtain horizontal profiles of AOD. In mountainous areas we can also perform measurements of vertical profiles thanks to the orography.

Airborne sunphotometer PLASMA

Y. Karol et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Airborne sunphotometer PLASMA

Y. Karol et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



In January 2011 an experiment to measure the vertical profile of AOD successfully carried out on the island of Tenerife, Spain. The measurements were made from sea level to an altitude of 2400 m in one hour. Horizontal coverage area is about 30 km. Along the road Izaña AERONET station (alt. 2391 m) is the closest, two more stations La Laguna (alt. 590 m) and Santa Cruz (alt. 54 m) are located at a distance of 40 km. It is possible to compare measurements of PLASMA and CIMEL photometers at different altitudes. The results of measurements of vertical profiles of AOD at two well calibrated channels (0.380 μm and 0.677 μm) in comparison with the measurements of the photometer CE-318 in the three reference stations are shown in Fig. 5. There is one additional reference point of AOD measured at 0.44 μm by a sunphotometer MICROTOS II (Morys et al., 2001). Measurements of PLASMA are consistent with other instruments with $\Delta\text{AOD} < 0.01$.

In July 2011 the instrument participated in DRAGON (Distributed Regional Aerosol Gridded Observation Networks) campaign in Washington, USA (Holben et al., 2011; Mortier et al., 2012). The goal was to obtain AOD horizontal profiles simultaneously with mobile lidar system between several sunphotometers in grid points. Figure 6 shows the PLASMA path between AERONET-DRAGON stations. Car measurements were performed during 15 days.

We present in Fig. 7 the AOD on 20th of July 2011 where high variability of AOD was observed. The horizontal profile obtained during 1 h from GSFC to ABERD AERONET stations. AOD(0.44 μm) varied from 0.44 to 0.72. The accuracy of measurements is lower than for ground-based experiments and is around $0.005 < \Delta\text{AOD} < 0.01$. AERONET-DRAGON stations were located at a distance 2–10 km from PLASMA. The accuracy of AERONET measurements is $\Delta\text{AOD} < 0.01$ but due to the distance between instruments and high aerosol variability we estimated the error in AOD given by AERONET stations at PLASMA route up to 0.04. Thereby there is a good agreement between PLASMA and AERONET measurements.

The Ångström exponent measured by PLASMA is also consistent with AERONET measurements with $\Delta\alpha = 0.05$. While the AOD varied a lot in space, the Ångström

exponent had lower variability. It means that the type of the aerosol in the atmosphere had not changed, the variation was only in its amount.

7 Conclusions

New airborne sunphotometer PLASMA was developed and successfully used for AOD measurements over a wide spectral range with $0.005 < \Delta\text{AOD} < 0.01$. Technically sophisticated but user-friendly instrument can be used as for onboard measurements (to obtain vertical profiles of the atmosphere) either for car measurements (to obtain horizontal profiles). PLASMA accurately follows the Sun by four-quadrant detector and its head can continuously rotate in azimuth plane that is important advantage of mobile instrument. Ground-based measurements of spectral AOD after intercalibration with CIMEL CE-318 show high accuracy of PLASMA with $\Delta\text{AOD} = 0.005$. Vertical profiles of AOD and aerosol extinction coefficient obtained during several flights in Lille are in good agreement with coincident lidar measurements. Since the instrument provides direct and reliable AOD measurements we are going to use PLASMA data for correction the algorithm of aerosol extinction coefficient retrievals. Car experiments within DRAGON campaign show promising results of using PLASMA in order to obtain horizontal profiles of AOD.

Acknowledgements. This study has been funded by CNES (Centre National d'Études Spatiales), CNRS (Centre National de la Recherche Scientifique), the University of Lille, and Région Nord-Pas-de-Calais. Y. Karol is supported by a fellowship from CNES and CNRS. PLASMA calibration was performed at Izana observatory using AERONET-EUROPE calibration center, supported by ACTRIS from European Union Seventh Framework Program (FP7/2007-2013) under grant agreement no. 262254. Emilio Cuevas-Agullo from the Meteorological State Agency of Spain (AEMET) is acknowledged for his help during the experiment in Tenerife. The authors are very thankful to AERONET for establishing and maintaining the sites used in this work.

Airborne sunphotometer PLASMA

Y. Karol et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



The publication of this article is financed by CNRS-INSU.

References

- Asseng, H., Ruhtz, T., and Fischer, J.: Sun and aureole spectrometer for airborne measurements to derive aerosol optical properties, *Appl. Optics*, 43, 2146–2155, doi:10.1364/AO.43.002146, 2004. 6815
- Bohren, C. and Huffman, D.: Absorption and Scattering of Light by Small Particles (Wiley science paperback series), Wiley-VCH, New York, 1998. 6816
- Hansen, J., Sato, M., and Ruedy, R.: Radiative forcing and climate response, *J. Geophys. Res.*, 102, 6831–6864, doi:10.1029/96JD03436, 1997. 6814
- Holben, B., Eck, T., Slutsker, I., Tanré, D., Buis, J., Setzer, A., Vermote, E., Reagan, J., Kaufman, Y., Nakajima, T., Lavenue, F., Jankowiak, I., and Smirnov, A.: AERONET – a federated instrument network and data archive for aerosol characterization, *Remote Sens. Environ.*, 66, 1–16, doi:10.1016/S0034-4257(98)00031-5, 1998. 6818
- Holben, B., Eck, T., Schafer, J., Giles, D., and Sorokin, M.: Distributed Regional Aerosol Gridded Observation Networks (DRAGON) White Paper, available at: http://aeronet.gsfc.nasa.gov/new_web/dragon.html (last access: 11 September 2012), 2011. 6822
- Kahn, R., Gaitley, B., Garay, M., Diner, D., Eck, T., Smirnov, A., and Holben, B.: Multiangle imaging spectroradiometer global aerosol product assessment by comparison with the aerosol robotic network, *J. Geophys. Res.*, 115, D23209, doi:10.1029/2010JD014601, 2010. 6815
- Kaufman, Y. J., Tanré, D., and Boucher, O.: A satellite view of aerosols in the climate system, *Nature*, 419, 215–223, 2002. 6814
- King, M., Byrne, D., Herman, B., and Reagan, J.: Aerosol size distributions obtained by inversions of spectral optical depth measurements, *J. Atmos. Sci.*, 35, 2153–2167, doi:10.1175/1520-0469(1978)035<2153:ASDOBI>2.0.CO;2, 1978. 6815, 6818

Airborne sunphotometer PLASMA

Y. Karol et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Airborne sunphotometer PLASMA

Y. Karol et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



- Matsumoto, T., Russell, P., Mina, C., Ark, W. V., and Banta, V.: Airborne tracking sunphotometer, *J. Atmos. Ocean. Tech.*, 4, 336–339, 1987. 6815
- Mortier, A., Goloub, P., Holben, B., Podvin, T., Blarel, L., Verwaerde, C., Karol, Y., Slutsker, I., Balois, J.-Y., Tanre, D., Berkoff, T., Victori, S., and Mathieu, R.: Aerosol Spatial Distribution during DRAGON experiment as seen by a mobile ground-based LIDAR-sunphotometer system-Preliminary results, Reviewed and revised papers of the 26th International Lidar Radar Conference, Porto Heli, Peloponnesus, Greece on 25–29 June, 411–414, 2012. 6822
- Morys, M., Forrest, Hagerup, S., Anderson, S., Baker, A., Kia, J., and Walkup, T.: Design, calibration, and performance of MICROTOPS II handheld ozone monitor and sun photometer, *J. Geophys. Res.*, 106, 14573–14582, 2001. 6822
- Ramanathan, V., Crutzen, P., Kiehl, J., and Rosenfeld, D.: Aerosols, climate, and the hydrological cycle, *Science*, 294, 2119–2124, doi:10.1126/science.1064034, 2001. 6814
- Remer, L., Kaufman, Y., Tanré, D., Mattoo, S., Chu, D., Martins, J., Li, R., Ichoku, C., Levy, R., Kleidman, R., Eck, T., Vermote, E., and Holben, B.: The MODIS aerosol algorithm, products, and validation, *J. Atmos. Sci.*, 62, 947–973, doi:10.1175/JAS3385.1, 2005. 6815
- Schmid, B. and Wehrli, C.: Comparison of Sun photometer calibration by use of the Langley technique and the standard lamp, *Appl. Optics*, 34, 4500–4512, doi:10.1364/AO.34.004500, 1995. 6818
- Schmid, B., Redemann, J., Russell, P., Hobbs, P., Hlavka, D., McGill, M., Holben, B., Welton, E., Campbell, J., Torres, O., Kahn, R., Diner, D., Helmlinger, M., Chu, D., Robles-Gonzalez, C., and de Leeuw, G.: Coordinated airborne, spaceborne, and ground-based measurements of massive thick aerosol layers during the dry season in Southern Africa, *J. Geophys. Res.-Atmos.*, 108, 8496, doi:10.1029/2002JD002297, 2003. 6815
- Schuster, G. L., Dubovik, O., and Holben, B. N.: Angstrom exponent and bimodal aerosol size distributions, *J. Geophys. Res.*, 111, D07207, doi:10.1029/2005JD006328, 2006. 6818
- Tanré, D., Deroo, C., Duhaut, P., Herman, M., Morcrette, J., Perbos, J., and Deschamps, P.: Description of a computer code to simulate the satellite signal in the solar spectrum: the 5S Code, *Int. J. Remote Sens.*, 11, 659–668, 1990. 6817
- Tanré, D., Bréon, F. M., Deuzé, J. L., Dubovik, O., Ducos, F., François, P., Goloub, P., Herman, M., Lifermann, A., and Waquet, F.: Remote sensing of aerosols by using polarized, directional and spectral measurements within the A-Train: the PARASOL mission, *Atmos. Meas. Tech.*, 4, 1383–1395, doi:10.5194/amt-4-1383-2011, 2011. 6815

Winker, D., Pelon, J., Coakley, J., Ackerman, S., Charlson, R., Colarco, P., Flamant, P., Fu, Q., Hoff, R., Kittaka, C., Kubar, T., Le Treut, H., McCormick, M., Mégie, G., Poole, L., Powell, K., Trepte, C., Vaughan, M., and Wielicki, B.: The CALIPSO Mission: a global 3D view of aerosols and clouds, Bull. Am. Meteorol. Soc., 91, 1211–1229, doi:10.1175/2010BAMS3009.1, 2010. 6814, 6815

5

AMTD

5, 6813–6834, 2012

Airborne sunphotometer PLASMA

Y. Karol et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

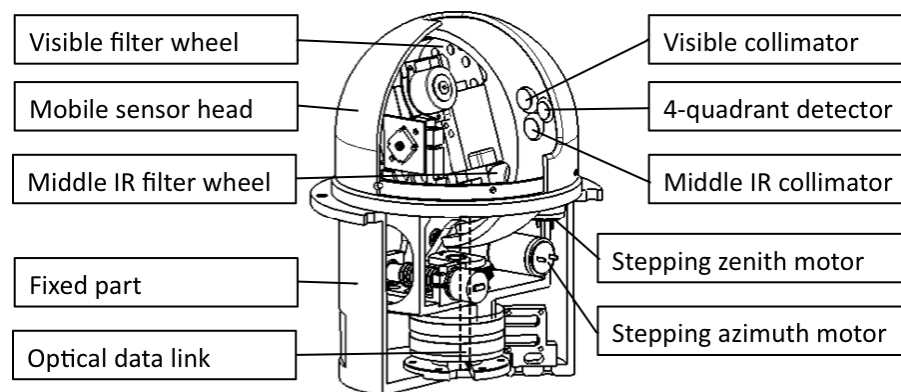
Printer-friendly Version

Interactive Discussion



**Airborne
sunphotometer
PLASMA**

Y. Karol et al.

**Fig. 1.** PLASMA scheme.[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[◀](#)[▶](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

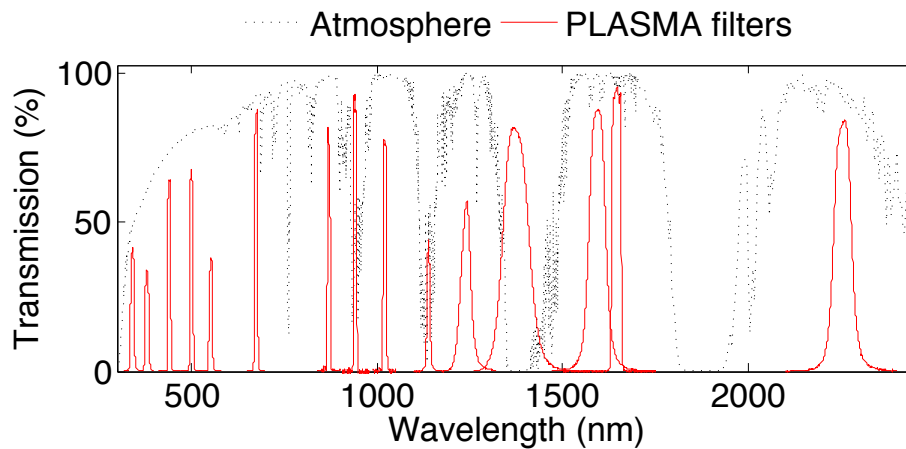


Fig. 2. PLASMA filter's transmission.

**Airborne
sunphotometer
PLASMA**

Y. Karol et al.

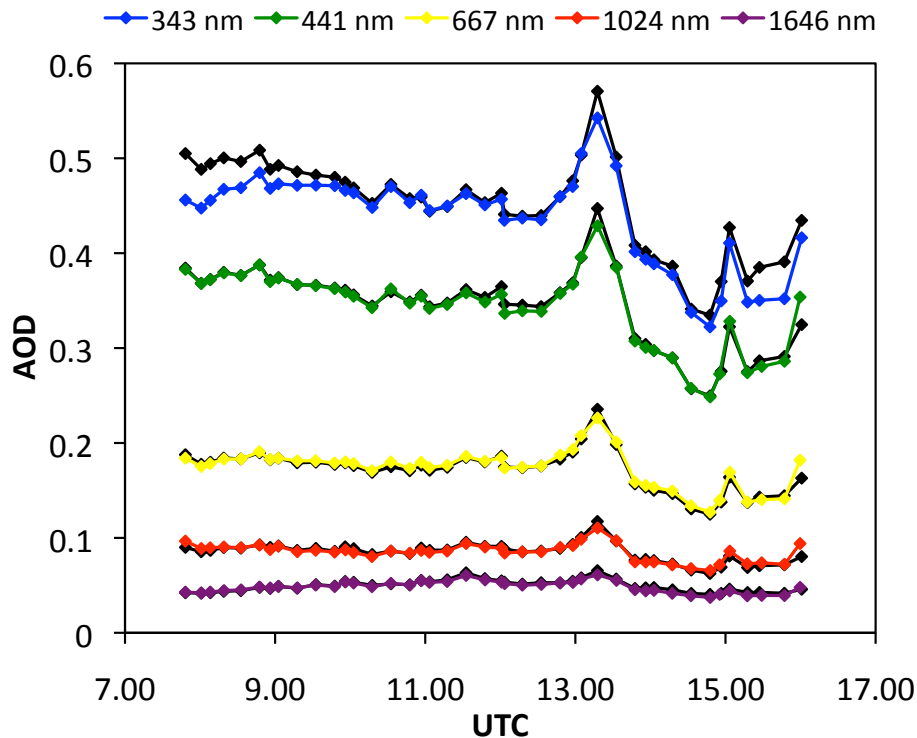


Fig. 3. Comparison of simultaneous ground-based measurements of PLASMA (colored lines) and CIMEL CE-318 (black lines) 18 April 2011.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Airborne sunphotometer PLASMA

Y. Karol et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

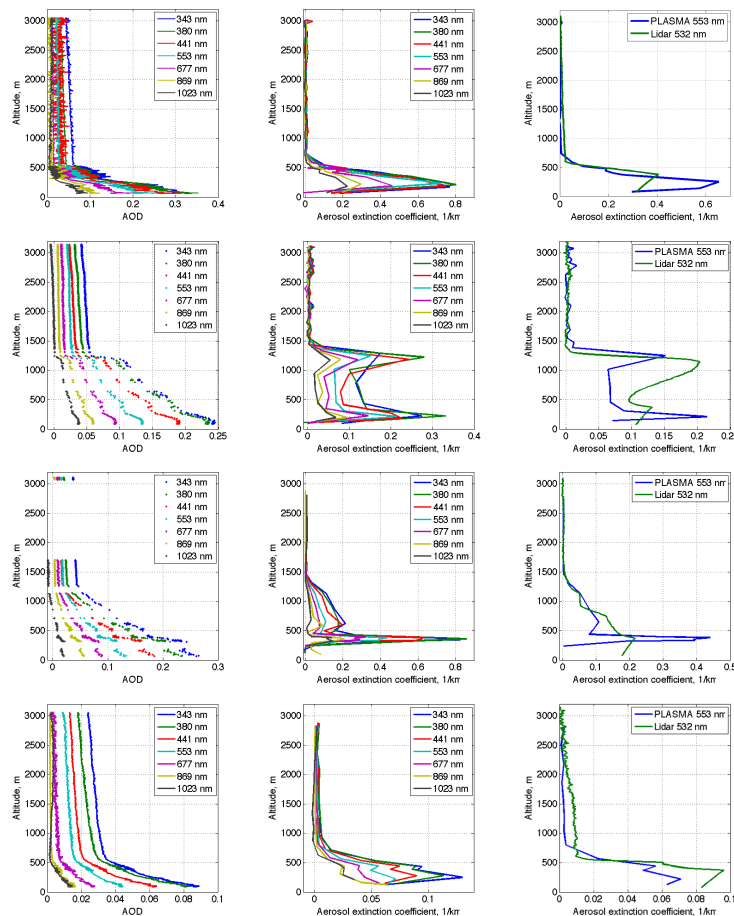


Fig. 4. PLASMA AOD (left), aerosol extinction coefficient (center) at 7 channels and aerosol extinction coefficient compared with lidar (right) as a function of the altitude acquired near Lille region the 12 October 2010, 28 September 2011, 29 September 2011 and 15 October 2011.

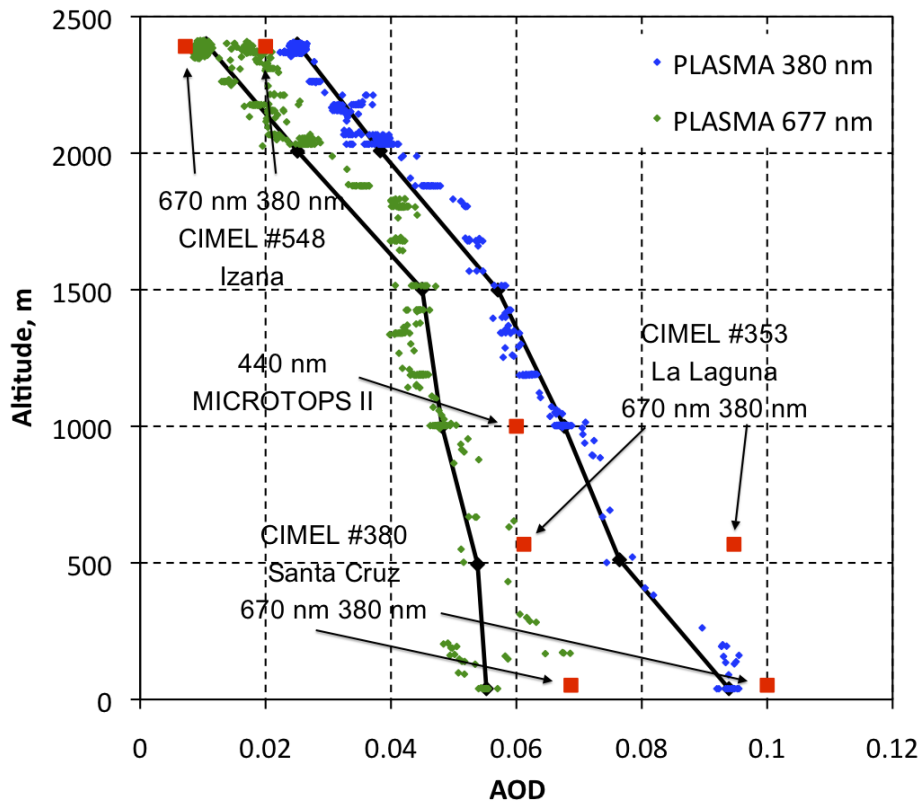


Fig. 5. Vertical profiles of AOD during car experiment 13 January 2011 in Tenerife island, Spain.

Airborne sunphotometer PLASMA

Y. Karol et al.

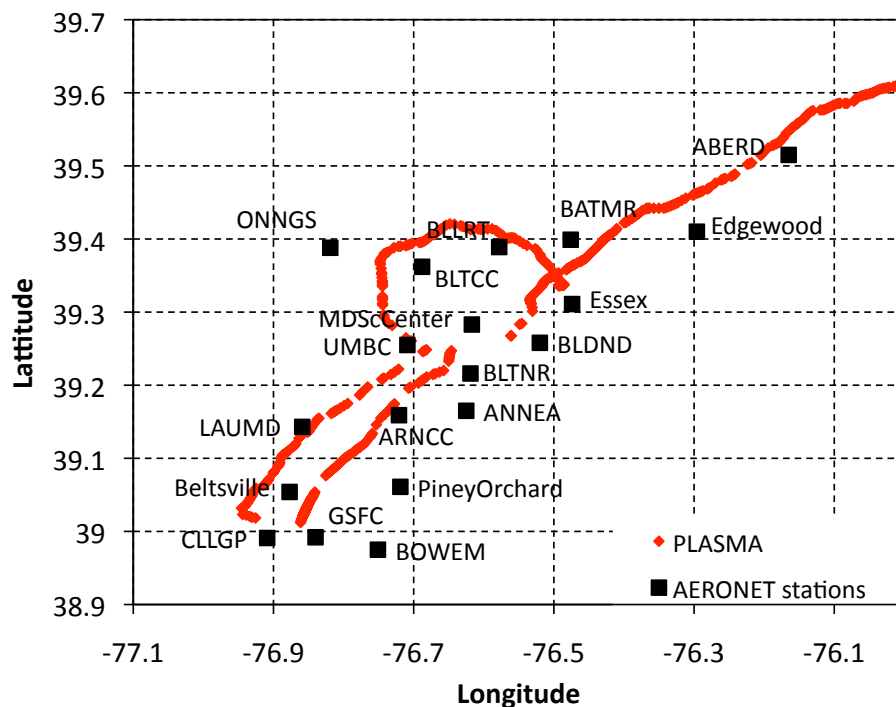


Fig. 6. PLASMA path (red line) and the closest AERONET-DRAGON stations.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



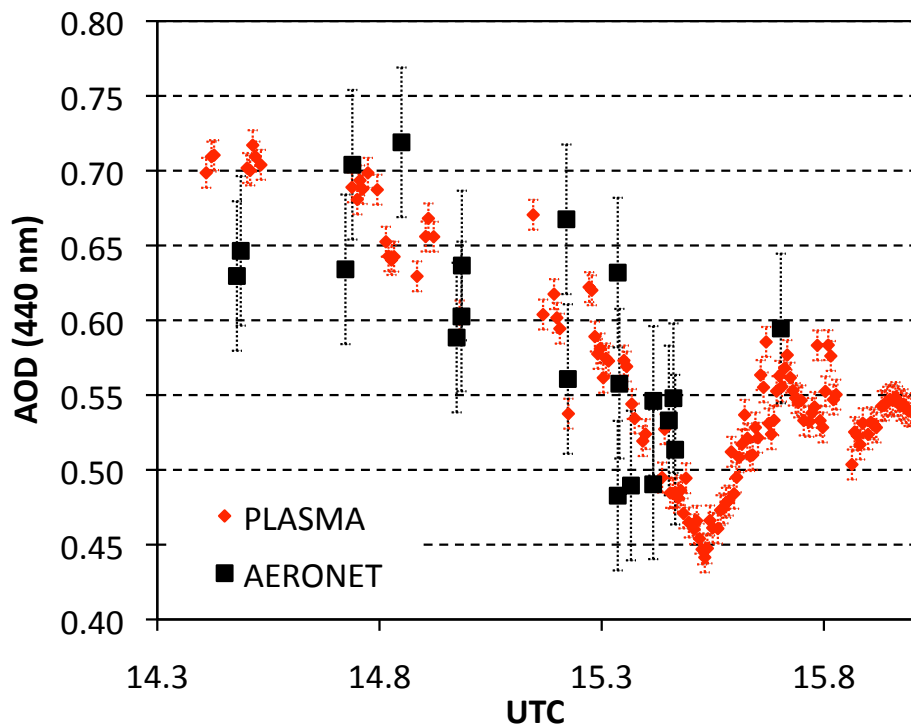


Fig. 7. AOD measured by PLASMA and AERONET-DRAGON stations.

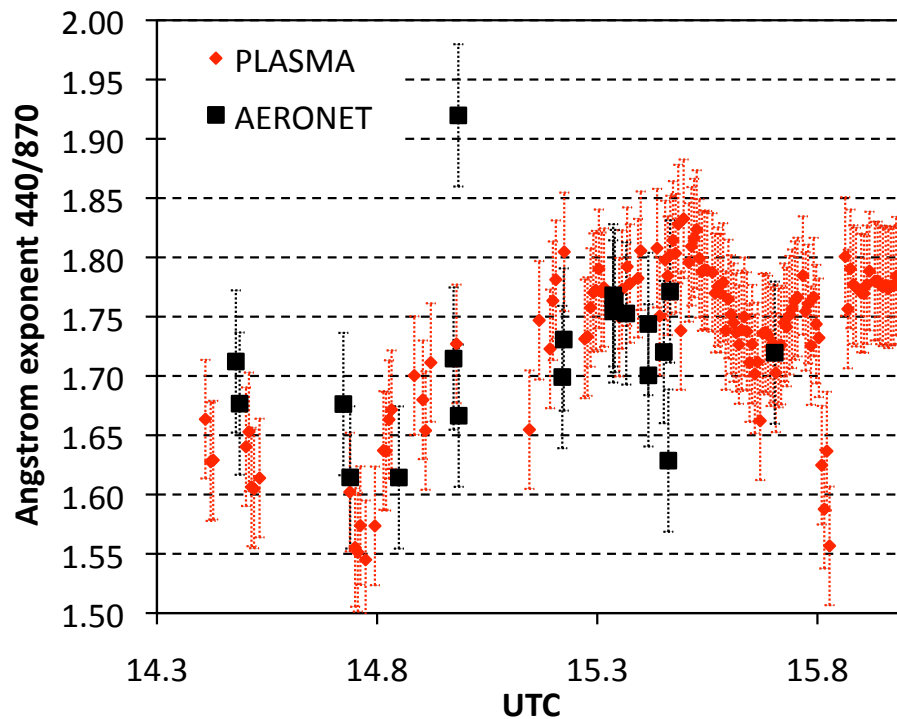


Fig. 8. Ångström exponent 440/870 measured by PLASMA and AERONET-DRAGON stations.