AEROSOL LIDAR MEASUREMENTS FROM AN ULTRA-LIGHT AIRCRAFT IN THE FRAME OF THE AFRICAN MONSOON MULTIDISCIPLINARY ANALYSIS (AMMA)

Patrick CHAZETTE, Joseph SANAK, Marie GELEOC, and François DULAC

Laboratoire des Sciences du Climat et de l'Environnement
Laboratoire mixte CEA-CNRS-UVSQ, CEA Saclay 701, F-91191 Gif-sur-Yvette, France, patrick.chazette@cea.fr

ABSTRACT

A new payload for an ultra-light aircraft has been designed including LAUVA (Lidar Aérosols UltraViolet Aéroporté), an eye safe and compact backscattering lidar system emitting at the wavelength of 355 nm. We operated this airborne configuration in the Sahel from the city of Niamey (Niger) during the first campaign of the African Monsoon Multidisciplinary Analysis (AMMA) in January-February 2006. We take advantage of the lidar capability of pointing in different directions to retrieve the vertical profile of the aerosol backscatter to extinction ratio during a transport event with a mixing of dust and biomass burning aerosols.

1. INTRODUCTION

It has been shown that an ultra-light aircraft (ULA) is a versatile platform for radiation and chemical measurements in the lower tropospheric column[1,2]. For the first time an ultraviolet eye safe lidar system has been embarked on an ultra-light aircraft. The handiness of such an instrumented platform makes it possible to plan new algorithmic approaches for the analysis of the lidar measurements in order to study the aerosol optical properties in the low and mid troposphere. It was operated within the framework of the first intensive field phase of the Monsoon Multidisciplinary Analysis (AMMA; http://amma.mediasfrance.org/) which took place in January-February 2006 in the West African Sahel. This phase of AMMA was dedicated to the study of tropospheric aerosols during the dry season. The main particle sources are known to be biomass burning and aeolian erosion.

We followed a double objective. The first one was to characterize the aerosol mixing between biomass burning and dust aerosols, which occurs during the dry season over the West African Sahel (10-18 °N). The second one was to document the vertical profile of the aerosol backscatter to extinction ration (BER) in a complex environment to prepare for the spaceborne mission CALIPSO. Indeed, previous studies have shown that the aerosol type could be different in the atmospheric column leading to significant variations in the BER against the altitude[3,4].

Here we present the first analysis of results obtained from an ULA flight in southeastern Niger from La Tapoa (12°29'N-2°24'E), close to the Benin border, to Niamey (13°31'N-2°07'E).

2. EXPERIMENTAL SETUP

The characteristics of the high performance ULA platform used and of the lidar system LAUVA are given in Tables 1 and 2, respectively.

Table 1: Ultra-Light Aircraft (ULA) characteristics

True airspeed: 17 to 40 m/s (60 to 145 km/h)
Ascent speed: up to 365 ft/min (110 m/min)
Descent speed: 825 ft/min (250 m/min)
Endurance: 3 hr (max 4 hr at 20 m/s)
Maximum altitude: 5.8 km

Table 2: Lidar general characteristics

Wavelength	355 nm
Mean energy per pulse	16 mJ
Pulse repetition rate	20 Hz
Pulse duration	7 ns
Beam diameter	20 mm
Divergence	< 0.2 mrad
Reception diameter	150 mm
Filter bandwidth	0.5 nm
Field of view	4 mrad
Detector	Photomultiplicator
Detection mode	Analog
Vertical resolution	1.5 m
Dimensions of the optical head	45 cm (H) x 28 cm (W) x 18 cm (D)
Weight of the optical head	~9 kg
Weight of the electronics	~20 kg
Electric supply	220 V
Consumption	< 500 W

The selected flight plan is shown in Fig. 1. The ULA took off on the 30th January 2006 at 0848 GMT from the bush aerodrome of La Tapoa. It described spirals until reaching an altitude of about 5 km above mean sea level (AMSL). It was then stabilized at this altitude to carry out a South-North leg between La Tapoa and Niamey. The descent occurred near Niamey and it landed at the international airport at 1044 GMT.

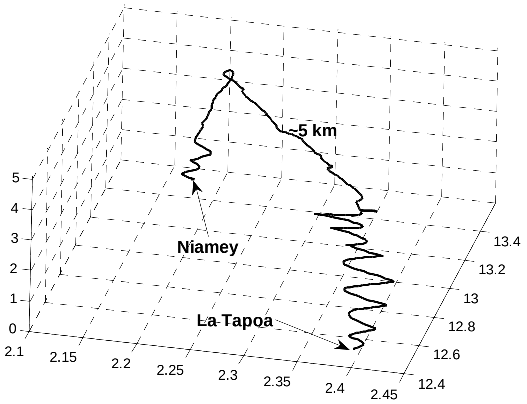

Fig. 1. Two-hour flight plan of the ULA between La Tapoa and Niamey (x-axis: longitude, in °E ; y-axis: latitude, in °N; z-axis: altitude AMSL, in km). The maximum altitude of flight was close to 5 km AMSL.

The lidar optical system was implemented so as to allow a rotation of the pointing direction. This made it possible to carry out horizontal forward shooting during the ascent and the descent, and nadir shooting at the ferry altitude. The ULA attitude has been measured thanks to an artificial horizon system installed on the lidar optical head. The localisation of the ULA was made using a Global Positioning System (GPS) instrument. The scientific payload also included pressure (P), relative humidity (RH) and temperature (T) Vaisala probes, and a small personal DataRam (pDR) scatterometer working at the wavelength of 880 nm. The molecular contribution to the lidar signal is calculated from the in situ measurements of temperature and pressure.

3. RESULTS

Vertical profiles of the aerosol extinction coefficient at 355 nm have been retrieved from the horizontal forward shootings during both the ascent above La Tapoa and the descent above Niamey (Fig. 2), assuming horizontal homogeneity of the aerosol structure. The two profiles are similar, highlighting the presence of 4 aerosol layers at the regional scale: between the ground and 1.5 km, between 1.5 and 2.5 km, between 2.5 and 4 km and above. Backtrajectories computed using the Hysplit model (courtesy of NOAA Air Resources Laboratory http://www.arl.noaa.gov) show that the respective air masses are from different origins. In the first layer, the aerosol is certainly composed of desert dust coming from the North, and more specifically from the Tenere area during the first part of the flight and from the western part of Niger, close to Mali, for the last part of the flight. The second layer is from a Sahelian origin with an air mass which skirted the border between Niger and Nigeria. The two highest layers are from the South-East, from northeastern Benin and Nigeria where biomass burning occurred according to the MODIS fire product (http://rapidfire.sci.gsfc.nasa.gov/firemaps/ ?2006021-2006030).

Differences between the air masses originating from desert and savannah regions can be observed on the vertical profiles of relative humidity (Fig. 3). The values of RH are larger than 50% for the highest layers whereas the dust layers below are significantly dryer (RH< 30%). Note that the two upper layers with likely smoke aerosol can also be observed on the RH profiles.

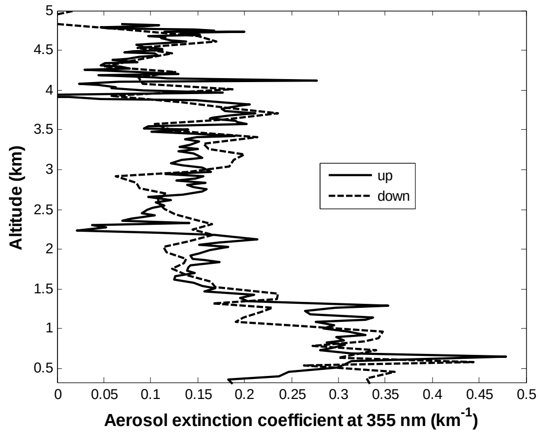

Fig. 2. Vertical profile of the aerosol extinction coefficient at 355 nm retrieved from horizontal shooting. Profiles are given for the ascent (up, La Tapoa) and the descent (down, Niamey) of the ULA.

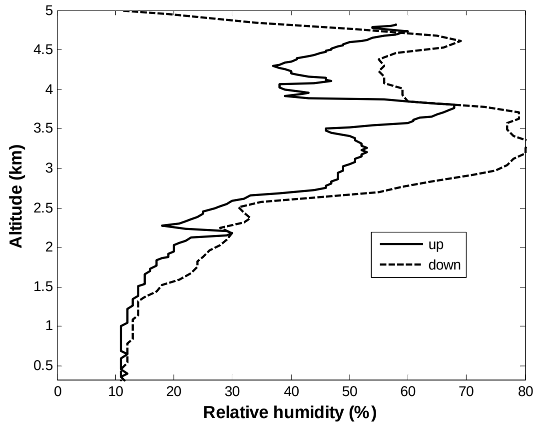

Fig. 3. Vertical profile of the relative humidity measured during the ascent and the descent of the ULA.

The vertical profiles of the aerosol scattering coefficient at 880 nm retrieved from the scatterometer during the ascent and the descent are given in Fig. 4. The same vertical structures to those retrieved from horizontal lidar measurements can be observed. The amplitude of the signal ratio between the lower (dust) and upper (biomass burning) aerosol layers is more marked in the near infrared than in the ultraviolet. This is consistent with the weak spectral dependency of the scattering or extinction properties for the dust aerosols as opposed to biomass burning aerosols for which they decrease with increasing wavelength[5].

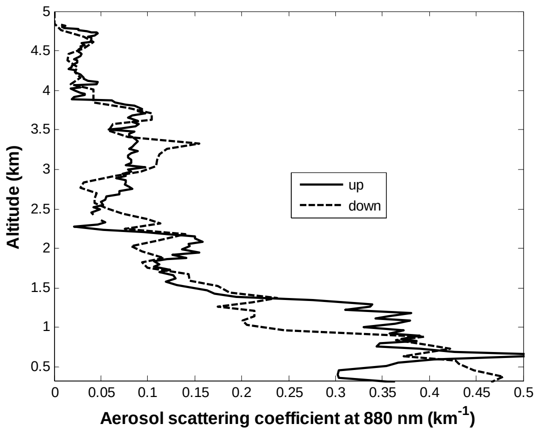

Fig. 4. Vertical profiles of the aerosol scattering coefficient at 880 nm.

Using the lidar-derived aerosol extinction profile from horizontal measurements allows us to retrieve directly the aerosol backscatter coefficient from the nadir looking profiles taken in the immediate vicinity of the horizontal measurements,. Above La Tapoa (ascent) and Niamey (descent), the mean values of the ten closest nadir lidar profiles are used.

The BER can then be assessed against the altitude as shown in Fig. 5. On the vertical profile corresponding to the ascent above La Tapoa, one observes a significant evolution of the BER between the desert and biomass burning aerosol layers. The mean values of the BER decrease in altitude from ~0.02 sr^{-1} to 0.007 sr^{-1}. The relative uncertainty that has been assessed on the lidar-derived BER is ~25%.

On the vertical profile corresponding to the descent above Niamey, the same mean value for the biomass burning aerosols is found whereas for the desert aerosols this value seems lower and close to 0.012 sr^{-1}. As mentioned previously, the airmass origin containing the desert aerosols changed between the measurements performed above La Tapoa and Niamey. The nature of the desert aerosols may thus be different. Nevertheless, there are also anthropogenic aerosol sources at Niamey and the aerosols trapped in the lower layers can be a mixture between mineral dust and combustion aerosols from fossil fuel and wood fires. This mixture can lead to a significant reduction in the BER.

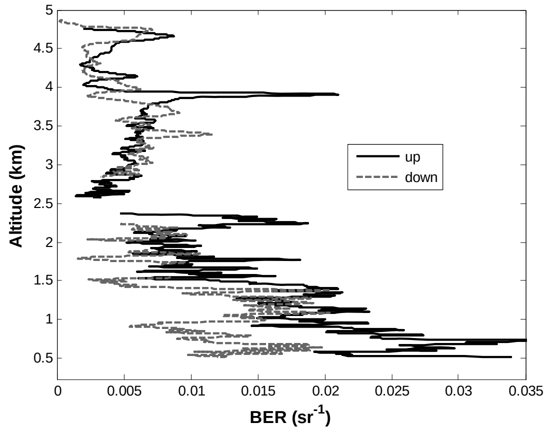

Fig 5. Vertical profiles of the backscatter to extinction ratio (BER) retrieved from the airborne lidar above La Tapoa (up) and Niamey (down).

The BER values found in the lower layers seem consistent with the literature. During SHADE (Saharan Dust Experiment), BER values of 0.024±0.007 sr^{-1} at the wavelength of 532 nm were found for the desert aerosols above the marine boundary layer of the tropical Atlantic Ocean[6]. From sun photometer measurements of the AERONET network (http://aeronet.gsfc.nasa.gov/) BER values of 0.023 sr^{-1} and 0.016 sr^{-1} at 550 nm were found for the desert and biomass burning aerosols, respectively.[7] Dulac and Chazette[8] found an equivalent BER of 0.017 sr^{-1} at 532 nm for a multilayer structure with desert, anthropogenic and marine aerosols over the Mediterranean. Mattis et al.[9] used the Raman lidar technique to measure the BER value of elevated dust layers during two episodes over Germany. They report BER values between ~0.013 and 0.020 sr^{-1} at 532 nm. For Asian dust over Japan, Liu et al.[10] and Murayama et al.[11] also report layer-averaged BER in ranges 0.018-0.024 and 0.022-0.025 sr^{-1}, respectively, at 532 nm.

BER values are not available for savannah biomass burning aerosols. For anthropogenic aerosols, a value of about 0.014 sr^{-1} at 532 nm has been found in Paris area within the framework of the ESQUIF (Etude et Simulation de la QUalité de l'air en région Ile-de-France) program[12]. Aerosols were mainly resulting from the automobile traffic. Stronger values of about 0.028 sr^{-1} have been obtained in the French Alpine valleys in winter when the aerosols are mainly resulting from wood and fossil fuel combustions[2].

4. CONCLUSION

We have implemented a light airborne lidar system on a ULA platform which was operated during the dry season in the Sahel. The coupling between horizontal and vertical lidar measurements allowed an assessment of the BER of the various aerosol layers present above Niamey and southwestern Niger. Two aerosol types have been identified: desert dust in the lower layer and biomass burning aerosols in the upper layers. The first one came from the North-North-East (Tenere) and the second one from the South-South-East (Benin and Nigeria). A significant difference was found between the BER of desert dust and biomass burning aerosols with values of 0.02 and 0.007 sr^{-1}, respectively, at the emitted wavelength of 355 nm. This is a first assessment for biomass burning aerosols from savannah fires, and values look significantly smaller than those reported for other anthropogenic aerosols. Such a variation of the BER value in the column can have a considerable implication on the error budget of the vertical profiles of the aerosol extinction coefficient that will be retrieved from the lidar system of the spaceborne mission CALIPSO, if constant BER values were used for its profile inversions.

5. ACKNOWLEDGMENTS

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