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Preliminary properties of Saharan aerosol over Tamanrasset (Algeria)

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Abstract
This preliminary study was carried out to present the desertic aerosol and the associated characteristics over Tamanrasset (Algeria) and their chemical composition. Two kinds of data were used: data of an international field campaign, combined data from sunphotometer and optical particle counter, which was conducted in February-November 2006 under the African Monsoon Multidisciplinary Analysis (AMMA) framework; and data (October 2006-January 2009) from a sunphotometer which was set up at Tamanrasset (Algeria) by the Izaña Atmospheric Research Center (Spain) in collaboration with l'Office Nationale de la Météorologie (Algeria). This study allowed to characterize this area of Sahara by: a) a bimodal granulometric distribution largely dominated by the coarse mode; b) a dominant component in Si, Al and Fe; c) a discrimination of two seasons: autumn-winter, characterized by low Aerosol Optical Depth (AOD) and high Angstrom Exponent (AE) and spring-summer, with strong and frequent mineral dust storms, characterized by high AOD and low AE.

Keywords: Aerosol optical depth, Angstrom exponent, aerosol distribution, chemical composition

Introduction
The atmospheric aerosols are among the essential components of the atmosphere. We define an aerosol as the suspension of solid and/or liquid particles in a gaseous environment, size generally included between 10^{-2} and 10^{2} µm and of very varied chemical nature [1] presenting a falling speed in normal conditions [2]. As one of the important components of the earth atmosphere system, aerosol plays an extremely important role both in the global climate change and biogeochemical cycle [3, 4]. These particles are crucial in the radioactive balance of the earth, because of their optical properties; they diffuse or absorb the solar and terrestrial radiation [5]. They are also involved in the hydrological cycle through their interactions with clouds [6].
The Sahara is one of the most interesting regions for aerosol studies, because on the one hand, emitted by arid surfaces of the earth; it represents the main component of the total mass of aerosol produced per year. The Sahara is the world's largest source of Aeolian soil dust [7-9]. Between 30% and 50% of mineral dust suspended in the atmosphere have as a source the Sahara and desert areas nearby [10]. On the other hand toxicological studies showed their role in some patients lung function, the release of asthma attacks and the rise of the number of deaths due to cardiovascular [11].
The present paper presents an overview of the aerosol observations performed at the Tamanrasset between February and November 2006, and AERONET data obtained during 2006 and 2009. Aerosol volume size distributions, chemical composition, aerosol optical depth, and Angstrom exponent are analyzed in order to characterize the Saharan aerosol.

2. Materials and methods
2.1. Sampling site and instruments
Tamanrasset is located in the middle of the Sahara in Algeria, in the heart of the Ahaggar massif at 1370 m above the mean sea level and 65 km south of the tropic of Cancer. This region is under the influence of the

Mediterranean weather for the most part of the year, and is affected by the West African monsoon during a short period in the summertime [12, 13].
Aerosols are now widely monitored by using various instruments in Tamanrasset site (22.79°N, 5.53°E). Two kinds of instruments were used: a continuously running instrument (sunphotometer) and an operator dependant instrument (optical particle counter). These instruments have been operated by the AMMA (African Monsoon Multidisciplinary Analysis) team during 9 months, from the 20th of February to 22th of November 2006. At the end of September 2006 until January 2009 a sunphotometer was set up at Tamanrasset by the Izaña Atmospheric Research Center of Spain in collaboration with National Weather Office of Algeria.
The sunphotometer (Model: CIMEL CE-318, Column-integrated daytime measurements, 6 channels (440, 500, 670, 870, 936 and 1020 nm), Narrowband (20 nm), Spheroid Almucantar algorithm for size distribution and SSA retrieval, Uncertainty: <0.01 for AOD and <0.03 for SSA) measurements represent Aerosol Optical Depth (AOD) and microphysical properties of aerosols integrated over the whole atmospheric column.
The optical particle counter (Model: GRIMM 108.0, Sampling 4 m from the surface, 15 classes for 0.15µm < r < 10µm, Time resolution: 6 s, Uncertainty: <3% in max. range) measures the concentration of particles in 15 size bins between 0.15µm and 10µm of radius at near ground level.

2.2. Aerosols optical properties
The intensity of the direct solar radiation incident is attenuated by the atmosphere by a factor $e^{-\tau_{ext}}$ where $\boldsymbol{\tau_{ext}}$ (no unit) is defined as the aerosols optical depth (AOD) directly measured by the sun photometer for six wavelengths (340, 440, 500, 670, 870, 1020 nm). The aerosol optical depth (AOD) is defined as the optical depth due to extinction by the aerosol component of the atmosphere. Aerosol optical depths typically decrease with increasing wavelength and are much smaller for long wave radiation than for shortwave radiation. Values vary widely depending on atmospheric conditions.
The Angstrom exponent (α) is inversely related to the average size of the particles in the aerosol: the smaller the particles, the larger the exponent. Thus, AE is a useful quantity to assess the particle size of atmospheric aerosols. α>1 is mainly determined by fine mode, submicron aerosols, while α<1 are largely determined by coarse, supermicron particles [14]. AERONET (Aerosol Robotic Network) provides values of the AOD for five wavelengths (440, 500, 670, 870 and 1020 nm).
AERONET was initiated by NASA Earth Observing System (EOS) in Africa and expanded rapidly with the support of many local governments and institutions [15]. The AERONET consists of a worldwide network of sun photometers that measures the optical properties of aerosols [16]. It also delivers a series of results from different inversion algorithms [17] in terms of particle size, refractive index, aerosol phase function and the aerosol asymmetry factor. The AERONET inversion retrievals represent a wide number of parameters and characteristics that are important and provide powerful information for understanding column integrated aerosol properties and for comprehensive interpretation of the optical aerosol regime. Several inversion algorithms for *ground* measurements [18] or space [19] have been proposed using the Mie theory and assuming spherical particles and homogeneous. AOD is both particle size and wavelength dependent [20]. Microphysical and optical properties are obtained by "Almucantar inversion" from sun photometer data [19]. Inversion of solar almucantar data is a simple and practical method of obtaining aerosol size distributions.

2.3. Theoretical background
2.3.1. Angstrom exponent α
The Angstrom exponent α represents the slope of the wavelength dependence of the AOT in logarithmic coordinates**.** The dependence of the optical depth to the wavelength is given by the Angstrom exponent α [21]. The angstrom exponents (α) have been calculated with respect to the filter channels at λ_1=440 nm and λ_2=870 nm of a Sunphotometer

$$\alpha(\lambda_1\text{-}\lambda_2) = -\left[\frac{\log(\mathrm{AOD}(\lambda_1)/\mathrm{AOD}(\lambda_2)}{\log(\lambda_1/\lambda_2)}\right] \quad (1)$$

2.3.2. Aerosol lognormal distribution
Standard statistics based on normal distributions are frequently not suitable for most airborne particle (aerosol) size distributions. Generally, lognormal distributions tend to be the best fit for single source aerosols. Among several statistical laws of the literature allowing to model the size distribution of various types of aerosols [24,

25], it has been observed and proved that atmospheric aerosols can be described rather well with a set of log-normal distribution functions [23, 24] .
The variation of the number of particles n(r) according to the radius r for a single mode is given by the equation (3)**:**

$$n(r) = \frac{dN}{d\ln r} = \frac{n_0}{\sigma_{0\sqrt{2\pi}}} \exp\left[-\frac{(\ln r - \ln r_0)^2}{2\sigma_0^2}\right] \quad (3)$$

Where n(r) is the number of particles of the natural logarithm of the radius between ln r and lnr +dln r; the differential quantity dN(r) expresses the number of particles having a radius between r and r+dr, per unit volume, according to the distribution function, n(r); r_0 being the modal radius, σ_0 the standard deviation of the natural logarithm of the radius (the width of the distribution) and n_0 is the number of particles in the considered mode.
It is not always appropriate to focus on the distribution of the number of particles. The logic of representing measured aerosol size distributions as combinations of log normally distributed "modes" (nuclei, accumulation, and coarse) was laid out in a seminal paper by [25]. The calculation of optical properties for lognormal distributions was discussed by [26], who show the logic of working with the volume (not the number). The distribution of the surface is more appropriate if one is interested in chemical reactions, in which aerosols are involved. If one seeks to assess the aerosol mass the distribution of volume V is interesting. Equation (4) expresses the idealized size distribution in function of the three parameters V_i, r_i and σ_i for each mode:

$$\frac{dV}{d\ln r} = \sum_{i=1}^{n} \frac{V_i}{\sqrt{2\pi}\ln\sigma_i} \exp\left[-\frac{1}{2}\frac{(\ln r - \ln r_i)^2}{(\ln\sigma_i)^2}\right] \quad (4)$$

with $\mathbf{V_i = A_i\sqrt{2\pi}\ln\sigma_i}$
The distribution $\frac{dV}{d\ln r}(r)$ it is that calculated from the parameters of the total modal volume V_i, the modal radius r_i and the modal standard deviation $\boldsymbol{\sigma_i}$ for each of the n modes.
The amplitude of each mode is denoted by the parameter A_i. Particle volume concentration is estimated by integrating the number size distributions measured by the optical particle counter, considering spherical particles for number to volume conversion. More information on this topic can be found in these following references: [27-30].

2.4. Analysis of chemical components of aerosols
The mineralogical and/or chemical composition of the atmospheric aerosols is very variable and depends at the same time on the transmitting source of the particles and atmospheric dynamics. Aerosol samples were collected at 1 m above the ground surface. Figure 1 shows idealized mass distribution and chemical composition of particulate matter according to atmospheric fine particles and coarse particles classification (Seinfled and Pandis, 1997).

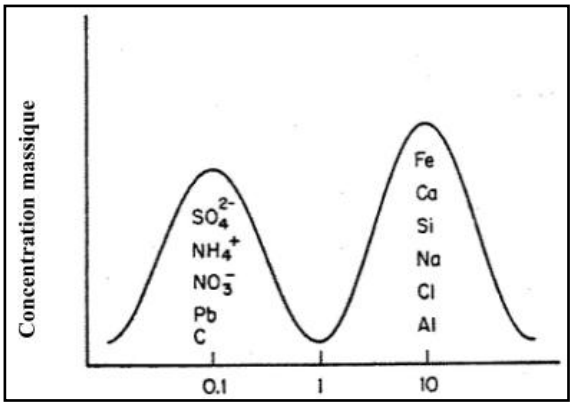

Figure 1. Idealized mass distribution and chemical composition of aerosols according to atmospheric fine particles and coarse particles classification (Seinfled and Pandis, 1997).

Daily dust samples were collected at Tamanrasset site for the period June 20th and November 21st, 2006. Particles with a radius greater than 0.2 μm are collected in Teflon filters. These filters are sent to "Laboratoire Inter-universitaire des Systèmes Atmosphériques" in France for the following chemical analyses: ICP composition of soluble components and metallic components by X-rays fluorescence. The results of their monthly average are shown by figure 3.

3. Results and discussion

3.1. Estimation of τ and α

Starting from the equations (1) and (2), with λ_1=440 nm and λ_2=870 nm, a statistical summary of the spectral AOD τ and the AE α is summarize in Table 1. Choice of the 440–870 nm wavelength range relies on the fact that these are highly accurate channels ($d\tau_\lambda$~0.01) of the AERONET sun photometers [16] and these channels are available in all AERONET instruments [30]. In this study, the values of Angstrom-exponent α were computed in the wavelength interval 440–870nm, using the AOD data of AERONET, applying the least-squares method to equation (1). AOD and AE statistics through the employed methods are reported in Table 1.

Table 1. Statistics of parameters for the year 2006-2009 evaluated from AERONET level 2 daily values

Parameters	Summer period		
	Mean	Std Dev	Range
AOD_{440}	0,402	0,222	0,077-1,743
AOD_{870}	0,339	0,220	0,053-1,723
$AE_{440-870}$	0,381	0,238	-0,105-1,042

Parameters	Winter period		
	Mean	Std Dev	Range
AOD_{440}	0,126	0,108	0,017-0,913
AOD_{870}	0,100	0,075	0,009-0,862
$AE_{440-870}$	0,638	0,313	0,001-1,364

From Tables 1 it is observed that the Angstrom exponent reached a maximum value in winter (~1.36) and minimum value in summer (~-0.10), which suggested that the fine particles contributed a much larger aerosol fraction during winter and the coarse particles were main parts during summer. The mean Angstrom exponent in summer period is 0.38 when the average AOD exceeds 0.33, indicating that aerosol events at this site are dominated by coarse particles (radii>1μm).

The aerosol optical depth values have been also found to be appreciably high during the summer period with the upper range for the AE value for the filter channel 440 nm being reported as 1.743 (Refer Table 1).

Figure 2 illustrates AOD 440 nm and AE 440-870 nm monthly mean values evaluated from AERONET level 2.0 at Tamanrasset between September 2006 and February 2009.

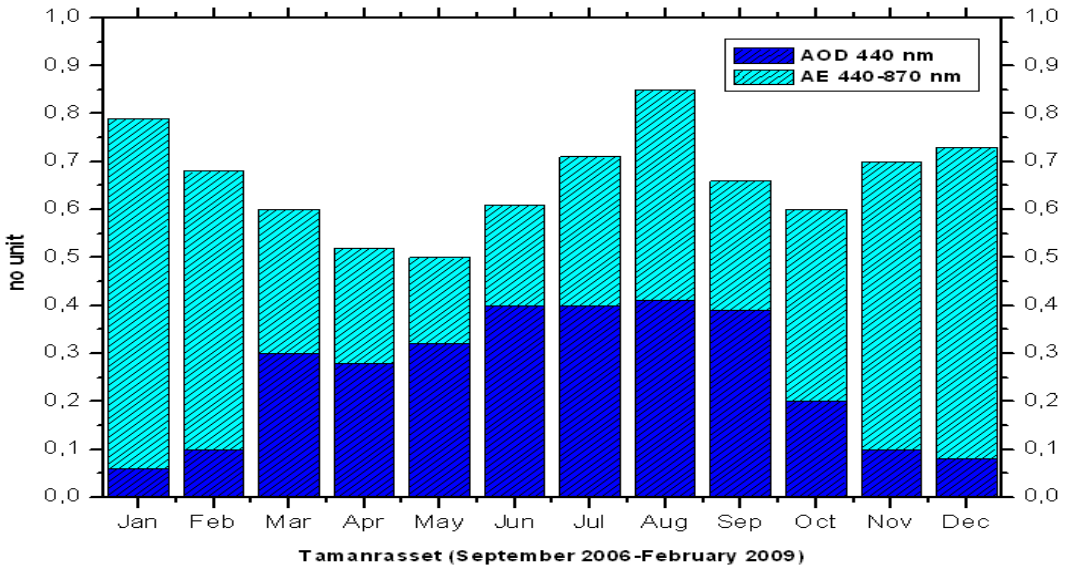

Figure 2. AOD and AE Monthly mean values evaluated at Tamanrasset (September 2006-February 2009)

The mineral storms of dust are frequent in summer-time while one observes the low AOD and the high values of the AE in winter time. Except for January marked by AE>0.7 translating a predominance of small particles, the whole of the other months is characterized by AE<0.7 and thus a predominance of large particles (r>1µm). A detailed analysis of AOD and meteorological data during the study period allowed to discriminate two seasons: a cold and dry season (autumn-winter) characterized by low AOD and high AE and a hot and humid season (spring-summer), characterized by the strong and frequent mineral dust storms characterized with high AOD and low AE [32, 33].

3.2. Aerosols volume distribution

It represents the density function of logarithmic total volume of particles with a resolution of 15 classes with radius between 0.15 and 10 µm. It is an integrated quantity of the column of particles expressed in m^3 per m^2 of air surface. In the Hoggar region the distribution is often broad with two overlapping modes. This bimodal distribution is characterized by a fine mode and a coarse mode with respectively modal radii of ~0.05 µm and ~5 µm. Figure 3 (extract of [34]) shows a sample of the spectra of a typical bimodal volume distribution in Tamanrasset (one spectrum every 30 min from 0600 UT to 0700 UT on January 7, 2006, respectively red, green and blue).

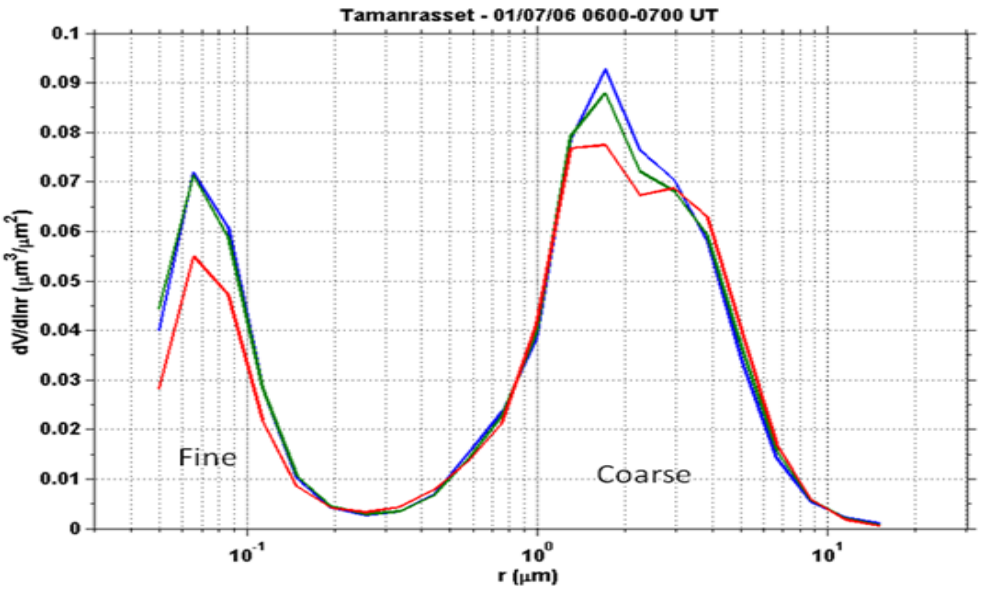

Figure 3. Sample of particle volume distribution measured at Tamanrasset (Algeria) on July 1st, 2006 (extract of [34])

3.3. Chemical composition of the aerosols

Despite the biogeochemical and climatic significance of Saharan dust, a little information is available on the mineral dust chemistry. Mineral particles usually display very complex element compositions [37]. Determination of the chemical composition of dust in the air is important relative to their effects on visibility biogeochemical cycles and human health. Also these last decades, many studies have focused on the sources of Saharan dust, with not very concordant results [36-40]. For more information on this topic refer to the study of [41]. Figure 4 shows results of analysis of samples between June 20th and November 21st, 2006 and revealed crustal elements from Saharan air mass dominated by Al, Ca, Fe, K, Mg, Mn, Na, Si and Ti.

Chemical composition of the Saharan aerosol shows that the dust is particularly rich in Si, Al and Fe which add up 82% of the mass concentration per m^3, and poor in P, Mn, Cr and Co. We note that Silicon is the prevailing chemical element of the desert mineral dust in Tamanrasset.

According to the researchers, the sand of the Algerian desert contains 71% of silicon, which constitutes the most important content in the world. In accordance with idealized model proposed by (Seinfled and Pandis, 1997) (refer Figure 1) the results of chemical composition agree with a station where coarse particle is the prevailing aerosol.

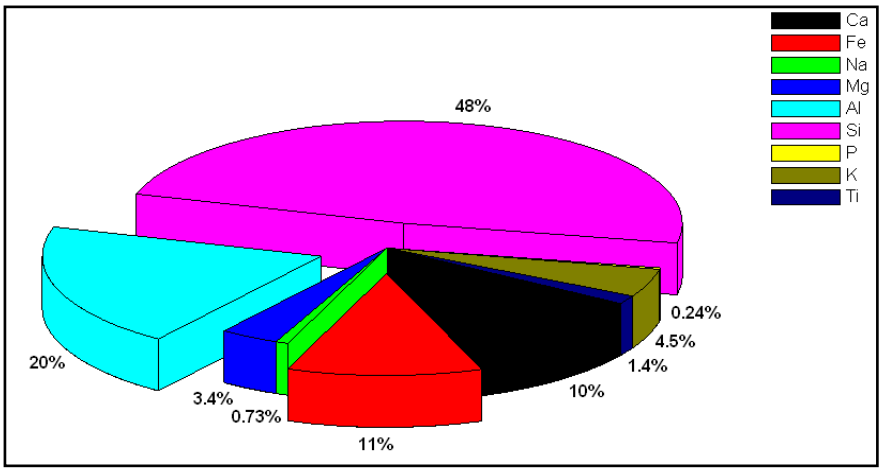

Figure4. Average distribution (%) of the biogenic salts between June 20th and November 21st, 2006

Conclusion

This work has been focused on the detailed analysis of desertic aerosol parameters over Tamanrasset (Algeria) during an international field campaign which was conducted in February-November 2006. In addition we also examined the AERONET data obtained between 2006 and 2009 to assess the chemical and optical properties of desert aerosols. The parameters analyzed were: Aerosol Optical Depth, Angstrom exponents, aerosol size distributions and chemical composition. The main results can be synthesized as follows:

a) The Algerian Sahara is impacted primarily by dust aerosol.

b) In most cases, the Angstrom Exponent is less than 0.7, and according to the classification of (Kaufman et al., 1994), this correspond to the presence of coarse particles, in accordance with typical desert aerosol properties.

c) Other measurements carried out at sites located in or near desert zones, have also highlighted the domination of the coarse mode particles accompanied by an increase in the values of the aerosols optical depth.

d) This area of Hoggar is modeled by bimodal lognormal size distribution peaking in the coarse mode ($r > 1$ µm).

e) The results of chemical composition agree with a station where coarse particle is the prevailing aerosol.

Finally both Aerosol Optical Depth and Angstrom exponent values show the behavior of a station where desert mineral dust is the prevailing aerosol and define the characteristic of the site. However, the characterization of Saharan aerosol type requires a long-term observed data and other parameters in order to improve our understanding of desertic aerosol, and this will be studied in detail in future works.

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