Detection of the distribution of size of the desert aerosols by multispectral method LIDAR (UV to IR), by using genetic algorithmes, compared with Chomette's model

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Abstract:

The aerosols constitute one of the principal sources of error in the forecasts of the climate, by the significant uncertainty which they introduce into the evaluation of radiative forcing. Their characterizations physics and optics constitute a challenge with which is currently confronted atmospheric research. During these research tasks, several methods of measurements were set including methods LIDAR (Light Detection And Ranging).

The interest of optic measurements of LIDAR teledetection is to give a direct access to the repartition of limited layers and to the optical extinction of atmospheric particles. The characterization of micro-physical properties of aerosols (size, concentration) had therefore less easy, because size distribution of aerosols interferes in an integral form with in a certain extent of the optical extinction by physical properties of the measurement.

Therefore, this has been realized in the case of less complex atmospheres (desert particles, acids, silica, fog, cloud).

The principal objective of our study is the detection of the distribution of size of the desert aerosols by multispectral method LIDAR, by using the model characteristic of Chomette.

Measurements of concentrations thus will be possible without any presentation of distribution contrary to other methods such as LIDAR (taking by impaction).

Keywords: *Desert aerosols, LIDAR, LIDAR (taking by impaction), Mie theory, Klett inversion, Chomette desert model.*

1. INTRODUCTION

The air which surrounds us is in the beginning made up of nitrogen (78%), oxygen (21%) and some rare gases (1%).But it contains also other substances from of which chemicals resulting from the human activity (heating, transport, industry…) and from natural phenomena (volcanos, decomposition of the plants…).Some of these substances can react between them and form in their turn other pollutants.

The aerosols are constitued of every fine particles in suspension in the atmosphere and they belong main by to terrestrial evaluation.The primaly aerosols are emitted directly as paticles. Their size is generally higher to the micron when they are produced mechanically and lower to the micron when they result from combustion process. The second aerosols, generally of sub-micronic size are issued of the transformation in particles of substances emitted in the atmosphere as gas form, either by the intermediary of the clowdy water drops . On a global everage, many million tons of aerosols are emitted every day by a multiplicity of sources, at the same time natural (volcanic, biological, desert, spray marine) and human (combustions industrial, dust, agricultural emissions), which induces a very great diversity of their properties. Among the components of tropospheric

aerosol, the desert aerosol emitted by arid surfaces of the sphere represents the main components, with a proportion of approximately 43 % [1] of the total mass of aerosol produced per year, confused natural and anthropogenic sources.
The contents of desert aerosol of the atmosphere are more variable and complex.
Properties and abundance of the particles can vary largely in space and in time. This great diversity and this variability are from several theoretical models, describing radiative parameters of the aerosols (absorption, diffusion and extinction coefficients ...). Among the most famous model, we have the well-known Chomette model.

II. THE DESRT MODELING OF AEROSOL CHOMETTE'S

Within the framework of a recent study of the cycle of the desert aerosol by modeling méso- scale, Chomette [2] was interested in the phenomena of transport and deposit and in their influence on the properties microphysics and radiative of this aerosol. The distribution in size of the emitted desert aerosol is influenced very little by the mineralogical composition of grounds Alfaro [3].The process of transport, even to long distance, does not assign the mineralogical composition of the aerosol as long as it is carried out in dry atmosphere Rahn [4] ,which implies a weak evolution of the complex index in the course of time.
In order to model the desert aerosol, a lognormal granulometric trimodal distribution was considered. Only one complex index of refraction characterizes the totality of mixture of particles.
These indices are borrowed from Volz [5] and Patterson [6] in the infra-red, and from Gram [7] in the visible one.
During transport in dry atmosphere, the granulometry of the desert aerosol evolves according to the phenomenon of sedimentation by gravity affecting mainly the large particles. The granulometric spectrum evolves then towards of the finer particles, as one moves away from the sources. Two granulometries obtained from insitu measurements D'Almeida [8] were selected in order to describe this behavior. The distribution "wind carrying dust " WCD) characterizes the desert aerosol transported above the continent after its rising, which excludes the presence only from largest the particles (they very quickly formed a deposit).The desert aerosol far from the sources is characterized by the distribution "background" (BG), a fine granulometry with few large particles compared to distribution WCD.
One second granulometry source included in this modeling, noted (A1) comes from the results from Alfaro [3] on the setting in suspension of the mineral particles out of blower, by using different types of ground (in particular of sahélian and Saharan origins).To supplement this granulometric description, a last distribution (A2) is deduced from A1 by modeling the sedimentation of the large particles of (A1) during transport far from the sources Chomette [2].

In order to answer to the preoccupation of public powers in health, the knowledge of the state of the atmosphere must be solved in time and space. For that, various instruments and systems are used in which optical method LIDAR [9] (Light Detection and Ranging) is the most important one.
An original LIDAR method, using a single wavelength, has been developed. It is based on a microanalyzer via X-Rays of impacted filters. This method allows access to the distribution of particle size, but it represents only taking his place.
To gain access to the geographical distribution of aerosols spatially and temporally and distinguish between small and big desert particles, we will use a multi-spectral LIDAR optical system which tends from IR to UV.
Indeed, we will try throughout this work to calculate the distribution of size of desert particles through the profile of the extinctions coefficients in terms of wavelengths taken from the Chomette model. This is based on the genetic algorithmes method.
To confirm the validity of our results, we will make a comparative study with that obtained Chomette model.

2- LIDAR PRINCIPLE

Aerosols clouds LIDAR (LNA) is an atmospheric instrument of teledetection, which makes it possible to measure the optical characteristics and microphysics of clouds and aerosols which are present in the atmospheric layer, it consists to send laser impulses in the atmosphere and to measure their backscatter versus time (Figure 1). The laser beam is diffused and absorbed at the same time by molecules (gas) and aerosols, contained in the atmosphere. The extinction increases with the quantity of aerosols and the concentration in molecules. A part of this light is backscattered towards the transmitter. In order to increase the solid angle of reception, a telescope placed coaxially to laser is used. The fact that the laser is pulsated allows a detection versus to time T and thus of distance z between the laser and the measurement point *(z=c.t/2)*, c being the speed of the light in the air).
The backscattered light intensity *I (z,λ),* with the wavelength λ and the distance z, has as an expression in the case of an elastic diffusion (by neglecting the multiple diffusion):

$$I(z,\lambda) = I_0(0,\lambda)\ {A_0}/{z^2}\ \beta(z,\lambda)\Delta z\chi(z,\lambda)\ \exp\left(-2\int \alpha_{ext}\ (z,\lambda)\ dz\right) \qquad (1)$$

- $I_0(0,\lambda)$ is the light intensity emitted with the wavelength l by the laser.
- A_0/z^2 is the solid angle of acceptance of the optical receiver (A_0 is for example the surface of effective detection of the telescope).
- $\beta(z,\lambda)$ is the total volume coefficient of backscatter.
- $\Delta z = c\Delta\tau/2$ with c is speed of light and $\Delta\tau$ the impulse duration of the laser.
- $\chi(z,\lambda)$ is the detection effectiveness.
- $\alpha_{ext}(z,\lambda)$ is the coefficient of the whole atmospheric extinction total.
- $\exp\left(-2\int \alpha_{ext}(z,\lambda)dz\right)$ Expresses Beer-Lamber law on the light propagation between 0 and z.

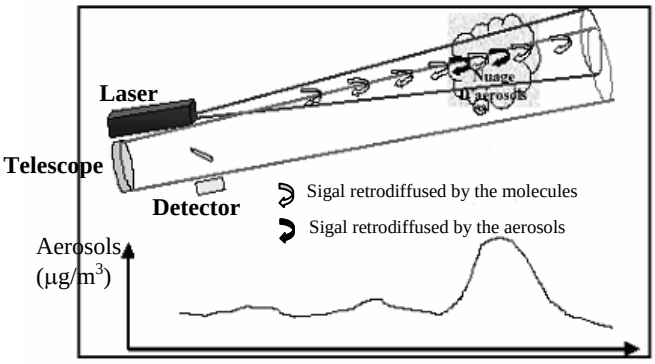

Fig.1 General diagram of the LIDAR

3- MEASUREMENT BY LIDAR

In order to give the detailed information on the distribution of particles size, their concentration and their composition, we give various methods:

3-1 LIDAR taking by impactions

The method of impaction taking [10] uses LIDAR method as well as electronic microscopy scan (EMS) and a micro-analyzer by X -ray, in order to determine the distribution and the nature of the particles. This method enables us to have the normalized distribution, the concentration and the composition of the particles on the ground, but it does not give access to the geographical distribution of aerosols. In fact it is representative of their taking place.

3-2 LIDAR measurement at distance [11]

This monospectrale optic method allows us to know the geographical repartition of aerosols as well as their dynamics, like their dynamics versus distance and time at the whole atmospheric layer. It allows to cartography in three dimensions the concentration in atmospheric aerosols and to follow its temporal evolution.
The coefficients of extinction and backscatter can be rewritten as well:

$$\alpha_{ext}^{Aero}(\lambda) = \int \sigma_{ext}^{Aero}(\lambda, r)\, \rho(r) dr = \int \pi . r^2 Q_{ext} \rho(r) dr \tag{2}$$

$$\beta_{Aero}(\lambda) = \int \sigma_{back}^{Aero}(\lambda, r)\, \rho(r) dr = \int \pi . r^2 Q_{back} \rho(r) dr \tag{3}$$

Where: α_{ext}^{Aero} and β_{back}^{Aero} : are respectively the effecacious sections of extinction and retrodiffusion. They are calculated by using the theory of Mie [12]:

$$\sigma_{ext}^{Aero} = 2\pi / K^2 . \sum_{p=1}^{+\infty} (2p+1). \mathrm{Re}(a_p + b_p) \tag{4}$$

$$\sigma_{back}^{Aero} = 2\pi / K^2 \left| \sum_{p=1}^{+\infty} (2\pi + 1)(-1)^n (a_p + b_p) \right|^2 \tag{5}$$

Diffusion coefficients a_p and b_p are defined by Ricatti-Bessel and Hankel function.
Q_{ext} and Q_{back} : are respectively the effectiveness of extinction and retrodiffusion.
$\rho(r)$: it is the predifined distribution of the atmosphere particles which can be written by an unspecified function of distribution.
For the aerosols, the distributions suggested are: the Djermendjian distribution [13] or lognormal distribution [14].
But with this LIDAR traditional technique with only one wavelength it is not possible to go up with the concentration of the various atmospheric aerosols types. For that it is necessary to use multispectral LIDAR systems, more difficult to implement.

3-3 Method using many wavelengths

This method is a technique of new inversion, based on the method of the genetic algorithms, in order to determine the distribution of size of the aerosols and the distribution of the refraction indexes starting from LIDAR measurements with several wavelengths without hypothesis on the distribution form where it is was the case of the precedent method.
$\rho(r) = N_0 . g(r)$ where N_0 is whole density of particle and $g(r)$ is function of normalized probability distribution.
If $g(r)$ is supposed to be limited inside a defined interval (r included between r_{min} and r_{max}), the integral equation (2) can then be approximated by a sum on a discrete number M of rays:

$$\alpha_{ext}^{Aero}(\lambda) = N_0 \sum_{i=1}^{M} \overline{K_{ext}(r_i, \lambda)}\, f(r_i) \tag{6}$$

Where:

$$\overline{K_{ext}(r_i, \lambda)} = 1/\delta r \int_{r_i - \delta r/2}^{r_i + \delta r/2} K_{ext}(r, \lambda) dr \tag{7}$$

is the average of the function on the interval of width δr centred on r_i and $f(r_i)$ is the fraction of the particles in the same interval.

$$K_{ext} = \pi r^2 Q_{ext}^{Aero}(r, \lambda) \tag{8}$$

In the same way, the coefficient of backscatter can be written as:

$$\beta^{Aero}(\lambda) = N_0 \sum_{i=1}^{M} \overline{K_{back}(r_i,\lambda)}\, f(r_i) \tag{9}$$

Where:

$$\overline{K_{back}(r_i,\lambda)} = \frac{1}{\delta r} \int_{r_i-\delta r/2}^{r_i+\delta r/2} K_{backt}(r,\lambda)dr \tag{10}$$

$$K_{Back} = \pi r^2 Q_{Back}^{Aero}(r,\lambda) \tag{11}$$

The number M of intervals used to solve the equations (6) and (9), depends on the number N of wavelengths during measurement. It is equal, to the maximum, the double of this number (to each wavelength are associated two parameters: (α_{ext} and β). The difficulties of the inversion of the equations (6) are from the multiple values for the nucleons of diffusion and solutions which are not single. In order to stabilize the solutions for areas specific of data, we impose that the solutions are positive.

In order to solve the equations (6), this one will be written according to the following matrix system:

$$\begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ . \\ \\ \\ . \\ \alpha_N \end{bmatrix} = N_0 \cdot \begin{bmatrix} K_1^1 & . & . & . & . & . & K_1^M \\ . & & & & & & \\ . & & & & & & \\ . & & & & & & \\ . & & & & & & \\ . & & & & & & \\ . & & & & & & \\ K_N^1 & . & . & . & . & . & K_N^M \end{bmatrix} \cdot \begin{bmatrix} g_1 \\ . \\ . \\ . \\ . \\ . \\ . \\ g_M \end{bmatrix} \tag{12}$$

Experimental data (α_{ext} and β) and the first calculation of the functions (7) allow to solve this matrix system. The used statistical approach,

based on the genetic algorithmic which is the used step in several problems of optimization. It allows to be free of the direct treatment of errors.

The initial population is a whole of vectors of distribution size $[\rho_i]$, where each individual ρ_i is a distribution of discredited size on M different sizes of particles. The uniform initial population is generated in a random way and the number of individuals should not remain fixed throughout the procedure.

The genetic algorithm advances from population to population by using standard genetic generators until the criterion of optimization is satisfied.

4- RESULTS AND DISCUSSIONS

This study is devoted to several recalls concerning the general properties of the aerosols, before to be concentrated on the desert aerosol as the aim of our work. We have tried to give a presentation of size distributions of aerosols desert by multispectral LIDAR method, by using laser source going from UV to mean IR. Concentration measurements will be then possible without any hypothesis contrary to LIDAR method (mono-wavelength).

4-1 Profile of extinctions coefficients

In order to determine the coefficients of extinctions versus to wavelengths, rough LIDAR signals are treated by multiplying them by z^2 (distance), then by taking the Napierian logarithm. Thus the obtained function will be then used in the Klett inversion [15].

However, concerning our work, we take the profile of the extinctions coefficient directly from Chomette model versus wavelengths (figure 2).
Wavelengths should be well chosen. Because it is necessary that they are close to dimensions of the particles so that the simulation step (the research of the distribution of size of desert particles) will be more sensitive. For an interval wavelengths (for example fixed by the experience), the simultaneous use of $\alpha_{ext}(\lambda)$ and $\beta(\lambda)$ gives access to big size interval. Consequently, the used spectral have been fixed in the following interval: (λ = 0.1, 0.5, 2, 5 and 9 μm).

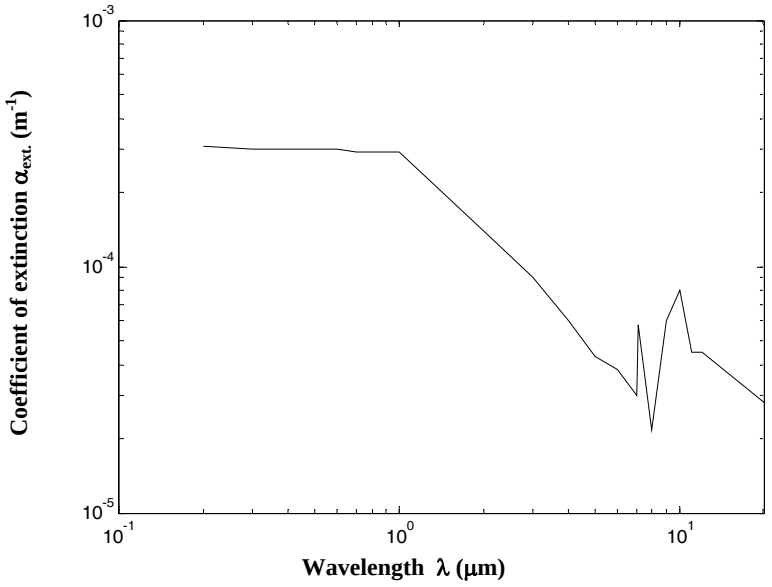

Fig. 2 Coefficient of extinction versus wavelengths [2]

4-2 Effectiveness factors of extinctions

The first results of validation of the estimate of the distribution of size of the aerosols by the multispectral LIDAR data based on the genetic algorithms have been very satisfactory. The effective sections (factors of effectiveness) of extinction and backscatter are thus calculated versus ray, for each type of particle, by using the Mie diffusion theory (for the particles at close symmetry to the spherical symmetry (figure 4). On the other hand, only one set of complex indices of refraction (figure 3) characterizes the mixture of particles entirely.These indices are borrowed from Volz [5] and from Patterson [6] in the infra-red, and from Grams [7] in the visible.

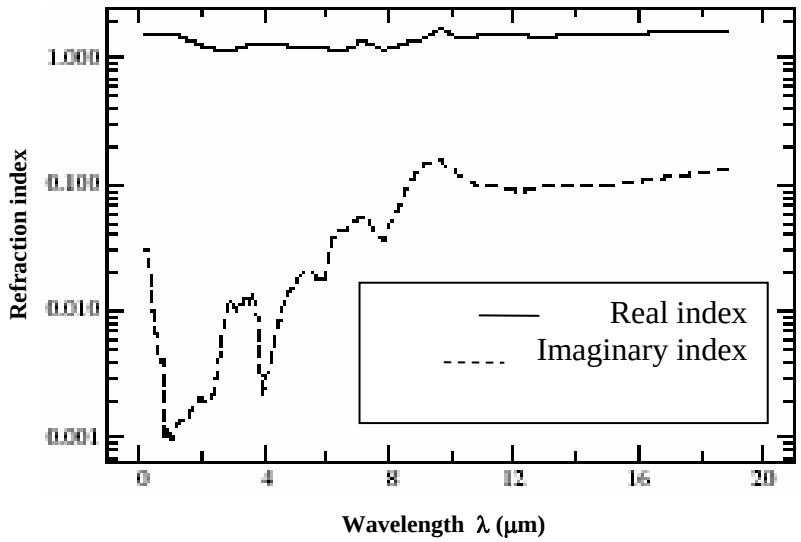

Fig.3 Indexes of refraction characterizing the fine modes of particles used in the modeling of Chomette. [2]

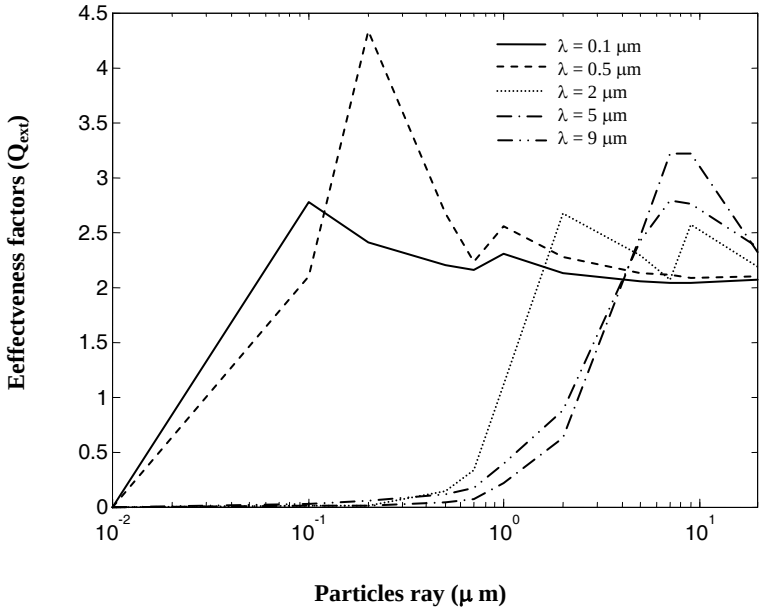

Fig.4 Effectiveness factors of extinctions of the desert particles calculated by the theory of Mie, versus wavelengths (λ = 0.1, 0.5, 2, 5 and 9 μm)

4-4 Distribution of size of desert particles

This whole optic LIDAR system (contrary to the method Taking by impactions), in which the interval of the wavelengths is reduced to 5 (as indicate previously), allows to determine very easily the principal modes of the distribution of size of the desert particles, this with an acceptable precision. Indeed, according to the (figure 5) (which represents the comparison between distribution of size obtained by our multispectral LIDAR with those of first values of Chomette model, which establishes the optical parameters of the desert aerosols), we notice that the results are very close and show a good correlation.

The two curves present each one a threshold for a ray of 0.01 μ m which corresponds to only one type of distribution of desert particles, one can compare them to a Gaussian curve, which enables us to deduce the standardized distribution directly *g(r)* by calculating the median ray (r_i) and the average standard deviation (ε_{quad}).

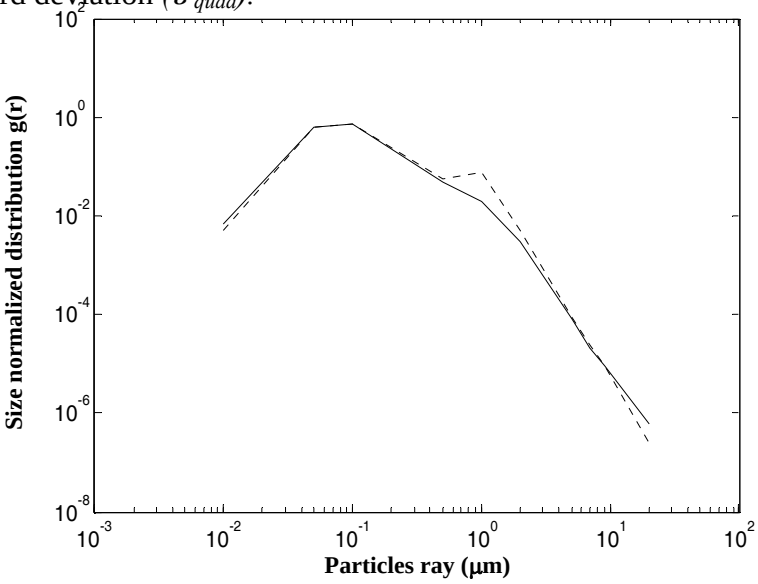

Fig.5 Comparison of size normalized distribution g(r) of desert aerosols, imposed by Chomette and al (continues line) and obtained by means of genetic algorithm (dotted line)

Finally For the calculations of errors of our simulation result based on the genetic algorithms, first we make the inversion so we can reproduce the coefficients of extinctions from the size distribution found, then to compare them with Chomette model (figure 6).

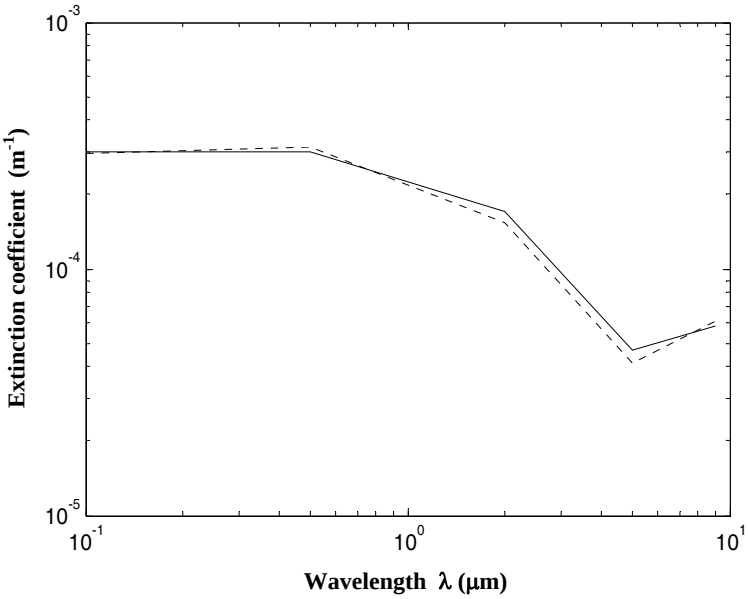

Fig.6 Extinction coefficient of given by Chomette and al model (continues line) and calculated (dotted line) from the distribution of size (fig IV.4) given by the genetic algorithms method.

5- CONCLUSION

LIDAR method allows then makes to characterize with quantitative manner gaseous pollutants, and also the urban and desert aerosols in chemical composition, distribution of size and finally in concentration.

throughout research, several methods of measuring desert aerosols by LIDAR have been implemented.

First of all,a method using a single frequency LIDAR coupled with microanalyzer X-Rays impacted filters, provide detailed information on the concentration and composition of atmospheric desert aerosols. But the takings do not provide access to geographical distribution. They are indeed, covering their places of taking. To increase the quality of information obtained by LIDAR and detect the distribution of size particle of desert particles only optical , we used a multi-spectral LIDAR system whose the profile of extinctions coefficients in terms of wavelengths has been taken for Chomette model, with consideration of the following wavelengths: *(λ* = 0.1, 0.5, 2, 5 and 9 *μm),* in order to have a diagnosis of small and big particles.

With regard to the interest of our work which was the detection of distribution of size of desert particle, the calculation was made by the method of genetic algorithms, with the aim of looking for a set of parameters, whose number was determined by 9 , these parameters represent rays of desert particles and this by comparing calculated coefficients extinctions with those of Longtin we we have used as an experimental measurements. The comparison did not give a perfect conformity because of errors due to the diversity of parameters to search by the calculation method

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