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Towards climatological study on the characteristics of aerosols in Central Africa and Mediterranean sites

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ABSTRACT

The atmosphere contains molecules, clouds and aerosols that are sub-millimeter particles having a large variability in size, shape, chemical composition, lifetime and contents. The aerosols concentration depends greatly on the geographical situation, meteorological and environmental conditions, which makes aerosol climatology difficult to assess. Setting up a solar photometer (automatic, autonomous and portable instrument) on a given site allows carrying out the necessary measurements for aerosol characterization. The particle microphysical and optical properties are obtained from photometric measurements. The objective of this study is to analyze the spatial variability of aerosol optical thickness (AOT) in several Mediterranean regions and Central Africa, we considered a set of simultaneous data in the AErosol RObotic NETwork (AERONET) from six sites, two of which are located in Central Africa (Banizoumbou and Zinder Airport) and the rest are Mediterranean sites (Barcelona, Malaga, Lampedusa, and Forth Crete). The results have shown that the physical properties of aerosols are closely linked to the climate nature of the studied site. The optical thickness, single scattering albedo and aerosols size distribution can be due to the aging of the dust aerosol as they are transported over the Mediterranean basin.

1. Introduction

Aerosols located in the troposphere have great importance due to diffusion and aging processes such as coagulation, humidification, scavenging by precipitation and gas to particle phase conversion (Schuster et al., 2006). These processes, combined with varying source strength and/or advection by local to synoptic meteorological processes, create a dynamic atmospheric constituent affecting climate, environment and public health (IPCC, 2007).

Ground-based aerosol remote sensing does not provide global coverage; however, its numerous spectral measurements of solar radiation are well suited to reliably and continuously derive aerosol optical properties (Masmoudi et al., 2003a). In spite of high temporal and spatial aerosol variability, there are a rather limited number of general categories of aerosol types with distinctly different optical properties which are associated with different sources and emission mechanisms (Mallet et al., 2003).

Aerosol optical thickness (AOT) at wavelength λ is the standard parameter measured by sunphotometers as those operating in AERONET (Holben et al., 1998). The AOT spectral dependence is mainly driven by the scattering efficiency and can be expressed by means of the classical Angstrom's equation ($AOT(\lambda) \sim \lambda^{-\alpha}$) (Angström, 1929). In the solar spectrum, the Angstrom exponent (α) is a good indicator of the dominant size of the atmospheric particles. AOT generated mainly by submicron particles are characterized by $\alpha > 1$ whereas supermicron aerosols would lead to $\alpha < 1$. As shown in numerous studies (e.g. Eck et al. (1999), Reid et al. (1999), Holben et al. (2001), Dubovik et al. (2002), Smirnov et al. (2000a), Pace et al. (2006) and Kaskaoutis et al. (2007)), the combined use of the AOT and α allows to distinguish between different aerosol types. As opposite to clean atmospheres ($AOT < 0.15$), dominated by oceanic aerosols, high values of AOT are characteristic of turbid atmospheres affected by biomass burning, dust plumes or urban pollution (Dubovik et al., 2002). Fluctuations of α reflect aerosol size distribution variations (Masmoudi et al., 2003b). The maximum value of α (equal to 4) corresponds to molecular extinction. Values near zero (or even negative) correspond to coarse-mode aerosols (sea spray and dust) indicating a non-AOT wavelength dependence, while values of α above 1.5 indicate significant presence of fine-mode particles (mainly smoke or urban aerosols). However, different aerosol types may be present in the air column at the same time, influencing the observed optical parameters (Chandra et al., 2004) and resulting into intermediate α values. Remer and Kaufman (1998)

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showed as well that relative humidity is a determining parameter for the size of aerosol particles. Hygroscopic growth at high relative humidities increases AOT (and reduces α), due to the enlargement of soluble particles such as sulfates (Levin et al., 1996).

Dust is the main component of the aerosol observed in the ocean (Ben-Ami et al., 2009; Duce et al., 1980; Prospero et al., 1989), and the Mediterranean Sea (eg. Becagli et al. (2012), Pandolfi et al. (2011), Viana et al. (2009) and Bergametti et al. (1989)), with the highest concentrations found over the equatorial and tropical North Atlantic. With the possible exception of sea-salt aerosol, mineral dust is globally the most abundant of all aerosol species in the atmosphere (IPCC, 2001). The major sources of contemporary mineral dust are found to be the desert regions of the Northern Hemisphere, in the broad "dust belt" that extends from the eastern subtropical Atlantic eastwards through the Sahara Desert (Prospero et al., 2002). Saharan dust is the main source of mineral dust in the world (Prospero, 1980; Prospero and Glaccum, 1981).

A climatological study of the optical thickness of aerosol determined by METEOSAT, and taken over a period of 5 years, Jankowiak (1992), has shown that the thick dust transfer over the North Atlantic appears mainly between the months of December and May. Prospero and Glaccum (1981) have found that the maximum concentration of aerosols occurs in the months of March and April in Cayenne (France) and Dakar (Senegal).

The present research work suggests the computation of the optical properties of aerosols from the sun photometer data. To analyze the spatial variability of optical thickness of aerosols, a set of simultaneous data at six sites was considered within the framework of the AERONET network: two sites in Central Africa; Banizoumbou and Zinder Airport (Niger), two sites in Europe; Barcelona and Malaga (Spain) and two sites in the Mediterranean basin; Lampedusa (Italy) and Forth Crete (Greece).

Firstly, a statistical study of the variations of optical thickness of aerosols τ_{ext} and Angstrom exponent α was carried out in the six selected sites during 2010. In a second step, the dependence of the optical thickness of aerosols with the Angstrom exponent was described. The inversion of the aerosol size distribution was examined not only to determine the particles mode, but also to compare the size of aerosols in the sites under study. Finally, the single scattering albedo (SSA) was derived from the radiation of the celestial surface. Besides, the weighted efficiency and volume of the radii were calculated for the different sites in order to characterize the parameters of absorption and diffusion according to the nature of aerosol.

2. Instrument and experimental sites

Aerosol optical properties in the entire atmospheric column are routinely observed within the AERONET (AErosol RObotic NETwork, Holben et al. (1998)) program. This is a federation of ground-based remote sensing aerosol networks established by National Aeronautics and Space Administration (NASA), (GSFC) (Goddard Space Flight Center), United States, and the Laboratory of Atmospheric Optics (LOA), Lille, France, and is greatly expanded by collaborators from national agencies, institutes, universities, individual scientists, and partners. The network consists of more than 500 globally distributed sun and sky-scanning automated radiometers. The standardized network procedures of instrument maintenance, calibration, cloud screening, and data processing allow for quantitative comparison of the aerosol data obtained at different times and locations (Holben et al., 1998; Smirnov et al., 2000). These instruments can only retrieve data during daytime, because they rely on extinction measurements of the direct and scattered solar radiation at several nominal wavelengths. The choice of detector material, the silicon and quartz can perform measurements of 300–1050 nm. Along with AOT observations, the AERONET aerosol retrieval algorithm (Dubovik and King, 2000) provides a complete set of column-effective aerosol microphysical parameters, including volume size distribution, refractive on index at four wavelengths (440, 670, 870 and 1020 nm) and fraction of spherical particles (Dubovik et al. (2006), also see description in Dubovik et al. (2011)), and 940 nm for measuring the water vapor content, while the other three positions can be adapted to the user wishes. The instrument is out of operation for some weeks while necessary yearly calibration is carried out. Consequently the data coverage in a given station is typically limited to 100–250 days per year. The typical uncertainty in the AOT measured by AERONET instruments ranges from 0.01 to 0.02 and is spectrally dependent with higher errors in the UV spectral range (Holben et al., 1998; Dubovik et al., 2000). This data is provided in three categories: (1) raw (level 1.0), (2) cloud-screened (level 1.5) following the methodology described by Smirnov et al. (2000), and (3) cloud-screened and quality-assured (level 2.0). In addition, using these microphysical parameters, the algorithm provides other column effective aerosol optical properties of interest to the scientific community, such as wavelength dependent Single Scattering Albedo SSA, phase function and asymmetry parameter, as well as integral parameters of bi-modal particle size distributions (Dubovik et al., 2002).

The intensity of the direct solar incident radiation is attenuated by the atmosphere by a factor of $e^{-\tau_{ext}}$ where τ_{ext} is defined as the optical thickness of extinction (unitless). Subsequently, we consider a fixed molecular radiation mitigation (correction of the Rayleigh diffusion and measurement of radiation in an «atmospheric window» where gaseous absorption is negligible) such that τ_{ext} corresponds only to aerosol extinction. Aerosol Optical Thickness (AOT) $\tau_{ext}(\lambda)$, dependent on the wavelength λ and the sum of thickness of optical absorption and diffusion is the integral between 2 altitudes z_{min} and z_{max} of the extinction coefficient, $\sigma_{ext}(z, \lambda)$ (m^{-1}):

$$\tau_{ext}(\lambda) = \int_{Z_{min}}^{Z_{max}} \sigma_{ext}(z, \lambda) dz \quad (1)$$

Since the optical thickness is typical to that of the atmospheric column, z_{min} and z_{max} are 0 and $+\infty$, respectively.

For a set of assumed spherical aerosols, the extinction coefficient, $\sigma_{ext}(z, \lambda)$ (m^{-1}) is written:

$$\sigma_{ext}(z, \lambda) = \int_0^{\infty} \pi r^2 Q_{ext}(m, r, z, \lambda).\, n(z, r) dr \quad (2)$$

where the extinction efficiency, designed by Q_{ext} (unitless), is strictly dependent on the refractive index m, the particle size r, the wavelength λ and altitude z. The size distribution of a set of particles, denoted by $n(r, z)$, is also, strictly speaking, dependent on altitude.

It is useful to introduce the effective extinction section; S_{ext} (m^2) produces the geometric section of the particle (equal to πr^2 for a spherical particle of radius r) and the efficiency factor of extinction, Q_{ext}.

The efficiency of aerosol to diffuse light (standardized by the mass of aerosols) has a maximum size of the aerosols of the order of wavelength. In the case of the solar spectrum, it precisely corresponds to the aerosol accumulation mode, while in «solar infrared», it corresponds to the coarse-mode aerosol. However, the anthropogenic aerosols have a radiative impact just as strong as that of natural aerosols because they are formed mostly of finer particles and therefore, interact more with solar radiation (visible) (Kacenelenbogen-Tilot, 2008).

Measuring the decrease of solar radiation by the atmosphere takes a simple technique of observation which is the direct vision