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Correlation between meteorological conditions and aerosol characteristics at an East-Mediterranean coastal site

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ABSTRACT

Since May 2011 Microtops sun-photometer measurements aiming to determine the aerosol optical depth (AOD) and its spectral dependence (Ångström exponent, $\alpha_{440/675}$) are performed routinely at the experimental station of the Port Said (Egypt) University (Lat.: 31.267°, Lon.: 32.26°, alt.: 21 masl). In parallel, an automated weather station is used to monitor the surface meteorological parameters (wind speed and direction, relative humidity, temperature, pressure…). This work uses the first year of original data (971 point measurements) with the double objective of determining the 1) seasonal variability of the aerosol at a site of the Egyptian Mediterranean coast, and 2) the potential correlation linking the aerosol characteristics to the surface meteorological conditions.

The 3-modal nature of the statistical distribution of the Ångström exponents measured during the year shows that 3 main types of aerosols can be distinguished. The most frequent observations (54% of all cases) correspond to fine particles associated with the largest (1.41 ± 0.23) $\alpha_{440/675}$ values. The probability of observing this fine aerosol increases in low wind conditions and when the air masses come either from the south-west, which is to say from the densely populated Nile delta, or from the north, which is to say from the more distant European pollution sources. This strongly suggests an anthropogenic origin for these fine particles. At the opposite side of the size-spectrum, coarse particles associated with the lowest mode of $\alpha_{440/675}$ (0.48 ± 0.22) predominate in 33% of the observations. The probability of observing them increasing in spring when the dry and strong (>6 m/s) desert-winds become more frequent suggests that these coarse particles are desert dust released by the wind erosion of arid surfaces. These particles are also responsible for the largest individual and monthly averaged (AOD_{500} = 0.50, in April) optical depths measured at the experimental site. Finally, by adding a supermicron marine component to the fine pollution aerosols advected from European sources, medium to strong winds from the north sector tend to increase the aerosol depth and decrease its spectral dependence. Besides the direct mixing of the coarse dust and fine pollution component, this effect is responsible for the occurrence of at least a part of the intermediate Ångström exponent ($\alpha_{440/675}$ = 0.91 ± 0.04) cases.

1. Introduction

One of the most important factors affecting the amount of solar radiation reaching the Earth's surface under cloudless sky conditions is the presence of aerosol particles (small particles either in solid or liquid state) in the atmosphere (Casiniére et al., 1997; Wen, 1996). More generally, atmospheric aerosols constitute one of the main sources of uncertainty in estimating Earth's radiation budget.

Depending on the nature of the process leading to their formation, aerosols can be categorized either as primary aerosols – when they are emitted directly under this form in the atmosphere (e.g., mineral particles or sea-salts released by

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the wind erosion of arid areas or of the sea surface, respectively) – or as secondary aerosol, when particles are formed by the condensation of super-saturated gas on condensation nuclei (Wen, 1996). Aerosol particles can be found in both the troposphere and the stratosphere but their concentration is particularly large within the atmospheric boundary layer. This concentration depends on a variety of factors such as location, atmospheric conditions, annual and diurnal cycles, presence of local sources (Stefan et al., 2006), and transport from distant sources as highlighted in many recent studies (e.g. Formenti et al., 2001; Pace et al., 2006; Meloni et al., 2007; Kalivitis et al., 2007; Santese et al., 2008)

Because they are able to scatter and absorb the solar and the terrestrial radiation, aerosols have a direct effect on the atmospheric radiative transfer. The smallest and most hydrophilic particles can also influence this transfer indirectly by acting as condensation nuclei and aiding in the formation of clouds (Eltbaakh et al., 2012). In the quantification of these effects aerosol concentration is one key parameter (Iorga and Stefan, 2005) but composition and size are also important. Indeed, according to the electromagnetic theory the aerosol scattering and absorbing properties at a given wavelength depend on the particles' size, complex refractive index, and, though to a lesser extent, shape.

For a good understanding of the aerosols' role in atmospheric processes, measurements in the near ground layer of the atmosphere where most anthropogenic aerosols are concentrated are desirable (Calvello et al., 2010). However, remote sensing of the aerosols from the ground and from space has also proven to be very informative. Indeed, the analysis of combined radiometric and in situ measurements shows in most cases a good correlation between surface and columnar aerosol properties (Chaudhry et al., 2007; Cheng et al., 2008; Choi et al., 2008; Gerasopoulos et al., 2007; Mukai et al., 2006; Schäfer et al., 2008; Schaap et al., 2009). This has led to an increased interest in expanding the coverage of integrated measurements into key areas representative of the different aerosol types and, thanks to the development of networks such as the AERONET or SKYNET, integrated observations of aerosol properties have become widely available. They provide useful information about local trends that are unobtainable through other means. For instance, measurements of the aerosol optical depth (AOD) provide estimates of the vertically integrated aerosol loading in the atmosphere (Calvello et al., 2010). Moreover the analysis of the AOD's spectral dependence, expressed under the form of the Ångström exponent α is precious for distinguishing different aerosol types. This methodology was used by Mukai et al. (2006) over an urban area in Japan, by both Pace et al. (2006) and Masmoudi et al. (2003) over sites of the western basin of the Mediterranean Sea, and more recently by El-Metwally et al. (2008, 2010, 2011) and El-Metwally (2013) for deriving the seasonal variability of the atmospheric aerosol loading over the megacity of Cairo. As a further support to aerosol characterization, inversions of radiometric measurements can also be performed to derive the particles columnar volume and/or number size distributions (Cachorro et al., 2008; Lyamani et al., 2005; Pavese et al., 2009; Perrone et al., 2005).

Being located at the crossroads of air masses coming from Europe, Asia, the Middle-East, and Africa, the Western and Eastern basins of the Mediterranean Sea are complex zones of mixing for aerosols of diverse origins. In this context, coastal areas are even more complicated because they are zones of direct interaction between the atmosphere, the land, and the ocean surface. In spite of their potential importance at the scale of the whole basins, the characteristics of aerosols present in these coastal areas and their correlation with local meteorological conditions have seldom been studied. The aim of this work focused on the southern coast of the Eastern Basin is to try and, at least in part, fill in this gap. More precisely, we analyze the results of the meteorological and Sun-photometer measurements performed in parallel for a full year (May 2011-April 2012) in the coastal city of Port-Said (Egypt). After assessing the seasonal variability of the measured AOD we propose to determine the characteristics of the main components of the aerosol in Port-Said and the factors controlling the magnitude of their contribution to the overall aerosol load. In particular, the influence of meteorological conditions such as wind direction, wind speed, and humidity will be investigated.

Practically, the work is organized as follows: Sec. 2 presents the characteristics of the experimental site, the instrumentation implemented on it, and the methods applied for the treatment of the raw measurements. Then, the results of the Sun-photometer measurements are presented and analyzed in the light of the meteorological conditions prevailing over the coastal area (Sec. 3).

2. Instruments and methods

2.1. The experimental site and its climate context

The climate of Egypt is governed mainly by its location in the north-eastern part of Africa on the margin of the largest desert in the world. Its latitudinal position, between 22° and 32° N places it firmly in the sub-tropical dry belt, although conditions on its northern coast are ameliorated by the presence of the sea. Globally, Egypt's climate can best be expressed as a contest between the hot and dry air masses of the Sahara and the cooler, damper maritime air masses from the north. In spring, eastward moving depressions are frequent. In the winter period the air masses coming from the north can bring rain with them in particular along the Egyptian Mediterranean coast on which Port Said is located at the northern entrance of the Suez Canal. The city is bounded by the sea on the north side, by the Manzal Lake from the west to the south, and by the Canal in the east (Fig. 1).

The experimental site selected for carrying out the meteorological and Sun-photometer measurements was the roof of the Faculty of Science in Port Said University (Latitude: 31.267°, Longitude: 32.26° and elevation: 21 m above mean sea level). The measurements began on May 2011 and are currently still going on. In order to be able to study the seasonal variability of both the aerosol characteristics and meteorological conditions, the dataset set used in this work covers the first full year (May 2011–April 2012) of these measurements.

2.2. Instrumentation

2.2.1. The automatic weather station

An Automatic weather station (AWS) developed by the Italian manufacturer LSI-Lastem was installed at the experimental site. This AWS is equipped with 8 different sensors monitoring the main atmospheric parameters among which air