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Aerosol properties and associated radiative effects over Cairo (Egypt)

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ABSTRACT

Cairo is one of the largest megacities in the World and the particle load of its atmosphere is known to be particularly important. In this work we aim at assessing the temporal variability of the aerosol's characteristics and the magnitude of its impacts on the transfer of solar radiation. For this we use the level 2 quality assured products obtained by inversion of the instantaneous AERONET sunphotometer measurements performed in Cairo during the Cairo Aerosol CHaracterization Experiment (CACHE), which lasted from the end of October 2004 to the end of March 2006. The analysis of the temporal variation of the aerosol's optical depth (AOD) and spectral dependence suggests that the aerosol is generally a mixture of at least 3 main components differing in composition and size. This is confirmed by the detailed analysis of the monthly-averaged size distributions and associated optical properties (single scattering albedo and asymmetry parameter). The components of the aerosol are found to be 1) a highly absorbing background aerosol produced by daily activities (traffic, industry), 2) an additional, 'pollution' component produced by the burning of agricultural wastes in the Nile delta, and 3) a coarse desert dust component. In July, an enhancement of the accumulation mode is observed due to the atmospheric stability favoring its building up and possibly to secondary aerosols being produced by active photochemistry. More generally, the time variability of the aerosol's characteristics is due to the combined effects of meteorological factors and seasonal production processes.

Because of the large values of the AOD achieved during the desert dust and biomass burning episodes, the instantaneous aerosol radiative forcing (RF) at both the top (TOA) and bottom (BOA) of the atmosphere is maximal during these events. For instance, during the desert dust storm of April 8, 2005 RF_{BOA}, RF_{TOA}, and the corresponding atmospheric heating rate peaked at −161.7 W/m^2, −65.8 W/m^2, and 4.0 K/d, respectively. Outside these extreme events, the distributions of the radiative forcing values at BOA and TOA are Gaussian with means and standard deviations of −58 (±27), and −19(±11)W/m^2, respectively. These two negative values indicate a cooling effect at the 2 atmospheric levels but the largest absolute value at BOA corresponds to a trapping of solar radiation inside the atmosphere. The averages of the instantaneous forcing efficiencies (FE) derived from measurements performed at solar zenith angles between 50 and 76° are −195 (±42) and −62(±17)W/m^2.AOD$_{550}$ for BOA and TOA, respectively. The value at TOA is larger than in other urban environments, which could be due to the desert dust component backscattering more solar radiation to space than absorbing urban aerosols. The lower absorption of solar light by desert dust also explains qualitatively the lower than usual value of FE_{BOA}. A more precise study of the effects of the desert dust and biomass burning aerosols shows that fluctuations of their monthly-averaged concentrations explain the departures of the TOA and BOA radiative forcings from the background situation. In April, the contributions of DD to the month averages of the instantaneous radiative forcing are as high as 53% at BOA, and 66% at TOA. In October, the biomass burning mode contributes 33 and 27% of these forcings, respectively. Noteworthy is that

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the contribution of DD to RF is never less than 17% (at BOA) and 27% (at TOA), emphasizing the importance of the mineral dust component on the transfer of solar radiation above Cairo, and this even in months when no major dust storm is observed.

1. Introduction

Several studies have demonstrated that both natural and anthropogenic aerosols have important effects on the climate of the Earth–atmosphere system (e.g., Haywood and Shine, 1997). Aerosol particles affect the climate directly by scattering and absorbing solar radiation and indirectly by favoring formation of clouds or by modifying their microphysical properties. However, as a consequence of their high spatial and temporal variability, these effects are strongly regional in magnitude and sign (Nakajima et al., 2003). Thus, the overall (annual, global) quantification of the impact of aerosols on the Earth's radiative balance is highly uncertain. This emphasizes the need for accurate data on aerosol and environmental properties and explains that multiple-measurement approaches have been designed to quantify more precisely the impacts of aerosols on climate, at least on a regional basis. These approaches seek to combine satellite observations, continued observations from ground networks, and data from dedicated field experiments (e.g., Kaufman et al., 2002).

Aerosol particles, among which desert dust, smoke from biomass burning, and urban–industrial pollution (Kaufman et al. 1997), can affect the radiation budget and the temperature field by changing the energy balance and distribution of solar and terrestrial radiation in the atmosphere. More precisely, the addition of aerosols to the atmosphere increases absorption of solar radiation and modifies the scattering of sunlight. The reflection of radiation to space may counteract the greenhouse warming by cooling the earth system (Charlson et al., 1992) and the redistribution of radiation is expected to change the temperature profiles (Alpert et al. 1998), the atmospheric stability and possibly cloud formation (Ackerman et al. 2000). At any given altitude of the atmosphere, the result of absorption and scattering is a modification of the vertical net flux of solar radiation. This perturbation of sunlight by aerosols is designated as the 'radiative forcing' (RF). The values of RF at the bottom (RF_{BOA}) and top (RF_{TOA}) of the atmosphere are key parameters in the quantification of the impact of aerosols on climate. However, the assessment of RF is a difficult task because it is characterized by a large spatial and temporal heterogeneity resulting itself from the wide variety of aerosol sources and types, the spatial non-uniformity and intermittency of these sources, the short atmospheric lifetime of aerosols, and the chemical and microphysical processes that occur in the atmosphere (Chin 2009).

With its newer generation of sensors, such as the Moderate Resolution Imaging Spectroradiometer (MODIS) implemented onboard NASA's Earth Observing System (e.g., King et al., 1992), satellite remote sensing is a promising tool for studying the distribution of aerosols and associated effects from global to local scales. However, satellite-retrieved properties are often uncertain because of necessary a priori assumptions, in particular over continents. Thus, networks of ground-based radiometers have been established to provide quality reference points. This is the case of the Aerosol Robotic Network (AERONET), a federated network of more than 200 automatic Sun/Sky radiometers worldwide (Holben et al., 1998), which has been established to measure aerosol optical thickness and other columnar aerosol properties. In areas such as the Mediterranean basin where significant aerosol loads of pollution, biomass burning and advected mineral dust have led to one of the largest regional TOA energy losses worldwide (e.g., Haywood and Boucher, 2000; Lelieveld et al., 2002; Andreae et al., 2002), the measurements by individual instruments can be particularly useful for the quantification of the regional impact of aerosols on the radiative energy balance. Provided a parallel individuation of aerosol types is possible, these local studies can also help reduce the uncertainties on the effect of individual aerosol species, which is necessary because according to the recent report of IPCC (2007) the direct radiative forcing by individual aerosol species is less certain than the total direct radiative forcing by all aerosols.

In this work we will use the measurements performed by the Cimel sunphotometer implemented in the city of Cairo for the duration of the Cairo Aerosol Characterization Experiment (CACHE), namely from the end of Oct. 2004 to the end of March 2006. This instrument was incorporated in the AERONET network and the inversion of its measurements allows assessment of 1) the seasonal variability of the overall radiative forcing, and 2) of the effects of individual aerosol species.

Practically, the paper is organized in two main parts: Section 2 provides a description of the local context, of the available database and of the methodology applied to invert the AERONET measurements, whereas Section 3 discusses the results in terms of variability of 1) aerosol properties and 2) impact on the radiative transfer of solar light at the top and bottom of the atmosphere.

2. Experimental site and methods

2.1. Site location and meteorological context

Cairo is located at the southernmost tip of the Nile delta, at the limit between lower and upper Egypt. With its 16 million inhabitants, Greater Cairo is one of the largest cities in the World and also one of the most polluted. This is a direct result of the growth in population and associated activities that have been observed during the last decades. Motorized traffic and industries located within the city itself or in the neighboring areas of Helwan (south of Cairo) and Shoubra El-Kheima (in the north) are particle sources active all year round but additional material produced by seasonal sources located outside the city can also be transported towards it at certain times of the year.

Meteorological factors also contribute to the seasonal variability of the aerosol loading. The general features of the