Aerosol Properties and direct radiative forcing in Beijing in spring of 2001

Xia Xiang-ao Wang Pu-cai Chen Hong-bin

(LAGEO, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, 100029)

Abstract: The physical and optical properties of aerosols in Beijing were analyzed based on ground-based remote sensing data collected by CIMEL sun/sky radiometers in spring of 2001. Aerosol optical depth at 6 wavelengths from ultraviolet to infrared was obtained from direct solar radiance measurements. Combined solar direct and scattering radiances were utilized to invert aerosol size distribution, refractive index and single-scattering albedo, as well as integral quantities such as modal radius, etc. Dramatic increase of aerosol optical depth from ~0.1 to high values of ~4 at 440 nm was observed during dust periods in Beijing; simultaneously, Angstrom wavelength exponent (α), a measure of aerosol size, decreased to nearly zero, showing aerosol neutral or anomalous extinction due to emission of abundant large dust aerosols into the atmosphere. Anthropogenic sources also contributed remarkably to high values of aerosol optical depth in BJ, but with combination with relatively large values of α. Aerosol refractive index and absorption in BJ demonstrated notable difference between dusty and non-dusty period due to large difference in these properties between dust aerosols and anthropogenic emissions. Dust activities may reduce atmospheric absorption due to input of dust aerosols with lower absorption than that of urban pollution. Hence, dust activities may influence aerosol direct radiative forcing over downwind regions via their effects on aerosol loading, but also through their effects on aerosol extinction properties. Taking the average values of aerosol optical depth, single-scattering albedo and Angstrom wavelength exponent corresponding to non-dusty and dusty period as the inputs to SBDART, the results showed notable differences in surface, TOA and atmospheric direct radiative forcing efficiency.

Introduction

Aerosol radiative forcing, via direct and indirect channels, remains to be one of large uncertainties in climate modeling and projection of future climate scenario in the present, in spite of much attention being paid to the issue in recent years, such as launch of the new generation of space-borne sensors designed specially for aerosol retrievals at the end of last century, execution of many large-scale comprehensive field experiments, et al. It's mainly due to the lack of a thorough regionally dependent understanding of the chemical, physical, and optical properties of aerosols and their spatial and temporal distributions (International Panel on Climate Change (IPCC), 2001). Satellite remote sensing is thought to be the valuable way to nonintrusive observations of aerosols properties globally; however, it just has a limited scope and accuracy due to influence from uncertainties of surface reflectance and poor characterization of aerosol properties. Large information content of ground-based aerosol remote sensing is best suited to reliably and continuously derive the detailed aerosol optical properties in key locations, which has played an important role in characterization of key aerosol types: urban-industrial aerosol, biomass burning aerosol, desert dust and marine aerosol (Eck, et al, 2003; Pinker et al., 2001). These significant results provided valuable data to improve and verify satellite retrievals, as well as to narrow the uncertainty in aerosol radiative forcing (Kaufman, et al., 1997). In this paper, we'll focus on aerosol properties retrieved from sun photometer measurements in the spring of

2001 in Beijing. One of objectives is to study the potential effects of dust transported from remote regions on aerosol properties and direct radiative forcing efficiency.

2.Experimental Site and Measurements

A Cimel sun/sky radiometer was transported to Beijing and installed on the top of Institute of Atmospheric Physics in the middle of March 2001, as a part of international ACE-Asia experiment. The same observation procedure and standardized data retrieval software as that of AERONET were used. The products include aerosol optical depth (τ_a) at 340, 380, 440, 500, 675, 870,1020nm, Angstrom wavelength parameter (α, calculated from τ_a within 440 nm to 870 nm), size distribution and its integrated quantities, refractive index, single scattering albedo etc. The description of instrument, calibration and data retrieval method are described in detail and is omitted here (Holben et al., 1998; Dubovik et al., 2000). The observation period is from 7 March to 16 May.

Four major dust storm episodes occurred in spring of 2001 around the following days: 21-26 March, 12-26 March, 4-14 April, and 29 April to 4 May associated with clod fronts (Zhang et al, 2003). Gobi desert in Mongolia and middle Inner Mongolia desert were attributed to dust emission and transportation to the downwind regions, additionally, Onqin Daga and Horqin deserts located in east Inner Mongolia also contributed a lot to dust emission and transportation (Gong, et al., 2003). In addition to the four large spatial dust activities, there are some local dust events occurred in different places and time. Beijing also experienced a few noticeable weather phenomena during the observation period, for instance, light fog, haze and smog, which contributed to deteriorated atmospheric environment combined with frequent dust activities.

3. Results

In the spring of 2001, generally, Beijing experienced heavy aerosol loading. The average of τ_a at 440 nm (440nm is used in the presentation below if not pointed out specially) is about 0.81, with standard deviation of 0.75. The maximum τ_a approaches to 4, and the minimum is about 0.1 that are two times larger than the background value. Figure 2 presents the histogram of τ_a and α. The peak occurrence of τ_a appears at 0.3. Nearly 50% observations of τ_a are beyond 0.5 and about 10% observations are beyond 2.0. The frequency of α less than 0.6 is approximately 30%, and the maximum frequency occurs at 0.9, which represents heavy impact of dust on atmospheric environment during the observation period. Figure 2 presents the daily average of τ_a and α and associated standard deviation, and also included is TOMS/AI. Generally, six groups of high values of τ_a occurred in Beijing during the measurement period, which are from 10 to 13 Mar., 21 to 24 Mar., 4 to 10 Apr., 16 to 18 Apr., 26 Apr. to 4 May and 13 May, respectively. High values of τ_a are combined with low α during the second, third, and fifth period, which indicates large aerosol particles are present due to dust aerosols transported from remote regions or produced by local sources. It's supported by surface weather observations, which shows that these periods are attacked by dusty activities. However, for the remaining three periods, relatively high values of α corresponded to high $\tau_{a,}$ which is indicative of noticeable anthropogenic influence on atmospheric environment. Certainly, other weather phenomena such as smog, haze, or light fog are recorded during these periods. Actually, in many cases, Atmospheric environment in Beijing is influenced by the combination of both anthropogenic emissions and dust activities. A typical example appeared around 1 May. Light fog occurred on 1 May, at 02:00, 05:00, 08:00, 11:00 (Beijing Time), and then companied by haze at 14:00 and dust event at 17:00 according to surface meteorological records. On subsequent two days, light fog, haze were intervened by sporadic dust events, until on 4 May, persistent and continuous dust activities were recorded at 08:00, 11:00, 14:00, 17:00, 20:00 and 23:00.

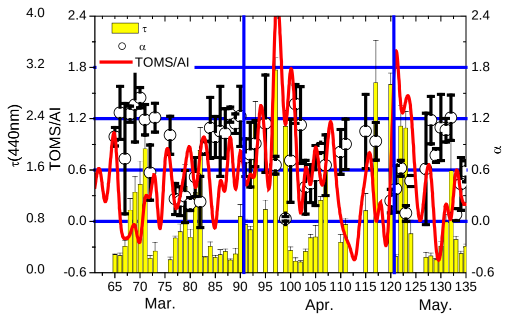

Fig1. Daily average of τ_a and α, also TOMS/AI

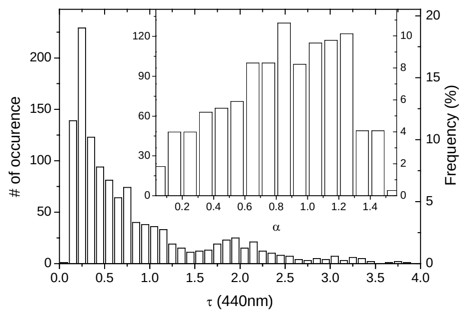

Fig2. Histogram of τ_a and α,

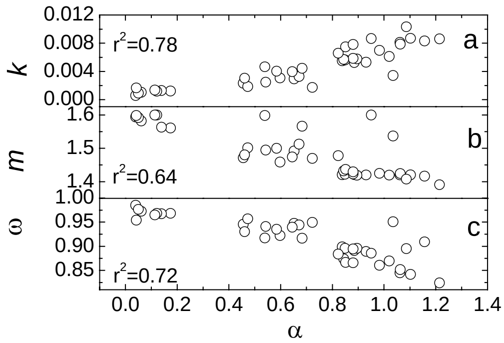

Fig3. The scatter-plot between (m-k*i*), ω with α

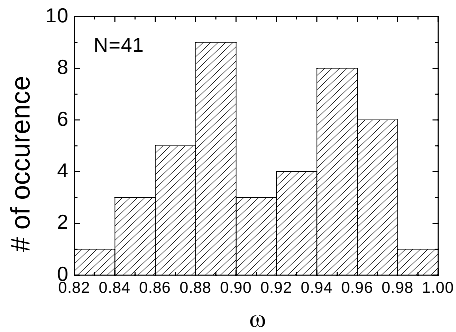

Fig4. Histogram of ω at 870 nm

The impact of dust activities is not only demonstrated by aerosol loading, but also by aerosol properties. Fig3 presents the scatter plot between aerosol refractive index (m-k*i*) as well as single scattering albedo (ω) and α. Obviously, with the decrease of α, i.e. increase of contribution from large dust particles, the magnitude of k increases linearly, and m and ω decreases linearly, which implies that there are distinctly different aerosol scattering and absorptive properties between anthropogenic aerosol and dust aerosol. Fig4 presents the histogram of ω at 870 nm. Surely, the histogram showed two-mode, the first mode concentrated on 0.90, but the second mode mainly clustered at 0.95.

Table1 the diurnal average and standard deviation of DRFE during dusty and dusty period (W/m^2)

	Non-dusty period			*Dusty period*		
	Surface	*TOP*	*Atmosphere*	*Surface*	*TOP*	*Atmosphere*
Ocean	-82.4±10.5	-38.4±8.0	+44.0±2.5	-72.7±9.4	-44.9±8.1	+27.8±1.3
Land	-60.1±6.4	-12.8±3.8	+47.3±2.8	-51.4±5.4	-21.7±3.9	+29.7±1.5

Intense frontal activity, taking place mostly during spring, provides a mechanism for injection of substantial materials into the lower and middle troposphere in Northern China. Aerosol absorption and its implicit importance in aerosol radiative forcing and climate effect are emphasized recently. The retrieved aerosol properties including ω and α corresponding to dusty case (α<0.6) and non-dusty case (α>0.6) were averaged and inputted into SBDART. The objective is to study the impact of dust on aerosol direct radiative forcing efficiency (DRFE). Table1 presents the results. With the advent of dust activities, aerosol DRFE at the surface decreases, and DRFE at TOP increases, correspondingly, DRFE in the atmosphere decreases remarkably. Dust aerosols exert their effect over land more remarkably than over sea.

4. Results

Ground-based sun-photometer observations were carried out in Beijing in spring of 2001. Aerosol properties, i.e. aerosol optical depth, wavelength exponent, size distribution, refractive index and single scattering albedo, were obtained based on these measurements and standard processing software.

Aerosol loading in Beijing is very high, with the averaged aerosol optical depth of 0.81. Dramatic variation of aerosol optical depth has been recorded, from the minimum value of about 0.1 to maximum value of nearly 4. Except dust activities, anthropogenic emissions are also attributed to high aerosol content in Beijing. The distinctly different aerosol properties were observed during dusty and non-dusty periods. Aerosol absorption will be decreased notably due to input of dust aerosols; as a result, aerosol direct radiative forcing efficiency is altered significantly, which is supported by SBDART calculation.

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