Variation of column-integrated aerosol properties in a Chinese urban region

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[1] Thirty-three months of aerosol data in Beijing are presented in this paper. Aerosol optical thickness (AOT) increases from January to June and then decreases gradually. However, airborne particulate matter with diameter less than 10 μm (PM_{10}) concentration exhibits higher values in winter and spring and lower concentration in summer. For the same PM_{10} concentration, AOT in summer is approximately two, three, and four times that in autumn, winter, and spring, respectively. AOT increases persistently during daytime, and the diurnal variation varies from about 15% in summer to about 45% in winter. The seasonal and diurnal variation of AOT is quite different from that of surface particle concentration. This is partly attributed to the variation of atmospheric mixing layer height. Aerosol volume concentrations increase with AOT by nearly identical magnitude for fine and coarse mode except in spring. The volume concentration of coarse mode in spring increases by a magnitude of more than two times that derived in remaining seasons. Aerosol fine mode radius increases with AOT, whereas coarse mode radius keeps relatively invariable with AOT. Mean aerosol single-scattering albedo at 440 nm is about 0.90 and decreases slightly with wavelength. Aerosol single-scattering albedos increase and their spectral dependence reverses during dust periods. Aerosol size and absorption in Beijing are close to results derived in Mexico City and Kanpur, but they are quite different from those in Maryland and Paris. Therefore different urban aerosol models should be created and used in satellite remote sensing in different urban regions.

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1. Introduction

[2] It has been recognized that aerosol particles influence the Earth's radiative balance directly by backscattering and absorption of shortwave (solar) radiation and indirectly by influencing cloud properties and lifetime [*Charlson et al.*, 1992]. The increase of aerosol loading is likely to account partly for a notable decrease of sunshine duration and downwelling surface solar irradiance [*Kaiser and Qian*, 2002; *Xia*, 2004]. Regional temperature change in Sichuan Basin and precipitation pattern change from the mid-1970s were suggested to be related to the heavy aerosol loading and aerosol strong absorption in China [*Li et al.*, 1995; *Xu*, 2001; *Qian and Giorgi*, 2000; *Menon et al.*, 2002]. However, our knowledge of aerosol effects on climate and environment is still limited. One of the reasons is that measurements of aerosol parameters on a global/regional scale are not complete, for example, in China. Therefore long-term, detailed global measurements from satellites and well-distributed ground networks are urgently required in order to characterize aerosol properties and to study their effects on climate and environment [*Kaufman et al.*, 2002; *Holben et al.*, 1998].

[3] In China, rapid economic growth and population expansion in the last 20 years led to a significant increase of aerosol optical thickness (AOT) over much of China. AOT at 750 nm observed from 46 stations in China increased from 0.38 in 1960 to 0.47 in 1990 [*Luo et al.*, 2001]. Specifically, Chinese cities experience high airborne particle concentrations because of airborne dust and primary particles emitted from coal and biomass combustion, motor vehicle exhaust, as well as secondary sulfates formed from the sulfur dioxide by atmospheric chemical reaction. Heavy aerosol loading in China has been reported on the basis of observations by ground-based instruments and satellites. *Xia et al.* [2005] studied aerosol physical and radiative properties and their spatial and temporal variation over north China on the basis of ground-based remote sensing data in spring 2001. The transportation of dust and industrial pollution to the downwind regions has been discussed by *Eck et al.* [2005] using Aerosol Robotic Network (AERONET) data and by *Husar et al.* [2001] using satellite and ground-based data. *Bergin et al.* [2001] measured aerosol radiative properties and chemical compositions in Beijing during July

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1999. A significantly low value of aerosol single-scattering albedo at 550 nm (0.81 ± 0.08) was reported.

[4] Given large advances in ground-based observation techniques and analysis methods, ground-based remote sensing of aerosols is best suited to derive reliably and persistently detailed aerosol properties in key locations of the world, for example, urban aerosols in the mid-Atlantic [*Remer and Kaufman*, 1998], biomass burning aerosols in South Africa [*Eck et al.*, 2003], dust aerosols in the Sahel [*Pinker et al.*, 2001], and maritime aerosols over the Pacific and Atlantic oceans [*Smirnov et al.*, 2002a]. These researches have benefited from the rapid growth of AERONET, a global ground-based network with the automatic CIMEL Sun/sky radiometer as the principal instrument. AERONET was initiated by the United States and France in the early 1990s and expanded rapidly to over 100 stations [*Holben et al.*, 2001].

[5] In March 2001, a CIMEL Sun/sky radiometer was installed temporarily in Beijing as a part of the Aerosol Characterization Experiment-Asia (ACE-Asia). Beijing became one of the permanent AERONET/Photométrie pour le Traitement Opérationnel de Normalisation Satellitaire (PHOTONS) sites in April 2002. This paper will focus on this heavily polluted and poorly understood region on the basis of AERONET data. It is the first time that detailed aerosol properties based on the 33-month AERONET data in Beijing have been presented, as far as we know.

[6] The paper is organized as follows. The experimental site, measurement, and methodology are described in section 2. Section 3 presents detailed results. Seasonal and diurnal variations of aerosol properties are presented in sections 3.1 and 3.2; sections 3.3 and 3.4 describe aerosol size distribution and single-scattering albedo. The conclusion and discussions are presented in section 4.

2. Site, Measurement, and Methodology

[7] Beijing is surrounded by mountainous area in the west, the north, and the northeast. In the east and south of Beijing, the elevation is close to sea level. There are four distinct seasons. The cold and windy weather mainly occurs in winter (December, January, and February) and spring (March to May) because of frequent outbreaks of cold air from west Siberia. Summer (June to August) in Beijing is characterized by relatively hot and humid weather and accounts for about 74% of annual precipitation. Autumn (September to November) is generally a good season with a relatively clear and clean sky. Winter is the heating season that regularly begins in mid-November and ends in mid-March. With a combination of gusting winds and loose surface soil in the upwind Gobi and sandy regions, the dust episode occasionally impacts Beijing in spring. There is not a dust storm every day, but one or two at the very least can be guaranteed in spring. Temperature inversion occurs frequently in Beijing due partly to its special terrain, especially in autumn and winter.

[8] The radiometer was installed on the roof (above 30 m height) of the Institute of Atmospheric Physics (IAP) office building. In March 2004, the radiometer was moved to the top of a building that is about 2 km away from IAP. The automatic tracking Sun and sky scanning radiometer takes measurements of solar direct radiances and diffuse sky radiances with a 1.2° full field of view.

4. Conclusions

[17] In this paper, we presented aerosol column-integrated properties (loading, size distribution, and absorption) in Beijing, a very polluted and highly populated megacity. The analysis was based on 33 months of AERONET data. A few conclusions were reached.

[18] 1. Much higher aerosol loading than the background level has been observed in Beijing. Monthly mean AOT at 440 nm in Beijing ranges from about 0.41 in January to more than 1.25 in June. Seasonal variation of AOT is distinct, with high monthly AOT in spring and summer and relatively low monthly AOT in autumn and winter. This seasonal pattern of AOT is quite different from that of the surface PM_{10} concentration. PM_{10} decreases steadily from its peak value in winter and early spring to its trough in summer. This inconsistency is partly ascribed to the seasonal variation of pollution boundary layer height that is determined by solar insolation and aerosol transportation. Additionally, other factors such as seasonal variation of relative humidity (aerosol hygroscopic growth) cannot be excluded.

[19] 2. The analysis shows a seasonally consistent diurnal variation of AOT in Beijing. AOT increases nearly monotonically during the daytime, and the diurnal variability varies from 15% in summer to 45% in winter. This is quite different from diurnal variation of surface PM_{10} concentration. The inconsistency is related to diurnal variation of the pollution boundary layer height and associated diurnal variation of aerosol dilution from the surface to a high level.

[20] 3. The relationship of PM_{10} concentration to AOT in summer is statistically significant, indicating that aerosols are well mixed, and surface observation is a good indictor of the column value. A good correlation between AOT and PM_{10} is derived in autumn and winter. The correlation coefficient is 0.70 and 0.61, respectively. A wide spread is evident in spring. The different ratios of AOT to PM_{10} have been derived for different seasons as a result of the seasonal variation of the height of pollutant layer.

[21] 4. Aerosol volume size distribution in Beijing shows two distinct modes. Volume concentrations of two modes increase with AOT by a nearly identical magnitude except in spring. Volume concentration of coarse mode in spring increases with AOT by about two times that in other seasons. Coarse mode radius and mode standard deviation of two modes remains relatively stable with AOT. However, fine mode radius in Beijing increases with AOT. Its increase trend in Beijing is about one third that in Maryland and Paris.

[22] 5. Aerosol single-scattering albedo in Beijing is about 0.90 at 440 nm and decreases slightly to the near-infrared wavelength. Aerosol single-scattering albedo will increase notably, and the spectral dependence will reverse if Beijing is impacted by dust weather. Aerosol size and absorption in Beijing is close to AERONET retrievals in Mexico City and Kanpur, but they are remarkably different from those retrieved in Maryland and Paris. This indicates that different urban aerosol models should be created and used in the spaceborne remote sensing of aerosols in different urban regions.