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Characteristics of aerosol optical properties and meteorological parameters during three major dust events (2005–2010) over Beijing, China

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ABSTRACT

Multi-satellite sensors are capable of monitoring transport and characteristics of dust storms and changes in atmospheric parameters along their transport. The present paper discusses aerosol optical properties and meteorological parameters during major dust storm events occurred in the period 2005–2010 over Beijing, China. The back trajectory model shows that the dust is transported from the Inner Mongolia and Mongolia arid regions to Beijing. High aerosol optical depth (AOD) at the wavelength 675 nm and low Ångström exponent (AE) values in the wavelength 440–870 nm are observed during dusty days. The aerosol size distribution (ASD) in coarse mode shows a large increase in the volume during dusty days. The single scattering albedo (SSA) increases with higher wavelength on dusty days, and is generally found to be higher compared to the days prior to and after the dust events, indicating the presence of high concentrations of scattering particles due to dust storm events. The physico-chemical properties of aerosols during dusty and non dusty days show distinct characteristics as reflected from the changes in the real and imaginary parts of refractive index (RI). In addition, the CO volume mixing ratio (COVMR) from Atmospheric Infrared Sounder (AIRS) shows a pronounced decrease on dusty days, while the H_2O mass mixing ratio (H_2OMMR) shows enhanced signal. Furthermore, enhanced level of water vapor (WV) using Moderate Resolution Imaging Spectroradiometer (MODIS) data is also observed in and around Beijing over the dust storms track.

1. Introduction

Since late 20th century, northern parts of China have experienced frequent dust storms (Chen, 2001; Zhou and Zhang, 2003) that affect the climate, visibility and air quality. The dust events observed in China are originated from Gobi and sand deserts of widespread arid and semiarid regions, which cover 13.6% area of the country (Zhu et al., 1986). Dust storms occur annually during spring season (March–May), and large quantities of aeolian dust are transported to downwind regions. As a result, they are not only accumulated in the nearby region, forming the Loess Plateau (Liu, 1985), but also undergo long-range transport depositing in the North Pacific Ocean (Duce et al., 1980; Shaw, 1980). Dust storms with strong winds affect air quality that has serious health threat to the people living in the affected regions (Nickling and Brazel, 1984; Littmann, 1991; Swap et al., 1996). Episodically, the dust from Mongolia and northern China is transported across the North Pacific basin, reaching North America and beyond (Yu et al., 2008). Dusts influence the air quality, optical properties of aerosols, meteorological and atmospheric parameters, hydrologic cycle,

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monsoon system and climate as they are capable of changing radiative characteristics of the atmosphere (Tegen et al., 2004; Lau et al., 2006; Prasad and Singh, 2007; Gautam et al., 2009; Singh, 2014). In addition, dust storms have also been shown to influence the vertical structure of trace gases such as carbon monoxide (CO) (Bhattacharjee et al., 2007).

Beijing, the capital of China, is one of the most populous cities in the world with a population of 20 million (as in 2011) covering an area of 16,800 km^2. It is located at the foothills of Yan Mountains and Taihang Mountains, in the North China Plain (Chen et al., 2009). Dust storms, affecting Beijing, generally originate in the primary source regions of Mongolia and Inner Mongolia (Zhang et al., 2012). Beijing has a typical continental monsoon climate with four distinct seasons; during spring season (March–May) dust events occur every year affecting weather conditions, for example, the significant visibility reduction, and the significant PM_{10} concentrations increase (Wang et al., 2008), that have long-term implications on human health.

Recently, ground-based Aerosol Robotic Network (AERONET) (Holben et al., 1998) and satellite data (Moderate Resolution Imaging Spectroradiometer (MODIS), Multiangle Imaging Spectroradiometer (MISR), and Ozone Monitoring Instrument (OMI)) have been widely used to study aerosol properties and changes in optical/radiative properties due to dust events. Spaceborne lidar systems like Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) have been used to understand the vertical variability of aerosols (Winker et al., 2007). Using satellite and ground observations, efforts have been made to study dust characteristics, its transport, short and long term impacts on climate around the world. The analysis of aerosol optical properties at different locations in the world shows robust differentiation in both the magnitude and spectral dependence of the absorption for desert dust, biomass burning, urban-industrial, and marine aerosols (Dubovik et al., 2002). In East Asia, maximum aerosol optical depth (AOD) together with low Ångström exponents (AEs) is generally observed during spring season due to dust storm activities (Eck et al., 2005; Kim et al., 2008). In northern China, large variations in AOD and AE have been reported under typical background, and for environments subjected to floating dust, and dust storm weather conditions. Occasionally, AE decreases to even zero or negative value during intense dust events (Xia et al., 2005; Cheng et al., 2006). Furthermore, the AOD and AE demonstrate contrary trends during all storm stages (pre-dust storm, dust storm, and post-dust storm), with the AOD indicating an obvious “Valley–Peak–Valley” pattern of variations, while AE demonstrate a “Peak–Valley–Peak” pattern (Xin et al., 2010). In Beijing, the AOD, AE, and single scattering albedo (SSA) show a distinct variation during dust and haze and foggy days (Yu et al., 2011). In general, higher AOD and lower AE are found over Beijing during dust events where dust is the major contributor of coarse mode particles to the net aerosol loading (Yu et al., 2013). Dust storms have also been associated with deterioration of regional air quality. For example, during the dust event of 16–20 April 2006 over Beijing, a pronounced increase in hourly PM_{10} concentrations was observed which are up to 1200 $\mu g/m^3$ (Wang et al., 2010), and during dust event of 26 April–3 May, 2012, the air pollution index (API) increased up to 473 $\mu g/m^3$ (Shen et al., 2013). The previous dust studies in Beijing mainly focus on one dust storm event or changes of few parameters acquired from ground-based measurements or satellite data. The comprehensive analysis of aerosol optical properties and meteorological parameters during dust storm events using ground and satellite data will help to find out dust impact on weather and climate at or above the surface level, and help to develop policy to reduce human health impacts of dust.

In the present study, we have studied the characteristics of aerosol and meteorological parameters using AERONET and satellite data during major dust storm events (2005–2010) over Beijing. We mainly focus on the changes in aerosol optical properties (AOD, AE, aerosol size distribution—ASD, refractive index—RI, and SSA from AERONET), API from ground based stations, and other parameters (water vapor—WV from MODIS, CO volume mixing ratio—COVMR, and H_2O mass mixing ratio—H_2OMMR from Atmospheric Infrared Sounder—AIRS). The Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model is used to determine the source of air mass and dust tracks.

2. Data and methods

In this study, we have considered data from ground based stations, MODIS, AIRS, and AERONET, and have analyzed the source of dust storms over Beijing using NOAA HYSPLIT model. The API simplifies the concentrations of several air pollutants to characterize air pollution level and air quality status in several levels (Zheng et al., 2014). It is related to the health impacts (Table 1). The API data (as of the year 2010) over Beijing is taken from the website of China National Environmental Monitoring Centre (CNEMC) (http://www.cnemc.cn/citystatus/airMap.jsp).

The AERONET is a network of ground-based sun photometers to measure aerosol optical properties and validate satellite retrievals of aerosol optical properties (Holben et al., 1998). Numerous aerosol parameters (e.g. size distribution, complex refractive index—RI, phase function, SSA, AE, water vapor, spectral and broad-band fluxes) are available at different locations around the world from the AERONET network. In

Table 1
API and health implications (Ministry of Environmental Protection of the People's Republic of China, 2008).

API	Air pollution level	Health implications
0–50	Excellent	No health implications
51–100	Good	No health implications
101–200	Lightly polluted	Slight irritations may occur, individuals with breathing or heart problems should reduce outdoor exercise.
201–300	Moderately polluted	Healthy people will be noticeably affected. People with breathing or heart problems will experience reduced endurance in activities. These individuals and elders should remain indoors and restrict activities.
300+	Severely polluted	Healthy people will experience reduced endurance in activities. There may be strong irritations and symptoms and may trigger other illnesses. Elders and the sick should remain indoors and avoid exercise. Healthy individuals should avoid outdoor activities.