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Characterizing a persistent Asian dust transport event: Optical properties and impact on air quality through the ground-based and satellite measurements over Nanjing, China

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HIGHLIGHTS

- Observe two Asian dust layers transported from the different paths and sources.
- Characterize the time-height evolution and optical properties of Asian dust.
- Verify impact of dust on air quality and mixture with anthropogenic aerosols.
- Evaluate modeling dust vertical profile and surface concentration.

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ABSTRACT

The optical properties, time-height distribution and impact on the local air quality from a heavy Asian dust transport episode are investigated with a synergistic ground-based, satellite sensors and transport model on 1 May, 2011 at Nanjing (32.05° N, 118.78° E, and 94 m ASL) in southeast China. Two dust layers located in the planetary-boundary-layer (PBL, <2.5 km) and free troposphere (3–6 km) are observed by a Polarization Raman-Mie Lidar, with the lower one originating from the Gobi deserts and the higher one from the Taklimakan deserts. The dust aerosol layer shows the depolarization ratios at 0.1–0.2 and strong extinction coefficients of 1.0 km^{-1} at 532-nm, while the extinction-to-backscatter ratios (e.g. lidar ratios) of dust are 47.3–55 sr below 2.5 km. During this dust intrusion period, the aerosol optical depths (AOD) dramatically increase from 0.7 to 1.6 at 500-nm whereas the Angstrom exponents decrease from 1.2 to 0.2. Meanwhile, surface PM_{10} and $PM_{2.5}$ concentrations show a significant and coincident increase with the peak value reaching 767 $\mu g/m^3$ and 222 $\mu g/m^3$, respectively, indicating the mixture of dust with the anthropogenic aerosols. Regional influences of the transported dust in east China are further illustrated by the AERONET-sunphotometer at Taihu and Xianghe sites (downwind and upwind from Nanjing), satellites MODIS, CALIPSO and model products. Furthermore, the model product of dust profile and surface concentration are evaluated with the ground-based and CALISPO observation. The results indicate the model is capable of simulating the right timing of dust transport event and most loading below 3-km altitude; normalization of model dust with the PM_{10} near the Gobi deserts improves modeling surface dust concentration in Nanjing.

1. Introduction

Asian dusts play an important role in Earth's energy budget, climate change and atmospheric environment due to their directly scattering and absorbing solar and Earth's radiance and indirect effects that modify cloud properties (IPCC, 2013). They are often transported over long distances and their influence can be identified on regional and global scales (Chin et al., 2007; Uno et al., 2009). For instance, Asian dusts are frequently observed in spring resulting in air pollution in the downwind areas of East Asia (Kim et al., 2010; Sakai et al., 2002, 2003; Liu et al., 2011; Li et al.,

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2015), even affecting North America (Fischer et al., 2009; Wu et al., 2015). They affect cloud microphysics and precipitation by providing cloud condensation nuclei (Rosenfeld et al., 2001).

Several field campaign measurements have been made to characterize Asian dust optical properties and their climate radiation effects (Hubert et al., 2003; Nakajima and Yoon, 2005; Huang et al., 2010a,b; Li et al., 2011). However with long-range transport, Asian dusts often mix with anthropogenic pollutants such as black carbon and sulfate, thus exhibiting relatively complex optical properties and radiative effects (Huang et al., 2010a,b; Yi et al., 2014). Meanwhile, atmospheric chemical transport models are increasingly being used to quantify Asian-dust transport and contributions to atmospheric particulate matter (PM) concentration (Uno et al., 2006). Uncertainties in model estimates result from factors such as lack of observational constraint, particularly in the free troposphere where much of the transport occurs. The mixing of the dust particles down to ground level and transfer rates between the boundary layer and free troposphere are not well characterized. Thus, it is still a challenge to quantitatively model the impacts of long-range transport of Asian dust on local air quality (National Research Council, 2009).

Although growing capabilities for satellites observing column–integrated aerosol optical depth (AOD) are used to broadly depict dust spatial distribution, the linkage between column amounts and surface concentration are not well understood. This limits the ability to quantify the effects of persistent transport on surface concentrations from column-integrated observations (Toth et al., 2014). To quantify Asian dusts effects and reduce the uncertainties in model estimate, comprehensive and multiple platform observations are necessary. In particular, range-resolved distribution and aerosol type classification are critical for evaluating dust aerosol loading, transport and evolution.

Air quality and visibility degradation are serious environment and health issues in China due to the complex pollutant emission from the rapid economic development and urbanization (Zhang et al., 2012). In particular, regional transports from the dust storms occurring in northwest China and Mongolia often cause severe air pollution in the continental China. A severe dust storm occurred on 28–30 April 2011, which was observed at ground stations in east China (Liu et al., 2013; Li et al., 2014; Fu et al., 2014). However, to our best knowledge for this event, there is a lack of characterizing dust optical/microphysics properties, time-height distribution and evolution, which is important to assess the impacts of dust aerosol on radiation-cloud-climate and regional air quality. It also provides a unique chance to evaluate transport model performance on profiling dust distribution and surface concentration.

In this paper, we present synergistic ground-based polarization Raman-Mie lidar, sunphotometer and PM samplers, satellite measurements and model analyses in Nanjing City, one of important megacities in the region of the Yangtze River Delta in southeast China. The goals of this study are to: 1) characterize the time-height distribution of transported dust and optical properties in the region scale; 2) quantify their influences on surface air quality (e.g. PM_{10} and $PM_{2.5}$, particulate matter with diameter <10 μm and 2.5 μm, respectively); 3) evaluate the transport model skills on profiling dust distribution and surface concentration with synergistic observations.

2. Instruments and methodology

2.1. Ground-based instruments

A synergistic suite of ground-based observing facilities are deployed on the roof of a 24-story building on the Gulou campus of Nanjing University (NJU-Urban Atmospheric Environments Observation Station, 32.05° N, 118.78° E, 94 m above sea level, ASL). This includes a Polarization-Raman-Mie Lidar (PRML), a CIMEL sunphotometer (CE-318), a visibility sensor (model GSN-1), aethalometer (Model AE-31) and an automatic air quality monitoring station, including in-situ samples for PM_{10} and $PM_{2.5}$ (TEOM Particulate Mass Monitor Series 1400) and gases (NO_x, Hg, CO_2/CO, and SO_2, etc.). The observation site is centrally located in the main urban area of Nanjing City (see Fig. 1), which is the second largest city in the eastern China, and forms with a high population density and large energy consumption.

The PRML is a polarization-sensitive Raman-Mie scattering Lidar. It is equipped with a linearly polarized laser source (Nd: YAG) pointed vertically, emitting a pulse of 120 mJ output energy at a wavelength of 532 nm and a 10 Hz repetition rate. The optical receiver is a Cassegrain telescope with 220 mm diameter and a field of view of 0.5–2 mrad. Three receiving channels are used to collect elastic-scattering and polarization signals (532- parallel and 532-perpendicular channels) and N_2-Raman scattering signals at 607-nm. The atmospheric backscatter signal profile is acquired with a vertical resolution of 7.5 m and 8-min temporal average.

Raman lidar permits the independent measurement of aerosol extinction and backscatter, and consequently the lidar-ratio (e.g. extinction-to-backscatter ratio) can be derived (Ansmann et al., 1992). Due to the inherent weak signal-to-noise ratio of Raman signal in the daytime, the elastic-scattering signal is used to retrieve aerosol extinction (Fernald, 1984). Corresponding algorithms can be found elsewhere (Xie et al., 2008; Su et al., 2013).

Total linear depolarization-ratio, “δv”, can be obtained from the ratio of the perpendicular polarization component to the parallel component of the backscattered signals, defined as:

$$P_{0//}(z)z^2 = C_{0//}Q_0(z)\left[\beta_{a0//}(z) + \beta_{m0//}(z)\right] \times \exp\left\{-2\int_0^z \left[\alpha_{a0//}(z') + \alpha_{m0//}(z')\right]dz'\right\}, \tag{1}$$

$$P_{0\perp}(z)z^2 = C_{0\perp}Q_0(z)[\beta_{a0\perp}(z) + \beta_{m0\perp}(z)] \times \exp\left\{-\int_0^z \left[\alpha_{a,m0//}(z') + \alpha_{a,m0\perp}(z')\right]dz'\right\}, \tag{2}$$

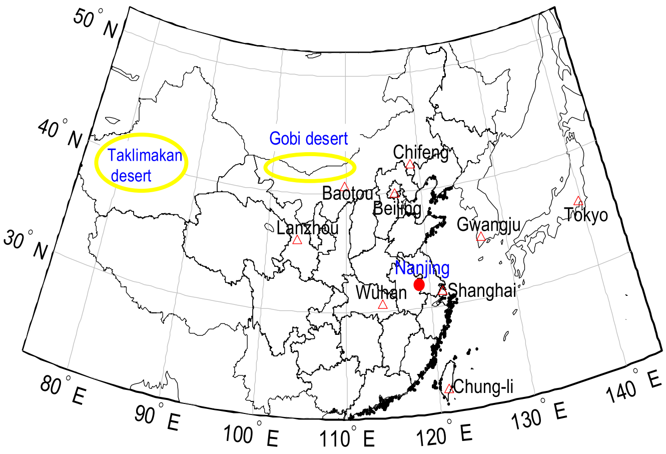

Fig. 1. Locations of ground-based site in Nanjing (red dot), PM_{10} sites at Chifeng and Baotou, and other lidar observations listed in Table 1. Gobi and Taklimakan deserts are marked. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)