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Vertical distribution of aerosol optical properties based on aircraft measurements over the Loess Plateau in China

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ABSTRACT

Vertical distributions of aerosol optical properties based on aircraft measurements over the Loess Plateau were measured for the first time during a summertime aircraft campaign, 2013 in Shanxi, China. Data from four flights were analyzed. The vertical distributions of aerosol optical properties including aerosol scattering coefficients (σ_{sc}), absorption coefficients (σ_{ab}), Angström exponent (α), single scattering albedo (ω), backscattering ratio (β_{sc}), aerosol mass scattering proficiency (Q_{sc}) and aerosol surface scattering proficiency (Q'_{sc}) were obtained. The mean statistical values of σ_{sc} were 77.45 Mm^{-1} (at 450 nm), 50.72 Mm^{-1} (at 550 nm), and 32.02 Mm^{-1} (at 700 nm). The mean value of σ_{ab} was 7.62 Mm^{-1} (at 550 nm). The mean values of α, β_{sc} and ω were 1.93, 0.15, and 0.91, respectively. Aerosol concentration decreased with altitude. Most effective diameters (ED) of aerosols were less than 0.8 μm. The vertical profiles of σ_{sc}, α, β_{sc}, Q_{sc} and Q'_{sc} showed that the aerosol scattering properties at lower levels contributed the most to the total aerosol radiative forcing. Both α and β_{sc} had relatively large values, suggesting that most aerosols in the observational region were small particles. The mean values of σ_{sc}, α, β_{sc}, Q_{sc}, Q'_{sc}, σ_{ab} and ω at different height ranges showed that most of the parameters decreased with altitude. The forty-eight hour backward trajectories of air masses during the observation days indicated that the majority of aerosols in the lower level contributed the most to the total aerosol loading, and most of these particles originated from local or regional pollution emissions.

Introduction

Atmospheric aerosols directly affect the Earth's radiative budget by scattering and absorbing solar and thermal radiation (Haywood and Shine, 1997), and indirectly by acting as cloud condensation nuclei or ice nuclei in cloud formation, thus affecting the optical properties and lifetime of clouds, and furthermore, modifying the precipitation regime. Atmospheric aerosols also have adverse effects on environmental quality including atmospheric quality, visibility (Waggoner et al., 1981; Horvath, 1995), and human health. The spatial and temporal variations of radiative forcing by aerosols are strongly influenced

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by the variability of aerosol concentration distributions and optical properties on local to regional scales. The aerosol geographical and temporal distributions are very variable due to diverse emission sources, particle transformations and different removal processes. All these factors cause large uncertainties in evaluating the effects of aerosols on both climate and the environment. For this reason, many studies, including observational studies and numerical simulations, have been carried out to understand the physical, chemical, and optical properties of aerosols (*e.g.*, Kleefeld et al., 2002; Adam et al., 2004; Elias et al., 2006; Fischer et al., 2011; Li et al., 2007; Yan, 2007; Sun et al., 2014; Wang et al., 2014; Zhao et al., 2014) and their effects on climate radiative forcing, clouds, and precipitation (Yin et al., 2002, 2010).

Till now, most studies focusing on aerosol optical properties have been carried out from the ground, and some measurements were conducted focusing on variations of aerosol optical properties in China (Qiu and Takeuchi, 2001; Zhang et al., 2002, 2004; Xu et al., 2002, 2004; Yan et al., 2008; Liu et al., 2012; Tao et al., 2014). There is still an urgent need to better understand the vertical distributions of aerosol optical properties. Aircraft observations can afford the principal advantage of yielding detailed information on aerosol properties with height, albeit within short time periods over geographic areas of limited extent, thereby enabling the question of aerosol optical properties in the vertical direction to be addressed (Bodhaine et al., 1991; Hänel, 1998; Sheridan and Ogren, 1999; Welton et al., 2002; Anderson et al., 2003; Han et al, 2003; Raut and Chazette, 2008; Li et al., 2011, 2012).

However, because of the strict control of airspace and high operating costs, there is still a lack of aircraft observations of aerosol optical properties in the lower troposphere over urban and rural areas, especially in the central and eastern regions of northern China. It is therefore a major objective of this paper to evaluate the uncertainty of measured aerosol properties such as aerosol spatial distribution, particle size distribution, particle scattering and backscattering coefficients, particle absorption coefficients, particle single scattering albedo, and other properties through aircraft measurements to provide valuable observation data for regional model calculations on aerosol and climate.

Shanxi Province is located in the Loess Plateau of northern China, and the north China plain lies to the east of this region. As one of the most important heavy chemical bases of China, the mixture of heavy air pollution from industrial activities results in a rather complex nature for aerosol optical properties in the local region. However, till now, few studies have been reported on measurements of the important aerosol properties and especially the vertical distribution of these properties in Shanxi province. As a key part of the International Aerosol-CCN-Cloud Closure Experiment (ACCCExp-2013), an airborne campaign was conducted in August 2013 in Shanxi Province on the Loess Plateau of China. Comprehensive observations of atmospheric aerosol characteristics in this region were collected for the first time. In this paper, the characteristics and vertical variation of aerosol optical properties are analyzed involving the statistical properties of the optical characteristics of aerosols such as aerosol scattering coefficients (σ_{sc}), backscattering coefficients (σ_{bsc}), Angström exponent (α), backscattering ratio (β_{sc}), mass scattering efficiency (Q_{sc}), surface scattering efficiency (Q'_{sc}), absorption coefficients (σ_{ab}) and single scattering albedo (ω), as well as the vertical distributions of these parameters, vertical profiles of aerosol concentration and particle size, the correlation between aerosol concentration and σ_{sc}, and the backward trajectories of air masses.

1. Description of the field campaign

1.1. Observation area

Shanxi Province is located in northern China. The Loess Plateau covers most of the province, and the average surface altitude of the entire province is above 1000 m. Shanxi province connects with the north China plain in the east, and Hebei province and Beijing city are at the east of the province. Shanxi is situated in the temperate continental monsoon climate zone. It is an important energy and chemical industrial center of China. In conjunction with the rapid economic growth in the region, the increase in industrial emissions of anthropogenic aerosol particles has a strong impact on the regional air quality and climate. This has garnered much attention from the public in recent years. The field observation was carried out in the central region of Shanxi Province, and three main observatories were included in this study: Taiyuan (112.55°E, 37.867°N, altitude 778 m above sea level, or asl), Wenshui (112.14°E, 37.26°N, altitude 800 m asl), and Xinzhou (112.70°E, 38.73°N, altitude 800 m asl). Fig. 1 shows the map of Shanxi province and the locations of the three sites. The flight observation was mainly carried out around the three sites.

1.2. Instruments and measurements

A Y-12 turboprop airplane was used as an aerosol observation platform. The typical speed of the aircraft was about 60–70 m/sec and the rate of climb or descent of the aircraft

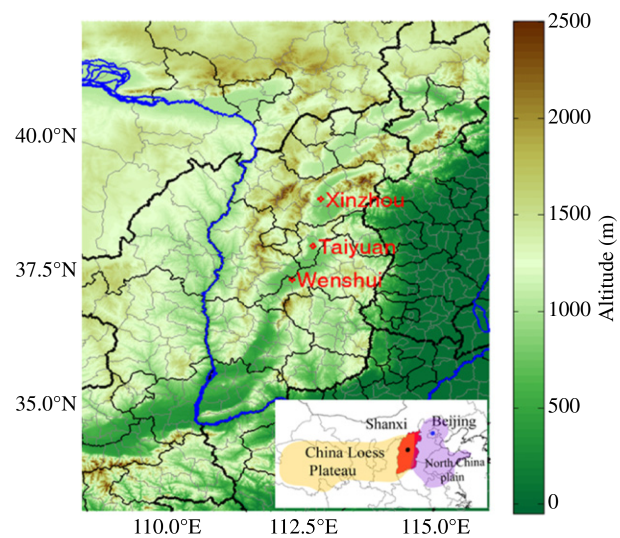

Fig. 1 – Map of Shanxi province over which flights were made and locations of the three main aerosol observatories (Taiyuan, Wenshui, and Xinzhou). The inert map shows the location of the observation area in China, in which the red shaded area represents Shanxi province.